A MANUAL FOR A COURSE ON THE ENVIRONMENTAL ASPECTS OF INDUSTRIAL DEVELOPMENT

Volume IV: The Nature of
Environmental Pollution

VOLUME FOUR

The Nature of Environmental Pollution

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Volume Four

-- THE NATURE OF ENVIRONMENTAL POLLUTION AND CONTROL --

"Introduction:
A Primer on Wastewater Treatment"

by
Federal Water Pollution Control Administration

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INTRODUCTION

Thousands of waste treatment plants will be constructed or expanded across the Nation during the years ahead to control or prevent water pollution.

This increased construction activity is the result of the passage of the Water Quality Act of 1965 which called for the establishment of water quality standards for all the interstate streams, coastal waters, and lakes, and the Clean Water Restoration Act of 1966 which increased Federal financial aid to cities to help build these needed plants.

Communities across the land will be planning, financing, and building the facilities to meet the water quality standards. Some cities will be constructing plants where none existed before. Others will be expanding inadequate facilities while some communities will be adding more advanced methods to handle new types of wastes.

It won't happen overnight. From drawing board to operation takes time. In some cases, projects will be built in stages. Consequently, more and more people will be watching this developing progress toward cleaner water. They will need to know more about waste treatment.

In this primer, the methods used now and processes being developed for the future to treat wastes are explained.

A PRIMER ON WASTE WATER TREATMENT

Collecting and Treating Wastes

The most common form of pollution control in the United States consists of a system of sewers and waste treatment plants. The sewers collect the waste water from homes, businesses, and many industries and deliver it to the plants for treatment to make it fit for discharge into streams or for reuse.

There are two kinds of sewer systems -- combined and separate. Combined sewers carry away both water polluted by human use and water polluted as it drains off homes, streets, or land during a storm.

In a separated system, one system of sewers, usually called sanitary, carries only sewage. Another system of storm sewers takes care of the large volumes of water from rain or melting snow.

Each home has a sewer or pipe which connects to the common or lateral sewer beneath a nearby street. Lateral sewers connect with larger sewers called trunk or main sewers. In a combined sewer system, these trunk or main sewers discharge into a larger sewer called an interceptor. The interceptor is designed to carry several times the dry-weather flow of the system feeding into it.

During dry weather when the sewers are handling only the normal amount of waste water, all of it is carried to the waste treatment plant. During a storm when the amount of water in the sewer system is much greater, part of the water, including varying amounts of raw sewage, is allowed to bypass directly into the receiving streams. The rest of the wastes are sent to the treatment plant. If part of the increased load of water were not diverted, the waste treatment plant would be overloaded and the purifying processes would not function properly. (A special research program is under way on the problem of storm and combined sewers.)

Interceptor sewers are also used in sanitary sewer systems as collectors of flow from main sewers and trunks, but do not normally include provisions for bypassing.

A waste treatment plant's basic function is to speed up the natural processes by which water purifies itself. In many cases, nature's treatment process in streams and lakes was adequate before our population and industry grew to their present size.

When the sewage of previous years was dumped into waterways, the natural process of purification began. First, the sheer volume of clean water in the stream diluted the small organisms in the water consumed the sewage or other organic matter, turning it into new bacterial cells, carbon dioxide, and other products.

But the bacteria normally present in water must have oxygen to do their part in breaking down the sewage. Water acquires this all-important oxygen by absorbing it from the air and from plants that grow in the water itself. These plants use sunlight to turn the carbon dioxide present in water into oxygen.

The life and death of any body of water depends mainly upon its ability to maintain a certain amount of dissolved oxygen. This dissolved oxygen--or DO--is what fish breathe. Without it they suffocate. If only a small amount of sewage is dumped into a stream, fish are not affected and the bacteria can do their work and the stream can quickly restore its oxygen loss from the atmosphere and from plants. Trouble begins when the sewage load is excessive. The sewage will decay and the water will begin to give off odors. If carried to the extreme, the water could lose all of its oxygen, resulting in the death of fish and beneficial plant life.

Since dissolved oxygen is the key element in the life of water, the demands on it are used as a measure in telling how well a sewage treatment plant is working. This measuring device is called biochemical oxygen demand, or BOD. If the effluent or the end-product from a treatment plant has a high content of organic pollutants, the effluent will have a high BOD. In other words, it will demand more oxygen from the water to break down the sewage and consequently will leave the water with less oxygen (and also dirtier).

With the growth of the Nation, the problems of pollution have become more complex. The increased amounts of wastes and larger demands for water have reduced the capacity of running water to purify itself. Consequently, cities and industry have had to begin thinking about removing as much as possible of the oxygen-demanding pollutants from their sewage.

Adequate treatment of wastes along with providing a sufficient supply of clean water has become a major concern.

Primary Treatment

At present, there are two basic ways of treating wastes. They are called primary and secondary. In primary treatment, solids are allowed to settle and are removed from the water. Secondary treatment, a further step in purifying waste water, uses biological processes.

As sewage enters a plant for primary treatment, it flows through a screen. The screen removes large floating objects such as rags and sticks that may clog pumps and small pipes. The screens vary from coarse to fine--from those with parallel steel or iron bars with openings of about half an inch or more to screens with much smaller openings.

Screens are generally placed in a chamber or channel in an inclined position to the flow of the sewage to make cleaning easier. The debris caught on the upstream surface of the screen can be raked off manually or mechanically.

Some plants use a device known as a cominutor which combines the functions of a screen and a grinder. These devices catch and then cut or shred the heavy solid material. In the process, the pulverized matter remains in the sewage flow to be removed later in a settling tank.

After the sewage has been screened, it passes into what is called a grit chamber where sand, grit, cinders, and small stones are allowed to settle to the bottom. A grit chamber is highly important for cities with combined sewer systems because it will remove the grit or gravel that washes off streets or land during a storm and ends up at treatment plants.

The unwanted grit or gravel from this process is usually disposed of by filling land near a treatment plant.

In some plants, another screen is placed after the grit chamber to remove any further material that might damage equipment or interfere with later processes.

With the screening completed and the grit removed, the sewage still contains suspended solids. These are minute particles of matter that can be removed from the sewage by treatment in a sedimentation tank. When the speed of the flow of sewage through one of these tanks is reduced, the suspended solids will gradually sink to the bottom. This mass of solids is called raw sludge.

Various methods have been devised for removing sludge from the tanks.

In older plants, sludge removal was done by hand. After a tank had been in service for several days or weeks, the sewage flow was diverted to another thank. The sludge in the bottom of the out-of-service tank was pushed or flushed with water to a pit near the tank, and then removed, usually by pumping, for further treatment or disposal.

Almost all plants built within the past 30 years have had a mechanical means for removing the sludge from sedimentation tanks. Some plants remove it continuously while others remove it at intervals. To complete the primary treatment, the effluent with the sludge removed leaves the sedimentation tank for chlorination before being discharged into a stream or river. Chlorine gas is fed into the water to kill disease-causing bacteria. It also helps to reduce odors.

Although 30 percent of the municipalities in the United States give only primary treatment to their sewage, this process by itself is considered entirely inadequate for most needs.

Today's cities and industry, faced with increased amounts of wastes and wastes that are more difficult to remove from water, have turned to secondary and even advanced waste treatment.

Secondary Treatment

Secondary treatment removes up to 90 percent of the organic matter in sewage by making use of the bacteria in it. The two principal types of secondary treatment are trickling filters and the activated-sludge process.

After the effluent leaves the sedimentation tank in the primary stage of treatment, it flows or is pumped to a facility using one or the other of these processes. A trickling filter is simply a bed of stones from three to ten feet deep through which the sewage passes. Bacteria gather and multiply on these stones until they can consume most of the organic matter in the sewage. The cleaner water trickles out through pipes in the bottom of the filter for further treatment.

The sewage is applied to the bed of stones in two principal ways. One method consists of distributing the effluent intermittently through a network of pipes laid on or beneath the surface of the stones.

Attached to these pipes are smaller, vertical pipes which spray the sewage over the stones.

Another much-used method consists of a vertical pipe in the center of the filter connected to rotating horizontal pipes which spray the sewage continuously upon the stones.

The trend today is toward the use of the activated sludge process instead of trickling filters. This process speeds up the work of the bacteria by bringing air and sludge heavily laden with bacteria into close contact with the sewage.

After the sewage leaves the settling tank in primary treatment, it is pumped to an aeration tank where it is mixed with air and sludge loaded with bacteria and allowed to remain for several hours. During this time, the bacteria break down the organic matter.

From the aeration tank, the sewage, now called mixed liquor, flows to another sedimentation tank to remove the solids. Chlorination of the effluent completes the basic secondary treatment.

The sludge, now activated with additional millions of bacteria and other tiny organisms, can be used again by returning it to an aeration tank for mixing with new sewage and ample amounts of air.

The activated sludge process, like most other techniques, has advantages and limitations. The size of the units necessary for this treatment is small, thereby requiring less land space and the process is free of flies and odors. But it is more costly to operate than the trickling filter, and the activated sludge process sometimes loses its effectiveness when faced with difficult industrial wastes.

An adequate supply of oxygen is necessary for the activated sludge process to be effective. Air is mixed with sewage and biologically active sludge in the aeration tanks by three different methods.

The first, mechanical aeration, is accomplished by drawing the sewage from the bottom of the tank and spraying it over the surface, thus causing the sewage to absorb large amounts of oxygen from the atmosphere.

In the second method, large amounts of air under pressure are piped down into the sewage and forced out through openings in the pipe. The third method is a combination of mechanical aeration and the forced air method.

The final phase of the secondary treatment consists of the addition of chlorine to the effluent coming from the trickling filter or the activated sludge process. Chlorine is usually purchased in liquid form, converted to a gas, and injected into the effluent 15 to 30 minutes before the treated water is discharged into a water-course. If done properly, chlorination will kill more than 99 percent of the harmful bacteria in an effluent.

Lagoons and Septic Tanks

There are many well-populated areas in the United States that are not served by any sewer systems or waste treatment plants. Lagoons and septic tanks are the usual alternatives in such situations.

A septic tank is simply a tank buried in the ground to treat the sewage from an individual home. Waste water from the home flows into the tank where bacteria in the sewage break down the organic matter and the cleaner water flows out of the tank into the ground through sub-surface drains. Periodically the sludge or solid matter in the bottom of the tank must be removed and disposed of.

In a rural setting, with the right kind of soil and the proper location, the septic tank is a safe and effective means of disposing of strictly domestic wastes. Septic tanks should always be located so that none of the effluent can seep into wells used for drinking.

Lagoons or, as they are sometimes called, stabilization or oxidation ponds also have several advantages when used correctly.

They can give sewage primary and secondary treatment or they can be used to supplement other processes.

A lagoon is a scientifically constructed pond, usually three to five feet deep, in which sunlight, algae, and oxygen interact to restore water to a quality equal to or better than effluent from secondary treatment. Changes in the weather affect how well a lagoon will break down the sewage.

When used with other waste treatment processes, lagoons can be very effective. A good example of this is the Santee, California, water reclamation project. After conventional primary and secondary treatment by activated sludge, the town's waste water is kept in a lagoon for 30 days. Then the effluent, after chlorination, is pumped to land immediately above a series of lakes and allowed to trickle down through sandy soil into the lakes. The resulting water is of such good quality, the residents of the area can swim, boat, and fish in the lake water.

THE NEED FOR FURTHER TREATMENT OF WASTES

In the past, pollution control was concerned primarily with problems caused by domestic and the simpler wastes of industry. Control was aimed principally towards protecting downstream public water supplies and stopping or preventing nuisance conditions.

Pollution problems were principally local in extent and their control a local matter.

This is no longer true. National growth and change have altered this picture. Progress in abating pollution has been outdistanced by population growth, the speed of industrial progress and technological developments, changing land practices, and many other factors.

The increased production of goods has greatly increased the amounts of common industrial wastes. New processes in manufacturing are producing new, complex wastes that sometimes defy present pollution control technology. The increased application of commercial fertilizers and the devlopment and widespread use of a vast array of new pesticides are resulting in a host of new pollution problems from water draining off land.

The growth of the nuclear energy field and the use of radioactive materials foreshadow still another complicating and potentially serious water pollution stiuation.

Long stretches of both interstate and intrastate streams are subjected to pollution which ruins or reduces the use of the water for many purposes. Conventional biological waste treatment processes are hard-pressed to hold the pollution line, and for a growing number of our larger cities, these processes are no longer adequate.

Our growing population not only is packing our central cities but spreading out farther and farther into suburbia and exurbia. Across the country, new satellite communities are being born almost daily. The construction or extension of sewer lines has not matched either the growth rate or its movements. Sea water intrusion is a growing problem in coastal areas. It is usually caused by the excessive pumping of fresh water from the ground which lowers the water level, allowing salt water to flow into the ground water area.

The Types of Pollutants

Present-day problems that must be met by sewage treatment plants can be summed up in the eight types of pollutants affecting our waters.

The eight general categories are: common sewage and other oxygen-demanding wastes; disease-causing agents; plant nutrients; synthetic organic chemicals; inorganic chemicals and other mineral substances; sediment; radioactive substances; and heat.

Oxygen-demanding wastes -- These are the traditional organic wastes contributed by domestic sewage and industrial wastes of plant and animal origin. Besides human sewage, such wastes result from food processing, paper mill production, tanning, and other manufacturing processes. These wastes are usually destroyed by bacteria if there is sufficient oxygen present in the water. Since fish and other aquatic life depend on oxygen for life, the oxygen-demanding wastes must be controlled, or the fish die.

Disease-causing agents -- This category includes infectious organisms which are carried into surface and ground water by sewage from cities and institutions, and by certain kinds of industrial wastes, such as tanning and meat packing plants. Man or animals come in contact with these microbes either by drinking the water or through swimming, fishing, or other activities. Although modern disinfection techniques have greatly reduced the danger of this type of pollutant, the problem must be watched constantly.

Plant nutrients -- These are the substances in the food chain of aquatic life, such as algae and water weeds, which support and stimulate their growth. Nitrogen and phosporus are the two chief nutrients present in small amounts in natural water, but much larger amounts are contributed by sewage, certain industrial wastes, and drainage from fertilized lands. Biological waste treatment processes do not remove the nutrients -- in fact, they convert the organic forms of these substances into mineral form, making them more usable by plant life. The problem starts when an excess of these nutrients over-stimulates the growth of water plants which cause unsightly conditions, interfere with treatment processes, and cause unpleasant and disagreeable tastes and odors in the water.

Synthetic organic chemicals -- Included in this category are detergents and other household aids, all the new synthetic organic pesticides, synthetic industrial chemicals, and the wastes from their manufacture. Many of these substances are toxic to fish and aquatic life and possibly harmful to humans. They cause taste and odor problems, and resist conventional waste treatment.

Some are known to be highly poisonous at very low concentrations. What the long-term effects of small doses of toxic substances may be is not yet known.

Inorganic chemicals and mineral substances -- A vast array of metal salts, acids, solid matter, and many other chemical compounds are included in this group. They reach our waters from mining and manufacturing processes, oil field operations, agricultural practices, and natural sources. Water used in irrigation picks up large amounts of minerals as it filters down through the soil on its way to the nearest stream. Acids of a wide variety are discharged as wastes by industry, but the largest single source of acid in our water comes from mining operations and mines that have been abandoned.

Many of these types of chemicals are being created each year. They interfere with natural stream purification; destroy fish and other aquatic life; cause excessive hardness of water supplies; corrode expensive water treatment equipment; increase commercial and recreational boat maintenance costs; and boost the cost of waste treatment.

Sediments -- These are the particles of soils sands, and minerals washed from the land and paved areas of communities into the water. Construction projects are often large sediment producers. While not as insidious as some other types of pollution, sediments are a major problem because of the sheer magnitude of the amount reaching our waterways. Sediments fill stream channels and harbors, requiring expensive dredging, and they fill reservoirs, reducing their capacities and useful life. They erode power turbines and pumping equipment, and reduce fish and shellfish populations by blanketing fish nests and food supplies.

More importantly, sediments reduce the amount of sunlight penetrating the water. The sunlight is required by green aquatic plants which produce the oxygen necessary to normal stream balance. Sediments greatly increase the treatment costs for municipal and industrial water supply and for sewage treatment where combined sewers are in use.

Radioactive substances -- Radioactive pollution results from the mining and processing of radioactive ores; from the use of refined radioactive materials in power reactors and for industrial, medical, and research purposes; and from fallout following nuclear weapons testing. Increased use of these substances poses a potential public health problem. Since radiation accumulates in humans, control of this type of pollution must take into consideration total exposure in the human environment -- water, air, food, occupation, and medical treatment.

Heat -- Heat reduces the capacity of water to absorb oxygen. Tremendous volumes of water are used by power plants and industry for cooling. Most of the water, with the added heat, is returned to streams, raising their temperatures. With less oxygen, the water is not as efficient in assimilating oxygen-consuming wastes and in supporting fish and aquatic life.

Water in lakes or stored in impoundments can be greatly affected by heat. Summer temperatures heat up the surfaces, causing the water to form into layers, with the cooler water forming the deeper layers. Decomposing vegetative matter from natural and man-made pollutants deplete the oxygen from these cooler lower layers with harmful effects on the aquatic life. When the oxygen deficient water is discharged from the lower gates of a dam, it may have serious effects on downstream fish life and reduce the ability of the stream to assimilate downstream pollution.

To complicate matters, most of our wastes are a mixture of the eight types of pollution, making the problems of treatment and control that much more difficult.

Municipal wastes usually contain oxygen-consuming pollutants, synthetic organic chemicals such as detergents, sediments, and other types of pollutants. The same is true of many industrial wastes which may contain, in addition, substantial amounts of heat from cooling processes. Water that drains off the land usually contains great amounts of organic matter in addition to sediment. Also, land drainage may contain radioactive substances and pollutants washed from the sky, vegetation, buildings, and streets during rainfall.

ADVANCED METHODS OF TREATING WASTES

These new problems of a modern society have placed additional burdens upon our waste treatment systems. Today's pollutants are more difficult to remove from the water. And increased demands upon our water supply aggravate the problem. During the dry season, the flow of rivers decreases in assimilating the effluent from waste treatment plants.

In the future, these problems will be met through better and more complete methods of removing pollutants from water and better means for preventing some wastes from even reaching our streams in the first place.

The best immediate answer to these problems is the widespread application of existing waste treatment methods. Many cities that have only primary treatment need secondary treatment. Many other cities need enlarged or modernized primary and secondary systems.

But this is only a temporary solution. The discharge of oxygen-consuming wastes will increase despite the universal application of the most efficient waste treatment processes now available. And these are the simplest wastes to dispose of. Conventional treatment processes are already losing the battle against the modern-day, tougher wastes.

The increasing need to reuse water now calls for better and better waste treatment. Every use of water--whether in home, in the factory, or on the farm--results in some change in its quality.

To return water of more usable quality to receiving lakes and streams, new methods for removing pollutants are being developed. The advanced waste treatment techniques under investigation range from extensions of biological treatment capable of removing nitrogen and phosphorus nutrients to physical-chemical separation techniques such as adsorption, distillation, and reverse osmosis.

These new processes can achieve any degree of pollution control desired and, as waste effluents are purified to higher and higher degrees by such treatment, the point is reached where effluents become "too good to throw away."

Such water can be deliberately and directly reused for agricultural, industrial, recreational, or even drinking water supplies. This complete water renovation will mean complete pollution control and at the same time more water for the Nation.

Coagulation-Sedimentation

The application of advanced techniques for waste treatment, at least in the next several years, will most likely take up where primary and secondary treatment leave off. Ultimately, entirely new systems will no doubt replace the modern facilities of today.

The process known as coagulation-sedimentation may be used to increase the removal of solids from effluent after primary and secondary treatment. Besides removing essentially all of the settleable solids, this method can, with proper control and sufficient addition of chemicals, reduce the concentration of phosphate by over 90 percent.

In this process, alum or lime is added to effluent as it comes from the secondary treatment. The flow then passes through flocculation tanks where the chemicals cause the smaller particles to floc or branch together into large masses.

The larger masses of particles or lumps will settle faster when the effluent reaches the next step -- the sedimentation tank.

Although used for years in the treatment of industrial wastes and in water treatment, coagulation-sedimentation is classified as an advanced process because it is not usually applied to the treatment of municipal wastes. In many cases, the process is a necessary pre-treatment for some of the other advanced techniques.

Adsorption

After the removal of most of the solids, the next problem facing the advanced waste treatment system is to get rid of the dissolved refractory organics. As the word indicates, this is the stubborn organic matter which persists in water and resists normal biological treatment.

The effects of the organics are not too well understood, but taste and odor problems in water, tainting of fish flesh, foaming of water and fish kills have been attributed to such materials.

Adsorption consists of passing the effluent through a bed of activated carbon granules which will remove more than 98 percent of the organics. To cut down the cost of the procedure, the carbon granules can be cleaned by heat and used again.

An improvement of the process through the use of powdered carbon is under study. Rather than pass the effluent through a bed of granules, the powdered carbon is put directly into the stream. The organics stick to the carbon and then the carbon is removed from the effluent by using coagulating chemicals and allowing the coagulated carbon particles to settle in a tank.

As would be expected, this finely ground carbon will take out even more of the refractory, or stubborn, organics. The potential widespread use of powdered carbon adsorption depends largely on the effectiveness of regenerating the carbon for use again.

Except for the salts added during the use of water, municipal waste water that has gone through the previous advanced processes will be restored to a chemical quality almost the same as before it was used.

When talking of salts in water, salt is not limited to the common kind that is used in the home for seasoning food. In waste treatment language, salts mean the many minerals dissolved by water as it passes thorugh the air as rainfall, as it trickles through the soil and over rocks, and as it is used in the home and factory.

Electrodialysis

Electrodialysis is a rather complicated process by which electricity and membranes are used to remove salts from an effluent. A membrane is usually made of chemically treated plastic. The salts are forced out of the water by the action of an electric field. When a mineral salt is placed in water it has a tendency to break down into ions. An ion is an atom or a small group of atoms having an electrical charge.

As an example, the two parts of common table salt are sodium and chlorine. When these two elements separate as salt dissolves in water, the sodium and chlorine particles are called ions. Sodium ions have a positive charge while chlorine ions have a negative charge.

When the effluent passes through the electrodialysis cell the positive sodium ions are attracted through a membrane to a pole or electrode that is negatively charged. The negatively charged chlorine ions are pulled out of the water through another membrane toward an electrode with a positive charge.

With the salts removed by the action of the two electrodes, the clean water flows out of the electrodialysis cell for reuse or discharge into a river or stream.

When a typical city uses its water the amount of salts in the water doubles. Fortunately, electrodialysis can reduce the amount of salts by about one-half or more. In other words, this process returns the salt content of the water back to where it was or even better than when the city first received the water.

The Blending of Treated Water

Properly designed and applied, the methods that have been explained will be able to supply any quality of water for any reuse.

But none of these process will stand alone. They must be used in a series or a parallel plan. In a series, all the sewage passes through all the processes, one after another, each process making a particular contribution toward improving the water. For example, the conventional primary treatment removes the material that will readily settle or float; the secondary biological step takes care of the decomposable impurities; coagulation-sedimentation, the third step, eliminates the suspended solids; carbon adsorption removes the remaining dissolved organic matter electrodialysis returns the level of the salts to what it was before the water was used; and, finally, chlorination provides the health safety barrier against disease carriers.

Basically the same result can be achieved by separating the effluent into two streams. In this instance, all of the waste receives the primary and secondary treatment but then is divided. Part of the effluent passes through the coagulation-sedimentation and adsorption processes which remove the organic matter. The other half of the sewage is treated by evaporation and adsorption to remove all impurities including the minerals.

After going separate ways, the two streams are mixed together, chlorinated, and then are ready for reuse or discharge into a stream. Splitting the effluent into two streams and then reblending helps reduce the cost of waste treatment for a more expensive process such as distillation.

Distillation or evaporation basically consists of bringing the effluent to the boiling point. The steam or vapor produced is piped to another chamber where it is cooled, changing it back to a liquid. The unwanted minerals and other impurities remain in the original chamber.

As most people have discovered, distilled water has a flat, disagreeable taste caused by the absence of minerals and air. But by blending this pure water with water that still contains some minerals, a clean, better tasting water results. And just as importantly, the more expensive distillation process is used on only part of the effluent, and the rest of the waste water is treated by the less costly procedures.

NEW CHALLENGES FOR WASTE TREATMENT

So far, the most readily available processes that will solve most current pollution problems have been covered. But the future holds many new challenges. Scientists are still looking for the ultimate system that will do the complete job of cleaning up water, simply and at a reasonable cost.

One such possible process under study is reverse osmosis. When liquids with different concentrations of mineral salts are separated by a membrane, molecules of pure water tend to pass by osmosis from the more concentrated to the less concentrated side until both liquids have the same mineral content.

Scientists are now exploring ways to take advantage of the natural phenomena of osmosis, but in reverse. When pressure is exerted on the side with the most minerals, this natural force reverses itself, causing the molecules of pure water to flow out of the compartment containing a high salt concentration.

This means that perfectly pure water is being taken out of the waste, rather than taking pollutants out of water as is the traditional way. And this process takes clean water away from everything - bacteria, detergents, nitrates.

Tests have shown that the theory works well, resulting in water good enough to drink. Efforts are now under way to develop large membranes with long life. Also, the process and equipment need to be tested on a large scale.

Many other techniques to improve waste treatment are under development in laboratories and in the field.

For example, special microscopic organisms are being tested for removing nitrates from waste water by reducing the nitrates to elemental nitrogen.

Chemical Oxidation

Municipal waste waters contain many organic materials only partially removed by the conventional treatment methods. Detergents are a good example. Oxidants such as ozone and chlorine have been used for many years to improve the taste and odor qualities or to disinfect municipal drinking water. They improve the quality of the water by destroying or altering the structure of the chemicals in the water.

However, the concentration of the organic materials in drinking water supplies is much less than it is in the waste-bearing waters reaching treatment plants. Until recently, the cost of the oxidants has prevented the use of this process in the treating of wastes. Now, improvements in the production and application of ozone and pure oxygen may reduce costs sufficiently to make their use practicable. When operated in conjunction with other processes, oxidation could become an effective weapon in eliminating wastes resistant to other processes.

Polymers and Pollution

In discussing the coagulation-sedimentation process, mention was made of the use of alum or lime to force suspended solids into larger masses. The clumping together helps speed up one of the key steps in waste treatment - the separation of solids and liquids.

During the past 10 to 15 years, the chemical industry has been working on synthetic organic chemicals, known as polyelectrolytes or polymers, to further improve the separation step.

Formerly, polymers have proved effective when used at a later stage of treatment - the sludge disposal time. Sludge must be dried so that it can be more easily disposed of. By introducing polymers into the sludge, the physical and chemical bonds between the solids are tightened. When this happens, the water can be extracted more rapidly.

Wider use of polymers is now being investigated. By putting polymers into streams or rivers, it may be possible to capture silt at specified locations so that it can be removed in quantity.

If polymers are put into raw sewage, waste treatment plants may be able to combine a chemical process with the standard primary and secondary stages. And this method of removing solids can be applied immediately without lengthy and expensive addition of buildings or new facilities.

The chemicals also hold promise as a means of speeding the flow of waste waters through sewer systems, thus, in effect, increasing the capacity of existing systems.

THE PROBLEM OF WASTE DISPOSAL

No matter how good the treatment of wastes, there is always something left over. It may be the rags and sticks that were caught on the screens at the very beginning of the primary treatment. It could be brine or it could be sludge -- that part of the sewage that settles to the bottom in sedimentation tanks. Whatever it is, there is always something that must be burned, buried, or disposed of in some manner.

It is a twofold problem. The sludge or other matter must be disposed of to complete a city's or industry's waste treatment. And it must be disposed of in a manner not to add to or upset the rest of the environmet.

If it is burned, it must be done in a way not to add to the pollution of the atmosphere. This would only create an additional burden for our already overburdened air to cope with. And air pollutants by the action of rain and wind have a habit of returning to the water, complicating the waste treatment problem rather than helping it.

There are many methods and processes for dealing with the disposal problem, which is sometimes referred to as the problem of ultimate disposal. The most common method for disposing of sludge and other waste concentrates consists of digestion followed by filtration and incineration.

The digestion of sludge takes place in heated tanks where the material can decompose naturally and the odors can be controlled. As digested sludge consists of 90 to 95 percent water, the next step in disposal must be the removal of as much of the water as possible.

Water can be removed from sludge by use of a rotating filter drum and suction. As the drum rotates in the sludge, the water is pulled through the filter and the residues are peeled off for disposal. For more effective dewatering, the sludge can be first treated with a coagulant chemical such as lime or ferric chloride to produce larger solids before the sludge reaches the filter.

Drying beds which are usually made of layers of sand and gravel can be used to remove water from sludge. The sludge is spread over the bed and allowed to dry. After a week or two of drying, the residue will be reduced in volume and, consequently, will be easier to dispose of on land or in water.

Incineration consists of burning the dried sludge to reduce the residues to a safe, non-burnable ash. The ash can be disposed of by filling unused land or by dumping it well out into the ocean. Since most of the pollutants have been removed by the burning, the ash will cause very little change in the quality of the water.

A very promising new method of sludge disposal gets rid of the unwanted sludge and helps restore a ravaged countryside. In many areas of the country, tops of hills and mountains were sliced away to get at the coal beneath. This strip mining left ugly gashes and scars in otherwise beautiful valleys of many States. It would take nature many years to restore the denuded areas.

With the new disposal idea, digested sludge in semi-liquid form is piped to the spoiled areas. The slurry, containing many nutrients from the wastes, is spread over the land to give nature a hand in returning grass, trees, and flowers to the barren hill-tops.

Restoration of the countryside will also help in the control of acids that drain from mines into streams and rivers, endangering the fish and other aquatic life and adding to the difficulty in reusing the water. Acids are formed when pyrite containing iron and sulfur is exposed to the air.

Sludge or other waste concentrates are not always costly burdens. By drying and other proceses, some cities have produced fertilizers that are sold to help pay for part of the cost of treating wastes. If not sold to the public, some municipalities use the soil enrichers on parks, road parkways, and other public areas.

Some industries have found they can reclaim certain chemicals during waste treatment and reuse them in manufacturing or refining processes. Other firms have developed saleable by-products from residues in waste treatment.

More studies are going on to find greater use for sludge to help solve the disposal problem and to help offset the cost of waste treatment.

COMMON SEWAGE TREATMENT TERMINOLOGY

Activated Sludge process removes organic matter from sewage by saturating it with air and biologically active sludge.

Adsorption is an advanced way of treating wastes in which carbon removes organic matter not responsive to clarification or biological treatment.

Aeration Tank serves as a chamber for injecting air into water.

Algae are plants which grow in sunlit waters. They are a food for fish and small aquatic animals and, like all plants, put oxygen in the water.

Bacteria are the smallest living organisms which literally eat the organic parts of sewage.

BOD, or biochemical oxygen demand, is the amount of oxygen necessary in the water for bacteria who consume the organic sewage. It is used as a measure in telling how well a sewage treatment plant is working.

Chlorinator is a device for adding chlorine gas to sewage to kill infectious germs.

Coagulation is the clumping together of solids to make them settle out of the sewage faster. Coagulation of solids is brought about with the use of certain chemicals such as lime, alum, or polyelectrolytes.

Combined Sewer carries both sewage and storm water run-off.

Communitor is a device for the catching and shredding of heavy solid matter in the primary stage of waste treatment.

Diffused Air is a technique by which air under pressure is forced into sewage in an aeration tank. The air is pumped down into the sewage through a pipe and escapes out through holes in the side of the pipe.

Digestion of sludge takes place in heated tanks where the material can decompose naturally and the odors can be controlled.

Distillation in waste treatment consists of heating the effluent and then removing the vapor or steam. When the steam is returned to a liquid it is almost pure water. The pollutants remain in the concentrated residue.

Effluent is the liquid that comes out of a treatment plant after completion of the treatment process.

Electrodialysis is a process by which electricity attracts or draws the mineral salts from sewage.

Floc is a clump of solids formed in sewage when certain chemicals are added.

Flocculation is the process by which certain chemicals form clumps of solids in sewage.

Incineration consists of burning the sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash. The ash can then be disposed of safely on land, in some waters, or into caves or other underground locations.

Interceptor sewers in a combined system control the flow of the sewage to the treatment plant. In a storm, they allow some of the sewage to flow directly into a receiving stream. This protects the treatment plant from being overloaded in case of a sudden surge of water into the sewers. Interceptors are also used in separate sanitation systems to collect the flows from main and trunk sewers and carry them to the points of treatment.

Ion is an electrically charged atom or group of atoms which can be drawn from waste water during the electrodialysis process.

Lateral sewers are the pipes that run under the streets of a city and into which empty the sewers from homes or businesses.

Lagoons are scientifically constructed ponds in which sunlight, algae, and oxygen interact to restore water to a quality equal to effluent from a secondary treatment plant.

Mechanical Aeration begins by forcing the sewage up through a pipe in a tank. Then it is sprayed over the surface of tank, causing the waste stream to absorb oxygen from the atmosphere.

Microbes are minute living things, either plant or animal. In sewage, microbes may be germs that cause disease.

Mixed Liquor is the name given the effluent that comes from the aeration tank after the sewage has been mixed with activated sludge and air.

Molecule is the smallest particle of an element or compound that can remain in a free state and still keep the characteristics of the element or compound.

Organic Matter is the waste from homes or industry of plant or animal origin.

Oxidation is the consuming or breaking down of organic wastes or chemicals in sewage by bacteria and chemical oxidants.

Oxidation Pond is a man-made lake or body of water in which wastes are consumed by bacteria. It is used most frequently with other waste treatment processes. An oxidation pond is basically the same as a sewage lagoon.

Primary Treatment removes the material that floats or will settle in sewage. It is accomplished by using screens to catch the floating objects and tanks for the heavy matter to settle in.

Pollution results when something -- animal, vegetable, or mineral -- reaches water, making it more difficult or dangerous to use for drinking, recreation, agriculture, industry, or wildlife.

Polyelectrolytes are synthetic chemicals used to speed the removal of solids from sewage. The chemicals cause the solids to coagulate or clump together more rapidly than chemicals like alum or lime.

Receiving Waters are rivers, lakes, oceans, or other water courses that receive treated or untreated waste waters.

Salts are the minerals that water picks up as it passes through the air, over and under the ground, and through household and industrial uses.

Sand Filter removes the organic wastes from sewage. The waste water is trickled over the bed of sand. Air and bacteria decompose the wastes filtering through the sand. The clean water flows out through drains in the bottom of the bed. The sludge accumulating at the surface must be removed from the bed periodically.

Sanitary Sewers, in a separate system, are pipes in a city that carry only domestic waste water. The storm water runoff is taken care of by a separate system of pipes.

Secondary Treatment is the second step in most waste treatment systems in which bacteria consume the organic parts of the wastes. It is accomplished by bringing the sewage and bacteria together in trickling filters or in the activated sludge process.

Sedimentation Tanks help remove solids from sewage. The waste water is pumped to the tanks where the solids settle to the bottom or float on top as scum. The scum is skimmed off the top, and solids on the bottom are pumped out to sludge digestion tanks.

Septic Tanks are used to treat domestic wastes. The underground tanks receive the waste water directly from the home. The bacteria in the sewage decomposes the organic waste and the sludge settles on the bottom of the tank. The effluent flows out of the tank into the ground through drains. The sludge is pumped out of the tanks, usually by commerical firms, at regular intervals.

Sewers are a system of pipes that collect and deliver waste water to treatment plants or receiving streams.

Sludge is the solid matter that settles to the bottom of sedimentation tanks and must be disposed of by digestion or other methods to complete waste treatment.

Storm Sewers are a separate system of pipes that carry only run-offs from buildings and land during a storm.

Suspended Solids are the wastes that will not sink or settle in sewage.

Trickling Filter is a bed of rocks or stones. The sewage is trickled over the bed so the bacteria can break down the organic wastes. The bacteria collect on the stones through repeated use of the filter.

Waste Treatment Plant is a series of tanks, screens, filters, and other processes by which pollutants are removed from water.

"Water Pollution: The Options of Control"[a]
from
A report by the Environmental Protection Agency

> We are left...with only a single certainty. A large portion of all U. S. waters consistently demonstrate quality characteristics that violate established criteria. These violations occur in densely populated and sparsely populated areas, in humid and arid climates, in industrialized, in agricultural, and in forested regions, and apparently without reference to either the prevalence or the intensity of waste treatment. The lack of a pattern makes it impossible to judge whether conditions are improving or deteriorating; but the consistency of the pattern of pollution suggests that there may be inefficiencies in current approaches to pollution abatement. --The Cost of Clean Water[1]

The invisible hand, that remarkable device that Adam Smith finds operating in the market economy to direct resources in the simultaneous prusuit of private gain and the common good, appears to falter badly in guiding the use of some natural resources. The magnitude of water pollution in the United States, for example, as well as other cases of environmental degradation, is in large part due to the failure of the market economy to impose the full environmental costs upon resource users. These costs, which take the form of polluted air and water, endangered wildlife species, and commercialized natural and scenic areas, are frequently shifted to third parties or to the public at large. This has happened because the private market has treated some resources, such as air, water, and wildlife, as essentially free goods, available for little or no charge as raw materials for production or as vehicles for waste disposal.

Because important environmental costs are not covered in the resource-use charges, the market economy's adjustment, in terms of both least firm cost and broader "public interest" objectives, falls short of the ideal. Since a polluting firm's prices do not fully reflect environmental costs, insufficient market distinction is made between production processes that create pollution and those that are without harmful effects upon the environment.

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[a]Environmental Issues: Population, Pollution and Economics. Edited by Lawrence G. Hines, W. W. Norton & Company, Inc., New York, 1973. ISBN #039309331

[1]Report to Congress by the Water Quality Office of the Environmental Protection Agency (Washington, D.C.: Government Printing Office, 1971), Vol. II, P. 55.

If there were a price penalty for polluting, the costs of abatement would be imposed upon the production process and adjustments would be made in resource use.

If environmental costs are not included in the producing firm's production outlays, they emerge at a variety of other places: in increased treatment costs for municipal and industrial water supplies; in water recreation that is of lower quality and at the same time less available and more costly; in increased health hazards from polluted waters, and added expenditures for disease and associated rehabilitation; and in the aesthetic degradation that accompanies pollution. In determining the appropriate approach to pollution abatement, "internalizing" environmental costs within the firm is a secondary but important objective. Some approaches will achieve the dual objectives of abatement and internalization of costs better than others.

The Emergence of a Water-Pollution-Control Program

Because really obvious external costs of water pollution did not arise until recent decades, when population and technology overloaded the capacity of many of the nation's streams and lakes to absorb wastes, the early concern about water pollution was limited primarily to those cases in which it was a health hazard. Water-borne epidemics, such as typhoid outbreaks in the middle and late nineteenth centry in North Boston, New York, and Plymouth, Pennsylvania, were the main reason for the early interest in controlling pollution, and the spread of chlorination of drinking-water supplies afforded most communities a less costly and more efficient means of protection than that of controlling pollution through waste treatment. Moreover, the pollution-abatement approach to water quality is more likely to be helpful to the downstream community than to the one building the treatment plant, and even with pollution abatement, moderate chlorination of the drinking-water supply is almost always recommended by health authorities.

Throughout the early half of the twentieth century, water pollution was viewed mainly as a local health issue; not until the mid-1950's did the federal government become active in promoting pollution abatement. The federal program, administered originally by the Public Health Service, consisted mainly of grants by the federal governement to encourage the construction of municipal waste-treatment facilities. The construction-grants approach to pollution control is still the mainstay of the federal water-pollution-control program, but other regulatory features have been combined with it. Recently, the federal control of water pollution has been vested in the Environmental Protection Agency. This agency, established along with the Council on Environmental Quality in 1970, has been given responsibility for programs dealing with air and water pollution, solid-waste disposal, and other areas of environmental concern.

Although there are important cases of interstate water pollution, where wastes from one state pollute a river or stream flowing through another state, the fact remains that water pollution originates at a specific location and control must be imposed at this point. Following the traditional federal-state division of authority, the jurisdiction over water pollution by the federal government was originally restricted to interstate or navigable waters, narrowly interpreted,* and it does not extend beyond the three-mile limit in our ocean areas. These limitations, particularly the inability to exercise control beyond the three-mile limit, have restricted the role of the federal government in pollution abatement, preventing any effective check upon the many localities that dump their wastes at sea.

Because of the division of authority in the American system, the federal government has found it necessary to resort to stratagems of indirection to persuade states and localities to cooperate in pollution-abatement programs. The standard form of federal persuasion has been the matched grant--financial aid from the federal government to assist in the attainment of a specific objective, such as the construction by a locality of a waste-treatment plant or the establishment by a state of a system of water-quality standards.

The Federal Construction-Grants Program

Initiated in 1956 on a relatively small scale, the federal water-pollution-control construction-grants program reached a combined federal-state-local expenditure level of approximately 5 billion dollars annually in the early 1970's. Under this program, starting in 1973 the federal government contributed 75 percent, and the state or municipality paid the remaining 25 percent, for local sewage-treatment facilities. In addition to assistance for the construction of sewage-treatment plants and interceptor sewers, grants are available under the federal program for the training of sewage-treatment-plant operators, for research in waste-treatment techniques, and for the construction and operation of demonstration waste-treatment plants, but these are of secondary importance compared with the outlays for municipal waste-treatment facilities.

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*For some purposes, such as regulation by the Federal Power Commission, the Supreme Court has accepted an interpretation of "navigable waters" that is so broad--including any stream deep enough to float logs, for example--that virtually no limitation has been placed on federal control. (Citizens Utility Company v. FPC, 297 F 2d. 1; 34 PUR 3d 481 [1960].) In the case of federal water-control activities, however, states have been very jealous of their authority and protective of the cost advantages that industry within their borders enjoys as a result of lesser regulation. In recent years, however, federal jurisdiction has been extended to the tributaries of rivers flowing across state lines.

The federal water-pollution-control program carries the clear imprint of the federal-state division of authority and the congressional policy intent. Since Congress cannot involve itself directly in the pollution-abatement decisions of states and localities, it has relied upon financial incentives to obtain compliance. For example, the contribution of the federal government to the construction of waste-treatment plants is contingent upon a minimum of secondary treatment under circumstances where the effluent from the plant is discharged into receiving waters protected by enforceable federal or state water-quality standards. By making grants contingent upon such qualifications, the federal government influences both the states' priorities of expenditures and the adoption of water-quality standards--increasing the states' share of water-pollution expenditures and stiffening the water-quality standards By establishing qualifications for the receipt of a grant and then making the financial incentive attractive, the federal government virtually assures that the lower levels of government will take actions they otherwise might delay or neglect.

Congressional preferences have been apparent in another aspect of the grants program--the formula for apportioning funds to states and localities. During the early years of the program, the federal contribution was limited to $250,000 per project, which meant that the program did not make a significant impact upon the needs of the larger communities, for whom a $250,000 contribution was inconsequential. The ceiling on the federal contribution was raised over the years and eventually removed, in 1968, but by this time the effect of the limitation was clearly apparent in the lag in the construction of waste-treatment facilities for larger cities. Whatever was the cause of this early arrangement--the desire to spread funds instead of exhausting them in a few metropolitan areas, or simply a rural-town bias on the part of Congress--the effect was to allocate construction grants according to objectives unrelated to the severity of the pollution problem.

The Waste-Treatment Approach

The federal water-pollution-control program has directed its greatest effort toward municipal waste treatment. The larger and more complex problem of industrial water pollution has not been ignored, but nothing comparable to the considerable federal investment in municipal treatment plants has been available to industry. There are good reasons for this, only one of which is that already approximately 40 percent of the municipal systems' load consists of industrial wastes from firms that are connected to municipal sewers.

Virtually without exception, municipal pollution-abatement facilities are confined to primary and secondary waste treatment, based on mechanical and biological processes. Primary treatment, the first step in the treatment process--and sometimes the only step--consists of the mechanical removal of scums, solids, sticks, and various other debris, generally by settling. Even this limited form of treatment can reduce the biochemical oxygen demand (BOD) by as much as 30 percent. Unfortunately, the removal of sludge solids during primary and later treatment stages may simply redistribute rather than eliminate pollution, shifting it, for example, from the Philadelphia are to the New Jersey coast if sludge disposal takes place at sea. If the sludge is incinerated, pollution of the air is exchanged for pollution of the water. Attempts to "recycle" sludge as a fertilizer or soil conditioner have been less than successful. In most metropolitan areas, where there is large-scale production of sludge the landfill approach accentuates an already critical shortage of nearby sites that can be used for waste disposal.

Secondary waste treatment accomplishes within the treatment plant the aerobic decomposition of wastes that otherwise would take place in receiving waters where there is sufficient free oxygen. Secondary treatment commonly employs either a trickling filter or activated sludge to achieve the decomposition of organic wastes. The trickling filter is simply a bed of rocks, tile, or similar rubble-like material, over which the waste water flows, increasing its exposure to oxygen in the air and providing a medium for the saprophytic bacteria that are largely responsible for the decomposition of organic wastes. The trickling-filter process requires a somewhat larger area for its operation and is less flexible than the activated-sludge process, as employed, for example, in the secondary stage of the South Lake Tahoe plant illustrated in Figure 10.1, but the end result is the same. In the activated-sludge process, instead of passing over a bed of rocks to increase its exposure to exygen after leaving the primary settling tanks, the waste water is transferred to an aeration tank, where it is mixed with bacteria-saturated sludge and injected with air. If the process is operating properly and the bacteria are cooperative, a few hours is sufficient to reduce the BOD of most degradable organic wastes by as much as 90 percent.* If the waste treatment terminates at this stage, chlorination of the effluent before it is discharged into a watercourse will remove most pathogenic bacteria.

After secondary treatment, the waste water exerts greatly reduced demands upon the oxygen supply of the receiving waters, but it may still carry a considerable burden of nondegradable materials which have effects ranging from subtle to lethal and which persist for a long period in the nation's streams without decomposition. Large amounts of phosporus and nitrogen pass relatively unchanged through the biological treatment processes, and

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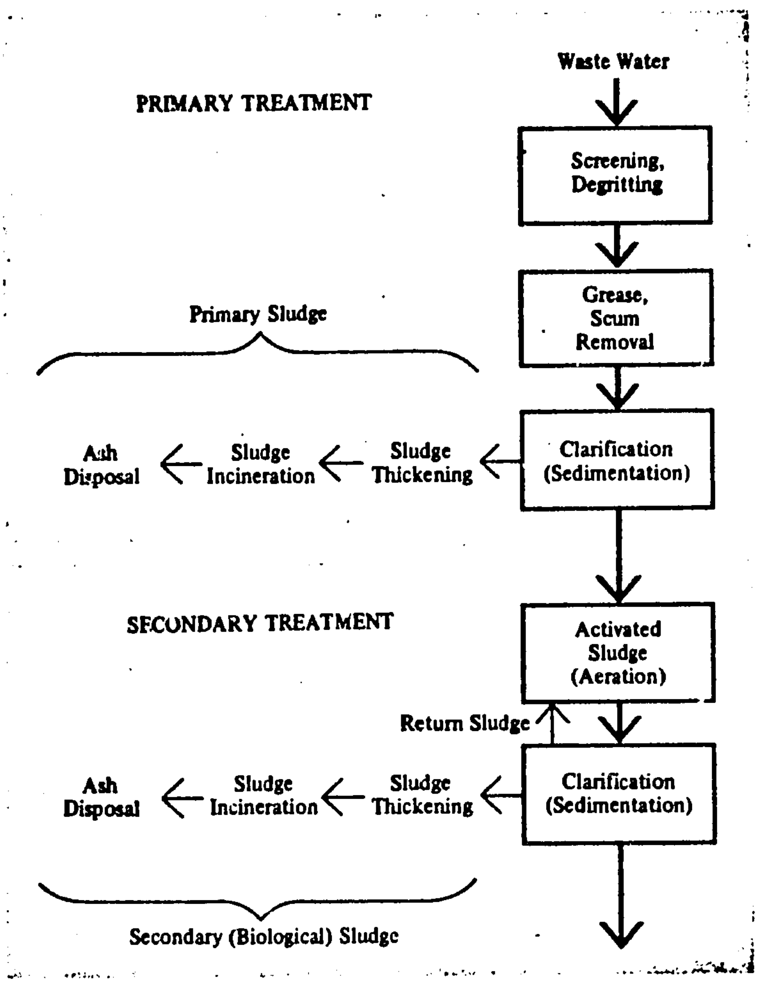
*A study by the Water Quality Office of the Environmental Protection Agency places the efficiency of the trickling-filter process in the United States at 81 percent mean BOD removal and that of the activated-sludge process at 87 percent mean BOD removal. (Ibid., p. 13.)

Figure 10.1. South Lake Tahoe, California, Primary and Secondary Treatment Facilities *



* Peter Forstenzer for *Fortune Magazine;* source for primary and secondary treatments: "Cleaning Our Environment—The Chemical-Basis for Action," American Chemical Society, 1969. Reproduced in *Fortune,* LXXXI (February 1970), p. 104.

secondary treatment is generally incapable of breaking down salts, most dyes, acids, the hard insecticides and herbicides, and a considerable variety of the new synthetic chemical compounds. Advances in the chemistry of synthetics have kept well ahead of the development of techniques to prevent new compounds from polluting the environment. Indeed, present methods of waste treatment have undergone very little basic change in the past half century. Leon Weinberger, former assistant commissioner of the Federal Water Pollution Control Administration, made the following appraisal of the lag in waste-treatment techniques in testimony before Congress in 1966:

> Present waste treatment methods were devised generally, for the pollution problems that existed 40 or more years ago. Although there have been improvements in these methods, they are proving to be increasingly inadequate for the concentration and complexities of many of today's wastes and the requirements being posed by the increased loads on receiving streams. In addition, no satisfactory methods were ever devised for many industrial wastes and some of the impurities found in municipal wastes.[2]

In response to concern over the growing deterioration of the environment, the federal government in 1970 undertook to ensure secondary treatment facilities for every community needing them and "also special additional treatment in areas of special need." At the time of the enunciation of this policy it was expected that the investment of the federal government would be somewhat greater than 2 billion dollars a year for five years--matched by a similar expenditure by state and local governments for a total of 20 billion dollars for the five-year period. Since 1970, the estimate has been revised upward for the required secondary-treatment investment, and if substantial advanced treatment is undertaken, investment costs will be many times those for primary and secondary facilities to process an equivalent amount of waste water.

The Costs of Transmission and Treatment

Before the wastes of home and industry can be neutralized by abatement, they must be collected and transported to the treatment plant. If a community does not have an integrated sewer system, the investment required to build such a system or correct the inadequacies of the existing system is likely to be much higher than the outlay for treatment facilities. And only limited financial assistance is likely to be available from higher levels of government to the local community for sewer construction. Assistance under the federal grants program is re-

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[2] The Adequacy of Technology for Pollution Abatement. Hearings of the House Subcommittee on Science, Research, and Development, 89th Congress, Second Session, Vol. I (Washington, D.C.: Governmental Printing Office, 1966), p. 139.

stricted to interceptor sewers and cannot be used for general modification of a sewer system. For the nation as a whole, the investment ratio of sewers to treatment facilities has been set at $1.75 for sewers to every $1.00 in treatment plants, and this ratio rises to $2.27/$1.00 in metropolitan areas. Although many sewer modifications are nonrecurring, they involve large investments and are a major financial hurdle for many communities.

Some smaller communities may find not only that the collection-and-treatment approach to pollution control involves large capital investment, but that the shift from ground disposal of wastes, as with the use of septic tanks, to stream disposal after treatment may acutally accelerate environmental deterioration when the treatment-plant effluent enriches the receiving waters. By concentrating the discharge of nutrient-rich effluent, the collection-and-treatment approach to water pollution may actually accentuate nuisance growth of vegetation.

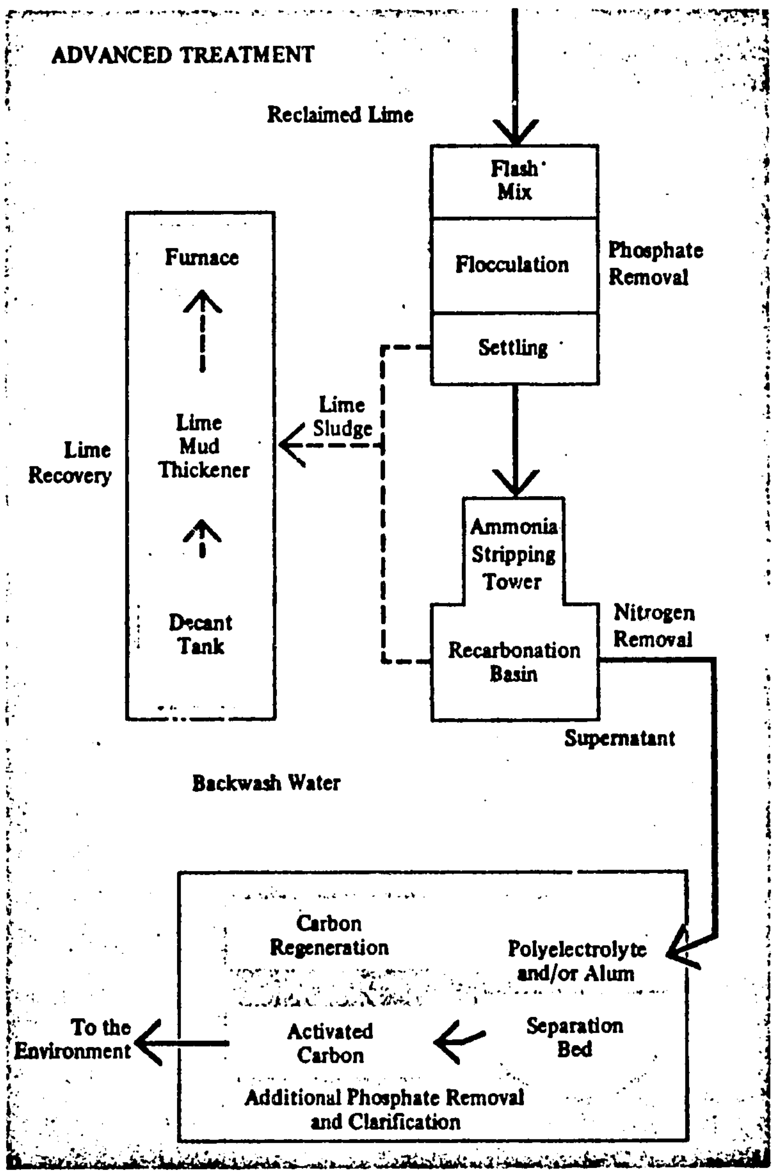
If the collection-treatment approach to water pollution is to check the fertilization of our lakes and rivers, biological treatment must be supplemented by more advanced physical-chemical techniques. Save for a few installations, such as the South Lake Tahoe, California, treatment complex, advanced treatment is still most likely to be encountered in the laboratory. Techniques of advanced treatment differ, but all are much more costly and complicated than the biological approach. The facility at the South Lake Tahoe plant, illustrated in Figure 10.2, is designed to combat two of the more troublesome by-products of modern society, phosphorus and nitrogen.

The Taft Sanitary Engineering Center, a federal pollution-control laboratory in Cincinnati, has devised a treatment process that performs much the same functions as that of the South Lake Tahoe plant, except for nitrogen removal. The Taft process is approximately five times as expensive as primary and secondary treatment combined, however, raising treatment costs to an estimated 58 cents per thousand gallons of waste water. This compares with an estimated cost average for primary treatment of 3 cents per thousand gallons and for secondary treatment of 7 cents per thousand gallons. Advanced treatment without nitrogen removal thus adds approximately 48 cents per thousand gallons to the cost. Any broad expansion of advanced-treatment facilities facing ths order of expense will add substantially to the costs for sewer modification and expansion of treatment facilities throughout the United States. Indeed, the cost of advanced treatment is so great that alternatives to the treatment approach become increasingly attractive.

Storm Sewers and Sanitary Sewers

Even though a community has a well-developed sewer system, it may be the wrong kind for protection of the environment. Periodically, many treatment plants in the United States are flooded with storm waters that flush their wastes untreated into

Figure 10.2. South Lake Tahoe, California, Advanced-Treatment Facility *



* Source: See Figure 10.1.

receiving streams. This occurs because many communities, including large metropolitan centers in the East, have sewer systems that combine street drainage (storm water) with sanitary flow (domestic and industrial wastes). To prevent the treatment facilities from being overrun, causing raw sewage to be discharged into the receiving waters, either a separate sewer system must take care of the storm flow or storage facilities must be available to hold back storm waters and permit them to pass through the treatment system so gradually that they do not disrupt the biological treatment process. Although a separate system of sanitary and storm sewers is generally considered preferable to storage, it is substantially more expensive and does nothing to reduce storm-water pollution. And in some cases--as in New York City and other large eastern centers--the costs of separating sewers may be so great and the technical problems so difficult that storm-water storage is the only feasible arrangement.

On the national scale, the problem is little less than staggering. Recent inventories show as many as 1,300 communities in the United States with combined sewer systems, and the national cost of separating these systems would greatly exceed that of providing secondary treatment to the communities involved. A frequently quoted estimate of the American Public Works Association places the expenditure for separation at 48 billion dollars and the lower-cost alternative of constructing storage facilities at 15 billion dollars. Admittedly, such estimates are rough approximations, subject to a wide range of error, but there is no doubt that the cost of changing the existing sewer systems would be extraordinarily large. And since the federal water-pollution-control construction-grants program is limited to treatment plants and interceptor sewer development, the costs of sewer modification would fall almost exclusively with heavy and unequal force upon the communities.

In view of a recent study by the Water Quality Office, which indicates that storm-water runoff in some areas may be a significant source of stream pollution, the construction of storage facilities actually appears preferable to sewer separation. Impounding storm waters and treating them along with other waste water before discharge into streams may be the only feasible way of preventing runoff pollution from our cities.

If the estimated cost of sewer modification is added to that for extending secondary treatment to most communities in the United States, the approximate cost of attaining the 1970 policy objective can be shown as follows:

Investment	Cost, in billions of dollars Low	High
Secondary Treatment	20	30
Sewer Modification		
Storage Facilities	15	
Separation		48
	35	78

The obvious question is, Can we buy clean streams and lakes for an investment of 35 to 78 billion dollars? By extending the federal grants program to provide all communities with secondary-treatment plants, will we eliminate water pollution? The 1970 federal policy goal strongly implies that the answer is Yes. Actually, the answer is clearly No.

Even if we separate our sewers and distribute secondary-treatment plants throughout the land, our lakes will not be free of algae and our streams will not run clear. In some cases, they may be even worse, overenriched by the concentration in the treatment effluent of nutrients that previously were reabsorbed by the soil through land disposal of wastes. The biological action of secondary treatment has little or no effect on certain industrial wastes and chemicals--salts, dyes, pesticides, mercury, phosphorous, and the like--and in additon simply changes the form of others, such as nitrogen, so that they remain in the treatment-plant effluent, only moderately reduced from their original loading when discharged. The form change of nitrogen--to nitrate--actually makes it more acceptable as a nutrient to a stream's organisms. As a result, the problem of the control of water pollution concerns more than the quantity of wastes generated by an increasing population and an expanding industry. It also involves the nature of the wates generated and the treatment processes employed in their abatement. Most of the recent increases in domestic and agricultural wates--phosphorus-based detergents, phosphorus-and-nitrogen-laden farm fertilizer run-off, the same elements from human wastes--are only moderately checked by biological waste treatment. In spite of a significant increase in secondary-treatment-plant construction between 1964 and 1968, the federal Water Quality Office finds that during this period three out of every four pounds of the phosphorus increase were discharged into receiving waters. By any standard, this is not progress.

Alternatives to Waste Treatment

Few environmental issues involve so many private and public aspects and afford such a diversity of approaches as water-pollution abatement. This chapter has centered mainly upon the waste-treatment approach, the dominant present program, but has acknowledged the generally superior approach of process change induced by pollution charges. Waste treatment and process change do not exhaust the ways of coping with pollution, however.

Aeration and low-flow augmentation provide additional options. Aeration, the injection of air into water to increase its free oxygen, has not been seriously considered as an abatement technique in the United States, but in the future it may constitute a lower-cost abatement alternative to waste treatment and low-flow augmentation.

Low-flow augmentation is the controlled release of impounded water to dilute the level of pollution in streams, thereby raising the quality of the water. The release of water generally takes place during the low-rainfall period of the summer, and low-flow augmentation has been widely cited by the Army Corps of Engineers as a supplementary benefit justifying flood-control projects. This approach to pollution abatement has a special appeal to state and local governments because the costs of low-flow augmentation are wholly absorbed by the federal government.

There are also federal programs of financial support for the firm investing in abatement equipment, such as those of the Small Business Administration and the Economic Development Administration. The Small Business Administration makes and guarantees hardship loans to firms that are independently owned and operated, a small business being simply "not the dominant firm" in an industry. The Economic Development Administration provides assistance regardless of the size of the business if the firm is located in one of the "depressed" areas, which by definition cover approximately one-third of the United States. The EDA is specifically authorized to provide financial and technical assistance "if pollution abatement action should tend to limit modernization, expansion, or solvency" -- a standard that is not overly restrictive.

ARE WE WINNING THE BATTLE AGAINST WATER POLLUTION?

As the quotation at the start of this chapter indicates, the question of whether the overall level of water pollution in the United States is getting better or worse is difficult to answer. In some problem areas, it is worse; in some regions, it is better. An equally important question is whether the construction-grants program is achieving the best results possible with this approach.

According to the United States General Accounting Office, the so-called watchdog agency of Congress that appraises such programs, construction grants have been allocated on the wrong basis. From fiscal 1957 to 1969, according to the GAO, the federal government made grants of about 1.2 billion dollars that generated treatment-plant construction of more than 9,400 units valued well in excess of 5 billion dollars because of the added contribution of state and local governments. In spite of this, however, the report finds that "the benefits have not been as great as they could have been because many waste treatment facilities have been constructed on waterways where major polluters--

industrial or municipal--located nearby continued to discharge untreated or inadequately treated wastes into the waterways."[3]

The GAO's point is that as a result of a "first come, first served" principle in allocating funds, treatment-plant investments have not been placed where they will make the greatest impact upon pollution. Obviously, spreading small investments in treatment facilities over a stretch of river that is increasingly heavily polluted will only slow the mounting pollution, not keep any one portion clean. If, instead, abatement facilities were concentrated in areas where pollution could be checked or reversed, at least a limited improvement would occur. As the federal program has developed, municipal pollution has been the main focus of attention, while increasing amounts of untreated or inadequately treated industrial wastes have overwhelmed the efforts in the municipal area. Unless municipal waste treatment appreciably checks or reduces water pollution, the benefits from these facilities are minor. Obviously, municipal investments should be made where they will do the most good. The problem is to determine what is the "most good" and to have this decision accepted by the areas involved.

The Principle of Maximum Protection

Maximum protection or improvement of water quality requires that no pollution abatement be undertaken where it will have little effect, and that instead, concentrated investments be made where the impact will be greatest. So long as appropriations for investment are limited, the abatement program will be less effective than it could be in checking environmental deterioration if the allocation of funds for the construction of treatment plants is determined on a basis other than that of where the facility will bring the greatest improvement in water quality. For example, larger appropriations to low-income and populous states will not necessarily result in a concentration of plants where the improvement in water quality will be greatest.

The maximum-protection principle is simple enough, simpler than the usual basis for allocating federal grants, but its application on an individual treatment-plant basis involves analysis that is much more complex than the conventional approach relying on population and income. Achieving maximum protection involves more than simply finding what complex of investments will reduce BOD the most. It requires the determinaton of where a BOD reduction will bring the greatest improvement in water quality. Equivalent reductions of BOD in different areas--the Platte River in Iowa and the St. Croix River in Minnesota, for example--are almost certain <u>not</u> to yield equivalent benefits.

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[3]Comptroller General, <u>Examination into the Effectiveness of the Construction Grant Program for Abating, Controlling, and Preventing Water Pollution</u> (Washington, D.C.: General Accounting Office, 1969), p. 13.

What the benefits are depends also upon the use of the river--whether predominantly for recreation, irrigation, or waste disposal--the number of people served by these functions, the availability of similar water resources within the area, and the quality of the river in the first place.

The broader the area in which the treatment-plant investment is to be made, the more alternatives there are to consider in the process of selecting locations. To determine the optimum investment in municipal treatment plants on a national scale, a comprehensive benefit-cost type of analysis would be required, comparing the yield from an investment in one area with that of another. Given the magnitude of such an undertaking and the less-than-perfect results from benefit-cost analysis, such extended analysis appears unjustified. Instead, an economically valid abatement choice can be made on the basis of river basins, with the distribution of funds to river basins determined in terms of "maximum protection." Applying the maximum-protection principle on this broader basis would bring its applicaton within comprehendible limits, reduce the number of investigations and comparisons required, and take advantage of some existing interstate arrangements, such as the Ohio River Valley Water Sanitary Commission (ORSANCO).

Although investment in municipal treatment facilities poses the same basic economic issue that arises with other public investment projects, there are significant differences in certain features of the water-pollution-control program. The main difference is that the stated objective of the construction-grants program is to extend secondary-treatment facilities to virtually all communities of any size, within a limited time. The investment decision, therefore, concerns not what communities to provide with treatment facilities and what communities to ignore, but what communities to equip with treatment plants now instead of next year or the year after. Under such a program, the benefit loss from the choice of a lower investment yield is limited to the time that elapses until the higher-yield plant is constructed, possibly as little as a year. Under the circumstances, the recommendation of the General Accounting Office that the timing of the construction of each plant be determined by a sophisticated form of operations research is clearly a case of analytic overkill.

INDUSTRIAL WASTE CONTROL OPTIONS

Industrial wastes are more abundant, and many are more difficult to treat, than municipal wastes, but the range of options for coping with industrial pollution is also more extensive. For these and other reasons, the federal government has adopted different approaches to municipal and to industrial water pollution in the United States. This has not been the case with municipalities. The federal grants program has been justified mainly on the grounds that most local governments face difficulty in raising revenue and that waste treatment is the only feasible way to cope with municipal pollution. Industry presents an entirely different situation: No similar financial problem is encountered --abatement or prevention of pollution is a legitimate cost of economic output--and industry is not limited to the waste-treatment approach. It may employ other forms of reducing water pollution, such as modifying manufacturing processes, recycling waste materials, and changing the nature of its products. Under these circumstances, it is clearly undesirable to tie industry to waste treatment through government subsidy, since this would mean the closing of options, such as process change, that might be much more desirable approaches to industrial pollution.

Many industrial wastes--such as those from meat-packing, canning, and papermaking--are susceptible to biological treatment by conventional primary- and secondary-treatment plants. As a result, as much as 40 percent of the waste load of municipal treatment plants comes from industry. Industry's use of municipal treatment plants raises questions of ethics and economics.* The construction costs of municipal treatment facilities are shared by federal, state, and local governments. The federal-state contribution to municipal waste treatment does not come from any special set of taxes, and taxpayers contribute generally to these facilities whether they are direct beneficiaries of pollution abatement or not. Firms that do not use a municipal system for disposal of their industrial wastes, and those individuals who live in a community unequipped with treatment facilities, nonetheless share in the federal and state contributions to municipal treatment-plant construction, providing a subsidy to the firms using the community system.

By contrast, in financing the locality's share, which may be minor for the treatment facility but major for sewer modification and plant operation, there is usually a rough correspondence between the benefits and the charges for treatment. For meeting construction costs, the locality is likely to depend heavily on the sale of bonds, which are almost certain to be serviced and redeemed with revenue from the general property tax and sewage rental fees. The same revenue sources will be called upon to cover the costs of operating the waste-treatment plant, in which case the revenue paid is at least roughly related to the benefit from disposing of waste through the municipal system. The sewage rental fees, in particular, approximate the concept of a user charge or effluent fee. Depending upon their magnitude and how they are levied, waste charges may exert strong pressure to decrease pollution. Before such levies are likely to be effective, however, they must be both substantial and specific. If they are

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*Whether to restrict industry's use of municipal treatment facilities is complicated by technical considerations. Economy of scale in treatment-plant size may be an irresistible economic inducement for the small and moderate-size community to accept industrial wastes in order to take advantage of the lower per-unit cost of larger-scale treatment plants.

slight, mere token payments, they will become "licenses to pollute" and will be ineffectual. The solution to this situation is simple, however--to raise the charge so that it provides an incentive to industry to reduce waste output.

The Effluent Charge and Its Variants

If we exclude the sewage rental fee, which generally takes the form of a flat fee or is related to the volume of waste discharge as reflected by water use, the use of effluent charges to decrease pollution has been quite limited. In part this has been because the conventional wisdom has endorsed the waste-treatment approach, but in addition serious questions have been raised about what to include in the pollutant index--BOD, dissolved solids, temperature, phenols, and so on--and how to monitor the discharge of the industrial firm.

In the few applications of the effluent charge in the United States, such as that initiated by Cincinnati in 1953, the assessment has involved simply a measure of BOD, and although this is clearly an incomplete pollutant index, the results have been impressive. After the introduction of a fee of 1.3 cents per pound of BOD, industrial loadings on the Cincinnati municipal treatment plant fell off by more than one-third, and they continued to decrease annually for the next decade. Other United States cities, such as Springfield, Missouri, and Otsego, Michigan, have also made effective use of the effluent-charge approach to curtail industry's use of their treatment facilities.

<u>The Ruhr Experience</u>. By far the most extensive use of effluent charges is that of the industrial cooperatives in Germany's Ruhr Valley, where water-management responsibility has been granted to these organizations by the state. Over the past fifty years, the cooperative associations have exercised control over water quality, land drainage, water supply, flood control, and waste disposal in the Ruhr Valley. To abate pollution of the Ruhr River, the associations have employed a system of effluent charges, with which treatment facilities are financed. Effluent charges are determined by one of two techniques, depending upon the Ruhr cooperative association involved, and the criteria are considerably more comprehensive than those employed in the few instances of such usage in the United States. One pollution index, although involving a number of phases, reduces essentially to the question of how much the industrial-waste discharge has to be diluted with fresh water in order for fish to survive. The other consists of a "population equivalent BOD" measure that accounts for both toxic wastes and biologically degradable material.

Even though the basis for determining effluent charges by the Ruhr cooperatives is considerably more advanced than that employed in the few United States applications, Allen Kneese, of Resources for the Future, an authority on the Ruhr case, considers the standards employed to be unsatisfactory. He points out that some substances, such as phenols, although neither particularly harmful to fish nor demanding of dissolved oxygen, may still be extreme contaminants in drinking water. In very small quantities, phenol--a by-product of the petrochemical industry --causes water to be unpalatable when chlorinated. The solution to the problem of inadequate effluent-charge criteria is to enlarge the factors covered, but this necessarily increases the complexity and the costs of administering the system. In spite of imperfections, however, the system of effluent charges adopted by the Ruhr cooperatives has induced extensive water-conservation measures by the firms in the Ruhr Valley. Moreover, the development of electronic equipment to monitor industrial wastes should make possible the expansion of the effluent-charge criteria without significantly increasing collection costs.

Pay to Pollute

A proposal that has few advocates among strict conservationists, but is advanced enthusiastically by those dedicated to the market allocation of resources, is the establishment of property rights in pollution. Although similar to effluent charges, the pay-to-pollute approach may differ in its ultimate objective. Both are designed to discourage pollution, but the pay-to-pollute approach implies permitting an "acceptable level" of pollution by those making the highest bids. An administrative agency, such as a state pollution-control board, is responsible for establishing permissible pollution levels and supervises the bidding for the right to pollute a particular watercourse.

The advocates of the pay-to-pollute approach contend that it will keep pollution within acceptable levels without distorting the market allocation of resources. The presumption behind this contention is that the highest bidder for the right to pollute a particular stretch of river is more productive than other polluters in the area. Other polluters, unable to buy pollution rights, will either have to change their production process to eliminate pollution, undertake waste treatment, or go out of business. Since the less productive firms are more likely to be unable to bid successfully for pollution rights, enforcement of strict pollution limits will have the greatest impact upon marginal and submarginal firms.

Social objectives as well as materialistic motives are considered to be within the recording capacity of the pay-to-pollute approach by its advocates. If conservationists decide that the pollution permitted by the control board for a reach of the Hudson River is too high, for example, they can enter the bidding and reduce pollution by buying rights and not using them. Finally, it is argued that by establishing a market in pollution rights, the efficiency of the market system can be brought to bear in the battle against pollution.

Superficially, the pay-to-pollute approach has much appeal: It strikes directly at the polluter, apparently with a minimum reliance upon bureaucracy to achieve this objective. Obviously, the establishment of property rights in pollution is an improvement over unlimited freedom to pollute. But as in the case of establishing water-quality standards, the key consideration is the enforcement of reduced pollution. The pay-to-pollute approach is an elaboration of the regulatory approach, as embodied in enforced water-quality standards, with reduced pollution allocated by competitive bid. And the enforcement of strict water-quality standards has repeatedly encountered state and local opposition because of the financial burden upon the polluters. Furthermore; the standards of the pay-to-pollute approach are not likely to be immune to pressure for moderation from firms and their employees, nor is such an approach likely to be successful without a large-scale administering bureaucracy.

The most serious drawback to establishing property rights in pollution is that the bidding process may not work. Although for some river stretches there are enough polluters so that spirited bidding may take place, this condition is absent on most rivers. Moreover, for those rivers that serve a concentration of polluting firms, it is not likely that the minimum standards of pollution will be established at very high levels. Where one or two large industrial firms pollute a river area, as in many single-industry communities, there will be too few bids to establish a competitive price for pollution rights--quite aside from the question of whether collusion in the bidding takes place with a small number of bidders.

Tax and Depreciation Subsidies

Accelerated depreciation or rapid write-off of machinery and equipment is sometimes permitted in the computation of a business firm's tax liability by states and the federal government. In 1971, for example, the federal Internal Revenue Service shortened the depreciation period by 20 percent in the hope of simulating economic activity. Investments by industry in pollution-abatement equipment are granted additional special accelerated depreciation privileges.

Durable machinery and equipment, such as blast furnaces and pollution-abatement devices, have varying life expectancies, and the payment for such assets is normally spread over the period of their useful life--ten, twenty, thrty, or more years. Different depreciation techniques may be followed, but the necessary condition for financial solvency is that the firm replenish the outlay made for the capital asset by the time the equipment is worn out or obsolete. If the equipment is paid for before it is used up --say in ten years when it will last twenty years--the first ten-year period will be one of high cost and low profit because of the increased depreciation charges, but the second ten-year period will be one of low cost and high profit because the depreciation charges will have been paid earlier.

Since in this situation costs are higher during the first ten years and profits lower, taxes based on net return to the firm are reduced during the period of accelerated depreciation. But this reduction is temporary unless the tax structure is changed, because in the second ten-year period, when the capital has been fully depreciated, profits will increase and taxes will be higher. Roughly, what is forgone in taxes in the period of accelerated depreciation will be made up later, when the equipment is fully depreciated but still usable.

Therefore, from the tax standpoint, rapid write-off is not much of an inducement to increase equipment purchases unless the business firm expects the tax rates to be more lenient in the period after the equipment has been fully depreciated. However, although the initial tax reduction from accelerated depreciation is a temporary, short-run gain for the firm, largely wiped out in the later period when taxes rise, compressing the payment for capital equipment into a shorter period of time does have an advantage: The cost of borrowing is substantially reduced. This reduction provides a stronger incentive to the firm to take advantage of accelerated depreciation. The cost of borrowing $100,000 for ten years is greater than the cost of borrowing this sum for five years. Savings in interest payments, rather than temporary tax reductions, make accelerated depreciation attractive to the business firm, especially during a period of high interest rates. Under provisions of the Tax Reform Act of 1969, the federal government permits firms to write off air- and water-pollution-abatement equipment in five years, irrespective of the useful life of the equipment, if it is added to plants that were in operation before January 1, 1969. In addition, six states also permit a five-year write-of of abatement equipment, and a few states exempt such equipment from sales and use taxes or allow credit against state corporation income-tax payments. But by far the most important tax concession involves the general property tax, which was not levied upon industrial-abatement equipment by twenty-four states in 1970, and the use of tax-exempt bonds to finance the purchase of abatement equipment. Industrial-revenue issues, a close relative of unicipal bonds upon which many states have conferred the same tax-exempt status, are expected to be offered for sale in 1973 in an amount exceeding a billion dollars in face value. The saving in interest charges, which results from the bonds' tax-exempt status, varies with market factors, but the interest rate is not infrequently more than two percentage points below that of the non-tax-exempt bonds. This advantage extends to the bonds' maturity and represents a substantial saving in financing costs. Both water-pollution-abatement equipment and air-pollution-abatement equipment are eligible for industrial-revenue-bond financing.

THE DIRECTION OF WATER-POLLUTION CONTROL

Although water-pollution abatement was one of the earliest areas of environmental concern because of water-borne disease, pollution of most of our lakes and streams is worse now than it was at the turn of the century. Treatment plants have not kept pace with either the volume of the waste load or the kinds of wastes that have been produced by our industrial system and increasing population. In part, this lag in the technology and capacity of treatment facilities has been a result of the efficiency of chlorination in protecting our water supplies: We could pollute our streams and still make them safe for use as water sources by chlorination. Only recently has the broader concern about environmental damage brought a new urgency to the abatement of water pollution.

But if water pollution is to be turned back in the United States, if the goal of "Clean Water by 1985"--announced by Congress with the passage of the Water Pollution Control Act in 1972--is to be achieved, waste-treatment facilities will have to go beyond biological treatment, industries will have to modify production processes, and more of the costs of abatement will have to be borne by industry. For the first time, the 1972 legislation on water pollution extends federal control to industry by establishing national abatement standards. If effectively administered, such standards will bring the "clean water" goal closer to realization.

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APPROPRIATE TECHNOLOGY IN PLANNING FOR WATER MANAGEMENT PROJECTS[a]

by

Daniel A. Okun, Sc. D.

Inasmuch as industrial development carries with it an obligation to provide water supply and wastewater collection and disposal facilities for the industry, and often for the associated community, the planning for such projects is worth exploring in some detail. The technology involved is extensive, but it is not our purpose here to discuss all the technology as the appropriate professional personnel can be expected to have the resources for exploiting the appropriate technology. However, there is a substantial difference between using existing technology as it is applied in industrialized countries as compared with such technology as it can be applied most economically and efficiently in developing countries. Not only does this difference apply to the planning, design, construction and operation of water supply and wastewater disposal facilities, but many of the principles described for such projects may be applied to the industrial developments themselves.

Mechanization and automation are beginning to appear in every phase of human activity. Not only are they ubiquitous in all manner of physical operations, they are now important in data management and analysis. Where do mechanization and automation fit in water and wastewater treatment plant design, and by analogy, in industrial design?

Three criteria should form the basis for decisions on the extent of mechanization and automation to be incorporated in designed systems; desired quality, required overall plant reliability, and system economy. The decision to incorporate a particular system of mechanization or automation depends on the environment within which the system must function. Factors to be considered include the relative costs of labor of all types, cost of equipment, complexity and essentiality of the system or its elements, and the service resources of the owner or the supplies of components.

Lessons learned from mistakes are often those which are learned most thoroughly, albeit painfully. About nine years ago,

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[a]A paper prepared for the International Program on the Environmental Aspects of Industrial Development.

in a provincial capital of a Latin American country, a typical rapid sand filtration plant, with modern instrumentation and control, was built. Each filter was equipped with electrically-operated valves, a modern rate control system and control tables with all normal appurtenances. In addition, the plant included a supervisory control center from which all plant functions could be monitored and controlled. All instruments and mechanisms were of high quality and rugged construction.

A few years after the completion of the plant, not one instrument was functioning! Most of the recorders and controllers had been removed from their mountings. When the flow indicators and recorders on the filter rate controllers failed, the controllers were simply wired down so that the control valve would stay in the wide open position at all times. It was not even possible to measure the raw water inflow or the rate of treated water delivery to the city as the venturi meter recorders were out of order. In this case, the misapplication of instrumentation and control was extreme. This control system was installed in a location where skilled maintenance was not available and where spare parts were extremely difficult to obtain. In addition, the function and purposes of the system were not understood by the plant operators. The end result was a water treatment plant relatively high in first cost which produced a water of lower average quality than could have been produced with a control system more suited to the local situation.

On the other hand, in industrialized countries, there are numerous situations where the increased use of instruments and automated controls improves the operation of plants.

Reliability

One of the principal concerns of managers is to provide a service with highest possible degree of reliability. Designers and plant operators are continually searching for the most reliable methods of plant control. Reliability, in this case, implies that a particular function will be performed or some process characteristic or quality will be controlled with little likelihood of failure. Reliability may outweigh economy.

Control of residual chlorine in wastewater treatment plant effluents provides an example of a situation where full automation may be more reliable than manual methods and in addition can result in both economy and higher quality effluent. Chlorine demand varies and control of chlorine dosage by a residual recorder-controller would maintain a more uniform residual is to be maintained, require either an overdose of chlorine or continual attention.

Control systems for such physical variables as pressure, tank level, flow and temperature have been in use for years. System components for the control of these physical variables have been developed to a point of high reliability. Their application enhances the reliability and economy of the entire plant operation.

The reliability of some of the newer instrumented and automated control systems is more uncertain. Perhaps a comparison with the reliability of manual methods is in order; in other words, man against machine. Realistic answers to the following questions may aid in achieving objectivity:

1. What is the probability of instrument or control system failure versus the probability of human error?

2. What is the probable magnitude of instrument or control system error versus human error?

3. What is the result of instrument or control system failure versus human error in terms of (1) plant effluent quality, (2) overall reliability of service and (3) cost?

<u>Economy</u>

As cost of labor increases while the relative cost of instruments and equipment decreases, the replacement of personnel through mechanization and automation becomes more attractive. The present cost of manning one around-the-clock seven-day position in the U.S. is about $50,000 per year. The elimination of such an annual cost would justify an investment in mechanization and automation of about $50,000 assuming the equipment is amortized over 15 years with interest at 6%. In developing countries, where wage rates are much lower and interest rates high, much less can afford to be invested in labor-saving automation and control.

Systems of automation are, moreover, completely dependent on proper maintenance attention if they are to provide the service for which they were designed. It is very wasteful of the designer to install automation unless he is assured that adequate funds will be available for their maintenance. It is discouraging to visit plants and see that many of the instruments are inoperative.

The proper maintenance of instrumentation and control systems requires highly trained personnel. Personnel of this quality is not always available and must frequently be trained on the job. The cost of training the necessary personnel and the relatively high wages that they command must be taken into consideration in any economic analysis.

<u>Other Considerations</u>

An important ancillary benefit deriving from automation is the opportunity to attract highly qualified engineers and scientists to the field of public water supply and pollution control.

These skilled personnel, freed from routine tasks, can use their energies for research and investigations leading to improved procedures. Mechanization can help eliminate many of the unpleasant tasks, now requiring manual labor, thereby encouraging the employment and retention of fewer but more highly skilled operators.

Modern systems of automation used in connection with appropriate data processing equipment can produce timely and valuable reports for management. In many of our facilities such reports are, at present, not available because of the tedious and time-consuming work required in their preparation. When such reports are prepared in the traditional manner, the information they contain is frequently outdated before the report is finished. The preparation of such reports by modern methods will leave more time for analysis and judgment, promoting a higher quality of operation and service.

Computers are rapidly becoming more reliable and relatively less costly. Specialized process control computers of both the digital and analog type are being developed. Some of these computers can be effectively used, at present, in the control of our water and wastewater systems. Curently, the most successful applications of computer control in these fields involve the simple measurement and control of such variables as flow, level, pressure, and temperature. With processes involving chemical or physical changes, which are more difficult to measure, progress is being made in the development of reliable automatic instruments.

Appropriate incorporation of mechanization and automation holds great potential in meeting the continually growing demands for expanded and higher quality water and wastewater service.

The Planning of Projects

When a major industrial development is contemplated, in the planning for the supporting services and for minimizing the detrimental impact of the facility on the environment during both the construction and operating phases, it is important that qualified professionals be employed to prepare the necessary feasibility studies. Whether the needs are for water supply, for water or air pollution control, for the disposal of solid wastes, for the control of the environment within the plant, or for the other utilities and services, a report outlining the technical, political and financial feasibility of alternative solutions must be prepared.

In dealing with the water phase of the environment, two approaches have been used. One is to call for a single contractor to be responsible for all phases of the project including the planning, design, provision of equipment and the construction. Such approaches have been given the name "turnkey". Turnkey approaches may be suitable where the client is fully familiar with what is needed, has the technical staff to prepare a set of tight specifications, and has the knowledge and depth of personnel necessary to review the provision of the facilities so as to be certain that what is being proffered is, in fact, appropriate and technically and economically the best that can be afforded for the available funds. However, this approach is seldom suitable for public water supply or water pollution control. Turnkey contractors, particularly where they are associated with manufacturers, have a stake in a certain type of equipment, and will offer designs that will maximize the use of proprietary devices so as to maximize their profit. Also, such approaches tend to increase the use of sophisticated equipment, while minimizing the use of labor. Turnkey contractors often pay little attention to the problems of operating the facility after the project is accepted.

The second approach is to employ consulting engineering organizations that have no tie with contractors or manufacturers, and whose only stake in the project is providing the best professional service to the client. Such an enineering organization would prepare a report offering several alternatives from which the client might choose. After the report has been accepted and the processes and approaches decided upon, detailed plans and specifications are prepared by the engineer and submitted for bids by independent contractors. These contractors may be local or may be a combination of local and foreign contractors. The engineer might select from a large number of purveyors of equipment that combination that appears to be the most suitable for the project. The consulting engineer may then serve to review proposals and help select the best. When construction is initiated, he may serve to supervise the construction on behalf of his client. When construction is complete, he may also assist his client with "start-up".

That the latter approach is to be preferred is evidenced by the fact that the World Health Organization on behalf of the United Nations Development Program and the World Bank as well as the regional development banks all require that consulting engineering organizations be used in the preparation of reports and plans and specifications.

In the selection of consulting engineers, full recognition should be given to the qualifications of the engineering organization in the field of specialty involved, namely, water supply and water pollution control, as well as his experience in working in the region of the world for which the project is proposed. While many engineering organizations are competent in a wide range of engineering designs, the provision of water supply and the design of sewerage and water pollution control facilities constitutes a specailty that is often not within the purview of the conventional civil engineering organization. Most civil engineering requires only an understanding of construction materials, structures, hydraulics, foundations and the like. The provision of water supply and the control of water pollution require, in addition, a sound understanding of the chemistry and biology of water and how these can be managed to provide the water quality desired. Also, a capability in training personnel for operation and maintenance of facilities is essential.

Competence in water quality management is generally designated as sanitary engineering, public health engineering, or environmental engineering. In the United States, engineers with this special competence in the environmental field are certified, becoming diplomates in the American Academy of Environmental Engineers. If engineers are to be selected from the United States, firms that are staffed by large numbers of diplomates are to be preferred. In other countries, the experience that the firm has in designing a wide range of water supply and water pollution control facilities is important in their selection.

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WATER AND INDUSTRIAL DEVELOPMENT

by

Daniel A. Okun

Few elements of the environment are as closely linked with industrial development as water which, in sufficient quantity and of suitable quality, is a prerequisite for industrial development. Not only must sufficient water of appropriate quality be available for industrial processing to make an industrial development viable, but water of potable quality must also be available for the population that services the industrial development.

Furthermore, the industrial development may have considerable impact on the water resources of the nation. In using water, the industry may foul it or heat it or otherwise make it unsuitable for domestic purposes, recreation or even other industrial purposes. Industry may actually consume water by evaporating it, thus denying the water to others. An industry that is entirely appropriate for one location, where water resources are ample and where its waste can be readily assimilated, may not at all be appropriate in another location within the same country, where scarce resources must be husbanded for the sustenance of communities. In this way industry may have a detrimental effect on tourism, which itself has a potential for economic development. Hence, water is of first importance amongst all environmental considerations in industrial planning, and is a significant element in developing a land use plan.

Sources of Water

An understanding of water resources includes an understanding of the following sciences: meteorology, water in the atmosphere; oceanography, water in the oceans; patamology, water in the rivers; limnology, water in the lakes; and geohydrology, water underground.

Water has unusual properties that influence its role: it has its maximum density as 4°C; it has high viscosity which permits it to transport sediment; and it is an excellent solvent and its chemical quality is affected by the materials that contact it in the air and on and in the earth. Water is not only abstracted for use, but in place it is a medium for the support of aquatic life, an aesthetic resource, and a locale for important recreational activities.

The following are the specific sources of water in general order of water quality:

Rain water.

Subterranean water: natural springs, artesian ground water, free ground water, limestone aquifers, infiltration galleries, infiltration basins, artificial recharge areas, and brackish ground waters.

Surface waters: mountain lakes, erosion or glacial lakes, mountain rivers, lower reaches of rivers, estuaries, and the ocenas.

Wastewaters, by reuse.

Water Supply Quality

Industrial water quality requirements vary from water of almost any quality that can be used for cooling to water of exceedingly high quality that is necessary for boiler feed or for food processing. Any one large industrial development may, in fact, have several water systems that range from raw water, that may be drawn from a river or the sea without treatment for once-through cooling, to a settled water for one process or a filtered water for another, to a disinfected water for potable supplies, to finally a demineralized water for boiler feed. An important principle, enunciated by the United Nations Economic and Social Council in 1958 states that "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade."

