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POLLUTION PREVENTION AND WASTE MINIMIZATION

DIGEST

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Pollution Prevention and Waste Minimization Digest

Water Environment Federation Digest Series

This publication has been compiled from some of the most recent information available on pollution prevention and waste minimization.

Grouped by subtopics, articles originally published in Federation periodicals, papers presented at Federation conferences, and chapters from appropriate MOPs are included in their entirety.

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Management and Policy

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Management Strategies for Pollution Prevention and Waste Minimization

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This chapter provides an overview of the alternatives available for managing the discharge of industrial wastewater. The goal of any pretreatment program is to manage the waste streams in a manner that ensures regulatory requirements are consistently and cost-effectively met. This chapter describes general, technical, and economic considerations and principles that should be addressed and evaluated before implementing any wastewater discharge

management strategy. Figure 3.1 shows the key components of a strategy for wastewater management at a manufacturing facility. The critical factor for successful development and implementation of a management strategy is the continuous commitment of everyone involved within the company, beginning with top management, to support the objectives of the agreed strategy. Management must recognize the benefits of pollution prevention and waste minimization and integrate these practices into the corporate or plant philosophy.

IN-PLANT SURVEY

In developing a wastewater management strategy, it is first necessary to have detailed information on the wastewater generated within the facility. In-plant surveys generate data on the sources, chemical compositions, quantities, variations, distribution, and discharge frequencies and durations of all industrial process waste streams. These data are used to establish a baseline description of the wastewater produced at the facility and develop or model possible management strategies. Additionally, the baseline data provide a starting point for considering the effect of future production growth, water conservation efforts, or changing regulatory requirements.

The most important aspect of conducting an in-plant survey is making it as complete as possible. This requires a full understanding of all production activities within the facility and detailed, accurate drawings of the plant showing the locations of the various processing units, their water distribution, and wastewater production and collection systems. The waste stream from each unit process is studied, measured, and analyzed to determine the frequency, quantity, and flow rate of the discharge and the nature and concentration of the pollutants present. If possible, flow measurements and sample collections should be performed using permanent monitoring stations. If these are not available, temporary data collection points should be used. The frequency, extent, and type of monitoring and sampling needed depend on the nature and variability of each waste stream. To ensure that the characterization of each waste stream is complete and representative, it is often appropriate to prepare an advance sampling and monitoring plan to guide the study.

Once all individual waste streams have been fully characterized, they can be sorted and grouped according to the types and/or concentrations of pollutants present, or the applicability of U.S. Environmental Protection Agency (U.S. EPA) categorical pretreatment standards. During the survey, raw material use and production records should be obtained. Correlations between production, or material use, and waste generation can then be developed for future decision making.

IDENTIFYING CATEGORICAL WASTE STREAMS. Any waste streams covered by categorical pretreatment standards should further be