In addition to the water quality requirements for industry, if an industrial development is to be sustained, it must be in a locale where its workers can be assured of a public supply of potable quality. Whereas in the industrialized countries of the world, and in a few (unfortunately too few) capitals of developing countries, a satisfactory water supply is available, most of the developing world is without such supplies. For example, of some 500 million urban population in developing countries in 1975, it is estimated that 200 million do not have piped water supply service, and for many of those who do have piped service, the reliability and the quality are generally questionable. Of the 1250 million rural population in developing countries, some 1000 million have no access to piped water supply service. An even smaller proportion of the population is served by sewerage or other adquate wastewater disposal system. Hence to develop industry, an important requirement is the quality of water management available.

Failure to provide water of suitable quality in the developing countries has resulted in an exceedingly high rate of enteric disease which, in addition to its debilitating effect on the population, interferes with the industrial and economic development of a nation. Parasitic diseases, the dysenteries, cholera and schistosomiasis all take an exceedingly heavy toll of the population of developing countries. An estimated half billion people are victims and five million infants die of enteric diseases each year and an estimated one hospital bed in four is occupied by a patient ill with enteric disease. Death rates from enteric disease in some of the non-industrialized countires are more than 100-fold greater than death rates in industrialized countries, the major factor being the quality of water management.

Proper water management constitutes a necessary investment in "social overhead capital," capital required for the orderly and productive activities associated with a healthy economy.

While the most important water quality problem in the developing countries originates from the improper disposal of human wastes, the introduction of industry initiates a whole new set of problems. Wastes from industry, unless rigidly controlled and monitored, inevitably contribute chemicals to the waters into which they discharge which may often be used as sources of drinking waters for communities in the vicinity. Often the wastes from these industrial plants, after appropriate treatment, may be innocuous. Food-processing industries that discharge the residuals of readily biodegradable organic materials are in this category. On the other hand, the revolution in synthetic chemicals has resulted in their extensive use in industry, both in connection with their own manufacture as well as in the processing of other materials.

It has been estimated that some 500 new chemicals are developed annually in the United States. It is clear that identifying them, let alone controlling them is a task that we in this country have not yet begun to address seriously. Some of these chemicals have been identified as being carcinogenic, mutagenic and/or teratogenic. Their significance when ingested from a water supply over a long period of time is generally not know, but there is reason to suspect that they have a serious potential for introducing chronic health damage. Thus, one of the major responsibilities in the location of certain types of industry is an assessment of their possible impact on water qualtiy for drinking as well as for aquatic life and recreation.

Some chemicals have a potential for being magnified in the biological chain. That is, they are absorbed by small species which are the food for larger species and finally they accumulate in fish or in plants that are used by humans as a source of food.

<u>Water Supply Requirements</u>

Industrial water supply requirements vary widely depending upon the industry. Per unit of capital investment, electronics manufacturing will have among the smallest water requirements and accordingly the smallest wastewater disposal problems, while a pulp and paper mill will have among the largest. The latter, together with other large water-using plants, may just not be appropriate for many locations. On the other hand, in-plant attention to the possibilities for recycling may sharply reduce the amount of fresh water required as well as the amount of wastewater discharged.

One of the best instruments available to government for the control of industrial wastewaters is the institution of effluent charges for discharge either into municipal sewerage or into surface waters. Such charges have the effect of encouraging reduction of waste production in plant operations as well as the introduction of recycling of both waste products and wastewater. For example, the wastewater of one process, with or without some modest treatment, might become the water supply for another. Effluent charges, as well as inadequate supplies of fresh water, encourage practices that have in effect reduced water requirements in major water-using industries by 95 per cent.

Water supply must also be made available for fire protection for the industry and for the other developments established in association with major industry, such as residential commercial and public areas. Whereas the requirements for potable purposes for sustenance of life amount to some two liters per capita per day, the actual requirements for drinking, food preparation, bathing and cleanliness depending upon the water-using facilities available in the home, may range from a low of 100 liters per capita per day to as much as 500 liters per capita per day. The larger figure generally provides water for the household for use in the watering of lawns and gardens particularly in arid areas.

If an industry is to be located in a virgin area, studies are required to indicate what the supporting population per employee is likely to be and requirements would be based upon providing the total community needs for this total population. Should no provision be made for the supporting population, slums are immediately created and the integrity of the industrial development is seriously threatened. Even if provision is made for housing for employees and their families, some provision also must be made for the service installations to serve the needs of this population. This may include a responsibility for the industry or government to provide services beyond the boundaries of the employees' housing and industrial areas, or supporting a community organization that would perform the same services.

Water Supply and Wastewater Disposal Systems

These systems vary in complexity depending upon the sources of water available, their quality, and the opportunity for the discharge of wastewaters without detriment to the environment. Often, the furnishing of these facilities involves the largest single investment after housing requirements for the community. Costs for complete water service may range from $200 to $600 per capita including the following facilities:

Development of the water source, either by the impoundment of streams by the construction of dams and reservoirs, which represents the highest cost, or the development of wells, or direct pumping from large rivers or lakes which represents the least cost.

The construction of transmission mains from the source to the treatment facility.

The construction of the treatment facility, which may provide only disinfection if the source is of high quality, or which may involve screening, sedimentation, flocculation and coagulation with chemicals, filtration and disinfection.

Storage of water in service reservoirs which should be elevated to provide water for fire protection and water service during power outages and other emergencies.

Distribution systems, often designed to be large enough to provide water for fire protection.

Service lines from the distribution system into the home which would include meters and the plumbing system in the home.

House plumbing for carrying away wastewaters from the house.

Lateral or common sewers to receive household wastes.

Main sewers or interceptors to receive the discharges from many laterals.

Wastewater treatment, the degree depending upon the requirements of the receiving stream. Primary treatment, namely, sedimentation of the solids, would generally be a minimum, with secondary or biological treatment often being necessary. In some cases, an even higher degree of treatment may be required, particularly where reuse of the wastewater is intended.

An outfall into the receiving stream or discharge to point of use.

Reference

Pescod and Okun, Water Supply and Wastewater Disposal in Developing Countries, Asian Institute of Technology, Bangkok, 1971.

AIR POLLUTION AND ITS CONTROL

By

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

AIR POLLUTION AND ITS CONTROL

1. Introduction

1.1 Purpose

The following material is an introduction to the study of air pollution and its control. It is a survey of the many topics that are included in such a broad area of study and is meant to provide the participant in the IPEAID course with a foundation of basic information, and to point the way to sources of more specific and more detailed information. This presentation is oriented towards people with industrial technical backgrounds who will be concerned with environmental decision making in the future.

1.2 Areas Covered

The topics discussed in the syllabus include the nature, sources, and transport of air pollution; the effects of air pollution on humans, plants, and the physical environment; air pollution standards; the nature of process emissions from selected industries; measurement and monitoring needs in air pollution control; control technology for industrial emissions; siting of industrial facilities; consideration of land use planning and energy; and the impact of the manufactured product on the environment.

The material that is presented is by no means inclusive. In many cases, considerable detail has been avoided to preserve the readability of the syllabus and to be consistent with the purpose of this course. More detailed discussion is provided for topics that have direct bearing on industrial processing. References that can be used to obtain additional information are included in the last section of the syllabus.

2. Nature of Air Pollution

2.1 The Atmosphere

The earth's atmosphere is composed of several layers, including the ionosphere, the warm layer, the stratosphere and the troposphere. The ionosphere, which begins at about 40 miles above the surface of the earth, is itself composed of several layers, and is characterized among other things, by its ability to reflect low-frequency radio waves. The warm layer is found from about 25 to 40 miles above the earth's surface. The temperature in this layer is reasonably stable and is higher than the temperature that prevails near the earth surface. The stratosphere is located from approximately 7 to 25 miles above the earth. In this layer, the ozone content reaches its peak and the temperature is relatively stable. The layer closest to the surface of the earth extends upwards for an average of 7 miles and is called the troposphere. The air in this layer is subject to considerable movement which results in what we call weather. Within the troposphere the temperature generally decreases with height, or "lapses." This rate of decline, or lapse rate, is about 10°C per kilometer (4°C per mile).

Nearly 3/4ths of the mass of the atmosphere, and almost all of the moisture and the solid particulate matter is contained in the troposphere. Over 99.9% of the volume of dry atmosphere is made up of four gases:

Nitrogen	78.1%
Oxygen	20.9%
Argon	0.9%
Carbon Dioxide	0.03%

In addition, the remaining rare gases and numerous trace gases, such as nitrous oxide, nitrogen dioxide, nitric oxide, carbon monoxide, ammonia, and sulfur dioxide, can also be found. In addition to the gases, solid particles also present. These include condensation nuclei - submicron particles that serve as nuclei for the condensation of water and other vapors - sea salt from the evaporation of the ocean's spray, and solid particles introduced into the atmosphere by industrial processes related to man's activity and by the wind. The amount of moisture in the atmosphere will vary widely depending upon location and season. The average concentration range is 1 to 2%.

The concentration of any trace component in the atmosphere will vary for each locality in which the concentration is being measured. This is because the sources of these components are localized. For example ammonia is introduced into the atmosphere largely from the decay of organic material. The concentration of ammonia in the atmosphere will be higher near marshes and other areas where decay processes occur.

Not only are there sources for the particles and gases found in the atmosphere, but there are also processes and places in which these materials are destroyed and removed from the atmosphere, called "sinks". The existence of sources and sinks means that the trace components will have varying lifetimes in the atmosphere that may range from several seconds to several years. The major sinks are the ocean (for many gases including CO_2 and ammonia), the earth's surface (for ozone and particulate matter), the biosphere, and the upper atmosphere. It is important to remember that the atmosphere is a dynamic system, one that is constantly undergoing change.

2.2 Air Pollution

The gases, vapors and particles that are introduced by natural and man-associated (anthropogenic) sources are removed from the atmosphere by the processes of dispersion, diffusion, reaction, absorption and adsorption. When the rate of introduction of unwanted materials into the atmosphere exceeds the rate at which they are dispersed, diffused, reacted with, absorbed or adsorbed, these gaseous and particulate materials will accumulate. At certain concentration levels, some of the particles and gases introduced into the atmosphere affect man and his environment because of their toxicity, their ability to damage, or their ability to create discomfort. Air pollution may be defined as the (local) accumulation of unwanted, undesirable, or toxic materials in the atmosphere to the point that they can cause insult to the environment, ranging from psychological irritation to death.

Although numerous gases and particulates could be considered pollutants, the U.S. has focused on a small group which are considered important because of two factors: a) amounts emitted by sources, and b) potential environmental impact. The principal pollutants include carbon monoxide, ozone (oxidant), nitrogen dioxide, nitric oxide, sulfur dioxide, inorganic sulfates, suspended particulate matter, and hydrocarbons. The term particulate matter includes solid materials, such as dust and flyash, and liquids in the form of fine mists, for example sulfuric acid mist.

The earliest air pollution was a visual insult - the clouding of the air in cities by smoke. There are references in the literature to the displeasure caused by air pollution in the 11th century. In the 12th century, King Edward II of England is supposed to have beheaded the operator of a coal fired furnace whose smoke was allowed to drift across the grounds of the castle. The term smog, meaning a combination of smoke and fog, was applied to the visible pollution associated with the severe (acute) episodes recorded in London, England; the Mevese Valley in Belgium; Donora, Pennsylvania; and other locations. The killer fog in London in 1952 was responsible for some 4,000 excess deaths; a Thanksgiving weekend episode in new York City in 1966 was responsible for some 200 excess deaths.

In recent years, there has been increasing concern for the damage potential of the pollutants that cannot be seen. Combinations of gases and particulate matter, or gases alone, can cause significant damage to man and his environment. There has also been an increased awareness of the potential dangers from exposures to low-levels of pollutants over long periods of time. These have led to the establishment of air quality standards and control strategies to meet them.

3. Pollutants and Their Sources

Although natural events such as forest fires and volcanic activity introduce tremendous quantities of pollutants into the atmosphere, this discussion will be limited to a consideration of gases and particulate matter produced by man's activities.

3.1 Units of Concentration

Typically the concentrations of air pollutants have been reported in units of parts per million (ppm), or parts per billion (ppb). This is a ratio of the volume of a given gas to a unit volume of the atmosphere. Recently there has been a shift towards using a mass per volume unit in the metric system - milligrams (mg) or micrograms per cubic meter (ug/m^3). The reasons for this probably include: the current trend to use metric units; ppm cannot be used for particulates, requiring separate units for gases and solids; and ppm does not reflect the fact the mass of the gases in the atmosphere decreases with height. In this summary, both units will be noted.

3.2 Particulate Matter

Particulate matter refers to discrete particles of solids or liquids emitted into or formed in the atmosphere. Particulates may result from the physical treatment of solids or liquids, the combustion of fuels, and natural processes. Examples of particulates include fly ash; fugitive dust from mining, crushing or grinding operations; mists produced by liquid scrubbers or cooling towers, wind driven soil; and volcanic ash. The U.S. Environmental Protection Agency estimated that in 1971, 27 million tons of particulates were emitted. Approximately 1/2 of this resulted from industrial processes and nearly 1/4 from fuel combustion by stationary sources.

Particles smaller than 1 micron (u) are generally formed by condensation processes in the atmosphere. Crushing and grinding of solids can produce particles as small as about 2u. Incomplete combustion and the unburnable portion (ash) of the fuel are two other sources of small particles. Particles larger than 10u typically are produced by mechanical processes such as grinding, and wind erosion. Generally, particles larger than 10u have high settling velocities and do not stay in the atmosphere very long. The average mass concentration of suspended particles (smaller than 10u ranges from 10 to 60 u/m^3 in nonurban areas, and from 60 to 200 ug/m^3 in urban areas. In heavily polluted areas these concentrations may be even higher.

3.3 Sulfur Oxides

The predominating form of oxidized sulfur in the atmosphere is sulfur dioxide (SO_2). Oxidized sulfur will be present in particulates in the form of sulfuric acid and sulfate. Sulfur dioxide primarily occurs from the combustion of fossil fuels, refining of petroleum, the smelting of sulfur-containing ores, and the manufacture of sulfuric acid. It is estimated by EPA that 32.6 million tons of SO_2 was emitted in 1971. A little more than 80% of this was produced by fuel combustion in stationary sources.

Estimated ground level concentrations for SO_2 in nonurban areas are from 0.5 to 5 ug/m^3 (0.2 to 1.9 ppb). In any particular area, the ground level concentration will depend upon the amount and type of fuel burned, and meteorological factors. Typically in larger cities, concentration of 75 ug/m^3 (0.3 ppm) are not uncommon.

3.4 Nitrogen Oxides

The term "nitrogen oxides" (NO_x) includes two gases: nitric oxide (NO) and nitrogen dioxide (NO_2). On a global bases the major source for these oxides, primarily emitted as NO, is bacterial action. In the United States and in other industrial countries, NO_x emissions are produced by fuel combustion. Some NO_2 can be emitted from specialized industrial processes such as the manufacturing and use of nitric acid, welding, and electroplating. However these make up a small portion of the total emissions. EPA estimates that 22 million tons of NO_x were emitted in 1971. Approximately 50% of this was from transportation sources (internal combustion engines), and 49% was from fuel combustion in stationary sources. Miscellaneous sources accounted for a very small fraction of the total emissions because the principal mechanism of formation of NO_x is the reaction of the nitrogen and oxygen at temperatures typically found in combustion processes.

Concentrations in urban areas are usually from 10 to 100 times those concentrations founded in rural areas. The average background concentrations in the U.S. are 8 ug/m^3 (4.3 ppb) for NO_2 and 2 ug/m^3 (1.6 ppb) for NO. Nitrogen oxides are considered important pollutants because they damage the environment and they start the formation of photochemical smog.

3.5 Carbon Oxides

Both carbon monoxide (CO) and carbon dioxide (CO_2) are important atmospheric components because of their significance to vegetative and photosynthetic processes. Carbon dioxide has been the subject of much study because of its ability to absorb long-wavelength radiation that otherwise would be lost to the other atmosphere, producing what is called the "greenhouse effect." Catastrophic damage could occur if the temperature of the earth would rise or fall significantly. Study of the factors causing temperature and climatic changes is continuing. However, no generally acceptable conclusions have been reached.

Carbon monoxide is a widely distributed air pollutant. Total emissions of carbon monoxide exceed those of all other pollutants combined. EPA estimated that in 1971, over 100 million tons of CO were emitted. Approximately 78% came from transportation sources, resulting from the incomplete combustion of fuel. Some small amounts of CO can be produced by biological processes, but compared to that produced by man's activity it is almost negligible. Background concentrations of CO in relatively unpolluted areas may range from .03 to 1.2 mg/m^3 (.03 to 1 ppm). In polluted areas, concentrations may be a hundred times greater than in nonpolluted areas. As examples, maximum 8-hour CO concentrations in Los Angeles, California ranging from 12 to 46 mg/m^3 (10 to 40 ppm) have been measured; concentrations in excess of 100 mg/m^3 (87 ppm) have been measured in underground garages and tunnels.

Carbon dioxide is emitted in the largest quantities of any gas - some 13 billion tons globally in 1971. However CO_2 is not generally considered a pollutant because of its involvement with biological processes and because of the enormous interchange of the gas between the atmosphere and the oceans - it comprises 0.3% of the atmosphere.

3.6 Ozone and Photochemical oxidants

Up to this point the pollutants that have been discussed have been "primary pollutants", that is, they exist in the atmosphere as a result of being emitted. There is another class of pollutants called "secondary pollutants." These are formed in the atmosphere by the chemical reaction of primary pollutants. Chief amount of this group are ozone and photochemical oxidant, which are formed by the action of sunlight on NO_2, and subsequent reactions with hydrocarbons. The reactions in this process for forming ozone are:

$$NO_2 + \text{sunlight} \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

The oxygen atom formed from the photodissociation combines with atmospheric molecular oxygen to form ozone. However, the presence of reactive hydrocarbons in the atmosphere allows formation of considerable ozone to occur through subsequent reactions. Furthermore, in addition to ozone, other oxidative compounds are formed such as PAN (peroxyacetyl nitrate) organic peroxides and hydroperoxides, and others. These compounds as a group are referred to as photochemical oxidant.

In addition to the ozone formed by the photochemical reactions, ozone is brought to the surface of the earth from the ozone layer by the mixing associated with major weather systems. Maximum ozone levels of from 20 to 100 ug/m^3 (10 to 50 ppb) have been recorded in nonurban areas, however most measurements were between 20 to 60 ug/m^3 (10 to 30 ppb). This natural background is primarily the result of atmospheric mixing, although a small amount is formed by natural electrical discharges. The concentration of ozone and photochemical oxidant vary widely from area to area, depending on the ratio of NO_2 to NO in the air and the amounts of reactive hydrocarbons emitted into the atmosphere, as well as local meteorology and topography, ambient temperature and the amount of sunlight that is received on a given day. In a few urban areas, peak concentrations of 17 mg/m^3 (0.85 ppm) have been recorded, while maximum hourly-averages of 5.9 to 12 mg/m^3 (0.3 to 0.6 ppm) are typical.

3.7 Hydrocarbons

The largest source of methane in the atmosphere is the natural decomposition of vegetation. Background concentrations of 0.7 to 1 mg/m^3 (1.1 to 1.5 ppm) have been recorded. In more inhabited areas, methane levels are often much higher - values of 4 mg/m^3 (6.1 ppm) have been observed. Volatile terpenes are another group of hydrocarbons that are produced by vegetation, specifically pine trees. The amount emitted into the atmosphere is considerable. In fact the blue haze associated with the Appalachian Mountain Region of the U.S. is a natural photochemical aerosol resulting from photochemical reactions involving these terpenes.

Methane does not participate in the reactions that generate photochemical smog. Thus non-methane hydrocarbons are considered more important pollutants. The primary sources of non-methane hydrocarbons are incomplete combustion of fuels, industrial emissions, storage and transfer of liquid fuels such as gasoline, and the use of hydrocarbons as solvents. It is estimated that in 1971 a total of 26.6 million tons of non-methane hydrocarbons were released to the atmosphere. Of this amount, 55% was emitted from mobile sources and slightly more than 20% from industrial processes. Concentrations of non-methane hydrocarbons in polluted areas have been measured in the range of 1.3 mg/m^3 (2 ppm) as methane.

3.8 Miscellaneous Gases

In addition to the gases and particulates discussed, other compounds may make significant contributions in the total air pollution picture. In any locality, emissions or accidental releases of ammonia, hydrogen sulfide, and other gases and odors may have a tremendous impact. Hydrogen sulfide is formed from industrial processes, such as the manufacture of kraft paper. Although it is a toxic gas, concentrations in the atmosphere rarely approach dangerous levels. Its sickening odor and its ability to darken certain paints make it an undesirable component of ambient air. Ammonia is largely produced by natural decay, and frequently is found in particulate matter as ammonium salts. Odorants associated with various processes such as fermentation, coffee roasting, and animal rendering are generally emitted in low concentrations but are frequently annoying in the locale in which they are emitted. They are probably more psychologically damaging than physically damaging.

4. Transport of Pollutants

As indicated in previous chapters, the atmosphere is not a static system. It is a dynamic system in which pollutants are continuously discharged or formed and also continuously removed or destroyed. The mechanisms by which solid and gaseous pollutants are dispersed in, and removed from the air include diffusion, settling, chemical reaction, rain-out and wash-out. The movement of the atmosphere has a singificant influence on these mechanisms.

4.1 Air Pollution Meteorology

In the troposphere, the layer of the atmosphere next to the earth's surface, the temperature of the air generally decreases with height above the earth's surface. The rate of this temperature-decrease with height is called the lapse rate. If a parcel, or small volume, of dry air moves upward, it will expand as the atmospheric pressure decreases. If no heat is added or removed, the temperature will fall at a rate called the dry adiabatic lapse rate. The amount of temperature decrease of the dry adiabatic lapse rate is approximately 10°C per kilometer of elevation. The <u>actual</u> decrease in the temperature of the troposphere with height at any point in time is called the environmental lapse rate. The rate may be less than, equal to, or greater than the dry adiabatic lapse rate. Depending upon which condition exists, the troposphere will be called unstable, neutral or stable. These terms describe the stability of the atmosphere, or its tendency to move in a vertical direction. The transport of pollutants in the atmosphere is dramatically affected by the stability.

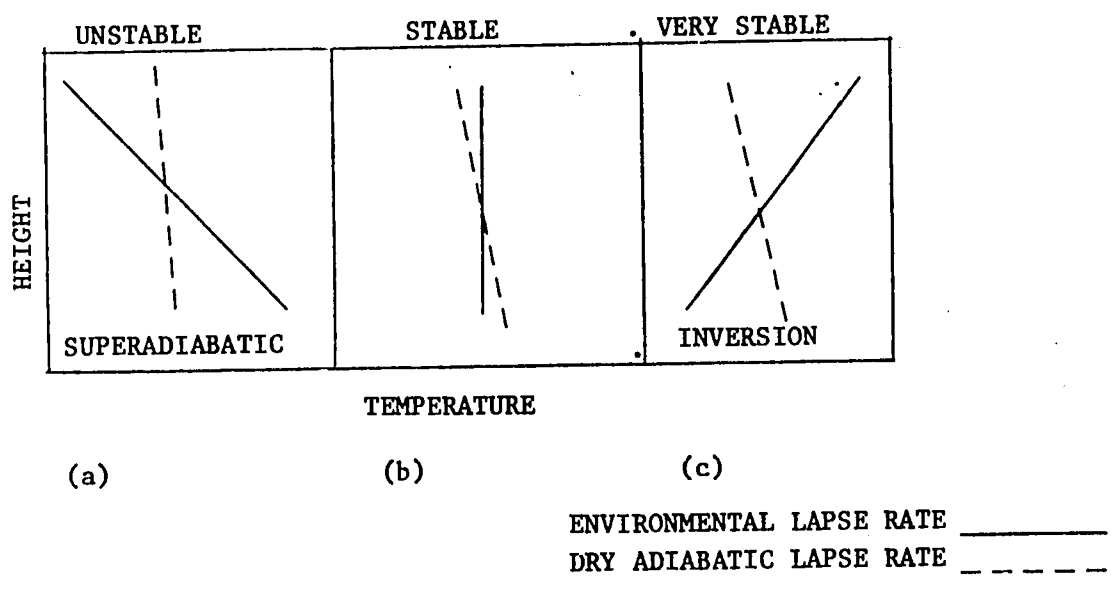


Figure 4-1. Stability of the air determined by the environmental lapse rate.

Figure 4-1 illustrates the variation of the stability of the atmosphere with changing environmental lapse rates. In figure 4-1a the superadiabatic or unstable situation is graphically represented. Under unstable conditions, the environmental lapse rate is greater than the dry adiabatic lapse rate, that is, there is a decrease of temperature with height greater than 10°C per kilometer. Recall that as a parcel of air rises, it cools at the adiabatic lapse rate. Under superadiabatic conditions, the temperature of the parcel will be warmer than the surrounding air, which will be at a temperature indicated by the environmental lapse rate. Because this parcel is warmer, and more buoyant than the surrounding air, it will rise even faster. Thus vertical movement in the atmosphere will be accelerated. This is referred to as an unstable condition.

If the environmental lapse rate is smaller than the dry adiabatic lapse rate, that is, the temperature is decreasing at a rate less than 10°C per kilometer, as shown in Figure 4-1b stable conditions will prevail. In this case, a rising parcel of air will be cooler and more dense than its surroundings. Because it will tend to fall vertical, motion will be depressed. This is referred to as a stable atmosphere.

If the environmental lapse rate is the same as the adiabatic lapse rate, then a rising parcel will neither be accelerated nor depressed. This condition is called neutral.

If the temperature increases with height, as shown in Figure 4-1c then the environmental lapse rate would be negative describing a condition is called an inversion. An inversion is an example of extreme atmospheric stability. Vertical motion in the atmosphere may be severely reduced or even halted.

Both unstable conditions, when vertical motion is accelerated, and very stable conditions, when vertical motion is depressed, have considerable effect on the movement of pollutants in the troposphere. This is most easily seen in the behavior of smoke plumes from stationary source stacks. In general there are five major types of plume behavior: looping, coning, fanning, lofting and fumigation. These are shown schematically in Figure 4-2.

Looping occurs during superadiabatic or unstable conditions. The visible plume will appear to loop because of the increased vertical mixing. Gases and particulate matter are diffused rapidly. Occasionally, air parcels will be pushed to the ground near the base of the stack. Looping usually occurs when skies are cloudless because strong solar heating of the ground is necessary to obtain a large superadiabatic looping rate.

Coning occurs during the weakly stable situation that occurs when the environmental lapse rate is less than, but near the dry adiabatic lapse rate. Under these conditions vertical motion is damped slightly, and so the plume cones, or fans, out in all directions. Coning typically occurs under cloudy skies with a brisk wind.

Fanning occurs during temperature inversions. The plume fans out from the stack almost in thin sheets because vertical motion is severely damped. Under such conditions, it is not unusual for the plume to travel for distances of many miles with very little dispersion. Most fanning occurs during the night time when ground-level inversions usually occur.

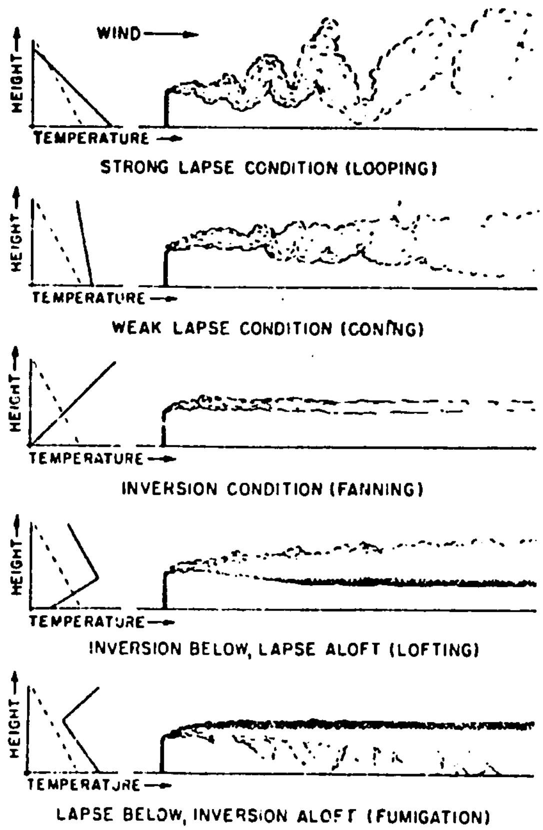


Figure 4-2. Schematic representatin of stack plume behavior under various conditions of vertical stability.

Lofting occurs when the plume is released at the top of an inversion, typically occurring late in the day. Here vertical motion is possible only above the inversion and so the upper edge of the plume spreads out far more than the lower edge.

Fumigation results from the emission of pollutants within an inversion layer. The gases and particles accumulate in the inversion, as in the description of a fanning plume. When solar heating breaks the inversion, the air will become completely mixed and the pollutants will be brought to the ground level.

This typically will occur early in the morning as the inversion slowly breaks.

From the standpoint of atmospheric transport, there is a maximum opportunity for diffusion of the plume to occur under looping conditions. Nonetheless, because of the rapid motion of the plume, high concentrations of pollutants can be brought to the surface within relatively short distances of the stack. Under coning conditions little diffusion occurs. The pollutants eventually reach the surface, but at considerable distances from the stack.

Similarly, under fanning conditions, very little diffusion can occur. The pollutants can be carried for great distances without reaching the surface. The problems begin when the inversion begins to break and the accumulated pollutants then touch down during fumigation. If the inversion has persisted for several days, when it does break, very high concentrations of pollutants may be brought to the surface.

Under lofting conditions, diffusion possibilities are excellent because vertical motion above the inversion is not limited. Further, the pollutants cannot reach the surface because of the inversion below the plume.

5. Effects of Air Pollution

Air pollution affects various sectors of the environment. Plants and other vegetation are susceptible to damage which can destroy them, or in the case of agricultural crops, reduce and impair the quality of their yield. The physical environment can be affected by erosion, and chemical weathering, or dirtied by soot or other particulate deposits. Animals and humans can be made sick or possibly even killed by air pollution.

The total damage to the environment done by air pollution is difficult to assess. Direct effects, for example, the medical costs of treating pollution-caused illnesses, the market value of a crop that is destroyed, or the cost of cleaning more frequently, are often easy to quantify. Indirect effects, such as the unpleasantness of odors, risks to human health and welfare or the visual effect of vegetation damage, are often very difficult to quantify.

Another cost of air pollution is called the avoidance cost. This is what must be spent to avoid the effects of pollution. As an example, EPA reported that coating low-voltage electrical contacts in electronic devices with gold, platinum and other precious metals to avoid the destructive effects of air pollution, cost over 20 million dollars in 1968. Another example of an avoidance cost is found in the use of clothes dryers. Of the $600 to $900 million spent on clothes dryers in 1972, how much was spent to buy increased convenience, and how much was spent to avoid hanging clean clothes in dirty air?

One estimate of the air pollution damage costs in the U.S. in 1968 is $16.2 billion. This estimate includes damage to materials, crops, and human health, and reduced property values. It does not include the cost of cleaning soiled materials, damage to animal health, avoidance costs, and other miscellaneous costs.

5.1 Effects on Vegetation

The nature of air pollution damage to vegetation has been changing as new pollutants reach significant concentrations in air. The destruction of foilage on large scale was initially the result of sulfur dioxide emitted from smelters and power plants. With the development of new industrial processes and products, and a tremendous increase in automobile emissions, extensive injury to trees and shrubs, farm crops and ornamentals from new causes have been reported. Nitrogen oxides, ozone and other photochemical oxidants such as peroxyacetyl nitrate (PAN) damage several crops including grapes, tobacco, and spinach. Damage from these pollutants was reported all over the U.S., as well as in other countries, and was not limited to the immediate vicinity of urban areas. Fluorides have caused extensive vegetation damage in the vicinity of fertilizer plants. Not only are plants susceptible, but livestock that feed on the vegetation on which the fluorides have been deposited, can be killed by a debilitating disease called fluorosis. The estimate for air pollution damage to crops alone in 1968, is $100 million.

5.2 Effects on the Physical Environment

Many materials are affected by air pollution. Metal corrodes, fabric weakens and fades, leather weakens and becomes brittle, paint discolors, concrete in buildings, and stone discolors and erodes, glass becomes etched and paper becomes brittled. Sulfuric acid, a common contaminant of the air in areas where large amounts of sulfur dioxide are emitted, causes the deterioration of many materials. When sulfuric acid is present on the surface of the particles, considerable damage may be done to painted surfaces and other metal parts. Ozone will cause rubber to crack; nitrogen oxides can produce considerable fading of textile and other dyes; particulates can soil buildings. Particulate air pollution decreases visibility and may also affect weather.

Recreational, aesthetic and psychological factors accompany the direct affects of air pollution on the environment. What is the psychological damage to the owner of the destruction of an ornamental shrub? What is the aesthetic damage caused by smog or haze that spoils a scenic view? What is the recreational damage to vacationers and sportsmen of the destruction of a forest area? The estimated damage to materials and property values in 1968 was estimated at $10 billion in the U.S.

5.3 Effects on Human Health

It is difficult to measure accurately in dollars the damage to human health caused by air pollution. Air pollution has been shown to aggravate existing illnesses, and to bring on death in the aged and the weak. There is strong evidence that air pollution is associated with a number of respiratory illnesses including chronic bronchitis, bronchial asthma, pulmonary edema, emphysema and lung cancer. This may be the result of the irritants that make up air pollution, such as acids and oxidants, and it may be the result of a reaction with specific chemical, such as benzo(a)pyrene, a known cancer-producing material. Because of the difficulty in accurately defining the relationship between air pollution and human sickness, it is difficult to determine what portion of the cost from lost work and health care resulting from respiratory injuries, colds, etc., are attributable to air pollution. One estimate of the damage to human health in the U.S. in 1968 is $6.1 million.

6. Air Quality Standards

Air quality standards are values that mark the limits of desired air quality. There are several kinds of standards that have been developed and applied in different situations. In this country, primarily ambient air quality standards and emission standards are used.

Ambient air quality standards were developed from the relationships between air pollution concentrations and the resulting environmental effects, called air quality criteria. Much of the data come from laboratory experimentation and so there is an added difficulty of extrapolating from short-term exposures to animals, to long-term exposures to humans, as would occur in the ambient air. Air quality goals were set from the criteria. These are the concentrations of pollutants with which we are willing to live, considering our desire to protect the health and welfare of the people and provide for technological growth. Once the goals are established, standards are set to allow for the orderly achievement of desired air quality. It follows that there must be standard methods of measurement and analysis of air pollutants to be sure that collected data are comparable.

In the United States, national emission standards were set as part of the strategy to reach the ambient air quality standards. Standards were set for both stationary and mobile sources, as a result of relating the impact of the emissions from such sources on existing air quality. At present, about 40 countries in the world have some kind of air quality standards.

7. Nature of Process Emissions

This syllabus will discuss two kinds of sources: mobile and stationary. Mobile sources include automobiles, trucks, buses,

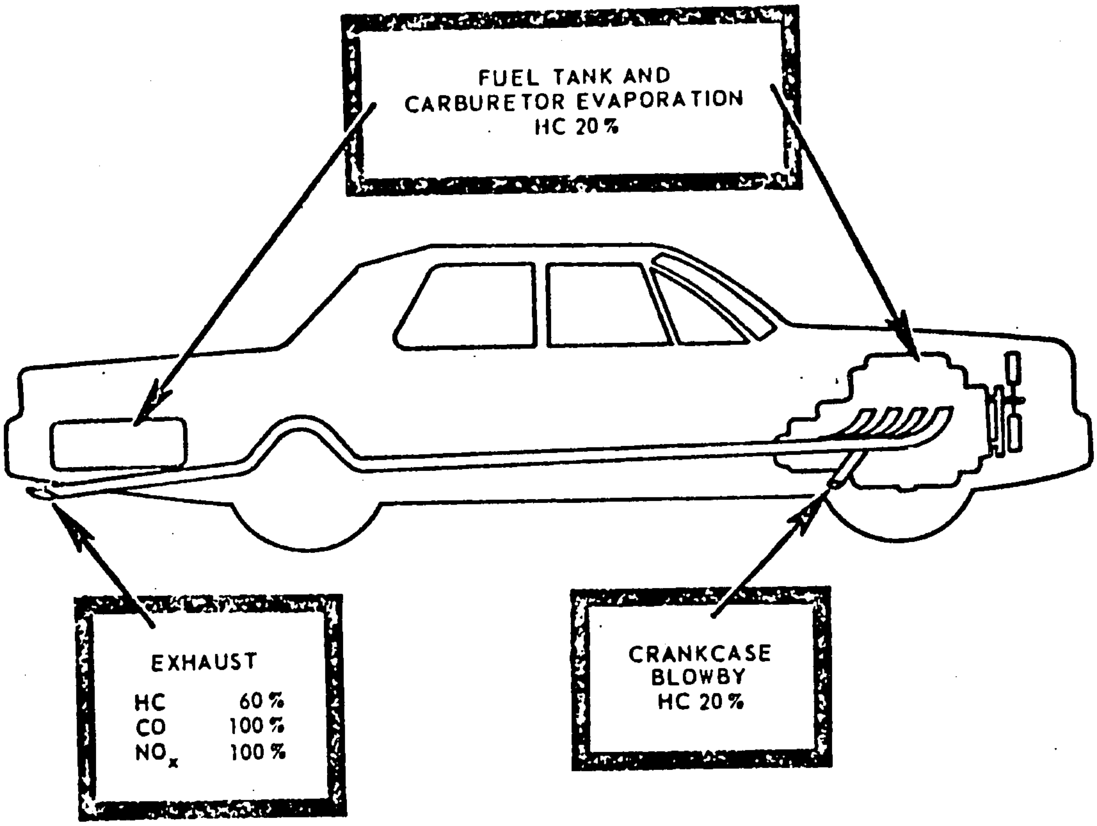


Figure 7-1. Approximate distribution of emissions by source for a vehicle not equipped with any emission control systems.

airplanes, etc. Stationary sources include fossil fuel fired power plants, cement plants, steel mills and other heavy and light manufacturing processes.

7.1 Mobile Combustion Sources

Although mobile combustion sources include all transportation vehicles, in terms of its impact on the atmospheric environment, the gasoline powered automobile is the most important. The pollutants emitted by automobiles include carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulates. Some of these alone are toxic, but it is the role they play in the photochemical reactions that produce smog that makes them particularly important.

There are three types of emissions that comes from the automobile: exhaust emissions - those that come directly out of the tailpipe; evaporative emissions - gasoline vapors that are lost directly to the atmosphere from the storage fuel and delivery system; and crankcase emissions - those that escape the combustion chamber past the piston rings in the cylinder and into the crankcase. Figure 7-1 shows the approximate distribution of emission from an uncontrolled automobile.

The principal emissions from the exhaust include CO, unburned HC, NO_x and particulate matter. Also emitted are partial oxidation products of hydrocarbons such as aldehydes, alcohols, etc., and high molecular weight HC. The amounts of CO and unburned HC emitted will depend on the air/fuel ratio and the stoichiometric completeness of the burning of the fuel in the engine's cylinders.

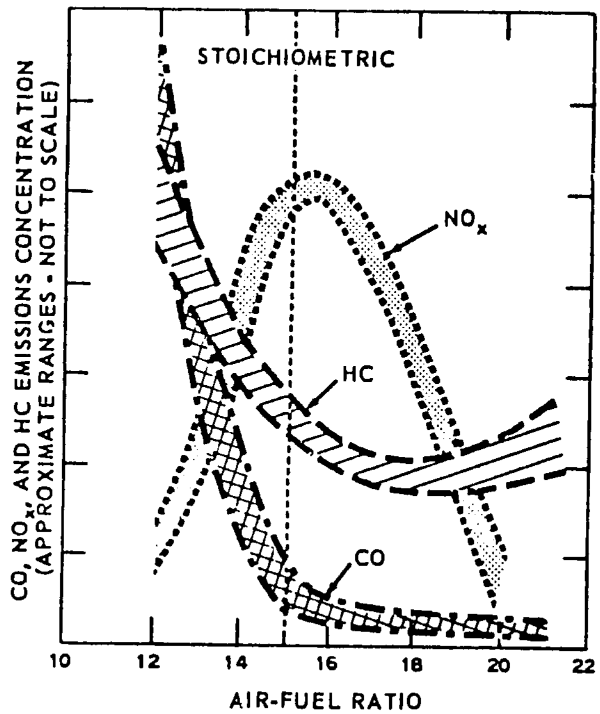


Figure 7-2. Effects of air-fuel ratio on exhaust composition.

As the ratio of air to fuel increases, theoretically, combustion becomes more complete, reducing the amounts of CO and unburned fuel to essentially zero. However as the combustion becomes more complete, combustion temperature increases, increasing the formation of NO_x dramatically. To reduce the NO_x, combustion temperature must be reduced. One way this can be achieved is by reducing the air/fuel ratio, however, then the production of CO and unburned HC will be increased. In theory this is what should occur, however the previous discussion does not take into account such factors as cylinder misfiring, which discharges the entire air/fuel mixture into the exhuast system, engine combustion characteristics, spark timing, and others.

Figure 7-2 illustrates the relationship between air/fuel ratio, combustion temperature and gaseous emissions.

Of the three types of emissions from the automobile, the exhaust emissions have proven to be the most difficult to control. Presently the U.S. auto makers have adopted a catalytic converter which insures complete combustion of organic material. Evaporative emissions have been drastically reduced by eliminating any vents to the atmosphere in the fuel storage and delivery system.

Crankcase blowby is the term used to describe the gases forced around the piston rings of the cylinder into the crankcase during the compression cycle. Prior to 1963 models, these gases, mainly HC, were discharged directly into the atmosphere. Newer cars use a system of crankcase ventilation that recycles the blowby back into the air intake, preventing the emission.

A cautionary note, in considering the impact of changes in automobile design and added air pollution control packages, it is important to keep in mind that a change in a model year takes nearly 10 years, at the present rate of automobile consumption in the U.S., to become spread over the entire automobile population. Thus emission changes introduced in 1975 will not produce an immediate change in ambient air quality.

7.2 Stationary Sources

7.2.1 Fossil Fuel Fired Power Plants. The major pollutants emitted from fossil fuel fired steam generators are particulates, sulfur oxides and NO_x. More particulates are emitted from the combustion of coal than from oil or gas. The composition of the particulate matter will vary with the fuel, but it is largely carbon, silica, aluminum and iron oxide.

The uncontrolled combustion of coal generates an amount of particulates (in pounds) approximately equal to seventeen times the percentage of ash in the fuel. Thus if the ash content is 10%, the estimated particulate emissions to the atmosphere would be 170 pounds of particulates per ton of coal. Aprpoximately 30 pounds of this is collected in the furnace. The uncontrolled emission factors for fuel oil and gas are 8 pounds per thousand gallons of oil, and 15 pounds per million cubic feet of gas. The use of fuel oil instead of coal reduces the amount of particulates by a factor of a hundred.

The amount of sulfur oxides that are emitted is directly related to the sulfur content of the fuel. Nitrogen oxides in the emission are generated from two mechanisms: a) the fixing of nitrogen and oxygen at the temperature of combustion and, b) the oxidation of nitrogenous compounds contained in the fuel. Other pollutants emitted include CO, the amount of which will depend upon the efficiency of the fuel combustion, and trace metallic oxides, which will vary in composition depending upon the fuel and its source.

Most large central-station power plants that burn coal use a pulverized coal furnace. The advantage of such a furance is that it provides for more complete combustion of the coal. The principal disadvantages of the furnace is that the fly ash is more difficult to collect and handle. The following table shows the typical gaseous effluents from a thousand megawatt (electrical) - MW - power station.

7.2.2 Iron and Steel Manufacturing. The principle emissions from iron and steel manufacture are particulate matter (metal oxides) and volatile hydrocarbons. These are emitted in two different stages in the production of iron and steel. Coke production, most commonly performed in by-product ovens, produces large amounts of volatile materials from the coal. The remaining processes in the production, refining and use of iron and steel primarily produce particulate matter. The size ranges of the particulates produced and their content will vary with the nature of the process. As examples, from 35 to 50% of the emissions from a blast furnace may be iron oxides and silicates; two-thirds or more of the particulate emissions from open-hearth furnaces will be iron oxide. The composition and size range will vary upon the charge to the furnace, the type of fuel used, etc.

7.2.3 Non-Ferrous Metal Industries. The smelting of zinc, copper and lead introduce large quantities of SO_2 into the atmosphere. This occurs primarily because the most important ores for these metals are the sulfides. Copper and zinc smelting introduced more SO_2 to the atmosphere than lead smelting largely because the lead ore is richer in the native metal. Refining processes for each of these metals generally produce more particulate matter than gases. The SO_2 content of the waste gas from zinc roasting and copper smelting is sufficiently high that it can be converted into usable sulfuric acid.

7.2.4 Pulp and Paper Manufacturing. The chemical production of wood pulp produces much of the emissions associated with the pulp and paper industry. Approximately 63% of the total production of pulp in the United States is generated by the kraft process.

The primary emissions from the kraft process are hydrogen sulfide, mercaptans, organic sulfides, and particulates. The principle problem with the gases is they have sickening odors. The types and quantities of sulfur compounds in the gases are dependent upon processing variables and the type of wood being pulped. Emissions occur primarily from the black liquor oxidation process, evaporation and concentration of the black liquor, the recovery furnace and the lime kiln.

Paper production may produce similar emissions although in lower concentrations than the pulping processes. Coating the paper may introduce other organic materials into the atmosphere depending upon the process involved.

Table 7-1. Emissions from a thousand MWE power station in tons per year

Pollutant	Fuel Type (coal)	Oil	Gas
Carbon Monoxide	600	90	0
Carbon Dioxide	7.0×10^6	5.2×10^6	4.1×10^6
Sulfur Dioxide	102×10^3	54×10^3	12
Hydrocarbons	240	736	0
Oxides of Nitrogen	24×10^3	24×10^3	13×10^3
Particulate	6×10^3	2.3×10^3	465
Totals (Not including carbon dioxide)	1,032,840	81,945	13,477

7.2.5 Petroleum Refining. The principal emissions from petroleum refining are, hydrocarbons, sulfur oxides, and CO. Lesser amounts of particulates, miscellaneous gases and vapors, and odor-producing compounds are also emitted. These are generated in the various processes by which the oil is distilled, cracked and reformed for the variety of end products that refinery produces.

7.2.6 Mining and Mineral Products. Most of the pollution associated with the mining and mineral products industry results from the mechanical processing of solids. Leaks in and around the mechanical equipment cause dust to be emitted. These particulates are referred to as fugitive dust.

7.2.7 Central Station Incinerators. Generally central station incinerators are of two types: single and multiple chamber. Typically the emissions from these incinerators are mainly CO, miscellaneous organic and inorganic compounds, and particulate matter. The amount that is emitted from each type of incinerator will vary. In general the multiple chamber incinerator produces fewer emissions because of better control over combustion. Table 7-2 presents typical emissions from single and multiple chamber incinerators.

Chamber temperature, burning rate and the uniformity of the charge are the principle factors that determine the completeness of the burning, and in turn, the nature and amount of emissions.

7.2.8 Odor-Producing Industries. There are several industries that substantial amounts of odor-causing materials. These include rendering, coffee roasting and chemical fermentation. In most cases, leaks at various points in the processes are the primary escape route for these materials. In some cases, however, emissions from the stack produce the problem. Most odor-causing materials are nitrogen- or sulfur-containing compounds produced by the destruction of organic matter. The transportation and storage of material collected for rendering may also create odor problems. Particulates and odor-causing compounds emitted from coffee roasting are mainly organic in composition.

8. Measurement and Monitoring

Measurement and monitoring refer to two different techniques of determining pollutant concentrations. The term measurement describes the process of determining concentrations at a given point in time. The term monitoring describes the process of determining the variation of concentration over a period of time. Measurement and monitoring of air pollutants determines how close the air quality is to the desired air quality, whether in the general atmosphere or inside a stack.

Table 7-2. Comparisons of Emissions from Single and Multiple Chamber Incinerators

Emissions	Multiple Chamber	Single Chamber
Particulate Matter (grains per standard cubic foot at 12% CO_2)	.11	.9
Volatile Matter (grains per standard cubic foot at 12% CO_2)	.07	.5
Total grains per standard cubic foot at 12% CO_2	.19	1.4
Total pounds per ton refuse burned	3.50	23.8
Carbon Monoxide (pounds per ton of refuse burned)	2.9	197 to 991
Ammonia (pounds per ton of refuse burned)	0.9	4
Organic Acids as Acetic Acid (pounds per ton of refuse burned)	.22	3
Organic Aldehydes as Formaladehyde (pounds per ton of refuse burned)	.225	64
Nitrogen Oxides (pounds)	2.5	.1
Hydrocarbons as Hexane (pounds of tone per refuse burned)	1	Not recorded

Ambient air monitoring and measurement techniques are used to determine community air quality. In-stack, or source monitoring and measurement techniques are used to determine the amount of source emissions. Both ambient air and source sampling are a necessary part of a strategy to meet community air quality standards.

Concentrations of pollutants in stacks, or at their source, are much higher than in the ambient air. Generally, special instrumentation is required to measure concentrations of pollutants in the very small quantities that they might be found in the general atmosphere. Although acceptable measurement methods exist for most air pollutants, acceptable continuous monitoring methods have yet to be developed for several key pollutants. A typical approach to developing a monitoring method has been to mechanize the measurement method. In some cases, the West-Gaeke for example, the approach worked. In others, for example, the continuous Saltzman, it did not.

Both measurement and monitoring procedures require two distinct steps: sampling and analysis. Sampling refers to the selection of the air to be sampled and its delivery to the analytical system. Analysis refers to the techniques of measuring the concentration of the pollutant in the air sample. Sampling considerations include how representative is the portion of air sampled to the atmosphere or the stack emission; what changes in the air are introduced by the sampling mechanism; how much air should be sampled to obtain a good answer. Analytical considerations include: how fast does the analytical procedure take; how accurate is the method; how reproducible is the method.

A commonly used analytical technique is the colorimetric method. With this type of method, a colored solution is formed as a result of the reaction of the pollutant and the collecting or analyzing solution, the intensity of which is directly proprotional to the concentration of the pollutant. The color intensity is measured by a spectrophotometer, which records the difference in the absorption of light of a specific wavelength by the colored solution and a non-colored or reference solution. Colorimetric techniques are convenient and reliable, and are generally usable over a range of pollutant concentrations.

8.1 Sulfur Oxides

One of the earliest techniques for measuring total sulfate was the lead peroxide candle method. This was developed in England in 1932 and was based on the reaction of SO_2 and lead peroxide. A paste of lead peroxide was applied to a cylinder of gauze acting as a carrier for the paste. The cylinders or "candles" were set out in the atmosphere in weather-proof shelters for about a month. During this time, the SO_2 reacted to form a black precipitate of lead sulfate. The candle was then stripped and the amount of lead sulfate weighed. The results were reported as milligrams of sulfate per hundred square centimeters of lead oxide per day, which is a sulfation rate. Over some concentration ranges, sulfation rates are proportional to the SO_2 concentration of the atmosphere.

The sulfation plate method is a greatly simplified version of the lead candle. The principle of the technique is the same, however small plates are used instead of candles. Lead peroxide converts reduced sulfur gases as well as SO_2 and SO_3 to sulfate. It also fixes sulfuric acid mist. Because of its lack of specificity the method has been replaced by techniques specific for the pollutants to be measured.

Early SO_2 concentration data were obatined with a conductometric technique. A change in the conductance of water is produced by absorption of SO_2. The method corrected for carbon dioxide absorption, but other gases such as hydrogen chloride, NO_2 and ammonia, etc., that probably were present in varying amounts, could have interfered with the technique.

The development of a colorimetric procedure, the West-Gaeke method, meant that the SO_2 could be measured specifically, even in the presence of the previously named interfering gases. The West-Gaeke procedure is based on the chemical reaction that occurs between the absorbing solution and the SO_2 producing a colored solution. Typically the ambient air measurement of SO_2 is accomplished through the use of bubblers, devices that mix the sampled air and the collecting liquid together under turbulent conditions to permit the transfer of the gas to the liquid phase.

We are also concerned about concentrations of sulfuric acid in the ambient air. As yet no acceptable measurement or monitoring technique has been developed. There is a method for measuring total sulfur content that has been used. It utilizes a flame photometric technique, in which the sample is burned and the number of sulfur atoms is measured.

Different measurement and monitoring methods are used to determine SO_2 concentrations in stacks because of the higher concentrations than are found in ambient air. The method currently in wide use, is the barium chloranilate method, another colorimetric method that is useful in the concentration range of several hundred to several thousand mg/m^3 (ppm) SO_2 found in stack gases.

Special instruments that use ultraviolet and infra-red light have been developed to monitor SO_2 in stacks. These are continuous read-out devices that show the behavior of SO_2 concentrations with time. They are reported to be reliable and to require relatively little maintenance.

8.2 Nitrogen Oxides

For measuring NO_2 in ambient air, perhaps the most widely used method has been the Saltzman technique. It is a colorimetric procedure requiring the sampling of the gas using a bubbler. By using a parallel sampling line and either scrubbing the sample free of NO_2, or oxidizing the gas stream, it is possible to use the Saltzman technique to determine the NO concentration as well. This technique was designed for short-term gas sampling, of the order of an hour; modifications have been made which permit the use of this technique of monitoring NO_2 and NO over a 24-hour period. Other chemical techniques have been developed that attempt to correct some of the inaccuracies and difficulties associated with the Saltzman technique. These are also colorimetric methods, but they use different absorbing solutions. None of these have been generally accepted.

In an attempt to get the continuous monitoring data that is needed for air quality management, an instrumental technique utilizing the principal of chemiluminesence has been developed. The chemical reaction of NO with ozone produces a small amount of light. The amount of light produced is directly proportional to the concentration of the reacting gases. This phenomenon, called chemiluminescence, provides a method for accurately measuring and monitoring low concentrations of NO and NO_2. (By reducing the NO_2 in the sample to NO, the NO_2 concentration can be determined).

A static monitor, patterned after the lead candle method, was developed using nylon fibers for collection of NO_2, as an indicator of the nitric acid concentration in the atmosphere. The NO_2 was removed from the nylon and measured by one of several analytical procedures. The method has not been used widely.

For NO_2 concentrations in stacks, a colorimetric procedure called the phenoldisulfonic acid method is employed. Here the concentration is reported as total NO_x. Continuous in-stack monitors have been developed for measuring NO_2. These also employ ultraviolet absorption techniques.

8.3 Hydrocarbons

There are two techniques that are most widely used to measure and monitor hydrocarbon concentrations: gas chromatography and total hydrocarbon analysis. Use of gas chromatography makes it possible to determine whether a particular gas is present, in addition to its concentration. Although originally used as a measurement technique, recent developments have made it possible to use gas chromatography for monitoring. In the total hydrocarbon analysis, the hydrocarbons are burned and the atoms of carbons are counted. Thus hydrocarbon concentrations are reported as methane concentrations. No information about the kinds of hydrocarbons present in the sampled air is available with this technique.

It is possible through the use of an infra-red or ultraviolet absorbing instrument to determine the concentration of a specific hydrocarbon in the atmosphere, or in the stack.

8.4 Oxidant

Oxidant refers to a group of oxidizing gases in the atmosphere. These include ozone, peroxides, hydroperoxides, NO_2, and others. Oxidant concentrations have been measured and monitored using the Mast instrument, which continuously records the amount of oxidizing material present in the atmosphere by using a coulometric technique. Potassium iodide solution is brought in contact with the sampled air. The iodide is oxidized to free iodine, which is reduced to iodide at the instrument's cathode. The amount of electrons required is directly proportional to the oxidant concentration. The presence of reducing gases such as hydrogen sulfide and others will interfere, but techniques have been developed for removing these.

Ozone is the component of oxidant that has generated the most concern. It has been measured by the neutral buffered potassium iodide method. This is another bubbler-colorimetric method, generally accepted as the reference method for ozone concentration determinations. Chemiluminescence also has been used to measure and monitor ozone levels. The reaction of ozone with Rhodamine B, or ethylene is most often used. Such measurements are specific for ozone, and also are reliable and allow for continuous monitoring.

8.5 Carbon Oxides

Both CO and CO_2 are very conveniently measured by infra-red spectroscopy, by measuring the difference in absorption of air containing the gases, and air free of the gases. These infra-red techniques can be applied to in-stack measurement and monitoring as well.

Because of the high concentration of CO_2 in the air - about 0.3% - chemical methods can be used to measure atmospheric and source concentrations of the gas. In one method, a chemical reaction occurs between the CO_2 and an absorbing solution containing a known amount of barium hdyroxide. The amount of barium hydroxide consumed is proportional to the amount of CO_2 in the sample.

For chemically measuring CO_2 and CO in stack gases, the Orsat gas analyzer has been used.

8.6 Particulates

Dust fall buckets are static monitors for particulates that are easy to use. They are placed at designated locations and collected once-a-month. The collected particulates are dried and weighed. Data are reported as tons of particulates per square mile. These buckets will collect only those particulates that fall from the atmosphere and so provide information on the soiling potential of the air. This technique does not provide information about the suspended particulates, which are important from a health standpoint. To measure and monitor the suspended particulate matter, filtration techniques have been used. These include tape, and high volume (HI-Vol) samplers. The tape sampler collects the dust on a roll of filter paper. The Hi-Vol collects particulates on an 8" x 10" filter held in a frame and mounted in a characteristically shaped enclosure.

In general airborne suspended particulates range in diameter from submicron particles up to about 100 u. The paper tape sampler was developed to measure and monitor the level of suspended particulates in the air. The tape passes a sampling port where the particulates are collected for about 1 hour. The tape then advances so that a clean area is moved in front of the sampling port. After the sampling is completed, the tape has a series of regularly spaced spots of filtered particulates. The particulates levels in the spots are analyzed in one of two ways. Either the transmission of light through the collected particulates, or the reflectance from the surface is measured. The transmission measurement is recorded in units called COH's, meaning "coefficient of haze." The reflectance measurements are reported in units called Ruds, meaning "reflectance units of dirt shade." COH's are intended to reflect the loss in visibility, while Ruds are intended to reflect soiling.

The Hi-Vol sampler filters a large volume of air over a 24 hour period through a square filter, typically 8" x 10" in size. Other techniques involving smaller filters and in some cases, reduced sampling flow rates, have been tried. The filters are efficient enough to trap submicron particles. The technique permits the collection of enough material not only to measure the concentration of particulates, but also to analyze the pollution composition. Once the particulate matter has been collected on the filter, it is equilibrated to a standard humidity and then weighed. The amount of particulate matter is reported in ug/m^3. Portions of the filter can be cut and treated to analyze for metals or other material collected. The remainder of the filter is saved for future analyses and reference.

No single monitoring technique for particulates has been generally accepted. It is important to know how visibility and soiling, as well as human health are affected by particulates. Unfortunately, a concentration of suspended particulates in ug/m^3 cannot give all the answers, therefore a number of measurement techniques are used to monitor the air quality.

For in-stack sampling, a very specific set of procedures must be followed to be sure that a representative sample of the air stream is obtained. Sampling must be performed iso-kinetically, meaning that the rate at which the air is drawn into the sampling line must be the same as the rate at which the air passes the sampling intake. To sample at rates lower or greater than the air flow rate would mean that certain sizes of particles would not be captured. In iso-kinetic sampling, the pressure drop across the sampler must be continuously measured along with the pressure in the stack, so that adjustments can be made to make sure that the gas flows are always matched. In addition, the plan of sampling must be carefully prepared so that the results are independent of the different air flow patterns that are found in each stack. A number of measurements are taken across the diameters of the stack and averaged. This insures that the amount of material collected will most closely approximate the amount of material that is emitted. The particulates are collected on a filter or in a thimble, and are weighed to determine the amount of material present in the stack emissions.

9. Control of Industrial Emissions

The control of industrial emissions can be accomplished using a wide variety of control equipment, often tailored specifically to the process and operating conditions of the source. There are six basic types of control equipment currently in use:

a. Mechanical collectors - generally for collecting solid particulate matter.

b. Scrubbers - for collecting particulates and gases.

c. Filters - for collecting particulate matter

d. Electrostatic precipitators - for collecting solid and liquid particulate matter.

e. Afterburners - for removing gases.

f. Adsorbers/absorbers - for collecting gases and vapors.

9.1 Mechanical Collectors

Mechanical collectors are generally used to remove solid particulate matter - dust, fly ash, fibers wood dust, etc., - in the size ranges larger than 5 u in diameter. They utilize the forces of gravity, inertial impingement and centrifugal separation to remove particulate matter from the exit air stream. Some of the mechanical collectors are used in conjunction with water sprays to remove particulates and gases. Most often they are used to recover the solid in a dry state.

9.1.1 Settling Chamber. Settling chambers rely on the gravitational force exerted on particles moving in an air stream to overcome the forces of flow when the velocity has been drastically reduced. Settling chambers are low in cost and are operated with low pressure drops. However their collection efficiencies are only about 50%-60%. Settling chambers typically are used to remove very large particles (larger than 50 u) from an air stream prior to the use of a high-efficiency collector. The settling chamber consists simply of a large chamber in which the velocity of the air stream is markedly reduced to allow the particles to settle, as shown in Figure 9-1. For the settling chamber to be effective, the air velocity through the collector must be uniform and relatively low, - 60 feet per minute (fpm) or less. Baffles and shelves may be added to the chambers in an effort to increase their efficiency. Baffles force sharp changes in direction for the air stream and so introduce some inertial impaction to the gravitational collection. Horizontal shelves make the velocity distribution more uniform and provide a surface for collecting the particles. However, the plates make the removal of the dust rather difficult. In addition to these drawbacks, settling chamber require considerable space for their installation. They are not very widely used.

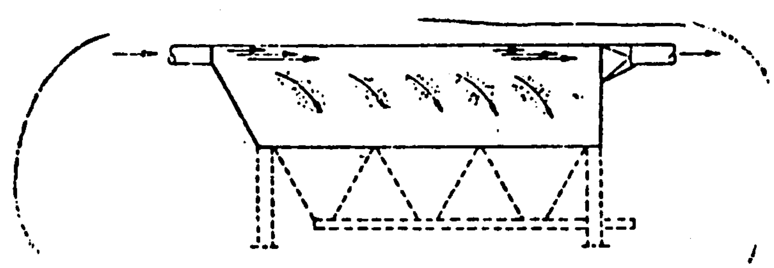


Figure 9-1. Gravity settling chamber.

9.1.2 Dry Centrifugal Collectors. Dry centrifugal collectors utilize the centrifugal force created by the design characteristics of the collector to separate the particulate matter from the carrier gas or air stream. In the conventional cyclone, a vortex is established by the tangential gas inlet. The dust particles are thrown toward the walls of the collector and are removed through a receiver at the base of the cyclone, as shown in Figure 9-2. The conventional cyclone is the most common example of the dry centrifugal collector.

Depending upon the design characteristics of the cyclone, it can operate with relatively low or high efficiencies of collection. It has the advantages of having few moving parts, being able to handle large flow rates, and being able to operate at high temperatures. Often three efficiency ranges are applied to cyclones - low, medium and high - depending upon their weight collection efficiencies. These ranges are 50%-80%, 80%-95%, and 95%-99%, respectively, and are related to the particle size - the larger the particle size the more efficient a given cyclone will be. In general, conventional cyclones are useful for collecting particles greater than 15 u in diameter. High efficiency cyclones may be used for collecting particles above 5 u in diameter. Cyclones may be packed together in a parallel arrangement called a multi-cyclone collector to obtain the benefits of both high efficiency and high gas flow. Cyclones are typically

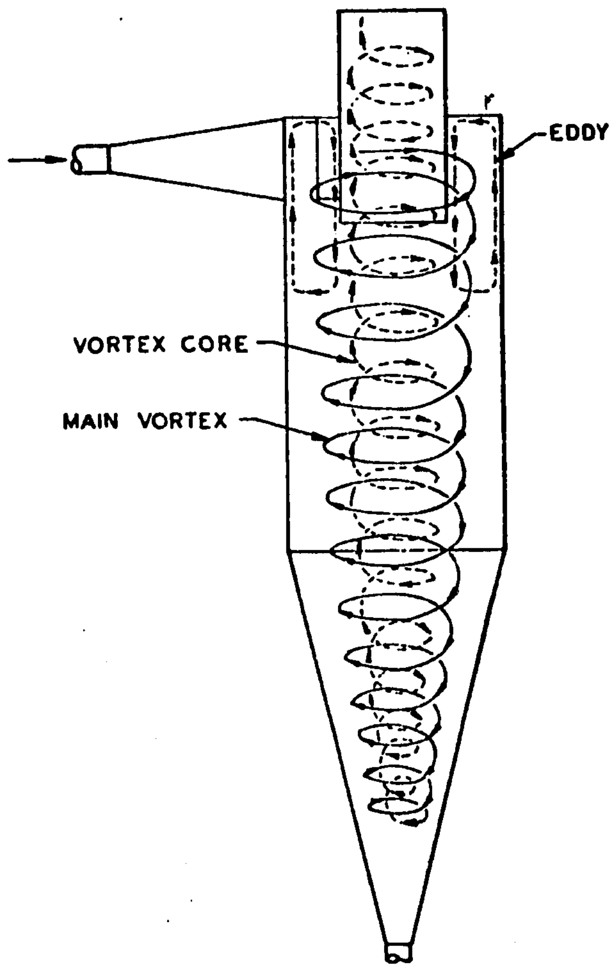


Figure 9-2. Typical cyclone

used in feed and grain mills, cotton gins, fertilizer plants, petroleum refineries, asphalt-mixing plants, and metallurgical, chemical and plastics plants. Table 9-1 shows representative performance of cyclone collectors.

9.1.3 Impingement Collectors. Impingement collectors depend upon a series plates to produce a radical change in air stream direction causing the particles to impinge on the plates, as shown in Figure 9-3. The type of collector shown is a flat louver impingement separator in which particles impinge upon the louvers. The particles than bounce off, or are washed off, the individual louver elements into an air stream called the dust circuit, which washes the bottom surface of the collector to remove the accumulated dust. These collectors can be used in series to increase their overall collection efficiency.

TABLE 9-1. TYPICAL PERFORMANCE OF CYCLONES

Process	Material	Air Flow (CFM)	Pressure Drop (inches of water	Efficiency (weight percent)	Inlet Load (grains per cubic foot)
Cleaning	Talc	2,300	0.33	93.0	2.2
Drying	Sand & gravel	12,300	1.9	86.9	38.0
Grinding	Aluminum	2,400	1.2	89.0	0.7
Planing Mill	Wood	3,100	3.7	97.0	0.1

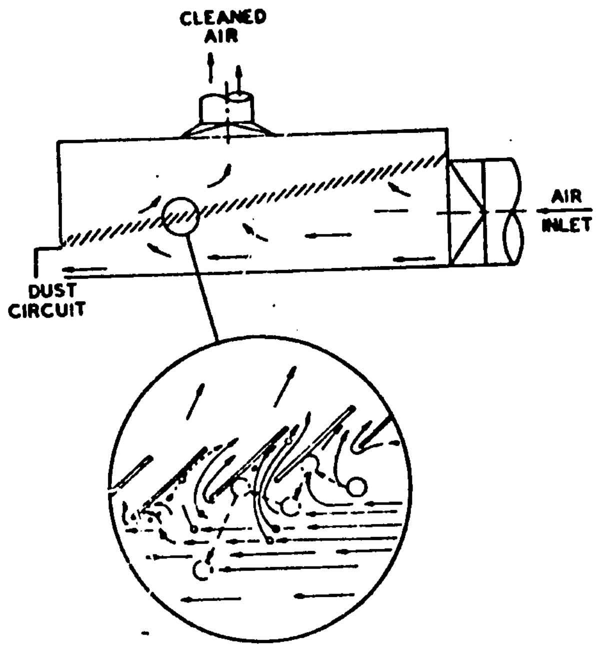


Figure 9-3. Flat louver impingement separator.

9.1.4 Dynamic Precipitator. The dynamic precipitator combines the operations of the fan and a dust collecting device in one package. The principle advantages of this unit are its compactness and the fact that the collection efficiency are relatively uniform over a limited size range. The major limitations are a tendency toward plugging, rotary imbalance resulting from the build-up of solids on the rotating impeller, and temperature limitations of the bearings and seals in the fan. The dynamic precipitator has a collection efficiency in between that of a conventional cyclone and a high efficiency cyclone.

9.1.5 Summary. Dry mechanical collectors can be used with a variety of solid particulate matter, and over a wide range of air flows, particles sizes and temperatures. The collectors are primarily used in situations where particle sizes are larger than 7.5-10 u, because they have relatively high collection efficiencies. If the air stream contains particles of smaller size, then they must be removed by other techniques. Table 9-2 summarizes the use of mechanical collection equipment.

9.2 Wet Collectors

In simple terms, wet collectors are scrubbers that use a liquid, usually water, to remove particulate matter and gases

Table 9-2. Use of Mechanical Collectors

Collector	Space Requirements	Volume Range CFM	Efficiency by Weight	Pressure Loss[a] in Inches H_2O	Temperature Limitations	Applications
Settling Chambers	Large	Space Available Only Limitation	Good Above 50 u	0.2 to 0.5	700-1000°F Limited only by Materials of Construction	Precollector for fly ash, and metallurgical dust.
Conventional Cyclone	Large	Normal Range up to 50,000 cfm	Approx. 50% on 20 u	1 to 3	700-1000°F Limited only by Materials of Construction	Woodworking paper, buffing, fibers, etc.
High Efficiency Cyclone	Medium	Normal Range up to 12,000 cfm	Approx. 80% on 10 u	3 to 5	700-1000°F Limited only by Materials of Construction	Woodworking material conveying, product recovery, etc.
Multi-Tube Cyclones	Small	Normal Range up to 100,000 cfm	90% on 7 1/2 u	4.5	700-1000°F	Precollector for electrostatic precipitator for fly ash, product recovery, etc.

Table 9-2. Use of Mechanical Collectors

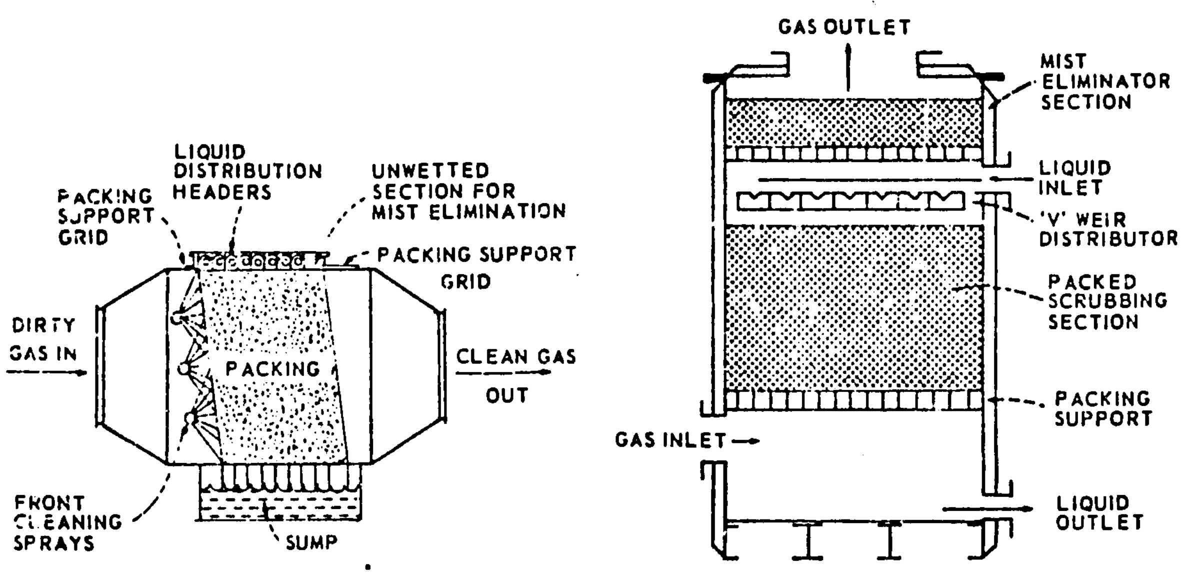
Collector	Space Requirements	Volume Range CFM	Efficiency by Weight	Pressure Loss[a] in Inches H_2O	Temperature Limitations	Applications
Impingement ment Separator	Small	Space Available Only Limitation	90% on 10 u	1 to 5	700°F	Coarse particle collecting boiler fly ash and cement clinker coolers. Recent design used for cleaning atmospheric air to diesel engines, and gas turbines
Dynamic Precipitator	Small	17,000 cfm	80% on 15 u	No loss (True fan)	700°F	Woodworking non-production buffing, metalworking, etc.

[a]Pressure drop is based on standard conditions

from an air stream by contact between the particles or gas molecules with the scrubbing liquid. For the collection of particles the scrubbing liquid may perform several functions:

a. carry away the collected particles.
b. capture the particles by impingement, and
c. absorb or react with bases in the air stream.

There are many designs for scrubbers. They may be modifications of dry mechanical collectors, as is the wet cyclone, or they may be designed for a particular cleaning application. Scrubbers may be filled with packing material (packed) to increased the surface area for contact between the scrubbing liquid and the particles or gases to be collected, or they may be unpacked. If the liquid flow is in the same direction as the air flow, the scrubber is called cocurrent; if it is opposite to the air flow, counter-current; or if it is at right angles to the air flow, cross-flow. A simplified diagram of a cross-flow and a counter-current flow packed scrubber is shown in Figure 9-4.



a. CROSS-FLOW SCRUBBER

b. COUNTERCURRENT-FLOW SCRUBBER

Figure 9-4. Packed-bed scrubbers

When gases need to be removed, only the counter-current scrubbers are used. The gas about to be discharged through the top of the scrubber is contacted by the cleanest liquid, and the incoming, most contaminated, gas is contacted by the most contaminated liquid.

The most commonly used packed scrubbers are counter-current, where the gas flow is upwards, vertically, against the gravity feed, downwards, of the absorbing liquid. One of the simplest types of wet scrubbers is the gravity spray tower. This is an unpacked scrubber in which liquid droplets either from spray nozzles or atomizers fall downward on a counter-current, rising air stream containing the dust particles. A mist eliminator is

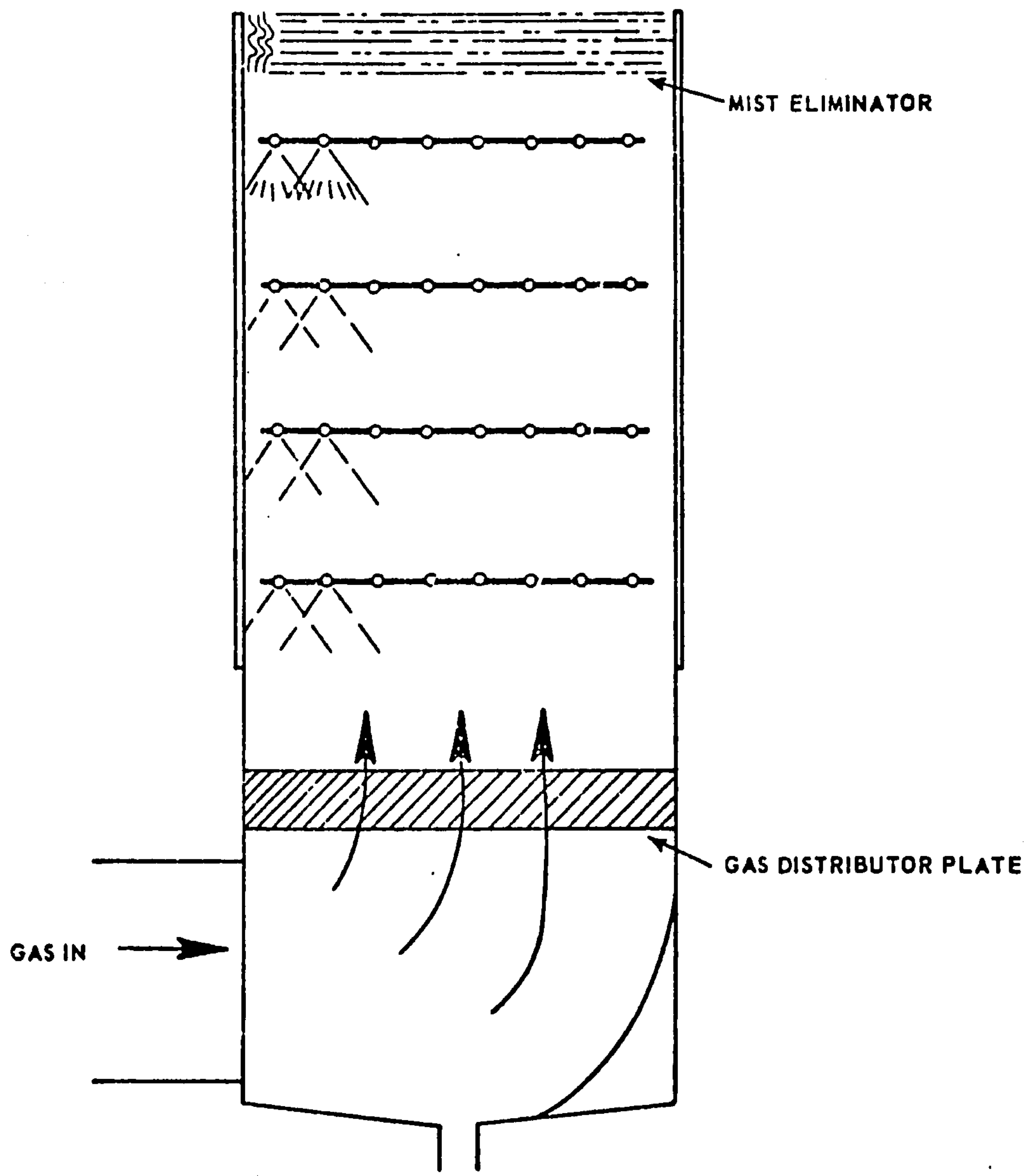


Figure 9-5. Typical layout for spray tower.

used at the top of the tower to prevent carry over of the droplets. A typical spray tower is shown in Figure 9-5. Irrigated cyclones may also be used to collect dust particles. In general they have higher efficiencies than their dry counterparts largely because of their abilities to reduce re-entrainment of the particles. Here the water is serving as a means of washing the collected surfaces free of collected particulate matter. One of the considerations in designing the scrubber system is the removal of the contaminant from the scrubbing liquid. It is easier to remove particulate matter from the scrubbing liquid than gaseous matter or material that is soluble in the scrubbing liquid.

Usually, higher pressure drops are required for higher efficiencies of collection. As an example, a pressure drop of 6 inches of water might provide 95% of collection of particles 5 u or larger, whereas a pressure drop of 10 to 12 inches of water might provide efficiencies of 90% or greater on particles 1-2 u in size. Much higher pressure drops would be required for efficient collection of particles less than 1 u in size. As particles become very small, diffusion and electrostatic forces are more important than inertial forces. Thus 1 u and smaller become increasingly difficult to remove by scrubbing.

9.2.1 Summary. Simple gas washers such as unpacked towers can be effective and efficient in removal of large diameter particles, particularly in the 7.5-10 u range. Packed towers improve the efficiency of collection and these can be effective down to 1 or 2 u. Use of higher energy scrubbers, such as venturi scrubbers - those that operate at high pressure drops - it is possible to obtain 90% collection efficiencies of particles in the sub-micron range.

9.3 Filtration

Filtration is one of the oldest and most reliable methods for removing dust, mist, fumes and other solid materials from gas streams. Although there are several types of filtering media used, fabric filters are in widest use. The fabric filter is capable of high collection efficiencies for particles as small as a 0.5 u and can remove substantial quantities of particles as small as 0.01 u. Fabric filters are used extensively in industrial operations because they are capable of handling high particle loads. The filters are usually made in the form of a tubular bag or envelope, that is slipped over a wide frame and hung in a container which allows a multiple number of the bags to be arranged. The dust can either be collected on the inside surface, or on the outside surface of the bag, depending upon the cleaning mechanism that will be employed. Figure 9-6 shows a simplified diagram of a dust collector called a bag house, where the dust is collected on the inside surface of the bag.

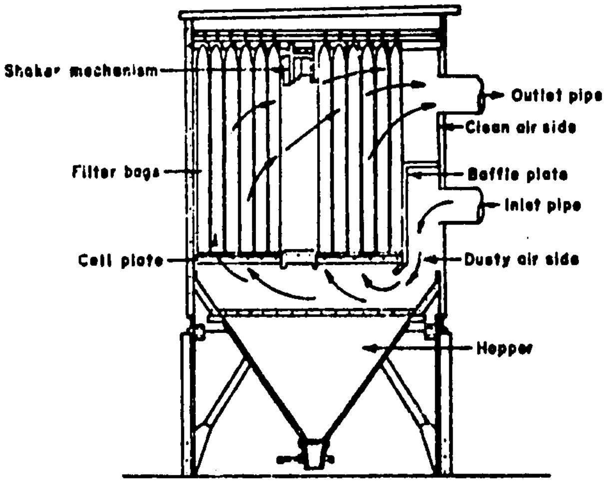


Figure 9-6. Single compartment baghouse filter. Mechanical cleaning is intermittently applied.

Figure 9-7 shows a picture of a baghouse in which the dust is collected on the outside. As many as several thousand bags may be installed in a bag house, usually compartmented to permit the cleaning of groups of bags while others remain in service. Particulate matter is removed from the air gas stream by impinging on, or adhering to, the fibers of the bag. The process is not simply fiber sieving because open spaces are sometimes a 100 u or larger, yet dust particles 1 u or smaller can be captured. Other processes involved in the filtration probably include inertial impaction, diffusion or electrostatic attraction, and possibly, gravitational settling. Certainly once mats or cakes of dust accumulate on the fabric, sieving as well as one of the other mechanisms is involved. It is necessary to build up a small cake on the fabric surfaces in order to achieve maximum collection efficiency.

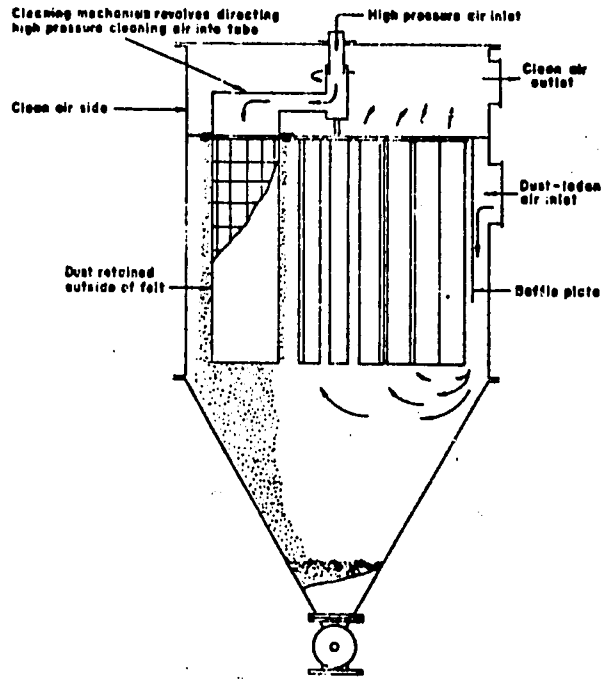


Figure 9-7. Reverse pulse filter.

Periodically the accumulated dust is removed but some small amount of the cake is always allowed to remain on the bag. Removal of the particulate matter is usually timed to occur when the particulate-generating processing is off or stopped. In most situations, the bag house is located above a hopper into which the particles or dust may fall when blown off, or shaken from the fabric. Mechanical shaking of the bags causes the dust to fall into the hopper. A reverse flow of air may also be used to help remove the cake from the filter bag. For large installations it is common to have the baghouse compartmentalized so that a section can be shut down for cleaning while other sections are operational. The removal of the accumulated dust is scheduled so that one portion of the total filter capacity is always being cleaned.

Dust removal can also be done during the filtering operation. This is generally accomplished by a reverse air flow either through a ring that traverses the length of the bag and pushes the air back through the bag; or through high pressure air jets that create a shock wave along the length of the bag to remove the cake, as shown in Figure 9-7.

Natural fibers are usable at lower temperatures, synthetics in the mid-ranges and inert materials like "Teflon", graphite, asbestos and "Nomex" nylon can be used at high temperatures. The nature of the fiber will also determine whether it is relatively resistent to attack by acids, bases, or organic solvents, or moisture. By the selection of appropriate filter media and structural materials for the baghouse, collection of particulates can be done in relatively corrosive atmospheres.

9.3.1 Summary. Some 80% of all manufacturing plants contain operations that produce dust particles of such a small size that use a highly efficient collection device such as a baghouse is desirable. In many cases, where the material that is filtered is reclaimed, the fabric collectors are an intergral component of the manufacturing process. Examples of solids that are reclaimed are metal oxides, carbon black, cement, clay and pharmaceuticals. Fabric filters can also be used to remove harmful or irritating emissions such as chemicals and abrasives. When alkaline additives are add to oil fired power plants to reduce the SO_2 concentration, baghouses are used to collect the solid product of the reaction. In general the efficiency of performance is high even for particles in the sub-micron range. The solid material can be collected either on the inside surface or the outside surface of the bag. A variety of the bag cleaning methods may be used depending upon the requirements of a particular installation.

9.4 Electrostatic Precipitators

Electrostatic precipitation permits the high efficiency removal of particulate matter down to the sub-micron range, with high gas volumes (50,000 to 2 million cfm), over broad temperature and pressure ranges. There are three steps to the separation of the particulate matter from the gas stream:

a. the charging of the particles of suspended matter,

b. the collection of the charged particles at a ground surface,

c. the removal of the accumulated pariculate matter.

There are two principal types of precipitators: high-voltage and low-voltage, also called single-stage and double-stage.

9.4.1 High-Voltage Precipitators - By far the type of electrostatic precipitator most widely used for industrial applications is the high-voltage or single-stage precipitator. Two designs are used in most single-stage precipitators: the flat-surface-type and the tube-type. In the first design, the particles are collected on flat collecting surfaces spaced from 6 to 12 inches apart. A wire or rod discharge electrode is located centrally between the surfaces. In tube-type precipitators the grounded collecting surfaces are cylindrical instead of flat and the discharged electrode is centered along the longitudinal axis of the tube. Both these kinds of precipitators are shown schematically in Figure 9-8 and 9-9. The potential difference between the discharged electrode and the collecting surfaces is high enough so that a corona discharge surrounds the electrode. Typically the electrodes are made from round wires however they can also be in the form of twisted roads, ribbons and barbed wire, as shown in Figure 9-10.

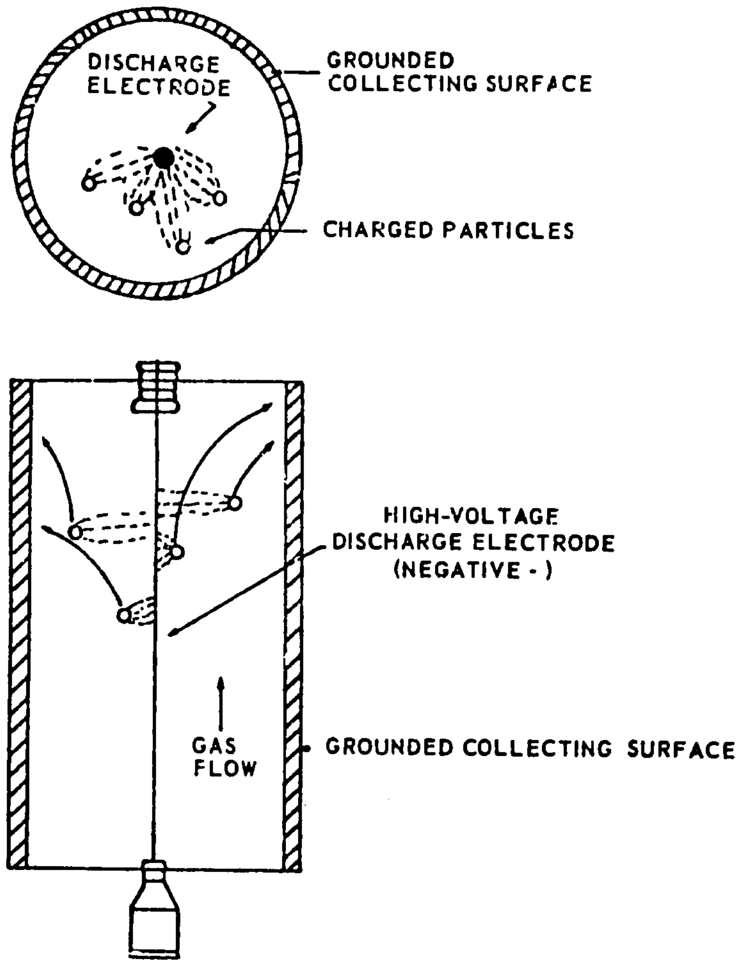


Figure 9-8. Schematic view of tubular-surface-type electrostatic precipitator.

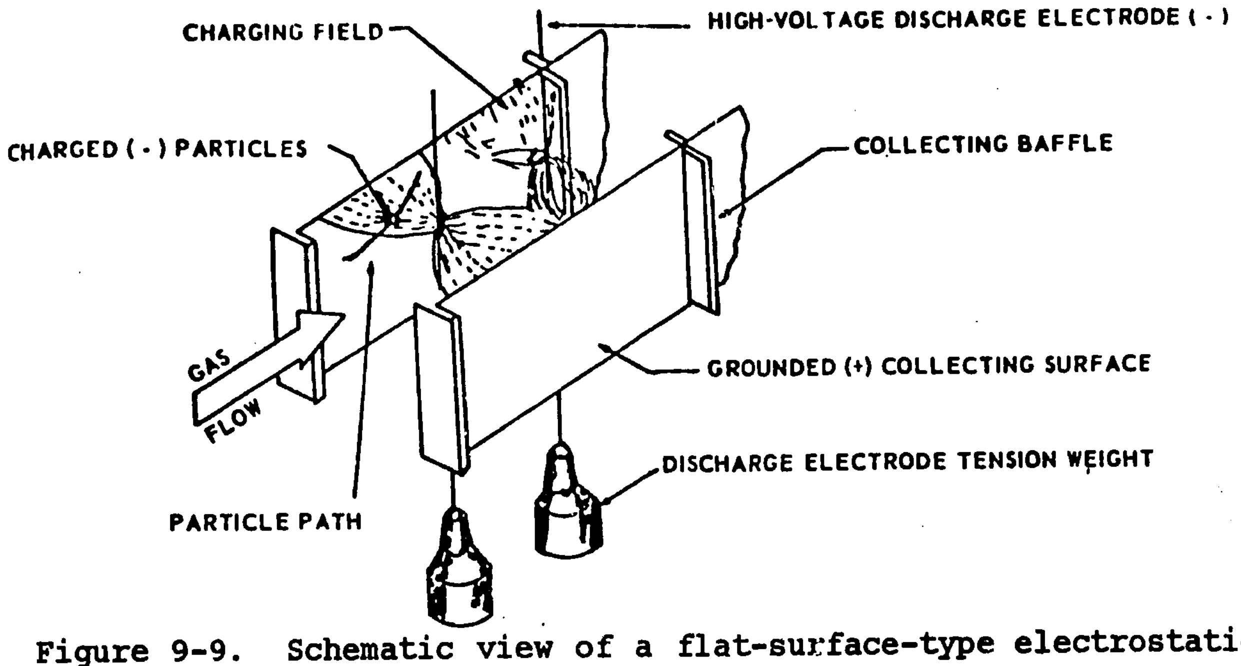


Figure 9-9. Schematic view of a flat-surface-type electrostatic precipitator.

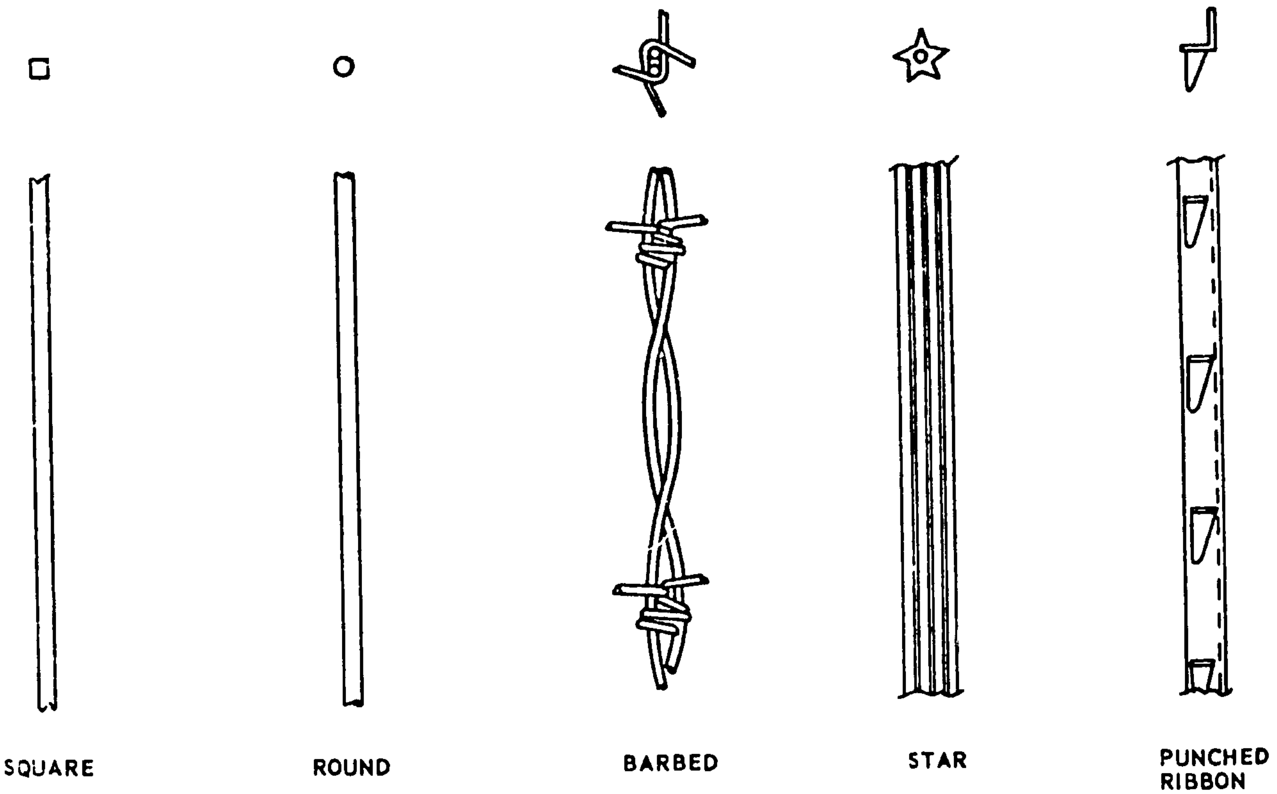


Figure 9-10. Discharge electrodes

Similarly the collecting plates, while often flat, can also have other shapes, such as expanded metal, or curtains of rods as shown in Figure 9-11. There special shapes are designed primarily to prevent re-entrainment of the dust.

Particles in the gas field passing through the corona are charged by the gas ions. The electrical field interacting with these charged particles will cause them to drift toward, and deposit on, the collecting plates or electrodes. If the particles are liquid droplets, they will collect on the electrodes and eventually drip into a sump. If the particles are solid however, the dust layer that forms eventually builds and must be removed by rapping the electrodes, to break loose the dust. Some of the dust may be re-entrained. However because this re-entrained dust has a larger average particle size than the original particles collected, because of agglomeration, it will quickly deposit on other nearby plates. Sprays can also be used to flush material from the collecting surfaces.

Operating conditions for the precipitator are usually set for the particular solid material to be collected. Any change in the character of the emissions will change the collection performance of the precipitator. Such factors as the resistivity of the solid, flow characteristics in the pecipitator, and moisture

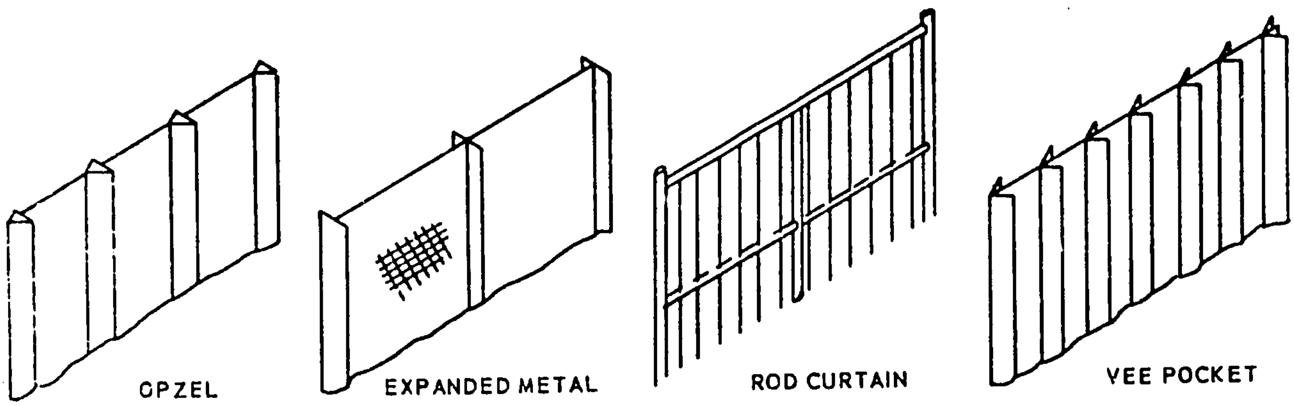


Figure 9-11. Collecting plates

content of the air stream are important in determining the efficiency of collection. High voltage precipitators have been used to collect a wide variety of solid and liquid particles. Typically their efficiencies will be in the range of 90-99+%. Electrostatic installations are common in fossil fuel fired power plants, steel mills, the cement plants, kraft pulp mills and sulfuric acid plants.

9.4.2 Low-Voltages Precipitators. The low-voltage, or two-stage, precipitator was originally designed as an air purifying device to be used as part of air conditioning systems. It is most effectively used in industrial applications for the collection of finely divided liquid particles as are associated with meat smoke-houses, asphalt plants, paper saturaters and pipe coating machines. Because of the need for close spacing of the plates, the use of low-voltage precipitators is generally limited almost entirely to the collection of liquid particles. Solid particles or sticky materials will accumulate and cause the plates to short. In the low-voltage precipitators, the ionizing and collection zones are separated. In the ionizing stage, fine wires, positively charged, are located 1 to 2 inches from parallel grounded tubes or rods. This creates a corona discharge through which the particles are passed. The second stage consists of parallel metal plates which are alternately charged positive and negative, or positive and ground. The latter design is shown in Figure 9-12.

The particulates are collected on the plates of the second stage. Liquid droplets will aggregate and wash off the plates into a collecting sump. Solid particles must be removed periodically by mechanical means.

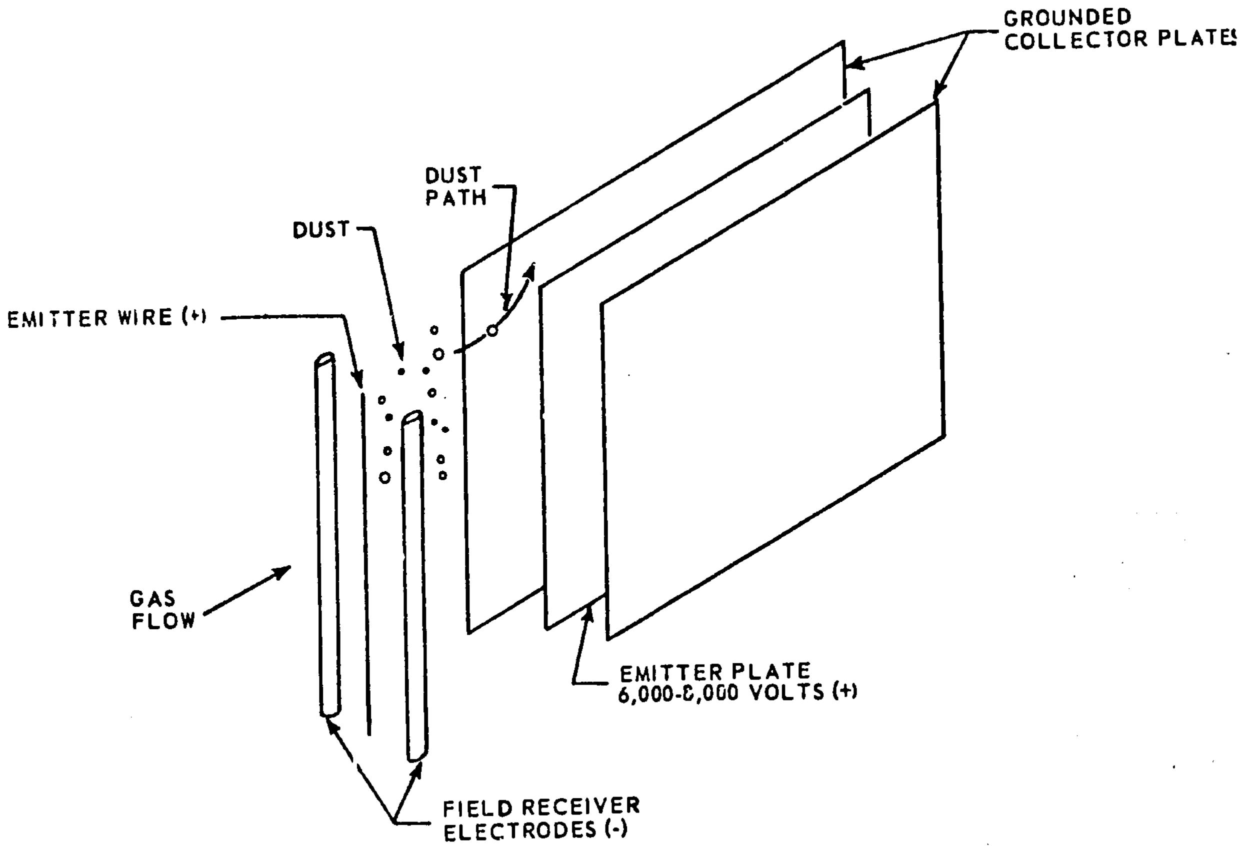


Figure 9-12. Operating principle of two-stage electrostatic precipitator.

9.4.3 Summary. Electrostatic precipitators are collection devices that can achieve high collection efficiencies, exceeding 99% in some cases, for particles of very small diameters. The design of the precipitators permits them to be used at very high gas loads and even very high temperature ranges, in some cases exceeding a 1000°F. They also operate at low pressure drops and tend to have low operating cost. Precipitators tend to be most efficient when operating conditions are constant. They cannot remove gaseous pollutants from the air stream and have other drawbacks which make them inappropriate for many applications. Electrostatic precipitators however are widely used in a number of industries including electric power, steel, pulp and paper, non-ferrous metals, chemicals, and paper.

9.5 Afterburner

Afterburners are gas cleaning devices that use a furnace for burning gaseous pollutants. The combustion may be done either by direct flame or by catalytic means. For particulates to be removed from an air stream by this process, they must be residue-free and readily combustible. Afterburners are used primarily to dispose of fumes, vapors and odors when relatively small volumes of gases or low concentrations of particulate matter are involved. In a direct flame combustor or afterburner, the flame is in direct contact with the particle-laden gas, as is shown in Figure 9-13. In a catalytic combustion unit shown in Figure 9-14, the particles and gases are consumed at the surface of the catalyst without any direct flame, after the air stream has been preheated. In the catalytic unit, the combustion is performed at a lower temperature in the direct fired afterburner.

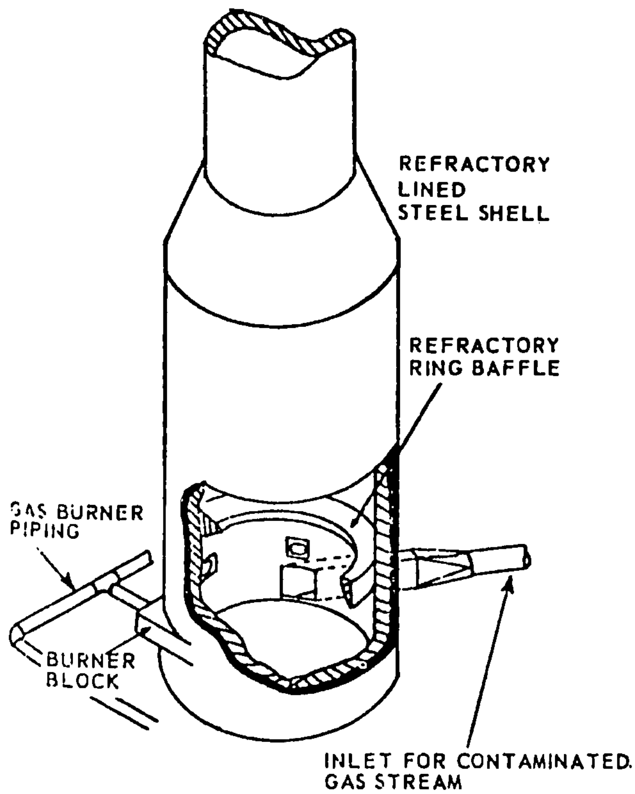


Figure 9-13. Typical direct-fired afterburner.

Although the catalytic afterburner requires less fuel and can operate at lower tempertures, it is sensitive to catalyst poisoning and plugging. Afterburners must be designed to allow adequate residence time to completely combust the material. Incomplete oxidation may permit the formation of other compounds that are more of a problem than the ones that are to be removed.

9.5.1 Summary. In general, incineration of gases and particulate matter is used to control odors, to reduce the opacity of plumes caused by organic aerosols, and as a means of rapidly reducing explosion hazards, for example using flares in petroleum refineries. Materials to be removed, or destroyed, must be combustible.

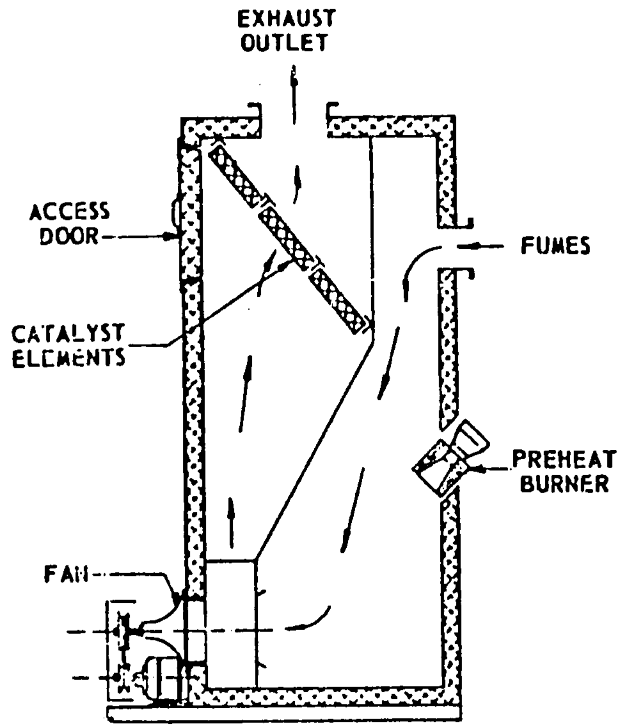


Figure 9-14. Catalytic combustion system including preheat burner and exhaust fan.

9.6 Removal of Gases.

For the removal of gaseous pollutants, one of the most effective means is the packed bed tower, shown in Figure 9-15. As in the packed scrubber, the flow of the gas is counter-current to the absorbing liquid. Typically, the gas flows up, and the liquid flows down. Relatively large volumes of air can be handled. Spray towers, spray chambers, and venturi scrubbers can also be used to remove gases.

9.6.1 Adsorption. Adsorption is another technique useful for removal of gases from an air stream. It is useful because it concentrates the pollutants, making their disposal or recovery easier. The adsorbent may be discharged with the pollutant still attached; or the adsorbed pollutant may be desorbed so the adsorbent may be recovered. If a chemical reaction occurs in the adsorption process the adsorbent may not be able to be recovered.

Activated carbon is a common adsorbent. Solid adsorbents are typically used in beds, either fixed or fluidized, requiring single passes or multiple passes by the air stream to get maximum recovery. Adsorption efficiencies exceeding 95% can be obtained using a well-packed bed of carbon granules. Adequate retension time in the bed is required to achieve high efficiencies. Flow rates must be limited to certain ranges to be sure that the bed is not disturbed. High humidities must be avoided because the condensed water might interfere with the adsorption process.

Typical processes in which adsorbents are used are food processing, checmial processing, and in such miscellaneous applications as pulp and paper manufacturing, tanning and asphalt product manufacturing.

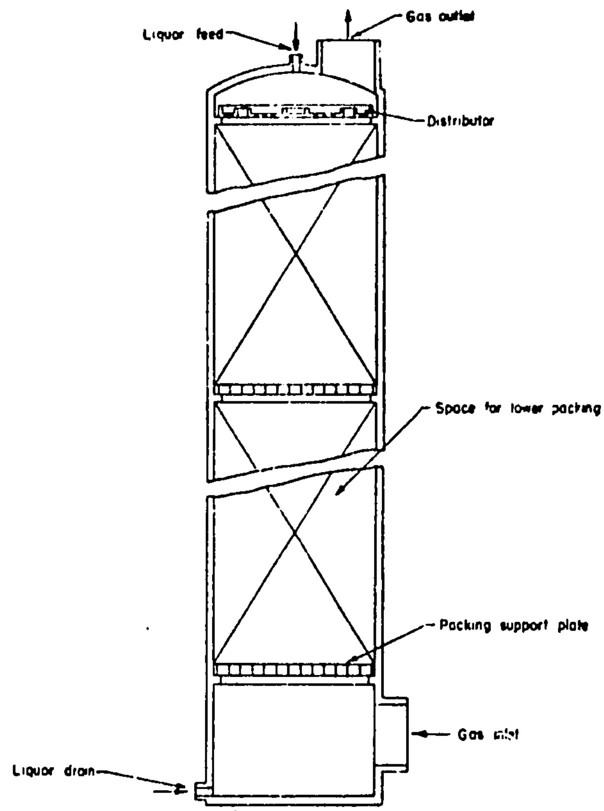


Figure 9-15. Typical packed tower.

9.7 Disperson

If the purpose of the control technique is to reduce the groundlevel concentrations, then atmospheric dilution can be utilized - emitting gases and particulates from a tall stack. No material is removed, rather the natural dilution capacity of the atmosphere is used to disperse the pollutants sufficiently so that the concentrations at the ground are within acceptable limits. The effectiveness of the dilution by the atmosphere will depend upon local meteorological conditions, local topography, and effective stack height. Tall stacks may not be suitable for every source, but they can be used in some cases.

9.8 Summary

The selection of a control device depends upon a variety of factors, some internal to the plant, and some external to the plant. This discussion provides some general information on the type and operation of control techniques presently being used.

The following table summarizes the advantages and disadvantages of several collection techniques.

Table 9-3. Advantages and Disadvantages of Collection Techniques

Collector	Advantages	Disadvantages
Settling Chamber	Low pressure loss; simple design; low cost	Much space required; low collection efficiency; difficult to collect solid materials; limited application.
Cyclones	Simplicity of design and maintenance; little floor space required; dry continuous disposal of dust; low to moderate pressure loss; handles large, medium and small sized particles; high dust loading; reasonably independent of temperature.	Low collection efficiency of small particles; sensitive to variable dust loading and flow rates; tends to clog.
Wet Collectors	Simultaneous gas absorption and particle removal; ability to cool and clean high-temperature, moisture-laden gases; corrosive gases and mists can be recovered and neutralized; reduced dust explosion risk; efficiency can be varied.	Corrosion and erosion problems; add cost of waste water treatment and reclamation; low efficiencies on submicron particles; contamination of effluent streams by liquid entrainment; freezing problems in cold weather; reduction in buoyance and plume rise; water vapor contributes to visible plume under some conditions.
Electrostatic Precipitators	99+ percent efficiency obtainable on even submicron particles; particles may be collected wet or dry; pressure drop and power requirements are small compared to other high efficiency collectors; maintenance	Relatively high initial cost; sensitive to variable dust loadings or flow rates; resistivity changes causes some material to be economically uncollectable; precaution required to safeguard personnel from high voltage; collection

Collector	Advantages	Disadvantages
	is nominal unless corrosion or adhesive materials are handled; few moving parts; can be operated at relatively high temperatures.	efficiencies can deteriorate gradually.
Fabric Collectors	Dry collection possible; collection of small particles possible; high efficiency possible.	Sensitivity to filtering velocity; high temperature gases must be cooled to below 500°F; affected by relative humidity; susceptibility of fiber to chemical attack.
Afterburners	High removal efficiency of sub-micron, odor-causing particles and vapors; simultaneous disposal of combustible gases and particulate matter; possible heat recovery; relatively small space requirement; simple construction; maintenance.	High operating cost; fire hazard; can only remove combustibles; may have high initial cost if catalysts are used; catalysts may require reactivation, and are subject to poisoning.
Adsorption	High efficiencies achieveables at reasonably high flow rates; can incorporate continuous regeneration processes for the adsorbent.	May have high maintenance cost if adsorbent must be discarded; may create disposal problems of poisoned adsorbent; extra step in the removal of pollutant from adsorbent.
Dispersion	Independent of temperature; low maintenance; simple construction.	May be limited by meteorological and topographical conditions; not applicable for toxic emissions; not usable where visual emissions will be exceeded.

10. Industrial Applications of Air Pollution Control Technology

The following information was adopted from the Air Pollution Engineering Manual, Second Edition (AP-40), published by the U.S. Environmental Protection Agency. What follows are descriptions of the uses of the technology for controlling emissions presented in Chapter 9. Several industries are used to illustrate the process for selection and operation of control systems.

10.1 Woodworking Operations

Woodworking exhaust systems are almost always equipped with air pollution control devices. If they were not so equipped, the entrained sawdust would result in excessive dust loading in exit gases and could easily cause a local nuisance. Air contaminant emissions from systems such as these are functions of the particular dust encountered and the particular control device employed. The dust particles are not excessively small in most sytems, and elaborate devices are not usually required.

Particles emitted by woodworking machines vary in size from less than 1 u, to chips and curls several inches long. Hammer-mill-type wood hogs emit particles running the complete size range, while sanders generate only very small dust particles. Wood waste particles from most other machines are larger in size, seldom less than 10u, and greater in uniformity. Other factors determining particles size are the type of wood processed and the sharpness of the cutting tool. Hardwoods tend to splinter and break, yielding smaller particles than soft woods, which tend to tear and shred. A dull cutting tool increases tearing and shredding, and produces larger particles.

Generally, the configuration of waste particles is of little importance. There are, however, instances where toothpick-like splinters and curls have presented difficulties in collection and storage, and in the emptying of storage bins.

10.1.1 Control Equipment. The simple cyclone separator is the most common device used for collecting wood dust ad chips from woodworking exhaust systems. In fact, cyclones outnumber all other devices by a large margin. The main advantage of simple cyclones over most other collection devices is their simplicity of construction and east of operation. They are relatively inexpensive, require little maintenance, and have only moderate power requirements. Properly designed cyclones have been found satisfactory for use with exhaust systems at cabinet shops, lumber yards, planing mills, model shops, and most other wood-processing plants.

The size and design of woodworking exhaust system cyclones varies with air volume and the type of wood waste being handled. Where fine sander dust predominates, cyclones should be of high-efficiency design with diameters not greater than 3 feet. Coarse sawdust, curls, and chips, such as are produced with ripsaws, moulders, and drills, can be effectively collected with low-efficiency cyclones up to 8 feet in diameter. Most woodworking exhaust systems are used to collect a mixture of wood waste that includes both fine and coarse particles. The exhaust system designer must, therefore, carefully consider the quantities of each type wood waste that will be handled. The presence of appreciable precentages of coarse particles in most systems allows the use of low- and medium-efficiency cyclones.

Baghouses are sometimes used with woodworking exhaust systems. Their use is reserved for those systems handling fine dusts, such as wood flour, or where small amounts of dust loses to the surrounding area cannot be tolerated. The efficiency of baghouses on woodworking exhaust systems is very high--99% or more. They can be used to filter particles as small as 0.1u in size. In some installations lower efficiency collectors such as cyclones are impingement traps are installed upstream to remove the bulk of entrained particulates before final filtering a baghouse.

10.1.2 Disposal of Collected Wates. Wood dust and chips collected with exhaust systems must be disposed of since they present a storage problem and a fire hazard. Very often a profit can be realized from this waste material. Wood wastes can be used productively for things such as:

a bulking agent for plastic products such as plastic wood, masonite, and others;

pressed woods such as firewood, fiberboard, firtex, and others;

soil additives;

smokehouse fuel--hardwood sawdust is burned to produce smoke for the processing of bacon, ham, pastrami, etc.:

floor sweeping compount--with or without oil, sawdust helps hold dust particles;

wood filler--sawdust can be mixed with water based resins and used as a wood filler;

floor cover in butcher shops, restaurants, etc.;

fuel for waste heat boilers--heat can be recovered to generate steam and hot water.

10.2 Open-Hearth Steelmaking

Air contaminants are emitted from an open-hearth furnace throughout the process, or heat, which lasts from 8 to 10 hours. These contaminants can be categorized as combustion contaminants and refining contaminants. Combustion contaminants result from steel scrap that contains grease, oil and other combustible material, and from the furnace fuel.

The particulate emissions that occur in greatest quantities are the fumes, or oxides, of the various metal constitutents in the steel alloy being made. The concentration of the particulates in the gas stream varies over a wide range during the heat, from 0.10 to a maximum of 2.0 grains per cubic foot (gr/scf). An average is 0.7 gr/scf, or 16 pounds per ton of material charged.

The test results in Table 10-1 for the open-hearth furnace show that 64.7% of the emissions are below 5u in size. The control device selected must, therefore, be capable of high collection efficiencies on small particles.

Another serious air pollution problem occurring with open-hearth furnace operation is that of fluoride emissions. These emissions have affected plants, which in turn, have caused chronic poisoning of animals. Control of fluoride emissions presemts a problem because they usually are in both the gaseous and particulate state.

TABLE 10-1. DUST AND FUME DISCHARGE FROM OPEN-HEARTH STEEL FURNACES

Furnace data	
Type of furnace	Open hearth
Size of furnace	50 ton
Process wt, lb/hr	13,300
Stack gas data	
Volume, scfm	14,150
Temperature, °F	1,270
Dust and fume data	
Type of control equipment	None
Concentration, gr/scf	1.13
Dust emissions, lb/hr	137
Particle size, wt %	
0 to 5u	64.7
5 to 10u	6.79
10 to 20u	11.9
20 to 44u	8.96
44u	7.65
Specific gravity	5

10.2.1 Control Equipment. Open-hearth furnaces have been successfully controlled by electrostatic precipitators. On some installations, the control system has been refined by installing a waste heat boiler between furnace and control device. In this manner, heat is reclaimed from the furnace exhaust gases, and at the same time, the gases are reduced in temperature to within the design limits of the control d^vice. In Table 10-2 are shown test results of a control system incorporating waste heat boiler and an electrostatic precipitator.

Table 10-2. DUST AND FUME EMISSIONS FROM AN OPEN-HEARTH FURNACE CONTROLLED WITH AN ELECTROSTATIC PRECIPITATOR

Furnace data:	
Type of furnace (constructed 1916)	Open hearth
Size of furnace, tons	63
Test interval	1 hr during heat working period
Fuel input	Natural gas, 21,000 cfh Fuel oil, 1.4 gpm
Waste heat boiler data:	
Gas volume, inlet, scfm	14,900
Gas temperature, inlet, °F	1,330
Gas temperature, outlet, °F	460
Water in waste gas, %	12.4
Steam production (average), lb/hr	8,400
Precipitation data:	
Gas volume, scfm	14,900
Dust and fume concentration (dry volume)	
Inlet, gr/scf	0.355
Outlet, gr/scf	0.004
Inlet, lb/hr	39.6
Outlet, lb/hr	0.406
Collection efficiency, %	98.98

10.3 Sulfuric Acid Manufacturing (Contact Process)

The only significant source of emissions from a contact sulfuric acid plant is the tail-gas discharge from the sulfur trioxide (SO_3) absorber. While these tail gases consist primarily of nitrogen, oxygen, and some carbon dioxide, they also contain small concentrations of SO_2 and smaller amounts of SO_3 and sulfuric acid mist. Table 10-3 shows the SO_2 and SO_3 discharged from two wet-gas sulfuric plant absorbers.

TABLE 10-3. SULFUR TRIOXIDE AND SULFUR DIOXIDE EMISSIONS FROM TWO ABSORBERS IN CONTACT SULFURIC ACID PLANTS

	Outlet of absorber No. 1	Outlet of absorber No. 2
Gas flow rate, scfm	9,600	7,200

Sulfur trioxide,	0.033	0.39
gr/scf		
% by vol as SO_2	0.002	
lb/hr	2.73	2.4
Sulfur dioxide,		
gr/scf	2.63	2.45
% by vol	0.22	
lb/hr	216	151.2

A well-designed contact process sulfuric acid plant operates at 90 to 95 percent conversion of the sulfur feed into product (sulfuric acid). Thus a 250-ton-per-day plant can discharge 1.25 to 2.5 tons of SO_2 and SO_3 per day. When present in sufficient concentration, SO_2 is irritating to throat and nasal passes and injurious to vegetation.

Tail gases that contain SO_3, because of incomplete absorption in the absorber stack, hydrate and form a finely divided mist upon contact with atmospheric moisture. Generally, the process temperature of gas going to the absorber should be on the lower side of the temperature range 150° to 230°C.

The optimum acid concentration in the absorbing tower is 98.5%. This concentration has the lowest SO_3 vapor pressure. The partial pressure of SO_3 increases if the absorbing acid is too strong, and SO_3 will be emitted with the tail gases. If a concentration of absorbing acid less than 98.5% is used, the beta phase of SO_3, which is less easily absorbed, is produced. A mist may also form when the process gases are cooled before final absorption.

Water-based mists can form as a result of the presence of water vapor in the process gases fed to the converter. This condition is often caused by poor performance of the drying tower. Efficient performance should result in a moisture loading of 5 milligrams or less per cubic foot. In sulfur-burning plants, mists may be formed from water resulting from the combustion of hydrocarbon impurities in the sulfur.

The SO_3 mist presents the most difficult of the emissions to control because it generally has the smallest particle size. The particle size of these acid mists ranges from sub-micron to 10u and larger. Acid mist composed of particles of less than 10u in size is visible in the absorber tail gases if present in amounts greater than 1 milligram of sulfuric acid per cubic foot of gas. As the particle size decreases, the plume becomes more dense because of the greater light-scattering effect of the smaller particles. Maximum light scattering occurs when the partile size approximates the wave length of light. Thus, the predominant factor in the visibility of an acid plant's plume is particle size of the acid mists rather than the weight of mist discharged. Acid particles larger than 10u are probably present as a result of mechanical entrainment. These larger particles deposit readily on duct and stack walls and contribute little to the opacity of the plume.

As stated previously, even with a well designed conventional contact sulfuric acid unit, the tail gas emitted to the atmosphere contains considerable SO_2; concentrations can be as high as 5200 mg/m^3 (2000 ppm). In recent years, the intensified emphasis on air quality standards has dictated that emissions of sulfur compounds from sulfuric acid plants to be greatly reduced. This can be accomplished by two methods, both utilizing basic technology that has been known for some years. One method involves "double, or total, absorption." In this process SO_2 is converted to SO_3 in a three-pass catalytic converter, and the SO_3 is absorbed in an absorption tower. The gases from this tower, still containing unreacted SO_2, are then recycled to another single-pass catalytic converter, and then to a final absorber.

The other method consists of a tail-gas unit added to the end of a conventional acid plant. One such unit absorbs the SO_2 in the tail gas in an aqueous ammonium sulfite-bisulfite solution. The absorbing liquid is then treated in such a way that the SO_2 is stripped and then returned to the sulfuric acid plant. Other similar processes exist.

By such applications, the SO_2 concentration in tail-gas emissions can be reduced to less than 1500 mg/m^3 (500 ppm), and total plant efficiency for sulfur recovery can be increased to greater than 99 percent.

10.3.1 Control Equipment for Sulfuric Dioxide Removal. Water scrubbing of the tail gases from the SO_3 absorber can remove 50 to 75 percent of the SO_2 content. Scrubbing towers using 3-inch or larger stacked rings or redwood slats are often employed. On start-ups, when SO_2 concentrations are large, soda ash solution is usually used in place of water. Water scrubbing is feasible where disposal of the acidic waste water does not present a problem.

Tail gases may be scrubbed with soda ash solution to produce marketable sodium bisulfite. A cyclic process using sodium sulfite-bisulfite has also been reported. Steam regeneration costs in the cyclic process are, however, relatively high, and the capacity of the scrubbing solution is limited by the low solubility of sodium bisulfite. The dilute scrubber solution has, moreover, little economic value.

The most widely known process for removal of SO_2 from a gas stream is scrubbing with ammonia solution. Single- and two-stage absorber systems respectively reportedly reduce SO_2 concentrations in tail gases to 0.08% and 0.03%. Two-stage systems are designed to handle SO_2 gas concentrations as high as 0.9%. High SO_2 concentrations resulting from acid plant start-ups and upsets could be handled adequately by a system such as this.

10.3.2 Control Equipment for Acid Mist Removal. Tube-type electrostatic precipitators are widely used for removal of sulfuric acid mist from the cold SO_2 gas stream of wet-purification systems. Tube-type precipitators have also been used for treating tail gases from SO_2 absorber towers. More recently, however, two-stage, plate-type precipitators have been used successfully. One such unit, lead-lined throughout to prevent corrosion, is designed to handle approximately 20,000 cfm tail-gas from a 300-ton-per-day contact sulfuric acid plant. This wet-gas plant processes hydrogen sulfide, sulfur, and spent alkylation acid. Dry gas containing SO_2, CO_2, oxygen, nitrogen, and 5 to 10 mg of acid mist per cubic foot of air enters two inlet ducts to the precipitator. The gas flows upward through distribution tiles to the humidifying section. This section contains 5 feet of 3-inch single-spiral tile irrigated by 800 gpm weak sulfuric acid. The conditoned gas then flows to the ionizing section which consists of about 75 grounded curtain electrodes and 100 electrode wire extensions.

Ionized gas then flows to the precipitator section where charged acid particles migrate to the collector plate electrodes. There are twelve 14' x 14' lead plates and 375 electrode wires. The negative wire voltage is 75,000 volts. Acid migrating to the plates flows down through the precipitator and is collected in the humidifying section flows to a 5-foot-diameter, lead-lined stack that discharges to the atmosphere 150 feet above grade.

The high-voltage electrode wires are suspended vertically by three sets of insulators. Horizontal motion is eliminated by four diagonally placed insulators, which are isolated from the gas stream by oil seals. All structural material in contact with the acid mist is lead clad. Electrical wires are stainless steel cores with lead cladding. Voltage is supplied from a generator with a maximum capacity of 30 kilovolt-amperes. A battery of silicon rectifiers supplies 75,000 volts of direct current to the electrode wires.

Table 10-4 shows the SO_3 and SO_2 emissions from the previously described two-stage electrical precipitator. The acid mist collection efficiency was only 93 percent. A mechanical rectifier was, however, supplying only 36,000 volts to the precipitator during this test. During normal operation, silicon rectifiers supply 75,000 volts to the electrode wires.

Table 10-4. SULFUR TRIOXIDE AND SULFUR DIOXIDE EMISSIONS FROM A TWO STAGE ELECTRICAL PRECIPITATOR SERVING A CONTACT SULFURIC ACID PLANT

	Inlet of precipitator	Outlet of precipitator
Gas flow rate, scfm	13,400	13,100
Gas temperature, °F	160	80
Average gas velocity, ft/sec	36.5	20.6
Collection efficiency,[a] %		93
Moisture in gas, %	0.8	4.1
CO_2, % (stack conditions)	5.9	6
O_2, % (stack conditions)	9.6	8.4
CO, % (stack conditions)	0	0
N_2, % (stack conditions)	83.4	81.2
Sulfur trioxide,		
gr/scf	0.062	0.0048
lb/hr	7.1	0.54
% by volume	0.0042	0.00032
Sulfur dioxide,		
gr/scf	4.1	4.1
lb/hr	470	460
% by volume	0.345	0.345

[a]A mechanical rectifier was supplying only 36,000 volts to the precipitator. During normal operation, silicon rectifiers supply 75,000 volts to the electrode wires. This should increase the acid mist collection efficiency appreciably.

Packed-bed separators employ sand, coke, or glass or metal fibert to intercept acid mist particles. The packing also causes the particles to coalesce because of high turbulence in the small spaces between packing Moderate-sized particles of mist have been effectively removed in a 12-inch-deep bed of 1-inch Berl saddles with gas velocities of approximately 10 ft/sec.

Glass fiber filters have not been very effectively in mist removal because of a tendency on the part of the fiber to sag and mat. Nevertheless, experimental reports on acid mist removal by silicone-treated glass wool are encouraging. A special fine glass wool with a fiber diameter between 5 and 30$_u$ was used. The coarser fibers allowed adequate penetration of the bed by the mist particles to ensure a reasonable long life and provided sufficient support for the finer fibers in their trapping of the small acid mist particles.

The glass wool was treated by compressing it into a filter 2 inches thick to a density of 10 pounds per cubic foot. It was then placed in a sheet metal container and heated at 500°C for 1 hour. By this treatment, the stresses in the compressed fibers were relieved, and the fiber mass could be removed from the mold without losing shape or compression. The fibers were then treated with a solution of methyl chlorosilane.

The threshold SO_3 concentration for mist visibility after scrubbing has been found experimentally to be about 3.6 x 10^{-4} gr/scf. The discharge gases from the silicone-treated filter had an SO_3 concentration of 1.8 to 2.5 x 10^{-4} gr/scf and no appreciable acid mist plume. A faint plume became perceptible at approximately weekly intervals but was eliminated by flishing the filter bed with water. The average tail-gas filtering rate for the treated filter was 15.6 cfm per square foot of filtering area for a pressure drop of 9.5-10 inches of water. The effective life of the silicone fiber is estimated to be at least 5,000 hours. The use of untreated glass wool fiber proved unsatisfactory in reducing the opacity of the acid mist plume.

Table 10-5 shows the SO_2 and acid mist emissions from the outlet of a typical silicone-treated, glass fiber mist eliminator. This control unit processes absorber discharge gas from a contact sulfuric plant. The acid mist collection efficiency for the fiber glass mist eliminator was 98.9 percent.

Table 10.5 EMISSIONS OF SULFUR DIOXIDE AND ACID MIST FROM THE OUTLET OF A SILICONE-TREATED, GLASS FIBER MIST ELIMINATOR SERVING A CONTACT SULFURIC ACID PLANT

	Mist Eliminator Inlet	Mist Eliminator Outlet	
	Acid Mist	Acid Mist	Sulfur Dioxide
Concentration, gr/scf	0.30	0.035	1.50
Concentration, ppm	200	25	1,300
Weight, lb/hr	45	0.5	160
Collection efficiency, %		98.9	
Gas flow rate, scfm		14,000	
Avg. gas velocity, ft/sec		19	
Gas temperature, °F		160	

Wire mesh mist eliminators are usually constructed in two stages. The lower stage of wire mesh may have a bulk density of about 14 pounds per cubic foot, while the upper stage is less dense. The two stages are separated by several feet in a vertical duct. The high-density lower stage acts as a coalescer. The re-entrained coalesced particles are removed in the upper stage. Typical gas velocities for these units range from 11 to 18 ft/sec. The kinetic energy of the mist particle is apparently too low to promote coalescence at velocities less than 11 ft/sec, and re-entrainment becomes a problem at velocities greater than 18 ft/sec. The tail-gas pressure drop through a wire mesh mist installation is approximately 3 inches of water.

10.4 Coffee Roasting

Dust, chaff, coffee bean oils (as mists), smoke, and odors are the principal air contaminants emitted from coffee processing. In addition, combustion contaminants are discharged if chaff is incinerated. Dust is exhausted from several points in the process, while smoke and odors are confined to the roaster, chaff incinerator, and, in some cases, to the cooler.

Coffee chaff is the main source of particulates, but green beans, as received, also contain appreciable quantities of sand miscellaneous dirt. The major portion of this dirt is removed by air washing in the green coffee-cleaning system. Some chaff (about 1 percent of the green weight) is released from the bean on roasting and is removed with roaster exhaust gases. A small amount of chaff carries through to the cooler and stoner. After the roasting, coffee chaff is light and flaky, with particles sizes usually exceeding 100 u. As shown in Table 10-6, particulate emissions from coffee processing are well below the limits permitted by typical dust and fume prohibitions.

Table 10-6. ANALYSIS OF COFFEE ROASTER EXHAUST GASES

	Contaminant concentration		
	Continuous roaster		Batch roaster
	Roaster	Cooler	
Particulate matter, gr/scf	0.189	0.006	0.160
Aldehydes (as formaldehyde), ppm	139	--	42
Organic acids (as acetic acid), ppm	223	--	175
Oxides of nitrogen (as No_2), ppm	26.8	--	21.4

Coffee roaster odors are attributed to alcohols, aldehydes, organic acids, and nitrogen and sulfur compounds, which are all probably breakdown products of sugars and oils. Roasted coffee odors are considered pleasant by many people. Nevertheless, continual exposure to uncontrolled roaster exhaust gases usually elicits widespread complaints from adjacent residents. The pleasant aroma apparently develops into an annoyance upon continued exposure.

Visible bluish-white smoke emissions from coffee roasters are caused by distilled oils and organic breakdown products. The moisture content of green coffee is only 6 to 14 percent, and thus there is not sufficient water vapor in the 400° to 500°F exhaust gases to form a visible steam plume. From uncontrolled, continuous roasters, the opacity of exhaust gases exceeds 40% almost continuously. From batch roasters, exhaust opacities normally exceed 40% only during the last 10 to 15 minutes of a 20-minute roast. Smoke opacity appears to be a function of the oil content, the more oily coffee producing the heavier smoke. The water quenching of batch-roasted coffee causes visible steam emissions that seldom persist longer than 30 seconds per batch.

10.4.1 Control Equipment.

Air contaminants from coffee-processing plants have been successfully controlled with afterburners, cyclone separators, and combinations of the two. Incineration is necessary only with roaster exhaust gases. There is little smoke. In other coffee plants exist gas streams where only dust collectors are required to comply with air pollution control regulations.

Separate afterburners are preferable to the combination heater-incinerator that may be used on the batch roaster. When the afterburner serves as the roaster's heat source, its maximum operating temperature is limited to about 1,000°F. A temperature of 1,200°F or greater is necessary to provide good particulate incineration and odor removal. A roaster-afterburner should always be preceded by an efficient cyclone separator in which most of the particulates are removed. A residence time of 0.3 second is sufficient to incinerate most vapors and small-diameter particles at 1,200°F. However, higher temperatures and longer residence times are required to burn large-diameter, solid particles.

Properly designed centrifugal separators are required on essentially all process airstreams up to and including the stoner and chaff collection system. Typically, cyclones are required at the roaster, cooler, stoner, chaff storage bin, and chaff incinerator. In addition, the scalper is a centrifugal classifier venting process air. Some plants also vent the green coffee dump tank and several conveyors and elevators to centrifugal dust collectors.

11. Location of Industrial Facilities

In the past, land for industrial facilities was selected primarily for its physical characteristics, for example: would the soil support the building, adequate drainage, and access to water, transportation and utilities. Less attention was given to meteorological or topographical features or the overall land use plan for the area. Land was zoned for industrial use in areas where there was little desire to have residential or commercial development. It was often felt that industrial communities should be separated from the residential communities.

Several factors have caused a shift from this simplified approach to plant siting. In the U.S., there has been a significant movement in population from rural communities toward urban communities, increasing the need to develop all available land. Industrial areas that were once separated from residential areas are now surrounded by them as a result of the growth in urban population.

There has been a greater recognition of the influence of the meteorological and topographical features on the impact of any air pollution associated with a particular industrial process. Location of major industrial facilities in mountain or river valleys, along sea coasts and in areas where there are frequent temperature inversions, has a greater impact on the local atmosphere than would be true if the facility was located elsewhere. Air pollution knows only natural boundaries and patterns established by physical features such as mountains and valleys, and peculiarities of air flow caused by local heating conditions or other factors. As a result of atmospheric dispersion, what is generated in one place will be carried to another place, perhaps at a considerable distance. To minimize the impact of pollutant emissions it is important to be aware of wind conditions and topographical features in the selection of a particular plant site in order to take advantage of the local turbulence and diffusion conditions.

12. Impact of Industrial Products

It is important that the anticipated impact of a product on the air environment be investigated as thoroughly as practicable. Some of the products and by-products of industrial processes may have, or do have, a significant effect on the atmosphere or on man directly. Examples of these include exhaust emissions from high-altitude aircraft, fluoro-chloromethanes used as propellants for aerosol spray cans, and noise from transportation, construction or manufacturing. The exhaust emissions and propellants are believed to have a destructive effect on the ozone layer, which will create problems resulting from increased ultraviolet radiation reaching the earth's surface. Noise was not discussed in this syllabus but it is a problem that has been attracting considerable attention because of the physiological and psychological stress produced in man.

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METEOROLOGY AND AIR POLLUTION[a]

By

Peter J. Robinson

INTRODUCTION

This paper presents a brief overview of the major meteorological factors influential in diffusing air pollution from a source or a series of sources. Air pollution has been observed, and related to weather, for several centuries, but only in the last score of years has serious scientific attention been paid to the phenomenon. Although our understanding of the processes acting is still far from complete, the present state of knowledge allows forecasting of pollution concentrations with reasonable accuracy. Most attention has been paid to urban areas, where source concentration would appear greatest, but there is an increasing awareness that agriculture is a significant pollution source, especially as mechanization increases. Air pollution must therefore be viewed as a world-wide problem. The objective of the paper is to indicate, in a non-quantitative way, how the atmosphere disperses pollution. Few references are given in the text, but the bibliography lists useful reference sources which contain many quantitative details. Similarly, no attempt is made to develop a universal "air quality control strategy". Such a strategy must be based on local conditions, with local measurements and available personnel. Rather, a more general and somewhat theoretical approach is adopted, from which such strategies may be developed.

The major processes influencing the transport of pollution from source to receptor are summarized in Fig. 1, which can provide the framework for subsequent discussion. The type of source, whether a discrete smokestack or an area of newly ploughed land, largely determines the height at which pollution is placed in the atmosphere. Thereafter there is downwind transport in response to the general regional wind direction and speed. As the plume moves downwind, vertical diffusion and horizontal diffusion spread the pollution into an ever deepening and widening plume. Material may be altered in composition and size during transport by chemical reactions with the atmospheric gases, both directly and as a result of photochemical effects in sunlight. During the transport, some of the larger particulate

[a]Paper presented at: International Program on the Environmental Aspects of Industrial Development, School of Public Health, University of North Carolina at Chapel Hill, May, 1977.

matter may be lost from the plume by direct gravitational forces, reaching the ground as fallout. Further, some material may be physically or chemically incorporated into raindrops and fall as washout. Although some effluent may diffuse high into the atmosphere and remain suspended indefinitely, much of the pollution will eventually reach the ground as the result of the diffusion process. Exactly where this occurs, and what the resulting concentration will be, will depend on the intensity of the diffusion process and the nature of the underlying terrain.

Implicit in this general discussion is consideration of the time and space scales of interest. The mean wind, giving the downwind transport, is variable both in time and space. The diffusion process is therefore essentially stochastic, albeit strongly dependent on atmospheric conditions. Since it is common to define air quality standards in terms of specific concentrations for a specific time interval at a given location, both scales must be considered for pollution forecasting.

THERMAL AND MECHANICAL TURBULENCE

Atmospheric diffusion is a three dimensional phenomenon which results from thermal and mechanical turbulence processes. Mechanical turbulence is created by obstacles to the windflow at the earth's surface, where the obstacles may vary in size from a blade of grass to a mountain range. Near-surface wind flow will have a basic speed and direction created by the large-scale atmospheric circulation. Super-imposed on the mean wind will be fluctuations in speed and direction caused by the mechanical turbulence. Hence pollution will be diffused in both a crosswind and a vertical direction. Further, the speed of the mean wind increases with altitude, from zero right at the surface to a value equal to that of the regional wind at an altitude of about 1000m. Wind moving upwards comes from a layer of relatively low velocity, has little momentum, and becomes embedded in a faster moving airstream. Conversely air which moves down is moving faster than the airstream which it enters. The vertical movement, therefore, is responsible for the familiar gusts and lulls of the horizontal wind. The ease with which these vertical motions can take place depends on the temperature structure of the atmosphere. This controls the thermal turbulence, the vertical motions caused by unequal heating of the air from place to place. Although both processes occur simultaneously, it is advantageous for the present purposes to separate them. Thermal turbulence and diffusion will be discussed first, since this largely influences only the vertical component. Thereafter mechanical influences may be introduced to consider vertical and horizontal diffusion.

STATIC STABILITY

The vertical temperature structure of the atmosphere produces the atmospheric stability. This is frequently called static stability to emphasize that it is, in itself, not dependent on horizontal motions. Consideration of stability starts with a "parcel" of air rising through the surrounding air. The parcel may be of any size, but an ideal example is the effluent from a smokestack. Any parcel will normally rise with sufficient rapidity for it to remain thermally isolated from its surroundings. As the parcel rises it will expand because atmospheric pressure decreases upwards. The energy needed for expansion will be obtained from the parcel's energy. Consequently the parcel cools as it rises. The cooling rate is constant. If the parcel is not saturated with water vapor, the cooling rate is the dry adiabatic lapse rate of temperature (DALR), approximately 1°C/100m. For a saturated parcel, the value of the Saturated (Wet) Adiabatic Lapse Rate varies somewhat depending on the initial temperature, but is close to 0.5°C/100m near the earth's surface.

In order to determine the stability, the appropriate lapse rate, which in most cases will be the DALR, must be compared to the vertical distribution of temperature of the environment through which the parcel moves. This Environmental Lapse Rate (ELR) is variable, and depends on the meteorological conditions. Two cases must be considered (Fig. 2). In Fig. 2a a parcel moving upwards is warmer, and therefore more buoyant than the environment. It will continue to move up through the atmosphere irrespective of the velocity with which it was originally placed in the atmosphere. Such conditions, called unstable, encourage good pollutant dispersal by spreading the pollution through a great atmospheric depth. Stable conditions work in the opposite direction (Fib. 2b). The parcel is cooler and denser than the environment and will tend to sink to the surface, leading to high pollution concentrations.

The Environmental Lapse Rate varies with time and location as a response to meteorological conditions. Two examples will suffice to illustrate the variations. Time variations are demonstrated in Fig. 3. On a cloudless, fairly calm, night the surface of the earth cools rapidly and sometime before dawn the surface air is much cooler than that above. This creates an inversion, an increase in environmental temperature with height, which is the inverse of the normal condition. This is a very stable situation. After sunrise solar radiation heats the ground surface. Heat is trnasferred to the air above, warming first the air immediately in contact with the ground. Consequently the lowest layers may become unstable, although the inversion may persist at higher levels. As the day progresses the heating continues, affecting a greater depth of the atmosphere and lifting the base of the inversion. By the middle of the afternoon the inversion may have been completely removed. Commonly, turbulent mixing in the lower layers is such that the ELR is close to the DALR. The tope of the mixed layer, corresponding roughly to the base of the inversion, is the mixing height. An estimation of mixing height, therefore, is a good general indication of the ability of the atmosphere to receive and disperse pollution. The mixing height will reach a maximum value, which may be effectively infinite if the inversion is completely burnt off, in the afternoon. Thereafter the weakening rays of the sun decrease surface heating, instability decreases and, as night progresses, cooling at the surface dominates again.

The second example, emphasizing location, concerns the subsidence inversion (Fig. 4). In any region where there is a tendency for air to descend towards the surface, either as a result of topography or the general atmospheric circulation, this type of inversion, with its attendant pollution problems, may develop. The descending air warms at the DALR. It frequently traps the surface air, which is cooler than the descending air, and leads to an inversion. Unlike the previous example, this will be a persistant problem, exemplified by the inversion that frequently dominates the meteorology of the Los Angeles area. Although these conditions can occur over any part of the earth's surface, they are usually associated with regions of high pressure, and are most marked around 30°N and S, where pressure is high almost year round, and, in middle latitudes, when anticyclones are present.

Accurate determination of stability must come from direct observations of the temperature distribution with height. If large depths of the atmosphere are to be considered, as when mixing heights are likely to be great, a radio-sonde can be used. Balloon-borne sensors transmit to a ground receiving station values of pressure, temperature and humidity as the balloon ascends. Tracking of the balloon also allows estimation of the mean wind. Use of this method, however, requires highly trained personnel and sophisticated instrumentation. If only a general indication of the conditions is required, it is frequently possible to use data collected by many national meteorological services. Such services release balloons once or twice a day on a routine basis, but the locations of the release are usually widely scattered, being concentrated on the major airports. Some degree of extrapolation and generalization is therefore necessary.

More detailed measurements of the lower part of the atmosphere at the site of interest are frequently needed. The most common method is to place thermometers at various levels on a tower or similar structure. An alternative is to use a tethered balloon with thermometers spaced along the anchor cable. Both methods give ELR directly, but again need specialized instruments and personnel.

In the absence of any observations, a method of estimation developed by Pasquill has proved very useful (Table 1). This requires only a simple observation of general atmospheric conditions. The method was developed for mid-latitude conditions and has been used at other latitudes. It emphasises diurnal variations, but can be used for subsidence inversions, for example, provided it is used with caution and appreciation of the prevailing conditions.

The effects of atmospheric stability on a continuous, elevated point source are demonstrated in Figure 5. The importance of the inversion is clearly displayed. This is a two dimensional representation, ignoring the crosswind diffusion that will occur in all cases. However, the figure gives a qualitative indication of the pollution concentration likely in various stability conditions.

ATMOSPHERIC DIFFUSION

The process of atmospheric diffusion requires temporal and spatial variations in wind speed and direction. A basic, realistic, assumption is that there is a mean wind blowing with constant speed and direction. Superimposed on this are eddies caused by mechanical turbulence and modified by thermal turbulence. The amount of downwind diffusion is small compared to the transport by the mean wind and so can be neglected. The amount of crosswind and vertical diffusion depends on the mean windspeed, its variation with height, the size, shape and spacing of upwind obstacles and on the static stability. No simple analytic solution for these complex interactions has been found, and stochastic methods have been adopted.

A common expression, representative of the many that have been developed, for a continuous elevated point source, is (W.M.O. 1972):

$$X = \frac{Q}{\bar{u}\pi s_y s_z} \exp(-y^2/2s_y^2) \left[\exp - \frac{(z-h)^2}{2s_z^2} + \exp - \frac{(z+h)^2}{2s_z^2}\right] \quad (1)$$

where $\bar{u}$ is the mean horizontal wind speed (the x-axis is oriented in the direction of the wind

X is the pollutant concentration
Z is source strength
s_y, s_z are the standard deviations of the distributions of concentration in the y (cross-wind) and z(vertical) directions, and are functions of downwind distance x.
h is the effective source emission height.

This model is based on the following assumptions:

a) Steady-state, homogeneous conditions - no time or space changes in wind or turbulence;

b) An inert, passive pollutant - no atmospheric chemical reactions or gravitational fallout;

c) Perfect reflection of the plume at the underlying surface - no ground absorption;

d) Statistical Gaussian forms for the cross-wind and vertical pollution distributions - implying a sampling time sufficiently long to smooth out irregularities, usually about 10 minutes.

The implications of the first two assumptions will be discussed later. Assumption (c) can usually be modified by a simple change in (1). For example, a pollutant that is completely absorbed at the ground would be modelled by multiplying the denominator in (2) by 2. The final assumption is necessary to allow any realistic estimates, and it is usually very convenient to sample pollution for periods of at least 10 minutes.

The effective stack height is the height at which the effluent ceases to have predominantly vertical motion and commences a downwind track. This height depends on both source characteristics and atmospheric conditions. The important source characteristics are, in addition to the physical height of the stack itself, the pollutant exit velocity and the temperature difference between the effluent and the environment. Frequently these two are combined to specify the heat emission rate, which is directly related to effective height. Within the atmosphere the mean wind speed, and its variation with height, is the major parameter. This in turn depends on the amount of turbulence. Generally, h increases as $\bar{u}$ decreases. Several empirical formulae have been developed to estimate h from values of wind speed and heat emission rate. No one general formula has yet been demonstrated to have universal applicability.

Determination of s_y and s_z presupposes measurements of concentration at a large number of points within the pollution cloud, which is extremely difficult to accomplish on a routine basis. Recourse therefore has frequently been made to observations of the standard deviation of the fluctuations of wind direction, since this is primarily responsible for the diffusion. From such measurements several diagrams relating s_y and s_z to downwind distance have been developed. Fig. 6 is an example. Since thermal turbulence plays a vital role, expecially in s_z, the results are stratified according to the Pasquill stability class.

In order to utilise (1) source strength Q and mean windspeed $\bar{u}$ must be measured. Q can usually be readily determined from knowledge of the industrial process under consideration, and involves engineering, rather than meteorological, calculation. The mean windspeed can be measured with an anemometer exposed some distance above the earth's surface. There is considerable uncertainty, however, concerning the correct level at which to measure the wind. Windspeed increases with height above the earth's surface. The rate of increase depends on the nature of the surface and its obstacles and on the static stability. Consequently the rate of diffusion will vary with height. No model adequately takes this into account. Most, like (1), assume that a single windspeed measurement, at a representative height, represents the mean flow for the whole depth of the pollution layer. It is usual to assume that a single fixed height, commonly 10 m above the surface, is sufficiently representative. The actual speed measurement is a simple instrumental technique, and data can be obtained routinely. Care must be taken in the initial siting of the instrument, to ensure that values uninfluenced by local obstacles are obtained. Hence, as far as possible, the anemometer should be close to the emission site, but over level terrain with few obstacles to wind flow.

Once Q and $\bar{u}$ have been measured and h and s_y and s_z estimated, (1) can be used to determine many parameters of interest. Suitable manipulation allows estimation of concentrations at any point on the ground or within the cloud, while maximum ground concentrations can easily be found. It must always be borne in mind, however, that this equation, or any similar one, is a statistical analogue to the real situation. Thus, any calculation will provide, at best, only a reasonable approximation to the true pollution. Further, in most situations such an approach will provide little direct information on the length of time a particular point will be exposed to a particular level of pollution, although average concentrations at the point may be calculated. This is the result of the initial assumption that steady state conditions prevail in the windflow and therefore that there is no variation in the nature of the downwind transport.

DOWNWIND TRANSPORT

Downwind transport is provided by the mean wind. In order to use (1) it must be assumed that the mean wind is constant in speed and direction throughout the averaging period required for assumption of a Gaussian pollution distribution. This is a good assumption for averaging periods in the order of 10 minutes. However, longer averaging times are needed when relating pollution to air quality standards. These are usually quoted as a concentration averaged over a specified time not to be exceeded with a specified frequency. For example, the U. S. primary standard for CO is $10 mg/m^3$ (9 ppm) maximum 8 hour concentration, which is not to be exceeded more than once per year. While the mean wind may remain constant for a few minutes, or even for a few hours, during the 8-hour averaging period it may change several times. Any forecasting of concentration therefore, involves forecasting changes in the mean wind. This requires a general weather forecast, which in turn requires a large number of standard meteorological observations from a large area around the site of interest. Usually such forecasts are provided by the national meteorological organisation in a general form, and can be modified and interpreted by a local air pollution specialist. Fortunately, in any one area, the variety of likely meteorological conditions are not infinite, and it is usually possible to develop an "air pollution climatology" to aid in forecasting. This would include details of frequency of occurence of winds with particular speeds and directions, likely variations in stability and mixing heights, and location, strengths and effective stack heights of local pollution sources.

Not only does the large scale atmospheric circulation influence local sources directly, but it may also be responsible for transporting pollution great distances. There is an increasing awareness that pollution is a world-wide phenomenon, with all points acting, to a greater or lesser degree, as both sources and receptors of pollution. At present pollution may be regarded, with some validity, as a national problem, but as pollution loads increase, flow across frontiers will also increase and non-local sources will become increasingly important in determining concentration at a receptor.

FALLOUT

The previous discussion has explicitly assumed that the pollutant is inert and passive. In reality, gravitational settling will almost always occur. The major factor influencing the rate of fallout is the size of the pollution particle. Fig. 7 indicates that there is a linear increase in residence time, , with decreasing terminal velocity, c. This, for a given substance, is directly related to particle size. The values for water droplets are shown in Fig. 7. The residence time must be an average value, because of the nature of turbulence, and m in the figure represents the fraction of initially airborne particles remaining suspended. The figure also indicates the maximum height likely to be attained, and how far downwind the particles will travel if $\bar{u}$ is 10 m sec^{-1}.

A diagram of the type exemplified by Fig. 7 is extremely useful in analysis of the likely time and space scales of an air pollution problem when the size distribution of the effluent is known, although the information must be combined with diffusion estimates and stability considerations. For example, if fanning conditions prevail (Fig. 5) and the effluent has a terminal velocity less than 1 cm sec^{-1}, little pollution will arrive at the ground by direct diffusion, while fallout is unlikely to be significant within 1 km of the source. Alternatively, even in trapping conditions, a pollutant with $c=10^3$ cm sec^{-1} will fall so quickly so close to the source that high concentrations are unlikely more than a few meters away. It is most likely, however, that there will be a range of effluent sizes, and both fallout and diffusion must be taken into account.

WASHOUT AND CHEMICAL REACTIONS

When pollution particles are incorporated into a cloud or intercepted by raindrops, they may become physically or chemically associated with the water. Their fate thereafter will be the same as that of the water. Although frequently this implies that there is an increase in particle size and a consequent increasing tendency to fall, the atmospheric processes producing the precipitation are complex, and usually involve strong upward air motion. The particles and droplets may therefore be suspended in the atmosphere for a considerable time. Consequently the rate of removal of pollution is greatly dependent on the rate of rainfall. The whole process may conveniently be termed <u>wash-out</u>.

The incorporation of pollution into water droplets depends on the size of the particles. Small particles are less efficiently collected than larger ones. Further, hydroscopic particles are more easily collected. The solubility and reactive nature of gaseous pollutants may have a considerable influence. Hence, for example, bromine is considerably more susceptible to washout than is iodine.

When pollutants, particularly gases, enter into chemical combination with normal atmospheric constituents, the major meteorological effect is the possible change in the size of the resulting molecule, hence affecting the fallout rate.

<u>TERRAIN CHARACTER</u>

All models of pollution dispersal assume that the dispersal takes place over an infinite, homogeneous surface. Such uniformly flat surfaces are extremely rare, and plume behaviour will be greatly influenced by topography and surface features. Terrain effects may be classified into two groups, the passive and the active.

In the passive group the terrain influences the airflow patterns, particularly the direction and speed of the mean wind, but does not itself generate a new circulation. This type of influence is shown in Fig. 8. Air flows down a smooth slope in such a way that high surface concentrations downwind of the source are produced. The actual concentration will depend on the factors already discussed. However, the centre line of the pollution cloud is no longer parallel to the earth's surface, and (1) must be modified to take this into account.

Active terrain effects involve the generation of a localised circulation. This is particularly evident in mountain valleys, along coasts and within urban areas. One example, for an urban area, will suffice to demonstrate these active effects (Fig. 9). If there is a reasonably strong regional wind the entire urban area will act as a source, giving an urban plume extending downwind. This may be analysed by (1), suitably modified for an area source. With light winds, or calm conditions, such as commonly occur at night, however, a city will generate its own circulation. This is essentially a closed system, with warm air from the central city moving up and out, to sink back to the surface in the suburbs or surrounding rural areas and to return to the central city. Any pollutant emitted will be continuously circulated and concentrations may become extremely high.

Generalisation of such effects is extremely difficult because of the great, almost infinite, variety of topograph and urban forms. Nevertheless, as the number of detailed investigations of specific sites increases, our understanding of the physical processes operating increases. Consequently our modelling ability expands, although we are still some time away from the development of reliable models in diversified terrain.

FURTHER OUTLOOK

The World Meteorological Organisation, an official United Nations Agency, is currently developing a basic syllabus in Air Pollution Meteorology. This will be used at specially designated centers at several locations to train personnel, at various levels from ovservers to research workers, in both theoretical and practical aspects of the field. The aim is to disseminate information and expertise throughout the world.

The World Meteorological Organisation feels that the state of the art of air pollution meteorology is sufficiently advanced to make such a venture worthwhile. The models of air pollution dispersal currently available can yeild satisfactory estimates and predictions of pollution concentrations in relatively simple conditions. Although in most areas conditions are far from simple, these models, suitably modified, can give useful results. However, they must be correctly applied in the appropriate meteorological conditions. This requires both instrumental observations to acquire the basic data and trained personnel to interpret these data. Once this requirement is met the established techniques should be capable of dealing with real problems, both present and future, in any area where development, and the consequent air pollution problem is increasing.

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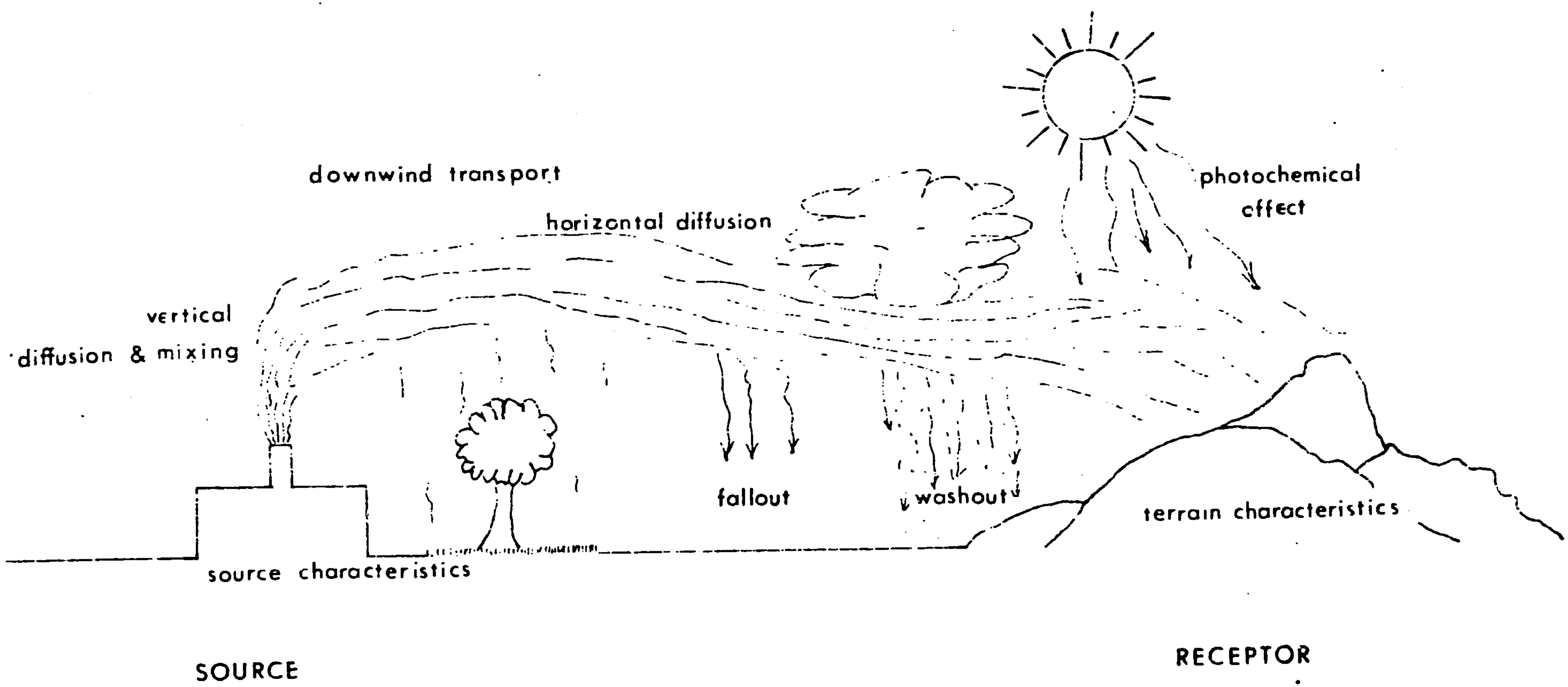
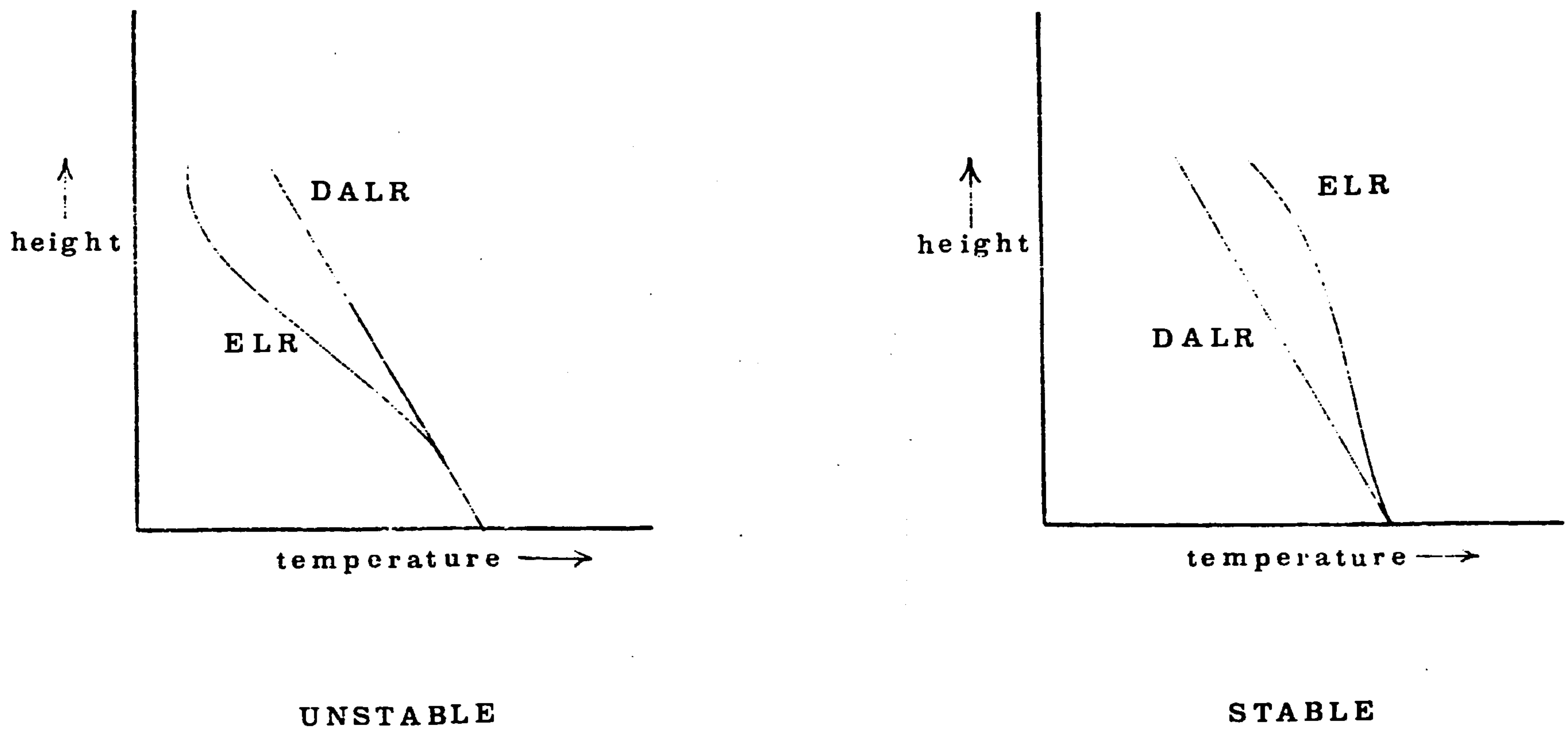
These are more general texts having great implications for air pollution meteorology.

Figure I



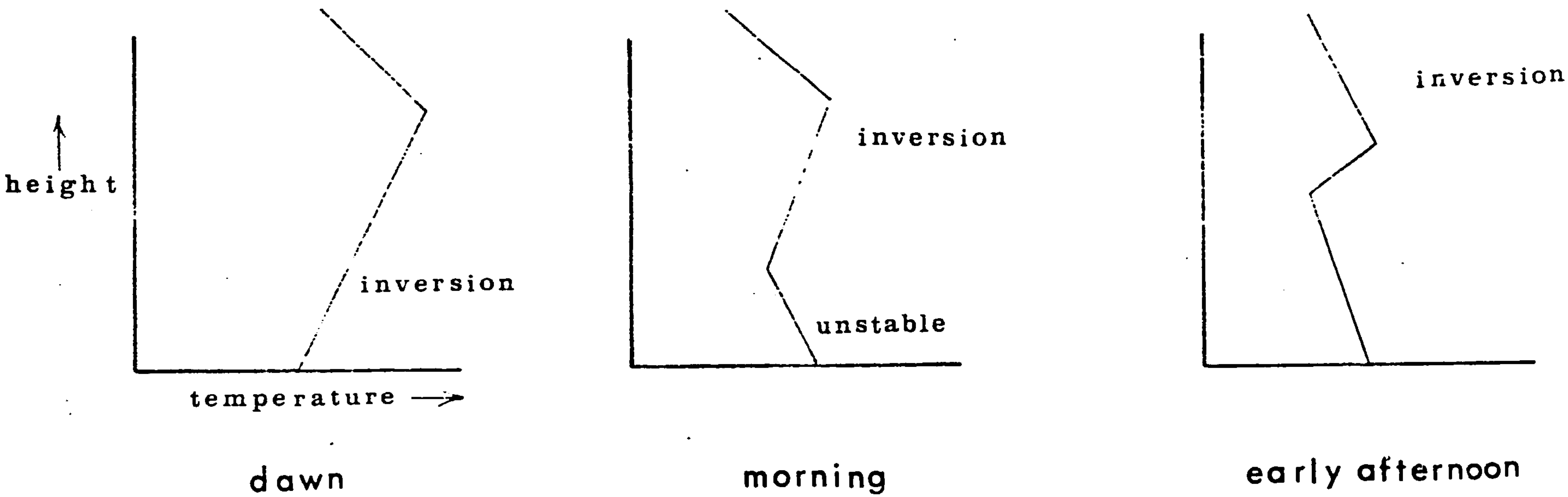
Schematic diagram of meteorological factors in air pollution dispersal.

Figure 2



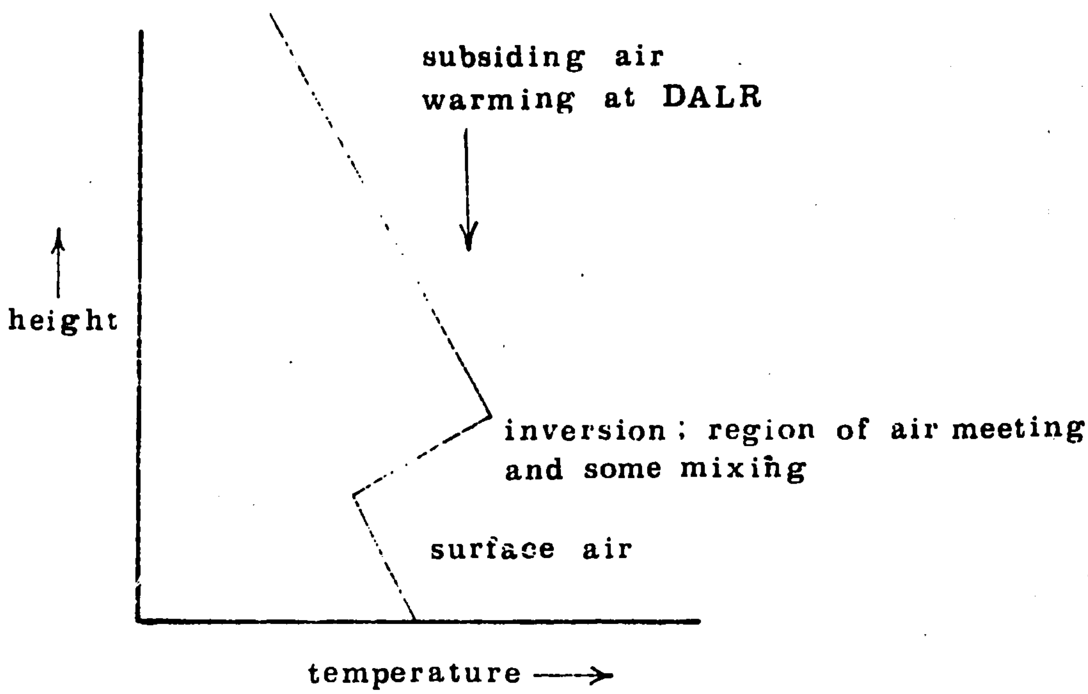
Stable and unstable atmospheric conditions

Figure 3

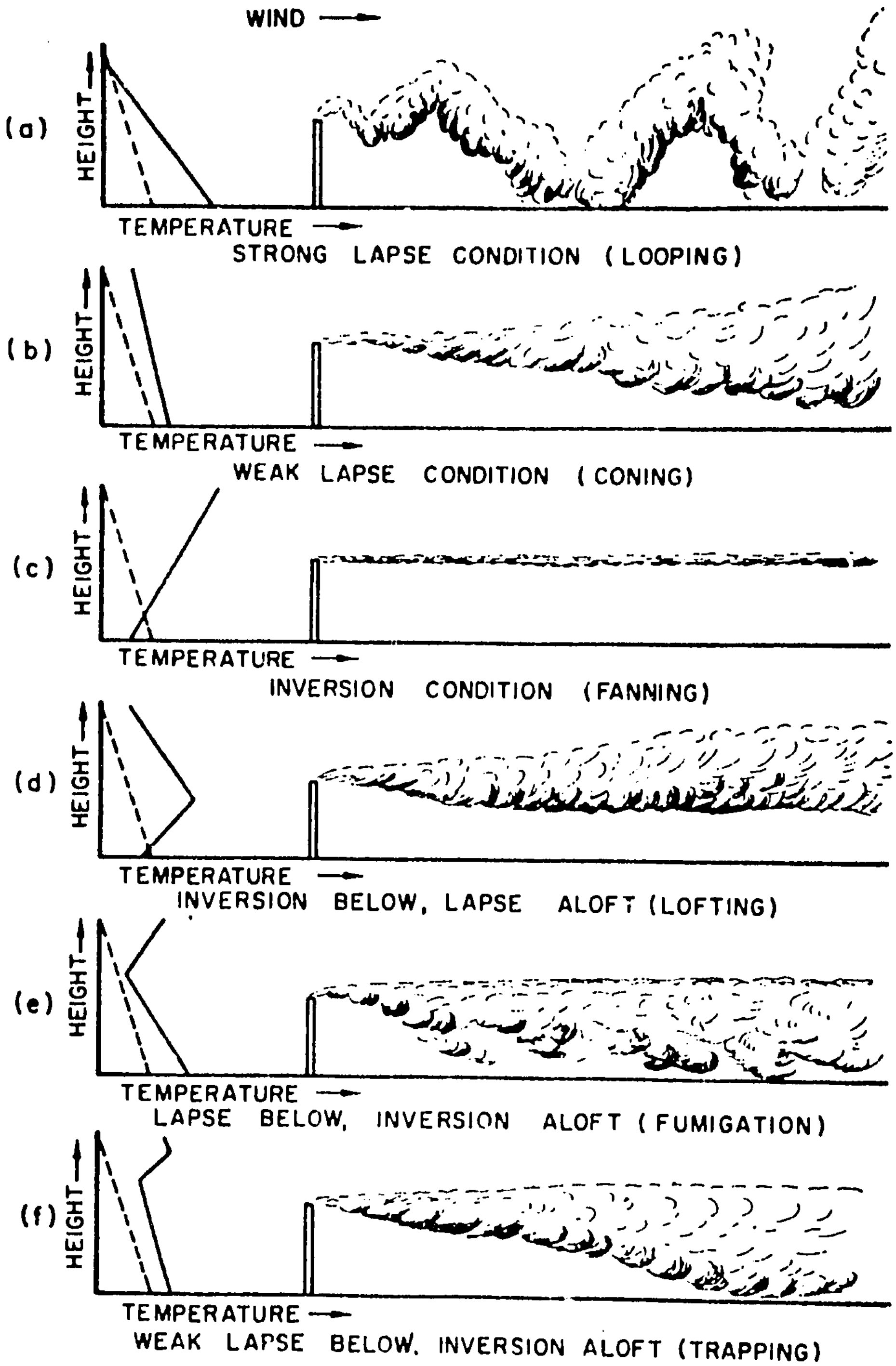


Diurnal variations in the environmental lapse rate in near cloudless conditions.

Figure 4



Atmospheric stability when a subsidence inversion is present.