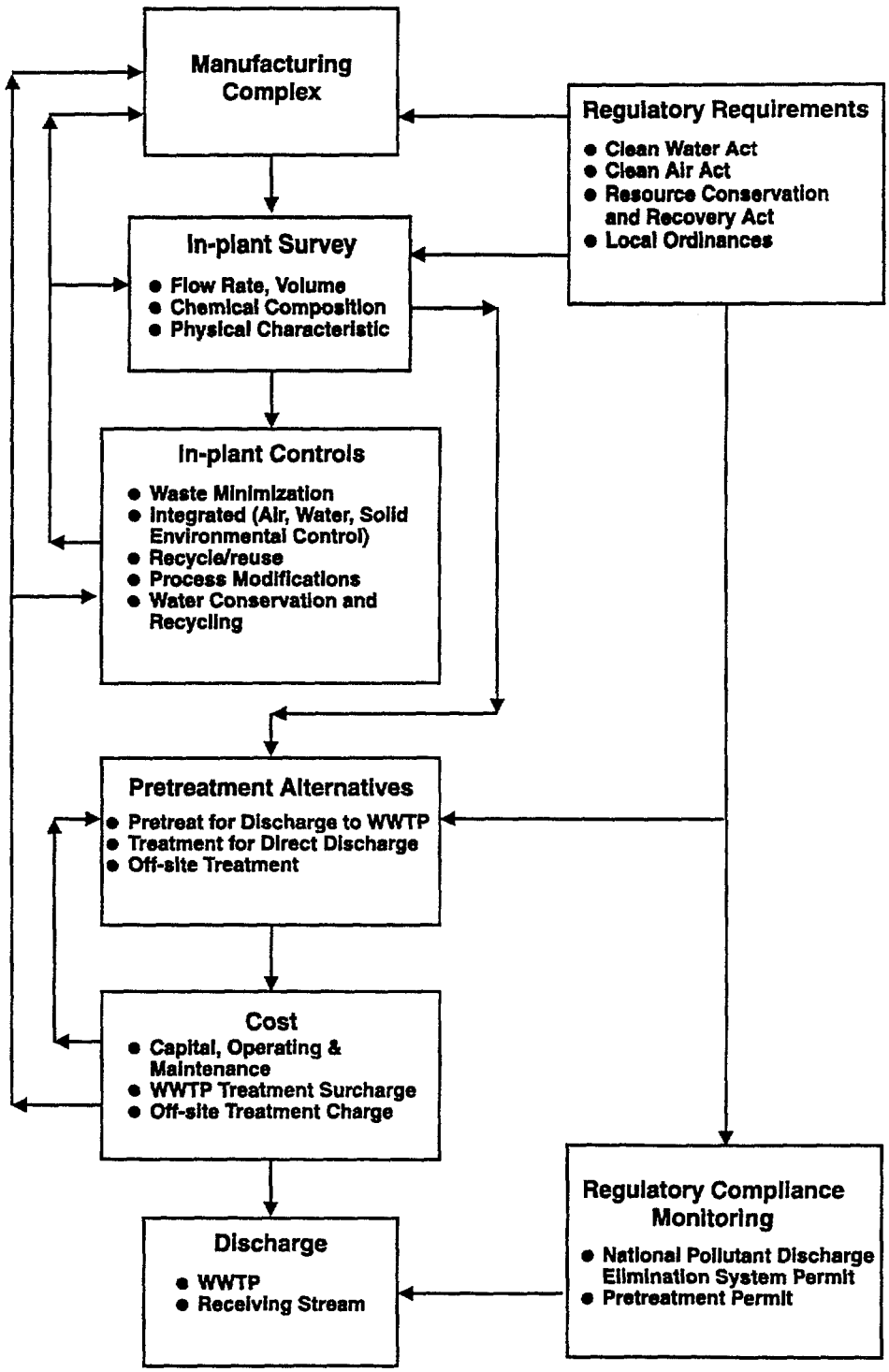

Figure 3.1 Strategy for wastewater management at a manufacturing complex.

identified as subject to either production-based standards, combined waste stream calculations, or both. In the case of production-based standards, the allowable concentrations of specific pollutants are directly related to the production rate of the process generating the waste stream. The combined waste stream formula is used to determine compliance of categorically regulated waste streams that are diluted by noncategorically regulated waste streams before pretreatment. U.S. EPA's Guidance Manual (1985) describes in greater detail the use of both production-based pretreatment standards and the combined waste stream formula.

IDENTIFYING WASTEWATER-GENERATING OPERATIONS. In performing the in-plant survey, it is important to include not only waste streams directly attributable to the various unit processes, but also waste streams generated from cross-media pollution control efforts, including waste streams from wet air scrubbers blowdown, sludge dewatering, or miscellaneous sources such as product change washouts, site cleanup efforts, yard drainage, noncontact cooling water, or secondary containment spillage. Although the volume of these auxiliary waste streams may be relatively small, their effect on the treatability of the total industrial wastewater generated by the facility may be significant.

In light of increasing restrictions and costs associated with off-site disposal of spent concentrated plating or solvent baths, many facilities are considering on-site treatment of these wastes. Although discharges generated from this activity typically are infrequent or on a slug-discharge basis, they must be considered and incorporated into the in-plant survey and management plan because of their potential to overload any treatment system that is designed to treat only regular or continuous flow process wastewater.

In conducting an in-plant survey, it may also be beneficial to categorize waste streams according to pollutant types to determine if some contain only conventional pollutants such as biochemical oxygen demand (BOD) and suspended solids. In many instances, waste streams containing only conventional pollutants may require no further pretreatment and be discharged without treatment to a wastewater treatment plant (WWTP). Classifying waste streams according to pollutant types also may expose any incompatibility between waste streams and the subsequent need to segregate the waste streams until the incompatibility is removed. For example, plating shops may generate both acidic and cyanide-containing waste streams that would be dangerous to combine before cyanide treatment is completed.