Plume behavior under various stability conditions. The broken lines at leaft are dry adiabaric lapse rates, the solid lines are environmental lapse rates. From Sellers (1965), after Bierly and Hewson (*J. Appl. Meteorol.*, 1:383-90, 1962)

FIGURE 5

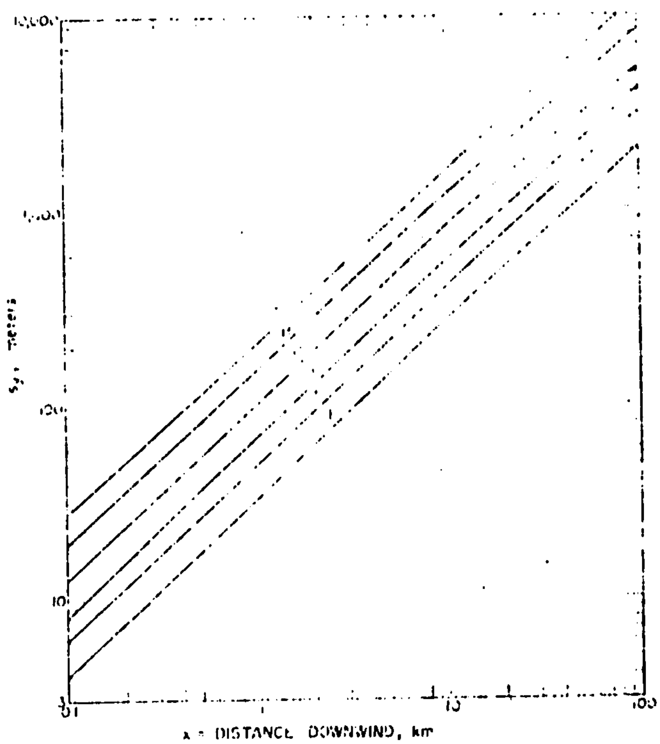
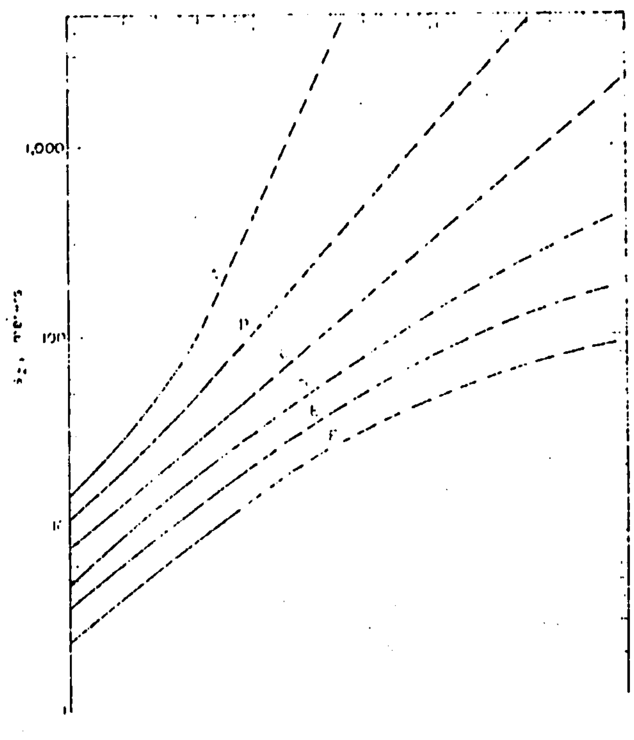
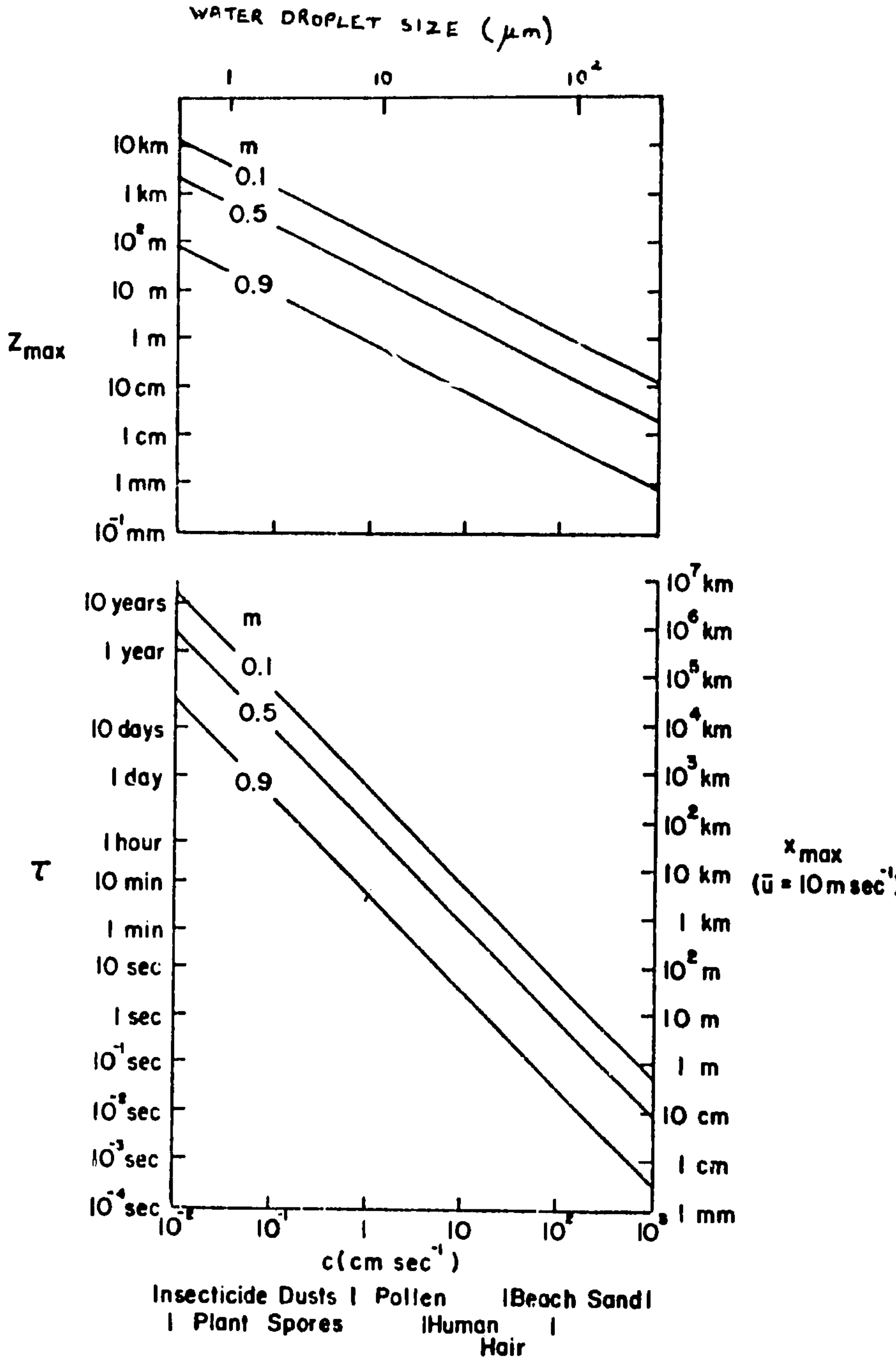


Figure 3.1 --- Standard deviation of the Gaussian distribution of pollutants in the cross-wind direction through a plume (Gifford, 1961)



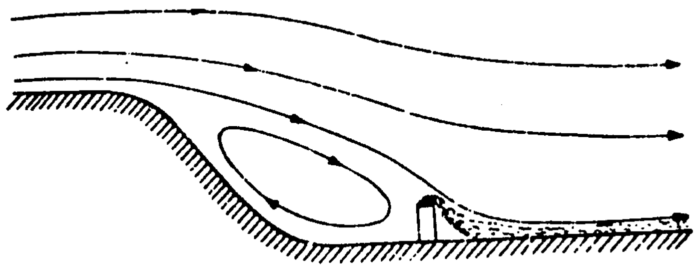
Standard deviation of the Gaussian distribution of pollutants as a function of Pasquill stability class. The upper diagram refers to the cross-wind direction, the lower diagram to the vertical direction. From W.M.O. (1972), after Gifford (*Nuclear Safety*, 2: 47-51, 1961)

FIGURE 6



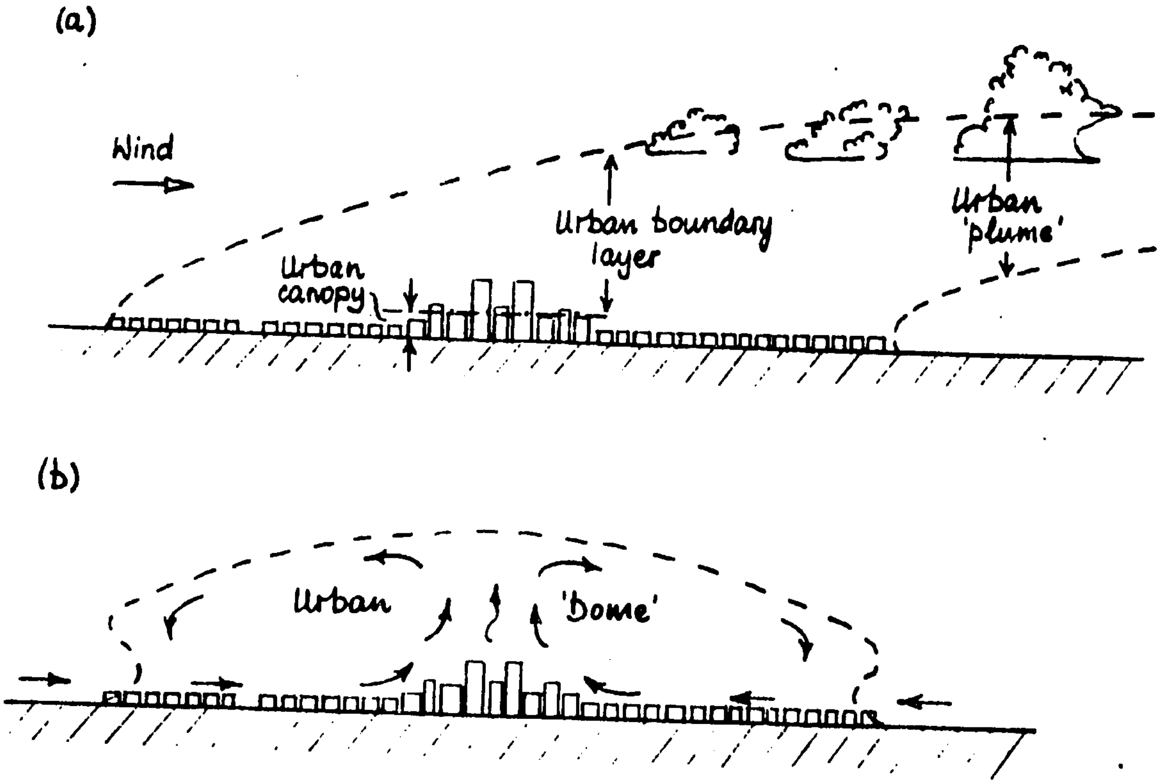
z_{max}, τ, and x_{max} as functions of m, c, and water droplet radius, for an eddy diffusivity of 10^4 $cm^2 sec^{-1}$. After Sellers (1965).

FIGURE 7



Schematic representation of downwash in a valley. From Munn (1966), after Scorer (*Int. J. Air Water Poll.*, 1: 198-220, 1959).

FIGURE 8



Schematic cross-section of a city illustrating the form of the modified atmosphere; (a) as observed with steady regional airflows, and (b) as suggested with near calm regional winds. From Oke in W.M.O. (1977)

FIGURE 9

FIGURE 10

Surface wind speed (at 10 m) m/s	Day: Insolation: Strong	Moderate	Slight	Night: Thinly overcast or ≥ 4/8 low cloud	≤ 3/8 cloud
< 2	A	A–B	B	—	—
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
> 6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night.

The Pasquill stability classification

From W.M.O. (1972)

A Collection of Source Materials on the Subject of

Solid Waste Management

by: John B. Carroll
F. Eugene McJunkin
Editors

Prepared for the International Program in Environmental Aspects of Industrial Development, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, North Carolina, 17 March 1975.

TABLE OF CONTENTS

INTRODUCTION

The following discussion is designed to provide the reader with an indepth information base on the subject of solid waste management. It is presented in essentially six parts by subject. Each part contains an in depth discussion of the topic and is generally concluded with an over view of the previous discussion.

The topics included in this discussion in the order of their presentation are:

1. Sanitary Landfill
2. Incineration
3. Composting
4. Dumping
5. Feeding Garbage to Hogs
6. Ocean Disposal

The subject matter has been drawn from American standards and practice, however, it has been edited to reduce the information to a state which can readily be interpreted in relation to other areas of the world. Where possible diagrams, tables, and photographic information have been included to aid in the discussion.

Sanitary Landfill*

The sanitary landfill is presently the only true disposal method and is basic to any solid wastes program. Incineration is a volume reduction process and produces residues which should be sanitary landfilled. Open burning and open dumping are not solutions to the disposal problem. Feeding hogs garbage is a form of reuse. Compost is a form of processing organic wastes, such as garbage and paper, to form a humus-like soil conditioner. Such a recycling process may be incorporated in the system to handle a small percentage of solid wastes. But local governments should not base any solid wastes management system predominantly on a salvage or compost program.

Sanitary landfill frequently is a versatile and economical disposal method. Almost any solid wastes can be disposed of in a sanitary landfill, and otherwise unusable land can often be reclaimed for community use. Major elements in the sanitary landfill process are proper placing of refuse, effective compaction, and adequate cover (see Figure B).

According to the American Society of Civil Engineers:

> Sanitary landfill is a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to

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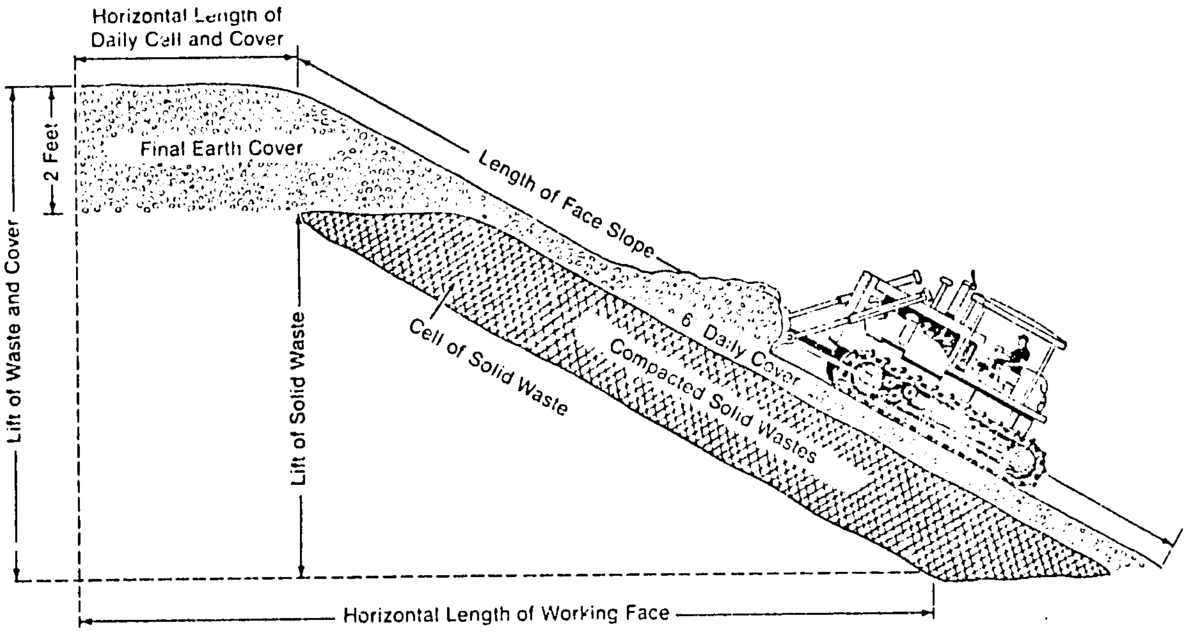
*Information taken from (I) in General Bibliography confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

No on-site burning should ever be permitted at a sanitary landfill. A sanitary landfill can be made operational in less time than an incinerator or compost plant.

FIGURE B: **sectional view of a sanitary landfill**



Soils and Geology

A study of the soils and geologic conditions of any area in which a sanitary landfill may be located is essential to understanding how its construction might affect the environment. The study should outline the limitations that soils and geologic conditions impose on safe, efficient design and operation.

A comprehensive study identifies and describes the soils present, their variation, and their distribution. It describes the physical and chemical properties of bedrock, particularly as it may relate to the movement of water and gas (Figure 4). Permeability and workability are essential elements of the soil evaluation, as are stratigraphy and structure of the bedrock.

Rock materials are generally classified as sedimentary, igneous, or metamorphic. Sedimentary rocks are formed from the products of erosion of older rocks and from the deposits of organic matter and chemical precipitates. Igneous rocks derive from the molten mass in the depths of the earth. Metamorphic rocks are derived from both igneous and sedimentary rocks that have been altered chemically or physically by intense heat or pressure.

Sands, gravels, and clays are sedimentary in origin. The sedimentary rocks, sometimes called aqueous rocks, are often very permeable and therefore represent a great potential for the flow of groundwater. If leachate develops and enters the rock strata,

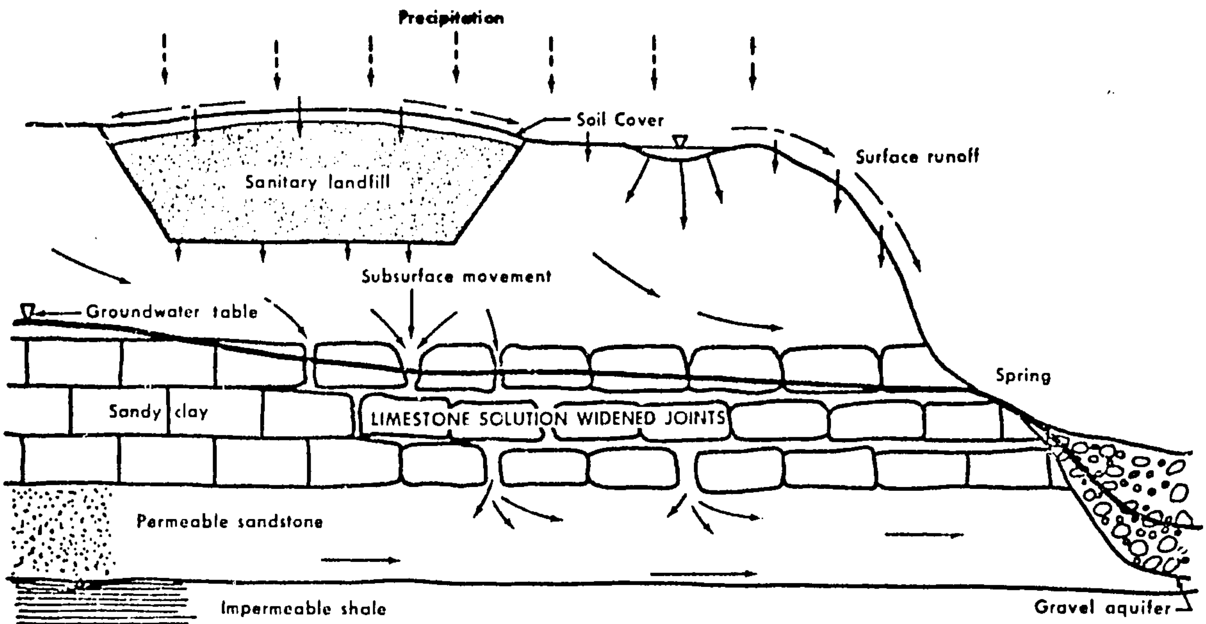


Figure 4. Leachate and infiltration movements are affected by the characteristics of the soil and bedrock.

contaminant travel will usually be greatest in sedimentary formations. Other rocks commonly classed as sedimentary are limestone, sandstone, and conglomerates. Fracturing and jointing of sedimentary formations are common, and they increase permeability. In fact, the most productive water-bearing strata for wells are formations of porous sandstone, highly fractured limestone, and sand and gravel deposits. Siltstones and shales, which are also of sedimentary origin, usually have a very low permeability unless they have been subjected to jointing and form a series of connected open fractures.

Igneous and metamorphic rocks, such as shist, gneiss, quartzite, obsidian, marble, and granite, generally have a very low permeability. If these rocks are fractured and jointed, however, they can serve as aquifers of limited productivity. Leachate movement through them should not, therefore, be categorically discounted.

Information concerning the geology of a proposed site may be obtained from the U.S. Geological Survey, the U.S. Army Corps of Engineers, State geological and soil agencies, university departments of soil sciences and geology, and consulting soil engineers and geologists.

Soil Cover

The striking visual difference between a dump and a sanitary landfill is the use of soil cover at the latter. Its compacted solid waste is fully enclosed within a compacted earth layer at the end of each operating day, or more often if necessary.

The cover material is intended to perform many functions at a sanitary landfill (Table 4); ideally, the soil available at the site should be capable of performing all of them.

TABLE 4

Suitability of General Soil Types as Cover Material*

Function	Clean gravel	Clayey-silty gravel	Clean sand	Clayey-silty sand	Silt	Clay
Prevent rodents from burrowing or tunneling	G	F-G	G	P	P	P
Keep flies from emerging	P	F	P	G	G	E†
Minimize moisture entering fill	P	F-G	P	G-E	G-E	E†
Minimize landfill gas venting through cover	P	F-G	P	G-E	G-E	E†
Provide pleasing appearance and control blowing paper	E	E	E	E	E	E
Grow vegetation	P	G	P-F	E	G-E	F-G
Be permeable for venting decomposition gas‡	E	P	G	P	P	P

* E, excellent; G, good; F, fair; P, poor.
† Except when cracks extend through the entire cover.
‡ Only if well drained.

The cover material controls the ingress and egress of flies, discourages the entrance of rodents seeking food, and prevents scavenging birds from feeding on the waste. Tests have demonstrated that 6 in. of compacted sandy loam will prevent fly emergence. Daily or more frequent application of soil cover greatly reduces the attraction of birds to the waste and also discourgaes rodents from burrowing to get food. The cover material is essential for maintaining a proper appearance of the sanitary landfill.

Many soils, when suitably compacted, have a low permeability, will not shrink, and can be used to control moisture that might otherwise enter the solid waste and produce leachate.

Control of gas movement is also an essential function of the cover material. Depending on anticipated use of the completed landfill and the surrounding land, landfill gases can be either blocked by or vented through the cover material. A permeable soil that does not retain much water can serve as a good gas vent. Clean sand, well-graded gravel, or crushed stone are excellent when kept dry. If gases are to be prevented from venting through the cover material, a gas-impermeable soil with high moisture-holding capacity compacted at optimum conditions should be used.

Enclosing the solid waste within a compacted earth shell offers some protection against the spread of fire. Almost all soils are noncombustible, thus the earth side walls and floor help to confine a fire within the cell. Top cover over a burning cell offers less protection because it becomes undermined and caves in, thus exposing the overhead cell to the fire. The use of a compactible soil of low permeability is an excellent fire-control measure, because it minimizes the flow of oxygen into the fill.

To maintain a clean and sightly operation, blowing litter must be controlled. Almost any workable soil satisfies this requirement, but fine sands and silts without sufficient binder and moisture content may create a dust problem.

The soil cover often serves as a road bed for collection vehicles moving to and from the operating area of the fill. When it is, it should be trafficable under all weather conditions. In wet weather, most clay soils are soft and slippery.

In general, soil used to cover the final left should be capable of growing vegetation. It should, therefore, contain adequate nutrients and have a large moisture-storage capacity. A minimum compacted thickness of 2 ft. is recommended.

Comparison of the soil characteristics needed to fulfill all of these functions indicates that some anomalies exist. To serve as a road base, the soil should be well-drained so that loaded collection vehicles do not bog down. On the other hand, it should have a low permeability if water is to be kept out of the fill, fire is to be kept from spreading, and gas is not to be vented through the final cover. These differences can be solved by placing a suitable road base on top of the normally low permeability-type cover material. A reverse situation occurs when landfill gases are to be vented uniformly through the cover material. The soil should then be gas permeable, have a small moisture-storage capacity, and not be highly compacted. As before, the criteria for moisture and fire control require the soil to have a low permeability. Leachate collection and treatment facilities may be required if a highly permeable soil is used to vent gas uniformly through the cover materials; if this is not done, an alternative means of venting gas through the cover material must be sought.

There are many soils capable of fulfilling the functions of cover material. Minor differences in soil grain size or clay mineralogy can make significant differences in the behavior of soils that fall within a given soil group or division. In addition, different methods of placing and compacting the same soil can result in a significantly different behavior. Moisture content during placement, for example, is a critical factor - it influences the soil's density, strength, and porosity.

The soils present at proposed sites should be sampled by augering, coring, or excavating, and then be classified. The volume of suitable soil available for use as cover material can then be estimated and the depth of excavation for waste disposal can be determined. Specific information on the top 5 ft of the soil mantle can often be obtained from the Soil Conservation Service, U.S. Department of Agriculture.

Sanitary landfilling is a carefully engineered process of soild waste disposal that involves appreciable excavating, hauling, spreading, and compacting of earth. When manipulating soils in this manner, the Unified Soil Classification System (USCS) is useful. Although recommendations for soil to be used at a landfill are often expressed in the U.S. Department of Agriculture textural classification system (Figure 5), the USCS is preferred because it relates in more detail the workability of soils from an engineering viewpoint. (Table 5).

Clay soils are very fine in texture even though they commonly contain small to moderate amounts of silt and sand. They vary greatly in their physical properties, which depend not only on the small particle size but on the type of clay minerals and soil water content. When dry, a clay soil can be almost as hard and tough as rock and can support heavy loads. When wet, it oten becomes very soft, is sticky or slippery, and is very difficult to handle. A clay soil swells when it becomes wet, and its permeability is very low.

Many clay soils can absorb large amounts of water but, after drying, usually shrink and crack. These characteristics make many clays less desirable then other soils for use as a cover material. The large cracks that usually develop allow water to enter the fill and permit decomposition gases to escape. Rats and insects can also enter or leave the fill through these apertures.

Clay soil can, however, be used for special purposes at a landfill. If it is desirable to construct an impermeable lining or cover to control leachate and gas movement, many clays can be densely compacted at optimum moisture. Once they are in place, it is almost always necessary to keep them moist so they do not crack.

The suitability of coarse grained material (gravel and sand) for cover material depends mostly on grain size distribution (gradation), the shape of grains, and the amount of clay and silt fines present. If gravel, for example, is poorly graded and relatively free of fines, it is not suitable as cover material for

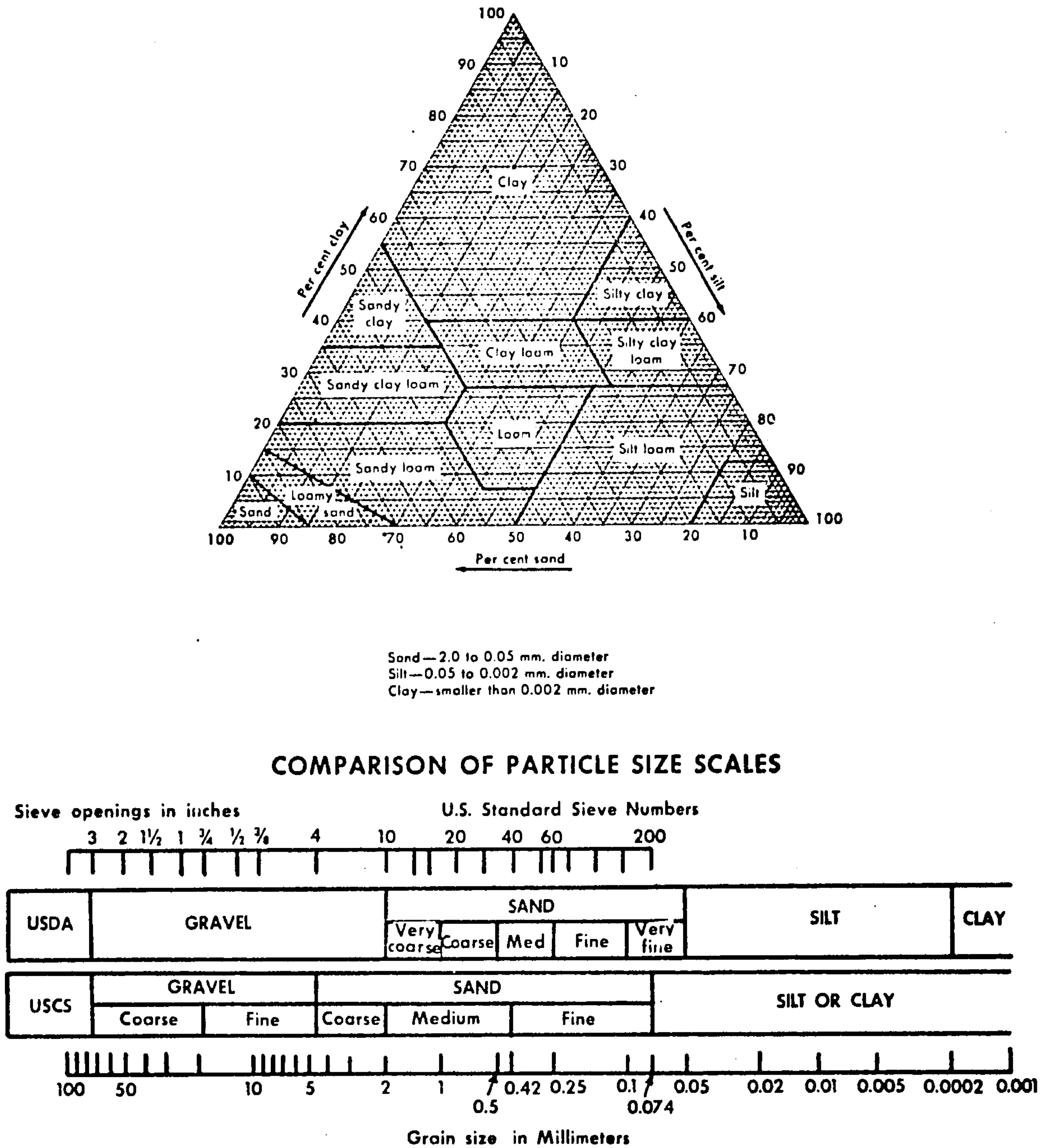


Figure 5. Textural classification chart (U.S. Department of Agriculture) and comparison of particle size scales.

moisture, gas, or fly control. It cannot be cmpacted enough, and the gravel layer will be porous and highly permeable; this would

TABLE 5
UNIFIED SOIL CLASSIFICATION SYSTEM AND CHARACTERISTICS PERTINENT TO SANITARY LANDFILLS

Major Divisions		SYMBOL Letter	SYMBOL Hatching	SYMBOL Color	NAME	Potential Frost Action	Drainage Characteristics*	Value for Embankments	Permeability cm per sec	Compaction Characteristics †	Std AASHO Max Unit Dry Weight lb per cu ft ¶	Requirements for Seepage Control
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		RED	Well-graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired steel-wheeled roller	125-135	Positive cutoff
		GP		RED	Poorly graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired steel-wheeled roller	115-125	Positive cutoff
		GM		YELLOW	Silty gravels, gravel-sand-silt mixtures	Slight to medium	Fair to poor Poor to practically impervious	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120-135	Toe trench to none
		GC		YELLOW	Clayey gravels, gravel-sand-clay mixtures	Slight to medium	Poor to practically impervious	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	None
	SAND AND SANDY SOILS	SW		RED	Well-graded sands or gravelly sands little or no fines	None to very slight	Excellent	Very stable, pervious sections slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Upstream blanket and toe drainage or wells
		SP		RED	Poorly graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Upstream blanket and toe drainage or wells
		SM		YELLOW	Silty sands, sand-silt mixtures	Slight to high	Fair to poor Poor to practically impervious	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Upstream blanket and toe drainage or wells
		SC		YELLOW	Clayey sands, sand-clay mixtures	Slight to high	Poor to practically impervious	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber-tired	105-125	None
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		GREEN	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium to very high	Fair to poor	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Toe trench to none
		CL		GREEN	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	Practically impervious	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired	95-120	None
		OL		GREEN	Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	None
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		BLUE	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Medium to very high	Fair to poor	Poor stability, core of hydraulic dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	None
		CH		BLUE	Inorganic clays of high plasticity, fat clays	Medium	Practically impervious	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	None
		OH		BLUE	Organic clays of medium to high plasticity, organic silts	Medium	Practically impervious	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	NOT RECOMMENDED FOR SANITARY LANDFILL CONSTRUCTION						

*Values are for guidance only, design should be based on test results

†The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled

¶Compacted soil at optimum moisture content for Standard AASHD (Standard Proctor) compactive effort.

allow water to enter the fill easily. Flies would have little difficulty emerging through the loose particles. On the other hand, a gravel layer no more than 6 in. deep would probably discourage rats and other rodents from burrowing into the fill and would provide good litter control. If gravel is farily well-graded and contains 10 to 15 percent sand and 5 percent or more fines, it can make an excellent cover. When compacted, the coarse particles maintain grain-to-grain contact, because they are held in place by the binding action of the sand and fines and cohesion of the clays. The presence of fines greatly decreases a soil's permeability. A well-graded, sandy, clayey gravel does not develop shrinkage cracks. It can control flies and rodents, provide odor control, can be worked in any weather, and supply excellent traction for collection trucks and other vehicles.

Many soils classified as sand (grain size generally in the range of 4.0 to 0.05 mm) contain small amounts of silt and clay and often some gravel-size material as well. A well-graded sand that contains less than 3 percent fines usually has good compaction characteristics. A small increase in fines, particularly silt, usually improves density and allows even better compaction. A poorly graded sand is difficult to compact unless it contains abundant fines. The permeability of clean sand soils is always high, even when compacted, and they are not, therefore, suitable for controlling the infiltration of water. They are also ineffective in constraining flies and gases.

A well-drained sandy soil can be easily worked even if temperatures fall below freezing, while a soil with a large moisture-storage capacity will freeze.

Practically the only soils that can be ruled out for use as cover material are peat and highly organic soils. Peat is an earthy soil (usually brown to black) and is composed largely of partially decomposed plant matter. It usually contains a high amount of voids, and its water content may range from 100 to 400 percent of the weight of dried solids. Peat is virtually impossible to compact, whether wet or dry. Peat deposits are scattered throughout the country but are most abundant in the States bordering the Great Lakes. Highly organic soils include sands, silts, and clays that contain at least 20 percent organic matter. They are usually very dark, have an earthy odor when freshly turned, and often contain fragments of decomposing vegetable matter. They are very difficult to compact, are normally very sticky, and can vary extremely in their moisture content.

Many soils contain stones and boulders of varying sizes, especially those in glaciated areas. The use of soils with boulders that hinder compaction should be avoided.

Soil surveys prepared by the Soil Conservation Service of the U.S. Department of Agriculture are available for a major portion of the country. Local assistance in using and interpreting them is available through soil conservation districts located in some 3,000 county seats throughout the United States. The surveys cover such specific factors as natural drainage, hazard of flooding, permeability, slope, workability, depth to rock, and stoniness. They are commonly used to locate potential areas for sanitary landfills. They also can serve as the basis for designing effective water management systems and selecting suitable plant cover to control runoff and erosion during and after completion of fill operations. Sanitary landfill owners and their consultants can avoid costly investigations of unsuitable sites by using soil surveys to select areas for which detailed investigations appear warranted. Using soil surveys for the foregoing purposes does not, however, eliminate the need for making detailed site investigations.

Land Forms

A sanitary landfill can be constructed on virtually any terrain, but some land forms require that extensive site improvements be made and expensive operational techniques followed. Flat or gently rolling land not subject to flooding is best, but this type is also highly desirable for farming and industrial parks, nd this drives up the purchase price.

Depressions, such as canyons and ravines, are more efficient than flat areas from a land use standpoint since they can hold more solid waste per acre. Cover material may, however, have to be hauled in from surrounding areas. Depressions usually result when surface waters run off and erode the soil and rock. By their nature, they require special measures to keep surface waters from inundating the fill. Permeable formations that intersect the side walls or floor of the fill may also have to be lined with an impervious layer of clay or other material to control the movement of fluids.

There are also numerous man-made topographic features scattered over the country - strip mines, worked-out stone and clay quarries, open pit mines, and sand and gravel pits. In most cases, these abandoned depressions are useless, dangerous eyesores. Many of them could be safely and economically reclaimed by utilizing them as sanitary landfills. Clay pits, for example, are located in most impermeable formations, which are natural barriers to gas and water movement. Abandoned strip mines also are naturally suited for use as sanitary landfills. Most coal formations are underlaid by clays, shales, and siltstones that have a very low permeability. When permeable formations, such as sandstones, are encountered near an excavation, impermeable soil layers can be constructed from the nearby abundant spoil. Abandoned limestone, sandstone, siltstone, granite, and traprock quarries and open pit mines generally require more extensive improvements because they are in permeable or often open-fractured formations. The pollution potential of sand and gravel pits is great, and worked-out pits consequently require extensive investigation and probably expensive improvements to control gas movement and water pollution.

Marsh and tidal lands may also be filled, but they are less desirable from an ecological point of view. They have little value as real estate, but possess considerable ecological value as nesting and feeding grounds for wildlife. Filling of such areas requires, however, the permanent lowering of the groundwater or the raising of the ground surface to keep organic and soluble solid waste from being deposited in standing water. Roads for collection vehicles are also needed, and cover material generally has to be hauled in.

REFERENCE

1. Black, R.J., and A.M. Barnes. Effect of earth cover on fly emergence from sanitary landfills. Public Works, 89(2): 91-94, Feb. 1958. Condensed and reprinted as Fly emergence control in sanitary landfills. Refuse Removal journal, 1(5):13, 25, May 1958.

Sanitary Landfill Design

The designing of a sanitary landfill calls for developing a detailed description and plans that outline the steps to be taken to provide for the safe, efficient disposal of the quantities and types of solid wastes that are expected to be received. The designer outlines volume requirements, site improvements (clearing of the land, construction of roadways and buildings, fencing, utilities), and all the equipment necessary for day-to-day operations of the specific landfilling method involved. He also provides for controlling water pollution and the movement of decomposition gas. The sanitary landfill designer should also recommend a specific use of the site after landfilling is completed. Finally, he should determine capital costs and projected operating expenditures for the estimated life of the project.

Volume Requirements

If the rate at which solid wastes are collected and the capacity of the proposed site are known, its useful life can be estimated. The ratio of solid waste to cover material volume usually ranges between 4:1 and 3:1; it is, however, influenced by the thickness of the cover used and cell configuration. If cover material is not excavated from the fill site, this ratio may be compared with the volume of compacted soil waste and the capacity of a site determined (Figure 6). For example, a town having a 10,000 population and a per capita collection rate of 5 lb per day must dispose of, in a year, 11 acre-ft of solid waste if it is compacted to 1,000 lb per cu yd. If it were compacted to only 600 lb per cu yd, the volume disposed of in a year would occupy 19 acre-ft. The volume of soil required for the 1,000-lb density at a solid waste-to-cover ratio of 4:1 would be a 2.75 acre-ft; the 600-lb density waste would need 4.75 acre-ft. A density of 800 lb per cu yd is easily achievable if the compacting of a representative municipal waste is involved. A density of 1,000 lb per cu yd can usually be obtained if the waste is spread and compacted according to procedures described in Chapter 6.

The number of tons to be disposed of at a proposed sanitary landfill can be estimated from data recorded when solid wastes are delivered to disposal sites. The daily volume of compacted solid waste can then be easily determined for a large community (Figure 7) or for a small community (Figure 8). The volume of soil required to cover eacy day's waste is then estimated by using the appropriate solid waste-to-cover ratio.

The terms used to report densities at landfills can be confusing. Solid waste density (field density) is the weight of a unit volume of solid waste in place. Landfill density is the weight of a unit volume of in-place solid waste divided by the volume of solid waste and its cover material. Both methods of reporting density are usually expressed as pounds per cubic yard, on an in-place weight basis, including moisture, at time of the test, unless otherwise stated.

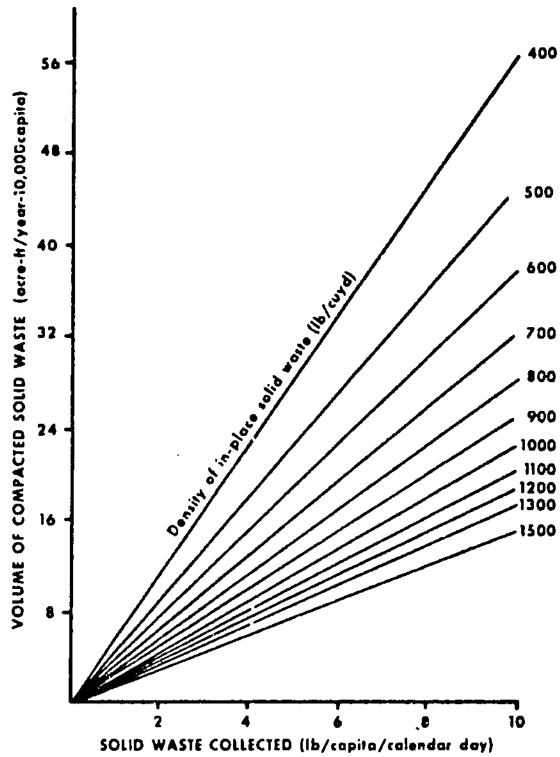


Figure 6. Determining the yearly volume of compacted solid waste generated by a community of 10,000 people.

Site Improvements

The plan for a sanitary landfill should prescribe how the site will be improved to provide an orderly and sanitary operation. This may simply involve the clearing of shrubs, trees, and other obstacles that could hinder vehicle travel and landfilling operations or it could involve the construction of buildings, roads, and utilities.

CLEARING AND GRUBBING. Trees and brush that hinder landfill equipment or collection vehicles must be removed. Trees that cannot be pushed over should be cut as close as possible to the ground so that the stumps do not hinder compaction or obstruct vehicles. Brush and tall grass in working areas can be rolled over or grubbed. A large site should be cleared in increments to avoid erosion and scarring of the land. If possible, natural windbreaks and green belts of trees or brush should be left in strategic areas to improve appearance and operation. Measures for minimizing erosion and sedimentation problems are outlined in the publication *Community Action Guidebook for Soil Erosion and Sediment Control*.[1]

ROADS. Permanent roads should be provided from the public road system to the site. A large site may have to have permanent roads that lead from its entrance to the vicinity of the working area. They should be designed to support the anticipated volume of truck traffic. In general, the roadway should consist of two lanes (total minimum width, 24 ft), for two-way traffic. Grades should not exceed equipment limitations. For loaded vehicles,

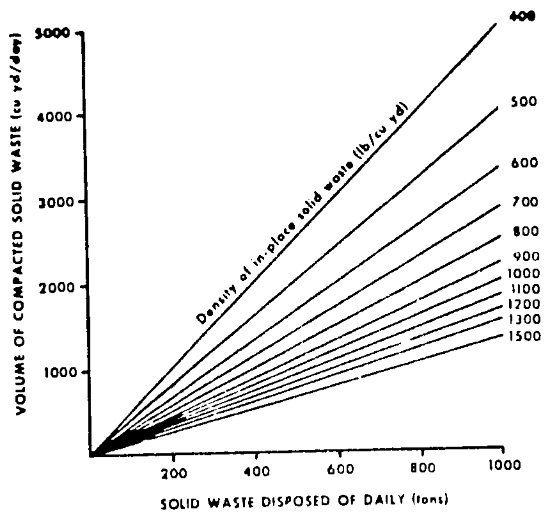


Figure 7. Determining the daily volume of compacted solid waste generated by large communities.

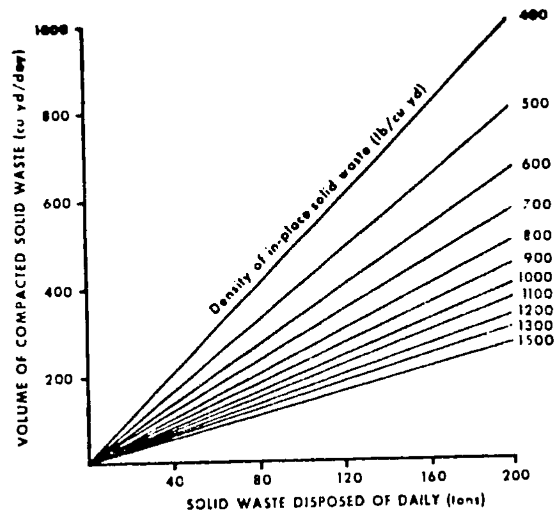


Figure 8. Determining the daily volume of compacted solid waste generated by small communities.

most uphill grades should be less than 7 percent and downhill grades less than 10. Road alignments and pavement designs have been adequately discussed elsewhere.[2,3] The initial cost of permanent roads is higher than that of temporary roads, but the savings in equipment repair and maintenance could justify the building of permanent, on-site roads.

Temporary roads are normally used to deliver wastes to the working face from the permanent road system, because the location of the working face is constantly changing. Temporary roads may be constructed by compacting the natural soil present and by controlling drainage or by topping them with a layer of a tractive material, such as gravel, crushed stone, cinders, broken concrete, mortar, or bricks. Lime, cement, or asphalt binders may make such roads more serviceable.

If fewer than 25 round trips per day to the landfill are expected, a graded and compacted soil will usually suffice. More than 50 round trips per day generally justifies the use of calcium chloride as a dist inhibitor or such binder materials as soil cement or asphalt. A base course plus a binder is desirable if more than 100 to 150 round trips per day are anticipated.

SCALES. Recording the weights of solid waste delivered to a site can help regulate and control the sanitary landfill operation as well as the solid waste collection system that serves it.

The scale type and size used will depend on the scope of the operation. Portable scales may suffice for a small site, while an elaborate system employing load cells, electronic relays, and printed output may be needed at a large sanitary landfill. Highly automated electronic scales and recorders cost more than a protable, simple, beam scale, but their use may often be justified, because they are faster and more accurate. The platform or scale deck may be constructed of wood, steel, or concrete. The first type is the least expensive, but also the least durable.

The scale should be able to weigh the largest vehicle that will use the landfill on a routine basis; 30 tons is usually adequate. Generally, the platform should be long enough to weigh all axles simultaneously. Separate axle-loading scales (portable versions) are the cheapest, but they are less accurate and slower operating. The scale platform should be 10 by 34 ft to weigh most collection vehicles. A 50-ft platform will accommodate most trucks with trailers.

The accuracy and internal mechanism of the scale and the recording device should meet the commercial requirements imposed by the State and any other jurisdiction involved, particulary if user fees are based on weight. Recommended scale requirements have been outlined by the National Bureau of Standards.[4]

Since weights are seldom recorded closer than to the nearest tenth of a ton and most applied loads are between 8 and 14 tons, a scale accuracy of $\pm$10.0 percent is acceptable. All scales should be periodically checked and certified as to standard accuracy.

Both mechanical and electronic scales should be tested quarterly under load. The inspection should include: (1) checking for a change in indicated weight as a heavy load is moved from the front to the back of the scale; (2) observing the action of the dial during weighing for an irregularity or "catch" in its motion; (3) using test weights.

BUILDINGS. A building is needed for office space and employee facilities at all but the smallest landfill; it can also serve as a scale house. Since a landfill operates in wet and cold weather, some protection from the elements should be provided. Operation records may also be kept at a large site. Sanitary facilities should be provided for both landfill and collection personnel. A building should also be provided for equipment storage and maintenance.

Buildings on sites that will be used for less than 10 years should be temporary types and, preferably, be movable. The design and location of all structures should consider gas movement and differential settlement caused by the decomposing solid waste.

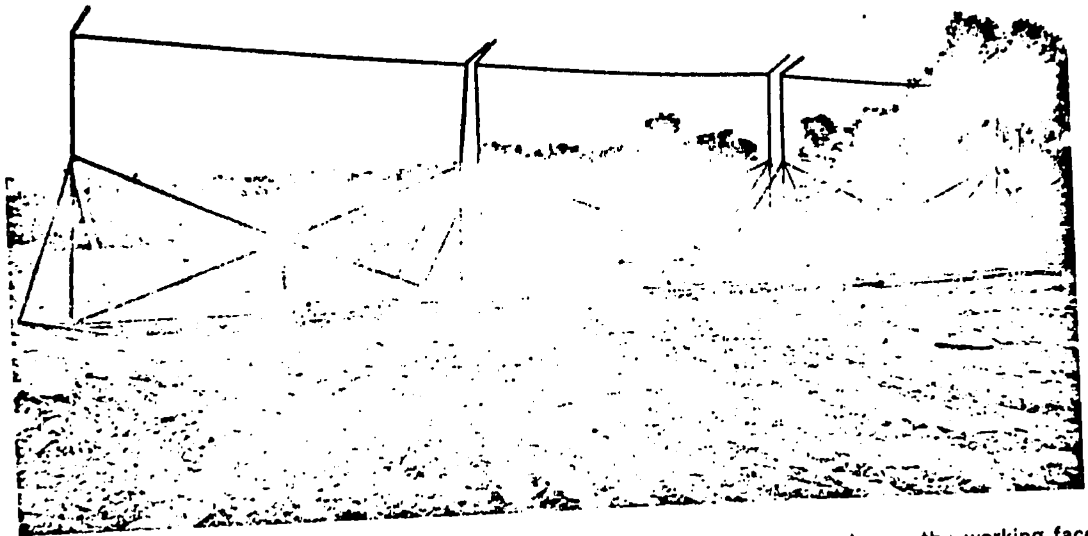


Figure 9. Specially designed and fabricated litter-control fences are often used near the working face of a sanitary landfill.

UTILITIES. All sanitary landfill sites should have electrical, water, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines, potable water may be trucked in, and an electric generator may be used instead of having power lines run into the site.

Water should be available for drinking, fire fighting, dust control, and employee sanitation. A sewer line may be called for, especially at large sites and at those where leachate is collected and treated with domestic wastewater. Telephone or radio communications are also desirable.

FENCING. Peripheral and litter fences are commonly needed at sanitary landfills. The first type is used to control or limit access, keep out children, dogs, and other large animals, screen the landfill, and delineate the property line. If vandalism and trespassing are to be discouraged, a 6-ft high fence topped with three strands of barbed wire projecting at a 45° angle is desirable. A wooden fence or a hedge may be used to screen the operation from view.

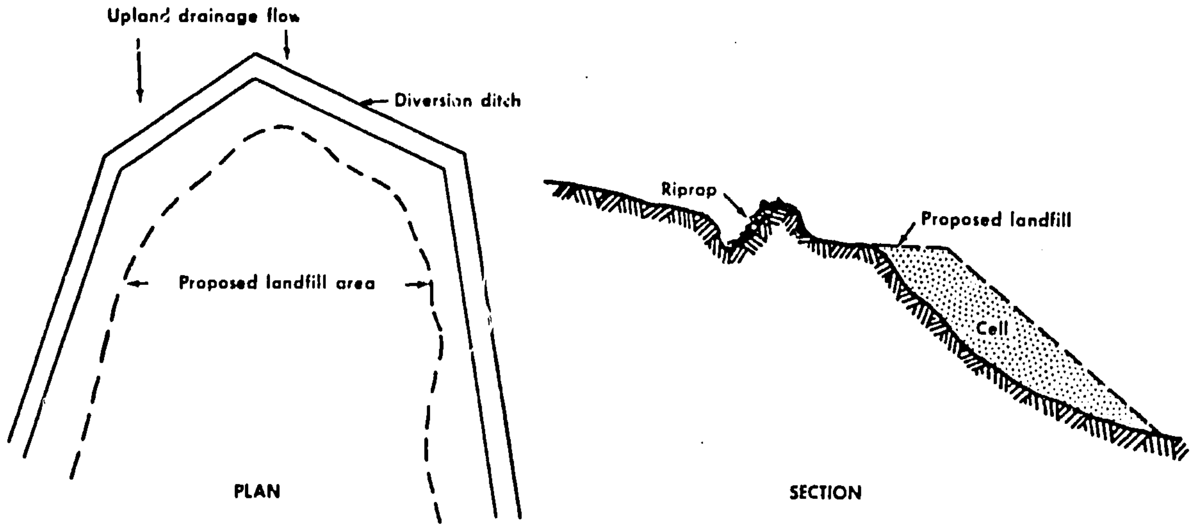


Figure 10. Plan and section views of the use of a diversion ditch to transmit upland drainage around a sanitary landfill.

Litter fences are used to control blowing paper in the immediate vicinity of the working face. As a general rule, trench operations require less litter fencing because the solid waste tends to be confined within the walls of the trench. At a very windy trench site, a 4-ft snow fence will usually suffice. Blowing paper is more of a problem in an area operation; 6- to 10-ft litter fences are often needed. Some litter fences have been specially designed and fabricated (Figure 9). Since the location of the working face shifts frequently, litter fences should be movable.

Control of Surface Water

Surface water courses should be diverted from the sanitary landfill. Pipes may be used in gullies, ravines, and canyons that are being filled to transmit upland drainage through the site and open channels employed to divert runoff from surrounding areas (Figure 10). Sump pumps may also be used. Because of operating and maintenance requirements, the use of mechanical equipment for water control is, however, strongly discouraged unless the control is needed only temporarily. If trenches or depressions are being filled, collection sumps and pumps may be used to keep them from flooding. Equipment sizes can be determined by analyzing storm and flood records covering about a 50-year period. Counseling and guidance in planning water management measures are available through local soil conservation districts upon request. A landfill located in a flood plain should be protected by impervious dikes and liners. The top of the dike should be wide enough for maintenance work to be carried out and may be designed for use by collection and landfill vehicles.

The top cover material of a landfill should be graded to allow runoff of rainfall. The grade of the cover will depend on the material's ability to resist erosion and the planned use of the completed site. Portable or permanent drainage channels may be constructed to intercept and remove runoff water. Low-cost, portable drainage channels can be made by bolting together half-sections of corrugated steel pipes. Surface water that runs off stockpiled cover material may contain suspended solids and should not be allowed to enter watercourses unless it has been ponded to remove settleable solids.

Groundwater Protection

It is a basic premise that groundwater and the deposited solid waste not be allowed to interact. It is unwise to assume that a leachate will be diluted in groundwater because very little mixing occurs in an aquifer since the groundwater flow there is usually laminar.

When issuing permits or certificates, many States require that groundwater and deposited solid wates be 2 to 30 ft apart. Generally, a 5-ft separation will remove enough readily decomposed organics and coliform bacteria to make the liquid bacteriologically safe.[5,6] On the other hand, mineral pollutants can travel long distances through soil or rock formations. In addition to other considerations, the sanitary landfill designer must evaluate the: (1) current and projected use of the water resources of the area; (2) effect of leachate on groundwater quality; (3) direction of groundwater movement; (4) interrelationship of this aquifer with other aquifers and surface waters.

Groundwater mounds, rises in the piezometric level of an aquifer in a recharge area, have been found at several landfills.[7] The mounds are reported to be up to 5 ft above the surround groundwater level, and they have intersected deposited solid waste. The investigators believe the water table probably rose because: (1) the permeability of the landfill's soil boundary decreased as a result of excavation and reworking; (2) more water infiltrated through the cover material and solid waste than through the undisturbed soils of the surrounding area.[7]

If a groundwater mound intersects the solid waste, leachate will undoubtedly enter the groundwater and may emerge as a spring around the toe to the fill where the groundwater table intersects the ground surface. Both surface and groundwaters may, therefore, be endangered if a mound forms.

An impermeable liner may be employed to control the movement of fluids. One of the most commonly used is a well-compacted natural clay soil, usually constructed as a membrane 1 to 3 ft thick. It must, however, be kept moist. If sufficient clay soil is not available locally, natural clay additives, such as montmorillonite, may be disked into it to form an effective liner. The use of additives requires evaluation to determine optimum types and amounts.

Since synthetic liners have been used to construct wastewater-holding-and-treatment ponds, they may have an application in solid waste disposal operations. They are usually made of butyl rubber, polyethylene, or polyvinyl chloride and are installed in multiple layers. (If the movement of both gas and leachate is to be controlled, polyvinyl chloride should work better than polyethylene because it is less permeable by gas.) The membranes must be put down carefully to avoid punctures, and layers of soil (usually sand) must be placed on both sides of them. Asphalt liners, which have been used to reduce seepage from canals and ditches, may also have an application in a solid waste disposal operation.

The use of an impermeable barrier requires that some method be provided for removal of the contained fluid. If a natural ravine or canyon is involved, the removal point should be the downstream end of the filled area. The fluid in a bowl-shaped liner could be pumped by a well or series of wells or it could exit through gravity outlets in the bottom of the liner. In the latter case, the pipes should be sloped 1/8 to 1/4 in. per ft.

It is often possible to permanently or temporarily lower the groundwater in free-draining, gravelly, and sandy soils. Drains, canals, and ditches are frequently used to intercept the groundwater and channel it to surface water or recharge area at a lower elevation. Doing this generally requires that the designer have a thorough knowledge of the soil permeabilities and the groundwater flow system in the area. It is inadvisable to use temporary methods, such as wells, to lower the water table because it will rise after pumping ceases, and the waste will be inundated. It is well to recognize that highly permeable soils that can be readily drained by ditching or pumping will offer equally little resistance to the movement of leachate from the decomposing solid waste. Even though groundwater can be kept from coming into direct contact with the solid waste, in most climates infiltrated surface water will probably enter the solid waste eventually, cause leaching, and then percolate through the underlying porous soil to enter the lowered groundwater. It is advisable, therefore, to view sites in highly permeable material with extreme caution.

Little work has been done to determine the types and costs of leachate treatment. Analysis of leachate samples from a few landfills and laboratory lysimeters indicates that leachate is a complex liquid waste and has variable characteristics. Since

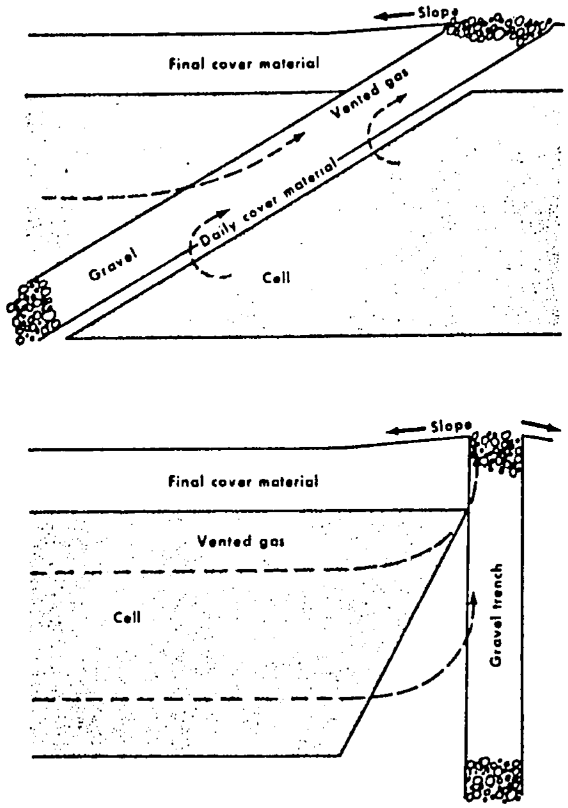


Figure 11. Gravel vents or gravel-filled trenches can be used to control lateral gas movement in a sanitary landfill.

most of the contaminants in leachate are water soluable, conventional biological and chemical treatment methods are probably required and, hopefully, will prove effective.

To help establish if a landfill is creating a groundwater and surface water pollution problem, a series of observation wells and sampling stations can be used to periodically monitor the water quality. Data on the upstream or uncontaminated water and downstream water quality are necessary to evaluate the pollution potential.

Gas Movement Control

An important part of sanitary landfill design is controlling the movement of decomposition gases, mainly carbon dioxide and methane. Traces of hydrogen sulfide and other odorous gases may also be involved.

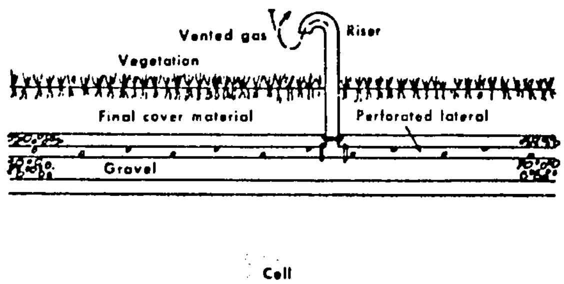


Figure 12. Gases are sometimes vented out of a sanitary landfill via pipes that are inserted through a relatively impermeable top cover and are connected to collecting laterals placed in shallow gravel trenches within or on top of the waste.

Methane (CH_4) is a colorless, odorless gas that is highly explosive in concentrations of 5 to 15 percent when in the presence of oxygen. In a few instances, methane gas has moved from a landfill and accumulated in explosive concentrations in sewer lines and nearby buildings. Gas from landfills has also killed nearby vegetation, presumably by excluding oxygen from the root zone. Carbon dioxide (CO_2) is also a colorless, odorless gas, but it does not support combustion. It is approximately 1.5 times as heavy as air and is soluble in water. The CO_2 reacts to a limited extent to form carbonic acid (H_2CO_3), which can dissolve mineral matter, particularly carbonates, in refuse, soil, and rock. If this occurs, the mineral content or hardness of the water increases, as has been noted at wells located near landfills and dumps.

In general, no problems arise when landfill gas can disperse into the atmosphere. If the fill has a relatively impermeable cover, however, the methane will try to vent into the atmosphere by moving laterally through a more permeable material.

The natural soil, hydrologic, and geologic conditions of the site may provide control of gas movement. If not, methods based on controlling gas permeability can be constructed. The following have been used or are considered possible.

PERMEABLE METHODS. Lateral gas movement can be prevented by using a material that is--under all circumstances--more permeable than the surround soil. Gravel vents or gravel-filled trenches have been employed (Figure 11). Preferably, the trenches should be somewhat deeper than the fill to make sure they intercept all lateral gas flow. The filter material should be graded to avoid infiltration and clogging by adjacent soil carried in by water. If possible, the trench should be built so that it drains naturally; field tile is often placed in the bottom of the trench. The surface of gravel trenches should be kept free of soil and vegetation, because they retain moisture and hinder venting.

In another method, vent pipes are inserted through a relatively impermeable top cover (Figure 12). Collecting laterals placed in shallow gravel trenches within or on top of the waste can be connected to the vertical riser. The sizes and spacings required have not been established, but they depend on the rate of gas production, total weight of solid waste, and the gas permeability of both the cover and the surrounding soil. In some cases, vertical risers have been used to burn off the gas. Pipe vents should not be located near buildings, but if this is unavoidable, they should discharge above the roof line.

Pumped exhaust wells may be used for gas venting. In this method, pipe vents are attached to the line of a suction pump to create differential driving pressure for gas movement. This method is costly and requires frequent maintenance.

IMPERMEABLE METHODS. The movement of gas through soils can be controlled by using materials that are more impermeable to it than the surrounding soil. An impermeable barrier can be used to contain the gas and vent it through the top cover or simply to block the flow of gas.

The most common method, and possible the most practical, calls for the use of compacted clay. The material must, however, be kept moist, otherwise it could shrink and crack. (Other fine grained soils may also be used, with the same stipulation.) The clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow (Figure 13). A clay layer 18 to 48 inch. thick is probably adequate, but it should be continuous and not be penetrated by solid waste or outcroppings of the surrounding soil or rocks. The liner should be constructed as the fill progresses, because prolonged exposure to air will dry the clay and cause it to shirnk and crack.

The use of synthetic membranes was described in the section of Groundwater Protection.

Sanitary Landfilling Methods

The designer of a sanitary landfill should prescribe the method of construction and the procedures to be followed in disposing of the solid waste, because there is no "best method" for all sites. The method selected depends on the physical conditions involved and the amount and types of solid waste to be handled.

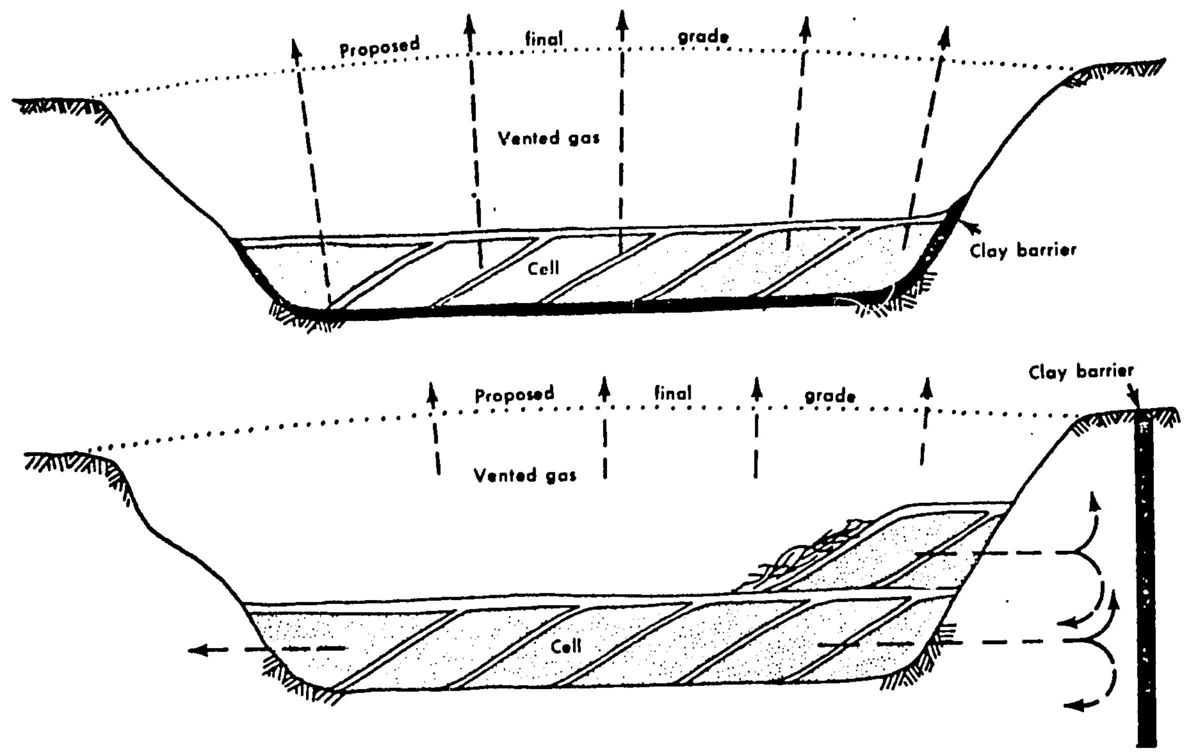


Figure 13. Clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow.

The two basic landfilling methods are trench and area; other approaches are only modifications. In general, the trench method is used when the groundwater is low and the soil is more than 6 ft deep. It is best employed on flat or gently rolling land. The area method can be followed on most topographies and is often used if large quantities of solid waste must be disposed of. At many sites, a combination of the two methods is used.

CELL CONSTRUCTION AND COVER MATERIAL. The building block common to both methods is the cell. All the solid waste received is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil cover constitute a cell. A series of adjoining cells, all of the same height, makes up a lift (Figure 14). The completed fill consists of one or moe lifts.

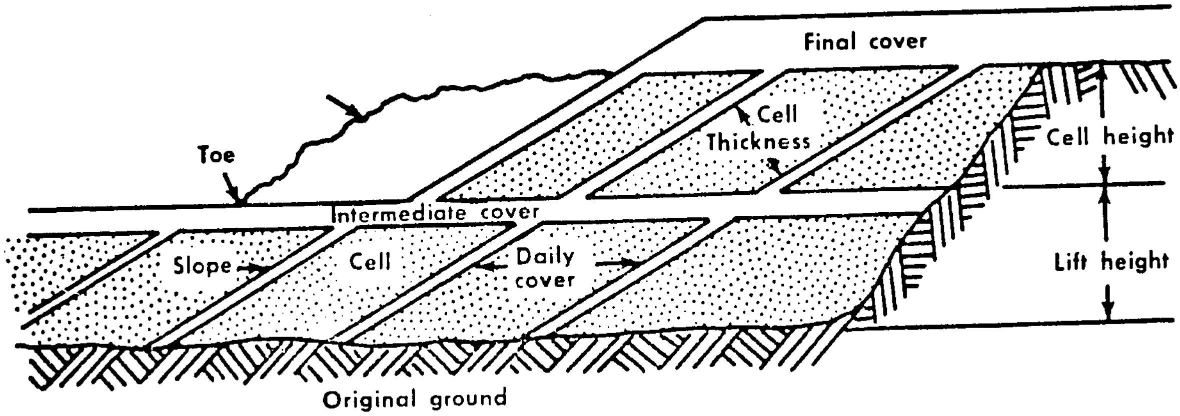


Figure 14. The cell is the common building block in sanitary landfilling. Solid waste is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil constitute a cell. A series of adjoining cells makes up a lift. The completed fill consists of one or more lifts.

The dimensions of the cell are determined by the volume of the compacted waste, and this, in turn, depends on the density of the in-place solid waste. The field density of most compacted solid waste within the cell should be at least 800 lb per cu yd. (It should be considerably higher if large amounts of demolition rubble, glass, and well-compacted inorganic materials are present.) The 800-lb figure may be difficult to achieve if brushes from bushes and trees, plastic turnings, synthetic fibers, or rubber powder and trimmings predominate. Because these materials normally tend to rebound when the compacting load is released, they should be spread in layers up to 2 ft thick, then covered with 6 in. of soil. Over this, mixed solid waste should be spread and compacted. The overlying weight keeps the fluffy or elastic materials reasonably compressed.

An orderly operation should be achieved by maintaining a narrow working face (that portion of the uncompleted cell on which additonal waste is spread and compacted). It should be wide enough to prevent a backlog of trucks waiting to dump, but not be so wide that it becomes impractical to manage properly--never over 150 ft.

No hard-and-fast rule can be laid down regarding the proper height of a cell. Some designers think it should be 8 ft or less, presumably because this height will not cause severe settlement problems. On the other hand, if a multiple lift operation is involved and all the cells are built to the same height, whether 8 or 16 ft, total settlement should not differ significantly. If land and cover material are readily available, an 8-ft height restriction might be appropriate, but heights up to 30 ft are common in large operations. Rather than deciding on an arbitrary figure, the designer should attempt to keep cover material volume at a minimum while adequately disposing of as much waste as possible.

Cover material volume requirements are dependent on the surface area of waste to be covered and the thickness of soil needed to perform particular functions. As might be expected, cell configuration can greatly affect the volume of cover material needed. The surface area to be covered should, therefore, be kept minimal.

In general, the cell should be about square, and its sides should be sloped as steeply as practical operation will permit. Side slopes of 20° to 30° will not only keep the surface area, and hence the cover material volume, at a minimum but will also aid in shredding and obtaining good compaction of solid waste, particularly if it is spread in layers not greater than 2 ft thick and worked from the bottom of the slope to the top.

<u>TRENCH METHOD</u>. Waste is spread and compacted in an excavated trench. Cover material, which is taken from the spoil of the excavation, is spread and compacted over the waste to form the basic cell structure (Figure 15). In this method, cover material is readily available as a result of the excavation. Spoil material not needed for daily cover may be stockpiled and later used as a cover for an area fill operation on top of the completed trench fill.

Cohesive soils, such as glacial till or clayey silt, are desirable for use in a trench operation because the walls between the trenches can be thin and nearly vertical. The trenches can, therefore, be spaced very closely. Weather and the length of time the trench is to remain open also affect soil stability and must be considered when the slope of the trench walls is being designed. If the trenches are aligned perpendicularly to the prevailing wind, this can greatly reduce the amount of blowing litter. The bottom of the trench should be slightly sloped for drainage, and provision should be made for surface water to run off at the low end of the trench. Excavated soil can be used to form a temporary berm on the sides of the trench to divert surface water.

The trench can be as deep as soil and groundwater conditons safely allow, and it should be at least twice as wide as any compacting equipment that will work in it. The equipment at the site may excavate the trench continuously at a rate geared to landfilling requirements. At small sites, excavation may be done on a contract basis.

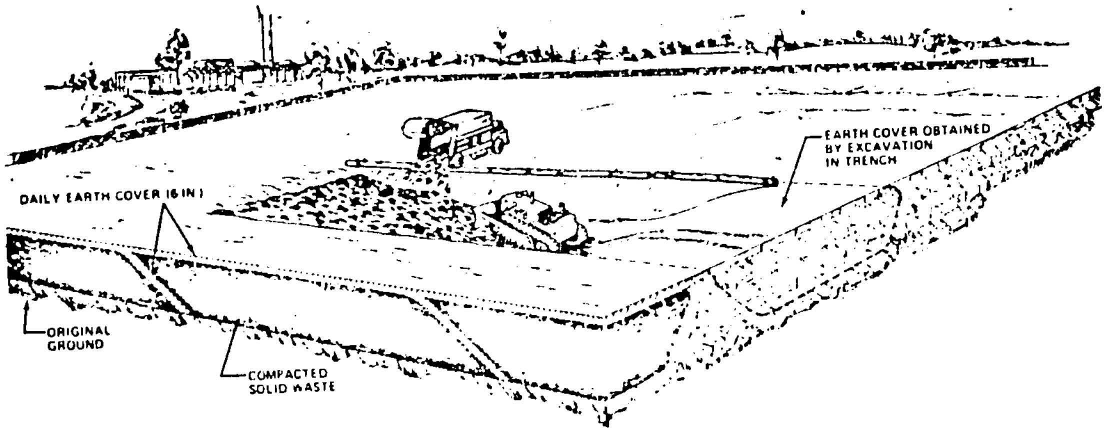


Figure 15. In the trench method of sanitary landfilling, the collection truck deposits its load into a trench where a bulldozer spreads and compacts it. At the end of the day, the trench is extended, and the excavated soil is used as daily cover material.

AREA METHOD. In this method, the waste is spread and compacted on the natural surface of the ground, and cover material is spread and compacted over it (Figure 16). The area method is used on flat or gently sloping land and also in quarries, strip mines, ravines, valleys, or other land depressions.

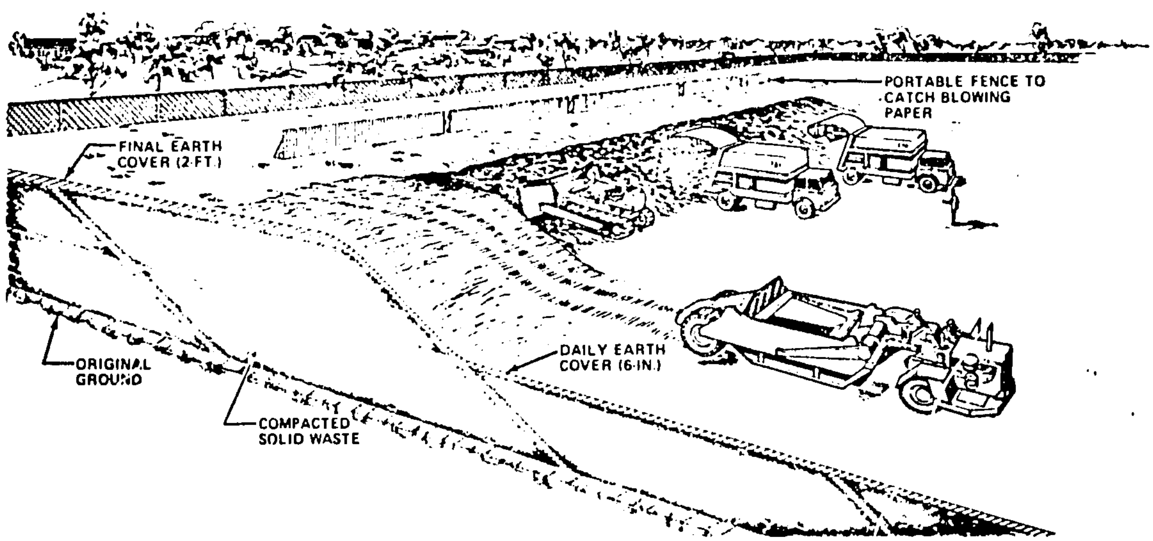


Figure 16. In the area method of sanitary landfilling, a bulldozer spreads and compacts the waste on the natural surface of the ground, and a scraper is used to haul the cover material at the end of the day's operations.

COMBINATION METHODS. A sanitary landfill does not need to be operated by using only the area or trench method. Combinations of the two are possible, and flexibility is, therefore, one of sanitary landfilling's greatest assets. The methods used can be varied according to the constraints of a particular site.

One common variation is the progressive slope or ramp method, in which the solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste (Figure 17). In this way, a small excavation is made for a portion of the next day's waste. This technique allows for more efficient use of the disposal site when a single lift is constructed than the area method does, because cover does not have to be imported, and a portion of the waste is deposited below the original surface.

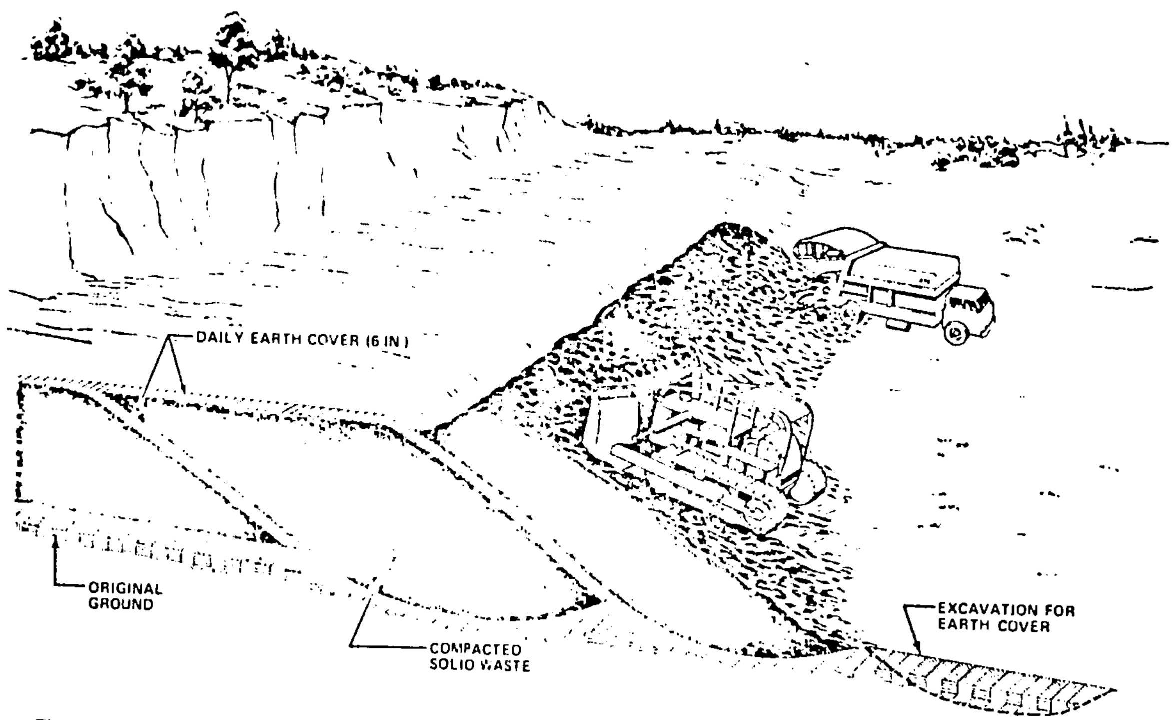


Figure 17. In the progressive slope or ramp method of sanitary landfilling, solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste.

Both methods might have to be used at the same site if an extremely large amount of solid waste must be disposed of. For example, at a site with a thick soil zone over much of it but with only a shallow soil over the remainder, the designer would use the trench method in the thick soil zone and use the extra spoil material obtained to carry out the area method over the rest of the site. When a site has been developed by either method, additional lifts can be constructed using the area method by having cover material hauled in.

The final surface of the completed landfill should be so designed that ponding of precipitation does not occur. Settlement must, therefore, be considered. Grading of the final surface should induce drainage but not be so extreme that the cover material is eroded. Side slopes of the completed surface should be 3 to 1 or flatter to minimize maintenance.

Finally, the designer should consider completing the sanitary landfill in phases so that portions of it can be used as parks and playgrounds, while other parts are still accepting solid wastes.

Summary of Design Considerations

The final design of a sanitary landfill should describe in detail: (1) all employee and operational facilities; (2) operational procedures and their sequence, equipment, and manpower requirements; (3) the pollution potential and methods of controlling it; (4) the final grade and planned use of the completed fill; (5) cost estimates for acquiring, developing, and operating the proposed site.

The designer should also provide a map that shows the location of the site and the area to be served and a topographic map covering the area out to 1,000 ft from the site. Additional maps and cross-sections should also be included that show the planned stages of filling (startup, intermediate lifts, and completion). They should present the details of:

1. Roads on and off the site;
2. Buildings;
3. Utilities above and below ground;
4. Scales;
5. Fire protection facilities;
6. Surface drainage (natural and constructed) and groundwater;
7. Profiles of soil and bedrock;
8. Leachate collection and treatment facilities;
9. Gas control devices;
10. Buildings within 1,000 ft of property (residential, commercial, agricultural);
11. Streams, lakes, springs, and wells within 1,000 ft;
12. Borrow areas and volume of material available;
13. Direction of prevailing wind;
14. Areas to be landfilled, including special waste areas, and limitations on types of waste that may be disposed of;
15. Sequence of filling;
16. Entrance to facility;
17. Peripheral fencing;
18. Landscaping;
19. Completed use.

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EQUIPMENT

There is a wide variety of equipment available for sanitary landfill operations. The types selected will depend on the amount and kinds of solid waste to be landfilled each day and on the operational methods to be employed at a particular site. Since money spent on equipment constitutes a large capital investment and accounts for a large portion of operating costs, the selection should be based on a careful evaluation of the functions to be performed and the cost and ability of various machines to meet the needs.

Equipment Functions

Sanitary landfill machines fall into three general functional categories: (1) those directly involved in handling waste; (2) those used to handle cover material; (3) those that perform support functions.

WASTE HANDLING. The practical and safe disposal of solid waste is the primary objective of a sanitary landfill. Although the handling of solid waste at a landfill site resembles an earthmoving operation, differences exist that require special consideration. Solid waste is less dense, more compactible, and more heterogeneous than earth. Spreading a given volume of solid waste requires less energy than an equal amount of soil.

Because of its size, strength, and shape, solid waste is not as conducive as soils to compaction by vibration. In the main, solid waste is compacted by the compressive forces developed by the overall massive loading of a landfill machine. If maximum compaction is desired, a large, heavy machine that is operated in accordance with the recommendations contained in Chapter 6 will give better results than a light machine. Since repeated loading of the solid waste improves its compaction, enough machines should be available that 2 to 5 compaction passes can be made during the operating day. If it is not possible to purchase a large machine, spreading the solid waste into thinner layers and making more passes with a lighter machine may suffice. The optimum number of passes depends on the moisture content and composition of the solid waste. Their exact relationships, as they affect density, have not, however, been determined.

Machines that operate on solid waste, especially during spreading and compaction, are susceptible to overheating because of clogged radiators, to broken fuel and hydraulic lines, to tire punctures, and to damage incurred when waste becomes lodged in the tracks or between the wheels and the machine body. The various accessories that are available to help alleviate these problems are discussed later in this chapter.

COVER MATERIAL HANDLING. The excavating, hauling, spreading, and compacting of cover material are similar to other earthmoving operations, such as highway construction. In landfill operations, however, rigorous control of moisture content to achieve maximum soil density is not usually practiced, although it is desirable to wet a very dry soil somewhat to hold down dust and to improve compaction. The equipment operator who spreads and compacts cover material should be capable of grading it as specified to drain the site. Specific earthmoving requirements vary according to the topographic and soil conditions present. Sand, gravel, and certain loamy clay and loamy silt soils can be excavated with wheeled equipment, but tougher natural soils require tracked machines. If the natural soil cover is thin, underlying formations composed of weathered or partially decomposed bedrock may make suitable cover material, but they may have to be broken with a crawler equipped with a rock ripper. Rippable materials include most uncemented shale, thinly interbedded limestone and shale, poorly cemented siltstone, and partially decomposed granitic rock types. These are, however, only generalizations, and a particular soil may be easier to excavate or more difficult to work because soil properties may change significantly from season to season. Glacial till can usually be excavated by heavy tracked equipment if the compact clay has a moderate to high moisture content, as in the spring and early summer. In the late summer and fall, when less rain falls, glacial tills or clay soils of similar texture and composition dehydrate and become very hard and difficult to excavate. They must often be ripped first. Freezing weather may also require the use of a rock ripper to remove the frost layer.

SUPPORT FUNCTIONS. A sanitary landfill requires support equipment to perform such tasks as road construction and maintenance, dust control, fire protection, and possibly to provide assistance in unloading operatons. Road construction and maintenance must be provided so that the working face can be reached in all types of weather. This often requires the adoption of a dust control program which, in turn, may call for the use of special equipment, such as a water wagon and sprinkler or a salt spreader. Mobile firefighting equipment may be stationed on the site or readily available nearby. Assistance in the unloading operation may include emptying collection trucks equipped with a movable bulkhead and pulling out vehicles that become stuck near the operating face during rainy weather. Unless there are many collection trucks requiring assistance, the spreading and compacting machine can handle the situation.

Equipment Types and Characteristics

A knowledge of the types and characteristics of earthmoving machines is essential if the right selection is to be made, especially since most machines can perform multiple functions.

CRAWLER MACHINES. Crawler machines are of two types: dozer and loader. Other common names for them are: bulldozer, crawler, crawler dozer, track loader, front end loader, and bullclam; many trade names are also used. They all have good flotation and traction capabilities, because their self-laying tracks provide large ground contact areas. The crawler is excellent for excavating work and moving over unstable surfaces, but it can operate approximately only 8 mph, forward or reverse.

The crawler dozer is excellent for grading and can be economically used for dozing waste or earth over distances of up to 300 ft (Figure 19). It is usually fitted with a straight dozer blade for earthwork, but at a sanitary landfill it should be equipped with a U-shaped blade that has been fitted with a top extension (trash or landfill blade) to push more solid waste.

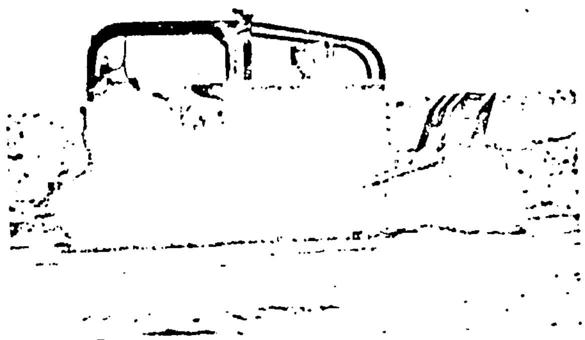


Figure 19. The crawler dozer is excellent for grading and can be economically used for dozing waste for up to 300 ft. It should be equipped with a U-shaped blade that has been fitted with a top extension to increase its pushing area.

Unlike the crawler dozer, the crawler loader can lift materials off the ground, but its bucket is not as wide, and it is not able, therefore, to spread as much solid waste. The crawler loader is an excellent excavator and can carry soil as much as 300 ft. There are two types of buckets usually used for sanitary landfilling: the general purpose and the multiple purpose (Figures 20-21). The general-purpose bucket is a scoop of one-piece construction. The multiple-purpose bucket, which is also known as a bullclam or 4 in 1, is of two-piece construction, is hinged at the top, and is hydraulically operated. It can thus clamp onto such objects as tree trunks or telephone poles and lift and place them in the fill, or it can crush junked autos or washing machines. It is also useful in spreading cover material. The general-purpose and multiple-purpose buckets come in many sizes. Matching a bucket to a machine should be done with the advice of the machine manufacturer. A landfill blade similar to that used on dozers can also be fitted to loaders.

RUBBER-TIRED MACHINES. Both dozers and loaders are available with rubber-tired wheels. They are generally faster than crawler machines (maximum forward or reverse speed of about 29 mph) but do not excavate as well. The plausible claim has been made that because the weight of rubber-tired machines is transferred to the ground over a much smaller contact area, they provide better compaction, but significant differences of in-place density have not been proven. Because their loads are concentrated more, rubber-tired machines have less flotation and traction than crawler machines. Their higher speed, however, allows them to complete more cycles or passes in the same amount of time than a crawler machine. Rubber-tired machines perform satisfactorily on landfill sites if they are equipped with steel guarded tires, called rock tires or landfill tires. Rubber-tired machines can be economically operated at distances of up to 600 ft.

Figure 20. Crawler loader with a general-purpose bucket of one-piece construction. The crawler loader is an excellent excavator.

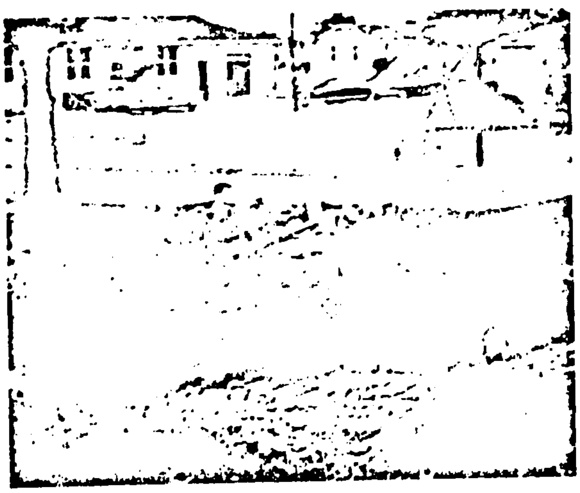


Figure 21. Crawler loader with a multiple-purpose bucket, which is also known as a bullclam or 4 in 1. The bucket can clamp onto such objects as tree trunks and telephone poles and lift and place them in the fill; it can also crush junked cars and washing machines.

Figure 22. The rubber-tired dozer is used only infrequently at sanitary landfills. Because of the rough and spongy surface formed by compacted solid waste, this machine does not grade as well as a crawler dozer.

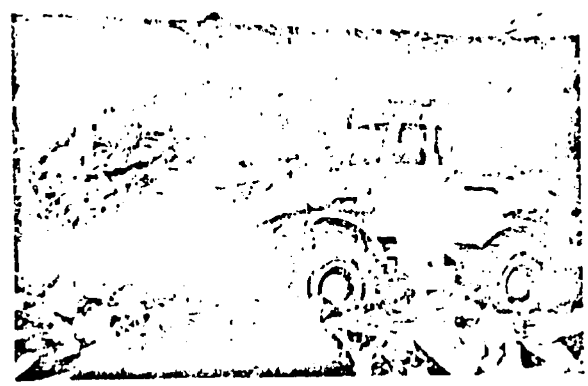
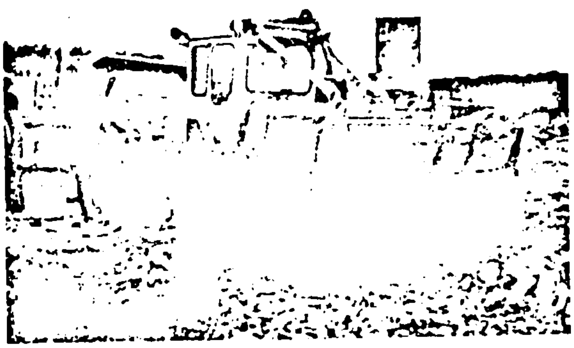


Figure 23. The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket. Because of its high operating speed, this machine is especially suited for putting cover material into haul trucks or carrying it economically for distances of up to 600 ft.

The rubber-tired dozer is not commonly used at a sanitary landfill. Because of the rough and spongy surface formed by compacted solid waste and the concentrated wheel loads, the rubber-tired dozer does not grade as well as a crawler dozer. The flotation of the crawler dozer makes it much more suitable for grading operations. The rubber-tired dozer should be equipped with a landfill or trash blade (Figure 22) similar to that recommended for a track dozer.

The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket (Figure 23). A particular asset of this machine is the high speed and mobility of its operation. When it is only needed part time at a sanitary landfill, it can be driven over public roads to perform other jobs. Because of its high operating speed, the rubber-tired loader is especially suited for putting cover material into haul trucks or carrying it economically over distances of up to 600 ft.

LANDFILL COMPACTORS. Several equipment manufacturers are marketing landfill compactors equipped with large trash blades. In general, these machines are modifications of road compactors and log skidders. Rubber-tired dozers and loaders have also been modified. The power train and structure of landfill compactors are similar to those of rubber-tired machines, and their major asset is their steel wheels (Figure 24). The wheels are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators (Figure 25).



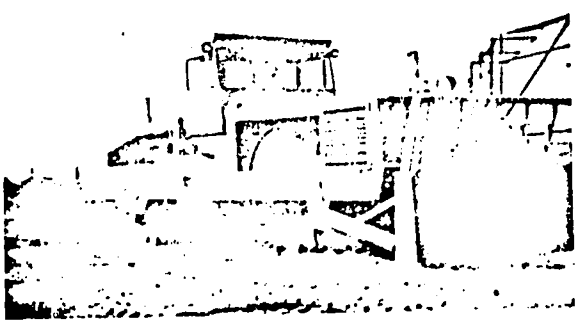


Figure 24. In general, landfill compactors are modifications of road compactors and log skidders. The power train and structure are similar to those of rubber-tired machines. The major asset of the landfill compactor is its steel wheels; it can probably achieve better compaction than a rubber-tired or crawler machine.

Steel-wheeled machines probably impart greater crushing and compactive effort than do rubber-tired or crawler machines. A study comparing a 47,000-lb steel-wheeled compactor, the same unit equipped with rubber tires, and a 62,000-lb crawler dozer indicated that under the same set of conditions, the in-place dry density of solid waste compacted by the steel-wheeled compactor was 13 percent greater than that effected by the crawler dozer and the rubber-tired compactor.

The landfill compactor is an excellent machine for spreading and compacing on flat or level surfaces and operates fairly well on moderate slopes, but it lacks traction when operating on steep slopes or when excavating. Its maximum achievable speed while spreading and compacting on a level surface is about 23 mph, forward and reverse. This makes it faster than a crawler but slower than a rubber-tired machine. Since landfill compactors operate at high speeds and produce good in-place densities, they are best applied when they are used only for spreading and compacting solid waste and cover material. When the cover material is a clay, it and some of the solid waste lodge between the load concentrators and must be continually removed by cleaner bars. The surface of a soil layer compacted with a landfill compactor is usually covered by pits or indentations formed by the load concentrators. Numerous passes are needed to minimize the roughness of the surface.

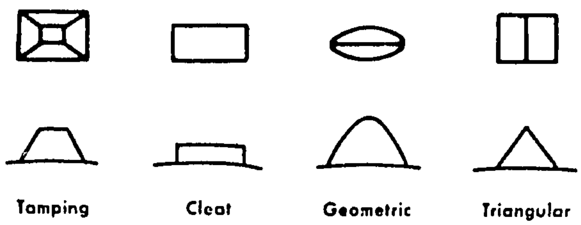
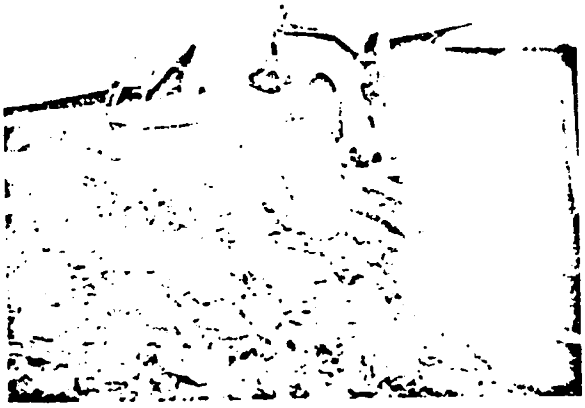


Figure 25. The wheels of a landfill compactor are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators.

SCRAPERS. Scrapers are available as self-propelled and towed models having a wide range of capacities (Figure 26). This type of earthmoving machine can haul cover material economically over relatively long distances (more than 1,000 ft for the self-propelled versions and 300 to 1,000 ft for towed models). Their prime function is to excavate, haul, and spread cover material. Since they are heavy when loaded, routing them over the fill area will help compact the solid waste. Hauling capacities range from 2 to 40 cu yd.



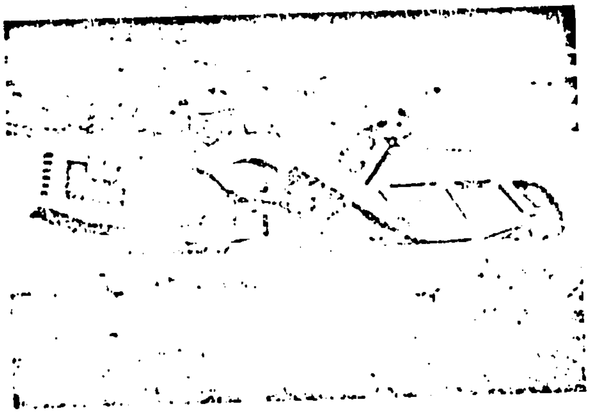


Figure 26. Scrapers are available as self-propelled or towed models; their prime function is to excavate, haul, and spread cover material. Capacities range from 2 to 40 cu yd.

DRAGLINE. Large excavations can be made economically with a dragline. Its outstanding characteristic is its ability to dig up moderately hard soils and cast or throw them away from the excavation. Because of this feature, it can also be used to spread cover material over compacted solid waste. It is particularly useful in wetland operations. The dragline is most commonly found at large landfills where the trench method is used or where cover material is obtained from a borrow pit. As a rule of thumb, the boom length should be two lines the trench width. Buckets used at landfills usually range from 1 to 3 cu yd.

SPECIAL-PURPOSE EQUIPMENT. Several pieces of earthmoving and road construction equipment are put to limited use on landfills that dispose of less than 1,000 tons a day. Their purchase may not, therefore, be warranted. When they are needed, they can be borrowed, leased, rented, or the work can be performed under contract.

The road grader can be used to maintain dirt and gravel roads on the site, to grade the intermediate and final cover, and to maintain drainage channels surrounding the fill.

Water is useful in controlling blowing litter at the working face and control of dust from on-site roads. Water wagons range from converted tank trucks to highly specialized, heavy vehicles that are generally used in road construction operations. They can also be used at the landfill to fight fires.

The road sweeper is a real asset at sites where mud is tracked onto the public road system. Its periodic use will encourage local residents to accept the landfill because roadways remain safe.

ACCESSORIES. The equipment used at landfills can be provided with accessories that protect the machine and operator and increase the effectiveness and versatility of the machine (Table 8).

Engine screens and radiator guards keep paper and wire from clogging radiator pores and causing the engine to overheat. A reversible fan can also help alleviate this problem, because the direction of air flow or vane pitch can be changed in less than 5 min. Under-chassis guards can be installed to shield the engine, and hydraulic lines and other essential items of the machine should also be protected if they are susceptible to damage (Figure 27).

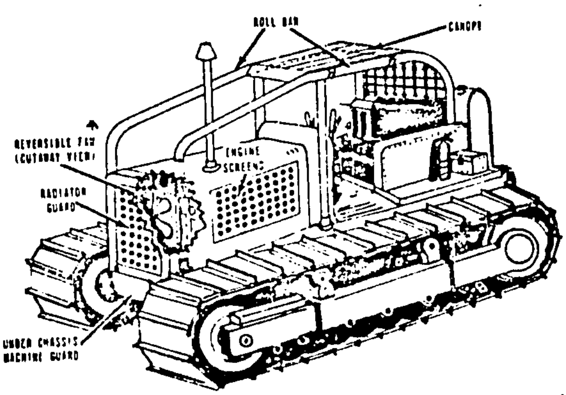


Figure 27. The equipment used at sanitary landfills can be provided with accessories that protect the machine and operator and increase their effectiveness.

TABLE 8

Recommended and Optional Accessories for Landfill Equipment

Accessory	Dozers Crawler	Dozers Rubber-Tired	Loaders Crawler	Loaders Rubber-Tired	Landfill compactor
Dozer blade	0*	0	—	—	0
U-blade	0	0	—	—	0
Landfill blade	R†	R	0	0	R
Hydraulic controls	R	R	R	R	R
Rippers	0	—	0	—	—
Engine screens	R	R	R	R	R
Radiator guards-hinged	R	R	R	R	R
Cab or helmet air conditioning	0	0	0	0	0
Ballast weights	0	0	R	R	R
Multiple-purpose bucket	—	—	R	R	—
General-purpose bucket	—	—	0	0	—
Reversible fan	R	R	R	R	R
Steel-guarded tires	—	R	—	R	—
Life-arm extensions	—	—	0	0	—
Cleaner bars	—	—	—	—	R
Roll bars	R	R	R	R	R
Backing warning system	R	R	R	R	R

* O, Optional.
† R, Recommended.

The operator's comfort, safety, and efficiency can be increased by providing roll bars, a canopy or cab, cab or helmet air conditioning, and backup warning systems. A canopy is especially desirable for machiens that operate in a trench into which waste is dumped from above. Cabs are particularly useful when the working area is very dusty or the operator must work in very cold weather. Because rubber-tired machines and landfill compactors operate at relatively high speeds, an audible backup warning system should be provided to alert other equipment operators and personnel in the immediate area. This system is also desirable on crawler machines, especially when two or more are operating in the same area.

Equipment versatility and effectiveness can be increased by use of a number of accessories. A hydraulically operated ripper is needed when extensive excavation must be carried out in hard soils. It should be mounted on a tracked machine to take advantage of its greater traction. (Back-rippers, hinged teeth attached to buckets or blades that dig into the soil when the machine is reversing, are not as effective as hydraulically operated rippers.) To give rubber-tired machines and landfill compactors more traction, their wheels can be ballasted with a calcium chloride solution or water, and steel or concrete counterweights can be used on loaders and landfill compactors.

Different power trains can be used on many large machines. The power shift and torque converter options are preferable to the dry clutch, direct-drive models because greater speed of operation and less strain on the engine and operator are possible with them.

COMPARISON OF CHARACTERISTICS. The ability of various machines to perform the many functions that must be carried out at a sanitary landfill should be analyzed with respect to the needs and conditions of each site (Table 9). General recommendations regarding the best types and sizes of machines to use at a specific landfill can be misleading. More exhaustive analysis is needed before the final equipment selection is made.

Size of Operation

Definition of functions and evaluation of equipment performance must be matched with the size of the landfill to determine the type, number, and size of the machines needed. No one machine is capable of performing all functions equally well. Neither can it be assumed that equipment effectively used at one site will be the most suitable elsewhere. Unfortunately, production rates expressed in tons of solid waste spread and compacted per hour are not readily available for comparison. Guides that have been proposed by equipment manufacturers and others should be considered only rough estimates of equipment needs for a particular landfill (Table 10).

SINGLE-MACHINE SITES. Particular difficulty is encountered when selecting equipment for a site where only one machine will be used. It must be capable of spreading and compacting both solid waste and cover material, but it may also have to be used to excavate trenches or cover material. In general, the most versatile machine for a small landfill is the tracked or rubber-tired loader. If the machine will not be used full time, a wheeled loader is preferable because of its mobility. If the machine is to stay at the site full time and will not be required to load cover material into trucks, a crawler dozer may be better.

Regardless of the size of a single-machine operation, the dependability of the machine should be high. Arrangements should be made in advance to obtain a replacement if a breakdown occurs, because this development is no excuse for unacceptable disposal. A replacement machine may be available through the equipment dealer, a local contractor, or a municipal public works department.

Performance Characteristics of Landfill Equipment*† TABLE 9

Equipment	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	G	E	E	G	NA
Carwler loader	G	G	E	G	G	NA
Rubber-tired dozer	E	G	F	G	G	NA
Rubber-tired loader	G	G	F	G	G	NA
Landfill compactor	E	E	P	G	E	NA
Scraper	NA	NA	G	E	NA	E
Dragline	NA	NA	E	F	NA	NA

* Basis of evaluation: Easily workable soil and cover material haul distance greater than 1,000 ft.
† Rating Key: E, excellent; G, good; F, fair; P, poor; NA, not applicable.

TABLE 10

Landfill Equipment Needs[1]

Solid waste handled (tons/8 hr)	Crawler loader		Crawler dozer		Rubber-tired loader	
	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)
0–20	<70	<20,000	<80	<15,000	<100	<20,000
20–50	70 to 100	20,000 to 25,000	80 to 110	15,000 to 20,000	100 to 120	20,000 to 22,500
50–130	100 to 130	25,000 to 32,500	110 to 130	20,000 to 25,000	120 to 150	22,500 to 27,500
130–250	150 to 190	32,500 to 45,000	150 to 180	30,000 to 35,000	150 to 190	27,500 to 35,000
250–500	combination of machines		250 to 280	47,500 to 52,000	combination of machines	
500–plus	COMBINATION OF MACHINES					

Note: [1]Compiled from assorted promotional material from equipment manufacturers and based on ability of one machine in stated class to spread, compact, and cover within 300 ft of working face.
* Basic weight without bucket, blade, or other accessories.

SMALL SITES. Municipalities disposing of less than 10 tons a day may find the cost of owning a small dozer or loader too high. If excavation and stockpiling of cover material are done on contract, a farm tractor equipped with a blade or bucket may be sufficient for spreading the solid waste. The tractor will not, however, be able to produce much compaction, even if the waste is spread in thin layers. The poor compaction achieved means that a larger fill area will be needed. This requirement, together with the total cost of the contract work, should be compared to the expense of owning and operating a small dozer or loader.

MULTIPLE-MACHINE OPERATION. It is easier to select equipment for a multiple-machine operation than it is for a one-machine operation. Such specialized machines as scrapers and landfill compactors may then be economical to use. If cover material has been stockpiled and more than one machine is available, operations need not be interrupted when an equipment breakdown occurs. As an added precaution, replacement machines should be available through a lease, contract, or borrowing arrangement.

Costs

The equipment selected for a sanitary landfill must not only be able to perform well under conditions present at the site, it must also do so at the least total cost. Equipment costs, both capital and operating, represent a significant portion of the expenses incurred in operating a sanitary landfill.

CAPITAL COSTS. Except for land, the cost of equipment may be the greatest portion of initial expenditures. The sanitary landfill equipment market is very competitive, but rough approximations of costs have been developed (Table 11). A crawler machine weighing 29,000 lb. without accessories costs about $29,000. With engine sidescreens, radiator guards, reversible fan, roll bar, and a multiple-purpose bucket, the same machine costs approximately $32,000. A new dragline can cost between $75,000 and $110,000 depending on the length of its boom and cables, and the size of its bucket. In general, most landfill equipment used for excavating, spreading, and compacting has a useful life of 5 years or 10,000 operating hours.

Machine Capital Cost

Machine type	Flywheel Horsepower	Weight (lb)	Equipped Machine: Approximate weight* (lb)	Equipped Machine: Approximate cost† ($)	Comment
Crawler dozer	<80	<15,000	19,000	21,000	landfill blade
	110–130	20,000–25,000	32,000	38,000	landfill blade
	250–280	47,500–52,000	67,000	70,000	landfill blade
Crawler loader	<70	<20,000	23,000	21,000	GPB‡—1 cu yd
	100–130	25,000–32,500	31,000	30,000	GPB—2 cu yd
	100–130	25,000–32,500	32,000	32,000	MPB**—1¾ cu yd
	150–190	32,500–45,000	45,000	46,000	GPB—3 cu yd
	150–190	32,500–45,000	47,000	49,000	MPB—2½ cu yd
Rubber-tired loader	<100	<20,000	17,000	21,000	GPB—1¾ cu yd
	<100	<20,000	18,000	23,000	MPB—1½ cu yd
	120–150	22,500–27,500	23,000	33,000	GPB—4 cu yd
	120–150	22,500–27,500	26,000	36,000	MPB—2¼ cu yd

* Basic machine plus engine sidescreens, radiator guards, reversible fan, roll bar, and either a landfill blade, general-purpose bucket, or multiple-purpose bucket as noted.
† June 1970.
‡ General-purpose bucket.
** Multiple-purpose bucket.

Table 11

The price of a used machine depends on its type, size, condition, and number of recorded operating hours. Specific resale values are available from auctioneers and manufacturers of earth-moving equipment. The condition and remaining useful life of used equipment should be determined by an exert.

OPERATING AND MAINTENANCE COSTS. Purchases of fuel, oil, tires, lubricants, and filters and any expenses associated with routine maintenance are considered operating costs. Expenditures on fuel account for approximately 90 percent of operating costs. The expense of operaring dozers, loaders, and landfill compactors varies according to type and make; the manufacturer should, therefore, be consulted for specific estimates. Gnerally speaking, direct operating costs are $3.00 per hour. The skill of the equipment operator, the type of waste handled, topography, and soil conditions also affect operating costs.

Maintenance costs, parts, and labor also vary widely but can be approximated by spreading one-half the initial cost of the machine over its anticipated useful life (10,000 hr). To make these costs more predictable, most equipment dealers offer lease agreements and maintenance contracts. Long downtimes usually associated with major repairs can be reduced by taking advantage of programs offered by most equipment dealers.

High operating costs are frequently associated with low initial costs of the equipment and vice versa. The purchaser should, therefore, require that equipment bids include estimated operating costs.

Actual operating and maintenance expenses should be determined during site operation by use of a cost accounting system.[2] This information can be used to identify areas where costs may be reduced; excessive fuel consumption, for example, may mean the machine needs adjustment or that operating procedures should be modified. Data from the cost accounting system can be used to more accurately predict operating and maintenance costs.

REFERENCES

1. SONTE, R., and E. T. CONRAD. Landfill compaction equipment efficiency. Public Works, 100(5):111-113, May 1969.
2. ZAUSNER, E. R. An accounting system for sanitary landfill operations. Public Health Service Publication No. 2007. Washington, U.S. Government Printing Office, 1969. 18 p.

GENERAL SUMMARY

Determining Land and Equipment Needs. The amount of land needed for sanitary landfill operation is based on the amount of solid wastes to be landfilled. The amount will vary with the seasons, and will be greater when local government disposes of commercial, industral, or agricultural solid wastes on a regular basis. There are no reliable formulas to determine residential, commercial, agricultural, and industrial waste amounts, so a careful study must be made of the solid wastes generated in the area that will be using the sanitary landfill. Weight is the most reliable basis since volume is a relative measure.

Roughly, one acre of land with a 15-ft. compacted lift of solid wastes will accommodate a population of 10,000 for a year. If additional lifts can be placed over the initial lift, the land area requirement can be reduced.

Sanitary landfill equipment needs are based primarily on the daily tonnage of wastes to be landfilled. It is best to use scales at the landfill to provide the necessary data to determine daily tonnage. Scales also provide an equitable basis for fees. In a small operation, one tractor with a bucket loader (and a dump truck if cover material must be transported) can operate very well; a large operation may require several pieces of compacting and earth moving equipment. (See Figure C showing equipment needs based on tonnage of wastes to be filled and population served.

FIGURE C: AVERAGE EQUIPMENT REQUIREMENTS

Population	Daily tonnage	Equipment			Accessory*
		No.	Type	Size in lbs.	
0 to 15,000	0 to 40	1	Tractor crawler or rubber-tired	10,000 to 30,000	Dozer blade Front-end loader (1 to 2 yd) Trash blade
15,000 to 50,000	40 to 130	1	Tractor crawler or rubber-tired	30,000 to 60,000	Dozer blade Front-end loader (2 to 4 yd) Bullclam Trash blade
		*	Scrapper Dragline Water truck		
50,000 to 100,000	130 to 260	1 to 2	Tractor crawler or rubber-tired	30,000 or more	Dozer blade Front-end loader (2 to 5 yd) Bullclam Trash blade
		*	Scraper Dragline Water truck		
100,000 or more	260 or more	2 or more	Tractor crawler or rubber-tired	45,000 or more	Dozer blade Front-end loader Bullclam Trash blade
		*	Scraper Dragline Steel wheel compactor Road grader Water truck		

*Optional. Dependent on individual need.

Source: U.S. Department of Health, Education and Welfare, Public Health Service, National Center for Urban and Industrial Health, Solid Wastes Program Publication Number 1792 Sanitary Landfill Facts (Washington: Government Printing Office, 1968), p. 17.

Site Suitability. Selection of a site involves consideration of topography, population, accessibility, hauling distance, cost time-in-motion, pollution potential, cover material, proximity of residences, citizen reaction, and ultimate usage. Sites should be chosen which will meet anticipated needs for at least the next ten years, but preferably for a 20- to 30-year period. This may mean selection of several sites, each having a life of from three to five years. Sites worth considering for use as sanitary landfills include gullies, ravines, eroded areas, marshlands, strip mines, gravel pits, and flat land.

Generally, the larger the parcel of land, the greater the economies to be gained, presuming the distance to the site is not unreasonably difficult to travel. Where disposal sites are distant, transfer stations may be required. Engineering consultants are usually enlisted to find potential landfill sites, evaluate their suitability, and determine whether transfer station operation would bring economies. If there is standing or flowing water on the land, it must be permanently diverted before beginning the fill.

A qualified soil specialist or geologist should check the topographic, soil, and geologic conditions to insure protection of the ground water. Subsoil should be impermeable. If not, adequate soil must separate the bottom of the waste fill from the highest known ground-water level. Proper surface drainage should be provided to minimize entry of surface waters into the landfill proper. Surface drainage must be consistent with the surrounding area so the finished construction will neither interfere wiht proper drainage on adjacent lands nor concentrate run-off water on adjacent areas. To allow normal surface drainage and to minimize erosion, the completed fill should have at least 1 per cent slope, and be seeded to promote stabilization of the cover.

Availability fo workable earth is an important factor in operating cost. If it cannot be excavated at the site, or brought in from nearby road construction or other sources, it may have to be purchased. Hauling and purchase can raise costs 25 to 50 per cent or more. The cover material should compact well and be applied thickly enough to prevent cracking and exposure of the filled wastes. In cold climates, cover material must be excavated before the ground freezes. However, freezing can be delayed by adding a mulch covering.

Before implementing a sanitary landfill operation, it is necessary to determine the final use of the land. This affects the final contour and whether all the land will be filled. Maps should be made of the present contour and property lines, and of the projected completed fill.

As wastes decompose, settling occurs. The more wastes were compacted originally, the less settling. Buildings should not be erected on filled land unless proper foundation conditions are provided.

In Waukegan, Illinois, the city's contractor is filling swampland to make it suitable for an athletic field and park. The unfilled high ground will be used to support a school building.

One of the greatest problems in obtaining a site for a sanitary landfill is overcoming public opposition, particularly if a previous landfill has been imporperly operated or if dumps exist. Equipment operating noise at a site is comparabe to that at any excavation involving heavy equipment. Gases, mostly methane and carbon dioxide, are produced by waste decomposition. Since the sanitary landfill encloses solid wastes in cells, the chance for spontaneous combustion of gas explosion is reduced. If fire should occur, it can be more easily controlled than a fire in an open dump since the oxygen supply in the cell is limited. Moreover, the danger of fire in a sanitary landfill is much less than in an open dump.

Summary of Design, Construction and Evaluation

SANITARY LANDFILL DESIGN
Site Location Requirements

The disposal site shall: (1) be easily accessible in any kind of weather to all vehicles expected to use it; (2) safeguard against water pollution originating from the disposed solid waste; (3) safeguard against uncontrolled gas movement originating from the disposed solid waste; (4) have an adequate quantity of earth cover material that is easily workable, compactible, free of large objects that would hinder compaction, and does not contain organic matter of sufficient quantity and distribution conducive to the harborage and breeding of vectors; (5) conform with land use planning of the area.

Site Design

The project plan shall include a general location map and topographic map of the area showing land use and zoning within 1/4 mile of the solid waste disposal site. The topographic map shall be of such a scale that it shows all homes, buildings, wells, watercourses, dry runs, rock outcroppings, roads, and other pertinent details.

The project plan shall also include a plot of the site that shows dimensions, location of soil or rock borings, proposed trenches or original fill face, winter cover stock piles, and fencing. Cross sections shall be included on the plot plan or on separate sheets that illustrate both the original ground and proposed fill elevations. The scale of the plot plan should not be greater than 200 feet per inch.

A report shall accompany the plans regarding; (1) population and area to be served; (2) anticipated types, quantities, and sources of solid wastes to be disposed of; (3) site geology, hydrology, and soil conditions; (4) source and pertinent engineering properties of cover material and teh projected method of protecting it for winter operations; (5) types and numbers of equipment to be used for excavating, earth moving, spreading, compacting and other purposes; (6) persons responsible for the actual operation and maintenance of the site and intended operating procedures; (7) ultimate plan for the completed site.

The design of the sanitary landfill shall include one or more topographic maps at a scale of not over 200 feet to the inch; controur intervals shall not exceed t feet. The maps shall show: the proposed fill area; any borrow sections; access roads; grades for proper drainage of each lift required and a typical corss section of a lift; special drainage and gas control devices if necessary; fencing; equipment shelter; existing and proposed utilities; employee facilities; and all other pertinent information to indicate clearly that the sanitary landfill will be developed, operated, and completed in an crderly manner.

The sanitary landfill should be designed by a registered professional engineer.

Operational Design Features

The disposal site shall be provided with operational features and appurtenances necessary to maintain a clean and ordely operation; (2) control of access to the site by fencing or other suitable means; (2) an all-weather access road (if excessively bad weather makes the working face inaccessible, it may be necessary to provide a landfill area near the entrance to the site; (3) suitable devices, such as portable fences, for litter control.

In addition to the required features, there are others that are highly recommended: (1) operational plans to direct and control the use of the site; (2) signs indicating traffic flow, hours of operation, and any charges for disposal; (3) scales for weighing the solid waste received (in public or other scales is acceptable; (4) dust control methods (these may require the use of chemicals, oils, or water sprays); (5) communication devices for emergency use and for operational control; (6) electrical service for operations and repairs; (7) fire protection and fire-fighting facilities adequate to ensure the safety of employees and provisions for dealing with accidental burning of solid waste in the landfill; (8) first-aid equipment and training.

Personnel and Personnel Facilities

In order to man and operate the site adequately the following are recommended: (2) a trained supervisor or foreman and trained equipment operators; (2) a shelter for employees to use during inclement weather; (3) a potable water supply for landfill personnel and collection crews; (4) sanitary toilets on or near the site; (5) training in the proper and safe operation of all equipment.

Equipment

To assure safe and efficient operation the following are required: (1) sufficient equipment for spreading, compacting, and covering operations; (2) arrangements whereby alternate equipment is provided within 24 hours following an equipment breakdown.

As a further aid, the following are recommended (1) safety devices on equipment to shield and protect operators; (2) maintenance and storage shelters.

SANITARY LANDFILL CONSTRUCTION

General

Certain operations must be carried out:

1. Access to the site must be controlled to keep unauthorized persons out and to assist the landfilling operation. (Access shall be allowed only when an attendant is on duty and only to authorized users).

2. Burning of waste material shall be prohibited.

3. Blowing paper shall be controlled by providing a portable fence near the working area, and the entire area shall be policed at least daily.

4. Salvaging and scavenging shall not be allowed at the working face.

5. Provision shall be made to ensure that no pollution of surface or ground water is created.

6. Provisions shall be made for on-site control of potential gas movement from the landfill.

Other operations are strongly recommended:

1. Operational records should be maintained daily. They should include the type, weight, and volume of solid wastes received; type and volume of cover material used; the portion of the landfill used (determined by cross section and survey); any deviations made from the original plan of operation; and equipment maintenance and cost records. A monthly report should be prepared that describes the amounts of solid waste received, the area of the fill used, the volume of the fill used, and the amount of the cover material used. The report should be submitted to the appropriate governmental agency. Cost records should be maintained and should conform to those recommended by the Solid Waste Management Office in An Accounting System for Sanitary Landfill Operations, U.S. Public Health Service Publication No. 2007.

2. Upland surface drainage should be diverted around the site to control infiltration at the fill site and erosion of the in-place cover material.

3. Conditions unfavorable for the habitation and production of insects and rodents should be maintained by carrying out sanitary landfill operations promptly and systematically. It is recommended taht the site be inspected regularly by an independent pest control firm and certified reports submitted to the appropriate government agency. Supplemental vector control measures should be instituted when necessary. Domestic animals should be excluded from the site, and proper control measures should be used to control wildlife, when necessary.

4. A detailed description and a plat of the completed fill site (as built) should be recorded with the proper local agency responsible for maintaining titles and records of land to provide

notice to future users and owners of the site. The detailed description should include but not be limited to: type and location of pollution controls, and original and final terrain descriptions.

5. Continual training of personnel in the proper operation of a sanitary landfill should be provided.

Landfilling

Certain procedures are required during landfilling:

1. The working face shall be as small an area as the equipment can safely and efficiently operate in.

2. The solid waste shall be spread and compacted in thin layers. In the construction of each cell, it shall be spread into layers that do not exceed 2 feet prior to compaction. The number of layers incorporated into a cell depends on the design and configuration of the site.

3. All solid waste shall be covered daily with at least 6 inches of compacted soil. Daily cover has three main functions: to provide insect and rodent control, to provide fire breaks between cells, and to prevent exposure and blowing of litter and to offer an aesthetically pleasing site at the end of the working day. The in-place cover must be maintained until further filling or the addition of final cover is made.

4. Final cover shall be applied to any surface that represents the final grade of the sanitary landfill; 2 feet of compacted soil is required. Trees, shrubs, and other plants often require more than two feet of soil to grow. Suitable grasses should be planted to prevent erosion and surface deterioration. Final cover shall be placed over any completed section of the fill within 7 days following the placement of solid waste within that portion.

Other procedures are recommended during landfilling:

1. Supervision should be available to coordinate all unloading activities.

2. Special provisions should be made for vehicles being unloaded by hand so that the flow of mechanically unloading vehicles is not impaired.

3. Final cover should be graded to drain surface run-off water. For this reason, it is best to slightly overdesign initial grades so that when settlement occurs, the surface will be sufficient for good drainage. The top surface should slope 2 to 4 percent, and the side slopes should not be so steep as to cause an erosion problem.

Special Waste Handling

Handling and disposing of waste sludges, waste liquids, and hazardous materials shall be given special consideration with regard to water pollution and the health and safety of employees. Large bulky items should be reduced in volume before daily cover is applied.

Supervision and Inspection

The following recommendations apply:

1. The supervisor of the operation should be an individual who has had experience in earthmoving, waste handling, and disposal.

2. Routine inspection and evaluation of landfill operations should be made by a representative of the appropriate regulatory agency. A notice of any deficiencies, together with any recommendations for their correction, should be provided to the owner or agent responsible for the use of the land and the appropriate individual or firm or governmental agency responsible for the landfill operation.

3. A representative of the appropriate regulatory agency should inspect the completed sanitary landfill before the earthmoving equipment is removed, and any corrective work should be performed before the landfill project is accepted as completed. Arrangements should be made for all cracked, eroded, and uneven areas in the final cover to be repaired as required during the years following completion of the fill.

SANITARY LANDFILL EVALUATION

This evaluation method is intended to measure the level of acceptability of the operations taking place at a disposal site, as well as to provide an overall comparison of its suitability to that of other evaluated sites. The evaluation consists of two subsets of evaluative criteria. The first subset comprises 10 Requirements, all of which must be satisfied if the site is to qualify as a sanitary landfill.

If the operation is a sanitary landfill, the second subset (13 Recommended Items) is provided to achieve a broader evaluation of other features of sanitary landfill design and construction. Operations vary due to size and locality, and certain items may not be required. An exceptional sanitary landfill would meet all Requirements and Items.

Each Requirement and Item in the evaluation is followed by a statement of what is needed to qualify, the reasoning for the statement, and the criteria that must be met. The sanitary landfill should be inspected in detail in order to complete the evaluation. (A suggested check list is included to aid in the evaluation.) Some criteria will require that the operator or supervisor answer certain questions, and precautions should be taken, therefore, to assure that the questions are understood and that the answers are reliable. If possible, written documentation should support the answers.

Sanitary Landfill Requirements

Requirement A: Open Burning Prohibited. No solid waste shall be burned at the sanitary landfill.

Basis: Open burning of solid waste creates odors, air polltuion, and fire and safety hazards. It also adversely affects public acceptance of the operation and proper location of future sanitary landfill sites. Local laws that allow or require the open burning of such materials as diseased elm trees and condemned dry foods are outmoded. Such materials can either be incorporated within the sanitary landfill or disposed of in such a manner as to prevent health hazards or nuisances. Open burning for any reason converts the operation to that of the open dump.

Open burning of solid waste on the site is prohibited at all times. Yes ___ No ___

Requirement B: Access Limited. Access to a sanitary landfill shall be limited to those times when an attendant is on duty and only to those authorized to dispose of solid waste.

Basis: If public use is allowed when no attendant is on duty, scavenging, burning, and indiscriminate dumping commonly occur. Men and equipment must then be diverted to restore sanitary conditions. When access to the site during operating hours is limited to those authorized, traffic and other accident hazards are minimized.

Access by unauthorized vehicles or pedestrians is controlled. Yes ___ No ___

Requirement C: Spreading and Compacting. Solid waste shall be spread in uniform layers not over 2 feet thick prior to compaction.

Basis: Successful operation and maximum utilization of a sanitary landfill depend on adequate compaction of the solid waste. In addition, settlement will be excessive and uneven if this is not done. Settlement permits invasion by insects and rodents and severely limits the usefulness of the finished area.

Compaction is best initiated by spreading the solid waste evenly in shallow layers, and better compaction is achieved if the working face is operated on a slope. Further compaction is provided by the repeated travel of equipment over the layers and, if necessary, by the use of special equipment.

Solid waste is properly spread and compacted. Yes ___ No ___

Requirement D: Daily Cover. A uniform compacted layer of at least 6 inches of suitable earth cover shall be placed on all exposed solid waste by the end of each working day.

Basis: Daily covering is necessary to prevent insect and rodent infestation, blowing litter, fire hazards, an unsightly appearance, and to control gas and water movement. Fly emergency generally is prevented by 6 inches of compacted soil. Daily covering also divides the fill into "cells" that will limit any underground fires that might occur. The cover material should be easily workable and compactible, should be free of large objects, and should not contain organic matter of sufficient quantity and distribution conducive to the harborage and breeding of vectors.

A uniform, compacted layer of at least 6 inches of suitable earth cover is used for daily cover. Yes ___ No ___

Requirement E: Final Cover. A uniform layer of earth cover compacted to a minimum depth of 2 feet shall be placed over the entire covered surface of each portion of the final lift. This shall be done not later than one week following the placement of solid waste within that portion.

Basis: A minimum final cover of 2 feet of compacted suitable earth cover will prevent emergency of insects from the compacted solid waste, minimize the escape of odors, prevent rodents from burrowing, provide for control of gas and water movement, support plant growth, and provide an aesthetically acceptable finished site. This cover also provides an adequate bearing surface for vehicles and is of sufficient thickness for cover integrity in the event of settlement or erosion. Workability and compaction characteristics should at least equal those provided for daily cover.

A minimum final cover of 2 feet of compacted earth cover is used as stated. Yes ___ No ___

Requirement F: Environmental Protection. The location and the operation must have the approval of the appropriate governmental agency, such as the State Department of Health. There shall be no contamination of ground or surface waters by deposited solid wastes or their products of decomposition, and no hazard or nuisance caused by gases or other products generated by the biologically or chemically active wastes.

Basis: Location, nature of the waste deposited, and substandard operational procedures may lead to pollution of surface waters or underground aquifers. Unless proper standards of location and operations are followed offensive and dangerous concentrations of gases may occur in the soil or above ground and adversely affect the environment. It may be necessary to provide special construction techniques or alter operations to control such conditions.

Solid waste is placed so that the environment is not and will not be adversely affected. Yes ___ No ___

Requirement G: Blowing Litter Controlled. Blowing litter shall be controlled by fencing placed near the working area or by the use of earth banks or natural barriers. The entire site shall be policed at least daily. Unloading shall be performed so as to minimize the scattering of the solid waste.

Basis: The purpose of the sanitary landfill is to dispose of solid waste in a nuisance-free manner. If papers and other light materials are scattered and the area is not policed, fire hazards, nuisances, and unsightliness result.

Blowing litter is controlled and the site and surrounding area routinely policed. Yes ___ No ___

Requirement H: Salvage Prohbiited. Salvaging shall not be permitted at the working face of the sanitary landfill.*

Basis: Nothing can be tolerated that interferes with the prompt sanitary disposal of solid waste. Salvaging at the working face delays the filling operation and creates unsanitary conditions. The accumulation of salvaged materials also provides harborage for vectors and promotes an unsightliness that can be detrimental to public acceptance of the operation.

Salvaging is never allowed at the working face. Yes ___ No ___

Requirement I: Operational Considerations. Provision shall be made for all-weather access roads leading to the disposal site, and written provisions and guarantees shall be made for the replacement of operating equipment when it is down for more than 24 hours.

Basis: The purpose of a sanitary landfill is the immediate disposal of solid waste, because this results in the elimination of nuisances and produces an aesthetically acceptable operation. A major breakdown of operating equipment for more than 24 hours reverts the sanitary landfill operation to an open dump. Access roads that are not negotiable by collection vehicles cause unnecessary delays in the disposal operation.

Sanitary landfills utilizing more than one piece of equipment are normally able to operate efficiently even if one piece of equipment has a major breakdown because it may have sufficient reserve capacity. Smaller operations that involve only one piece

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*Any salvage or reclamation of solid waste materials must take place in a systematic and controlled manner at some site other than the operating area. If such a facility is physically located on the same land plat or nearby, it should not be considered part of the sanitary landfill operation.

of equipment require some type of prior written agreement that guarantees the equivalent of standby equipment within 24 hours after any major breakdown.

Heavy duty use of equipment requires that a schedule of inspection and miantenance be followed to keep it operational under normal conditions (See Recommended Item 5).

Provisions have been made to assure all-weater access roads and to guarantee the equivalent of standby equipment within 24 hours following major breakdown to normal operating equipment. Yes ___ No ___

<u>Requirement J</u>: Special Waste Handling. Toxic, pathogenic, corrosive, flammable, explosive, and other hazardous wastes shall be handled only if special provisions are made.

<u>Basis</u>: Materials such as oil sludges, chemical wastes, magnesium shavings, empty pesticide containers, and contaminated medical wastes can be a special hazard to employees and to the environment if their presence is not known or if they are improperly handled. The site must also have special evaluations to determine that there will be no adverse effects on the environment.

Suitable procedures are established and followed for disposal of special wastes or the wastes are excluded. Yes ___ No ___

Sanitary Landfill Recommended Items

<u>ITEM 1</u>: Instructions for Users. Signs should be posted that clearly indicate the purpose of the operation, the owner or operator of the site, hours of operation, instructions for after-hours delivery, materials accepted or excluded, fees charges, and emergency telephone numbers.

<u>Basis</u>: The site is typically intended to include use by the general public, and guidance must, therefore, be given regarding the location and purpose of the activity and its relationship to the user. Proper use of the site is not guaranteed, but instruction is an essential step in gaining compliance.

A sanitary landfill may sometimes be called a "land reclamation project" or something similar but <u>never</u> a "dump," because this term connotes an unacceptable operation. Provision of some method of storage, such as a bulk container near the gate, is an added service for the small hauler or householder who arrives after hours. Persons arriving at the site should quickly be able to determine if their material will be accepted and if so, the cost per unit (ton, cubic yard, etc.). If there should be an emergency such as a fire, either during or after working hours, or a person is injured, clearly posted numbers will expedite obtaining assistance.

Suitable informational and directional signing is provided at the entrance and/or other appropriate locations. Yes ___ No ___

ITEM 2: Measuring Facilities. Provision should be made for weighing or adequately measuring all the solid waste delivered.

Basis: A suitable method of measuring incoming or deposited solid waste is desirable to provide a reliable quantity of data to determine trends and to estimate needs. Estimates of volumes based on truckloads rather than weights are misleadin. Weighing is the best basis for establishing fees, and scales should be required as an integral part of the operation. Determination of the volume increments in deposited solid waste may be done by making periodic volumetric surveys; this permits the use-rate and remaining capacity of the site to be evaluated.

Suitable fixed or portable scales have been installed and are used continuously, or the sanitary landfill is routinely "cross-sectioned" at least every 30 days to determine volumes in place. Yes ___ No ___

ITEM 3: Communications. Telephone or radio communications should be provided.

Basis: Communications are desirable at the generally remote sanitary landfill sites, in case of emergency. If the sanitary landfill is part of a combined collection and disposal system, good communications will result in better performance throughout the system.

Reliable communciations are installed at the site. Yes ___ No ___

ITEM 4: Employee Facilities. Suitable shelter and sanitary facilities should be provided for personnel.

Basis: Shelter should be available to employees during inclement weather, and toilet and handwashing facilities are desirable.

Permanent or temporary shelter of adequate size is provided along with safe drinking water, sanitary handwashing and toilet facilities, suitable heating facilities, screens, and electricity (if needed). Yes ___ No ___

ITEM 5: Equipment Maintenance. Provision should be made for routine maintenance of equipment and for prompt repair or replacement.

Basis: Equipment breakdowns of a day or more result in the accumulation of uncovered solid waste (as at an open dump) with all the attendant health hazards and nuisances. Systematic, routine maintenance of equipment reduces repair costs, increases life expectancy, and helps to prevent breakdowns. In the event of a breakdown, prompt repair of equipment will materially shorten down time.

Facilities for routine maintenance are available, and provisions for major maintenance and repair have been made. Yes ___ No ___

ITEM 6: Unloading Area and Working Face. The unloading of the solid waste should be controlled and restricted to an area where the material can easily be incorporated into the working face with the equipment available.

Basis: Proper operation requires systematic placement of the solid waste in a restricted unloading area. Unloading must be coordinated with spreading and compacting. Controlled unloading reduces work, conserves landfill volume, permits better compaction, minimizes scattering of solid waste, and expedites unloading.

The type and size of the unloading area depends on the amount of solid waste received, the type of oepration, and the size of the working face. A large working face increases the area to be compacted and covered, with resulting high cost, delays, and unnecessarily exposed solid waste.

Unloading is controlled at all times by signs or a supervisor, and the size of the unloading area is balanced with the size of the working face to allow collection vehicles to unload promptly. Yes ___ No ___

ITEM 7: Fire Protection. Suitable measures should be taken to prevent fires and to control them if they start.

Basis: Fires endanger life and property. Smoke and odors are nuisances to nearby property owners, endanger disposal personnel, and interfere with sanitary landfilling operations. Deliberate burning makes sanitary landfills almost the equivalent of open dumps.

An adequate supply of hoses and of water under suitable pressure is available or a stockpile of earth is maintained reasonably close to the working face of the fill to smother fires; suitable fire extinguishers are on all equipment and in all buildings. Yes ___ No ___

ITEM 8: Bulky Waste Handling. Large or bulky items, sewage solids or liquids (septic tank or cesspool pumpings, sewage sludge, and grit), and other materials that are hard to manage should be disposed of only if special provisions are made.

Basis: Sewage solids or liquids are hard to handle, potentially infectious, and capable of creating health hazards or nuisances if not properly handled. When the sanitary landfill design includes special provisions for the disposal of such large or bulky items as car bodies, refrigerators, water heaters, demolition wastes, tree stumps, logs and branches, they need not be excluded.

Suitable procedures are established and followed for disposal of hard-to-handle materials. Yes ___ No ___

ITEM 9: Vector Control. Conditions unfavorable for the production of insects and rodents should be maintained by carrying out routine operations promptly in a systematic manner. Supplemental vector control measures can be instituted if necessary.

Basis: Proper operation denies insects and rodents food and harborage. Incoming solid waste loads and a rural setting are, however, natural environment for vectors. If any appear, a supplemental vector control program will quickly eliminate them.

Vector control is adequately provided. Yes ___ No ___

ITEM 10: Dust Control. Suitable control measures should be taken wherever dust is a problem.

Basis: Excessive dust at the sanitary landfill can slow down operations, cause accidents, harm equipment, create aesthetic problems, and lead to injuries.

Dust control measures are applied as needed. Yes ___ No ___

ITEM 11: Accident Prevention and Safety. Employees should be instructed in the principles of first aid and safety and in the specific operational procedures necessary to prevent accidents. An adequate stock of first-aid supplies should be on hand.

Basis: The use of heavy earth-moving equipment, the maneuvering of collection trucks and other vehicles, and the infectious, explosive, or flammable items that may be in solid waste can create accident hazards. Since some sites are in remote locations, it is particularly important that personnel be oriented to accident hazards, trained inf first aid, and provided first aid supplies. For reasons of safety, only those authorized to use the site should have access to it.

Employees are given periodic safety training, an adequate first-aid kit and at least one employee trained in first-aid are available at the site at all times. Yes ___ No ___

ITEM 12: Drainage and Grading. The entire site should be graded or provided with drainage facilities to minimize runoff onto the sanitary landfill, to prevent the erosion of earth cover, and to drain rain water from the surface of the sanitary landfill. The final surface of the sanitary landfill should be graded to a slope of at least one percent, but no surface slope should be so steep as to cause erosion of the cover. The surface drainage should be consistent with the surrounding area and should in no way adversely affect proper drainage from adjacent land.

Basis: Runoff from lands adjacent to the site, unless diverted, and rain falling on the surface of the site may percolate into the sanitary landfill and contaminate either ground or surface waters. Cover material may also be removed by erosion, and standing water may permit mosquitos to breed or interfere with access, unloading, compacting, or placement of cover. To have the sanitary landfill recognized as an acceptable solid waste disposal method, it is important that the complete sanitary landfill blend with its surroundings and not impair adjacent land usage.

The sanitary landfill is properly graded and drained. Yes ___ No ___

ITEM 13: Plan Development and Execution. A sanitary landfill should be planned and designed by a qualified individual. Planned use of the site following construction should be an integral part of the planning, design, and construction. A daily log should be maintained by the supervisor to record such operational information as type and quanitty of solid waste received, type and volume of cover material used, the portion of the site used, and deviations made from the plans and specifications. A copy of the original plans and specifications, a copy of the daily log, and a plan of the completed sanitary landfill should be filed with the local governmental agency responsible for maintaining titles to land.

Basis: Completed sanitary landfill sites are ultimately utilized for a variety of purposes. When the ultimate use of the site is known beforehand, the operation can be planned so that suitable building sites, roads, and utilities can be provided. Final grades can be established and allowances made for landscaping and drainage. A record of the construction of the sanitary landfill is necessary for the most efficient utilization of the completed site and for the prevention of health hazards or nuisances.

Plans, record keeping, and reporting are achieved as delineated above. Yes ___ No ___

Evaluation. The following is a summary of the advantages and disadvantages of the sanitary landfill solid wastes disposal method.

Sanitary Landfill

ADVANTAGES

1. Where land is available, the sanitary landfill is usually the most economical method of acceptable wastes disposal.

2. The initial investment is low compared to that of other disposal methods.

3. A sanitary landfill is complete or final disposal method, compared to incineration and composting where items such as residue and unusable materials require further disposal.

4. A sanitary landfill can be put into operation within a short period of time.

5. A sanitary landfill can receive most types of solid wastes.

6. A sanitary landfill is flexible; increased quantities of solid wastes can be disposed of with little additional personnel and equipment.

7. Submarginal land may be reclaimed for uses such as parking lots, playgrounds, golf courses, and airports.

DISADVANTAGES

1. In highly populated areas, suitable land may not be available within economical hauling distance.

2. People often confuse sanitary landfills with dumps. Location of sanitary landfills in residential areas can result in extreme public opposition.

3. A completed landfill will settle and require periodic maintenance.

4. Special design and construction must be utilized for buildings constructed on completed landfill because of the settlement factor.

5. Without proper planning, methane, an explosive gas, and the other gases produced from the decomposition of the wastes may become a hazard or nuisance factor and interfere with the use of the completed landfill.

6. Potential for ground-water pollution exists if the landfill is not properly planned, designed, and operated.

Sanitary landfill is the most inexpensive disposal method known today. It is especially suitable for rural areas, mountainous areas, or areas which have an air pollution problem. In communities where land is limited or extremely expensive, this method may not be suitable unless a cooperative agreement can be reached with neighboring jurisdictions. A properly operated sanitary landfill produces no objectionable odors, vector problems, or blight, and is especially suited to the reclamation of marginal land. A sanitary landfill is basic to any other solid wastes processing operation since all product some materials which must be sanitary landfilled.

INCINERATION

Incineration is a controlled process for oxidizing solid, liquid or gaseous combustible wastes to carbon dioxide, water and ash. Sulfur- and nitrogen-containing compounds will produce their corresponding oxides and should not be incinerated without considering their effect on air quality. Halogenated hydrocarbons not only affect the air quality but may corrode the incinerator.

While the incinerated material is largely converted to gases and water, some end-products remain to be disposed of. These include particulate matter carried by the gas stream, ashes, metal, glass, combustibles not completely destroyed, and process water.

Where land for land-disposal is unavailable or too remote for economic hauling, incineration has certain advantages. A properly designed and carefully operated incinerator can be located adjacent to a process plant, thereby reducing hauling time and cost considerably. If the incinerator is properly designed, the operation can be adjusted to handle solid wastes of varying quantity and character. The residue is only a small fraction of its original weight and volume and is nuisance-free and suitable for fill material.

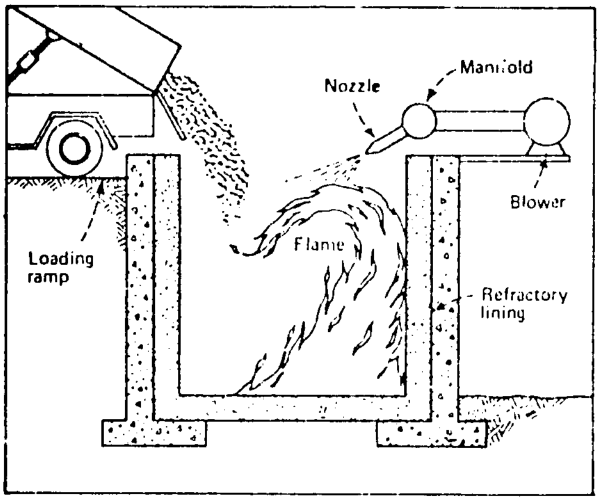
Conventional incinerators are designed for a heat release of 25,000 Btu./cu.ft., but ordinary trash has a lower heating value of 5,000 Btu./lb., while industrial wastes average 15,000 Btu/lb., but may run higher.[30] Rotary kilns and Herreshoff furnaces are the most useful, with open pits being fairly popular. For special wastes such as sludge and tars, vortex furnances and fluidized beds are used.

Open-Pit Incinerators

Open-pit incinerators vary from the pedestal-mounted oil burner used by Union Carbide[3] to the Du Pont pit.[31] These incinerators solve the problem of high heat flux by eliminating the enclosure. The pedestal mounted burner handles highly combustible liquid wastes, while the Du Pont pit is better for solid wastes. Their chief drawback is the high particulate concentration at ground level. This requires careful placement of the pit on the plant property.

The Union Carbide installation at Taft, La., burns 600 gal./hr. of organic liquids containing up to 25% water, without visible smoke. The installation consists of two oil burners firing horizontally and mounted about 5½ ft. above grade. The firing area is surrounded by earthworks for personnel protection. Heat is dissipated by direct convection and radiation. By the very nature of the design, there is always excess air.

The open-pit incinerator was originally developed at Du Pont for the safe destruction of nitrocellulose that presents an explosion hazard in a conventional closed incinerator.[32] The incinerator as shown in Fig. 4 has an open top and an array of closely spaced nozzles that create a rolling action of high-velocity air over the burning zone. Very-high burning rates, long residence times leading to complete combustion, and high flame temperatures are achieved. Visible smoke is readily eliminated and smuts are contained by proper screening. E. S. Monroe, Jr., the inventor, has stated that particulate emissions of less than 0.25 grain/cu.ft. have been achieved for specific industrial wastes. Oversized wastes and plastics that create problems in conventional incinerators are easily destroyed in the open-pit incinerator. It should be noted that the concentration of particulates is slightly higher than conventional incinerators,[33] 0.25 against 0.2 grain/cu.ft., and there is no way to clean the exit gases. Although these pit incinerators are used for liquid wastes, they are more efficient for solid wastes, especially rubber and plastic.



OPEN-PIT incinerators handle high heat flux—Fig. 4

Du Pont has waived proprietary interest in the design, and an undetermined number (probably 100) have been built. A commercial design is marketed by Thermal Research and Engineering Corp.[32] Most of this discussion is based upon their published data.[32]

The incinerator consists of a rigid shell either reinforced-concrete or steel-lined, with refractory on the floor and walls. Empirical and theoretical calculations indicate the optimum width to be 8 ft. between refractory walls. The capacity is determined by length - usually between 8 and 16 ft. The pit is about 10 ft. with cleanout doors located at either end. Normally, a screened enclosure is placed over the pit to contain large airborne particles and for insect and rodent control when burning garbage.

The over-fire air is supplied from a manifold running along one edge of the pit with alternating 2- and 3-in. nozzles directed downward at an angle of 25 to 35 deg. across the incinerator. Charging is from the opposite side of the nozzles from a loading ramp. The pit should be oriented so that the loading ramp is located upwind. The high-velocity air jets create turbulence in the burning zone, and the excess air aids complete combustion. When the equipment is properly operated, the air pattern creates a sheet of flame under the air manifold on the back wall, rolling the flame across the top of the pit. Particulates and unburned gases are largely returned to the burning zone - more or less eliminating the smoke. Smoke intensity rarely exceeds Ringelmann #1 when properly operated.

A variety of wastes have been burned in the pit incinerator. It readily accepts heavy timbers, cable reels and construction wastes. It burns plastics and similar high heat-release materials that might detonate, or erode the refractory in a closed unit. It effectively handles numerous types of manufacturing and process wastes, plant trash, plastics, tires and other rubber wastes. Styrene plastics emit a dense, black smoke and are best handled in a closed incinerator with an afterburner.

Materials that form dangerous products of combustion should be avoided. Wet or dense materials compact in the pit and prevent the penetration of air. Wet bark and sawdust are good examples. Liquid wastes generally present the same problem, although modified versions of the pit have been successfully used to cope with them.

Operating capacity of the pit depends on the lower heating value of the feed, combustion characteristics, quanitty of overfire air, size and configuration of the pit, and method of charging. Not less than 100% excess air is required, and 300% is usual. Du Pont's criteria are: 850 cu.ft./min. of overfire air at 11 in. of water column per foot of length for standard trash (5,000 Btu./lb.).

The incinerators are charged intermittently by dump trucks, although hydraulic rams and skip hoists have been used. The rate of charge depends on the material being burned, in order to meet the heat-release capability of the pit. High-heating-value materials such as plastics are fed in small quantities at frequent intervals. The operator's skill is the major factor in minimizing emissions while maintaining a high burning rate.

Emissions tests are run using a high-volume air sampler both upwind and downwind of the incinerator. A rather high level of particulates will be found within a radius of 200 ft. but beyond this the concentration is well within most air standards.

Direct operating costs are low. Two men can operate two pits. The only other costs are for energy to drive the blower and operate the loader and the cleanout device. No auxiliary fuel is used, as lighting off a small amount of combustible material will ignite the pit. Maintenance is slight and largely consists of repair of the refractory.

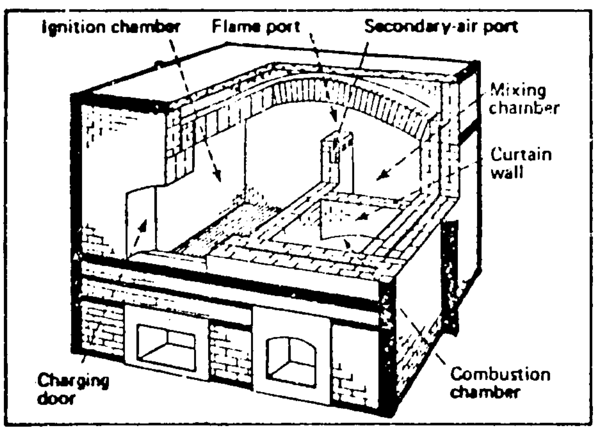
Capital cost is low. An average price for a commercial unit 16 ft. long, 8 ft. wide by 10 ft. deep, completely installed, including a covered storage building for the waste and a screened enclosure for the pit is about $65,000. The capacity is 5,000 lb./hr. of low heat-release material, and about half that for high heat-release material.

Closed Incinerators

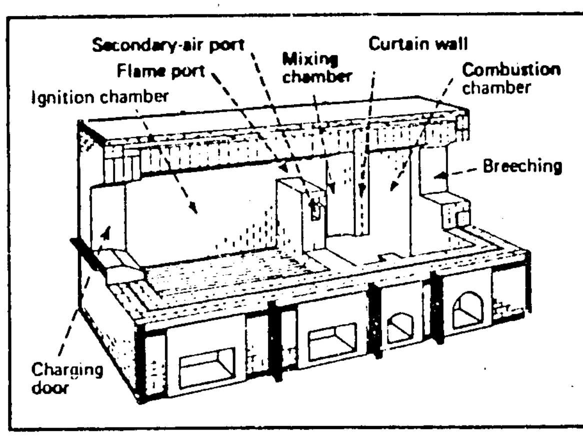
Incinerators commonly used for industrial wastes include the multiple-chamber, rotary-kiln, Herreshoff, and vortex or suspended-bed. The multiple-chamber is used for commercial and industrial solid wastes usually up to 1 ton/hr. This is the basic design of municipal incinerators, and much larger capacities are possible. The rotary-kiln or Volund furnace is extremely versatile for burning solids, liquids, sludges, and drummed wastes. The Herreshoff or multiple-hearth is also versatile and is largely used for sludges and high-heat-release materials. The vortex furnace is useful for burning sludges, tars and oils. There is also the fluidized bed, which finds specialized applications.

Multiple-Chamber Incinerators

There are two fundamental types of multiple-chamber incinerators: (a) the retort type, so-called from the U-shaped, or return, flow of the combustion gases as shown in Fig. 5; and (b) the inline type, named for the straight-through flow of combustion gases, as shown in Fig. 6. The Federal "Interim Guide"[34] compares these types.



RETORT type multiple-chamber incinerator—Fig. 5



INLINE type multiple-chamber incinerator—Fig. 6

The retort type of design is distinguished by the following features:

1. Arrangement of the chambers causes the combustion gases to flow through 90-deg. turns in both horizontal and vertical directions.

2. Return flow of the gases permits the use of a common wall between the primary and both secondary chambers.

3. Mixing chambers, flame ports, and curtain-wall ports have length-to-width ratios in the range of 1:1 to 2.4:1.

4. Bridge-wall thickness under the flame port is a function of dimensional requirements in the mixing and combustion

chambers. The resulting bridge-wall construction is unwieldy in incinerators in the range of about 500 lb./hr.

Distinguishing features of the inline design are:

1. Flow of the combustion gases is straight-through the incinerator with 90-deg. turns in only the vertical direction.

2. Inline arrangement of the component chambers gives a rectangular plan to the incinerator. This style is readily adaptable to installations that require separated spacing of the chambers for operating, maintenance, or other reasons.

3. All ports and chambers extend across the full width of the incinerator and are as wide as the ignition chamber. Lenghth-to-width ratios of the flame-port, mixing-chamber and curtain-wall to port-flow cross sections range from 2:1 to 5:1.

A retort incinerator of optimum size offers the advantages of compactness and structural economy due to its cubic shape and reduction in exterior wall length. The retort incinerator performs more efficiently than its inline counterpat in the capacity range of 50 to about 750 lb./hr. The inline incinerator is well suited to high-capacity operation but is not too satisfactory for service in small sizes. The secondary-stage combustion of the smaller inline incinerators is less efficient than that of retort types. The inline incinerator functions best when the unit has a capacity of over 1,000 lb./hr.

Inline and retort incinerators, in the capacity range between 750 and 1,000 lb./hr., are equally efficient. The choice is dictated by personal preference, space limits, nature of the refuse, or charging conditions.

Factors that tend to cause a difference in the performance of the two types are: (1) proportioning of the flame port and mixing chamber, in order to maintain adequate gas velocities within the dimensional limitations imposed by the particular type; (2) maintenance of proper flame distribution over the flame port and across the mixing chamber; and (3) flame travel through the mixing chamber into the combustion chamber.

The additional turbulence and mixing, promoted by the turns in the retort incinerators, allow the nearly square sections of the ports and chambers in small units to function adequately. In the retort sizes, above 1,000 lb./hr., reduced effective turbulence in the mixing chamber that is caused by the increased size of the flow cross-section results in inadequate flame penetration, effluent distribution and secondary-air mixing.

Certain weaknesses of the small inline type are eliminated as the size of the unit is increased. For intance, with an inline incinerator of less than 750-lb./hr. capacity, the shortness of grate length in the ignition chamber tends to inhibit flame propagation across the width of the chamber. This, coupled with thin flame distribution over the bridge wall, may result in smoke (from a smoldering fuel-bed) passing straight through the incinerator and out of the stack without adequate mixing and secondary combustion. Inline models in sizes of 750 lb./hr. or larger have grates long enough to maintain burning across their width to provide flame distribution in the flame port and mixing chamber

Since smaller inline incinerators have relatively short grates, a problem of construction is added. Usually, the bridge wall is not provided with any structural support or backing; and because secondary-air passages are built into it, the wall is very susceptible to mechanical failure. Careless stoking and grate cleaning in short-chambered inline incinerators can ruin the bridge wall in a short time.

Incinerators under 2,000 lb./hr. may be standardized for construction purposes to a great degree. However, incinerators of larger capacity are not readily standardized because problems of construction, material usage, mechanized operation with stoking grates, induced-draft systems, and other factors make each installation a custom design.

The relative costs in 1968 of incinerator and air-pollution-control equipment of various capacities, exclusive of foundations, are given in Table II. These incinerators can be operated as a part-time assignment for one or two men. The price of power and fuel affects operating costs. Gulf Coast costs have been given as $15 to $16/ton.[35]

Approximate Costs of Multiple-Chamber Incinerators—Table II

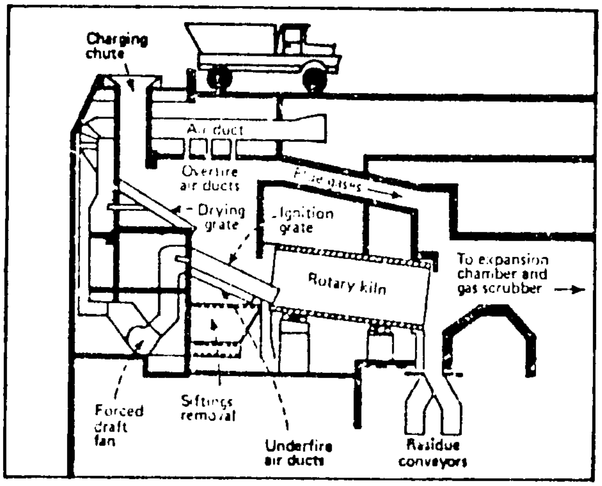
Capacity Lb./Hr.	Incinerator Cost, $	Wet Scrubber Cost, $
100	1,700	3,000
150	2,000	3,600
250	2,700	4,400
500	5,000	6,200
750	9,500	7,600
1,000	12,500	8,800
1,500	20,000	11,200
2,000	25,000	13,200

Source is Ref. 34. Cost data are for 1968.

Rotary Kiln

The rotary kiln as used by Dow Chemical Co., has previously been described by Novak.[36] This unit is a 65-million-Btu./hr. kiln that disposes low-ash liquid residues and solid chemical wastes such as plastic trimmings, strands, powders, Styrofoam, paper, wood, and other solids with varying heat values. A pack-feed mechanism is used to feed packs and drums filled with waste chemicals into the incinerator.

The rotary kiln as used in municipal installations is shown in Fig. 7.[37] A similar installation in Atlanta is connected to a



ROTARY kiln incinerates municipal refuse—Fig. 7

waste-heat boiler and generates steam. Refractory maintenance is a high-cost item, with the refractory being replaced about once a year. Cost data are scarce but Atlanta has an installed cost of about $10,000 per daily-ton of feed capacity.

Multiple-Hearth Furances

The Herreshoff furnace is the standard multiple hearth used in metallurgical operations and for burning sulfur for acid production, and consists of vertically stacked hearths raked by rabble arms rotated from a common shaft. Waste is discharged from the bottom hearth. This incinerator is almost as versatile as the rotary kiln and is commonly used to incinerate sewage and other sludges as well as regenerate activated carbon. This is one of the few types of incinerators for which detailed operating costs are available. Table III shows installed and operating costs less labor, amortization and overhead. These furnaces can be operated by one man, so actual costs may be estimated.

Vortex Furnace

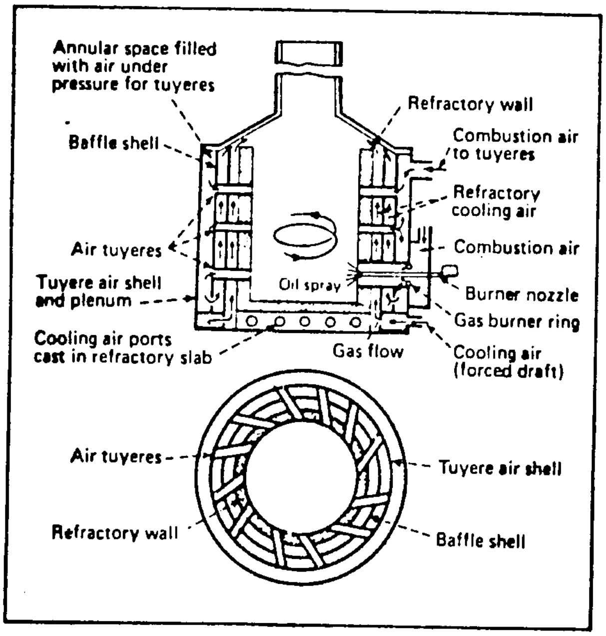
Use of the vortex furnace for chemical wastes has been described by Coleman and Cheek.[38] According to Smith,[39] the unit has proved reliable over a period of time. While this furnace primarily burns oily materials, similar furnaces have been used

Costs of Multiple-Hearth Incinerators—Table III

Population	10,000	20,000	50,000	100,000	1,000,000
Sludge incinerated,* (ton/wk., wet basis)	**28**	**56**	**139**	**278**	**2,780**
Sludge incinerated, (ton/wk., dry basis)	7	14	35	70	695
Operating schedule, hr./wk.	35	35	70	70	168
Furnace feed, lb./hr.	1,600	3,200	3,960	7,920	33,000
Furnace required, O.D.	10 ft. 9 in.	14 ft. 3 in.	14 ft. 3 in.	18 ft. 9 in.	22 ft. 3 in. (Two)
Hearths	5	5	6	6	8
Installed cost, $	120,000	185,000	200,000	310,000	750,000
Fuel cost, $/wk	27.50	45	30	45	50
Power cost, $/wk	9.00	12	13	25	165
Total utility cost, $/wk	36.50	57	43	70	215
Operating cost, $/ton dry solids	5.20	4.06	1.24	1.01	0.31
Filtration cost, $/ton dry solids	8.00	8.00	8.00	8.00	8.00
Maintenance cost, $/ton dry solids	0.70	0.60	0.60	0.50	0.40
Total disposal cost, $/ton dry solids	**13.90**	**12.66**	**9.84**	**9.51**	**8.71**

* Dry solids removed in process = 0.18 lb./(day)(capita); cake moisture = 75%, volatile content = 65%; heating value = 10,000 Btu./lb.
Source: Bartlett-Snow (Div. of Bangor Punta operations). Cost data as of 1967.

for burning municipal waste and for calcining lime and phosphate rock.



VORTEX furnace primarily handles oily wastes—Fig. 8

As shown in Fig. 8, the cylindrical furnace is tangentially fired with a modified oil burner. In operation, the furnace is preheated for 1 hr. to a temperature of 800 to 1,000 F. Operating temperature is 1,200 to 1,600 F., with 20% excess air. Waste oils, fuel gas and primary air pass through a hot ignition tunnel. Tangential firing creates a vortex of hot gas and primary air that flow upward through the hot combus tion chamber. As the gases rise, preheated high-velocity secondary is introduced from tangential tuyeres, maintaining the vortex.

The heat release in this unit is unusually high, about 100,000 Btu./(hr.) (cu.ft.). This has resulted in slagging of the refractory. As may be expected, some refractory is wasted by erosion.

There are few installations of vortex furnaces, and cost is not readily available. Because of the high maintenance, operating costs will be high. But the high heat-release lowers capital cost.

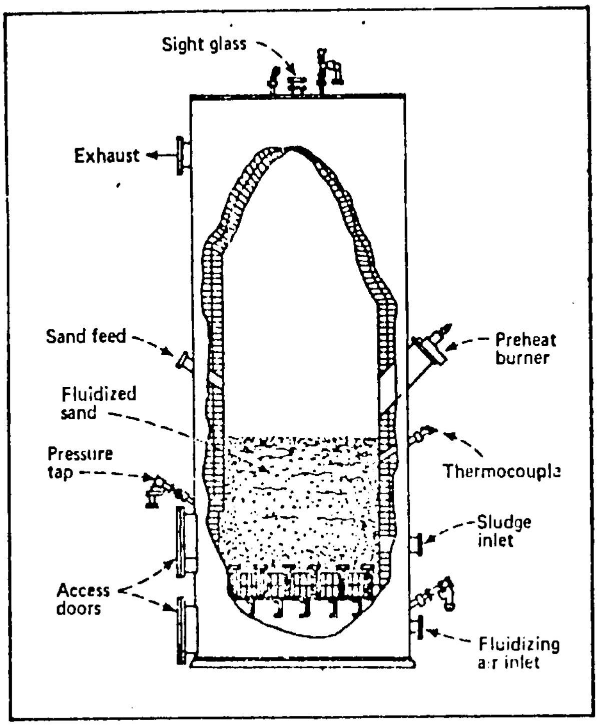
Fluidized Beds

The fluidized bed is very popular in Europe and is used for sewage sludge[40] in this country. Aside from an oil refinery in Mandan, N.D.,[40] some sulfite paper-mills, and facilities for processing nuclear wastes,[41] fluidized beds are not common in industry other than for recovering lime sludges.[42] The advantages and drawbacks have been well outlined by Bailie.[42]

Sand is commonly used as the heat-transfer agent, with consequent disadvantages. The fluidized bed has certain constraints that limit its range of operation. Because the bed is made up of sand particles, the temperature cannot exceed 2,000 F. so as not to approach the softening point of the bed. The gas flowrate at operating conditions cannot exceed the terminal velocity of the sand nor can it be less than the minimum fluidization velocity. These velocities, as well as heat transfer to the cooling surface, depend upon the particle size and the elutriation rate of combustible solids from the bed.

Also, it is necessary to reduce the combustible material in size before it can be fed to the fluidized bed. The bed can accept quite a large range of particle sizes in the feed. The rather violent agitation of the bed helps to suspend large particles that would ordinarily find their way to the bottom, and retains them long enough to allow them to burn.

Violent agitation of the bed particles gives rise to several desirable characteristics. The particles act as a large heat reservoir (16,000 Btu./cu.ft. at 1,400 F.) and their movement throughout the bed keeps it at constant temperature. No hot zone will develop.



FLUIDIZED BED gives rapid combustion--Fig. 9

The conductive-convective heat-transfer coefficient between the bed particles and foreign material placed in the bed is an order of magnitude higher than that between the gas and the foreign material. The foreign material receives radiation from the bed, which completely surrounds the material. When a combustible particle is added, transfer of energy is rapid, and the particle quickly reaches its ignition temperature. Combustion begins, and its heat is rapidly transferred to the bed.

Because of the violent motion of both the gas and the solid, contact between the burning particle and the oxygen in the gas is excellent. Excess air as low as 5% has been used in the burning of coal in a fluidized bed. The reduction in the excess air required for complete combustion reduces the size and the cost of gas-handling and cleanup equipment srequired to meet air-pollution standards.

Distillation products are consumed in the fluidized bed before they leave, which reduces the amount of unburned hydrocarbons in the exit gases. This results in cleaner stack emissions, and savings in scrubbing equipment. Because of the strict requiremets against atmospheric pollution that may be anticipated in the future, these reductions on scrubbing equipment can result in considerable savings.

In comparing combustion in conventional furnaces and fluidized-bed furnaces, we find that the fluidized-bed furnace operating at a constant temperature of 1,400 F. will have about

90% of the available energy released in the bed, and 50 to 80% of this could be removed to generate steam by placing heat-transfer surfaces in the bed. The maximum temperature developed in a conventional furnace far exceeds that generated in the fluidized-bed furnace. The relatively low-temperature operation of the fluidized bed is less demanding on the materials of construction.

The fluidized bed has a high volumetric heat-generation rate of 100,000 to 200,000 Btu./(hr.) (cu.ft.), leading to compact size. The bed is of simple construction. These factors mean a realtively low capital investment for this furnace.

The removal of heat from the bed may be an economic necessity. Besides the generation of steam, it reduces the amount of gas-handling equipment because excess air is not needed to keep the bed cooled to reasonable temperatures. It also reduces the temperature of exhaust gases, making materials of construction less restrictive and resulting in higher volumetric heat-generation rates.

Because of the widely varying composition of the fuel fed t the incinerator, it is doubtful whether the plant could operate effectively without an auxiliary fuel supply to maintain stable bed-temperatures. Waste low-grade coal, not acceptable for most combustion processes, can be mixed with the solid feed to increase the heating value; fule oil can be sprayed into the bed to maintain constant-temperature control; the preheat burners may be used to maintain temperature in case of interruption of the amount or quality of the waste. The rate of power generation is controlled by the bed temperature and the air flow-rate that causes the motion of the inert particles in the bed. The fuel used has a relatively minor effect as long as it can burn at a sufficient rate to maintain the bed temperature. Switching from gas to liquid to solid fuel gives the facility great flexibility.

The general design is shown in Fig. 9. Capital costs range slightly higher than a Herreshoff, $60 to $120/(lb.) (hr.) of feed, but overall operating costs are lower when firing sludges.

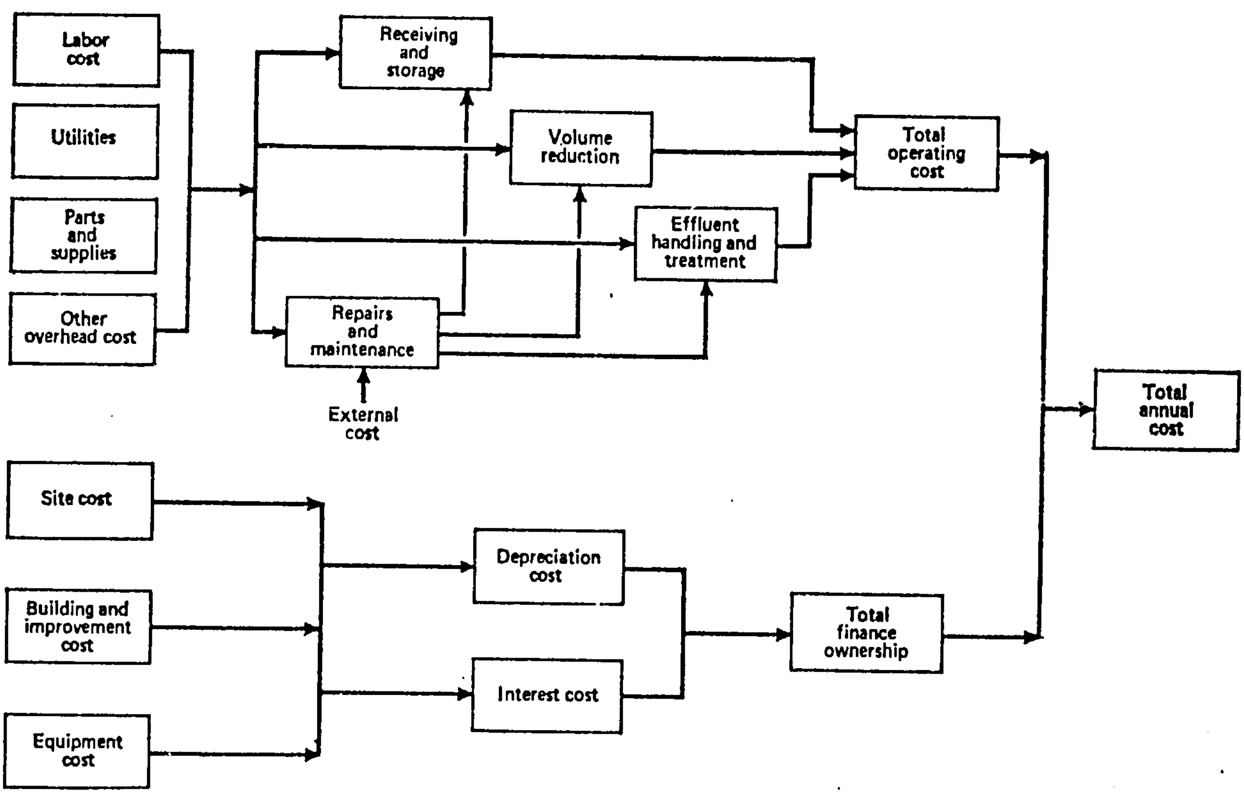
Afterburners on Incinerator Stacks

Afterburners are used on the stack of incinerators when burning particularly smoky materials such as rubber or polystyrene, or to eliminate noxious odors. These incinerators most commonly strip insulation from cable to recover the metal. Fig. 10 shows a multiple-chamber incinerator that burns rubber rings from oil-well packers. Frequently, the afterburner is used to upgrade inadequate incinerators when the particulates are combustible.

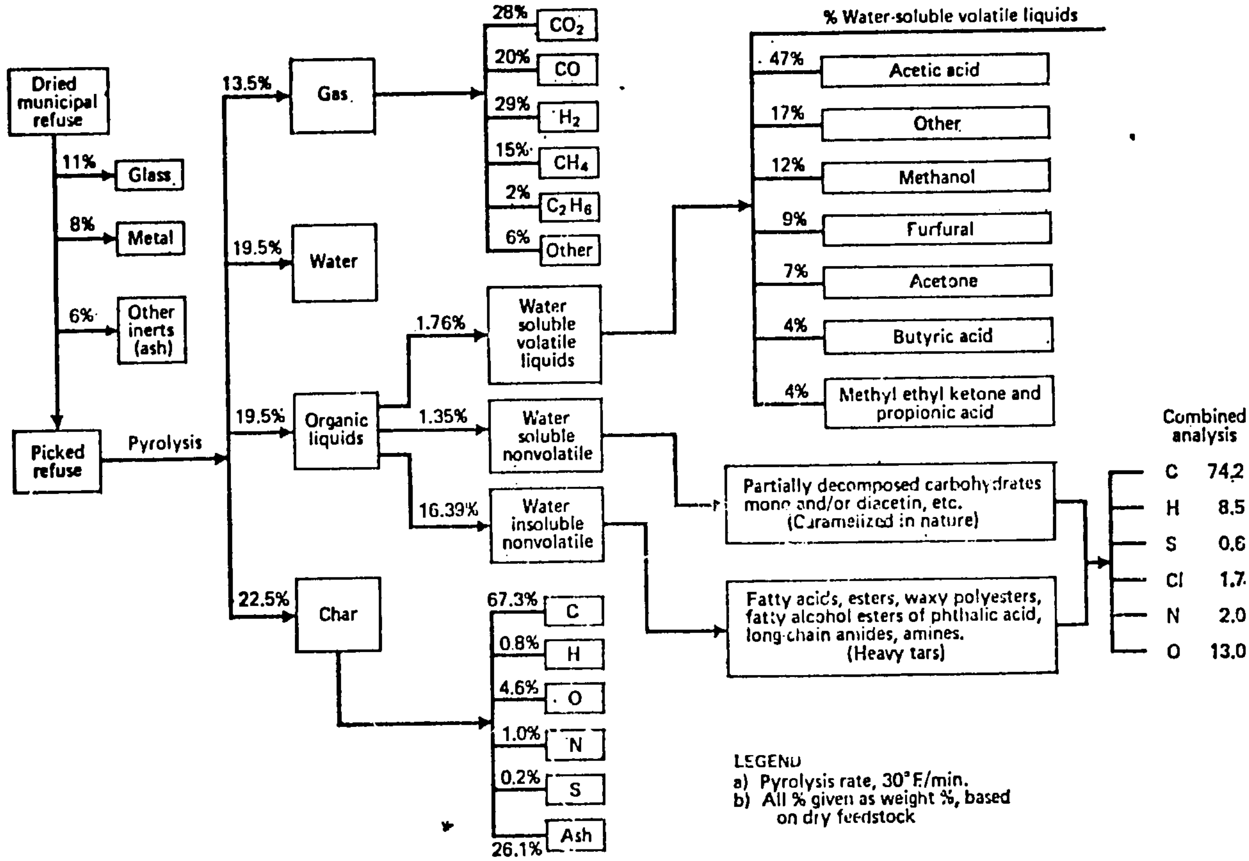
The afterburner is simply an additional combustion chamber inserted in the stack. The residence time for combustion of carbonaceous particulates depends upon particle size, excess air and temperature.[43] Afterburners that provide a residence time of

INCINERATOR, burning rubber cff oilwell packers, shows effect of afterburner on stack gases—Fig. 10

0.3 sec. with 9.2% oxygen will burn out all particles under 7 microns at 2,000 F.



ALLOCATION of costs for the incineration of solid wastes—Fig. 11



PYROLYSIS of municipal wastes yields products ranging from gases to solids—Fig. 12

Operating Costs

Published operating costs vary from as low as $2/ton to several hundred dollars per ton. Actual costs vary significantly with utilization rate, estimated life and interest rate. For industrial use, the best comparison would be cost per pound per hour of feed. This minimizes the effect of utilization rate, although the preheating requirement makes one-shift operation unduly expensive. Because of the relatively small throughput, the average cost of disposal in the CPI exceeds $30/ton when costs are properly allocated. Fig. 11 is adapted from the Bureau of Solid Waste Management and shows allocation of incineration costs.

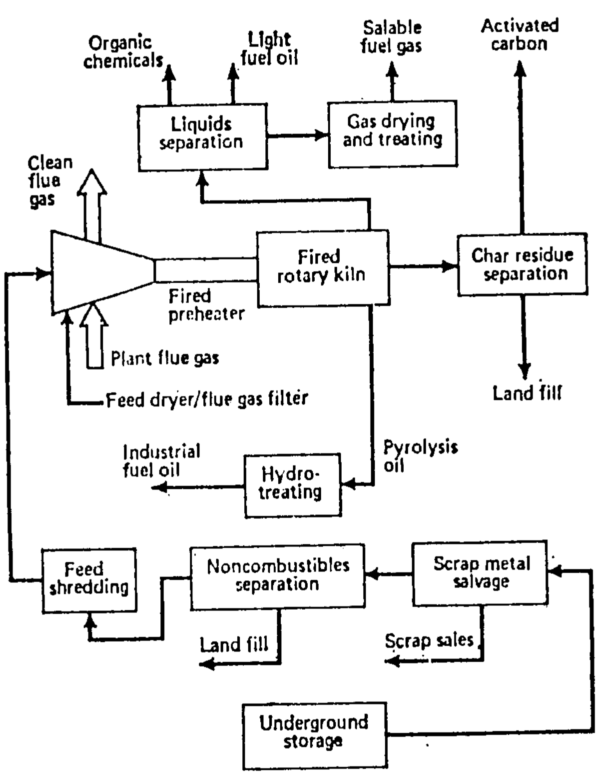
Steam Generation Provides Savings

In an effort to cut such costs, steam is sometimes generated. Because heat recovery and water cooling of incinerators reduces the voluem of gas to be treated for pollution control, substantial savings are possible in equipment costs. The increasingly stringent pollution-control regulations increase the economic feasibility of steam generation.

While the generation of steam from municipal waste is farily common in Europe, it is less so here. The most successful unit in the U.S. is at the Norfolk Navy Yard; it burns 180 tons/day of ships' rubbish, trash from maintenance operations, and garbage. According to Parisius[45] of the U.S. Navy Facilities Command, this unit has operated for four years with only minimum problems. Designed by Metcalf & Eddy, it was built by Foster Wheeler, with the grates supplied by Detroit Stoker. About 50,000 lb./hr. of steam is generated at 275 psig., or roughly 1 lb. of refuse produces 1.8 lb. of steam. Although corrosion has been slight, there have been problems with deposits. Various materials of construction are being studied by Battelle Memorial Institute by means of probes in this unit.[46]

Wood wastes and bagasse are commonly used to generate steam.[47] The Merichem Co. operates a packaged boiler that incinerates tars by means of a supersonic burner.

The generation of steam in industrial plants may be accomplished when using virtually any type of incinerator. As the price of fule and air-pollution control equipment rises, steam generation to offset incinerator costs will increase.



SOLID WASTES pass through many stages—Fig. 13

Pyrolysis of Wastes

Only recently has it been realized that pyrolysis has advantages over incineration for carbonaceous wastes. The reaction takes place in a closed system, minimizing air-pollution problems. At larger throughputs capital cost is lower and the system provides its own fuel. Additionally, there is a potential of recovering chemicals or synthesis gas for manufacture of methane or higher hydrocarbons.

The Ford Motor Co. at San Jose, Calif., tested a Lantz converter to pyrolyze 40 to 50 tons/day of industrial waste.[48]

The Lantz converter is a sealed, airtight retort cylinder with an insulated shell. The gas-fired retort, about 20 ft. long, revolves slowly on a slight incline like a rotary kiln. Waste is injected through a star valve. The retort operates at about 1,200 F., and the wastes are pyrolyzed, in the absence of oxygen, to steam, volatile material, carbon dioxide and charcoal. Steam, carbon dioxide and carbon monoxide are trapped and vented. The volatile gases include hydrogen, methane, ethylene and propylene. A 100-

ton/day plant is claimed to produce enough gas to generate 400,000 kw./day of electricity. Some 30 to 35% of the iput becomes charcoal.

Operating Costs of 5,000-Ton/Day Pyrolysis Plant—Table IV

Fixed Costs	$ Million	
Labor	0.49	
Supervision	0.15	
Overhead	0.64	
Maintenance, onsite	1.00	
Maintenance, offsite	0.24	
Taxes and insurance	0.49	
Total fixed costs	3.01	$1.65/ton
Variable Costs		
Water and power	0.20	
Fuel	0.70	
Total variable costs	0.90	$0.49/ton
Total operating costs	3.91	$2.14/ton

Source: Ref. 49.

Total Investment for 5,000-Ton/Day Pyrolysis Plant—Table V

Investment	$ Million
Inside battery limits	16.0
Offsites	6.4
Total	22.4
Additional Costs	
Contingency (25%)	5.6
Construction interest, first year (8% x 33%)	0.7
Construction interest, second year (8% x 67%)	1.5
Startup extraordinary (assumed 8% x 100%)	2.4
Total additional costs	10.2
Total investment (includes working capital)	32.6

Source: Ref. 49.

An exhaustive economic analysis of a commercial-size refuse pyrolysis plant was made by Cities Service Oil Co.[49] While this study was for municipal refuse at large tonnages, the economic statements are consistent with practices in the CPI and may be extrapolated for rough estimates of pyrolysis and incineration units. Fig. 12 is a schematic and Fig. 13 a flowsheet of the pyrolysis process. It closely resembles the Lantz and Landgard processes. Table IV gives the total operating cost as $2.14/ton (comparable to $8/ton in a municipal incinerator of similar size. Table V is the total investment, including working capital. While theoretically the products have sales value, practically they should be considered as fuel. The mixture is difficult to separate. Industrial wastes may result in a different product mix.

The main thrust of research in the pyrolysis of industrial waste has been with discarded rubber tires and other polymers. The Bureau of Mines and Firestone[50] have done extensive work on the destructive distillation of scrap rubber. Some recovery of the monomers is possible but the yield resembles that obtained by Cities Service. Conoco has reportedly made carbon black by pyrolyzing scrapped tires.

Beyond economic attractiveness, the pyrolysis char is readily converted to activated carbon. A large, cheap source of activated carbon would make it economically feasible to treat large quantities of polluted water. The spent carbon could then be disposed of as a nonpolluting fuel.

Since acetone and methyl alcohol were originally made by the destructive distillation of wood, it is odd that the vast amounts of papermill wastes have not been considered for pyrolysis. The wood bark and fibers could be slurried with a high-sulfur residual fuel oil to a fuel coker, to produce a low-sulfur coke.

General Summary

INCINERATION

Incineration is a combustion process by which materials are reduced primarily to carbon dioxide, other gases, and ash. By this method, the volume of solid wastes is reduced, conserving the life of the necessary companion sanitary landfill. Incinerators must be designed and operated to meet stringent air pollution controls. An incinerator is normally rated on the number of tons it has the capacity to burn in a 24-hour period or in tons per hour.

<u>The Plant and the Process</u>. The basic parts of an incinerator plant are the building, scales, storage pit, bucket and crane, charging hopper, furnace (which includes grates, primary and secondary combustion zones, and gas cleaning chamber), residue conveyor, air pollution controls, stack, and quench water controls (see Figure D).

Most solid wastes collection is carried out five or six days a week during daylight hours. It is usually more economical to operate an incinerator on a 24-hour basis or at least until all wastes are burned each day. To permit even operation of the incinerator during the remaining hours of the plant operating day, a solid wastes storage area or pit must be provided at the incinerator plant. Thus, solid wastes can be fed into the charging hopper as needed and vehicles can be emptied conveniently.

For good design, storage of at least 30 hours' capacity should be provided, based on the rated full capacity of the plant. Ideally, the plant should be operated so that the pit is completely emptied daily, and not less than once weekly for safe operation. Plant operating shifts and hours of furnace operation should be planned around this schedule. If the pit is not emptied weekly, material on the bottom will begin to decompose, which produces odors and increases the danger of pit fires by spontaneous combustion.

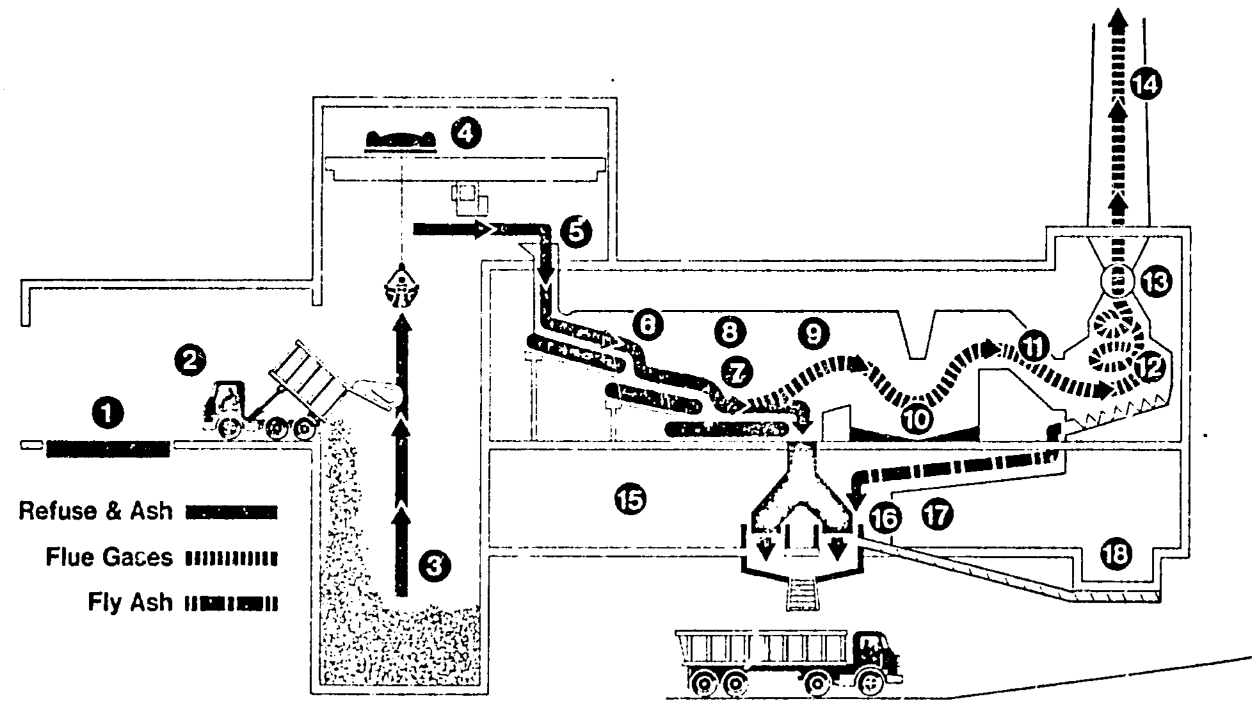
Because the percentage of garbage in refuse has decreased markedly in recent years, the need for auxiliary fuel to fire an incinerator is minimal or unnecessary.