PREPARING MASS BALANCES. The information obtained from the in-plant survey of the various wastewater-generating operations is used to prepare mass balances of the flow and waste loads within the facility. Mass balances serve as important cross checks to confirm that all flows and

pollutant loads have been accounted for in the survey and that no major waste stream or pollutant-generating operations have been missed.

Properly prepared mass balances provide data that can be used in preparing a treatment strategy and determining flow equalization requirements. They also serve as indicators of potential areas where waste minimization or pollution prevention practices should be considered or implemented.

Developing flow and waste load balance for an entire facility can be a complex undertaking, especially if there are multiple wastewater-generating processes that operate independently of each other and flow through a combined wastewater collection system. However, it is often desirable to prepare individual mass balances for each wastewater-generating process. Each individual mass balance is prepared by accounting, as accurately as possible, for the conversion of raw materials into products, solid wastes, wastewater loadings, and so on over a specific period of time. Because water often serves as both a raw material and a cleanup agent, its consumption and fate must be monitored closely during the mass balance period, and wastewater flows, product incorporation, and evaporative losses must be measured accurately. The individual mass balances, once prepared, can be consolidated into an overall mass balance for the entire facility. If possible, the results of the combined mass balance should be verified by measuring the flow of the total effluent from the facility over a representative period of time while simultaneously analyzing it for pollutants of concern.

IN-PLANT CONTROL

Once the mass balance for the facility is completed and the sources and loadings of the various waste streams have been determined, it is appropriate to consider options for the control and reduction of pollutants to reduce the concentrations and volumes of the waste streams that need pretreatment.

Ideally, the first choice is to eliminate the generation of specific pollutants by substituting different raw materials that generate no wastewater or only wastewater that is compatible with the WWTP and requires no pretreatment. Because it is often impossible or economically infeasible to eliminate pollutant-generating raw materials from the production process as a result of product specifications or other reasons, the possibility of recycling or reusing the wastewater generated during the production process should be evaluated and explored. In some instances, the concentrated solutions obtained from the cleanup operations can be recycled as part of the starting materials for the next production run. If it is not feasible to recycle generated wastewater internally, the possibility of having an outside party either reclaim or reuse the wastewater should be explored.

If efforts to either eliminate, recycle, or reclaim wastewater through changes in production activities are unsuccessful, steps should be taken to

reduce the quantity of wastewater that requires treatment. These steps include implementing good housekeeping practices, using spill-control measures such as spill-containment enclosures and drip trays around tanks; eliminating any "wet floor" areas; and using rinses that are either static or do not have any overspray. Proper housekeeping should be practiced at all times, because it can be one of the most cost-effective measures for reducing pollutant loadings and maintaining compliance with regulatory requirements.

A facility's pollution prevention and waste minimization effort should be continuous rather than an isolated activity. For this type of program to succeed, specific measurable goals should be established and communicated to everyone at the facility. All successes should be recognized and publicized. Without continuous commitment and support from all levels of staff to achieve the goals of waste minimization through raw materials substitution, process modification, recycling (wastewater segregation and reuse), reclamation, and good housekeeping practices, chances for the long-term success of the program are decreased and any "significant" achievements may be only temporary. The management strategy for the control and treatment of a facility's wastes needs to be incorporated at the beginning of the plan and linked with all other components of the planning and implementation process. Benefits of a well-implemented plan include lower costs, improved product quality, increased production, improved public relations, reduced liability, and successful regulatory compliance.

WATER CONSERVATION AND RECYCLING. Efforts to conserve and recycle water should be incorporated into a waste minimization program or initiated as a separate activity with its own specific goals. The benefits of reducing the volume of wastewater discharges through recycling, reuse, and other conservation methods may include lower capital costs for the construction of a smaller pretreatment system and lower operating costs for the system because of possible reductions in the variability of the waste stream being treated. Additionally, smaller user charges for discharging to the WWTP can result if the WWTP's fees include a volume component. However, simple reduction of water alone, in the absence of other measures, may do little to reduce the ultimate treatment costs unless increased concentration results in increased treatment efficiency. Actually, the higher pollutant concentrations obtained when reducing only the volume of a waste stream may increase the risk that the treatment capability of the system is exceeded, thereby resulting in discharge violations. Because there are instances where it is more efficient to treat concentrated streams rather than dilute them, it is important to investigate the effect that any concentration change resulting from water conservation may have on the treatment process.