THE IMPORTANCE OF TEMPERATURE

The rate of combustion is directly related to the composition of the solid wastes, the burning surface, and the amount of oxygen supplied both over and under the fire. The temperature of combustion will vary considerably because of the wide range of heat values inherent in the mixture of wastes to be incinerated. To burn the materials thoroughly, furnace temperatures must be maintained between 1500° and 1800° F. Equipment is essential to record temperatures and measure oxygen supplies. When furnace temperature is too high (over 1800°) deposits (called clinker and slag) adhere to grates and refractories (furnace walls and ceiling linings). These deposits can cause serious damage by jamming grates and causing the refractory to wear, melt, and cave in. Periodic maintenance is essential to remove these deposits. (For detailed information of refractory types, see APWA Municipal Refuse Disposal, listed in bibliography.)

FIGURE D:

basic incinerator design



1. Scales
2. Tipping Floor
3. Storage Bin (Pit)
4. Bridge Crane
5. Charging Hopper
6. Drying Grates
7. Burning Grates
8. Primary Combustion Chamber
9. Secondary Combustion Chamber
10. Spray Chamber
11. Breeching
12. Cyclone Dust Collector
13. Induced Draft Fan
14. Stack
15. Garage - Storage
16. Ash Conveyors
17. Forced Draft Fan
18. Fly Ash Settling Chamber

After combustion, gases and particulate matter pass into an air pollution control device (such as a baffle, wet scrubber, cyclone collection, or electrostatic precipitator) designed to remove them. Any remaining gas, steam, or particulate matter is drawn by induced draft fans or natural ventilation up the refractory-lined stack and into the atmosphere.

After combustion, residue and ash remaining in the primary combustion zone reach the end of the grates, then fall into a water bath to be quenched and cooled. Quench waters contain many dissolved organics and solids, and require treatment prior to reuse or discharge. If not recirculated, waters should be treated and discharged into a sanitary sewer. Residue is then taken to a sanitary landfill.

Consultant Services. An incinerator plant is an extremely complex piece of equipment. Since most local government engineering staff members do not have the specialized knowledge to plan and design an incinerator plant, a consulting engineer is usually retained.

The design should be prepared by one engineering consultant so that all the component parts will be coordinated. The design consultant should be retained from the initial drawing of the plans to the completion of the plant. This means that the consultant should be responsible for seeing that the plant can be and is operated for a continuous period of six months or more at design capacity by plant personnel trained by equipment manufacturers. (For a detailed discussion of using consultants, see Guide Number 9, Personnel.)

Evaluation. An incinerator plant design should be simple, functional, economical, and attractive. This includes the equipment not usually housed within the main building, such as settling and cooling ponds for recirculating water. The plant should operate well at full design capacity with as little maintenance and repair as possible. It should be nuisance free, and it must have a sanitary landfill.

A NACORF survey of cities and counties using incineration uncovered some unacceptable shortcuts which had been "sold" to officials. Many of these shortcuts were part of "package-deal" incinerators offered as turnkey operations. This reinforces the need for public officials to secure competent engineering advice in choosing the incineration system.

Incineration is an effective volume reduction method where land appropriate for sanitary landfill is limited, and money and water are abundant. Incineration can handle about 80 per cent of typical urban solid wastes and reduce weight at least 70 per cent if the plant is operated properly. The remaining residue, along with non-incinerable materials, must be sanitary landfilled. With this system, much less land is needed to sanitary landfill wastes.

The cost of incineration is high. Construction cost (including elaborate air pollution control devices) runs about $7,000 to $12,500 per ton capacity of the plant. Operating costs run about $5 to $9 per ton plus amortization. These high costs are spread among maintenance, power, personnel, and administration. Incineration equipment must be replaced at least every 15 to 20 years.

Skilled operators and continued maintenance are essential. It is foolish to invest a million or more dollars in a plant and then fail to staff it with trained people at adequate salary.

INCINERATION - ADVANTAGES

1. Land requirements for the plant are small.
2. Operation is not dependent upon weather conditions.
3. It can be put in urban industrial areas, reducing haul distance.
4. It provides volume reduction.
5. It reduces landfill requirement for solid wastes disposal.
6. It produces a stable, odor-free residue.

INCINERATION - DISADVANTAGES

1. The plant is expensive to construct and operate.
2. Improper operation or inadequate equipment produces air and land pollution.
3. Highly skilled personnel are essential.
4. Continuing maintenance is a necessity.
5. Disposal of residue must be provided.

COMPOSTING

While composting is not the universal answer to solid waste management, it does have a place despite the possibility that this place will not become well established in the United States for many more years. There are a variety of uses for compost, but in general its primary use is to supply humus to the soil; and, as yet, humus cannot be artificially produced.

The German farmer has recognized the need to maintain the marginal organic content of his soil by operating a generalized agricultural system that resulted in materials moving from the soil to crops to animals and back to the soil. The efficiency of the system was such that there was a need to supplement the organic content of the soil by a source outside the system. Thus it was found that compost could produce results that were comparable to the results obtained by commercial fertilizers applied to mineral-deficient soils. The comparable results created some confusion as to the role of compost in the soil, but studies have now shown that compost is beneficial to the soil as a source of humus and not of minerals. There is some indication that the reformation now occurring in German agriculture may result in an increasing demand for a ready source of humus as the farms become more mechanized and livestock production becomes a specialized industry.

In the United States the vast land areas available per capita have resulted in single-use or low-level utilization of the land resources. As a result, the soils are considered young anf fertile although suffering from poor management in many areas. If the future of the United States is close to what is predicted, the day will possibly come when a greatly decreased land area per capita will require the preservation of our lands for intensive agricultural production by transforming municipal wastes into compost or humus for the soil.

EQUIPMENT

Storage Pit. Since composting plants receive only the domestic and some small part of the commercial refuse from a community, we can understand that these plants generally have a small intake of material, ranging fro 40 to 200 tons per day. Thus, the storage bunkers (pits) are designed to receive and hold approximately four collection-vehicle loads of refuse. The storage capacity is adequate to maintain plant operations, but when an operational breakdown occurs, an immediate and readily convenient alternate disposal system has to be available. Most of the bunkers are of a trapezoidic design with the two side walls sloping to a conveyor belt along the bunker bottom. The sloping walls help move the refuse onto the conveyor belt but create a problem by allowing the material to bridge-over the conveyor belt. It can be a very difficult job to break this bridge. The best solution to the problem in existing installations has been to construct a vertical falsewall along one side producing one straight and one sloped side. On new installations, a wider conveyor bottom would be recommended (conveyors 6 feet wide or more); however, none of the European installations visited had such wide conveyor bottoms. The Joint U.S. Public Health Service-Tennessee Valley Authority composting plant at Johnson City, Tennessee, uses a wide conveyor, which may be an effective solution to the problem. Most of the installations on the Continent had dust control equipment for the bunker area, but it was either not used, broken, or considered ineffective in operation. In plants where the storage bunker was too small, refuse would be discharged on the ramp and pushed in by a tractor as the bunker was emptied. General design called for a steel conveyor belt at the bottom of the bunker to feed a rubber conveyor belt that moved the refuse to the next processing stage.

Refuse Preparation. As the refuse moved from the storage bunker to the first processing step, some salvage and sorting operations were performed. Most of the plants were doing away with picking or sorting because of increasing labor costs and the small income from salvage. In general, the picking operation was inefficient and greater benefits could have been obtained by better education of the collection crews and the residents. Pickers removed rocks, tires, large pieces of iron, bottles, large sheets of plastic, and other materials considered undesirable for composting. No paper salvage was performed, and in general, the emphasis seemed to be on plastic removal rather than glass. Salvaged wine bottles are still a source of income, but the thrifty European, the increasing use of plastics, and the one-way bottle make bottle salvaging a neglibible source of plant income. The nonsalvageable materials removed were placed in large portable containers for transport to the landfill or incinerator.

An over-band magnet, a drum-head magnet, or both, were standard equipment in all compost plants visited. The drum-head magnet is simply an electromagnetic roller at the end of the conveyor belt. The magnetic field places the ferrous material in a different trajectory than the other materials leaving the belt. The over-band magnet is an electromagnet directly over the conveyor belt. An endless belt positioned between the refuse and the magnet sweeps the material out of the magnetic field into a storage container. For greater efficiency two or more magnets might be located at different stations in the process. The iron removed was baled for storage and sale. German scrap iron suffers the same low price as U.S. scrap and was sold for whatever price it would bring, or else given away in exchange for the removal.

Processing: Grinders. Following intake, the refuse could be processed by grinding, rasping, or the Dano drum, depending on the composting system being used. If grinding is used, commercial grinders are supplied by the Buhler Company (double- or single-rotor grinders), the Hazamag Company (double-rotor grinder), or the Gondard Company. Gondard grinders are coming into greater use. The Gondard grinder was discussed previously, but it is worth repeating that the ballistic separation action by this mill actually provides a mechanical sorting or removal of much of the noncompostable material. The Hazamag grinder uses a high-speed double rotor with swinging arms made of flat steel. The Buhler single-rotor grinder uses flat steel arms equipped with a pivoting sledge-hammer-type head at the end. In either grinder, after some wear, the grinding surface can be reversed for additonal use. The double-rotor Hazamag and the single-rotor Buhler mill are used for primary grinding; the double-rotor Buhler is generally used for secondary grinding.

As is standard practice for as much European equipment as possible, the grinders are powered by electric motors. It is noted that both grinders were considerably overpowered, but the Buhler mill seemed to be equipped with more excess power than the Hazamag. The excess power is required for starting and for overcoming slugs of material, or materials difficult to grind. Hazamag seemed to be relying on the inertia and grinding action of the double rotor to overcome the hard spots. In addition, the Hazamag mill was more heavily constructed than the Buhler. In the double-rotor Buhler mill used for secondary grinding, the two rotors turn at different speeds, and it was reported that the hammers of the faster rotor had about one-third the life of the slower rotor hammers.

All the grinders are very noisy in operation. None of the mills could grind nylon, especially nylon stockings. The stockings would sometimes accumulate on the rotor until they had to be slashed or burned away with a torch.

Processing: Rasp. Developed by the Vuilafvoer Maatschappij (VAM) firm, the rasp is marketed by the Dorr-Oliver Company. It is a vertical cylinder with a diameter of 15 feet and a total height of 7 feet, containing both a grinding floor and a discharge floor. The grinding floor is formed from wedge-shapd sections with alternate sections being constructed with round holes (from about 0.5-inch to 1.5-inch diameters) or with 0.5-inch steel pins projecting from the section. The pins also extend part way up the wall all around the inside. There are eight heavy hinged arms that can rotate at various speeds up to 25 rpm. The arms move the material over the floor that serves to alternately screen and rasp the material. The arms can lift up over ungrindable material until such time as a trap door can be opened and the rejects swept out the door by the arms. The material passing through the grinding floor falls on the discharge floor and is moved out a discharge opening by a rotating arm attached to the center spindle. Compared to a grinder, the rasp is physically larger, requires about one-fourth the power, is somewhat quieter in operatonn, requires less maintenance, and has a higher first cost. The grinding and rasp system of composting appears to be quite competitive in the open market.

Processing: Dano Drum. The Dano drum, usually 9 to 12 feet in diameter and 60 feet or more in length, is rotated at a speed of about 1 rpm during the working day and at about ¼ to ½ rpm at night. The raw refuse is usually given magnetic separation before being discharged into the drum, where a slight inclination of the drum requires about 2 to 5 days for the material to pass through the drum, detention time being a direct function of the speed of rotation. The drum is operated half full, and the slow rotation provides aeration and the self-grinding action that is effective in the reduction of the raw refuse. When the material reaches the end of the drum, a short section of 1.5-inch-diameter screen is used to remove large pieces of reject material. The rejects are periodically discharged from the drum via a trap door in the screen. A characteristic of the drum compost is the presence of small balls of paper. There is some thought that the small, moist, porous ball provides a better microbiological environment than the material produced by a rasp or grinder. Compared to a grinder, the drum has the same advantages as the rasp.

A satisfactory aeration system has not yet been designed for the drum, and, as a result, many operations have been known to have serious odor problems. A recent solution developed for the odor problem has been the use of underground tile fields. The hot, odorous gases are drawn from the drum and forced into a perforated tile distribution network covered by about a meter of soil or compost. The cover material does an excellent job of removing the odors, and the technique is reported to enjoy wide success. When compost is used for the filtering cover material, the hot rising gases create a very nice hotbed, and the compost meisters enjoy performing small-scale growing experiments to demonstrate what their product can do.

CURING

A common method for providing compost curing is the compost windrow. With the practice so widespread, it is noteworthy that no efficient and effective equipment for windrow turning is yet on the market. Windrow turning is accomplished by the use of an end-loader and some type of elevating conveyor that piles the material in the triangle-shaped windrow. The height of the windrows is a function of the amount of compost produced and the storage area available.

At the June 1967 INTAPUC Conference, a model and diagram of a windrow turning machine was on display. The machine looked like a self-propelled stern wheel from a river boat. The wheel was supported by rails on concrete walls on each side of the windrow. As the wheel moved against the windrow, the paddle or cups elevated the compost to an overhead position where it then fell onto a conveyor constructed in the center of the wheel. The conveyor moved the material to the new windrow position. The machine is simple enough and appeared to have the capacity that would be required, but would have the disadvantages of an inability to shred the compost and to clean all of the windrow from the ground. Only one machine of this kind is reported to have been built and it is operating in the Bahama Islands.

No single test has been developed for establishing the frequency of windrow turning. The frequency is usually established by the following variables: the windrow temperature as measured by a thermometer placed in the windrow, windrow or compost odor, and moisture content as evaluated by the compost meister's nose, sense of touch, and experience. Until effective and reliable test procedures are developed, composting, like brewing, will remain an art dependent on the compost meister to determine how much moisture to add to the raw refuse or compost windrow, the turning frequency for the windrow, and when the compost is ready for sale. This reliance on the compost meister has developed a fraternity of these men, and they circulate from plant to plant as the opportunities develop. A good meister seems to be someone with the ability to work with people, who doesn't mind being in the "garbage business," and is willing to serve time as an apprentice.

PREPARATION FOR SALE

At most composting operations visited, when the compost is judged to be finished, it will be screened once before loading. In some operations a final grinding will precede the screening in order to provide an evenly blended and uniform texture of material. Since glass is one of the most objectionalbe materials in compost, much effort is directed toward its removal. In general the machines used are one of three types. Ballistic separation is one of the most common principles used for glass and other hard particle removal. The first type, known as the ballistic separator, is the largest machine. Compost falling into one end of the machine strikes a high-speed horizontal rotor. The rotor paddles are often short railroad tracks. The paddles or impellers strike the compost and propel it in a horizontal or slightly upward trajectory. Hard, dense, and resilient particles will obtain a high speed and long trajectory, while the soft, light and inelastic particles travel only a short distance. The trajectory paths are confined in a horizontal enclosure, the length and partitioning of which can be adjusted according to the need. The second machine, the secator, is probably the most common device used, mainly because it is cheap and mechanically reliable. Compost falling from the end of a conveyor strikes a shield or bounce plate that directs the material vertically downward onto a revolving drum. The strike plate may direct the material onto the top center of the drum or slightly off center in the direction opposite that of the drum rotation. The heavy and resilient particles will bounce off the drum into a collection bin, while the light and inelastic materials are carried on the drum under the strike plate and into the storage area. The speed of the drum and the position of the strike plate are set in accordance with operating experience. A third machine type used is the inclined plate conveyor. Compost falls onto a steel plate conveyor that moves at an angle upward against the falling compost. Heavy and resilient particles bounce down and off the conveyor while the lighter material is carried upward. This method seems to be the least satisfactory of the three.

Another system observed was a vibrating conveyor belt. The heavier particles and glass would settle downward through the material to the belt. Near the end of the belt a scraper was set and could be moved up or down to remove the upper material from the belt, thus literally scraping the compost from the glass and other materials.

In general, any of these systems alone would be considered satisfactory. For improved quality the compost would sometimes be exposed to two or more of the preceding systems, or the same system twice. This, of course, introduced additional expense. The problem with this equipment is that greater glass removal results in considerable loss of compost and an operational balance between a maximum amount of glass removed and a minimum amount of compost rejection must be attempted.

Screening or sieving of compost is universal at composting plants in order to provide a gradation of the final product. There is, of course, a direct relationship between the amount of screening of the compost and the final cost. Most of the screens were the vibrating type, with a few plants using small drum-type screens. The screening operation was one point in the system where the operator could have a direct influence on the amount of compost produced. The screen openings could be changed to produce compost in accordance with the greatest sales demands. In the situation where there was no market demand and large stockpiles of material were unwanted, the screen size was sometimes drastically reduced; this greatly increased the reject material and cost per ton of compost produced, although to the untrained eye the plant operation appeared normal.

An experimental sieve for glass removal is being tested. The sieve is an adaptation of a coal sieve that operates on the counter-flow principle. The compost enters the top and falls onto a fine mesh, inclined, vibrating screen. Air, blown at high velocities upward through the screen, suspends the compost a short distance above the screen while at the same time moving the material up the slope of the screen, and eventually out of the machine. The heavier particles remain on the screen and are moved downward and off. Initial tests indicate that the machine works satisfactorily except that some amounts of the heavier compost are removed with the rejects. This may be solved with some modification of the machine or additional processing equipment.

The use of a cross-flow air current for large particle removal was also observed. The air current was directed across the compost falling from a conveyor. The installation did seem effective in removing wine corks, bottle caps, some plastic, and bits and pieces of other material, but the effectiveness is directly related to the preceding operations.

PRODUCTION COSTS

The most frequent questions asked at a composting plant always seem to be how much does it cost to produce the compost, and what is the income from the sales? At most plants these data seem readily available, and the computation (expenses less income) to arrive at the unnecessary operational subsidy seems easy. It usually is not. To attempt to relate economic data from one operation or plant to the same type of plant in a different area, or to a different type of plant, presents an even greater problem. The confusion is compounded when the different economies of two countries enter the picture. Among the many factors that create confusion in economic comparisons are types of refuse received, economics of the area surrounding the plant, plant age, plant mechanization, labor costs, salvage operations, remoteness of plant, and marketability of the compost. The reporting of operational cost data may be confused by the inclusion or exclusion of such things as capital costs, income from salvage, ancillary equipment utilized in the process, taxation or organizational support funds, and so on. Most of the plant operators recognize this problem but for various reasons have no desire to correct the situation. Most operators, however, work toward the goal of keeping the operational subsidy at the minimum level.

It was observed that most of the compost plants were located adjacent to the sewage treatment plants. The sewage sludge was recognized as useful in the composting process, and composting was considered a good method for sludge disposal. The cost accounting system usually included the expense of the equipment needed to transport and incorporate the sludge with the refuse but seldom recognized, by means of charges to the sewage treatment plant or something similar, the benefits of using composting for sludge disposal. The economy of composting could present a different dpicture if the expense for an alternate means of sewage sludge disposal were recognized. It might be assumed, in general, that is it is necessary to compare economic data for composting operations, an acceptable method of standardized accounting must be developed and utilized.

In most of the operations the "expenses" exceeded the "income," but the necessary subsidy was justified as a reasonable expense for the solution of the solid waste problem. When questioned why composting was the system used, some operators sooner or later admitted that a high-powered salesman had influenced the judgment of the local political body. This is not an uncommon problem. The surprising element was that even though the system didn't prove profitable, as long as the plant subsidy was kept low, the operation was considered acceptable. In most cases composting was justified on the basis that incineration capital costs were too great, that there was a lack of room for tipping, or that the watershed laws forbade the deposition of any type of raw refuse on the ground. The law, however, was unclear on the difference between "raw" and "treated" refuse. Some serious questions might be raised about a law that forbids depositing "raw" refuse but fails to establish standards for acceptable residues that are deposited on the ground. There are no standards or quality control regulations established for compost produced unless the compost is mistakenly marketed as fertilizer. There are definite quality control standards for fertilizer production.

COMPOST SALES

Present technology is such that there is no problem connected with producing compost; the problem is what to do after the compost is produced. One of the most effective organizations for the utilization of compost is Vuilafvoer Maatschappij (VAM) of Amsterdam, Holland. One of the largest stockholders in the company is the Dutch government. The company has three major sections: technique, agriculture research, and sales; the operation of one section directly affects the other sections.

The history of VAM illustrates the evolution that has taken place in composting. VAM's first plant was built at Wijster in 1932 when there was a large demand for coarse, low-quality compost to use in land reclamation. At that time about 80 percent of the plant's production went to the land reclamation companies. By 1940, 90 percent of the plant's compost went to farms and only 10 percent to the reclamation companies. This drastic change resulted from the fact that during World War II commercial fertilizers were almost impossible to obtain, and it was necessary to utilize compost to maintain much-needed crop production. The movement to utilize compost carried through to the middle 1950's, and by then the widespread use of compost had resulted in the recognition of several new uses. Cattle were found to prefer grazing on pasture that had been covered with compost rather than stable manure; mixing compost with farm manure increased the organic content of soil; compost could be used as bedding material for chickens and pigs; it was found that compost was effective in curing anemia in pigs. These new uses, of course, increased the demand for compost. In the 20 years between the middle of the 1930's to the 1950's only 1 composting plant was in operation, but since then a total of 15 additional plants have begun to produce compost.

During the 1950's vegetable growing, flower cultivation under glass, and flower bulb cultivation became a large horticultural industry in Holland. This new industry had interesting effects on compost production. A finer quality product was required and the processing of the compost became more complex and expensive. This requirement and ability to produce a finer quality product opened up a new market, a market for what is known as "refuse heating manure"--freshly ground refuse devoid of any sharp particles. This is in great demand by greenhouses. The essential feature of the material is the large amount of heat produced during the decompositon of the organic matter. It is difficult to try to match the supply-and-demand aspects of the product because of the large seasonal demand and the need for the material to be fresh.

Flower bulb cultivation along the sandy North Sea coast created a big compost market when it was found that the use of handplaced reeds and straw could be replaced by mechanized application of compost. The compost resulted in labor savings and, in addition, had the benefit that it could be left and worked into the soil to become additonal organic matter. The ever-increasing population density and demand for recreation areas and parks have created a market for a peat-compost mixture. The peat compost in a 1:1 mixture is said to make the land ready for cultivation quicker and to give the plantings a faster start.

Finally, the changing economy of Holland is resulting in more leisure hours for the city dwellers: hours spent growing flowers in window boxes or on small plots of land. It is more agreeable to apply the compost to the soil than to use animal manures, as there is no relatioship between the "power" of a material and its odor. Thus, while most compost is sold in bulk, there is an increasing demand for small quantities in attractively packaged bags. It is interesting to note that while the compost neister curses plastic as one of the biggest problems in producing quality compost, the sales people find it the most attractive way to market the product.

From the standpoint of total sales, horticultural and recreational uses rank at top, while general agriculture is near the bottom. As a result of the above, the sales demands are met by compost of one of the following classes: (1) horticulture quality; (2) super-quality; (3) peat compost; and (4) town refuse heating manure.

The VAM was established to develop and maintain a market for compost. The government is a strong partner in this organization because it recognized that the proper sale of compost provides a solution to municipal manure (refuse and sewage sludge) disposal problems, as well as maintaining the basic fertility of its limited agricultural land. From its long experience, the VAM company sets forth the following points as being necessary for continued compost sales: (1) a good outlet in the neighborhood of compost producing plants; (2) absence of competitive products such as farm manure, heating manure, etc., unless they have long supply distance; (3) cooperation by a large and well-stocked government information center; (4) the production of exclusvie quality products that can be guaranteed completely; (5) favorable trading results with the buyers and no government restrictions; (6) very dry years when drops have had bad yields or dies early because of lack or organic matter; (7) the importance of marketing a product with a trademark.

In conclusion, VAM does not hesitate to state that the production of compost is not a money-making proposition. The government is, of course, providing support for the organization, but the amount of the support is undefinable. The important fact is that the compost is sold. Several other countries are faced with problems similar to those in Holland, and some have the federal government involved; yet none has a sales group comparable to VAM and none enjoys the success in compost utilization that Holland does.

SPECIAL SYSTEMS

A composting system can be considered to have two parts; one part is for the preparation of the material and the other is for providing the required biological environment. Most of the present composting systems can be placed in one of four categories: (1) composting in fermentation cells with prior crushing of the refuse, followed by windrow curing; (2) composting in fermentation cells, followed by windrow curing; (3) composting in windrows without prior preparation, followed by compost product preparation; (4) composting in windrows with prior treatment of refuse without subsequent treatment of compost.

The following is a discussion of several special composting operations observed. While the systems presented are unique and generally the only operations of the kind in the world, the system components still fit the above categories.

Van Maanen System. The operation, first established in 1932, could be nicknamed the "open-dump composter." The majority of the refuse received is railhauled from Den Haag, Holland, about 175 kilometers to the composting plant at Wijster, Holland. The rail cares simply discharge the refuse onto the ground from rail spurs built on viaducts. Immediately after discharge, water sprinkling systems are operated to moisten the refuse. The operations are scheduled to provide up to 7 months' storage in the windrow if possible. After the desired curing time, the compost is transferred via gantry crances and an endless train of mining cars to the processing building. The material brought to the building is first subjected to a thorough screening by successively coarser screens. The fine material first removed by the screen and given a magnetic separation is nearly free of glass and other undesirable items and makes the best quality compost produced. The material removed by the coarse screens is treated by magnetic separation, then either by a roller crusher or a hammermill. This lower grade compost can then be further refined by ballistic separation and stockpiled for sale. Rejects are used to raise the level of the property adjacent to the windrow area.

The operation is well isolated from nearby farms. As would be expected there are vector and odor problems and a potential groundwater pollution problem connected with the operation. The Dutch government uses the 60-acre site as an experimental laboratory for evaluating vector control programs. Odors are a problem and efforts to use chemical masking agents have not been successful. An underdrain system designed to collect the leachate has been destroyed by corrosion, and some work is now being done to develop a new collection system and provide some measure of treatment for the water collected. A barge canal near the site was used to transport some of the compost to market, but trucks have now replaced the barges. It was reported that the fish in the canal were used as biological monitors for water pollution problems. This may be true, of course, provided that there are fish in the canal near the plant and that they are still sensitive to pollution. This is undoubtedly the lowest cost composting system in operation, but not necessarily the most desirable.

Baden-Baden System. The system was developed and is used at the city of Baden-Baden, Germany. It might be nicknamed the "modified tip composter." While being somewhat similar to the Van Maanen system, the operation is on a much smaller scale and provides better environmental control. Refuse is discharged from the collection vehicles into a small storage bunker, then lifted by crane to an overhead receiving hopper. The hopper feeds a rotating drum that was formerly used to screen out ashes but now serves as a flow equalizer for a sorting conveyor where magnetic separation and some hand-picking is performed. The refuse passes from the conveyor into a second drum and is mixed with sewage sludge (from sludge drying beds) until a 50- to 60-percent moisture content is developed, and then the material is discharged into a truck or wagon for transport to the windrow area.

The windrows are constructed on two lines of large-diameter, perforated concrete pipe. In former times air was blown into the pipes and out through the windrow, but odors became a very serious problem. The odor problem has been corrected by drawing air into the pipes through the windrow; the air drawn in is used by the air supply in the bulky waste burner on the site. Water is applied to the windrows and they are turned if necessary. Water pollution problems are handled by discharging drainage into storm drains or to the surrounding marshy area. After an appropriate period of curing, the compost is trucked to the plant, ground, and sieved for sale. The primary purpose of the plant is reported to the satisfactory disposal of sewage sludge and not the production of compost. The compost that is not sold is used to raise the level of an adjacent marsh.

Caspari-Meyer Brikollare System. This process could be nicknamed the "cookie-cutter composter." The Brikollare system, while being the latest thing in composting, is also probably one of the more highly mechanized and expensive systems developed. The system actually replaces windrow curing with a "block" or "controlled" environment curing.

Refuse delivered to the plant is processed by magnetic separation and some hand sorting before discharge into a Dorr-Oliver rasp. After the rasp, the material is again processed by magnetic separation and balistic separation. The material is then transferred via conveyor to the "brick" machine. Raw sludge, dewatered by a vacuum filter, is conveyed to a pug mill blending tank where three parts refuse and one part sludge is blended to produce a mixture with about 50 to 60 percent moisture content. After blending, the material is conveyed to a holding or surge tank for the bricking machine. By an elaborate and complex mechanical system, a measured quantity of the material is placed in a mold, vibrated for compaction, extruded from the mold, and stacked on a wooden pallet. The resulting brick, measuring about 15 x 15 x 20 centimeters, has the appearance of dark, raw papier-mache. A half-moon slot parallel to the long axis, runs along the middle of the bottom of the brick. When the pallet if full, a fork lift is used to transport the material to the curing shed. While the bricks are stored for about two weeks in the shed, temperatures of about 60° C are obtained and maintained, and large quantities of mold form. No odors were reported to be produced by the bricks.

The curing process was reported as follows. The group of stacked bricks provides a body of heat that maintains the temperature near the optimum for the desired biological activity. Much of the exterior surface of the brick is open to the atmosphere and aerobic decomposition takes place, while inside the brick, anaerobic activity takes place. As the products or byproducts of the anaerobic activity are transferred outward, they encounter the anaerobic-aerobic interface where they are transformed outward, they encounter the anaerobic-aerobic interface where they are transformed or modified into unobjectional products. As the curing continues, the brick moisture moves outward and air moves inward and the microorganisms maintain the balance.

Experiments at the plant have shown that when the ground-up bricks are used as insulation material around the brick stockpiles, the stored bricks can still obtain air, and the stockpiles can be stored almost indefinitely. The bricks have the advantages of no odor in long-term storage and a reduction in the size of storage area needed. When the bricks are to be sold, they are passed through a hammermill and the compost is then screened to the desired grade. It is necessary to process only as many bricks as may be needed to produce the quantity of compost desired by the buyer. Although this system is expensive and is vulnerable to mechanical breakdowns, it provides excellent environmental control and produces a desirable product.

Humboldt. The Humboldt system is experimental and is now being developed and tested. The refuse is processed by magnetic separation while being conveyed from the storage bunker to a pug mill for shredding and mixing with sewage sludge. The pug mill has been modified to include shearing knives spaced at intervals along the twin rotors. The homogenized and shredded material discharged from the pug mill is placed in a tall, conical drum that looks very much like an elongated concrete mixer. The material moves downward by gravity and is discharged at the bottom by a scraper system. At the center of the drum are pipes used for the injection of air and moisture when necessary. Hopefully, the system will not require windrow curing and has the advantages of a minimum of mechaniczation, reduced power requirements, and a controlled environment. Nylon stockings present a problem in the pug mill because they do not shear and then become wrapped about the rotor and entangle pieces of refuse. The result is a hugh ball of material jams the machine. The process is patented and now operating on a pilot scale. When a full-scale plant might be constructed is unknown, and it is still too early to evaluate the potential application of this system.

RESEARCH

Soil Effects. Studies carried out to date indicate that compost has definite short- and long-term advantages when added to the soil for crop production. The exact mechanisms that create these benefits are unknown, but seem to be tied into the mysteries that still surround the material the material known as humus. Compost has been shown to increase the biological activity in the soil; this has been related to the fact that compost-produced crops experience less plant disease. The compost mineral analysis is well known and reveals that the material is definitely not a fertilizer; yet when applied to the soil, the compost produces a crop response that is very similar to that obtained with commercial fertilizer. Compost has been proven to provide a rapid start for plant growth and seems to be able to sustain the quick-start advantage through to the maturity of the plant. One hypothesis is that the dark color of the compost provides a better retention of radiant heat, and the radiant heat aids the growth process. Current experiments at Braunschweig, Germany, are testing this hypothesis.

Dr. Koepf at the Agricultural University at Stuttgart-Mohringen is undertaking studies on the relationship of nitrogen and the soil. The results of this work will certainly have an influence on compost utilization. Dr. Koepf and his colleagues have just completed work on the background levels of nitrogen present in natural streams, and, in an effort to understand the source of the background levels, Dr. Koepf plans to study the fate of nitrogen applied to the soil. The studies may indicate how much nitrogen goes to the atmosphere, how much nitrogen enters the soil; and of the nitrogen that enters the soil, how much passes through the soil to the water, how much is utilized by plants and micro-organisms, how much is retained by the soil, and what forms of nitrogen can best be utilized by the life systems of the soil.

It was noted that when immature compost was being sold, the compost meister usually advised the buyer not to use the material for at least two weeks. The meister had learned by experience that early application of the compost to soil results in adverse effects on crops because the microorganisms extracted nitrogen from the soil in order to complete their actions on the compost. A test for compost maturity in relation to nitrogen was observed. The test apparatus is also used for determining soil moisture *in situ* and consists of a pair of tongs with a wedge-shaped head that clamps about a special piece of porous paper. The instrument is inserted in the soil for a period of time, removed, and a measurement of the penetration of the moisture from the paper edge is referenced to a correlation curve to determine soil moisture. The same procedure is used in a compost sample with specially treated paper. The moisture content of the compost is measured as above, and then chemical additives are placed on the moist area. Color change determines absence or presence of nitrogen, with color intensity providing indication of the quantity. This test can be correlated with the compost maturity and used for guidance in future operations. Test accuracy was not guaranteed and its mechanism was not completely understood.

A test devised for compost utilization was observed and will be mentioned here even though out of context. Plant seedlings or seeds were placed in samples of compost of various ages. The sample with the youngest age that produced the desired plant response was judged to be the material mature enough for sale. The disadvantages of this test were: the large area needed to grow the seedlings; the necessity to keep repeating the entire process; and the need to wiat for a period of about five days before results were known. Another study indirectly related to compost and soil effects involved earthworms. Two windrows of ground refuse were placed side-by-side, one as control, the other inoculated with earthworms. After two months it was observed that the control pile was anaerobic at the center and decomposing slowly while the inoculated windrow had decomposed rapidly into compost.

<u>Erosion Control</u>. The high population density of Germany requires maximum production from the agricultural land available, and sustained high-level productivity over a long period of time, so that soil losses must be minimized. One of the prominent German crops with a tremendous erosion potential is grapes grown on hillside vineyards. The grapevine growth is such that there is no ground cover, leaving the soil with a maximum exposure to the erosion-producing elements of nature. In the past, the hillsides were terraced for erosion control, but this is not an efficient utilization of the area available, and gradually the terraces have been replaced by the open mountainside. Both the German government and the Wine Growers Association have recognized the potential problem and have put forth money to determine what control techniques can be utilized.

Compost has been found to be a very effective material for erosion control, and the wine growers are probably the largest group using compost in Germany. Dr. Bosse, at the Bad Kreuznach compost plant, is employed by the Wine Growers Association to study the relationship of compost to erosion control and soil improvement in vineyards. About 90 percent of the plant production was being used on vineyards. On the hillsides where hand labor is necessary, the vineyard rows are planted 1.2 meters apart, while on the flatter areas the rows are 3.2 meters apart to allow the use of machinery. Studies have found that while the method of plowing has some influence, the application of 100 cubic meters of compost per hectare every three years is effective in erosion control. Based on the fact that compost has been demonstrated to be an excellent material for erosion control, studies were in progress to determine the optimum amount and frequency of application needed to provide long-term benefits and maximum crop production by soil improvement with compost.

An interesting erosion control study has been made by German scientists. The question arose as to how much soil had been lost by erosion over the years. Hundreds of years ago when the land was first being cultivated, the hillside rocks were quite a nuisance. In clearing the fields the rocks were piled along boundary lines or at whatever distance a man could stagger with a large rock or throw a small one. The results of these efforts can be seen today as long rockpiles along the hill slopes. It was agreed that the earth under these piles should be at approximately the original elevation and, therefore, some of the windrows of stone were moved and precise measurements were made of the differences in elevation of the original and the present ground levels. The results indicate that approximately three inches of soil had been lost in several hundred years.

Pathogen Studies. Detailed studies have recently been completed in Germany on the subject of pathogen survival during the composting process. The principal investigator for these studies was Dr. D. Strauch, a doctor of veterinary medicine at the Justus-Liebig University Institute of Human Health Protection and Animal Health at Giessen, Germany. His primary interest was the epidemiologic study of the role of composting in relation to man, animals, and the soil. His studies, quite thorough, were performed on a variety of compost processes, and with a high degree of probability concluded that as long as proper temperatures, humidity, gas exchange, and detention times were maintained in the process, the end product contained no hazards for man or animals. His study procedures and findings have been published in German[7] and summarized in English.[8]

Dr. Strauch developed several interesting techniques during his studies. In one technique he used a Perlon plastic or cloth mesh bag that he named the "inoculation" bag. Two of these bags usually were used in his studies. Both bags were filled with 100 grams compost or ground refuse, and a hypodermic syringe or gelatin capsule was used to inoculate the bag with a known number of the organisms studied; a sealed ampule containing a known quan-

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[7]Strauch, D. Veterinarhygienische Untersuchungen bei der Verwertung fester und flussiger Seidlungsabfalle. Heft 18. In Schriftenreihe aus dem Gebiete des offentlichen Gesundheitswesens. Bundesministerium fur Gesundheitswesen, Bad Godesburg, 1964.

[8]Banse, H.J., and D. Strauch. The importance of pre-fermentation in composting. Compost Science, 6(3):17-23, Autumn-Winter 1966.

tity of the same organism was placed in the other bag. The two sealed bags were then placed at a desired location in the compost windrow. The ampule provided data as to whether the pathogen destruction was a temperature function alone, while the bag, allowing free exchange of gases, nutrients, and most everything except the test organism, provided data on which microbiological interactions might be operating to destroy the pathogens. The results obtained were considered highly satisfactory. A different technique was required when the composing process included a fermentation cell such as the Dano drum. For this Dr. Strauch developed what he called his "sputniks," hollow, perforated metal spheres that were bolted together. He would place his inoculated bags in these spheres and expose the spheres to the composting process. In the first attempts to use the spheres in the Dano drum, it was found that they very quickly bounced through the drum. In order to closely simulate the movement of the material through the drum, the spheres were wired into place inside the drum and periodically the drum would be entered and the spheres transferred to a new position. Dr. Strauch felt the results obtained were quite reliable. Among the organisms tested by Dr. Strauch were Bacillus anthrax, Salmonella enteritidis, Erysipelothrix rhusiopathise and Psittaservirus.

Other studies have been carried on by other investigators, but the results obtained were generally incomplete and nonconclusive. Research work on other aspects of composting had found that the optimum temperature for biological activity in composting is in the range of 40 to 50°C. With a humidity between 40 to 60 percent even the most resistant sporozoa are killed. It was found that antibiotic substances produced under the above conditions operated to control the pathogenic organisms.

In developing controls for the production of hygienic compost, two points must be kept in mind. The necessity for an optimum environment is pointed out above. The second point relates to how compost improves the soil. It is known that the processes occurring in compost enhance the soil biological activity, that needed plant micro- and macronutrients are produced, and that the compost finally becomes humus. The mysteries of humus are still unsolved. In order to produce the preceding benefits, compost must be placed on the soil as soon as possible. Therefore, as soon as the decomposition of the refuse in an optimum biological environment has satisfied the public health requirements, the process should be terminated in order that beneficial continuing actions can take place in the soil.

Reclamation. German studies are being made currently on the use of compost for the reclamation of marginal land. One scientist, Dr. H. Kick, is said to have done considerable work on the utilization of compost in the reclamation of land; however, it was not possible to contact Dr. Kick. From general discussion it was learned that other authorities believed that compost would be an excellent material to use for such activities. Obstacles to the use of compost would be determining: (1) who should pay for the production of the compost, its transportation, and its application; (2) how would the benefits and costs of the reclaimed land be distributed. It seems evident that there would have to be considerable government support for such operations, and at present, there are many other projects marked with high priorities for what German government funds might be available.

GENERAL REMARKS

At the International Association of Public Cleansing (INTAPUC) conference there was an abundance of composting processes on display. The well-known composting systems were represented as well as several new processes that claimed to be long-awaited answers to problems of composting. It is suggested here that the old and new compostin systems are developing in the wrong direction. The quality of compost needed to meet the market demand should be produced as simply and cheaply as possible. Some of the oldest and simplest installations visited produced a quality of compost equal to the product produced by modern, highly mechanized and very expensive systems. Mechanization is, of course, needed to offset increasing labor costs, but, on the other hand, increased mechanization usually has resulted in greater mechanical unreliability. Increased mechanization is also related to the fact that the principal marketing agents for composting systems are equipment or machinery companies that desire inclusion of as many of their products in one system as possible. If composting is to maintain a place as an acceptable technique in the solid waste utilization cycle, the process must be kept as simple as possible to avoid mechanical unreliability and excessive capital costs. Additionally, the composting operation needs access to an efficient sales department that can develop and promote new or existing products and markets.

Summary: COMPOSTING

The Plant and the Process. Composting is a method of handling and processing solid wastes to produce as the end product a humus-like material which may be used as a soil conditioner. The process requires separation of non-compostable materials which must be disposed of by other means. Technically, composting is biological degradation of organic matter under controlled conditions of aeration, temperature and moisture.

Since the organisms necessary to make compost accompany almost all solid wastes, most materials begin to decompose within a few hours. Garbage degrades quickly; paper, cloth, wood chips, and leather less quickly; most plastics and rubber degrade very slowly if at all.

Composting as generally used in discussions of commercial and municipal processes refers primarily to aerobic decomposition (in the presence of oxygen). However, composting of solid wastes may take place in the absence of oxygen (anaerobically). Odors produced by the aerobic decomposition process are less objectionable. The aerobic process is quicker and achieves higher temperatures, thus guaranteeing a relatively germ-free product, free of live weed seeds and insect larva. The anerobic process is slow, smelly, and does not achieve temperatures high enough to destroy all pathogens. Anaerobic decomposition also produces noxious gas by-products such as hydrogen sulfide.

In most processes, it is difficult to control the oxygen balance throughout the wastes. Thus, it is possible to have aerobic and anaerobic decomposition taking place simultaneously in different parts of the wastes.

One commercial method is by windrow (pile) composting in which the processed wastes are placed in long rows on concrete, asphalt, or the ground. The rows are mechanically turned about once a day for the first week, then twice a week for about a month.

Some elaborate systems mechanically mix, agitate, and aerate the composting material in enclosed units. This speeds the process so that relatively inert material can be produced in as little as five to seven days.

After conversion into a brown humus-like material, further refining may be necessary to remove undesirable particles (such as metals, glass, ceramics, plastics, rubber, and leather), depending on final use.

Evaluation. The promise that the compost will be sold and thereby pay for the cost of the process is seldom realized. There is no automatic market for compost. The rate of plant failure speaks for itself (see Figure E).

Developing a market may not mean selling compost for profit. It may mean finding someone who will take it free in large quantities on a reliable and continuous basis. The local government may be able to use most of it to maintain grass, trees, and shrubs in city and county parks and along highway median strips and shoulders. Some local governments give it to farmers. In

FIGURE E: 1968 STATUS OF U.S. COMPOSTING OPERATIONS

Location	Company	Process	Capacity (Tons per day)	Status
Altoona, Pa.	Altoona FAM, Inc. Fairfield Engr. Co.	Fairfield-Hardy	45	Operating
Boulder, Colo.	Rich Land Co.	Windrow	100	Closed
Elmira, N.Y.	National Organic Corp.	Windrow	100	Construction stopped
Gainesville, Fla.	Gainesville Metropolitan Conversion Corp.	Metro	200	Operating for research purposes
Houston, Texas	Biochemical Sales, Inc.	Snell	300	Closed
Houston, Texas	Metropolitan Waste Conversion Corp.	Metro	360	Operating
Houston, Texas	National Organic Corp.	Windrow	300	Construction delayed
Johnson City, Tenn.	PHS-TVA Cooperative Program	Windrow	50	Operating for research purposes
Largo, Fla.	Peninsular Organics, Inc.	Metro	50	Closed
Mobile, Ala.	City of Mobile	Briquetting	300	Operating (with windrows)
Norman, Okla.	International Disposal Corp.	Naturizer	35	Closed
Phoenix, Ariz.	Arizona Biochemical Company	Dano	300	Closed
Sacramento, Calif.	Dano of America, Inc.	Dano	40	Closed
St. Petersburg, Fla.	International Disposal Corp.	Naturizer	105	Closed
San Fernando, Calif.	International Disposal Corp.	Naturizer	70	Closed
Springfield, Mass.	Springfield Organic Fertilizer Co.	Frazer-Eweson	20	Closed
Williamston, Mich.	City of Williamston	Riker	4	Closed
Wilmington, Ohio	Good Riddance, Inc.	Windrow	20	Closed

Houston, experiments are underway to determine whether compost can be used for animal feed. Failure to find a reliable end use for the product means that government will have to foot the bill to sanitary landfill the compost as well as its residue.

There is a widely held misconception that compost by itself is a fertilizer. Compost is only a conditioner used to make soil more manageable and increase its ability to hold moisture.

Composting finds its greatest application in agricultural communities. Communities should be careful to avoid the usual pitfalls when considering the compost process. Shysters sell bottled enzymes "to stimulate action to make solid wastes compost." Since bacteria are already present, the action starts whether enzymes are added or not. Glass, metals, tin foil, and other solids will not compost and must be removed; foreign material in the compost will greatly affect the ability to find a use for the end product. Since all wastes cannot be composted, something must be done with the other (inorganic wastes). They must either be landfilled, sold as salvage, or given away. Sanitary landfilling this material is the only continuously reliable method since the other systems depend heavily on a fluctuating market demand for the used item, and most inorganics do not incinerate well.

Few compost plants operate economically. A private experimental plant in Houston has had a short-term successful record. This plant might be described as a waste utilization plant. Much of the salvage is reprocessed by sister companies and the port provides economical access to overseas markets. The firm sells plastics to Japan; paper for pulp, cans for copper, and glass for reflective paints and for reuse in glassmaking.

Although recycling usable materials should be a national long-range goal, it is unwise to base an entire solid wastes management system on recycling wastes unless a guaranteed market is developed in advance. The payment for the recycled goods must be at least sufficient to meet the additional costs of extra manpower for sorting materials and extra time for transporting the material to the user, and for sanitary landfilling the remaining solid wastes. Local governments must consider composting as a treatment or process prior to disposal. They must be prepared to pay a reasonable price for this operation.

Composting

ADVANTAGES

1. Compost can be used as a soil conditioner.

2. Composting is a recycling method.

3. Composting is a volume reduction method.

DISADVANTAGES

1. There are presently few outlets for the compost and the salvaged materials.

2. All wastes will not compost.

3. A sanitary landfill is still needed to dispose of those materials which are not salvaged or will not compost.

Checklist for Transfer, Processing and Disposal Operations

- ___ All-weather access and egress roads
- ___ Dust control measures
- ___ Posted regulations
- ___ Employee facilities - washrooms, lunchrooms, lockers
- ___ Scale house and weigh station
- ___ Fenced grounds
- ___ Designated place and container for wastes to be received after hours at the gate
- ___ Landscaping and litter control
- ___ Employee safety program
- ___ Fire fighting equipment available
- ___ No open burning practiced
- ___ Communications
- ___ Adequate screening
- ___ Banning of scavenging
- ___ Efficient recordkeeping

Commercial Composting with Salvage
Metropolitan Waste Conversion Corporation,
Houston, Texas

In operation since November, 1966, Metropolitan Waste Conversion Corporation converts solid wastes into salvageable items and compost products. The Metro Waste operation consists of removing all salvageable and non-compostible materials, grinding what is left and then subjecting it to a digesting process which converts it into organic compost.

The process begins when trucks dump waste materials into a continuous conveyor which moves onto a sorting station where such non-compostible materials as ceramics, rubber, glass, and non-ferrous metals are removed by hand. Ferrous metals are removed by powerful magnets and sold as scrap metal. Approximately 15 per cent of the material, such as corrugated cardboard, rags, and newsprint, is salvaged, bailed, and sold. The remaining material moves to two sets of grinders and is then mixed with thickened sewage sludge and placed in a specially designed digestor for six days. It is then reground and packaged for distribution.

Since the present market for compost is seasonal (spring and fall) large quantitites must be stored at the plant site, usually outdoors. These stock piles have a slightly musty odor that usually cannot be detected more than several hundred feet away. However, some people object, claiming that compost was "garbage" when it entered the plant so it must be "garbage" even after processing. The plant, located in an industrial park and surrounded by residential communities and small businesses, has extended an open invitation to homeowners and businessmen to visit. More than 100 persons have done so. Invariably, they are impressed by its operation and convinced that the plant and process does not constitute a health hazard, as is frequently rumored.

Metro Waste is now working with fertilizer companies to market the product as a blend of organics and chemicals, experimenting with the use of compost instead of wood fibers for hydromulching, and collaborating with a paper company on the use of compost for reforestation programs. To determine proper application amounts and frequency for crops such as cotton, citrus, soybeans, rice, and vegetables, Metro Waste is working with farmers, universities, and county agricultural agents. It also works with a biological laboratory to insure constant quality control and safety of the compost material.

Metro Waste's Houston plant, costing approximately $2 million, has a rated capacity of 360 tons per day. The compost product, after final grinding, sells for about $12 per ton in bulk with no upgrading. The company pays rent on the land and taxes on the building and machinery in Houston, and is treated as any other industry by the city. Original plans for the Houston plant called for a work force of 35 persons including the manager, but Metro Waste found it could conduct an efficient and satisfactory operation with 29 men.

The City of Houston, Texas, has developed a balanced system for wastes disposal by integrating the three acceptable solid wastes processing methods - incineration, composting, and sanitary landfill. The city operates an incinerator and a sanitary landfill. It also contracts with the Metropolitan Waste Conversion Corporation to compost up to 360 tons of solid wastes daily, for which the city pays $3.87 per ton. With these three processing methods, the city has alternatives available in the event that one of the disposal sites must be temporarily closed down.

Dumping

What Constitutes a Dump? The Bureau of Solid Waste Management uses the word "dump" to describe any site where solid wastes are left uncovered for a period of more than a day. Although it is a hazardous and unsatisfactory operation, it is the most widely used practice. A dump also is an accumulation of wastes from one or more sources at a central disposal site under little or no management.

Dump operation seems inexpensive; few operators are needed and maintenance costs are low. Actually, the hidden costs of a dump are rodent and insect infestation, poor community relations, excessive demand on health and fire deparmtne time, stench, air and water pollution, and land value depreciation.

Cleaning Up an Old Dump. An old dump can be transformed into a sanitary landfill by adopting sanitary landfill operating standards. Before bringing additional solid wastes to the disposal site to be sanitary landfilled, several steps must be taken:

1. Thoroughly extinguish all fires.

2. Exterminate all rats and other vectors. (If this is not done, these vectors and vermin will invade the surrounding community. Residents will believe the new sanitary landfill is the cause.)

3. Compact all solid wastes, and if practical consolidate them into limited areas.

4. Cover the dump with compacted earth.

Kenilworth disposal site in Washington, D.C., once the nation's most notcrious open burning dump, ceased burning operations Febraury 15, 1968. After extinguishing all firest, exterminating all fectors, and compacting the wastes, the tons of accumulated charred wastes were covered. By April, a sanitary landfill was in full opreration.

Progress and Problems in Cleaning Up Dumps
City of Beaufort and Beaufort County,
South Carolina

"Beaufort has made more progress in taking care of its solid wastes than any other county in the state. It is now correctly disposing of about 50 percent of it, which puts it a giant step ahead of most counties." This assessment of the situation in Beaufort County, South Carolina, was made by a representative of the Environmental Sanitation Division of the State Board of Health, which has surveyed the status of solid wastes management in all of South Carolina's 46 counties.

The transition from open dumps and burning began in 1956, largely through the efforts of the county health department's chief sanitarian, who was aided by the state health department.

Survey results and recommendations were presented to the city council, which liked the idea of ending open dumping and burning and instead operating a disposal site which could eventually be used for park and recreation purposes. Other economies of the proposal were particularly attractive. It was estimated that $10,000 per year might be saved by eliminating the 8-mile haul to the local dump, and instead landfilling the wastes on property within the city limits. An ordinace regulating the handling and collection of "garbage" and "waste matter" was adopted.

Members of the county Board of Directors (governing board) proved equally receptive to proposals for cleaning up Beaufort County. The board's public service committee prepared guidelines on "Recommended Standards for Sanitary Landfills." Program direction was assigned to the county supervisor of roads and bridges, who gave his full support to use of county equipment and personnel for the maintenance of disposal sites.

The county now maintains three sites, with long-range plans calling for 11 strategically located sites. A crawler tractor with front-end loader, run by a full-time operator, is transported between the sites to compact wastes in trenches and apply daily cover.

The local terrain is dotted with natural pits and depressions; owners are often anxious to have the land improved. Such land is usually leased to the county for $1 per year to be filled. During the first seven years, two pits were reclaimed through city-county cooperation and are presently being used for ballfields and other recreational activities.

Beaufort County faces special industrial waste problems: pesticide container and wastes disposal; liquid wastes from fertilizer plants; toxic wastes from soybean processing; culls, peels, and seeds from canneries and truck farms; and wastes from local fisheries. Beaufort is currently trying new techniques to improve disposal of these by-products.

Though solid wastes problems in Beaufort County have by no means been solved, the county finds itself well ahead of most communities its size across the country (population in excess of 45,000). Local officials are actively seeking guidelines and are receptive to suggestions which might provide solutions to their problems. Although limited by inadequate funds and staffing, they are attempting to implement a satisfactory, workable program.

Feeding Garbage to Hogs

Feeding hogs uncooked gabage is prohibited by every state and by federal law. Yet some communities continue to feed hogs raw garbage. A 1967 U.S. Senate Committee on Agriculture Report on the Federal Meat Inspection Act cites a World Health Organization report stating that in the United States one in six persons has trichinosis - this is the highest rate in the world.

To insure necessary and adequate protection of people and hogs, pathogenic organisms must be destroyed. This requires that food wastes be cooked at 212°F for 30 minutes, which is difficult to enforce.

Although it may be convenient for the hog farmer to have a garbage route to get swill for swine, allowing farmers to have their own garbage routes requires the separation of garbage and refuse (which is inconvenient for the homeowner), and in the long run endangers health. As of July 1, 1968, Wisconsin completely outlawed feeding any type of public or commercial garbage to swine. Since most places fail to prepare garbage properly, other states and local governments must enact this prohibition.

General Summary of Foregoing Topics

Every solid wastes management system must be designed to meet the particular needs of the community to be served.

To design a collection system, it is necessary to examine the types of storage containers and collection equipment, route and crew organization arrangements, manpower availability, topographical conditions, degree of homeowner participation feasible, and types and amounts of solid wastes generated.

To design a disposa ystem, environmental conditions (air, water, and land), cost considerations, and public attitudes must be evaluated to select the method or combination of methods most appropriate. Although the community will need to rely on sanitary landfill for final disposal of solid wastes, incineration and/or composting may be additional processing steps used.

Methods of processing or disposal which cause pollution, such as dumps, open burning, flue-fed burners and conical burners, are not satisfactory and should not be part of a solid wastes management system. The conditions under which hogs may be fed commercial garbage legally and safely are widely disregarded and difficult to enforce; therefore, local government should not consider feeding hogs garbage to be part of the local solid wastes management system.

Good solid wastes management requires that collection, processing, and disposal be coordinated. In a large solid wastes management system, coordinating collection and disposal operations through the use of transfer stations may bring economies and increased efficiency. Coordination is also essential between public and private operation.

Another area where coordination is necessary is that between local government and the citizen. The citizen must know what is expected of him to make the solid wastes management system effective. In addition, there is a relationship among the amount of citizen participation required, the degree of service provided, and the cost of the service. For example, set-out/set-back collection is more expensive than curb service because the collection crew must do more work. With curb service, the citizen must participate by carrying his solid wastes container to the curb and back on collection days. Another illustration of this relationship is the difference in cost between having local government provide pickup service as opposed to having the citizen bring bulky items directly to the disposal site.

In the operation of a comprehensive solid wastes management system, the management of industrial and agricultural wastes and hard-to-handle items such as abandoned automobiles should not take a back seat to the collection and disposal of residential and commercial solid wastes. In addition, all services should be performed to meet the highest standards of environmental sanitation and personnel safety. Good solid wastes management is an asset to a modern community. The development of solid wastes technology is rapidly expanding just as the types and amounts of solid wastes bring produced are changing and increasing. Therefore, the solid wastes management system local government selects today must be flexible enough to adopt tomorrow's technology to meet tomorrow's needs.

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MARINE DISPOSAL

The major objective of this investigation was to inventory major classes of wastes being barged to sea. These findings were summarized in topical discussions of a description of the various major types of waste, a summary of the principal offshore disposal sites; a discussion of disposal methods, amounts, and costs.

DESCRIPTION OF WASTES

Wastes currently being transported aboard barges and ships for disposal at sea from the U. S. coastal cities surveyed have been summarized into seven major categories and ranked according to total volume: (1) dredge spoil, (2) industrial wastes, (3) sewage sludge, (4) refuse, (5) radioactive wastes, (6) construction and demolition debris, (7) military explosives and chemical wastes, and (8) miscellaneous.

For detailed information regarding the characteristics and problems associated with the disposal of these wastes, the reader should consult the following references: American Petroleum Institute, Revelle and Co-Workers, Tarzwell, Moss, U. S. Department of Agriculture, U. S. Coast Guard, Kurak, Sax, California State Department of Public Health, Burd, and Sittig, National Academy of Sciences, and American Burd, and Sittig, National Academy of Sciences, and American Chemical Society.[1-13]

Dredge Spoil

Dredge spoil consists of sediments containing various concentrations of alluvial sand, silt, clay, and municipal or industrial waste sludges dredged to improve and maintain navigation channels. It is these sludges which put the Corps of Engineers into the municipal and industrial waste disposal business giving the Corps a responsibility neither within its charter nor desired by that agency. Most of the dredging operations are conducted by the Corps with seagoing hopper dredges. These spoils are normally disposed of in open coastal waters generally not more than three to four miles from the dredging site.

Industrial Wastes

Industrial wastes originate from a variety of manufacturing and processing operations including petroleum refining, steel and paper production, pigment processing, insecticide-herbicide-fungicide manufacturing, chemical manufacturing, oil-well drilling operations, and metal finishing, cleaning, and plating processes, as well as many others. A brief description of several types of industrial wastes currently being disposed of at sea follows.

<u>Refinery Wastes</u>. Wastes from petroleum refining operations are produced during the chemical refining processing used to

extract various products from the crude oil. These include spent caustic solutions, sulfuric acid sludges, dilute process water solutions, spent catalysts, petrochemical wastes, and chemical cleaning wastes. In many cases solid wastes, such as spent clay, catalysts, and sludges are slurried with liquid chemical wastes for disposal at sea.[1-3] The spent caustics and acid sludges also contain varying amounts of contaminants including: sulfides, sulfates, phenolates, napthenates, sulfonates, cyanides, heavy metals, mercaptides, chlorinated or brominated hydrocarbons and other organic and inorganic compounds.

Spent Acids. Large quantities of spent sulfuric acid and ferrous sulfate are produced by steel mills. The acid, or "pickle liquor," is usually withdrawn from the operation and disposed of when one-half or two-thirds of the acid is converted to ferrous sulfate. Typical wastes contain up to 7 percent free acid and up to 30 percent ferrous sulfate. In recent years some steel mills have converted a portion of their pickling operations to hydrochloric acid which has resulted in reduced volumes containing spent hydrochloric and sulfuric acids.

Another major waste results from titanium pigment manufacturing in which the ore, with iron as a principle impurity, is digested with sulfuric acid. The wastes include the liquor with 7 to 9 percent free sulfuric acid and 8 to 10 percent ferrous sulfate and a mud slurry with 15 to 20 percent inert solids.

Pulp and Paper Mill Wastes. Pulp and paper mill wastes include the organic constituents of wood being pulped, dissolved salts from the digestion process, undigested pulp, and fibers that escaped processing. Depending on the process, the wastes may contain a sulfate cooking solution (calcium, magnesium or ammonia), "black liquor" (sodium hydroxide, sulfide, sulfate) and organic constituents including lignin, hexose and pentose sugars.

Chemical Wastes. Chemical manufacturing, chemical laboratories, metal cleaning finishing and electroplating processes, and a variety of other industrial operations all produce a host of complex waste chemicals. These include murcuris or arsenical compounds, organic acids, pesticide chlorinated hydrocarbons, alkalaes, anilines, cyanides, and other highly toxic substances. Chemical industry wastes are particularly complex in their composition and behavior.

Oil Drilling Wastes. Oil-well drilling wastes disposed of at sea consist primarily of drilling muds containing barite and diatomaceous clays and cuttings (rock chips) from the drill hole. This type of waste is physically similar to dredging spoils.

Waste Oil. These wastes consist principally of oil sludge that remains after any re-refining process. In the case of oil tankers, the wastes are oil residues resulting from tank cleaning operations (butter-worthing). Sources of waste oil are numerous, diverse, and include service stations, ship tanks, tank cars, etc. At present, the Oil Pollution control Act of 1961 restricts the disposal of these wastes at sea to areas beyond the 50-mile limit.

Sewage Sludge. Total solids in sewage include large and small suspended particles as well as matter in true solution. The weight of these solids is usually 0.03 percent or less of the total sewage solution by weight. Solids are removed and treated by screening, grit removal, primary sedimentation, final sedimentation, anaerobic digestion and thickening. Thickened sludges currently being disposed of at sea from barges generally range between 3 to 5 percent solids by weight.

Refuse

The survey revealed that only limited disposal of refuse and garbage at sea occurs. These wastes originate primarily from canneries and from commercial and naval vessels. Cannery wastes consist of ground fruit pits, skins, etc., and are disposed of on a seasonal basis. The composition of vessel refuse depends on the type of vessel, geographic location, and season, and consists of varying amount of food, paper, plastics, metal, glass, and similar wastes.

Radioactive Wastes

The nuclear energy industry produces high activity, intermediate activity, low activity, and so-called nonactive wastes. Activities range from hundreds of thousands of curies per gallon for high activity wastes to microcuries per gallon for low activity wastes. Solid wastes include contaminated laboratory or process equipment, clothing, and other items. Between 1946 and 1967 the U.S. Atomic Energy Commission (AEC) disposed of limited quantities of solid packaged radioactive waste materials at designated disposal sites in the Atlantic and Pacific Oceans. In most cases these wastes were packaged in weighted 55-gallon drums. Most of these wastes are now disposed of on land. Nuclear vessels regularly discharge low-level liquid coolant wastes at sea under strict AEC regulations.

Construction and Demolition Debris

Typically, these wastes consist of masonary, tile, stone, plastic, wirign, piping, wood, and excavation dirt. At the present time, the only sea disposal of this type of waste is from New York City.

Military Explosives and Chemical Warfare Agents

This category includes unserviceable or obsolete ammunition such as shells, mines, solid rocket fuels, propellents, agents. Until 1964, the disposal of explosives was conducted primarily from barges and ships. Since then, gutted World War II Liberty ships have been utilized, being sunk with the wastes aboard in water depths greater than 6,000 feet.

Miscellaneous

Included in this category are various types of rejected or contaminated products, such as foodstuffs, appliances, small batches of toxic wastes (usually barreled) such as pesticides and complex chemical solutions. Wastes in this category are usually disposed of in small lots, and records regarding their disposal are difficult to obtain as the disposal operations are not often sanctioned by any regulatory agency.

Selection of Disposal Areas

Results of the present study show that past determinations of whether or not a given offshore area was suitable for waste disposal have been based primarily on the following considerations: (1) the disposal area should be far enough away from the coast and/or have an ocean depth deep enough to ensure that no identifiable wastes return to public beaches or interfere with fishing or recreation in coastal areas; (2) the disposal areas should be within a reasonable distance from the coast so that the costs of tug and barge operations are minimized.

In a small number of cases, the potential harm to the environment and the restrictions that the waste disposal operations might place on future exploitation of natural resources (i.e., fishing, minerals, oil research) were taken into consideration. Some studies have been conducted of various environmental aspects of individual disposal operations; these, however, have been limited in both scope and duration and in most cases were conducted after the disposal operations were in progress.

Disposal Methods and Costs

Methods employed for sea disposal of the various wastes consist primarily of transporting the wastes in bulk or containers aboard towed or self-propelled barges. Dredge spoil is handled routinely by U.S. Corps of Engineers aboard their oceangoing hopper dredges. Bulk wastes are normally discharged from tank barges while underway. Containerized wastes might, depending on local practices, be weighted and sunk, or ruptured at the sea surface by axes or rifle fire and allowed to sink. In a few cases highly toxic chemical wastes such as arsenic and cyanide are carried to sea regularly as deck cargo on merchant ships. The containers are then discharged overboard in undetermined areas once the ship is at least 300 miles from shore. In addition, an accepted method of disposal of spent caustics from oil refineries is as ballast on outgoing crude oil tankers that is discharged far at sea.[3]

TABLE 2
AVERAGE AND REPORTED RANGE OF COSTS PER TON FOR MARINE DISPOSAL OF WASTES IN U.S. COASTAL WATERS
1968

Type of Waste	Total U. S.		Pacific Coast		Atlantic Coast		Gulf Coast	
	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton
Dredging spoils	$0.40/ton	$.20 - .55	$0.43/ton	None	$0.54/ton	$.40 - .55	$0.25/ton	$0.20 -.25
Industrial wastes Bulk	$1.70/ton	$0.60-9.50	$1.00/ton	$0.60-9.50	$1.80/ton	$.60-7.00	$2.30/ton	$.75-3.50
Containerized	$24/ton	$5-130	$53/ton	$50 - $130	$7.73/ton	$5 - $17	$28/ton	$10 - $40
Refuse and Garbage	$15/ton	$5 - $60	$15/ton	$5-$60				
Sewage sludge	$1.00/ton	$.80 - 1.20			$1.00/ton	$.80-1.20		
Construction and demolition debris	$0.75/ton	$.70 - 1.35			$0.75/ton	$.70 -1.35		
Explosives	$15/ton	$15 - $90						
Miscellaneous	$15/ton	$5 - $600	$15/ton	$5 - $600				

Environmental Effects
of Barging Wastes to Sea

Little is known about the immediate effects of solid and liquid wastes on the marine environment, even though a number of pioneer studies have been carried out. Even less information is available on long term or genetic effects.

An adequate understanding of the response of the marine environment to solid and liquid wastes barged to sea requires continuing investigation programs. To date, funds have been available only for short-term studies often directed to specific questions such as maximum permissible barge discharge rates.

More attention has been paid to the disposal of sewage and sewage sludges, both raw and treated, because of the well-known ability of shellfish to concentrate pathogenic bacteria for human consumption. Sludges barged and discharged to the New York Bight have resulted in high levels of fecal coliform contamination in surf clams[1] and the Food and Drug Administration has recently closed affected areas to further harvesting.[40] In contrast, some 400 tons per day of sewage solids, of which approximately one-fourth is organic, have been discharged through submarine outfalls into Santa Monica Bay, California, with no apparent effects on fish abundance.[2,3] Although the fish were able to avoid possibly harmful concentrations, studies of other Southern California receiving waters indicated severe effects on giant kelp (macrocystis). The discharge attracted scavengers (sea urchins) that grazed on the mature plants and increased turbidity so that the young kelp did not develop.[4]

The great differences in effects of waste disposal at sea underscore the need for broad and critical research. A brief review and discussion of the literature on environmental effects of waste disposal at sea is presented in Appendix D. Information summarized on the following pages summarizes the state of knowledge of the effects of barged wastes and provides a basis for identifying further research needs. (James L. Verber has revised, updated, or compiled several of the tables in this report. He estimates that nearly 78.5 percent of all wastes discharged at sea are polluted.--Ed.)

Dredge Spoils

The discharge of dredge spoils at sea results in anomalously rapid sediment build-up at the disposal site, in addition to temporary discoloration of the water by turbidity. The sediment build-up would be expected to have significant effects on bottom-dwelling organisms and the life forms dependent upon them in the food chain. Turbidity may be expected to affect various aspects of the water column and the contained biologic assemblage. Reviews of the literature[5,6] regarding the effects of turbidity on marine fish and crustaceans in coastal waters indicate that, prior to Saila's work on a Narraganset Bay dredge spoil disposal site, there was virtually no information available on the subject. Consequently, much of the following discussion is based on the work by Saila, Polgar, and Rogers.[5]

Bottom Sediment Build-Up. The effects of fish and shellfish of rapid local build-up of sediment as the result of dredge spoil disposal can include destruction of spawning areas, reduction in food supplies and vegetational cover, trapping of organic matter (with resultant development of anaerobic bottom coditions), and the absorption and adsorption of organic matter (including oil).

Turbidity. The effects of turbidity on fish and crustaceans can be direct or indirect. Direct effects cause an immediate response or even mortality by suffocation; turbidity can also result in reduced growth and decrease survival of larval stages of fish and shellfish. Saila and co-workers summarized the possible indirect effects of turbidity (and siltation) as follows: (1) reduction in light penetration resulting in reduced photosynthesis; (2) reduction of visibility to some feeding organisms; (3) destruction of spawning areas; (4) reduction of food supplies; (5) reduction of vegetational cover; (6) trapping of organic matter, resulting in anaerobic bottom conditions; (7) flocculation of planktonic algae; (8) absorption or adsorption of organic matter (including oil) or inorganic ions.

The effect of dredge spoils depends in large part on the location and characteristics of the disposal site. For example, if dredge spoils are discharged in inshore waters normally quite turbid because of wave action or the tidal flushing of turbid waters out to sea, then the effects of the associated turbidity (but not necessarily the sedimentation) would almost certainly be negligible.

The situation would be significantly different where spoils polluted with oil, sewage, chemicals etc. are dredged from channels and the confines of harbors and transported to sea for disposal. Once these sediments are discharged in other locations, the resulting turbidity (and associated pollution) can be spread extensively bo coastal currents. In this regard, Biggs estimated that disposal of spoils from the approaches of Chesapeake Bay increases the turbidity of the water over an area of about 1 to 1.5 square nautical miles around the disposal site, and that discharged solids are dispersed over a bottom area at least five times that of the defined disposal area.[7]

Saila and co-workers investigated the effects on local fishing resources (particularly the northern lobster) of increased turbidity and siltation in relation to the disposal of dredge spoins in 100 feet of water off Narragansett Bay.[5] The results of biological assays and field experiments showed that adult lobsters were able to tolerate, with no adverse effects, turbidities as high or higher than those actually encountered in the disposal area for periods of time equivalent to those during which the spoils seem to remain in suspension. The one case of high mortality observed in the laboratory bioassay tests was believed to be the result of an unidentified toxic substance contained in the dredging spoil, rather than the concentration of suspended particles.

Interpretation of turbidity measurements at the point of discharge by the same investigation revealed that a fraction of the total turbidity cloud consisting of oils and/or light organic material remained near the surface. If present in sufficient quantities for an adequate length of time, this material could pose a possible pollution threat to the adjacent shore area, particularly during the summer season when a drift from the disposal site is predominately shoreward. The dispersion rate of the remaining turbidity cloud was sufficiently rapid that no direct adverse effects to marine resources of economic importance would be expected.

Comparison of the bottom topography before and after the disposal operation indicated that the volume of sediment added to the volume of excess material present in the site was about 2,004,000 cubic yards, which compares favorably with the 1 960,000 cubic yards dredged by the Corps of Engineers; on the basis of this comparison, most of the dredging spoils remained within the designated disposal area. On the basis of the biological and physical data obtained prior to and during the December 1967 to July 1968 Narragansett disposal operation, Saila and coworkers concluded that the spoil disposal site was acceptable from the point of view of minimizing the damage to locally important marine resources.[5]

Another aspect of dredge spoil disposal has been discussed by GRoss, who showed that the volumes of dredge spoils and other sediment-like wastes (construction and demolition debris) disposed of in Long Island Sound and the New York Bight disposal areas represent the largest single source of sediment entering dirdctly into the Atlantic Ocean from North America.[8] From Corps of Engineers records, GRoss estimated that the mass of waste solids from the New York City area disposed at sea increased from an average of 6.8 million tons per year during 1960 to 1963 to 8.6 million tons per year for the period 1964 to 1968.

Most of the disposal sites referred to by Gross are in areas where there is little natural deposition of sediment to dilute or bury the man-moved solids that in many cases consist of highly polluted harbor sediments. The effect of these sediments on the biota is not well understood at this time. Gross also points out that disposal of spoil from barges or dredges is significantly different from natural processes whereby river-borne sediment is deposited on the ocean floor. Disposal operations are highly localized and involve the instantaneous release of several thousand cubic yards of spoil, which produces a thick layer of sediment that may or may not subsequently be dispersed over a wider area by current action.

Gross emphasized the lack of knowledge regarding the deposits formed by the present disposal operations and the absence of comparative data on existing conditions before disposal operations began. Along these lines, he points out that the present disposal operations are, in effect, gigantic, unplanned experiments and, if treated as such, much could be learned from them.

The Corps of Engineers had earlier recognized the growing need to determine the environmental impact of waste disposal on coastal areas.[9] In 1968, the Chief of Engineers authorized a study of various disposal sites in coastal waters in order to determine the environmental effects produced by the disposal of wastes at sea in these areas. The New York Bight disposal areas were chosen for the initial research because of the large volume of wastes currently being discharged there.

The Coastal Engineering Research Center was responsible for defining the research program. As part of this program, the Sandy Hook Marine Laboratory of the U.S. Bureau of Sport Fisheries and Wildlife has undertaken an intensive two-year biological-chemical field sampling program of the mud, cellar dirt, sewage sludge and acid disposal grounds in the New York Bight, with the Lamont Geological Observatory of Columbia University carrying out supporting research on water transport and diffusion. (Cooperatively, the Food and Drug Administration has been conducting bacteriological and chemical studies in the same area.--ED.)

Industrial Wastes

The industrial wastes to be discussed below include waste acids, paper mill wastes, chemical wastes, oil drilling wastes, and waste oil. These wastes are typically dissolved or suspended in a water media for bulk discharge at sea from tank barges. In some cases, the material is barreled and dropped over the side.

The majority of studies of the environmental effects of industrial wastes in the sea have been carried out in Gulf of Mexico waters, because the Galveston District of the Corps of Engineers requires filing of laboratory and field studies of the wastes in support of disposal applications. In order to facilitate comparison of the environmental studies of the key information from the study results has been summarized (Table 8).

Waste Acid. Studies of the dispersion and environmental effects of acid-iron wastes discharged from barges in the New York Bight disposal area have been investigated by Buelow, Redfield and Walford, Ketchum and Ford, Ketchum, Yentsch, and Corwin, and most recently, by several research workers at the Bureau of Sport Fisheries' Marine Laboratory in Sandy Hook, New Jersey.[7,10-13] These wastes consist of ferrous sulfate and spent sulfuric acid in a freshwater solution, and are the byproducts of a titanium paint pigment manufacturing process.

The studies reported here showed that the toxic effects of these wastes are minimal. Laboratory toxicity tests conducted by Ketchum and co-workers to determine if the acid-iron wastes had any effect on the growth of green plankton algae showed and concentrations of wastes which severely limited growth are found only close to the discharge barge and are diluted rapidly at sea.[12] Zooplankton from samples immediately behind the barge were temporarily immobilized, but recovered rapidly on dilution with unpolluted water a short distance astern of the disposal barge.[10]

Additional findings of the study by Ketchum and co-workers showed that the accumulation of iron hydroxide, resulting from the chemical reaction of the wastes with seawater, was about twice as great in 1957 as that observed in 1948, and 50 percent more than that observed in 1950.[12] This was less than might have been expected, however, from the increase in the discharge rate that had occurred over the same period. No evidence was found to indicate that the general turbidity of the waters caused by the iron precipitate has increased outside the general disposal area. Ketchum[14] and Wuestefeld[9] reported that, since establishment of the acid-iron disposal operation in 1948, a concentration or bluefish has developed on the outher boundaries of the disposal area, thus creating a highly popular sport fishery that did not previously exist.

<u>Paper Mill Wastes.</u> This waste is the so-called 'black liquor' produced by the sulfate process used in paper manufacture; it includes sodium carbonate, sodium sulfate, sodium hydroxide and other chemicals. The wastes described by Hood and Abbott[15] were discharged off the Texas coast in 1955 and contained about 45 percent solids, were water soluble but quite viscous, and had a pH greater than 13. Laboratory studies using four species of phytoplankton showed the concentration of black liquor affecting photosynthesis (i.e., threshold toxicity) was about 0.05 grams per liter, and the lethal concentration was on the order of 1 gram per liter. Tests on zooplankton produced no acute toxicities in concentrations up to 0.4 grams per liter; greater concentrations were not tested because it was impossible to boserve the zooplankton as a result of the opaque characteristics of the wastewater mixture. Visual observations at sea confirmed the non-toxic character of the wastes, as zooplankton in samples taken immediately astern of the discharge barge were observed to be swimming about normally.

Field evidence also showed that the absorbent component of the waste sank almost immediately, leaving only a slight discoloration at the surface that was visible for only 30 to 40 minutes after discharge. A minimum dilution ratio of waste to water immediately behind the barge was calculated to be on the order of 1 to 300,000 or a concentration of 0.03 grams of waste per liter, which is well below the values given previously for threshold and acute toxicity on phytoplankton. Bacterial action should result in the ultimate disintegration of the organic components of the

TABLE 7
DUPLICATE SITES[1]

Atlantic						
Area[2] Lat. N.	Long. W.	Industrial	Explosive	Radioactive	Dredging	Refuse
44°26'	67°46'	X			X	
44°24'	68°55'	X			X	
42°25'	70°35'	X	X	X		
38°54'	73°17'	X	X			
38°30'	72°06'	X	X	X		
38°05'	73°24'	X	X			
41°33'	65°33'		X	X		
Pacific						
37°40'	123°25'		X	X		
37°35'	122!50'	X				X

[1]Compiled by James L. Verber, Food and Drug Administration.

[2]Sites usually 25 or more square miles.

TABLE 8
SUMMARY OF ENVIRONMENTAL STUDIES ON INDUSTRIAL WASTES DISCHARGED AT SEA

Waste Type	Description of Disposal Area				Barging Characteristics				Waste Characteristics	Laboratory Toxicity Studies		
Industrial	Distance from shore (miles)	Water depth (feet)	Latitude	Longitude	Amount of waste/trip	Depth of discharge	Rates of discharge tons/min.	Towing speed (knots)	Given description	Type of test organisms	TLM (range)	Remarks
Spent sulphuric acid	15 from New Jersey coast	80	40°20'N	73°40'W	3200 tons 5000 tons	15 feet	18 70	6 7	Fe_2SO_4 (10%) H_2SO_4 (8.5%)	Marine phytoplankton.	27-35.5 mg/l 6-16 day test duration.	Investigated effects of various concentrations of iron on growth of algae.
Chlorinated hydrocarbons	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1200 tons	12 feet	5	6	Beta-chloropropylene (22%), trichloropropane (5%), isopropylchloride (38%), allylchloride (11%), misc. chlorides (33%), heavy ends (3%), pH - 9.8, specific gravity - 0.9 - 1.34.	Marine phyto-, and zoo-plankton, anemones, brine shrimp, bacteria, fish.	0.02-2.5% saturated 0.0005-1g/l, 2-24 hr test duration.	Investigated acute toxicity and inhibition to photosynthesis.
Paper mill wastes (black liquor)	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1300 tons	10 feet	5	6	Paper mill wastes, 47% solids, BOD_5-100,000 ppm Na_2CO_3, Na_2SO_4, NaOH etc., pH - 13. Specific gravity 1.27 at 60°C.	Marine phytoplankton zooplankton.	0.001-1.0g/l, 22 hr test duration.	Investigated acute toxicity and inhibition to photosynthesis.
Ammoniasulphate (mother liquor)	100 S of Freeport, Texas	2760	27°35'N	95°20'W	1700 tons		7	4	Ammonium sulfate (23%), nitrogen (8%), carbon (12%), organics (29%) (alcohols, esters, amides), IOD-90 MG/L, BOD_5 57,000 ppm, pH -4.3, S.G. 1.23.	Brineshrimp, top-water minnows.	1.25% by volume 200 ppm, 24 hr test duration.	Acute toxicity.
Waste liquor	70 S of Freeport, Texas	960	27°48'N	94°54'W	2400 tons		5-24	6	Na_2S (Na_2S_2) (6%) (Na_2S_3) NaHS 1% S (total) (6%), NaCl (21%), organic 2%, solids (dissolved and suspended), specific gravity 1.24 at 60°C.	Marine phytoplankton, top-water minnows, brine shrimp.	0.0005-0.18% by volume, 24 hr test duration.	Acute toxicity.
Chlorinated waste liquor	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1400 tons (proposed)		13-25 (recommended)	5 (recommended)	(Organic waste) chlorinated organics (10-15%), inorganic salts (Na_2SO_4) (5-6%); (acid) chlorinated organics (1%), sulfuric acid (10-15%), nitric acid (0.1%).	Marine phytoplankton, top-water minnows, brine shrimp.	0.02-0.64% by volume, 24 hr test duration.	Acute toxicity, waste acid more toxic to fish than brine shrimp.
Sodium sludge (containerized)	110 S of Galveston, Texas	2400	27°36'N	94°36'W	15 55-gal. drums (500-570 pounds per drum)	Surface	Variable	10	Metallic sodium (75%), calcium (24%), barium, magnesium, potassium (1%).			
Pesticides	95 SSE of Galveston, Texas	720	27°49'N	94°30'W	50 55-gal. drums per trip	1200 ft	1 barrel/2 mins. (600' intervals on bottom	3	Anilines (chlordaniline, monochlorobenzene), liquid organics (methanol, p-xylene, chlorobenzene), dry chemicals–insoluble (*thiram, thiram-E, thionex, zineb, ferbam, monuron*, carbon disulfate).	Minnows, largemouth bass, salmon, bluegills, mosquito fish, channel catfish, bluegill sunfish.	1-135 mg/l, 48-96 hr test duration.	Toxicity values obtained from literature.
Caprolactam wastes	35 S of Sabine Bank Light	60	29°10'N	93°40'W								

TABLE 8

SUMMARY OF ENVIRONMENTAL STUDIES ON INDUSTRIAL WASTES DISCHARGED AT SEA—(Continued)

Waste Type	Reported Field Observations			Mixing Characteristics			
Industrial	Physical-Chemical	Biological	Observed effects	Initial dilution	Diffusion coefficient $cm^2/sec.$	General study conclusions	References
Spent sulfuric acid	pH, iron concentration (0-60'), wind, weather, sea state.	Plankton (0-60'), benthic organisms, pelagic fish (30').	Water discoloration, plankton temporarily immobile, iron settled rapidly from surface layer, no appreciable accumulation of iron found in bottom sediments.	1:5,000	2.9×10^3	Mixing and diffusion of wastes occurs rapidly in the wake of the barge. No evidence to indicate adverse effects. Each new proposed waste disposal operation needs careful study prior to allowing ocean disposal.	1, 10, 11, 12, 40
Chlorinated hydro-carbons	Temp. (0-900'), salinity oxygen, waste concentration (0-500'), surface currents, wind, weather, sea state, bottom mud.	Plankton, O_2 evolution, C_{14} uptake, chlorophyll-A, visual inspection of *sargassum* weed.	Water discoloration: fish, plankton killed on direct contact of waste, no harmful effects seen after 2-4 hrs. Bulk of waste sank. Low diffusion of waste at depth.		2.5×10^3 (average)	Disposal of toxic wastes at sea can be accomplished with only a slight effect on organisms in the biomass within a limited oceanic area. Each new waste disposal operation needs careful study prior to sanctioning it.	16, 17, 18, 19
Paper mill wastes (black liquor)	Temp. (0-900'), salinity (0-600'), waste concentration surface samples, pH, oxygen (0-600'), wind, weather, sea state.	Plankton (0-100'), O_2 evolution, C_{14} uptake, chlorophyll-A.	Slight water discoloration. No mortality to marine life. Bulk of waste sank.	1:300,000	2.5×10^3 (average)	Disposal of "black liquor wastes" in the deep sea can be accomplished without determinable effects on marine biota. Ultimate disposal is expected to be accomplished by bacteria. Advisable to monitor each separate load of waste to determine toxicity in laboratory.	15
Ammoniasulphate (mother liquor)	Waste concentration (0-150')		No fish mortality. No floating oil. Bulk of waste sank. Maximum waste concentration at depth.		9×10^2	No undesirable effects were observed. Diffusion great enough to ensure good dispersion to minimize harmful effects to biota.	22
Waste liquor	Waste concentration (0-150'), temp., salinity pH, oxygen, (0-600').	Plankton, pelagic fish, *sargassum* weed communities.	No evidence of subsurface maximum waste concentration.	1:10,000-1:100,000 in 2 hrs		Disposal should produce no significant mortality in the biota, nor any prolonged effects.	21
Chlorinated waste liquor						No significant mortality would be expected from disposal of this waste in the open ocean. It is suggested that a full-scale disposal operation be properly monitored and continued to verify preliminary study results.	20
Sodium sludge (containerized)	pH	Plankton, fish, *sargassum* weed.	No mortality to fish. Flying debris hazardous to disposal personnel. 30% mortality to plankton due to collection methods.			Explosions caused by reaction of sodium with seawater had no significant effects on *sargassum* and zooplankton populations. Absence of fish-kiln was probably due to barrenness of disposal area.	23
Pesticides				100:1	0.002×10^3	Consideration of available toxicity and diffusion data from literature sources indicate that the zone of water containing toxic concentrations of waste surrounding each disposal drum will be limited in extent and duration and will not endanger motile aquatic life in the disposal area to a significant degree.	24
Caprolactam wastes	Temperature (0-60'), salinity (surface), wind, weather, sea state.	Plankton, bottom samples, C_{14}, chlorophyll-A,-B,-C.				Limited scale (one day) of survey precluded any significant results. Recommend future surveys be conducted on 3-day basis for better results.	

black liquor wastes while the inorganic fraction, principally sodium sulfate, would rapidly lose its identity when mixed with seawater.

Chemical Wastes. For convenience of discussion here, the chemical waste subcategory is divided into chlorinated hydrocarbons, ammonia sulfate, waste liquor, sodium sludge, and pesticides.

Chlorinated Hydrocarbons. The chlorinated hydrocarbon waste category includes betachloropropylene, trichloropropane, isopropylchloride, allychloride, miscellaneous chlorides, and other constituents discharged by chemical and petrochemical plants. The disposal operations discussed here are confined to the Gulf of Mexico. Although wastes containing various percentages of chlorinated hydrocarbons are discharged off the Atlantic and Pacific coasts, their environmental effects have not been investigated primarily because in those areas such studies are not a prerequisite for obtaining a disposal permit.

Four separate chlorinated hydrocarbon disposal operations in Gulf waters have been studied by Hood and his associates[16-18] at the Texas A & M Research Foundation. Their work included field and laboratory investigations of the effects of these wastes on various marine organisms, with emphasis on phytoplankton, zooplankton, and fish. Observed effects at the disposal site included sinking of the bulk of the waste, discoloration of the water, and the death of fish and plankton on direct contact with the undiluted waste. After two to four hours, the surface waste field was found to be sufficiently diluted so that no effect on marine life was observed.

Because the inherent patchy distribution of the microorganisms at sea makes it difficult to obtain statistically significant results, the effects of various toxicity levels on phytoplankton and zooplankton were tested by Hood under controlled laboratory conditions. Inhibition to photosynthesis and respiration caused by the wastes was determined by using standard oceanographic procedures for measuring carbon-14 uptake and oxygen evolution. Comparison of the results with those obtained fron uncontaminated control samples maintained under identical laboratory conditions provided an index of inhibition. Acute toxicity tests were also conducted on the plankton and various species of fish. Results of the laboratory toxicity studies showed that the inhibition to photosynthesis and respiration is a much more sensitive and meaningful measure of the toxic effects of organic contaminants in seawater than acute toxicity tests on organisms such as fish.

The effects of wastes on organisms endemic to the disposal sites was assessed in the field by examining the flora and fauna associated with the seaweed, Sargassum, present both within the outside of the disposal area. It was found that direct contact with the undiluted hydrocarbon wastes at the point of discharge was generally lethal to the small crabs, shrimp, fish, snails, etc., but in most cases samples taken in the disposal area showed conditions had returned to normal within three to eight hours.[15-19]

With regard to diffusion and dispersion of the hydrocarbon wastes, Hood and Stevenson estimated that about seven square miles of surface area would be affected by a single disposal operation.[17] Further their work indicated that within three to nine hours, the wastes in the surface layers were diluted to levels below the limit of detection by the analytical method used.[18,19] In contrast to this, slow dispersion of the wastes occurred at depths from 50 to 500 feet. For example, at one station the waste concentration at 500 feet was roughly equivalent to that observed at the surface in the actual disposal wake 42 hours earlier.[16] Because of the possibility of these waste-laden waters working their way shoreward to bottom fishing areas or regions of upwelling, it was recommended that future disposal areas should be located seaward of the 400 fathom line.

Hood concluded that chlorinated hydrocarbon wastes could be discharged at sea with only minor adverse effects on marine organisms within the dispersal area.[18,19] It should be pointed out, however, that Hood's work did not examine the possible effects of the wastes at depth or of bottom contamination on benthic organisms, even though samples of bottom mud within the disposal area contained from 10 to 100 percent of the original surface concentration of hydrocrabon waste.[16]

Ibert, Wilson, and Harding carried out laboratory tests on the toxicity of two chlorinated hydrocarbon wastes produced by a chemical plant; this study was in preliminary support for an application for marine disposal off the Texas coast.[20] The tests, which used top-water minnows, brine shrimp, and various phytoplankton, measured both the median toxicity level at 24 hours and the critical concentration range, defined as that dilution range between which there is no mortality on the one hand and no survival on the other. In the case of the test plants, 50 percent survived at concentrations of 0.05 to 0.5 percent by volume on 24-hour exposure to the hydrocarbon wastes, and the waste, which included dilute sulfuric acid, was somewhat more toxic, i.e., 50 percent survival at concentrations of 0.02 and 0.05 percent by volume. This greater toxicity should be greatly reduced in a marine disposal operation because of the rapid neutralization of sulfuric acid which occurs in seawater.[10]

Ibert and associates estimated that the waste would be diluted below the 0.006 percent concentration range within an hour by using a pumping rate between 8 and 15 tons per hour while underway at five knots, and concluded that no significant mortality would be expected from the disposal of either waste in the open ocean.

Waste Liquor. Ibert and Harding carried out laboratory and field studies on an industrial waste liquor being discharged off the Texas coast.[21] The waste consisted of various compounds of sodium, hydrogen, and sulfur, along with sodium chloride in an aqueous solution (specific gravity greater than 1.25) that was completely miscible in seawater. On the basis of the laboratory toxicity studies, they concluded marine disposal would produce no significant mortality, nor any prolonged deleterious effects, nor would the concentrations of the waste persist beyond two hours after discharge.

Because the wastes were about 25 percent more dense than seawater, the bulk of the materials sank rapidly from the surface layer, but to the depth covered by sampling (164 feet) there was no evidence of plunging of the wastes in an undiluted stream. Further dilution and dispersion of the wastes were expected to occur on the bottom but sampling was not carried out to confirm this fact.

The reported maximum value of the waste concentration 1.5 miles astern of the barge was less than one in 10^5 (.001%), which was within a factor of two of the minimum value of TL_M reported earlier for the phytoplankton used in the toxicity tests.[21] In spite of these favorable results, it was recommended that future operations use a significantly reduced pumping discharge rate per mile of vessel track in order to insure adequate dispersion under all oceanographic conditions.

Ammonium Sulfate Mother Liquor. MacSmith studied the effects of ammonia sulfate mother liquor on brine shrimp and minnows in the laboratory, as well as the diffusion of these wastes during discharge.[22] This waste material is saturated with ammonium sulfate and contains about 10 percent organic carbon as alcohols, amides, esters, etc.; it is generated in obtaining ammonium sulfate from sulfuric acid in a fertilizer manufacturing process. Smith's work included chemical analyses, biodegradability and toxicity studies, and preliminary diffusion calculations, as well as sampling at sea to determine actual diffusion.

On the basis of the preliminary diffusion and toxicity studies, it was concluded that the wastes would not produce adverse effects on the environment or organisms within the disposal area. A trial disposal operation verified the predictions that diffusion would be sufficiently rapid to minimize the harmful effects to the biota.

Sodium Sludge. Stein reports a study of the disposal of sodium sludge off the Texas coast.[23] The sludge consisted of approximately 75 percent metallic sodium and 24 percent metallic calcium, and was a waste product from a petrochemical plant. The barreled sodium sludge was punctured and dropped overboard; when seawater made contact with the sodium, the drums exploded (Figure 7). Field observation and sampling indicated that the explosions and elevated pH (resulting from the interaction of the sodium with seawater) had no significant effects on the Sargassum and zooplankton communities as compared to those in the control area. An absence of floating dead fish may have been due to the barrenness of the area.

Corps of Engineers records indicate that on two occasions unpierced barrels loaded with sodium sludge have been retrieved from Gulf waters by fishermen. In these cases, it is almsot certain that the disposal operators did not dispose of the barrels in the designated disposal area.

Pesticides. Waller studied the probable environmental effects of the proposed marine disposal of wastes from a Gulf Coast plant that manufactures herbicides and fungicides.[24] The waste included chemicals of the following types: anilines (primarily chloroaniline and aniline with small amounts of monochlorobenzene); liquid organic solvents (methanol, p-xylene and chlorobenzene); and dry chemicals including Thiram, Thiram- E, Thionex, Zineb, Ferban, Monuron, and carbon disulfate. Because of their toxic nature, these wastes are disposed of in weighted steel drums. To facilitate discharge and dispersal along the bottom, a small air space is left in each drum to ensure deformation and rupture of the drum on the ocean floor.

Waller evaluated toxicity data on these waste materials on the basis of the available literature, and concluded that:

> The herbicides and fungicides are generally more toxic than the liquid organics. These dry chemicals, however, have a very low solubility so that once in solution a relatively low dilution ratio (on the order of 100:1) will reduce the concentration below the mediam tolerance limits (TL_M). . . . In addition, the susceptibility to biodegradation and chemical instability in an aqueous environment would further reduce localized toxic conditions.[24]

A mathematical model was developed by Waller to consider the dissolution of the slightly soluble solid material with subsequent diffusion into the surrounding seawater and simultaneous chemical degradation. He calculated that, at a discharge rate of one barrel every two minutes from a barge moving at three knots, the drums would be spaced at 600-foot intervals on the ocean floor. In the case of a waste material dissolving over a period of one year, calculations showed that, based on an eddy diffusion coefficient of 2 cm^2/sec, a 100 to 1 dilution is reached at a maximum distance of 54 feet, 30 days after discharge. He considered this approach to be conservative in that no allowance was made for biological degradation or strong currents that could greatly increase the dispersion.

No actual at-sea tests were conducted on this disposal operation. Therefore a follow-on at-sea monitoring program would be highly desirable, particularly in light of potential adverse effects.

Drill Cuttings and Drilling Muds. The rock chips produced by the bit in drilling an oil well are termed drill cuttings. On offshore drilling platforms along the southern California coast, these cuttings are generally washed and discharged below the rig. Although the resulting solid waste accumulation is volumetrically of little significance because of its possible effect on marine life it has been discussed by Turner, Carlisle, and Ebert who reported that the cuttings were found to have no effect, either adverse or beneficial, on the environment.[25,26] Turner and co-workers suggested that, if the cuttings were to be disposed of several hundred feet away from the drilling platform and capped with stones or other rubble, they could provide an artificial habitat for sportfishing.[25]

The disposal of drilling muds and cuttings in deep water from a barge has also received cursory investigation by the THUMS Long Beach Company in cooperation with several Federal and State agencies, including the Corps of Engineers.[27] Observations on the disposal operation consisted of aerial photographs and visual inspection at the sea surface to assess the extent of surface contamination. On the basis of the one-day study, it was concluded that the disposal operation posed no threat to the environment.

Waste Oil. Although environmental studies have not been made on the single industrial waste oil disposal operation noted during the survey, some very significant work has been carried out on the wastes from tank cleaning operations conducted by oil tankers at sea. Based on the earlier work of ZoBell regarding the oxidation of hydrocarbons by marine bacteria, Moss has shown the importance of discharging these wastes in a finely divided or atomized form in order to optimize bacterial degradation.[28,29] Moss' calculations show that the full quantity of waste oil (at an average concentration of 0.13 milligrams/liter) resulting from cleaning the tanks of a 45,000 dwt tanker underway at 16 knots would be oxidized by bacteria in 2 to 4.5 days, depending on whether the wastes were discharged continuously over a 24-hour period, or discharged as fast as the tanks were cleaned.[29] The broader aspects of the environmental effects of oil in the marine ecosystem have been summarized recently by Holcomb and Blumer.[30,31] Holcolb concludes that ". . .little is known about the long-term effects of oil in the marine environment."[30, p. 204]

<u>Discussion.</u> The information indicated in the preceding paragraphs when summarized represents virtually everything we know of the environmental effects of industrial wastes discharged at sea from barges (Table 8). This minute body of information is totally disproportionate with both the amounts of wastes handled and the potential damage that these wastes can do. It should be noted that the limited scope of the work accomplished to date reflects the economic and environmental constraints which have been applied in the past. There is abundant evidence that these constraints are changing so that it is reasonable to assume that future marine disposal of wastes will be limited to those operations which have been shown not to cause damage.

Sewage Sludge

Sewage sludge discharged at sea is the residual from municipal sewage treatment plants and is generally 3 to 10 percent solids by weight. It is discharged from tank barges at one disposal site in the New York Bight and another off Cape May, New Jersey. There are no similar operations on the Gulf or Pacific coasts, although large volumes of sludge are discharged in southern California coastal waters through submarine outfalls.

The effects of sewage sludge on the marine environment have been investigated by Buelow and associates,[1,32-34] and for the southern California outfalls, by Carlisle, North, Pearson, Rittenburg, Gunnerson, Brooks,and Grigg and Kiwala and many others.[3,4,35-39]

The environmental effects of barge disposal of sludge in the designated sites in the New York Bight and off Cape May, New Jersey (Figure 2) were studied by Buelow and asosciates at the U.S. Public Health Service's Northeast Technical Services Unit, FDA Laboratory.[40] This sudy was the outgrowth of the increased concern by Federal and State health agencies and the shellfish industry over the possible contamination of the commercial surf clam beds adjacent to the sewage sludge disposal grounds. Of particular concern was the possibility that the surf clams might accumulate and concentrate bacteria, viruses, and other toxic substances present in the sludge; these substances could, in turn, be transmitted to consumers of the shellfish. Results of this study indicate that sludge settles rapidly to the bottom and that, except in the immediate wake of the barge discharge, the highest coliform contents occurred in the samples from the near-bottom water.

Because of the preliminary nature of their field investigations, Buelow and co-workers were unable either to approve the present disposal sites or to recommend their relocation. Preliminary results, however, of the current Corps of Engineers study of the New York City sludge disposal area indicate that, because ofthe high bacterial contamination found in surf clams adjacent to the sludge disposal grounds[40] harvesting clams should be prohibited from within a 6 mile radius of the center of the disposal grounds.

Buelow has also concluded that the sludge from the disposal area off Cape May poses a potential threat to existing commercial surf clam beds and shellfish beds located to the south and west of the present disposal site, as they are in a direct line to receive sludge carried by the prevailing tidal currents. In addition, Buelow pointed out that the New York sludge disposal area within a few miles of the head of the Hudson Submarine Canyon, and the apparent southerly drift of the sludge on the bottom towards the head of the canyon, constitute a potential threat to the lobster and red crab populations which may breed in the shallower portions of the canyon.[1]

The work on several major southern California submarine sewage outfalls by the various investigators cited above demonstrated the presence of coliform concentrations in the upper layer of bottom sediment adjacent to the outfalls. In connection with these studies, Gunnerson has divided the various factors, which are important in reducing bacterial populations in sea-water, into three categories[37]: (1) bacteriologic factors endemic to the marine environment - these include competition for food, predation, salinity, sunlight, temperature, pressure, etc. All of these factors may be combined into a single factor - namely, mortality; (2) settling behavior of suspended solids - this is dependent on the size, shape, flocculating characteristics, and density of the sludge particles which in turn are a function of the type of sewage treatment process. Particle characteristics are also important because the bacteria are concentrated within or on the particles; (3) dispersion of the effluent field - this takes place as the sludge field moves downstream from the outfall.

Gunnerson set up a simple mathematical expression relating these three factors.[37] Using this relationship in an investigation of the persistence of coliform bacteria in the primary effluent from the Hyperion Outfall off Los Angeles, he showed that sedimentation is, by far, the most important factor in the disappearance of coliform bacteria from the surface layer of the water column.

The results of work by North and by Grigg and Kiwala to investigate the environmental effects of sewage disposal from the Whites Point outfall in 65 to 195 feet of water off Los Angeles reveal that, shoreward of the 10-fathom curve, large-scale ecological changes have occurred.[4,39] For example, many species that normally occur over rocky substrates at these depths (e.g., kelp, lobster, abalone, and many species of fish) are either rare or no longer present. The length of coastline affected by the sludge deposit has spread from two miles in 1954 to six miles in 1969, at least a three-fold increase in length in 15 years. In contrast, Carlisle reports that sewage sludge disposal from the Hyperion outfall in 320 feet of water in Santa Monica Bay has apparently had no measurable effects on fish abundance.[3]

In summary, studies have indicated that sewage sludge in large concentrations destroys the marine habitat in the immediate vicinity of the sludge field; that the sludge drifts slowly along the bottom because of currents; that coliform and related toxic substances are potential threats to shellfish within a radius of 5 to 10 miles of the site; that the toxic substances and coliform bacteria associated with the sludge are concentrated in bottom sediments; and that a great deal more field and laboratory work is required to accurately predict the detailed behavior of the sludge and the probable environmental response.

Refuse

Although there have been no sizeable municipal refuse disposal operations at sea from the United States in the past 25 years,[41] several U.S. coastal cities (including New York, Oakland, and San Diego) had previously dumped their refuse at sea. These operations were generally unsatisfactory because of the associated fouling of beaches and resultant public disfavor and eventual preventative legal actions. The results of the present survey show, however, that in 1968 there was small-scale disposal at sea of refuse from military installations in Long Beach and San Diego and from a cannery in the San Francisco Bay area (Chapter II). Black also reports that the city of Charlotte Amalis on St. Thomas Island, Virgin Islands, in 1962 began disposing at sea a daily average of 280 cubic yards of refuse.[41]

Studies associated with the past disposal of refuse at sea have been either investigations to establish the sources of wastes found on public beaches, or examinations of the economic and technical feasibility of conducting such disposal operations.

Only in the last two or three years have there been serious attempts to determine the possible environmental effects of disposal of refuse and related solid waste in the ocean. These studies[42-44] are an outgrowth of the several new methods that have been proposed to facilitate effective marine disposal.[45-50] Probably the most comprehensive study to date is that directed by Dr. Melvin W. First and conducted jointly by the Harvard School of Public Health and the University of Rhode Island's Graduate School of Oceanography with funds from the U.S. Public Health Service and the Atomic Energy Commission.[42,51] Systems analysis techniques were employed in this study to evaluate several distinct but interrelated aspects of the feasibility of utilizing shipboard incinerators in connection with marine disposal of refuse from Boston.

Besides defining costs and operating characteristics of the incinerator vessels, the study examined what effects the incinerator residues would have on a variety of marine organisms. Both acute and chronic toxicity tests were carried out on species ranging from phytoplankton and lobster larval to flounders and clams. Oceanographic studies were made in order to predict the movement of incinerated solid wastes along the bottom under various conditions. Meteorological studies were conducted to determine safe burning sites for every weather pattern likely to be experienced in the general offshore region proposed for the disposal operations.

Oviatt has summarized the studies on the toxic effects of incinerator residue on selected marine species.[43] Short- and long-term toxicity tests were performed on a series of organisms including clams, shrimp, scallop, lobster larvae, and fish. The quahaug (*Mercenaria mercenaria*) was the most resistant; 90-day quahaug bioassays in residue concentrations up to 10 percent by weight failed to produce mortalities or significant changes in growth. The common mummiehog survivvd with no mortalities in 40-day bioassay tests with residue concentrations up to 30 percent by weight. First- and second-stage lobster larvae and the common prawn did not experience significant mortality in residue concentrations of 1 percent or less. Of all the fish species tested, the juvenile menhaden was the most sensitive with less than 50 percent surviving 50 days of exposure to the incinerator residue in concentrations exceeding 1 percent by weight. The sea scallop was the most sensitive bottom organism tested and significant mortality occurred in concentrations greater than 3 percent by weight. Additional work has been described by Rogers.[44]

The toxicity effects reported were not considered a serious drawback to the proposed disposal program because calculations show that about 25 years of daily disposal of 500 tons over a 1-square-mile area would be required to equal the toxic level of one present residue concentration.

Oceanographic studies showed that incinerator residue (including cans) in 50 feet of water would drift under storm conditions with the net movement caused by the combined effects of the wave orbital velocity associated with passing waves and the tidal currents found in the area.[52] Once the cans and other debris begin to rock back and forth as a result of wave orbital motion, weak but steady tidal currents cause a net movement in the direction of the current. Calculations indicate that wave heights greater than 3 feet can move debris down to 50 feet, wave heights above 9 feet can move debris at 100 feet, and wave heights above 12 feet can move debris at 200 feet. On the other hand, burnt cans disintegrate at a fairly rapid rate so that, at depths beyond 100 to 200 feet, disintegration was likely to occur long before the object moved a significant distance.

Observations on a simulated incinerator residue disposal site in 180 feet of water were conducted in 1968 with the aid of a research submarine. Some 25 dives were conducted to observe and photograph marked objects planted on the bottom and the effects of actual incinerator residue deposited earlier in the study area.[53] The general conclusion was that incinerator wastes on bottom in 100 to 200 feet depths off Boston would not drift significantly.

The disposal of municipal refuse and garbage at sea (baled or otherwise caused to sink) has received serious consideration in the past year by such major U.S. coastal cities as New York, Philadelphia, and San Francisco,[49] and increasing pressure for marine disposal is a certainty as the coastal population grows. At present, virtually no information is available on the probable effects on the marine environment of a large-scale disposal operation. Considerable work would be necessary before undertaking such disposal. In this regard, it is worthwhile to note that the results of a recent study on the disposal of solid wastes from Westchester County, New York, conducted for the New York State

Pure Waters Authority,[54] showed that barge-haul and disposal of baled refuse at sea was technically feasible and less costly than rail-haul and sanitary landfill or incineration. At-sea disposal was not recommended, however, ". . .because of the difficulty in[53] proving that it will not unbalance the ecology of the area...". In Philadelphia, a well publicized application for a permit to dispose of refuse at sea was prepared. No action has been taken on this proposal.[54 p. 4]

In considering the uncertaintities inherent in evaluating the ecological impact of solid waste disposal at sea, it is important to note that the Bureau of Sport Fisheries and Wildlife (under a cooperative agreement with the Burau of Solid Waste Management) is investigating the beneficial uses of marine disposal of refuse specifically, the costs and benefits of building artificial fish habitats from wastes such as rubber tires and baled refuse.[56] Such baled refuse might also provide food for fish.

Radioactive Wastes

The environmental effects and dispersion of radioactive wastes in the ocean have been the subject of considerable research over the past 20 years. Although containerized radioactive wastes were not disposed of at sea in 1968, much of the knowledge stemming from previous research is pertinent to an understanding of the environmental effects of present marine solid waste disposal operations. Disposal at sea resumed in 1969, therefore, even though a comprehensive review of the voluminous literature on the subject was beyond the scope of this study, selected basic studies particularly pertinent to other marine disposal operations were reviewed and are discussed in this section. The reader interested in more detailed information is referred to the references cited later in this section.

In 1956, the National Academy of Sciences-National Research Council (NAS-NRC) organized a series of committees to study the various aspects of the biological effects of atomic radiation. In the report of the Committee on Oceanography, Revelle and associates presented a critical evaluation of the state of knowledge available at that time regarding the physical, chemical, biological, and geological processes involved in the interaction of radioactive wastes with the marine environment.[57] On the basis of this evaluation, it was concluded that most of the physical and biological processes in the ocean were too poorly understood to permit precise predictions of the results of the introduction of a given quantity of radioactive materials at a particular location in the sea. The Committee proposed that several basic problem areas should be attacked in the future, in order to obtain the necessary knowledge required for assessing the effects of radioactive waste disposal in the ocean. These include: dispersion in the upper mixed layer of the sea; circulation in the intermediate and deep ocean layers; exchange of water properties between the surface and deeper layers; sedimentation processes;

effects of biosphere on the distribution and circulation of elements; uptake and retention of elements by organisms used as food for man; effects of atomic radiation on populations of marine organisms.

In 1958, the U.S. Bureau of Commercial Fisheries, U.S. Atomic Energy Commission, and the Office of Naval Research jointly requested that the NAS-NRC Committee on Oceanography undertake a detailed evaluation of the problems of disposal of both liquid and solid low-level radioactive wastes into the ocean off the Pacific, Atlantic, and Gulf coasts of the United States. The primary objectives of this program were to provide estimates of the level of radioactive wastes that could safely be disposed of at sea, and the most satisfactory locations and methods for disposal to insure that the present or future use and enjoyment of the resources of U.S. coastal areas would not be impaired.[58]

Of the several potential hazards accompanying sea disposal of radioactive wastes, the most critical from the point of view of the NAS-NRC program is the possibility of return of the radioactivity to man. Next in importance is the possible damage to marine organisms from exposure to radioactive wastes. Two avenues through which damage could possibly occur are: (1) transport of the radioactive wastes from the disposal sites to the coastal zone, thereby curtailing the present or future use and enjoyment of the resources of the region; (2) uptake of the radioactive wastes by one or more of the trophic levels in the marine biota, with possible return to man via commercially important fish and shellfish.

Three reports have been published as a result of the NAS-NRC studies.[58-60] Carritt and co-workers studied physical diffusion of low-level radioisotopes from containerized waste disposal areas located in relatively shallow waters on the continental shelf.[58] Pritchard and associates investigated the problem of physical diffusion associated with the disposal of low-level liquid radioactive wastes discharged in the surface layer of the sea from nuclear vessels.[59] The study by Isaacs and co-workers concentrated on the biological aspects of the problem, including the possibility modification of the ecological regimen; in particular they considered the effects of the containerized wastes in attracting fish and other marine organisms, and the subsequent transfer of the wastes from the deeper waters via biological processes.[60]

The Pritchard report summarized the key factors that determine the fate of radioactive material introduced into the marine environment and showed a schematic presentation of the step-by-step considerations that should be made in evaluating the suitability of any marine locale as a receiver of nuclear wastes (Figure 14). The general procedure is the same whether the evaluation concerns containerized wastes or liquid wastes discharged from outfalls and vessels. A similar sequence of considerations

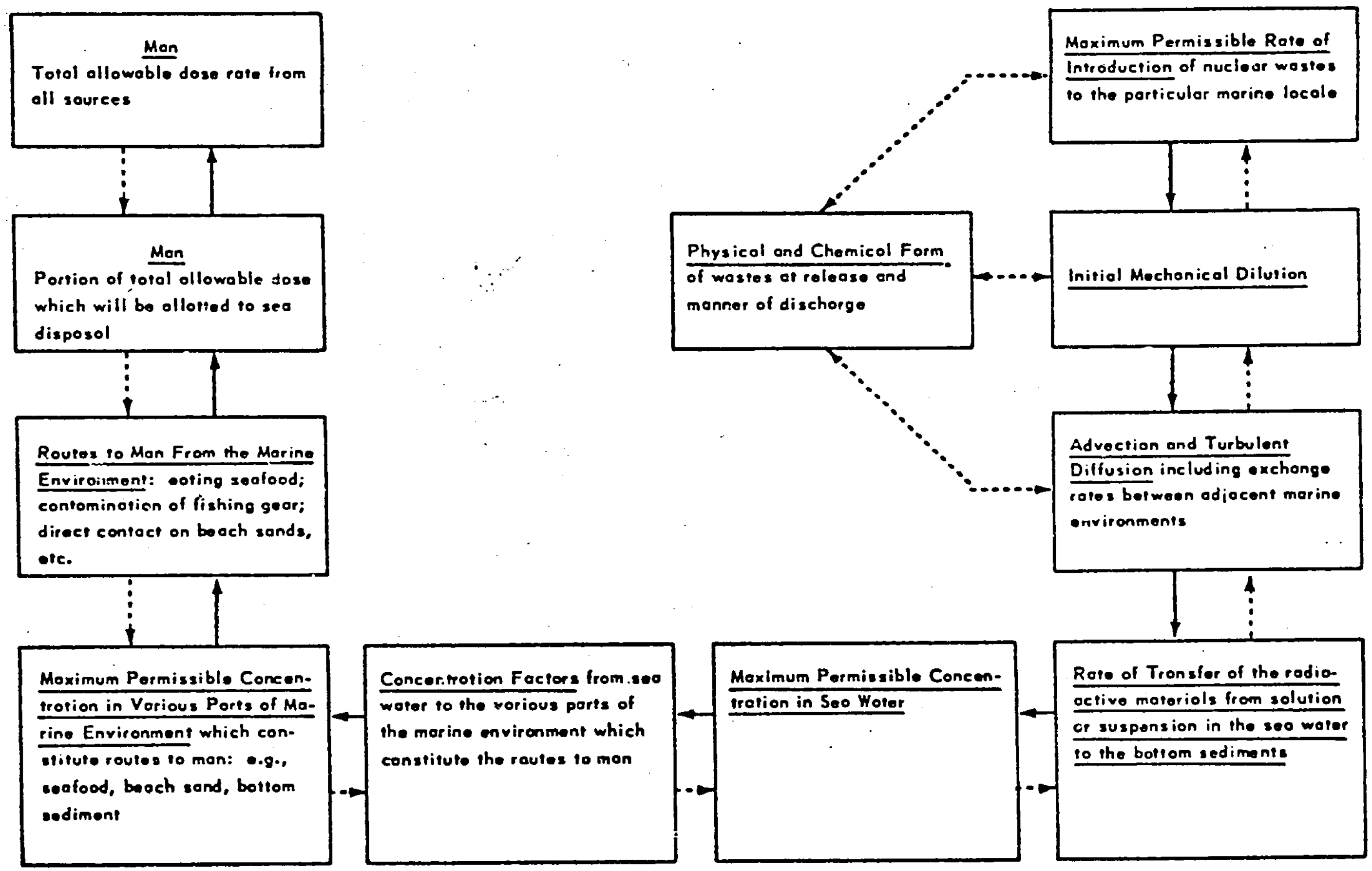

FIGURE 14. Schematic presentation of the step-by-step considerations that should be made in evaluation the suitability of any marine locale as a receiver of nuclear wastes. (From Pritchard *et al.*[59])

is appropriate in the evaluation of potential oceanic sites for non-radioactive solid waste disposal.

In the Carritt study, a series of 28 shallow water disposal sites were proposed for the Atlantic and Gulf coast area.[58] For these sites, the maximum allowable annual rate of disposal for a site two miles in diameter was calculated to be 250 curies of strontium-90 or its equivalent. This value is based on a modification of the diffusion equation for the continuous release of a contaminant at a known rate, under a steady-state condition of supply from a ruptured container containing not more than two curies of strontium-90 or its equivalent. The effects of adsorption by bottom sediments and uptake by marine organisms are not considered in this equation.

The Isaacs report set the maximum permissible number of disposal sites off the U.S. and Canadian Pacific coast at 40, with a maximum of 20 between the Mexican Border and the Columbia River. In determining the allowable rate of disposal for the recommended sites, Isaacs and associates considered two general situations. For each disposal site located below the region of growing marine plants (euphotic zone), yet within the vertical range of human food fish and other human food organisms, they recommended that packaged radioactive wastes (Figure 12) can be disposed of "...at a rate equivalent to 150 curies per year of material that has a maximum permissible concentration in sea water (MPCC) of 1.5×10^{-5} microcuries per kilgram, with soluble isotopes not exceeding 40 millicuries per drum and insoluble isotopes not exceeding 0.5 millicuries per drum on an average basis."[60]

In depths below the vertical limit of human food fish, the annual limit for radioactivity in each disposal area was given as:

$$Q = 5 \times 10^{6} (\overline{MPCC}) (d - b)$$

where Q is the maximum disposal quantity of the isotopes in curies per year. $\overline{MPCC}$ is the weighted mean allowable concentration (in micro curies per kilogram) of the isotopes in seawater, d is the depth of the disposal area in meters, and b is the limiting depth of a human food organism in meters. On the basis of this relationship, a disposal locaton situated in 4,400 meters (14,436 feet), with b set at 2,400 meters (7,874 feet), would have an allowable disposal of 150,000 curies per year.[60]

From an evaluation of the environmental data associated with the two existing disposal sites (one off San Francisc in the vicinity of the Farallon Islands and one in the Santa Cruz Basin), Isaacs and colleagues recommended that the Santa Cruz basin site should be relocated to the Santa Barbara basin.[60] This change was on the basis of the latter's anaerobic properties, higher rate of sedimentation, bottom characteristics and sparse amount of benthic life, and water circulation. This example points out the fact that the deepest location farthest from shore is not necessarily the best site for disposal of a given waste material.

All of the past efforts to assess the potential hazards of radioactive disposal at sea have been hampered by lack of factual data and the complexity of the physical and biological processes in the ocean. As a result of these limitations, the calculations expressing safe disposal concentrations contain an additional safety factor to allow for the deficit of information on this problem. Each of the NAS-NRC studies cited recommended that further research be conducted in the seven categories cited earlier. Because of the 1963 curtailment of marine discharge of radioactive waste, relatively little of this research has been carried out.

Another recommendation of importance concerns the necessity for monitoring and maintaining records of the amount and location of radioactive waste disposal operations. Both the Carrit and Isaacs studies also pointed out the need for periodic observation of the disposal sites in order to document the distribution of nuclear activity and its effects on the biota, and to provide an indication of whether or not the original assumptions made to determine allowable discharge rates are valid.[58,60] Isaacs and his associates recommended that the monitoring and observation program be conducted by an agency other than the AEC or its contractors.

To the writer's knowledge, only three sites used for disposal of containerized radioactive wastes have actually been resurveyed by the AEC (or with AEC funds). These are: (1) a site off the Farallon Islands near San Francisco;[61] (2) the aforementioned site at the Santa Cruz basin, some 70 miles west of Los Angeles;[60] (3) a site about 130 miles east-southeast of Cape May, New Jersey.[13,58,62] For the two West Coast sites, the results of beta-gamma counting of sediment samples indicated that no radioactivity above natural background levels was present. Similar counts for the site off Cape May, however, produced indications in 1961 of possible leakage of radioactive materials from the containers.[13,62] Despite these findings, no further investigations of the disposal areas have been reported. The need for, and the problems associated with, ongoing environmental monitoring of marine waste disposal operations are discussed in more detail in Chapter IV.

Military Explosives and Chemical Warfare Agents

Surplus or obsolete explosives and chemical and biological warfare agents (CBW) have been disposed of at sea for many years. Summaries by Busby, Hunt, and Rainnie and by Kurak indicate the extent of recent oceanic disposal operations including the Navy's CHASE program (discussed in Chapter IV).[63,64]

Although the environmental effects of explosives disposed in the ocean are probably quite limited, they certainly pose hazards to man and his equipment. Busby and co-workers discussed the hazards that explosive wastes present to operations conducted with research submarines and indicated that, although most of the explosive disposal sites (Figures 1-3 are situated in at least 6,000 feet of water, large amounts of explosive ordinance have come to rest in the shallow waters of the Continental Shelf as a result of combat operations.[63]

CBW agents, on the other hand, because of their inherent toxicity, constitute potential hazards of considerably greater significance. Unfortunately, the nature ad scope of these hazards are not well understood. In a recent study by a specail panel of the National Academy of Sciences to consider proposed marine disposal of CBW agents by the Army, it was noted that while

> ". . . various chemical warfare agents have been repeatedly disposed of in the oceans by the United States and other nations. . . we have no information regarding possible deleterious effects of these operations on the ecosphere of the seas."[65]

According to Boffey and to Ludwigson, on three occasions in the past the U.S. Army had disposed of chemical weapons in the ocean, but had made no effort to determine whether or not there would be harmful effects on the environment.[66,67] These reported instances do not include a 1958 disposal operation in which the Ramy disposed of 8,000 tons of mustard and lewisite gas by loading it aboard a surplus vessel, towing her to sea, and scuttling her.[64]

The CHASE disposal operation represents a decided improvement over the previous method of barging explosive wastes to sea, but its use for disposal of CBW agents is questionable because of the possibility that detonations of the associated explosives in the cargo after sinking would liberate the CBW material. In this regard, at least two of the vessels sunk in the CHASE program have not detonated according to plan.[67,68]

The National Academy of Sciences' special panel on disposal methods for CBW agents stated that certain CBW agents already embedded in concrete could be disposed of in the sea without serious environmental effects, but specified that this was accepted as a last resort solution in the event land disposal would pose unnecessary hazards to disposal personnel.[65] The panel also recommended that in the future the Army should assume that all chemical weapons will require eventual disposal and should, consequently, build disposal facilities that will not require dumping at sea.

<u>General Considerations.</u> Our present understanding of the short- and long-term responses of the more important marine food

chain organisms to various types of waste is extremely limited. For example, wastes may have a detrimental effect through alterations in the natural environmental conditions (i.e., temperature, pH, etc.) or through physiological and other changes resulting from the addition of the wastes, or through both. Thus, in determining the toxic effects of wastes, it is important to consider environmental, physiological, and accumulative effects. Not only are marine organisms directly affected by wastes, but also indirectly through their interaction with other forms of organisms which comprise their food, competition, and predators. The situation is further complicated by the fact that different species and different developmental or life stages of the same species may vary widely in sensitivity or tolerance to different wastes. Thus, unfavorable conditions which may be tolerable for long periods by adults may be entirely unfavorable for spawning, and thus possibly endanger survival of the species.

From the foregoing, it can be seen that a great deal of work remains to be done in order to establish both the short- and long-term environmental effects of various classes of wastes in the marine ecosystem. Laboratory tests on specific organisms, both on a short- and long-term basis, are required in order to establish safe discharge rates of the various wastes. The results of these tests must then be tested in the field to determine their adequacy for protection of marine life in the disposal area.

The latter requirement will involve extensive research, both on the organisms themselves and on effective sampling and bioassay techniques. For example, Hood and co-workers have shown that field sampling utilizing standard oceanographic techniques was inadequate for the purpose of obtaining test organisms in the Gulf of Mexico. Furthermore, examples collected periodically on this basis reflect only the conditions at the time that they were collected, and there was no way to determine if the organisms were endemic to the disposal area or migratory in nature. Similarly, there is no way to determine whether or not the wastes are responsible for more subtle sublethal effects on the biota as the waste field moves out of the original area under the influence of ocean currents.

Principal Areas of Environmental Research Needs

Substantial research efforts related to the environmental effects of waste in the sea are required in three major areas to insure that the ocean environment is not damaged by discharges of waste and that the pollution problems that currently exist in most major U.S. rivers, lakes, and estuaries are avoided. These three areas are: development of baseline environmental data, laboratory studies of waste toxicity, and studies of the fate of wastes in the environment and its effects on the biota.

Baseline Environmental Data

In order to properly evaluate the effects of introducing any given foreign substance into the marine environment, it is essential to have an adequate understanding of the various natural fluctuations of the biota and water mass characteristics that are normal for the area in question. Without such an understanding, it is impossible to distinguish between normal variations and those resulting from the presence of the pollutant.

Baseline studies carried out prior to discharging wastes are the most effective means of providing reference data for use as a standard in measuring the effects of introduction of wastes. For an existing discharge, a control study area is set up in the general vicinity of the disposal operation but far enough removed so that it is not affected by the discharged material. In either case, a broad-spectrum study program is required. Physical and chemical studies of the control area serve to identify the natural processes reponsible for the observed distributions of oceanographic properties, such as temperature, salinity, etc. Biological studies concentrate on both the quantity and quality of the biota, as well as the natural diversity of the fauna in the area.

Laboratory Studies of Waste Toxicity

The bulk of the toxicity test programs carried out to date on the various wastes being discharged at sea are discussed in Appendix D; they are limited both in scope and number. It is sometimes overlooked in establishing concentration limits based upon deaths of natural organisms that we don't want sick ones either. Substantial additional work is required not only on acute toxicity, but on chronic or sublethal toxicity as well, particularly for industrial wastes.

Nearly all toxicity bioassay experiments performed to date have been acute toxicities (TLM_{50}) which are only 96 hours in duration. Little has been done to observe the survival, reproduction, and behavior of successive generations to determine chronic toxicity levels of various wastes. Data resulting from some acute tests indicate although test animals survived certain concentrations, there was little or no reproductive capability in the first or second generation.

Because of the diversity of the marine fauna and the wide variety in types of wastes disposed at sea, short-cut methods are needed for determining the toxic effects of wastes both on a short- and long-term basis. For example, at the National Marine Water Quality Laboratory in Kingston, Rhode Island, toxicity studies have been centered around those organisms which comprise the largest percentage of the biomass in the marine environment. Another shortcut used at this laboratory is to determine which of the abundant organisms is most sensitive to each particular waste. These organisms are then used in tests to determine the long-term effects of the wastes.

Another important item for research is the development of standard test procedures which can easily be performed without expensive or elaborate instrumentation or highly trained personnel. The Marine Water Quality Laboratory has developed a bioassay technique that uses brine shrimp (Artemia) whose eggs are easily obtainable throughout the country. To further standardize these tests, sea-salts now on the market in convenient packages are recommended for the preparation of artificial seawater.

Research in toxicity effects on the marine environment resulting from barge disposal is nonexistent and urgently needed. Results of investigations around submarine outfalls in 400 feet of water or less over the past 20 years cannot be extrapolated to the much deeper truly oceanic conditions. Nevertheless, the data from the outfall studies provide useful guidance.

Fate of Wastes and Effects on the Biota

Understanding the fate of the waste after discharge requires an understanding of how the waste physically mixes and disperses in the sea, how the waste degrades chemically and biologically, and what components of the waste tend to concentrate either in the bottom sediments or in various plants and animals in the food chain.

Waste Dispersion. At present, the understanding of how wastes mix and disperse after discharge at sea is limited; generalized theoretical models are too imprecise to allow effective prediction for a specific disposal situation. Environmental studies are required to verify predictive models. Present disposal operations afford excellent opportunities for conducting important full-scale, at-sea experiments on mixing.

Improved sampling methods and equipment should be developed in order to obtain the necessary synoptic data to verify mixing models at all depths in the sea.

Because of the irregular frequency of many discharge operations, and the high costs of ship time for monitoring programs, research is also required to determine the most desirable spatial and temporal at-sea sampling patterns for various types of discharge operations.

Effects on the Biota. The research studies cited in earlier sections of this chapter constitute the bulk of the work on biologic response to barge-discharged wastes carried out to date. Although this work is extremely valuable, the fact remains that it merely scratches the surface of the problem. It is not an exaggeration to state that the environmental effects of past and present discharges are, with essentially no exceptions, not even qualitatively known, let alone measured. It follows that a major research effort in this area is essential.

POSSIBLE BENEFICIAL USES OF SOLID WASTES IN THE MARINE ENVIRONMENT

Although there are severe problems caused by tug and barge disposal of some classes of wastes, a large portion of solid wastes could be disposed of at sea so as to derive benefit. The greatest potential appears to lie in providing artificial habitats for fish.

The coastal zone of the United States is a relatively narrow strip of land bordering our coasts (and the Great Lakes) that contains nearly half of the Nation's population. As our economy and population expand, the coastal zone is becoming increasingly subject to conflicting uses of the relatively limited marine resources available. These uses include fisheries, recreation, fossil fuel and mineral resources development, marine transportation, real estate development, and the disposal of a variety of solid and liquid wastes. Few of these uses are compatible, let alone complimentary. The question of beneficial uses was investigated in the present survey, and results indicate that the only volumetrically significant beneficial use of solid waste in the marine environment as in the construction of artificial reefs for fish habitats. In addition, some suggestions have been made for using selected solid wastes for the construction of breakwaters or islands.

According to current estimates, 82 million persons (12 years or age or older) reside in the marine coastal zone of 23 states.[69] This population is forecast to increase by 17 percent to 96 million by 1980, a 30 percent increase. Total expenditures associated with these activities are expected to nearly double from $13 billion to $23.6 billion over the same period.

Artifical Habitats for Fish

At present there are some 104 artificial habitats or reefs along the U. S. coasts (Figure 1 to 3). Most of these are experimental in character and have been established either by research scientists or local sportfishing interests. Typically, they are relatively small features made up of a variety of solid waste materials including cars, tires, etc., often placed near wrecked vessels. A discussion of various aspects of the potential for large-scale use of solid waste for construction of such artificial habitats follows.

<u>Fishing Pressure</u>. As the number of sport fishermen in the United States continues to grow at the rate of ten to fifiteen percent annually, it is evident that the fish population that attracts these enthusiasts cannot remain static. According to Winslow and Bigler in 1965, at least 40 percent of the 80-odd

million* coastal zone population participated in sport fishing from the shore and small craft in U.S. coastal waters.[69] The threat of widespread over-fishing is significant. In 1965, sportfishing in coastal waters represented a significant fraction of the $108 billion water-oriented recreational industry. Some areas are already heavily overfished. For example, the sheepshead and weakfish have nearly disappeared from the waters of New York and New Jersey.[70] Similarly, populations of black seabass, sheepshead, abalone, and lobster have been seriously reduced as the result of increased fishing pressures off the Southern California coast. It may be that artificial habitats will increase fisheries resources so as to minimize or referse the effects of overfishing.

Lack of Natural Habitat. Most of the continental shelf within reach of sport fisherman and skin divers operating from small craft is an unproductive, flat, lifeless, sandy desert with very few relief features. Sport and commercial fishermen have known for years that naturally-occurring banks, pinnacles, and hills as well as shipwrecks on an otherwise featureless sea floor attract a variety of fish. These areas of high relief, whether natural or artificial, furnish a firm substrate for the encrustration of organisms, such as barnacles, mussels, and coral, and also provide the necessary protection food, and spawning areas for the fish. There is substantial evidence that in nearshore areas where junked cars and rubble have been dumped by man fishing has improved.[26]

Current Status

Recent studies conducted by the California Department of Fish and Game and the Bureau of Sport Fisheries and Wildlife's Sandy Hook Marine Laboratory have shown that properly constructed habitats are a very effective means in congregating the available fish from a given area.[26,71] It has been postulated that the artificial habitats constructed with solid waste serve to increase the populations of other migratory fish by providing additional spawning sites for adults and protection and food for the juveniles.[71]

At the present time, because of the ease in handling availability, long-life, and low cost, automotive tires are the most attractive material for constructing artificial reefs. Research at the Sandy Hood Marine Laboratory has shown that of several materials tested (wood, glass, concrete, metal, etc.) in the environment, rubber was found to be the most desirable substrate

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*This number is significantly higher than the popular often-cited figure of eight million salt water fishermen, but appears to be reasonable and consistent with a national percentage of fishermen compared to total population. Further, these figures do not include the additional population that also participated in sportfishing aboard chartered fishing vessels.

for colonization by the majority of invertebrate organisms in the area.[71] During 1969, over 30,000 tires were implanted on three different experimental reefs. Each reef is being inspected by biologist-divers to assess the effectiveness of the tires to increasing the productivity of the area and to inspect the development of new fish around the habitat. Support for this program has been supplied by the Bureau of Solid Wastes Management. Several types of artificial habitats have been constructed with such waste as car bodies, tires, and rubble, and the various marine life have been attracted to them (Figures 15 to 20).

A report describing the characteristics of the various existing artificial reefs off the Atlantic and Gulf coasts is currently being prepared by the Bureau of Sport Fisheries and Wildlife's Sandy Hook Marine Laboratory.

It has been suggested that baled refuse would provide both food and habitat as a means of enhancing the production of the environment. The Sandy Hook Marine Laboratory has been carrying on an experimental program to monitor the effects observed in placing baled refuse in shallow water (Figure 20.) The initial experiment was inconclusive because of storm damage, but further observations of various types of bales areschedulec.

Availability of Potentially Suitable Solid Waste Material

With regard to the availability of wastes suitable for use in construction of artificial habitats, of the 110 billion tons of solid waste generated annually in the United States, it is estimated that 10 million tons of construction debris, 9 million junked cars, and 100 million old vehicular tires are disposed of annually.[72,73] Although a portion of the cars and tires are reduced and converted into usable scrap, it is likely that a significant fraction of the scrap cars, tires, and debris produced in the populous coastal zone must be disposed of. For example, 20,000 abandoned cars were reported by the city of Philadelphia and over 36,000 by the city of New York in 1968.[74] Sittig reported that 5,000 tons per day of construction demolition waste are deposited in sanitary landfills operated by Los Angeles County.[75] During the present survey, it was determined that New York City annually disposes of over 500,000 tons of demolition and construction debris in landfills and ocean disposal sites.

Estimated Costs

Although evidence gathered over the past 10 years shows that artificial habitats constructed of solid wastes substantially increase sport fishing productivity in local sites, no large-scale program has been undertaken. In examining some of the reasons, it is seen that the cost of preparation and emplacement of the junked cars was relatively high and that the metal was corroded in 3 to 5 years with resulting loss of the reef (see

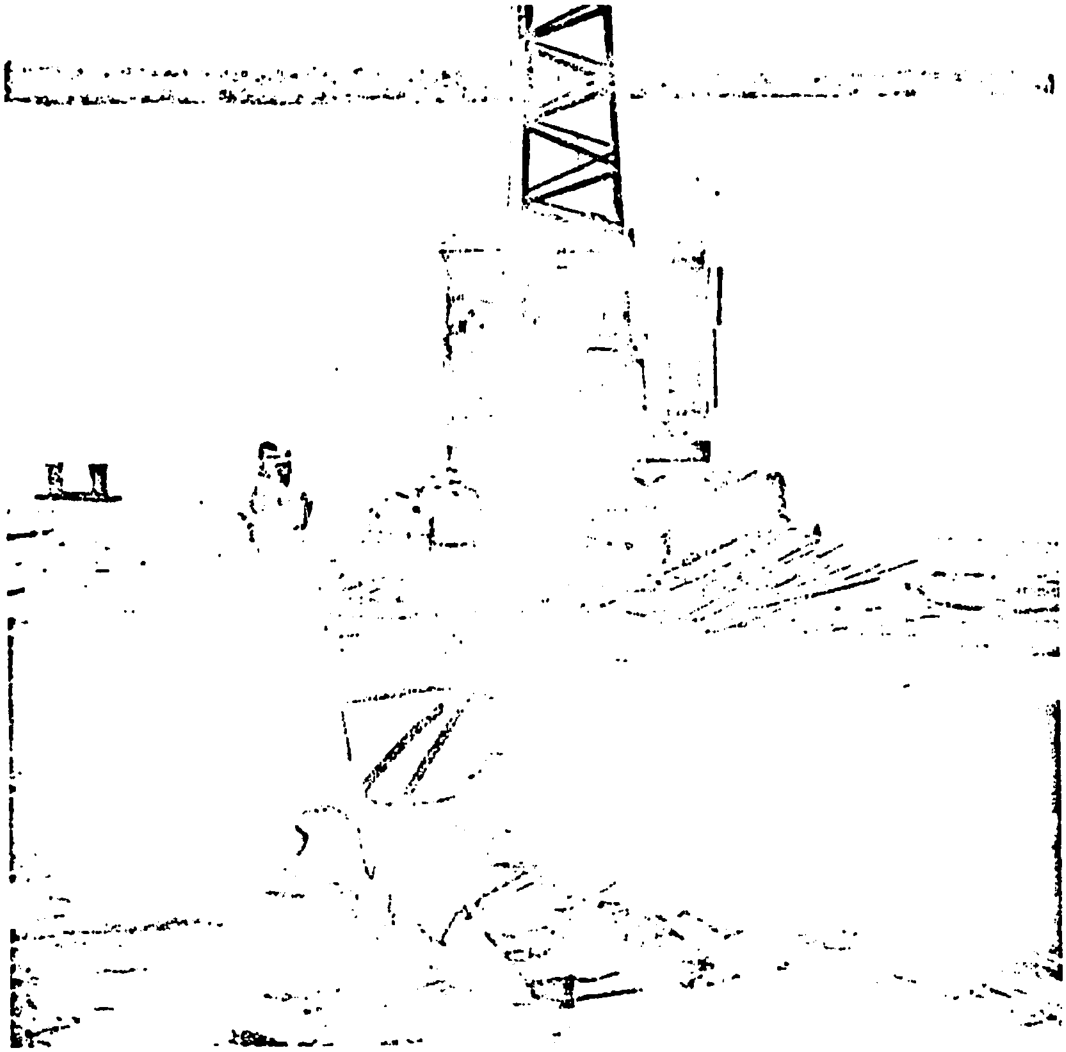

FIGURE 21. Method used to implant junked cars for establishment of an artificial fishing reef in shallow water off the New Jersey coast. (Photograph courtesy of Richard Stone, Sandy Hook Marine Laboratory.)

Figure 16). Estimates made by researchers at the Sandy Hook Marine Laboratory indicated that the cars cost from $70 to $100 each because of the cost of handling, barging, and implanting (Figure 21). Although the use of concrete culvert was favorable as a habitat, it too was considered too expensive and heavy to be feasible for reef construction.

Over the last three or four years, experimental work with rubber tires showed these cost less than a dollar each, and could be assembled and implanted by local fishing and diving clubs. One method uses four to seven tires joined with steel rodding and weighted with concrete ballast. These units become useful fish habitats after one to two years, when they are thoroughly encrusted with marine growth.

Although it is possible to construct effective artificial fishing reefs from certain types of solid wastes, present practice favors disposal in landfills or recycling as scrap steel. It is conceivable, however, that in only a few years, land values and the volume of solid wastes will make extensive reef construction attractive. In this regard, the controlled building of these reefs in the marine environment for the benefit of sport fishermen would be analogeous to the onshore reclamation of canyons and undesirable parcels of land utilizing sanitary landfill techniques for th purpose of creating parks, golf courses, etc. In any event, there is an immediate and continuing need for research and development related to this area.

Other Beneficial Uses of Solid Wastes

Other potential beneficial uses of solid waste materials is the marine environment include its use as a building material in artificial islands, surfing reefs, and floating breakwaters.

Surfing Reefs. Griff has proposed that demolition rubble be used for constructing artificial surfing reefs off the California coast to supplement the natural reef or shoal areas now heavily congested with an estimated 600,000 surfers.[76] With proper construction, he envisions that these reefs could also serve sport fishermen and skin divers. Griff estimates that a prototype surfing reef constructed of quarry stone off the coast of Southern California would cost about $150,000. Compared to other Engineers, this figure does not appear excessive. For example, $330,000 was spent on sand dredging last year for beach replenishment in the area of Newport Beach, California.[76] Griff points out that at present there are no definitive studies to guide the design and construction of multiple-use artificial reefs close to shore, and that further research should be conducted to evaluate their potential.

Floating Breakwaters. Another concept noted during the survey was the proposed use of scrap tires for the construction of a moored, floating offshore breakwater to attenuate wave action.[77] This structure would consist of large truck tires joined to form flexible foating barrier. Related experimental work has been carried out by Uniroyal using a series of baffles to break up the orbital motion of waves, thus dissipating the energy offshore. Costs for the materials for a floating breakwater constructed of used tires are estimated at $600 per 100 lineal feet. Costs for anchors and related mooring tackle, and for installation and maintenance will probably be many times the cost of the basic materials.

Additional research on this concept may find a way to successfully combine the surfing/fishing reef with the breakwater and use both construction rubble and tires.

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WASTE DISPOSAL IN THE MARINE ENVIRONMENT - A LITERATURE REVIEW

Environmental effects of marine disposal of solid and liquid wastes from barges and other vessels may be divided into physical and chemical aspects, biological aspects (including public health) and their interrelationships.

At present, we have a theoretical understanding of mixing and diffusion phenomena which tells us where the waste material should go. In addition, we have a rudimentary understanding of the probable effects of a given waste concentration on certain organisms. By contrast, we have only a very limited understanding of how the waste actually disperses and how the ecosystem actually responds to the presence of the pollutant.

A series of carefully conducted laboratory bioassay tests is generally the first step in defining the level of dilution that is safe for a given set of conditions. Unfortunately, there are significant problems associated with achieveing successful test results, and there are more difficult problems associated with effective prediction of the actual mixing of diffusion rate to be expected at the disposal site.

The broader aspects of oceanic circulation were discussed in Appendix C, as are the marine ecological interrelationships generally known as the food chain. More detailed considerations are presented below.

WATER QUALITY REQUIREMENTS

A water quality standard is a plan established by governmental authority as a program for water pollution abatement, and includes water use classifications, water quality criteria necessary to support these uses, and a plan for implementation and enforcement. Water quality criteria are the scientific requirements on which a decision or judgement may be based concerning the suitability of water quality to support a designated use.[1] In essence, water quality criteria are the parameters or measuring sticks used to evaluate whether the specified water quality standards are being met.

The Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965,[2] authorized the States (and the Federal Government) to establish water quality standards for interstate (including coastal) waters. Specific guidelines for the establishment of these standards are contained in the Act. If a given State fails to adopt standards consistent with these guidelines, the Secretary of Interior is authorized to develop the necessary water quality standards for the body of water in question.

Water quality criteria for the coastal waters (extending out to 3 miles) have been established by most coastal states. There are no water quality criteria for waters beyond the 3-mile territorial limit of the United States. Where they exist, these criteria are generally of a descriptive nature, and specific allowable waste concentrations and other quantitative measures are rarely included. Exceptions to this are the several California State Water Quality Board Resolutions which specify limits for such measures as pH, dissolved oxygen, and waste concentration at given distances from the waste disposal barge.

Water quality standards and criteria depend upon the beneficial uses of the water, which for open coastal waters include: (1) propagation of fish, shellfish, and other marine life; (2) boating and navigation; (3) esthetic enjoyment; (4) commercial and sport fishing; (5) skindiving; (6) transport, dispersion, and assimilation of wastes; (7) bathing. The relative importance of these beneficial uses varies geographically and seasonally. In considering the level of water quality required for the various uses by marine life, man, or industry; water quality criteria are typically defined on the basis of physical, chemical, bacteriological, or biological characteristics or parameters.[3] Many of these same parameters are used in research studies designed to assess the probable effects of waste discharge in marine waters.

PHYSICAL PARAMETERS

The principal physical parameters include color, odor, turbidity, particulate matter (i.e., floatable and suspended solids), transparency, salinity, temperature, and density of the water column (which is a function of temperature and salinity). Also included are hydrodynamic characteristics such as eddy diffusivity, and geological characteristics such as the composition, grain size, and distribution of bottom sediments.

As McKee has pointed out, physical parameters are most often used to assess the changes that take place in well-defined environmental relationships as a result of the addition of potential pollutants.[3] For example, the addition of waste material contained in large volumes of fresh water media will alter the horizontal and vertical salinity distribution. This will in turn change the existing vertical stability of the water column, which could have a direct effect on the ultimate mixing of the wastes.

There is a substantial body of published work dealing with general problems of mixing, diffusion, and dispersion in marine waters and in related topics (in particular see Orlob, Okubo, and Foxworthy).[4-6]

Numerous factors control the dilution and dispersion of the waste, including such large-scale oceanographic features as density distribution, permanent currents, and tides, as well as local morphology, wind currents, mass transport, and wave action.

In general terms, currents move the water mass containing the waste field away from its point of origin while dilution and dispersion of the waste field take place more or less contemporaneously. When waste material is discharged at sea, components heavier than sea water sink and the lighter fractions float. Dispersion or lateral spreading of the waste is a function of the sinking rate of that waste, and the interaction of forces producing lateral movement. The nature of the sinking action depends on whether or not the waste is a solid or a liquid.

Solids sink (or settle) according to Stokes' law[7] except for modifications introduced by the hydrodynamic shape of the body or particles, and the horizontal forces of currents. The behavior of solids with densities (or bales of solids with composite densities) close to that of sea water is somewhat more complex and need not be discussed here.

Liquid wastes discharged in sea water are diluted and dispersed by the initial dilution of the waste, and subsequent dispersion of the diluted waste field. The denser components of the liquid sink with some attendant dispersion until they encounter a density level in the water column equal to their own. At this depth, a submerged waste field forms with subsequent mixing and lateral dispersion according to isentropic principles.[8] For the components with densities close to sea water, mixing and dispersion take place predominately in the surface water layer under the influence of turbulence produced by winds, waves, currents, and the passage of the disposal tug and barge.

For engineering purposes associated with the disposal of wastes at sea, the turbulent mixing phenomenon or eddy difusion is best approximated by a modification of Fick's Law,[9,10] which holds that the turbulent mass transfer of a property of a fluid (i.e., temperature, salinity, etc.) per unit of time is proportional to the average concentration gradient. The proportionality constant is called the coefficient of eddy diffusivity; it is not a physical constant but depends on the nature of the turbulent motion.

Since the coefficient of eddy diffusivity is fundamental to an accurate understanding of mixing, considerable attention has been given to the determination of the appropriate value of this coefficient for various mixing situations found in the ocean. Most investigators have limited their studies to the horizontal component of eddy diffusivity in the surface layer of the sea.

Pearson and Orlob each assembled values of the eddy diffusivity coefficient obtained by several investigators;[3,4] the broad range of values (between 10^4 and 10^6) has caused several investigators to suggest that the Fickian equation may be an inadequate model for completely describing eddy diffusion processes.[5,6]

Although there has been considerable disagreement in the literature on how to formulate a diffusion law adequate to describe oceanic mixing processes, it is generally evident from the values summarized earlier and in more recent work[11] that the magnitude of the eddy diffusion coefficient increases greatly with the scale of the disturbance being considered. For further discussion, the reader is referred to the references cited.[9,4,11]

Specific studies of the mixing of barge-delivered waste in the sea suggest that mixing and diffusion of wastes generally takes place rapidly in the wake of the disposal barge.[12-14] This mixing is hastened by the added turbulence associated with the passage of the tug and barge and the pumped discharge of the waste. The precision of the diffusion coefficients calculated from studies of various disposal operations is somewhat doubtful because it is difficult to distinguish between the natural diffusion of the waste and that induced by the barge effect just mentioned. From the experimental work at sea, it was estimated that the effect of the barge was to increase average mixing rates by a factor of three,[13] although stirring by the barge produced highly irregular patches of relatively undiluted waste, which is in agreement with the description of the mixing process presented by Eckart. How long these discrete patches may retain their identity is now known, but it is probably on the order of 3 to 4 hours. Hood, Stevenson, and Smith emphasized that the actual pattern of diffusion in the wake of a barge will be understood only through additional experimental work at sea.[15]

In connection with studies of the disposal of water mill wastes off the Texas coast, Hood and Abbott developed a predictive equation for diffusion.[16] Using this equation, good agreement between the predicted and observed waste concentration in the wake of a chlorinated-hydrocarbon disposal barge 5 minutes after discharge were obtained.[13]

CHEMICAL PARAMETERS

The chemical measures used in defining water quality criteria were summarized by MCKee.[3] They include: hydrogen ion concentration (pH); dissolved gases (oxygen, carbon dioxide, etc.); chlorinity; nitrogen analysis (ammonia, nitrites, nitrates); organic carbon (COD) and total carbon; biochemical oxygen demand; nutrients (phosphates, nitrates, silicates, etc.); heavy metals (copper, lead, zinc, etc.); oily substances (hydrocarbons of industrial origin); trace organics (pesticides, detergents, etc.).

In the past, determinations of most of the foregoing chemical measures have resulted in only micro-quantities for which the effects on beneficial uses are difficult to establish. Chemical analyses of the bottom sediments have, however, often proven useful in assessing the overall impact of pollution, owing to the integrating characteristics of sedimentation and biological accumulation. Generally, the first seven parameters establish the numbers of organisms which are found in the marine environment. The last three may be more critical, for they may either preclude the existence of any life or may so alter the ecosystem that only undesirable forms can survive. It is these compounds whose biological effects must be characterized.

BIOLOGICAL PARAMETERS

In a highly simplified way, the biological assemblage in the sea can be subdivided into three zones: the flora and funa which live in the surface and near surface (euphotic zone) waters; the assemblage living in the mid-water zone; the bottom (or benthic) dwellers.

The surface and near-surface waters are by far the most heavily populated zone; phytoplankton abound and the fauna range from the microscopic zooplankton up through the food web to the large fish and mammals. Within this zone the greatest concentrations occur in relatively shallow coastal waters; these concentrations include our commercial and sport fish as well as sharks, seals, and whales. Also found at the surface are seasonal concentrations of fin fish and shellfish larvae that spawn in open water to return later to near-shore and bottom waters.

The mid-water depths (or mesopelagic zone) are characterized by a low animal population. Nearly all the planktonic forms are absent, which results in attendant limitation of the higher orders in the food web. There is a sparse population of nonfood fish and invertebrates such as giant squid, viper fish, angelfish, and octopus.

The bottom or benthic animals are found in somewhat increased numbers relatively nearshore, since the bottom is able to nourish more life than the water column by accumulating all the debris that falls from the surface. Benthic animals can be divided into two basic groups: the epifauna or animals that live on top of the sediments, such as lobster, shripm, and flounder; and the in-fauna or those living within the sediments, such as clams, worms, and other burrowing organisms.

The principal biological parameters used in defining water quality criteria so as to protect the biological assemblage include: species diversity indices, median toxicity tolerance (TLM) limits from bioassay tests, fish catch statistics, principal species tabulations from plankton and trawl hauls, and measures of primary productivity. Species diversity indices and bioassay tests are becoming increasingly important while the other parameters are less useful in marine environmental control.

Species Diversity Indices

Ecologists have long identified polluted environments with a decrease in the number of species, although the total number of organisms of a given species may increase because of reduced competition. Thus, an examination of the diversity of the organisms in an area may provide a measure as to the general health of the environment. Any organism capable of avoiding the waste field, or which spends a limited portion of its life cycle in the test area, is considered of questionable value as a suitable indicator organism. For this reason, sessile forms or organisms that have little motility (such as bi-valves) are generally used. Stein and Denison evaluated the relative merit of "diversity indices" and concluded that the use of biological indicators are superior to chemical and physical measurements used alone. They strongly emphasize, however, the need for quantitative sampling techniques for the proper development of biological indices for evaluating pollution effects.[17]

Bioassays

The bioassay method consists of preparing a series of test solutions of the waste in water at various selected dilution levels, adding the population of test organisms, and observing their reactions and survival for definite time periods. Certain specifications such as temperature control, number and size of test organisms, volume of test solution, and maintenance of dissolved oxygen are usually incorporated in the test procedures.

Although there are several types of bioassays, two are in general use: (1) the acute static bioassay, in which the test solution is not changed during the duration of the experiment and (2) the flow-through bioassay, in which the test solution is continually renewed. The advantages and disadvantages of these methods have been discussed by McKee, McKee and Wolf, Hueck and Adema, and Hood, Dube, and Stevenson.[3, 18-20] It is generally agreed that the flow through bioassay provides a more realistic appraisal of the actual short- and long-term toxicity of a waste in terms of reproduction and growth; however, because of the requirements for complicated equipment, including metering devices and the provision for a large volume of the waste, this method is not as widely used as the acute static bioassay.

Thus, most of the present criteria for the toxicity of wastes are based on static bioassays conducted for each specific situation according to standard procedure establishment by the American Public Health Association.[21] Toxicity data generally are reported as the median tolerance limit (TLM), which is the concentration of waste that kills 50 percent of the test organisms within a specified time span.

It should be noted that the acute TLM value does not represent a "safe" concentration, as believed by manu, but merely the levels at which half the test organisms are killed. In contrast to acute bioassays, some investigators have conducted bioassay experiments on planktonic organisms, which are interpreted in terms of the concentrations of wastes that inhibit physiological processes (photosynthesis or growth) by 50 percent, rather than the concentration required to cause a 50 percent mortality of the test organisms.[3,17,20] In many cases, significant differences have been found between the acute TLM concentrations and those that are low enough to permit normal reproduction and growth.

To allow for these unknown effects of wastes, the National Technical Advisory Committee on Water Quality proposed that, in the absence of toxicity data other than acute TLM values an "application factor" should be applied to the TLM values in order to obtain permissible concentration of wastes that can be discharged at a given location. The application factor is defined as "...the concentration of a material or waste that is not harmful, divided by the 96-hour TLM value for that material."[1] In practice, very few application factors have been determined for the numerous types of wastes and, as a consequence, the Committee has suggested the use of interim application factors until test data become available. These are given as: 1/100 of the 96-hour TLM for pesticides, metals, and other persistent toxicants; 1/20 for ammonia, sulfides, and other unstable or biodegradable materials; and 1/10 for waste materials with noncumulative toxic effects. When two or more toxic materials that have possible additive effects are present in the same waste, a simple additive mathematical relationship is used to determine the permissible concentration.[1]

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"SOUND, THE UNWANTED FORM - NOISE"[a]

by

Emil T. Chanlett

The opening sentence of the foreward by the editors of Noise as a Public Health Hazard (Ref. 11-8) is: "Noise-in the sense of 'unwanted sound"- has been a problem since Eve first poked Adam in the remaining ribs and told him to stop snorig." Characterizing noise as unwanted sound, as in Eve's case, means that it is defined subjectively. Noise is an objectionable sound. It is in the wrong place at the wrong time. It is told that Britishers living near the combat airfields of World War II blessed the roar of the nightly takeoffs to subdue the Nazi and gave thanks for each return, however faltering the engine sounds be. With World War II ended, it was not long before nearby residents complained of the noise of night training flights. Just as glare is misplaced brightness, noise is misplaced sound. Furthermore, there are some disagreeable effects on hearing thresholds, speech intelligibility, and physiological states. Some of these effects are well documented by medical facts correlated with environmental measures. To that extent, the effects are not subjective but a normal response of a large portion of exposed people, with immediate recognition that a small portion are very sensitive to noise and another portion are able or willing to endure it.

The Nature of Sound, Units for It, and Its Measurement

Sound is a mechanical energy from a vibrating surface, transmitted by a cyclic series of compressions and rarefactions of the molecules of the material through which it passes. In a pure tone, the wave pattern of the alternating positive and negative sound pressure is an ideal sinusoidal form with fixed wavelength, frequency, and amplitude. As our experience indicates, sound is transmitted through gases including air, liquids, and solids. Only a vacuum, in which there are no molecules to compress and decompress, alternately, fails to transmit mechanical energy as sound. The speed of transmission is a function of the transmitting medium and its temperature. The speed in air is 340 m/s at 20°C (1,125 fps at 68°F). The speed of sound is proportional to the absolute temperature of air. In water, it is 1,470 m/s (4,860 fps). In steel, it is 5,000 m/s (16,500 fps).

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[a]From Environmental Protection, Chapter 11 by E. T. Chanlett, McGraw Hill, Inc., NY, 1973.

As in the case of light, all frequencies travel at the same speed. Frequencies are not expressed in hertz, equal to cycles per second. The audible range for an exceptionally good human ear is 35 to 20,000 Hz. A more limited range of 80 to 15,000 Hz is conisdered normal for young adults who have had no hearing losses or ear abnormalities. Even that range is wider than that in which most of us in adult years can hear. For the testing of hearing, the standard procedure is to use eight frequencies, 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz.

A vibrating source producing sound has some total power expressed in watts and designated W. In free space that power is transmitted omnidirectionally in a spherical form. The intensity I is the power per unit are of the spherical boundary. Intensity decreases inversely with the square of the radius r of the sphere. Intensity is not readily measured directly. Instruments have been devised to measure the effective sound pressure. As sound pressure is alternately rising to a maximum pressure of compression and dropping to a minimum pressure or rarfaction, the square root of the mean-square and sound pressure P_{rms} must be used. The P_{rms} equals $0.707P_{max}$. Derivations and calculations are given in Ref. 11-9 (pp. N2-3, N2-4). Figure 11-8 diagrams the relations.

These values do not provide a practical unit for sound or noise measurement for two reasons.

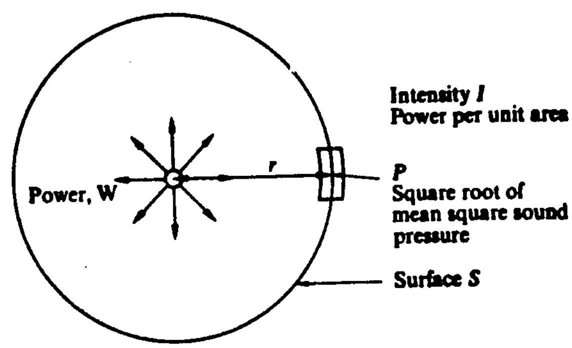

FIGURE 11-8
Relations of a sound source with a power of W (watts) to intensity *I*, and root-mean-square sound pressure. [*Source*: *Ref.* 11-9, *p. N*2-3.]

1. There is a tremendous range of sound power and sound pressures produced. Expressed in microbars, one-millionth of 1 atmosphere of pressure, the range is from 0.0002 microbar (ubar), the minimum sound pressure a health young human ear can detect, to 10,000 ubars for peak noises within 100 ft. from large jet and rocket propulsion devices. In units of physics, 1 ubar equals 1 dyne/cm^2.

2. Our ears do not respond linearly to increases in sound pressure. The nonlinear response is essentially logarithmic, as are our other sensory responses to odors, pressures, and weight differences. This nonlinear response pattern is described by the Weber-Fechner law.

Table 11-2 THE DECIBEL SCALE OF SPL, WITH SOUND PRESSURES IN MICROBARS, AND RECOGNIZED SOURCES OF NOISE IN OUR DAILY EXPERIENCES

Sound pressure, μbar	SPL, dB/0.0002 μbar	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	Studio for sound pictures
0.0063	30	Studio for speech broadcasting
0.02	40	Very quiet room
0.063	50	Residence
0.2	60	Conventional speech
0.63	70	Street traffic at 100 ft
1.0	74	Passing automobile at 20 ft
2.0	80	Light trucks at 20 ft
6.3	90	Subway at 20 ft
20	100	Looms in textile mill
63	110	Loud motorcycle at 20 ft
200	120	Peak level from rock and roll band
2,000	140	Jet plane on the ground at 20 ft

The needs are met by a term, sound pressure level (SPL), expressed as a logarithmic ratio to a reference level and stated in a dimensionless unit of power, the decibel (dB). The reference level is 0.0002 ubar, the threshold of human hearing. The expression looks formidable but has the advantage of resulting in values of two and three integers for the SPL we experience in our increasingly noisy environment. The expression is

$$SPL = 20 \log \frac{P}{Po} \text{ dB}$$

with P_o equal to 0.0002 ubar.

Table 11-2 orients you to the decibel scale of SPL by giving examples of recognized noise levels, the sound pressure in microbars, and the SPL in decibels.

Here are some examples of the arithmetic of the decibel SPL scale:

$$dB = 20 \log \frac{P}{P_{ref}}$$

where P_{ref} = 0.0002 ubar threshold for human ear response.

At p = 0.0002,

$$dB = 20 \log \frac{0.0002}{0.0002} = 20 \log 1 = 20(0) = 0$$

At P = 0.2,

$$dB = 20 \log \frac{0.2}{0.0002} = 20 \log 1,000 = 20(3) \quad 60$$

At p = 20,

$$dB = 20 \log \frac{20}{0.0002} = 20 \log 100,000 = 20(5) = 100$$

At P = 20,000,

$$dB = 20 \log \frac{20,000}{0.0002} = \log 100,000,000 = 20(8) = 160$$

The unit decibel is not uniquely reserved to describe the power of sound and noise. It will be encountered in other uses in electronic technology. As the SPL-decibel scale is logarithmic, decibel values are not additive. For example, an SPL of 74 dB from one source superimposed on one of 75 dB does not result in 149 dB. An SPL of 77.6 dB results. To determine the total effect, it is necessary to convert decibel readings to intensity ratios, add the intensity ratios, then reconvert the new sum back to a decibel value. Reference 11-9 (p. N2-5) details an example and more conveniently provides Table 11-3 for determining the cumulative decibel values of two or more known observations on individual sources. The value in the difference column in Table 11-3 is always added to the highest of the two decibel values being handled.

Very few sounds or noises are in a single frequency or pure tone. The human ear is not uniformly sensitive to all frequencies nor does it perceive noise equally across the frequency spectrum. For audiometry some scheme of frequencies had to be agreed upon. The use of three expressions of physical auditory stimuli, expressed in units unique to these, requires an analysis of the frequencies of the noise. These are the loudness in sons, and noisiness in noys or as the <u>perceived noise</u> level in decibels (PNdB). Therefore, the frequency of sound is assigned an octave

Table 11-3 DETERMINING THE CUMULATIVE DECIBEL SPL WHEN THE DIFFERENCES BETWEEN TWO OR MORE LEVELS ARE KNOWN

Difference between levels, dB	No. of dB to be added to higher level
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

SOURCE: Ref. 11-9, p. N2-6.

band distribution. An octave is any frequency range with an upper value twice that of the lower. Until 1960 the frequency limits generally used were 75 5o 150 Hz, 150 to 300 Hz, and on tc 4,800 to 9,600 Hz. Since then by international agreement among workers in acoustics, the frequencies given in Table 11-4 have been in use. Each octave band is specified by the center frequency, which is the geometric mean of the high and low cutoff frequencies of a particular band. Note that 125 Hz is not the arithmetic mean of 90 and 180. It is the square root of their product. Instruments for analyzing sounds by frequencies are called octave-band sound analyzers. There are full-octave and divided-octave analyzers, a constant-bandwidth analyzer and a constant percentage bandwidth analyzer. To interpret and to attempt to compare readings from the types of sound analyzers available, it is necessary to know what type was in use. W. Rudnose's excellent statment, Primer on Methods and Scales of Noise Measurement is recommended for those ventruing to measure the noisy environment (Ref. 11-8, pp. 18-34).

Table 11-4 FREQUENCIES FOR ACOUSTIC MEASUREMENTS SHOWING THE GEOMETRIC-CENTER FREQUENCIES AND THE LIMITS OF THE OCTAVE FILTER PASSBANDS

Center frequencies, Hz	Limits of band, Hz
63	45–90
125	90–180
250	180–355
500	355–710
1,000	710–1,400
2,000	1,400–2,800
4,000	2,800–5,600
8,000	5,600–11,200

SOURCE: Ref. 11-10, p. 47.

Before reaching the sophistication of a sound analyzer, field measurements are made with a sound-level meter. By a microphone, battery-powered amplifier, and meter scaled in decibels, SPLs are read. There is no separation into octave bands. There is a separation by means of electrical circuits known as weighting networks. These three networks, A, B, and C, have distinct responses to different frequencies. They simulate the characteristics of the sensitivity of the human ear for different frequencies. The ear has less sensitivity to frequencies below 400 Hz and above 10,000 Hz at low sound intensities. As can be seen in Figure 11-9, curve A is less responsive below 400 Hz than B or C is. The A wieghted network is intended for use at low SPL, 55 dB or less. At high sound levels, human response shows less difference with frequency. The B network, used least in practice, is flatter than the A weighting. It is intended for

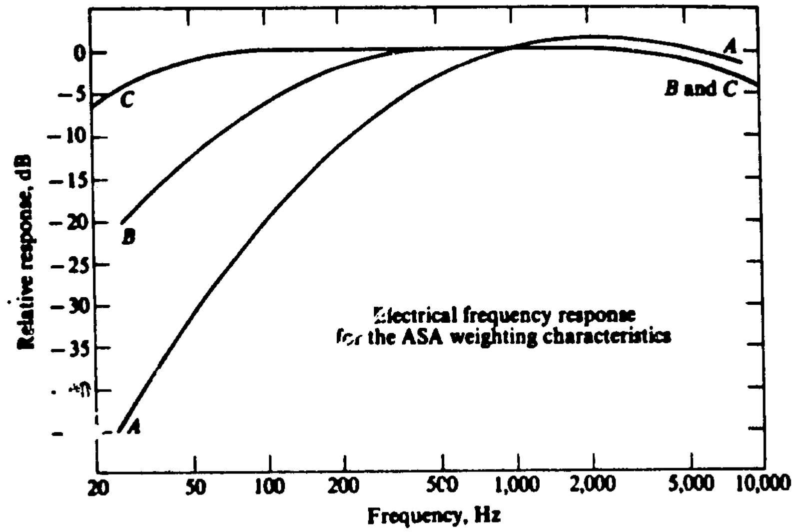

FIGURE 11-9
Frequency response curves of *A*, *B*, and *C* weighted networks on SPL meters. (*Source*: *A. P. G. Peterson and E. E. Gross, Jr.,* "*Handbook of Noise Measurement,*" *5th ed., p.* 8, *General Radio Co., West Concord, Mass.*, 1963.)

SPLs from 55 to 85 dB. The C response is quite flat from 40 to 6,000 Hz. It is used for SPLs above 85 db. It comes closest to indicating actual SPLs, as SPL is based on a flat response. When readings are not on the C network, the sound pressure should be recorded with the network letter as a suffix, as 50 dBA or 60 dBB. In the united States since 1969, the decibel A value has taken on added interest as permissible noise exposures of the Department of Labor are stated in exposure time in hours per day and decibel A sould level with the meter set for slow response (refer to Table 11-5).

Sound-level meters and sound analyzers are designed to measure steady noises with few interruptions. Impulse noises, as from a drop-hammer forge or a gun, require a different arrangement of the instrumental elements of microphone, amplifier, and read-out. The requirements depend on the frequency and the rise time to peak pressure of the impulse sound. Readout is usually by an oscillograph, as dial indicators are too slow and easily misread. Sonic boom from high-speed aircraft poses another measurement situation, as there is a time pattern described by a stretched out N with a compression peak and a rarefaction peak. What must be determined is the peak-to-peak pressure difference. Meaningful noise measurement requires the proper instrumentation in correct calibration on the hands of a skilled person (Refs. 11-8, pp. 18-28, and 11-10, pp. 40-51).

Effects of Noise

Information on effects of noise is best for hearing loss due to noise at work. Other effects of occupational noise, except speech intelligibility interferences, are less certain. These are changes in psychological and physiological states, including annoyance and sleep interruptions. The last two are the principal complaints against community and aircraft noise. Property damage by actual vibrational or boom destruction and by depreciation because noise paths and patterns impinge on the property is known, and is to some degree measurable and predictable. Effects on animals seem to have been studied very little. These effects are of concern for wildlife around airports and along highways, and for fish and wildlife in the pathways of sonic boom. In the first instances habitats may be lost, but the creatures have a chance to migrate and to reestablish beyond the reach of the noise. If there are bad immediate effects on those in the sonic boom paths, there is no escape time. Noise effects are examined as hearing changes and losses, interference with speech communication, annoyance and sleep interruption, other physiological and psychological responses, and the impairment of property values.

Two baselines are needed to evaluate hearing changes and losses ascribed to noise exposure. These are provided in Fig. 11-10 and 11-11. The first is the curve of auditory sensitivity. It indicates that very much higher SPLs are needed for hearing at frequencies below 400 and above 8,000 Hz. The human ear is most sensitive in the frequencies needed for hearing speech largely from 500 to 4,000 Hz. It is a marvelous product of evolution. Indeed, ears or hearing mechanisms of all animals are remarkable. A splendid account of these developments is in Ref. 11-11 (pp. 38-75). The second set of base lines, Fig. 11-11, shows the hearing-loss levels that come with age, presbycusis. For speech communications, the severe losses illustrated in the frequency curves of 12,000, 8,000, and 6,000 Hz are not of consequence, as these are above the speech frequencies. The importance of data on presbycusis in medical-legal evidences on losses ascribed to occupational exposure is evident. This holds particularly in United States workmen's compensation procedures, in which the awards are scaled to the extent of disability.

There are two types of hearing changes caused by noise exposure. Temporary threshold shift (TTS) is the lessened ability to hear weak auditory signals, from which there is recovery in a matter of hours and at most in 2 to 4 weeks. Noise-induced permanent threshold shift (NIPTS) is a loss from which there is no recovery. The relations between the two are not clear. It cannot be assumed that the second is an extension of the first in terms of changes in the auditory response system (Ref. 11-8, p. 40). For both conditions higher SPLs for long time periods increase severity. By its nature TTS has been easier to study. Some things that are known about TTS is that it increases linearly with the average noise level, from about 80 dB up to 130 dB. It is proportional to the fraction of time that the noise is pre-

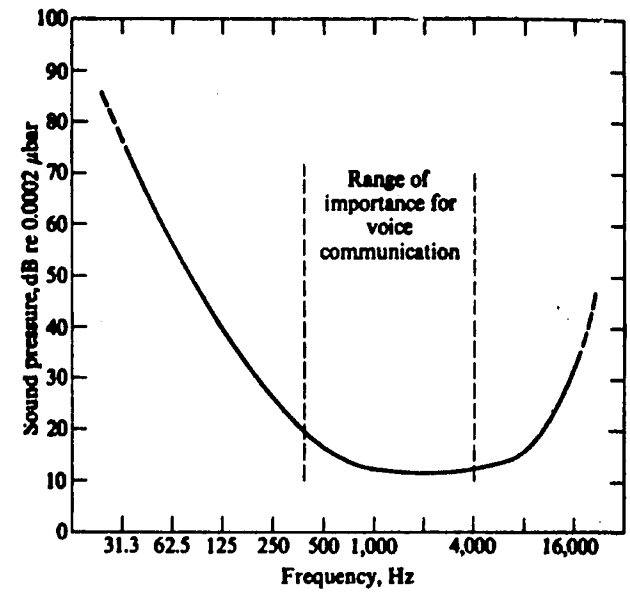

FIGURE 11-10
Curve of auditory sensitivity.

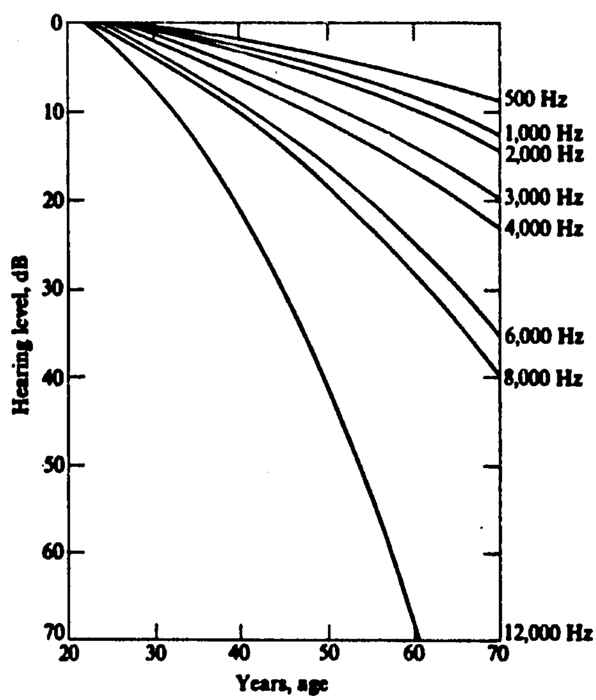

FIGURE 11-11
The relation between age and hearing level. [*Source*: *R. Hinchcliffe, The Pattern of the Threshold of Perception for Hearing and Other Special Senses as a Function of Age, Gerontologia,* 2:311 (1958).]

sent; therefore steady noise is the major offender. Noise with its maximum energy in the low frequencies produces less TTS than that at high frequencies. The locus in the ear structure of physiological impairment associated with TTS is specific, the hair cells of the cochlea. There is no treatment specific or palliative. The remedy is removal from the noise to allow recovery. Recovery is exponential, with the greater regains in the periods immediately after removal. For those with lossess less than 40dB, complete recovery within 16 hours is usual (Ref. 11-8, pp. 41, 42).

From extended observations several things can be said about NIPTS, a form of deafness (Ref. 11-8, pp. 44-47).

1 Exposures of 8 h/day for several years, to SPLs above 105 dBa are sure to produce NIPTS in a normal unprotected ear.
2 The first and most severe NIPTS is at frequencies in the neighborhood of 4,000 Hz. The ear transmits sound to the brain best at frequencies between 1,000 and 4,000 Hz. In this range more energy reaches the cochlea.
3 If there is going to be partial recovery of the loss, that is, if part of the loss is TTS, almost all such recovery will occur in 2 weeks. There will be some added recovery in a month. Single event injury, as a gun shot near the ear, may show recovery up to 2 months.
4 Noise-induced permanent threshold shift is not progressive after the person is removed from the noise. Neither is a noise-damaged ear more susceptible to further injury than a normal ear.
5 Regular exposure to moderate noise does not make the ear more resistant to occasional exposures to high-intensity noise. The ear does not toughen.
6 Susceptible individuals cannot be identified before they suffer hearing losses. Monitoring audiometry detects early NIPTS before it becomes severe.

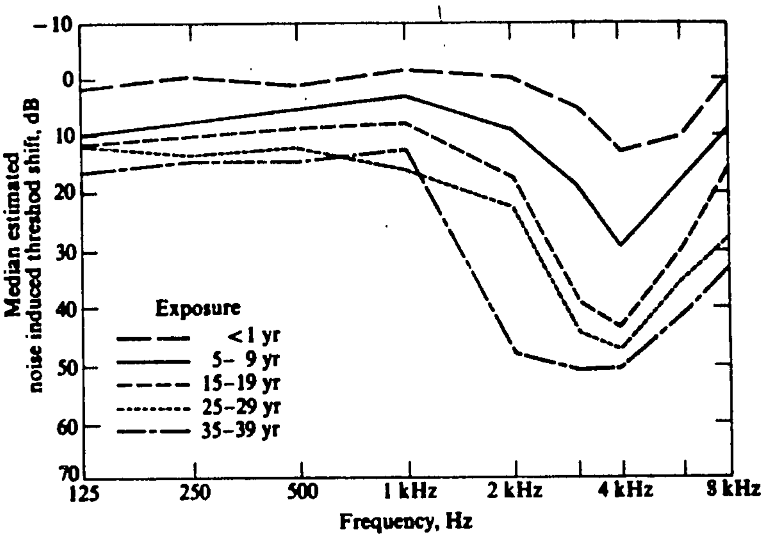

FIGURE 11-12
Median noise-induced hearing changes for jute weavers as a function of years of exposure. [*Source*: *W. Taylor et al., Study of Noise and Hearing in Jute Weaving, J. Accoust. Soc. Am.*, **38**:113 (1965).]

7 After onset, further NIPTS cannot be avoided by reducing the noise exposure. There is no way to restore loss from NIPTS.
8 In the occupational setting, NIPTS will appear in almost all men exposed 8 h/day to broadband noise above 105 dBA. It will appear in about 50 percent of those exposed similarly to a level of 95 dBA. It will not appear in anyone at a level below 80 dBA.

Figure 11-12 shows the characteristics of noise-induced hearing losses among workers in noisy operations. The maximum losses at 4,000 Hz and the increases with time of exposure are usual. Extensive and detailed data of a like sort for a variety of manufacturing operations in the federal prison industries were gathered by audiometric and environmental observations from 1953 to 1959. The operations produced overall noise levels of from 75 to 110 dB. Shifts in hearing level correlated well with duration and severity of exposure. It was greatest among the four noisiest operations in furniture making, the weave rooms of a cotton and a woolen mill, and the twist room of the cotton mill. The findings supported the damage-risk criteria that had been proposed up to that time for exposure to continuous spectrum noise (Ref. 11-12).

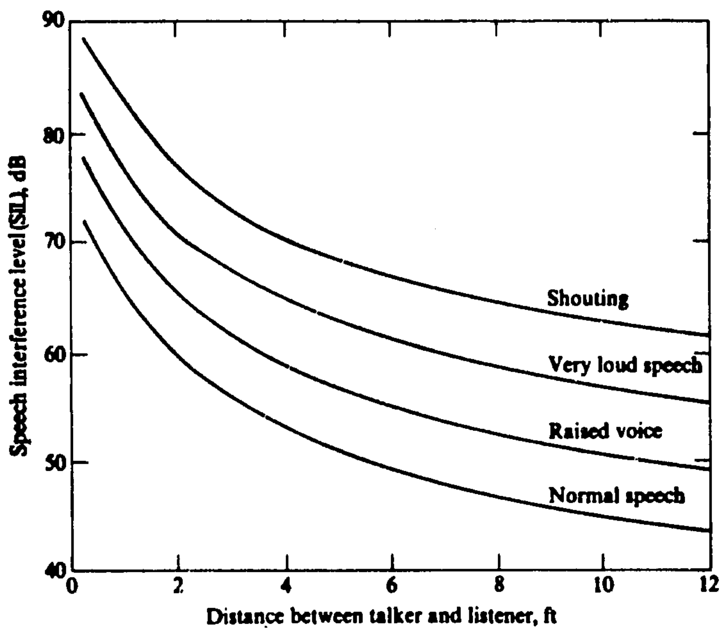

FIGURE 11-13
Transmission distances at four voice levels in the face of SILs of 40 to 90 dB.
[*Source*: "*Bioastronautics Data Book*," *NASA, SP*-3006, *p*. 301, 1964.]