Water conservation alternatives include, but are not limited to, the reuse of cooling water as product makeup or cleanup water, collecting stormwater for noncritical water uses, flow-restricting or water-saving devices, and the

recycling of water in closed-loop systems. Once all internal applications for waste reuse, recycling, and conservation are maximized and implemented, the possibility remains that treated wastewater, if suitable, can be used by outside contractors for irrigation, dust control, or other tasks that normally would use fresh water. If the treated effluent is discharged to a WWTP, consideration should be given to the presence of any potential pollutants that may interfere with the WWTP's ability to reclaim its treated wastewater or use it for wetlands reclamation projects.

PRETREATMENT

Pretreatment of industrial wastewater before discharge to a WWTP may be necessary for several reasons. As described in Chapter 2, some industries are subject to federal or local pretreatment standards because they discharge organic and/or inorganic pollutants that can damage conveyance systems, cause inhibitory effects or pass through the WWTP treatment processes, or interfere with selected sludge-disposal alternatives. Other industries may voluntarily choose pretreatment to reduce or avoid WWTP surcharges on pollutants such as BOD and suspended solids. In rare instances, the wastewater solids or residuals resulting from the pretreatment process may be valuable in their own right, such as when they contain significant amounts of precious metals. Pretreatment systems can be installed to assist with the reclamation of these materials.

The type of pretreatment selected, be it physical, chemical, or biological, depends on wastewater characteristics, applicable pretreatment standards, and anticipated production changes that may affect wastewater characteristics. Physical treatment methods are designed primarily to remove suspended solids, settleable solids, and oil and grease. Chemical treatment typically removes dissolved and colloidal solids, nutrients, heavy metals, and similar pollutants. Finally, biological treatment is typically used to remove biodegradable organics and nutrients in industrial wastewater. The processes most often used for industrial wastewater treatment are provided in Table 3.1.

Before selecting pretreatment options, industries must consider several factors that will affect the decision-making process. U.S. EPA has issued numerous pretreatment standards relative to specific industrial categorical wastewater discharges for both existing sources and new sources. In addition, states and municipalities have frequently supplemented the federal standards with pretreatment requirements that take into account local conditions. Conditions such as stringent water quality standards reflected in the WWTP's National Pollutant Discharge Elimination System (NPDES) permit or the WWTP's treatment process characteristics may require more restrictive industrial discharge limits in some cases. The selection of pretreatment options must guarantee that the constructed pretreatment facility, as well as its

Table 3.1 Processes applicable to industrial wastewater treatment.

Pollutant	Processes
Biological oxygen demand (biodegradable organics)	Aerobic biological: activated sludge, aerated lagoons, trickling filters, rotating biological contactors, oxidation ditches, stabilization basins, packed bed reactors Anaerobic biological: anaerobic lagoons, anaerobic filters, anaerobic contact, fluidized bed reactors
Total suspended solids	Sedimentation, flotation, screening, filtration, coagulation/flocculation/ sedimentation or flotation
Refractory organics (COD, TOC)	Carbon adsorption, chemical oxidation
Nitrogen	Ammonia stripping, nitrification and denitrification, ion exchange, breakpoint chlorination
Phosphorus	Precipitation, biological uptake, ion exchange
Heavy metals	Membrane filtration, evaporation and electrodialysis, chemical precipitation, ion exchange
Dissolved inorganic solids	Ion exchange, reverse osmosis, electrodialysis
Oil and grease	Coagulation/flocculation/flotation, ultrafiltration
Volatile organic compounds	Aeration, chemical oxidation adsorption, biological treatment

discharge, will comply with all regulatory requirements. Additionally, long-term considerations should be addressed in the selection process, including provisions for additional treatment in the future to meet changing regulatory requirements or for the addition of modular systems to account for long-term flow variations. In some instances, field-scale pilot testing, trial uses of modified production processes, or research and development must be conducted before implementation of a pretreatment program.

PHYSICAL SEPARATION. Physical separation processes typically include flow equalization, screening, sedimentation, flotation, filtration, aeration, and adsorption. A brief description of each physical treatment method and a discussion of the advantages and disadvantages follow. More detail is found in Chapter 5.

Screening is used to remove coarse solids (rags or pieces of wood, for example) and prevent damage to or clogging of downstream equipment. Manually cleaned screens work well, but cleaning them requires labor and may cause overflows from clogging. Mechanically cleaned screens also perform well, but they may become jammed because of obstructions such as bricks or pieces of wood.

Flow equalization dampens flow variation and thus achieves a fairly constant flow rate to the sewer system. It also dampens the concentration and mass flow of wastewater constituents, yielding a more uniform loading to the WWTP. Flow equalization helps reduce shock hydraulic, organic, and nutrient loads and can reduce the required size of pretreatment facilities.

Sedimentation is the removal of suspended solids by gravity separation in a quiescent basin. Typically, sedimentation is highly reliable. However, the sludge collector mechanism may occasionally jam. The proper design of bottom slope and scraper blades and the appropriate number of arms will reduce this problem. Surface scum may cause odors that can be controlled by frequent removal. Short-circuiting and poor performance may occur if inlet and outlet designs are inadequate.

Dissolved air flotation (DAF) is used to remove suspended solids by causing them to rise to the surface. One DAF process consists of saturating some or all of the wastewater feed or a portion of recycled effluent with air under pressure. The pressurized wastewater is held for up to 3 minutes in a retention tank and then released to atmospheric pressure in the flotation chamber. Upon exposure to atmospheric pressure, microscopic air bubbles are released which attach to oil and suspended particles, floating these particles to the surface where they are skimmed off as float solids. Dissolved air flotation systems are reliable, but chemical addition is often used to enhance performance. These systems require little land area, but air compressor noise must be controlled, and the sludge must be treated and receive proper disposal (Viessman and Hammer, 1985).

Filtration is a solid–liquid separation process in which the liquid passes through a porous medium to remove fine suspended solids. Filtration is reliable and requires little use of land. However, backwash water will need to be treated, resulting in the production of solids, which require disposal.

Aeration may be used to strip volatile compounds from industrial wastewater. Diffused aeration or mechanical aeration typically are used. The aeration process is simple in concept and typically reliable. Generally, land requirements are small and sludge is not generated in an aeration system designed simply for aeration and not biological treatment. Proper design must ensure that offgases do not cause air pollution problems.

Adsorption is the accumulation of a substance at the surface of a solid material (usually activated carbon) called an adsorbent. Carbon systems generally consist of vessels in which granular carbon is placed, forming a filter bed through which wastewater passes. Adsorption systems require little land.

Under anaerobic conditions, biological activity in carbon beds may generate hydrogen sulfide, which has an unpleasant odor. Spent carbon may create a land disposal problem, unless regenerated. However, regeneration systems are expensive and may cause air pollution. Granular carbon systems often require pretreatment to reduce solids loadings to the beds. Powdered carbon may be used instead of granular carbon, but typically it is fed to wastewater using chemical feed equipment rather than being contained in a bed or column (Weber, 1972).

The three major membrane processes are reverse osmosis, electrodialysis, and ultrafiltration. Reverse osmosis is the pressurized transport of a solvent across a semipermeable membrane that impedes passage of solute (pollutants) but allows solvent (usually water) flow. Fouling of the membrane may result from the deposition of colloidal or suspended materials in the wastewater; thus, pretreatment typically is required to avoid frequent cleaning requirements. Chemical recovery and wastewater reuse are possible.

In electrodialysis (a physical-chemical process), an electric current induces partial separation of wastewater components. The separation is achieved by alternately placing cation and anion selective membranes across the current path. When current is applied, the cations pass through the cation exchanger membrane in one direction, and the anions pass through the anion exchanger membrane in the other direction. Chemical recovery and wastewater reuse are possible, but power costs are typically high and membrane fouling may be a problem.

For ultrafiltration, wastewater is pumped past a membrane. Under the applied pressure, water and most dissolved constituents pass through the pores of the membrane, while larger molecules such as colloids and emulsified oils are retained. The process typically has high capital and operations and maintenance costs, and membrane fouling may be a problem. However, it seems to be a reliable technology for certain applications.

CHEMICAL PRETREATMENT. Chemical pretreatment processes typically include pH neutralization, chemical precipitation, oxidation-reduction, and ion exchange. Each type of chemical treatment and its advantages and disadvantages are discussed below.

Neutralization involves the addition of acids or bases to wastewater for adjusting pH to an allowable range, typically pH 5 to 9. Acidic wastewaters typically are neutralized with lime ($Ca(OH)_2$), caustic soda ($NaOH$), or soda ash (Na_2CO_3). Slaked lime is often used because it is less expensive than $NaOH$ and Na_2CO_3. Sodium hydroxide is also sometimes preferred because of its lower maintenance requirements and ease of use. Alkaline wastewaters are typically neutralized with sulfuric acid, hydrochloric acid, or carbon dioxide.

Neutralization is relatively simple and reliable but typically requires automatic feed equipment, pH monitors/controllers, and multiple mixing tanks.