Interference with speech communication by noise impedes our activities and understanding of one another at work, in the home, and in the general social scene. With the increase of the speed and power of machines in manufacture, construction, office work, on the highways, and in the home, the interference noise has become all pervasive. Those responsible for the success of electronic communication have given much effort to defining the speech interference level (SIL). It is the average SPL of noise in decibels in the three octave bands, 600 to 1,200 Hz, 1,200 to 2,400 Hz, and 2,400 to 4,800 Hz. These are the frequencies which carry a large part of our spoken words in the range of maximum auditory sensitivity. When the SIL is over 75 dB, a loud voice is needed to get the word more than 1 ft and telephone use is impossible. When the SIL is between 65 and 75 dB, a raised voice can pass the word about 2 ft. A loud voice would move it 4 ft, and a shout 8 ft. Telephone conversation is difficult at the 65 to 75 dB SIL. Things get better at the 55 to 65 dB SIL, with telephone conversation unimpaired. An SIL of 55 dB is tolerable in open office areas. A 45-dB SIL or lower is desirable for private offices and conference and class rooms. Figure 11-13 diagrams the transmission distance at four voice levels in the face of SILs of 40 to 90 dB. The real remedy is to quiet down the space in which interference is happening. There has been some use of sound-powered amplifiers used at close range. Amplifier system such as hearing aids are of no use, as the SIL is amplified along with the spoken word. In some bad situations, prearranged vocabularies and sign language are used, with writing as the last resort.

To venture into the annoyance effects of noise is to encounter the subjective response of people to noise head-on. Facts are few. Those collected by the questionnaire route are fraught with many biases, imposed by the questioners, the questioned, and finally the interpreter of the assembled answers. A brilliant example is the Oklahoma City, Oklahoma, study on resident reaction to sonic boom from a series of planned overflights at supersonic speeds. The questioners did their best to hold an objective stance throughout. The questioned showed acceptance at the start of the series, the posture of the "good sport." As the series wore on, their sportsman's view of the field experiment wore off and their attitude became increasingly antagonistic. The interpreters of the data, at least in press releases, saw a rosy picture in the data of community acceptance of being shook-up six to eight times a day by sonic boom. The U.S. Air Force claims officers see a greenish picture, the shade of the reverse side of our paper currency, paid out to satisfy, claims or to silence the raucous but spurious claimants. The British have reported community studies on responses to noise of multiple origins and from aircraft in airport zones (Ref. 11-10, pp. 99-107 and 206-234).

The central London noise survey of 1963 by field measurement supported the opinion surveys against street traffic noise. It predominated in 84 percent of 400 locations at which noise analyses were made. In the remaining 16 percent of the locations, the predominant noises were industrial, 7 percent, railway, 4 percent; building operations, 4 percent; and unclassified, 1 percent. The traffic noise reached 90 dBA, with diesel trucks the main source, followed by buses, and occasional motorcycles and sports cars. This 1963 survey was away from airport areas. These received separate attention.

At London's Heathrow Airport the nearly 200,000 aircraft movements per year in 1965 is expected to reach nearly 350,000 by 1975. The 1975 projected traffic requires nearly 1,000 landings and takeoffs per day. Small wonder that the planners for second airports for large cities encounter firm and furious resistance from public and private sources whenever a proposed site is revealed. The resident and property owner objections are to the noise, the annoyance, and the limitations of property use these impose. The Heathrow study of 1961, the start of the jet engine era, presaged what has come. Nearly 2,000 of the 1,400,000 residents within 10 mi of Heathrow were interviewed in depth, while on-the-ground noise from aircraft was measured at 85 locations. Figure 11-14 gives a statistical summation of the annoyance rating--from 1 equals "little annoyed" to 4 equals "very much annoyed"--of the PNdB (Perceived Noise in Decibels), and of three groupings of the number of overflights per day. Note that the latter numbers are rather few compared with what must now prevail in some sections of the Heathrow area. The figure is nevertheless much like Leo L. Beranek's graphic composit of four studies (Ref. 11-8). Beranek uses a descriptive annoyance scale from "noticeable" to "unbearable," a range of 20 to 40 overflights a day, and an outdoor PNdB of 80 to 130.

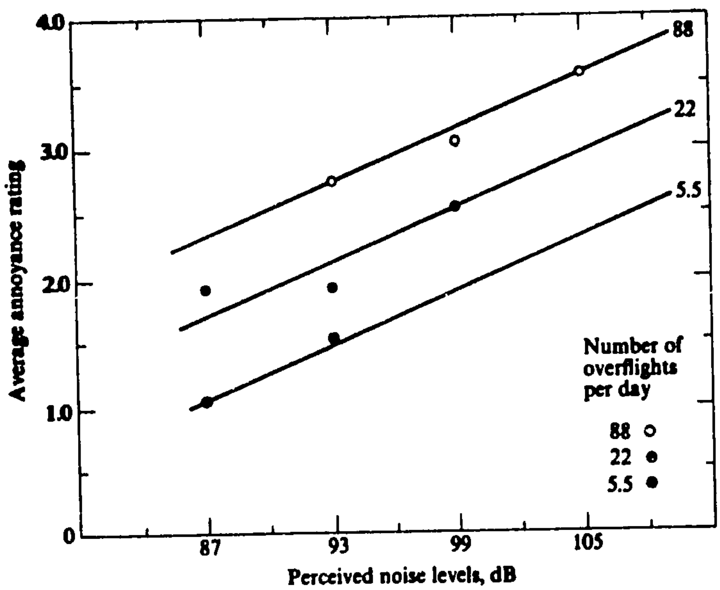

FIGURE 11-14
Relation between average annoyance and perceived noise levels from jet aircraft. (*Source*: *Ref.* 11-10, *p.* 225; *original from Committee on the Problem of Noise*, 1963, London.)

Beyond hearing loss and anoyance, what other noise effects have been considered? Four items are found in research reports on noise effects. There is not clear agreement on any of these. The reason is that there is a large network of an individual's whole personality, environmental adaptation, and value set involved in his real or imagined reaction to noise.

1 Disruption of sleep and rest is a common and accepted product of noise, particularly loud unexpected noise. At the other end of the scale is the drip, drip of the faucet and the second undropped shoe. There is the case of the window-air-conditioner noise in the bedroom being welcome to mask more distant noise sources. People accommodate to noise. Disruption results when an added or new noise penetrates the accommodation level.

2 Changes in work capacity or performance due to noise or its reduction has not been demonstrated in field studies, with one exception. That exception is for tasks requiring vigilance in monitoring instrument control panels. Under noisy conditions there is a loss of attentive response. The importance of this mounts as more tasks require responding to signals from automated systems. The results of some field studies have been in doubt or subsequently disproved because of lack of control group observations. Efficiency in complex tasks may be reduced initially by noise, but the loss is regained with exposure time and practice. There are favorable responses in morale, motivation, and attitude in worker groups when management shows concern for them. This response to noise reduction rather than the noise change itself may produce improved outputs. Because such factors enter, it has not been possible to determine cause-effect relations between noise reductions and such measureables as accident rates, absenteeism, and turnover (Ref. 11-9, p. N4-11).

3 There have not been any disease symptoms or physiological impairment attributable to noise other than hearing loss. There are responses such as pupil dilation, reduced blood flow to the skin owing to vasoconstriction, and temporary increase in blood pressure (Ref. 11-8, pp. 89-91). In part, these responses are in keeping with elemental alert and defense reactions to danger signals.

4 With physical signs of noise stress difficult to assess and very much in doubt, the much less measurable and indefinite mental signs or even behavioral signs of noise stress are wholly uncertain. W. Burns cites a U.S. Navy study among jet aircraft carrier crews to determine if noise increased the probability of signs of nervous conditions to which a man might be predisposed. No evidence to support the hypothesis was obtained (Ref. 11-8, pp. 113-114).

The hard facts readily available on the costs of property damage from noise is limited to the special case of sonic boom damage from U.S. Air Force supersonic flights over the continental United States. The Air Force procedures and experiences on sonic boom claims for the fiscal years, July 1 through June 30, 1956 through 1968, are summarized by W. F. McCormack (Ref. 11-8, pp. 270-277). The number of claims rose from 36 in 1956 to a peak of 9,574 in 1965, the year of the Oklahoma City test flights. The total claims for the 12 years were 38,483, for $22,209,000. Of these about one-third were approved in whole or in part for a total of about $1.5 million. The damages adjudicated were rather minor, covering broken or cracked glass, damage to plaster, and fallen objects. The Oklahoma City sonic-boom-effect tests required 1,253 supersonic flights in the first 6 months of 1964. The tests produced 4,901 claims for an average of $93 per claim, predominantly for glass and secondarily for plaster damage. Human injury from sonic boom is very infrequent and limited to being cut by glass or struck by falling objects. Domestic animal injury is also rare. No effects have been found on productivity of female animals or the hatchability of eggs. Any damage to egg shells is minimal. A high percentage of animal claims are for injury resulting from startle and occasionally panic among confined animals.

Acceptable Noise-Level Risks

The goal of studies of human effects from noise and of existing environmental noise levels is to determine a set of values which most people can accept, tolerate, or withstand with some indentifiable risk of impairment, speech interference, or annoyance. There has been agreement in the United States for such levels in the occupational setting. Table 11-5 states permissible noise exposure in the SPL-dBA for time periods of 8 to ¼ h/working day, or less. The noise exposure range is from 90 dBA for 8 hours to a maximum of 115 dBA for 15 min or less in an 8-hour working day. When occupational noise remains below these levels, nearly all workers may be repeatedly exposed to such noise without impairing their ability to hear and understand normal speech. Hearing impairment has been medically defined as an average hearing threshold level in excess of 25 dB at 500, 1,000, and 2,000 Hz. The permissible exposures have been adopted by the American Conference of Governmental Industrial Hygienists, and in 1971 were adopted by the Department of Labor for use under the Occupational Safety and Health Act of 1970.

Table 11-5 PERMISSIBLE NOISE EXPOSURES IN OCCUPATIONAL SETTINGS

Duration/day, h	Sound level, dBA
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

SOURCE: *Federal Register*, 34(96), Tuesday, May 20, 1969, Washington, D.C.

The noise readings are those observed in using a standard sound-level meter operating on the A weighting network with slow meter response. The exposure to impulsive or impact noises should not exceed 140 dBA peak sound pressure. K. D. Kryter notes that these permissible noise exposures appear to accept the risk of unlimited hearing losses at frequencies above 2,000 Hz, and that the use of the decibel A weighting leads to underestimates of relative damage risks to higher-frequency bands. He suggests the use of a decibel D weighting network, as it is more responsive from 2,000 to 10,000 Hz than the A weighting network (Ref. 11-13, pp. 159 and 162). The justification for using the decibel A readings is that many industrial noises are low frequency and that hearing losses above 2,000 Hz have not been considered in damage criteria for workmen's compensation in United States procedures. Meeting the permissible noise exposures will not remedy many speech interference situations. Shouting would be required at face-to-face range for speech communication in almost all environments just meeting the permissible noise exposures given in Table 11-5.

Table 11-6 RECOMMENDED NOISE LIMITS IN SWITZERLAND

	Background noise		Frequent peaks		Rare peaks	
Area	Night, dBA	Day, dBA	Night, dBA	Day, dBA	Night, dBA	Day, dBA
Health resort	35	45	45	50	55	55
Quiet residential	45	55	55	65	65	70
Mixed	45	60	55	70	65	75
Commercial	50	60	60	70	65	75
Industrial	55	65	60	75	70	80
Traffic arteries	60	70	70	80	80	90

Measurement with microphone at open window recommended.
Desirable values 10 dB less, but not more than 30 dB less.
Background noise: mean value (average noise value without peaks).
Frequent peaks: 7–60 peaks/h.
Rare peaks: 1–6 peaks/h.
SOURCE: Ref. 11-8, p. 101.

Defining community noise has moved from the rather crude surveys of the 1920 to 1940 period of isolated measurements and complaint compilations. Two parameters in use are the noise rating (NR) and the PNdB. From such measurements, suggested or recommended values for varying community situations are proposed. A very straightforward example without resort to these special parameters is given in Table 11-6. It is the result of the deliberations of a group of Swiss experts who were called upon by their government to provide a base for community planning, police action, and court judgments. The group recognized the compromises between scientific knowledge and the need for practical protective action (Ref. 11-8, p. 101). Note the differentiation among use of areas, for day and night levels, and among background, frequent-peak, and rare-peak noise levels, all on the decibel A scale. The notes below the table define the point of measurement and the terms used. The British Committee on the

Problem of Noise of 1963 recommended noise levels in decibel A for the inside of dwellings which should not be exceeded more than 10 percent of the time. These were grouped for three residential areas and for day and night as follows: country, 40 day, 30 night; suburban, 45 day, 35 night; busy urban, 50 day, 35 night. With a good quality of wall construction, these interior noise levels can be maintained between dwelling units of apartment buildings. Wall attenuations of 45 and 50 dB can be attained with proper materials and workmanship. This means a neighbor's 80-dB noise would be contained in his apartment. European building standards have been more specific in sound transmission requirements than those in use in the United States.

The NR scheme is of British origin. It has been proposed for adoption by the International Standardization Organization. Its application requires the use of a family of NR curves in which the decibel intercept at 1,000 Hz is the NR number. A recorded noise spectrum is given an NR by comparing it with the NR curves. The NR can be interpreted for particular situations by the use of two tables covering several room occupancy uses and corrections for differing swelling requirements (Ref. 11-10, pp. 115-120). The NR scheme has a number of applications. One is to predict community reaction to noise. Table 11-7 shows five levels of estimated community reaction for five ranges of corrected NR. Under present traffic patterns and motor vehicle design and condition, very few of our busy metropolitan commercial arteries will escape the last two reaction classifications, threats of community action and vigorous community action. Readings in five major intersections such as Times Square and Union Square in the Borough of Manhattan ranged from 64 to 76 dB. As there is habituation to existing noise, the introduction of a new noise, such as the transformer station, poses unpredictable resident responses. P. N. Borsky points out that very few annoyed people carry their serious complaints through formal official channels. In British and United States experience that number is from 6 to 10 percent, the tip of an iceberg of the actual number of annoyed citizens (Ref. 11-8, p. 191).

Table 11-7 ESTIMATED COMMUNITY REACTION AT FIVE RANGES OF CORRECTED NR

Estimated community reaction	Corrected NR
No observed reaction	Less than 40
Sporadic complaints	40–50
Widespread complaints	45–55
Threats of community action	50–60
Vigorous community action	Above 65

SOURCE: Ref. 11-8, p. 186.

Instruments measure the physical characteristics of sound. There is no instrumental measure of loudness, which is our subjective response to the sound energy reaching our ear and brain.

To measure or to find an equivalence scale of the sensation of loudness, three terms are in use, the phon, the sone, and the PNdB and an associated unit, the noy.

The phone expresses the loudness level, judged by listeners, hence subjective, to be equivalent in loudness to the SPL in decibels of a simple tone at 1,000 Hz. From compilations of many subjective responses, a graph of equal loudness contours has been constructed. The value in phons can be read for known octave band analyses in decibels. Figure 11-15 shows equal loudness contours in phons of 20 to 15,000 Hz (Ref. 11-10, p. 305).

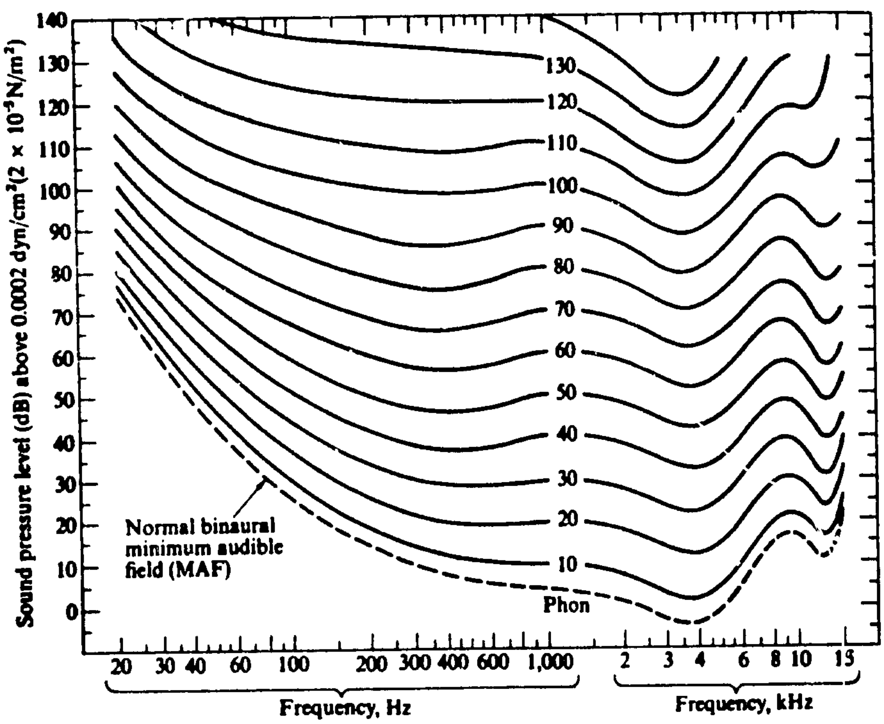

FIGURE 11-15
Equal loudness contours in phons for pure tones. [*Source*: *International Standardization Organization*, R226, 1961.]

The sone is a unit of loudness. It is defined as the loudness a listener perceives when hearing a simple tone at 1,000 Hz, 40 dB above threshold, an SPL of 40 dB. That loudness is 1 sone. Other sounds are then judged as twice as loud, 2 sones; as three times as loud, 3 sones, and so on. The loudness of 1 sone, as defined, equals 40 phons. For simple tones an average young person will indicate a 10-phon increase in loudness level for each 10-dB increase in SPL in frequencies from 600 to 2,000 Hz. Correspondingly, he will rate the sound as twice as loud, that is 2 sones. The usefulness of all this is the converse. The acoustic expert uses these responses and units to analyze complex sounds and to calculate their loudness. Figure 11-16 is a nomogram for converting from phons to sones. For a sample calculation on sones, see Ref. 11-10 (pp. 306-308).

The PNdB has been devised by Karl D. Kryter to cope with the noise annoyance from jet engines. Due to the high frequencies of jet noise, the overall SPL values do not correlate with the judgments of noisiness. Kryter's scale of "equal-annoyance contours" gives more weight to the high frequencies. The PNdB scale of noisiness is analogous to the sone scale of loudness. Kryter designates the unit as the noy with a base of 40 dB above threshold in a bandwidth of one octave rather than the simple tone of 1,000 Hz used for the sone. W. Burns provides a graph of contours of perceived noisiness in noys as adopted by the International Standardization Organization in 1966. The x axis is frequency in hertz. The y axis is in SPL in decibels. Burns gives a sample calculation illustrating how a frequency band analysis of jet aircraft noise is converted to PNdB. A table or a formula must be used to convert noy values to a PNdB number (Ref. 11-10, pp. 308-312). The Port Authority of New York has adopted 112 PNdB as the limiting noise from jet aircraft. The London Heathrow uses a 110 PNdB for day operations and a considerably lower value of 100 PNdB for night operations. These limits apply to ground-level readings during takeoff, made in residential areas nearest to the runways. Usually the planes are at an altitude of 600 to 1,200 ft when passing such monitoring points. Beranek states that perceived noise level in PNdB can be approximately by adding 13 dB to the decibel A reading of a standard sound-level meter. Such readings are at the maximum intensity of the noise which lasts only for a second (Ref. 11-8, pp. 256-275). At 112 PNdB, those dwelling near New York airports are far from rural quietude.

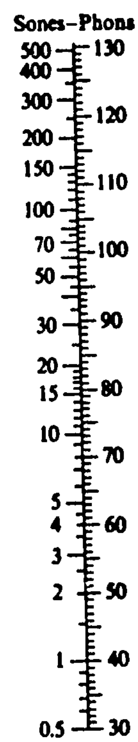

FIGURE 11-16
Nomogram for the conversion of phons to sones. [*Source*: *International Standardization Organization*, R532, 1967.]

The Rationale of Noise Control

There are three elemental approaches to noise control, reduction of vibrating sources, enclosure of the source, and attenuation by absorption after generation and release.

1 Noise is produced by an aerodynamic disturbance such as air moving in a duct, discharging from a pneumatic tool, and being pushed about along the surfaces of speeding cars and trucks, beat about by propellors, or squeezed and thermally expanded through jet engines. Or noise is generated by the vibration of structures purposefully set in motion, as an internal-combustion engine or the shuttle of a loom. Noise is also produced by a surface that is vibrating as it is connected to the moving parts of machinery, such as a fan housing or a mounting of a punch press or packaging machine. Control at the source then depends on altering the aerodynamic characteristics of the vibrating air by dimensional changes, by smoothing its flow to reduce turbulence, and by absorbent materials along its path. Control of vibrating surfaces requires choices of such alternatives as flexible materials in toto or at joints and mounts to limit vibration, or the use of solid rigid material of such mass that the sound energy cannot vibrate it. Other alternatives are the use of viscous frictional coatings such as car body undercoatings which resist vibratory motion, or the use of porous materials which absorb the mechanical and sound energy so that the surfaces vibrate very little if at all. In control at the source, attention is directed to the vibrating components which create the noise. Eforts by mechanical engineers, who design machinery, to moderate built-in noise have just begun. Equipment noise specification at the time of purchase is being more widely practices. It is more economical to pay more for quieter equipment than to pay to control the noise from it after installation and during use.

2 The escape of noise can be prevented by complete enclosure of the noisemaker. With provision for heat dissipation, motors and production machines can be put on vibration mounts and housed in sound-absorbent materials. Escape can be somewhat reduced by partial enclosure. Absorbent baffles at air inlets and outlets can reduce the escape of fan noise. Mufflers control the escape of exhaust air and gas noise partly by altering the aerodynamics and partly by absorbing existing vibrations.

3 The behavior of noise which has already been generated and which has escaped into a room can be modified. Acoustic characterisitcs which influence the behavior of emitted noise in a room are the absorption coefficients of surfaces exposed to the noise; the reverberation time which depends on the noise source and the room; and the transmission losses through the walls, floor, and ceiling. Acoustically, reverberation time of a room is the period required for any

sound to decrease by 60 dB after the source is cut off and absorption takes place. In practice the concern is for the steady state of noise that results from a steady source from which the room continuously absorbs a part of the radiated sound energy. In this dynamic state, reverberation time is measured to determine the average absorption characteristics of a room. This technique of control depends on reducing the noise level by improving the absorption characteristics of the room. Suspended absorbent baffles have been used in the always noisy weave rooms. Modification of wall and ceiling qualities is the principal procedure, and floors as well were change does not interfere with floor serviceability. Application of this approach is a demanding task for a skilled, experienced acoustic control expert.

The methods of noise control in the United States are well formulated for controlling industrial noise. The publication of the American Industrial Hygiene Association (Ref. 11-14) sets forth the procedures in principle and practice. The principles embrace plant planning; substitution of quieter equipment, processes, and materials; reduction at the source and reduction by transmission by air. Explanation of these tenets and thirty-three plates covering control of typical noisy machines and tools illustrate the practice. Community noise control has been dependent on zoning of land use and regulatory action on complaints. With traffic the dominant source of noise, more effective results would come from traffic routing and stricter control of major-artery planning, design, and material selection. Deflecting embankments and absorbing trees and shrubs are helpful. Noise transmission within buildings in the United States has worsened with the use of lightweight wall construction and extensive duct work for the widely used forced-air systems for space heating and cooling. Thin-section floors and ceilings have higher transmission of noise. The use of thin concrete pourings and precast panels make noise control between dwelling units of apartment buildings and from street and air space above less effective. Year-around air tempering has helped against outside noise by making it unnecessary to open windows for ventilation.

The Society of Automotive Engineers has standardized on a loudness level of 125 sones as a "new-vehicle standard" for trucks. Under most conditions of use it is doubtful that this will meet the proposed environmental sound level of 88 dBA measured 50 ft from the moving-vehicle source. Tire noise is a major contributor. New York State has a law limiting truck noise to 88 dBA with 2 dBA as a tolerance. The unresolved tire-noise problem has limited enforcement to speeds less than 35 mi/h! In 2 years, six summonses were issued where traffic exceeds 1,000 trucks per hour (Ref. 11-8, p. 310). Much remains to develop community demand for traffic noise control that compels action by officials, truckers, and manufacturers. To the credit of the Society of Automotive Engineers is their development of standards on sound levels for passenger cars, tractors, bulldozers, shovels, cranes, home lawn mowers, and power garden tools.

The issue of aircraft noise is summed up by Leo L. Beranek of Bolt, Beranek and Newman, acoustical consultants, in two statements (Ref. 11-8, pp. 263 and 269).

> The noise that residents of a neighborhood experience from aircraft flyovers may be reduced in varying amounts by a variety of methods:
>
> 1 Reduce the noise power generated by aircraft when the engines are operated at full thrust.
>
> 2 Require aircraft to reduce thrust and climb at a lower rate when above some minimum safe altitude and when over inhabited areas.
>
> 3 Turn aircraft away from residential areas during the climb-out phase of takeoff.
>
> 4 Institute preferential runway systems to direct aircraft away from communities.
>
> 5 Limit the number of operations and maintenance runups during nighttime hours (e.g., 11 p.m.-7 a.m.).
>
> 6 Increase the rate of climb or descent upon takeoff or landing.
>
> 7 Construct runways in directions away from noise-sensitive areas.
>
> 8 Soundproof and air-condition residences.
>
> In conclusion, I wish to emphasize that aircraft noise will not go away by itself. In the next 10 to 15 years the only possible, significant alleviation of annoyance will be through improved flight procedures and substantial modification of houses to exclude exterior noise.

Principles of Industrial Toxicology[a]

by

D. A. Fraser

General Considerations

This material has not been designed for physicians or others who have been specially trained in the field of industrial toxicology. Rather it has been prepared for the purpose of providing a certain amount of background for those non-specialists who may be called upon to understand and interpret data which are largely medical in nature.

Toxicology Defined. In simple terms, toxicology may be defined as the study of the action of poisons on the living organism. Industrial toxicology is concerned with the human organism and consequently lies within the broad field of medicine. Since medicine cannot be considered an exact science in the same sense that chemistry, physics or mathematics are so considered, toxicologic phenomena cannot always be predicted with accuracy or explained on the basis of physical or chemical laws. It is this unpredictability which frequently reduces conclusions and decisions to opinion rather than fact.

Poison defined. In attempting to define the term "poison", a major consideration is that of quantity or dosage. A poison may be defined as a substanfe which causes harm to living tissues when applied in relatively small doses. A clearcut distinction between poisonous and non-poisonous substances is not always easy to make.

Effective Dosage. Generally speaking, industrial toxicology is concerned with the effects of substance which gain entry into some part of the human body. Almost any substance can cause harm when applied directly to the skin. Among the factors which are concerned in effective dosage, the most important are:

1. Quantity or concentration of the material

2. Duration of exposure

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[a]Duplicated for the International Programs in Environmental Aspects of Industrial Development. Costa Rica, Guatemala, North Carolina and Salvador. 1975.

3. State of dispersion (size of particle or physical state, e.g. dust, fume, gas, etc.)

4. Affinity for human tissue

5. Solubility in human tissue fluids

6. Sensitivity of human tissues or organs

Obviously there are possibilities for wide variations in any of these factors.

Methods of expressing effective dosage:

1. Threshold Limit Values (TLV), formerly Maximum Allowable Concentration (M.A.C.).

   For gases and vapors the TLV value is usually expressed in parts per million (p.p.m.), that is parts of the gas or vapor per million parts of air.

   For fumes and mists, and for some dusts, the TLV is usually given as milligrams per cubic meter (mgm/m^3) or per ten cubic meters of air.

   For some dusts, particularly those containing silica the TLV is usually expressed as millions of particles per cubic foot of air (M.P.P.C.F.)

   TLV values have gained wide acceptance in industrial toxicology as a means of expressing concentrations of potentially harmful substances. They purport to represent the average amount of a substance to which persons may be exposed for eight hours a day for a period of months or years without danger to health.

   Literal acceptance of this concept is fraught with great danger for the following reasons:

   a. A great majority of all published TLV values are based either on speculation, opinion or limited experimentation on rats, mice, guinea pigs or other laboratory animals. In very few isntances ahve the values been established firmly on a basis of examinations of human subjects correlated with adequate environmental observations.

   b. Concentrations of dangerous materials in any working environment rarely remain constant throughout a work day. The occurrence of "surges" is well known.

   c. Industrial exposures frequently involve mixtures rather than single compounds. Very little is known about the effects of mixtures.

d. Individuals vary tremendously in their sensitivity or susceptibility to toxic substances. The factors controlling this variability are not well understood. It is dangerous to assume that conditions which are safe for some individuals will be safe for all.

e. For some substances, concentrations which may be considered "safe" may still result in discomfort or annoyance.

f. A single TLV value is usually given for substances which occur in the form of salts or compounds of different solubility or in different physical states (e.g., lead, mercury).

If these limitations of TLV's are understood and accepted, the published TLV values can be used to great practical advantage. The principal usefulness is found in connection with the design of ventilating equipment. It should not be assumed, however, that attainment of concentrations at or even below the published TLV limits will necessarily prevent all cases of occupational poisoning, nor should it be assumed that concentrations which exceed the given limits will necessarily result in cases of poisoning. The concept known as Haber's Law, which involves the product of concentration and time (C x T = K), expresses an index of the degree of toxic effect. This, too, may be misleading since little is known of the relative effectiveness of large doses over a short period of time as compared with smaller doses over a longer time period.

2. Minimal lethal dose and LD50.

In experimental toxicology it is common practice to determine the quantity of poison per unit of body weight of an experimental animal which will have a fatal effect. (A scale commonly used is milligrams of poison per kilogram of body weight). That amount per unit of body weight which will kill an experimental animal under certain standard conditions is known as the minimal lethal dose (M.L.D.). A more commonly used figure in experimental industrial toxicology is the amount which will kill one half of a group of experimental animals. This is known as the LD50, representing 50 percent fatalities.

The Manufacturing Chemists Association bases its definition of the term "poison" on the LD50 test. In its publication entitled "Warning Labels" (6th edition, 1961) it states the following: "Poison: A substance or mixture of substances which falls within any of the following categories.

(a) Produces death with 14 days in half or more than half of a group of 10 or more laboratory white rats weighing 200-300 grams at a single dose of 50 milligrams or less per kilogram of body weight, when administered orally; or

(b) Produces death within 14 days in half or more than half of a group of 10 or more laboratory white rats weighing 200-300 grams, when inhaled continuously for a period of one hour or less at an atmospheric concentration of 200 ppm. or 2 milligrams or less per liter of gas, vapor, mist, or dust, provided such concentration is likely to be encountered by man when the substances are used in any reasonable foreseeable manner; or

(c) Produces death within 14 days in half or more than half of a group of 10 or more rabbits tested in a dosage of 200 milligrams or less per kilogram body weight, when administered by continuous contact with the bare skin for 24 hours or less.

"If available data on human experience with any substance in the above named concentrations indicate results different from those obtained on animals, the human data shall take precedence in any classification of a substance as poisonous."

The official U.S. Governmental concept of hazard rating is set forth in Federal Hazardous Substances Labelling Act which became fully effective in 1962. In this act, a substance is considered "highly toxic" if it has the characteristics described above in the Manufacturing Chemists Association definition of a poison. (See above) A toxic substance is defined as follows:

"(1) Any substance that produces death within 14 days in one-half of a group of white rats each weighing between 200 grams and 300 grams, at a single dose of more than 50 milligrams per kilogram but not more than 5 grams per kilogram of body weight, when orally administered.

"(2) Any substance that produces death within 14 days in one-half of a group of white rats each weighing between 200 grams and 300 grams, when inhaled continuously for a period of 1 hour or less at an atmospheric concentration of more than 200 parts per million but not more than 20,000 parts per million by volume of gas or vapor or more than 2 milligrams but not more than 200 milligrams per liter by volume of mist or dust, provided such concentration is likely to be encountered by man when the substance is used in any reasonably foreseeable manner.

"(3) Any substance that produces death within 14 days in one-half of a group of rabbits weighing between 2.3 kilograms and 3.0 kilograms each, tested at a dosage of more than 200 milligrams per kilogram of body weight, when administered by continuous contact with the bare skin for 24 hours.

"The number of animals tested shall be sufficient to give statistically significant results and be in conformity with good pharmacological practice.

"(4) Any substance that is 'toxic' (but not 'highly toxic') on the basis of human experience."

3. "Range Finding" Tests

This approach to determining and expressing the degree of toxicity of chemicals used in industry has been developed primarily by H. F. Smyth, Jr., and his collaborators. Its greatest usefulness is in testing new compounds for which no toxocological information exists. The basis of the test is a comparison of the potency of an unknown compound with that of a more familiar material. This is possible since there are a number of chemicals for which fairly extensive toxicological data are already available. By this technique a certain amount of valuable information can be obtained within a space of about three weeks.

4. Hazard Rating

This term is used in the present notes to indicate in a general way whether a material has high, moderate, or slight toxicity or has no poisonous properties at all. This is obviously a somewhat crude method of expressing toxicity, but is of value as a rough guide to be followed until further information can be obtained.

The hazard ratings of industrial chemicals are based on an interpretation of all available data, particularly TLV, LD50, and Range Finding data.

5. Maximum Acceptable Concentration used by American Standards Assn. is more restrictive than TLV. It signifies a value which should not be exceeded at any time. (The term "Acceptable Concentration Standard" is now used by the A.S.A.)

Hazard ratings based on acute, single exposure experiments may be misleading since it cannot always be assumed that a large amount of a toxic agent is more dangerous than a small amount. (See below under Individual Susceptibility.)

Classes of Toxic Substances

Toxic or harmful substances encountered in industry may be classified in various ways. A simple and useful classification is given below, along with definitions adopted by the American Standards Association.

1. Dusts: Solid particles generated by handling, crushing, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rocks, ore, metal, coal, wood, grain, etc. Dusts do not tend to flocculate except under electrostatic forces, they do not diffuse in air, but settle under the influence of gravity.

2. Fumes: Solid particles generated by condensation from the gaseous state, generally after volatilization from molten metals, etc., and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

3. Mists: Suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, and atomizing.

4. Vapors: The gaseous form of substances which are normally in the solid or liquid state and which can be changed to these states either by increasing the pressure or decreasing the temperature alone. Vapors diffuse.

5. Gases: Normally formless fluids which occupy the space of enclosure and which can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature Gases diffuse.

This classification does not include the obvious categories of solids and liquids which may be harmful nor does it encompass physical agents. The latter, strictly speaking, cannot be considered "substances". Living Agents, such as bacteria, molds, and other parasites comprise another group of "substances" that would appear in a comprehensive classification of industrial health hazards.

Routes of Absorption

In the physiologic sense, a material is said to have been absorbed only when it has gained entry into the blood stream and consequently is carried to all parts of the body. Something which is swallowed and which later is excreted more or less unchanged in the feces has not necessarily been absorbed, even though it may have remained within the gastro-intestinal tract for hours or even days. The industrial toxicologist is concerned primarily with three routes of absorption or portals of entry through which materials may enter the blood stream: the skin, the gastro-intestinal tract and the lungs.

Absorption through the skin: Those who are familiar with the history of medicine will recall that before the introduction of modern methods in the treatment of syphilis a part of the standard therapy consisted of mercury injunctions. The effectiveness of this treatment depended on the fact that certain forms of mercury could be absorbed throughthe intact skin. Today it is recognized that skin absorption may be a significant factor in occupational mercury poisoning as well as in a number of other industrial diseases. In the case of metals other than mercury, entry through the skin is relatively unimportant except for some of the organic compounds such as tetraethyl lead.

Skin absorption attains its greatest importance in connection with the organic solvents. It is generally recognized that significant quantities of these compounds may enter the body through the skin as a result either of direct accidental contamination or indirectly when the material has been spilled on the clothing. An additional source of exposure is found in the fairly common practice of using industrial solvents for removing grease and dirt from the hands and arms, in other words, for washing purposes. This procedure, incidentally, is a fruitful source of cases of dermatitis.

Gastro-intestinal absorption: It has already been suggested that the mere fact that something has been taken into the mouth and swallowed does not necessarily mean that it will be absorbed. Naturally, the less soluble the material is, the less is the likelihood of absorption. In the past it has been common practice to attribute certain cases of occupational poisoning to uncleanly habits on the part of the victim, particularly failure to wash the hands before eating. There is no doubt that some toxic materials used industrially can be absorbed through the intestinal tract but it is now generally believed that with certain notable exceptions this portal of entry is of minor importance. One outstanding exception is the case of the radium dial painters who followed the practice of "pointing" their brushes between their lips, thus ingesting lethal quantities of radio-active material. Accidental swallowing of harmful amounts of poisonous compounds in single large doses has also been known to occur. In general it can be said that the "dirty hands" theory of poisoning has been pretty well discredited.

Absorption through the lungs: The inhalation of contaminated air is by far the most important means by which occupational poisons gain entry into the body. It seems safe to estimate that at least ninety percent of all industrial poisoning (exclusive of dermatitis) can be attributed to absorption through the lungs. Harmful substances may be suspended in the air in the form of dust, fume, mist or vapor, and may be mixed with the respired air in the case of true gases. Since an individual under conditions of moderate exertion will breathe about ten cubic meters of air in the course of an ordinary eight hour working day it is readily understood that any poisonous material present in the respired air offers a serious threat.

Fortunately all foreign matter which is inhaled is not necessarily absorbed into the blood. A certain amount, particularly that which is in a very finely divided state, will be immediately exhaled. Another portion of respired particulate matter is trapped by the mucus which lines the air passages and is subsequently brought up in the sputum. (In this connection it might be mentioned that some of the sputum may be consciously or unconsciously swallowed thus affording an opportunity for intestinal absorption.) Other particles are taken up by "scavenger cells" following which they may enter the blood stream or be deposited in various tissues or organs. True gases will pass directly from the lungs into the blood in the same manner as the oxygen in inspired air. Because of the fact that a great majority of the known industrial poisons may at some time be present as atmospheric contaminants and thus constitute a potential threat to health, programs directed toward the prevention of occupational poisoning generally place major emphasis on some form of ventilation to reduce the hazard.

Storage and Excretion

Relatively little is known about storage depots of industrial chemicals other than that lead tends to accumulate in the bones and inorganic mercury in the kidneys. Transport mechanisms have not been extensively studied. Particulate matter when inhaled can be phagocytosed and remain in the regional lymph nodes where it may have little effect as in the case of coal dust or may produce pathological changes as in the case of silica and beryllium.

Excretion of heavy metals is usually studied only in the urine. This may be due in part to the relative ease of sampling and analysis. Nobody enjoys analysing feces. Sweat, saliva, bile, milk are not easy to collect for analysis. Gases and volatile vapors are commonly excreted via the lungs. This can be used as a measure of earlier absorption.

Acute and Chronic Effects

Industrial toxicology is generally concerned with the effects of low-grade sub-lethal exposures which are continued over a period of months or years. It is, of course, true that toxicological problems are not infrequently presented as a result of accidents which create sudden massive exposure to overwhelming concentrations of toxic compounds. The acute poisoning which results may cause unconsciousness, shock or collapse, severe inflammation of the lungs or even sudden death. An understanding the nature of the action of the offending agent may be of great value in the treatment of acute poisoning but in some instances the only application of toxicological knowledge will be establishing the cause of death.

The detection of minute amounts of toxic agents in the atmosphere and in body fluids (blood and urine) and the recognition of the effects of exposure to small quantities of poisons is among the principal jobs of the industrial toxicologist. The manifestations of chronic poisoning are often so subtle that the keenest judgment is required in order to detect and interpret them. The most refined techniques of analytical chemistry and of clinical pathology are called into play, involving studies of the working environment and of exposed individuals.

In order to demonstrate that chronic industrial poisoning has taken place or is a possibility it must be shown that an offending agent is present in significant concentrations, that it has been absorbed and that it has produced disturbances in the exposed subject. Significant concentrations are commonly expressed in terms of Threshold Limit Values (TLV). Absorption of a substance may be proven by demonstrating its presence in the blood or urine in concentrations above those found in non-exposed persons, or by finding certain metabolic products in the excreta. To prove that disturbances have occurred in an exposed subject may require the application of all of the diagnostic procedures used in medicine. This includes a medical history, physical examination, blood counts, urinalysis, x-ray studies and other measures.

A few of the more widely used industrial chemicals, notably lead and benzene, will produce changes in the blood in the very early stages of poisoning. Other chemicals, particularly chlorinated hydrocarbons, give no such early evidence of their action. Heavy metals such as mercury and lead produce their chronic harmful effects through what is known as "cumulative action". This means that over a period of time the material which is absorbed is only partially excreted and that increasing amounts accumulate in the body. Eventually the quantity becomes great enough to cause physiologic disturbances. Volatile compounds do not accumulate in the body but probably produce their chronic toxic effects by causing a series of small insults to one or more of the vital organs.

Site of Action of Poisons

Brief mention has already been made of the fact that different poisons act on different parts of the body. Many substances can produce a local or direct action upon the skin. The fumes and mists arising from strong acids, some of the war gases and many other chemicals have a direct irritating effect on the eyes, nose, throat and lower air passages. If they reach the lung they may set up a severe inflammatory reaction called chemical pneumonitis. These local effects are of greatest importance in connection with acute poisoning. More important to the industrial toxicologist are the so-called systemic effects.

Systemic or indirect effects are those which occur when a toxic substance has been absorbed into the blood stream and distributed throughout the body. Some materials such as arsenic, when absorbed in toxic amounts, may cause disturbances in several parts of the body: blood, nervous system, liver, kidneys and skin. Benzene, on the other hand, appears to affect only one organ, namely, the blood-forming bone marrow. Carbon monoxide causes asphyxia by preventing the hemoglobin of the blood from carrying out its normal function of transporting oxygen from the lungs to the tissues of the body. Although oxygen starvation occurs equally in all parts of the body, brain tissue is most sensitive to this insult; consequently the earliest manifestations are those due to damage to the brain. An understanding of what organ or organs can be damaged, and the nature and manifestations of the damage caused by various compounds is among the more important functions of the industrial toxicologist.

At the cellular level, toxic agents may act on the cell surface or within the cell, depending on "receptors" or binding sites. A familiar example is the affinity of arsenic and mercury for sulfhydryl (S-H) groups in biological material.

"Individual Susceptibility"

The term "individual susceptibility" has long been used to express the well known fact that under conditions of like exposure to potentially harmful substances there is usually a marked variability in the manner in which individuals will respond. Some may show no evidence of intoxication whatsoever; others may show signs of mild poisoning while still others may become severely or even fatally poisoned. Comparatively little is known about the factors which are responsible for this variability. It is believed that differences in the anatomical structure of the nose may be concerned with different degrees of efficiency in filtering out harmful dusts in the inspired air. Previous infections of the lungs, particularly tuberculosis, are known to enhance susceptibility to silicosis. Most industrial toxicologists believe that obesity is an important predisposing factor among persons who are subject to occupational exposure to organic solvents and related compounds. Age and sex are also believed to play a part and previous illnesses may be significant.

Other possible factors relating to individual susceptibility are even less well understood than those just mentioned. It has been suggested that different rates of working speed, resulting in variations in respiratory rate, in depth of respiration and in pulse rate may play a part. The action of the cilia, those tiny hairs which are present in the cells which line the air passages, may have some importance. The permeability of the lungs may influence absorption and the efficiency of the kidneys may govern the rate at which toxic materials are excreted, but the underlying nature of these possible variations is not at all known.

There is considerable literature purporting to show that nutritional factors may have something to do with susceptibility to occupational poisoning. Most of the published material is rather unscientific and unconvincing but a few reports recently published strongly suggest that there actually exists a relationship between the nature of the diet and susceptibility to poisoning. There is as yet no substantial evidence that the addition of vitamin concentrates or special foods will have protective value, but when diets are deficient in some of the essential nutritional elements it appears that poisoning is more likely to occur. There is considerable evidence that indulgence in ethyl alcohol will significantly increase the possibility of occupational poisoning occurring, particularly from organic solvents.

Other "host factors" that may play a role in "individual susceptibility" are endocrine status, genetic make-up (heredity), intestinal flora and personal hygiene.

Toxicity by Analogy

Because of the paucity of toxicological information on many chemical compounds used in industry there frequently is a tendency to assume that compounds which are closely related chemically will have similar toxic properties. While this may be true for a limited number of substances it is by no means universally true.

As mentioned elsewhere, many chemical compounds, when absorbed by the body, undergo a series of changes (detoxication processes) before they are excreted. The intermediary products depend largely on the chemical structure of the original material, and minor differences in structure may result in totally different intermediary and end products. This principle is well illustrated in the case of benzene and toluene, which are closely related chemically but whose metabolism is dissimilar. The degree of toxicity of the two is also very different. For some chemicals, e.g. methanol, metabolic intermediates may be responsible for important toxic effects.

When a person is exposed to a mixture of chemicals, there is always the possibility of combined action. This may enhance or diminish toxic response.

Absorption vs. Poisoning

As mentioned above, with the exception of external irritants, toxic substances generally must be absorbed into the body and distributed through the body by means of the blood stream in order for poisoning to occur. In other words, poisoning ordinarily does not occur without absorption. On the other hand, absorption does not necessarily or always result in poisoning. The human body is provided with an elaborate system of protective mechanisms and is able to tolerate to an amazing degree the presence of many toxic materials. Some foreign materials are excreted unchanged through the urine and feces. Toxic gases, following absorption, may be given off through the lungs. Some chemical compounds go through processes of matabolism and are excreted in an altered form. Some of these processes are known as detoxication (or detoxification) mechanisms. In some instances the intermediary products in a detoxication process may be more toxic than the original substance, e.g. formic acid and formaldehyde from methyl alcohol.

Since absorption must precede poisoning, the question often arises as to where the dividing line between absorption and poisoning is to be drawn. An answer to this question frequently entails considerable difficulty. There is no doubt that when absorption reaches a point where it causes impairment of health, poisoning has occurred. Impaired health manifests itself by the presence of altered structure, altered function, or a combination of the two. These impairments, in turn, result in abnormal symptoms, abnormal physical or laboratory findings, or combinations of these.

When absorption has produced both abnormal symptoms and abnormal objective findings there is no question that poisoning has occurred. In the opinion of the writer, absorption which produces objective evidence of altered structure or function should also be called poisoning, even though there may be no abnormal subjective symptoms. When subjective symptoms constitute the only basis for distinguishing between absorption and poisoning, the distinction becomes a matter of medical opinion requiring individual evaluation.

Causal Relationship and Competent Producing Cause

The industrial toxicologist frequently becomes involved in medico-legal problems, since actual or suspected cases of occupational disease often result in workmen's compensation claims or negligence suits. A successful legal action on the part of a claimant or plaintiff depends upon his ability to demonstrate, usually through medical or other expert testimony, that occupational exposure caused harm to his health.

A competent producing cause is one which conceivably could have produced the harmful effect. It involves possibility.

Causal relationship exists when a competent producing cause actually did produce the harmful effect. It involves probability.

Medico-legal cases are usually adjudicated on the basis of opinion, because of the fact that medicine is not an exact science. It has been said, and truthfully, that in medicine anything can happen. Decisions then, must be made on the basis of the most probable explanation of a set of circumstances. Medical opinion, to be convincing, must be based on actual facts or observations, but the same set of facts or observations may be subject to more than one interpretation. Hence the importance of opinion.

Workmen's compensation laws are usually written or interpreted in such a way that in cases of doubt (sometimes reasonable doubt) a decision is rendered in favor of the claimant. Socially this is probably correct, at least in theory. This practice, however, tends to place the burden of proof on the defendant rather than on the claimant. Competent producing cause is all too often considered to be synonymous with causal relationship. Often it devolves upon a defendant to attempt to prove that a competent producing cause was in fact not the actual cause of an illness. Obviously this may entail considerable difficulty. It is not sufficient for the defendant merely to deny the existence of causal relationship. Successful defense requires an opinion (diagnosis) other than that of an occupational disease which will provide a more convincing explanation of the observed facts. Often this requires the highest degree of diagnostic acumen as well as the most astute legal procedure.

Principles of Prevention

Any effective program for the prevention of occupational poisoning depends on teamwork. Key members of the preventive team are the industrial physician with his knowledge of toxicology, the industrial hygiene engineer with his understanding of control measures, and the chemist who provides basic analytical data. The industrial nurse because of her intimate contact with employed personnel, often provides the first clue to the existence of a potentially dangerous situation. Safety men and supervisors also play an important part, while a well-informed working force, instructed to recognize danger signs, constitutes an additional safeguard.

It was pointed out above that an understanding of the basic principles of industrial toxicology is fundamental in any program of prevention. One must know what materials can cause poisoning and the relative toxicity of various compounds and groups of compounds. Another essential is an understanding of how toxic substances are absorbed, and the relative importance of the various routes of absorption. Realization of the fact that inhalation is the principal mode of entry means that preventive measures will be directed mainly toward reducing atmospheric contamination. For protection against chemicals that can be absorbed through the skin, suitable impervious gloves and work clothing can be provided.

Although very little is known about "individual susceptibility", the few facts which are available may be helpful in selectively placing certain persons in jobs where their age, sex, state of nutrition or previous illnesses will not constitute any extra threat to their well-being. Thorough familiarity with the so-called maximum allowable concentrations, their interpretation and applications is essential for the engineer who is called upon to design ventilation systems. All who are concerned with a preventive program must know that months or years of exposure may elapse before toxic manifestations appear, and the physical in particular must be prepared to detect and recognize the earliest evidences of poisoning. Failure to apply these few fundamentals may be costly not only in terms of lost production and lost income but also in terms of health and even of life.

Preventive procedures are often spoken of as falling into two major categories: (1) medical control and (2) engineering control.

1. Medical control. This term is used to describe those procedures which are applied to the employed person. It includes:

   (a) Preplacement physical examinations. One purpose of these examinations is to protect workers with unknown susceptibility against any potentially harmful exposure. An individual found to have healed pulmonary tuberculosis, for example, should not be placed in a job entailing exposure to silica dust nor should one with former liver disease be exposed to chlorinated hydrocarbons.

(b) Periodic examinations. A major purpose of these is to detect any existing evidence of poisoning at an early stage when corrective measures can be expected to result in complete recovery. Correction may call for improved industrial hygiene practices, for temporary or permanent change of job assignments or both of these.

(c) Education. The purpose of this is, to inform workers and supervisory personnel of the nature of any potentially harmful materials with which they may come in contact. An informed working force may be expected to accept and observe recommended precautionary measures.

(d) Personal protective devices. With few exceptions, personal protective devices should be relied upon only when the application of engineering measures offers insurmountable difficulties. Protective clothing is usually worn to prevent injuries and so will not be discussed.

Protective masks have been widely used, (or rather misused) to reduce the inhalation of potentially harmful dusts, fumes, vapors, mists and gases. In general it can be said that reliance on masks is justified only when exposures are of short duration (minutes) and low frequency (10-20 times daily).

Protective masks or respirators obviously should be properly selected for the purpose for which they are intended. To be effective they must be individually fitted to the user. In the filter or canister types the filtering units must be replaced regularly and with adequate frequency. A program of regular cleaning, repairing and replacing of worn out parts is highly desirable. Those who are obliged to wear respirators or masks should be fully instructed as to proper use and maintenance. Unless these rules are followed it cannot be said that masks and respirators are being properly used and it might be preferable not to use them at all.

2. <u>Engineering Control</u>. In this category are included those procedures which are applied to the working environment rather than to the individual. The most important engineering control measures are:

(a) Substitution of a less toxic in place of a more toxic material, when this is possible technologically. Common examples of this approach are the use of steel shot in place of silica sand in sand blasting.

(b) Enclosure of a process. This has its widest application in the chemical industries where frequently it is possible and practicable to design totally enclosed systems for carrying out the manufacture or processing of chemical compounds.

(c) Segregation, which may be accomplished by confining a potentially dangerous process to a segregated or enclosed area to prevent contamination of adjacent work spaces. In some situations segregation can be accomplished by locating a process in an open shed or even completely out of doors.

(d) Ventilation, which is perhaps the most important engineering control measure. Ventilation may be general or local. General ventilation consists in rapid dilution of contaminated air with fresh air usually by fans located in windows or overhead in work areas. Fans or blowers may operate by bringing fresh air into a space, thus forcing contaminated air out through natural openings such as doors and windows, or by drawing off contaminated air thus creating a partial vacuum which is filled by the entry of fresh air. Unpleasant drafts of air, particularly near open doors and windows, are sometimes produced when natural ventilation is produced in large volume.

Local ventilation usually consists in providing air suction close to the point where potentially harmful dusts, fumes, vapors, mists or gases are generated. This permits removal of the contaminants with relatively small quantities of air and prevents contamination of adjacent work spaces. Collection and disposal of contaminants removed by local exhaust ventilation sometimes presents a major engineering problem. In some processes, especially those involving the use of volatile chemicals, it is common practice to install a recovery system as part of the ventilating equipment. This may result in savings sufficient to defray the cost of installing and operating the vnetilating system.

(e) Wetting. The use of water to limit the dispersal of atmospheric contaminants finds its chief application in the control of dust. This procedure is widely used in rock-drilling and it is also useful when sweeping is done in a dusty work-room.

(f) Neutralization or inactivation of chemical compounds is sometimes useful in connection with local exhaust ventilation and in cleaning up contaminated areas.

(g) General housekeeping procedures, while perhaps the simplest of all control measures, is none-the-less extremely important and valuable. Regular clean-up schedules, particularly where dust is a problem, are essential in any control program.

In addition to the specific procedures just enumerated, it is often important to conduct regular appraisals of the working environment by means of dust counts, air analyses and similar tests, thereby checking on the effectiveness of the preventive measures.

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THE ENVIRONMENT AND THE INDUSTRIAL WORKER[a]

by D. A. Fraser

Industrial Hygiene has been defined as "The science and art concerned with the recognition, evaluation and control of those hazards to health that arise from the work place". The realization that work may involve certain risks and indeed may result in illness or traumatic injury is not new. Indeed in 400 B.C. Hippocrates described cures of lead poisoning in men engaged in refining metals. And in 600 A.D. Pliny the Elder recommended the use of masks made from the bladder of animals to protect workers refining from noxious fumes and mists. An Italian physician Bernardo Ramazzini published the first text on Industrial Medicine entitled "De Moribas Artificum Diatriba" in 1700. It was not until the early 19th century that laws concerned with the well being of workers began to appear in Great Britain: "The Health and Morals of Apprentices" - 1802, "Child Labor Laws" - 1833, "Protection of Health of Workers" - 1901. The Swiss in 1881 enacted a Workman's Compensation Law and were immediately followed by many other European nations. The first such act in the United States was passed in 1911 by the state of Wisconsin and by 1920 42 States had followed this lead. These laws, it should be noted, were concerned only with compensating the worker after an injury occurred.

In 1914 the United States Government faced with World War I and the need to conserve manpower in the defense industries created a Division of Occupational Health within the Public Health Service. The activities of this Division were further stimulated by the need for conservation and the control of disease and injury during World War II. Other Federal Laws applying to particular industries or groups of workers were enacted during this period but the motivation appears to have been principally economic and social conscienceness had not developed to the point of prevention or great concern for the workers. Apart from workmen's compensation the recourse of an injured worker was through a civil suit and the English Common Law defenses of (1) the worker assumed the known risk of the job, (2) the worker's own negligence contributed to the accident, (3) there was negligence on the part of a fellow employee, were perfectly valid defenses. The first industrial hygienists were usually physicians concerned with the diagnosis of strange and exotic diseases and seeking the cause of these illnesses in the work environment. As the causes

[a]International Program in Environmental Aspects of Industrial Development, 1975.

were found the need to quantitate exposures and to recommend control measures materialized and engineers, chemists and other specialists were needed.

On December 29, 1970 the Occupational Safety and Health Act was signed into law. This act was designed to insure a safe and healthful working environment for American workers. The responsibilities for implementing this Act are divided between the Department of Labor and the Department of Health, Education and Welfare. The Department of Labor is required to: (1) promulgate mandatory occupational safety and health standards, (2) to inspect workplaces and to cite and penalize violations of these standards, (3) to collect and analyze health statistics, (4) to supervise training of employees and employers in occupational safety and health, (5) to administer grants to the States to encourage local programs for implementing the Act. The Department of Health, Education and Welfare is to: (1) to conduct research relevant to occupational health, (2) to develop criteria and recommend safe exposure levels for toxic substances, (3) to publish annually a list of all known toxic substances, (4) to conduct investigations at the request of employers or employees, (5) to provide education to ensure a supply of adequately trained personnel to carry out the provisions of the act. If the provisions of the Occupational Safety and Health Act are enforced vigorously the effect on American labor and American industry will be profound indeed.

Recognition of Industrial Diseases

An effective program of occupational health differs from other public health activities such as water and air pollution control in several ways. Although its aim is the prevention of illness rather than the treatment of disease the first essential element is the recognition of sickness in the workforce which requires the diagnostic skills of the physician. It is concerned with only that portion of the day, or of a mans life that is spent at work. The number of hazards or insults is as diverse as the number of industries and processes. At the same time the number of people exposed to a given hazard may be relatively small and the normal public health surveillance techniques may be inadequate. Once diagnosed, the illness must be differentiated from ordinary community diseases and identified as work related. Something of the exposure which produced the illness must be surmised. Superimpose on this the adaptability of the human body to stress, the natural defenses against disease and the unwillingness of most men to admit to illness and the physician in industry is facing formidable problems. The new and powerful tools of industrial epidemiology and statistics are beginning to be applied to the recognition of industrial diseases but the lack of adequate medical histories, exposure information and the difficulty of locating even death certificates for previous employees makes these studies very expensive and often physically impossible. In spite of this, the alert physician has often recognized an industrial hazard in its early stages and prevented a disaster which may have involved large numbers of workers. Thus, the plant physician for the Goodrich Company in Louisville, Kentucky, in reviewing death certificates of prior employees noted the second diagnosis of angiosarcoma (cancer of the liver) as a cause of death and was astute enough to search previous records to find a third. Realizing the rarity of this disease, he informed the State Health Service and alerted the world to the potential of vinyl loride to produce liver cancer. His revelation lead to the immediate reduction of the permissible level of exposure for this substances from 500 ppm to 50 ppm and the subsequent reduction to 1 ppm thus protecting thousands of future workers in this industry from unnecessary risk of cancer.

While the physician in industry practices medicine and his efforts are directed primarily toward the patient his counterpart and collegue the industrial hygienist addresses himself to the evaluation of the work environment and the design of control systems to reduce exposure to hazardous materials and to maintain a healthful working environment. Between these extremes a variety of specialists contribute their knowledge to make safe processes possible. Among these are the industrial nurse (often a primary contact with the worker and a source of information concerning their responses to changes in work conditions) the analytical chemist, the toxicologist and the physiologist. Thus, the solution of industrial health problems always involves a team of people addressing the common problem, the health of the worker.

Evaluation of the Environment

Early industrial hygienists recognized the need for a yardstick by which to judge the safety of exposure to chemicals. In 1920 Warren Cook published a list of 20 substances with which he had some experience and suggested the airborne concentrations of those that he considered safe. That list has now grown to approximately 500 and is published annually as the "Threshold Limit Values" (T.L.V.) by the American Conference of Governmental Industrial Hygienists. This same list was recently published in the Federal Register by the U. S. Department of Labor and has thus become part of the Federal Regulations. The concentrations listed are considered safe for an 8 hour exposure, 5 days per week for a normal working lifetime. They are designed for the healthy adult male worker and not young children, the elderly or infirm and thus should not be confused with community air quality standards. In setting the limits the committee considers several factors; the hazard in using the substance or the likelihood of producing damage; the comfort or lack of irritation of the worker. Thus these limits do not provide a direct comparison of the relative toxicity of the compounds. The recommended concentrations are usually listed both as parts per million (by volume) and as milligrams per cubic meter of air. Special terms such as millions of particles per cubic foot of air or number of fibers per cubic centimeter of air are used to refer to numeral dusts or asbestos fibers. Other rules apply when the dust contains more than 1% of free crystaline silica. In the latest (1973) T.L.V.

list values or charts are also given for permissible exposures to certain physical agents (heat, stress, noise, microwaves). Sonizing radiation is not included these standards are published by the Atomic Energy Commission.

Armed with this list and suitable sampling techniques the industrial hygienist is prepared to make an estimate of the risk to health in the industrial environment. In the past, every airborne chemical in the environment required a separate analytical method. Modern analytical technology is greatly simplifying these techniques and today most sampling for solvent vapors is done by drawing a known volume of air through a small glass tube filled with charcoal. The charcoal is then extracted with a suitable solvent (CS_2) and the extract analyzed by gas chromatography. Portable instruments such as infra red spectrophotometers and light-scattering photometers (for airbone particles) are also available although quite expensive. The Threshold Limit Values are based on time-weighted-average (TWA) concentrations and may dictate the sampling and analytical method of choice. Thus if one were interested in "peak" concentrations a "grab" or instantaneous sample might be indicated while to establish the TWA concentration a longer term integrated sample ··uld be better. In any case it is essential that the pump oı air moving device be calibrated carefully so that the amount of contaminant can be related to the volume of air from which it was extracted and the concentration calculated correctly.

Control of the Industrial Environment

During an inspection of an industrial premises one of the most obvious, if not sophisticated observations that is made, relates to housekeeping. Sloppy handling of solvents and chemicals must lead to airborne concentrations of vapors or dusts. Most reports will contain either praise for good housekeeping, or recommendations for improvement of the aspect. It is often found that this is a direct reflection of the morale of the workers or the adequacy of the supervision.

Probably the easiest and most economical recommendation that can be made involves the substitution of a less hazardous or toxic substance for one that is being used, for example toluene or stoddard solvent for benzine or perchoroetheylene for carbon tetrachloride. Sometimes a process modification is indicated such as welding instead of soldering to eliminate lead exposure or wet drilling instead of dry to reduce dust.

The major remedy available to the industrial hygienist, however, is ventilation. This may be in the form of general room ventilation to reduce odors, humidity or temperature but more often will involve local exhaust ventilation to remove the offending contaminant at the source and to prevent its escape into the room atmosphere. The techniques of local exhaust ventilation are described in a book entitled "Industrial Ventilation" published by the American Conference of Government Industrial

Hygienists". An efficiently designed exhaust system will offer protection to the worker and eliminate the need for respirators or other personal protective devices. Design, installation and testing of such a system should be supervised by a competant industrial hygienist since few contractors are familiar with the health related objectives of the system and many examples can be found of expensive and technically attractive installations which do not provide adequate protection to the employees.

In the event that none of the above approaches is possible, respirators, cannister gas masks, air line respirators may provide a last resort or temporary solution. Since these devices all depend on voluntary compliance by the worker they may not be reliable. A worker in a hazardous environment who contracts an occupational illness will generally be awarded compensation even though an approved respirator was provided by the company.

The Future Unfolds

Occupational health and the responsibilities of the industrial hygienist cannot be divorced from a changing social climate and increased social consciousness. Legislation to protect the worker has been provided by the Congress and it can be expected to be implemented. If additional legislation is required it will be provided Labor unions are taking an increasing interest in protecting the health of their members. This is evident in their demand for appropriate legislation and in their willingness to bargain with management for provision for this in their working contracts and indeed to share cooperative programs and faculty sponsored studies with their management and universities. The cost of controls to meet new regulations will lead to process changes which in turn will require evaluation for implications to health. Improved technology and speeding up of old equipment will introduce new problems. The search for new sources of energy will introduce new processes and require novel controls. As men retire from work at an earlier age and at the same time have life extended by medical advances new diseases - some related to their work experience - will appear. New terms such as ergonomics, social factors, psychological factors are already appearing in the industrial hygienists vocabulary.

PRINCIPLES FOR CONTROLLING THE OCCUPATIONAL ENVIRONMENT[a]

BY

Jack E. Peterson, Ph.D.

Introduction

Hazards and potential hazards in the occupational environment can be purely mechanical in nature, or they can take the form of materials which are capable of causing fire or explosion or of producing injury by inhalation, skin or eye contact, or by ingestion. Physical forms of energy such as noise, non-ionizing and ionizing radiation, and heat are also potential hazards. Most basic to the control of any hazard is the concept that it can be controlled. Once the hazard is defined properly and the need for and the degree of necessary control is determined, then the only requirements are imagination, trained personnel and money to put the control methods to work.

The basic principles for controlling the occupational environment consist of substitution, isolation and ventilation. Not all basic control principles are applicable to every form of hazard, but all occupational hazards can be controlled by the use of at least one of these principles. Ingenuity, experience and a complete understanding of the circumstances surrounding the control problem are required in choosing methods which will not only provide adequate control, but which will consider installation, operating and maintenance costs and personal factors such as employee acceptance, comfort and convenience. Furthermore, hazards, costs and benefits can change with time so that hazard control systems need continuous review and updating. The aim, then, must be not only to devise efficient hazard control methods, but to evaluate the effectiveness of those methods at regular intervals.

Substitution

Usually, when one thinks of controlling a hazard he thinks automatically of adding something to do the controlling. For

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[a]FROM Industrial Environment - Its Evaluation and Control, US Department of HEW, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, 1973.

example, an engineer is more likely to think of controlling a vapor hazard by ventilation than by substituting a less hazardous material for the one which is causing the problem. Yet, substitution of less hazardous materials or process equipment, or even of a less hazardous process, may be the least expensive as well as the most positive method of controlling an occupational hazard.

Unfortunately, substitution is not a technique easily taught. No one can sit down with a slide rule, pencil and paper and decide how to best use substitution to eliminate an occupational hazard. Instead, the principle of substitution is demonstrated best with examples so that by analogy the student may apply what he has learned to his particular problem.

Process

One of the main hazards to our atmospheric environment results from the use of gasoline-powered internal combustion engines in nearly all of our automobiles.[1] Control of this source of air pollution is being attempted in many ways, from the passage of laws to the modification of gasoline to the substitution of a less hazardous process. Substitute processes range from diesel engines to electric motors, and even include the greatly increased use of mass transit systems. That there is no agreement on the best "less hazardous process" (or in fact, that process substitution is necessary) indicates that more study is needed and problem solutions may be political as well as scientific.

Choosing a substitute process is not always difficult. For instance, dipping an object into a container of paint almost always creates much less of an inhalation problem than does the process of spraying that object. Cutting is usually less noisy than breaking or snapping; mechanical stirring causes less material to become airborne than does sparging; generating electric power from nuclear energy causes less air pollution than does the use of fossil fuel, but hydroelectric power is less polluting than either; and distillation usually causes fewer problems than does crystallization.

After considering many examples of process substitution, one principle appears to stand out: the more closely a process approaches being continuous (as opposed to intermittent), the less hazardous that process is likely to be. This principle is a fairly general one and applies to energy hazards such as noise, as well as to the more familiar material hazards. This principle is not always useful, but is application should be considered whenever hazard control by process substitution is attempted.

Equipment

Where the process itself does not need to be changed to reduce hazards, the needed control often can be achieved by substituting either equipment or materials handled, or both. Substituting equipment is nearly always less expensive than substituting processes and often can be done "on the job." On the other hand, finding a substitute material may be easy or may require extensive research and/or process changes. For these reasons, equipment is substituted more often than either processes or materials.

Equipment substitution is often the "obvious" solution to an apparent hazard. An example might be the substitution of safety cans for bottles to store or contain flammable solvents, or the substitution of safety glass for regular window glass in the sash of a "fume" hood. Examples such as these can be multiplied indefinitely because they are obvious on inspection.

One of the main requirements for efficient equipment substitution is the awareness of alternates. Persons concerned with hazard reduction must familiarize themselves with all kinds of "safety" equipment as well as with the processes and process equipment in their jurisdiction. For example, sideshield safety glasses are unlikely to be substituted for regular spectacles unless someone knows the need for, as well as the existence of, the side-shield glasses. Unless omeone knows that neoprene gloves are being ruined by contact with chlorinated hydrocarbons, and also knows that polyvinyl alcohol gloves are available and impervious to this kind of attack, a substitution is unlikely.

Realistic suggestions for process equipment substitution are often based on a background in both engineering and industrial hygiene, but even without an extensive background, a fresh look at an old process or problem can pay large dividends. The man who gets out and around within a plant, a company, a city or a nation is likely to observe new solutions to problems and thus is likely to be able to apply them elsewhere. Good equipment substitution is based on common sense, ingenuity, keeping up w;ith the state of the art, and the experience of working with people processes and the equipment used by both.

Material

After equipment substitution, material substitution is the technique most often used to reduce or to eliminate hazards in the occupational environment. Examples abound. The substitution (forced by a tax law in 1912) of red for white phosphorus in matches drastically reduced both an industrial and a "general" hazard. Substitution of perchloroethylene for petroleum naphtha in the dry cleaning industry essentially eliminated a serious fire hazard. Using tritium-activated phosphors instead of radium-based paint for watch and instrument dials has reduced the hazards associated with the manufacture of the dials, and in addition has reduced by a small amount the background radiation experienced by the general public. Removing beryllium phosphors from fluorescent lamps not only elimianted a hazard to the general public, but also eliminated a more serious hazard to the men manufacturing such lamps.

Many years ago the principal cold cleaning solvent was petroleum maphtha. Because of its fire hazard, a substitute material was sought. Carbon tetrachloride appeared to be ideal because of its low flammability, good solvent power, and low price. Experience and a great deal of research, however, showed that a serious fire hazard had been traded for a perhaps even more serious vapor inhalation hazard. Today, carbon tetrachloride is being supplanted by several other chlorinated hydrocarbons, notably 1, 1, 1-trichlorethane, trichloroethylene, perchlorethylene and methylene chloride. Each of these substitutes is far less toxic and far less hazardous to handle than is carbon tetrachloride, although each has its own hazards. In addition, the fluorinated hydrocarbons are being used more and more despite their expense, mainly because their inhalation and fire hazards are so low.

The principle of material substitution carries with it the same type of reward and the same potential hazards as other kinds of substitution. Substitution of a different material can reduce or eliminate hazard, but one hazard can be substituted for another inadvertently. A careful watch must be kept for unforeseen hazards that may crop up when any kind of substitution is used. An excellent source of information about the toxic properties and hazards of materials and their substitutes is the Hygienic Guide series published by the American Industrial Hygiene Association.

Isolation

Isolation is the term applied when a barrier is interposed between a hazard and those who might be affected by that hazard. The barrier may be physical, or distance or time may provide the isolation considered necessary.

Stored Material

Stored material rarely poses an overt hazard, and therefore, whether it is raw material or finished product, those concerned are likely to take it for granted and to assume that it poses no threat. This assumption can be dangerous.

When flammable liquids are stored in large tanks above ground, common practice is to group the tanks on a "tank farm" but to isolate each tank from the others by means of a dike made of earth or concrete. If a major spill does occur the (possibly flaming) liquid is restrained by the dike from coming close enough to other storage tanks to affect them. For more positive protection, tanks are buried to interpose an even more formidable barrier between their contents and the general environment. A further example is to restrict the volume of material stored in a single container. This exemplifies the use of isolation to reduce a hazard by imposing many small barriers rather than one large one between the contents and the environment.

Where the principal hazard of a liquid arises from inhalation rather than from fire, the imposition of a physical barrier becomes much more difficult than simply building a dike. When the quantities are relatively small (up to a few tens of gallons, perhaps) the best storage technique uses both isolation and ventilation. An example of this practice is the more and more common use of ventilated storage cabinets in laboratories.[2] Such cabinets are usually made of fire resistant material and air is drawn through them constantly by means of a fan which discharges out-of-doors. This type of arrangement interposes both a physical and a ventilation barrier between the contents of storage vessels and the laboratory environment and in addition, may free much valuable hood space for other than storage use.

Solids usually are stored either in original containers (bags, cans, or drums), bins, or simply in piles which may even be out-of-doors. Except in unusual cases, solids rarely pose problems in storage which compare in magnitude with those of liquids and gases. Outside storage piles can be unsightly and can be the source of air pollution problems; in such cases a physical barrier is the usual answer. The barrier may be as simple as a tarpaulin or as complex as a storage building with several kinds of materials handling equipment.

Equipment

Most equipment used in processing operations is designed to be safe if it is used properly. On the other hand, there are times and cases where this is far from true. Equipment that is operated under very high pressure, for instance, may well pose a severe hazard even when operated correctly. In such cases, the proper action to take is to isolate the equipment from the occupational environment. Usually physical barriers are used and the barriers may be very formidable ones, indeed. Extensive use may be made of armor plate as well as reinforced concrete, mil steel, and even wood. Viewing the work area may be done by remote controlled television cameras, simple mirrors or periscopes.

Equipment isolation may be the easiest method of preventing hazardous physical contact, for instance with hot surfaces. Insulating a hot water line may not be economical from a strictly monetary standpoint, but may be necessary simply because that line is not sufficiently isolated from people by distance.

Inhalation hazards can often be reduced markedly by equipment isolation. One example is that of isolating pumps. Nearly all pumps used in industry can leak and will do so, at least occasionally. Proper planning should take this fact into consideration, perhaps by arranging vessels and piping so that pumps handling hazardous materials can all be located in one area. That area, then, can be isolated physically from the remainder of the process equipment. If, then, the pump room (and/or each pump) is ventilated properly, minor leaks will be of no consequence, and major ones will be repairable without a serious inhalation hazard to the mechanic.

Process

Process isolation is usually thought to be the most expensive of the isolation methods of hazard control, and thus is probably the least used. Nevertheless, with today's space-shot-perfected techniques, some extremely complex processes and equipment have been shown susceptible to remote control, and in principle there is probably no process which cannot be operated remotely if the expense of remote operation is justified.

Process isolation techniques were given great impetus when men sought ways in which to handle radioisotopes safely. They found that the hazard from external radiation sources could be attenuated with shielding and distance, but both of these techniques required the development of very sophisticated methods of remote operation. Master-slave manipulators were designed to allow direct "handling" of equipment from very remote locations and this, in turn, accelerated the development of different viewing methods, complex electronic systems, and the theory and philosophy of remote operation.

The modern petroleum processing plant is an example of the use of remote processing. Many of the newer plants are based almost completey on centralized control with automatic sampling and analysis, remote readout of various sensors, on-line computer processing of the data, and perhaps actual computer control of process equipment. These techniques were not developed with hazard control uppermost in mind; instead, economy of operation was the spur, but safety was a by-product.

Computer-controlled processing also appears to be gaining acceptance in the chemical industry. For the most part, this change has been in response to economic pressures because, despite their high initial costs, computer-controlled continuous processing plants can be operated with much less expense than that associated with manual operation, and at the same time produce a superior product. Such plants enjoy the advantages of remote operation and also those of continuous processing with attendant relatively low volumes of materials actually being handled. This combination can result in a very low hazard potential.

Process isolation, however, by its very nature can pose some rather extreme hazards. That is, when human intervention is required, the potential hazard may rise abruptly from near zero to near certainty. In such cases, full use must be made of techniques of isolating the man from his environment.

Workmen

Isolating workmen from their occupational environment has been used since antiquity, and will continue to be necessary in the foreseeable future. The first blacksmith to don an apron of hide was using this principle just as certainly as is the present day radioisotope handler with his plastic airsupplied sealed suit and its connecting "tunnel."[3] Pliny, the Elder, wrote about the use of pig's bladders by miners to reduce the amount of dust inhaled[4] and today advertising men extol the virtues of masks made of polyurethane foam to accomplish the same thing.

Using personal protective equipment of any sort exemplifies the principle of isolating man from his occupational environment. Protective equipment for workers should usually be designed for emergency or temporary use, but this does not always hold true. Experts in the safety field stress the continual use of some sort of eye protection if only because loss of vision is such an extreme penalty to pay for a moment's inattention. Hard hats and safety shoes with steel toecaps are other examples of protective equipment designed to be cheap insurance against severe loss. Some kinds of personal protective equipment are so ubiquitous as to be almost a badge of the trade. The butcher's apron, the chef's tall hat, the welder's helmet, the first baseman's glove, the logger's boots and the fullback's shoulder pads are all devices designed to help isolate man from his occupational environment.

Today it is possible to isolate anyone from practically any environment for nearly any length of time. We can send men through the vacuum of space to the moon, for instance, or send them to the depths of the sea, completely protected from rather extreme environments. Nevertheless, even though essentially complete protection is possible, it is rarely used.

Completely isolating a man from his occupational environment is difficult and expensive; therefore, when worker isolation is necessary, it is usually partial rather than complete. Even partial isolation can result in discomfort (consider wearing a gas mask all day, for instance), and in such cases other techniques of controlling the environment should be considered seriously. Face shields, ear plugs, rubber gloves and the like should always be available if their use is warranted, but the aim of the engineers and planners should be to make their continual use unnecessary. Furthermore, all emergency protective equipment should be inspected periodically and tested if necessary to assure that it will perform its intended function in use.

Testing of protective equipment and planning for its proper use (see Chapter 36) are both very complex fields. By its nature, most equipment of this type is designed for use at times when all of the hazards are not delineated readily — where, in fact, the real hazards may never be known. For instance, canister-type gas masks have been regarded as suitable for respiratory protection in emergencies provided that the air still contains enough oxygen to sustain life. Chemical reactors, tanks, sewers and buildings on fire don't always provide enough oxygen to sustain life, and therefore, injuries do occur from asphyxiation. Furthermore, the canister on the mask may not be designed to protect against the air contaminant(s) actually present and again people are injured despite their gas masks. While the traditional gas mask still has uses, in many cases it should be replaced by one of the supplied-air type which can be worn in an oxygen-deficient atmosphere which contains unknown concentrations of unknown gases, vapors and particulates. This type of mask will do a good job in such atmospheres provided that it fits,[5] that the reservoir contains sufficient air for the necessary time, and that the regulator is functioning properly.

Gas masks are not the only pieces of protective equipment that actually may not protect in the emergency where they are used, but they exemplify the idea that obtaining equipment for protection is no guarantee that the equipment will be effective. Judicious testing of equipment designed to isolate man from his occupational environment is a necessity.

Ventilation

Ventilation (see Chapters 39 and 42) can be used to insure thermal comfort as well as to keep dangerous vapors from the breathing zone of a worker. It can be misused in an attempt to blow away radiant heat or used properly to control the dust hazard from a grinder. Ventilation equipment is found everywhere, much of it designed, engineered, and used improperly, even though a similar expenditure of time, effort and money could well have resulted in adequate or better-than-adequate control of the occupational environment.[6]

From the point of view of the engineer, ventilation systems can be either local or general in nature, and they can attempt control mainly by exhausting or supplying air properly. These designations cannot, of course, be absolute because, for instance, local supply for one area is general supply for any other part of that room or building. Nevertheless, the intention of the planner will control this discussion.

Local Exhuast and Supply

Localized ventilation systems nearly always attempt to control a hazard by directing air movement. The velocity of the moving air may also be a consideration, but except in high velocity-low volume systems, it is used only to assure that the direction of movement is the correct one.

There are two main principles governing the correct use of local exhaust ventilation to control airborne hazards. The first is to enclose the process or equipment physically as much as possible. The second is to withdraw air from the physical enclosure (hood) at a rate sufficient to assure that the direction of air movement at all openings is always <u>into</u> the enclosure. All other considerations are secondary. If these principles are followed, no airborne material will escape from the enclosure so long as the enclosure is intact and the ventilation system is operating properly.

There are times where no enclosure is possible and where control of airborne hazards must be accomplished simply by the direction and velocity of air movement. These cases are not exceptions to the basic principle because, at the point where control must be assured, if the direction of air movement is always into the hood there will be control of materials suspended in that air. Similarly, if an air-tight enclosure were to be used, then no air need be moved to assure control of a vapor or an aerosol, but the principles have not been violated.

Three of the problems associated with local exhaust systems stand out. First, and most obvious, is that of poor design. All too many ventilation systems appear to have been laid out by someone who has no knowledge of how to handle air properly. These systems abound in abrupt expansions and contractions, in right-angle entries, in the overuse of blast gates to attenuate problems, and so on. Since the advent of the ACGIH Ventilation Manual,[7] poor exhuast or supply system design has had no excuse because good technique is so easily available.

The second problem is that of inadequate exhaust. It is exemplified by the exhuast system which has been added to from time to time, until nothing associated with the system works at all well. The solution is simply to make sure that all systems, old as well as new, are well engineered.

The third problem of local exhaust systems is that of inadequate supply. People who are willing to install extra hoods at the drop of a hat (probably adding them to an already overloaded exhaust system) almost uniformly seem to feel that adequate supply air is a luxury or frill which they can do without. This tendency is accentuated by the widespread knowledge of a "rule of the thumb" which states that so long as the number of air changes per hour in the building is less "X" there is no need for a separate supply system. (The value of "X" varies from thumb to thumb, but is likely to be from 2 to 4.) This rule assumes that the building isn't "tight" and that infiltration of air will equal or exceed that exhausted.

Almost all buildings "leak" a little, and some leak a lot of air. Nevertheless, another principle of controlling the occupational environment by local exhaust is "always supply at least as much air as will be exhausted." A mechanical air supply system can and will do many things that infiltration cannot. A mechanical system can supply air that is filtered (and thus clean), tempered (warmed or cooled as necessary) and in the proper location to eliminate drafts and to avoid excessive disturbance of air at the faces of local exhaust hoods. None of these benefits can be gained by counting on infiltration for supply.

Local supply in itself is used occasionally to effect control or to assist in control of local exhaust. A combination of supply and exhaust, for instance, is sometimes used as a "push-pull" system to control vapors from large open tanks, the supply air being used to "push" vapors into the exhaust system. If properly engineered, such systems can work well and can effect control by the movement of much less air than would be necessary if only exhaust were used.

The main use of local supply systems is not, however, to control hazardous vapors but, instead, to reduce heat stress problems. For this application, air is usually supplied on an individual basis and each man is allowed to control the direction and/or the velocity of air impinging on his work station. The air used is not cooled, but is supplied at high velocities (up to 500 fpm); it cools by sweat evaporation and by convection, if its temperature is below the man's skin temperature (as is usually the case).

General Exhaust and Supply

General exhaust and supply systems attempt to control the occupational environment by dilution. This principle can be used for many types of problems, ranging from hazardous vapors to locker room odors to problems of dust, humidity and temperature. A principle of general ventilation is that it be used to control problems that inherently are widespread. That is, it makes snese to use general exhaust and supply ventilation to control the temperature and humidity of all the air in an office building, but it does not make sense to try to control the fume generated by one welder with an exhaust fan located in the opposite wall. General ventilation is almost always unsuccessful when used to control "point" sources of airborne contaminants, and in addition, is very wasteful of air when used for such purposes.

Even local systems must have air to exhaust, and usually that air is supplied by a general system -- one that is not associated with any particular hood or exhaust port. Some dilution of air contaminants will take place because of the general supply system, but its main purpose is simply to provide air to be thrown away by the exhaust system.

Air moving equipment can be expensive, and air filtering and tempering equipment can be even more so. Therefore, some engineers attempt to save money by recirculating some exhaust air back into the supply system. While this practice is standard in office buildings, it is rarely applicable in factories and shops because the air handled by the exhaust system cannot usually be cleaned adequately. Once-through systems, therefore, are standard except where the contaminant in the exhausted air is an easily handled particulate with a low inhalation toxicity. Sawdust, for example, is usually low in toxicity (although some woods are sensitizers), and the particles may be large enough to be removed easily from an air stream. In such a case, recirculation of some part of the exhaust air could be considered.

Inadvertent recirculation of exhausted air is a growing occupational health problem. When exhaust stacks and supply inlets are not separated adequately, part of the exhaust air will be captured by the inlet and recirculated to the building. This problem is prevalent in buildings designed by archtiects who are more concerned with the appearance of a roofline than they are with the health of those who will work in the building." The problem also occurs between buildings, especially when roof elevation differences are not great, and elsewhere when little or no attention has been paid to the possibility of recirculation.

Recent work has shown that the best way to prevent recirculation is to discharge exhaust air in such a manner that all of it will escape from the "cavity" which forms as a result of wind moving over and around buildings.[10,11] The intake can then be located at any convenient place, usually close to the roof, with assurance that recirculation will be negligible. Unfortunately, the prediction of cabity height above a roof is not yet an exact science, but enough is known so that intelligent decisions can be made. The recirculation problem must be considered whenever highly toxic, highly hazardous, or highly odorous materials are discharged by an exhaust system, whether or not a mechanical supply system is present.

Education

The first and most basic principle of almost any discipline is that knowledge is needed in order to apply that discipline to practical problems. Some knowledge comes with experience, but experience can be a poor teacher. More or less formal education can supplement experience and can direct it into the most productive channels. Nearly all people will line responsibility in industry, and many with staff responsibility, can become involved with controlling the occupational environment. All of these people can profit from education in this area.

Management

Few managers become involved directly in the practical aspects of hazard control, yet very little hazard control is done without management backing. Managers exist mainly to motivate people (or to allow people to motivate themselves), but even expert motivators cannot channel activity into areas of which they are ignorant. Education of management should deal much more with the "why" of hazard control than with the how, when, where or whom.

There has been very little effort to formalize the education of managers in most industries; usually they are taught about hazards in meetings, conferences and personal chats by men who work for them. Informal education is better than no education at all, but the present best hope is the recent proliferation of short courses prepared and presented for representatives of high echelon management. A short course is the easy way to obtain quite a lot of valuable information with a small expenditure of time. This approach has been used successfully in the field of hazard control and much more use of it should be made in the future.

Short courses for managers should identify hazards in broad areas; details should be reserved for examples. The courses should concentrate particularly on the costs and benefits of controlling the environment, but should not completely neglect humanitarian aspects. Legal requirements which must be met should also be a part of the course content, but where a "carrot" exists, its use will almost always produce better results than will a club. Particularly for managers, the carrots (rewards) should be searched out, found and emphasized.

Engineers

At least a portion of the work of every industrial hygienist can be traced to equipment and/or process design failure. In many "failure" cases the person who designed the equipment or process simply was not aware of the potential consequences of the failure, or that such a failure was possible. Examples range from the purchase of equipment noisy enough to be hazardous, to the use of carbon tetrachloride or benzene as solvents, to the specification of gasoline-powered lift trucks for an enclosed warehouse, to the omission of a necessary fire door. In general, these failures arise from ignorance rather than from malice or form a "devil-may-care" attitude. Furthermore, the decision which resulted in a failure probably was made by someone quite far removed from the consequences of the decision -- a planner, perhaps, or an engineering designer.

Educating engineers in regard to environmental hazards has, in the past, taken place mainly on the job by association with more experienced people. In recent years a few short courses have been given to supplement on-the-job training, but all too often any remedy applied is both too little and too late.

The logical place for engineers to be exposed to the knowledge that the environment abounds with hazards is when they are students at the undergraduate level. What is necessary then is not a program designed to turn these people into industrial hygienists or safety engineers, but instead, a course or courses which tend to open their eyes to the consequences of decisions they may make in their professional capacity. Undergraduate engineers (and most graduate engineers, for that matter) simply are not aware that it is perfectly possible to write noise specifications for much equipment; that carbon tetrachloride and benzene have excellent, much less hazardous, substitutes; that LPG fueled lift trucks generate much less cargon monoxide than do gasoline-powered lift trucks, that electric lift trucks are available and entirely suitable for most lift truck tasks; or when and where to install fire doors. The hazard gamut is so large that the typical short course can only scratch the surface, and a semester-long exposure stands a much better chance of getting the idea across.

Several colleges and universities already offer one or more courses surveying the fields of industrial hygiene for undergraduates especially in engineering curricula. With such courses as the foundation, short courses later in professional life should be able to keep engineers reasonably well up to date on environmental hazard control provided, of course, that they regularly read the literature related to the field.

Supervisors

In most circumstances, the further a supervisor is from actual control of a process, the more he deals with menand the less he deals with things. Supervisors usually work only through other people and consequently, they become aware of most environmental hazards from other people, or through their actions. In the case of an obvious hazard within his jurisdiction, a supervisor either can deal with the hazard with his own resources or he can solicit aid from others. Generally, which action to take is rather obvious, but some of the hazards posed by the occupational environment are subtle rather than obvious, and most supervisors are not equipped to deal with the subtle variety at all.

Education of supervisors usually should be process and process equipment oriented. The aim of the education should be to teach them about the subtle hazards that may be found in the environment of their employees and when and under what circumstances to request aid in solving the problems those hazards pose. Supervisors who are knowledgeable and well informed about hazardous processes, operations and materials are often able to control hazards early enough so that outside aid is not necessary except for periodic checks or reviews.

Workmen

Traditionally, a little effort has been made to teach workmen about either the equipment or the materials that they handle. In the past few decades, safety engineers have shown over and over again that there are direct benefits to be gained from teaching workmen about the physical hazards in their environment and how to avoid those hazards. More recently, industrial hygiene engineers have begun, usually in periodic safety meetings, to teach workmen about the hazards of materials and energies and, perhaps not surprisingly, have found similar benefits.

Hazards associated with the occupational environment impinge first on the men who work directly with materials, process equipment and processes. As these men are the first affected, they may well be the first to recognize adverse effects, and if so, if they are knowledgeable about the effects of the materials and energies they work with, they may be able to pinpoint problems before those problems become severe.

The main arguments against educating workers about the real and potential hazards of the materials and energies to which they are exposed have been that such knowledge would create apprehension, caused malingering, and give the unions another club to hold over the head of management. Where worker education has been used, however, groundless fears have evaporated, attendance has improved, and unions have been more cooperative, especially in matters concerning the health and safety of workmen.

An aware workman can often anticipate and circumvent hazards before they become serious to him, his fellow workers, or to the physical facilities. Furthermore, once the source of a hazard has been found, workmen, rather than supervisors or engineers, quite often have the best ideas of how to eliminate the problem with the least effort and expense. And finally, aware workmen often can be used to assist in industrial hygiene surveys,[12] thereby freeing the industrial hygiene engineer for perhaps more productive tasks.

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