To reduce chemical use and costs, mixing of alkaline and acidic wastewaters should also be considered.

Chemical precipitation is another chemical treatment method often used to treat industrial wastewater. Chemical coagulation (rapid mixing) and flocculation (slow mixing) are used to precipitate dissolved wastewater contaminants and form floc particles, which settle readily in sedimentation basins. Chemical precipitation can effectively remove heavy metals and phosphorus from industrial wastewater. The major disadvantage of chemical precipitation is that it may generate relatively large amounts of inorganic sludge, which typically must be dewatered and landfilled. If the sludge contains metals at toxic levels or is otherwise hazardous, it must be disposed of as a hazardous waste. In addition, close operator attention and rigorous cleaning are necessary to maintain a mechanically reliable chemical feed system (U.S. EPA, 1980; Viessman and Hammer, 1985; and Weber, 1972).

Oxidation-reduction is used occasionally to remove pollutants from industrial wastes, for example, to reduce chromium from its hexavalent form to its trivalent form before chemical precipitation. Additionally, ozone oxidation may be used to remove dissolved organics and cyanide during pretreatment; however, alkaline chlorination of cyanide is a more common practice than ozone oxidation. Hydrogen peroxide or potassium permanganate may also be used for some industrial wastes. Oxidation-reduction systems have a high mechanical reliability. Offgases must meet air pollution requirements, however, and oxidation-reduction may not be economically attractive in some cases (Eckenfelder, 1982, and Weber, 1972).

In the ion exchange process, ions held by electrostatic forces to charged functional groups on a solid surface are exchanged for ions of similar charge in the wastewater. Ion exchange may be used for removing heavy metals, ammonia, and radioactive pollutants. The process is reliable and relatively easy to operate if automatic controls are used.

Ion-exchange systems require periodic monitoring, inspection, and maintenance, and pretreatment of the wastewater may be required to prevent resin fouling. Scaling can occur where wastewaters high in magnesium and/or calcium are treated. In addition, disposal of waste brine and rinse water is required. Recovery of valuable chemicals may be possible (Cherry, 1982; U.S. EPA, 1980; and Weber, 1972).

BIOLOGICAL PRETREATMENT. Biological pretreatment of industrial wastewater may be used to reduce BOD/suspended solids loads to WWTPs, degrade potentially toxic organic compounds, or reduce nutrient levels. Biological systems include activated sludge, lagoons, trickling filters, rotating biological contactors, and anaerobic processes. Where wastes are compatible, however, economies of scale often indicate that WWTP treatment of biodegradable wastewater better serves the community than does installation of several biological pretreatment systems.

The activated sludge process uses an aeration tank in which wastewater and microorganisms are mixed; the microbes biooxidize the waste matter and synthesize new cells, and the biological solids are then removed by final settling. Several modifications of the activated sludge process are available. The one selected should best meet the pretreatment requirements. The process typically is reliable, but sludge disposal, aerosol and odor potential, and energy consumption may cause problems. Skilled operators are required for optimum performance (Reynolds, 1982, and U.S. EPA, 1980).

Aerated lagoons are medium-depth (typically 2 to 4 m [6 to 12 ft]) basins and function similarly to the activated sludge process but without recycle. In addition to being reliable, aerated lagoons require only basic wastewater operator skills. Air emissions from the lagoons must meet air pollution requirements, however, and potential effect on groundwater from lagoon seepage must be evaluated in design and operations. A liner may be required (Metcalf and Eddy, 1991). Facultative lagoons are typically 1- to 2.5-m (3- to 8-ft) deep basins in which wastewater is stratified into an aerobic surface layer, a facultative layer, and an anaerobic bottom layer. Facultative lagoons are also reliable and require basic operator skills. Like aerated lagoons, air and groundwater discharges must be evaluated and appropriately addressed.

Trickling filters consist of a fixed bed of rock or plastic media over which wastewater is distributed for aerobic biological treatment. Biological slimes that form on the media assimilate and oxidize substances in the wastewater. The biomass repeatedly falls off the media (sloughing) and must be removed in a settling tank following the trickling filter. Though not as efficient as activated sludge systems, trickling filters are typically reliable. They have limited flexibility, however, are susceptible to upsets, and may have difficulty operating in cold weather (Metcalf and Eddy, 1991, and Reynolds, 1982).

Rotating biological contactors are fixed film reactors normally consisting of plastic media mounted on a horizontal shaft in the tank. As wastewater flows through the tank, the media, approximately 40% immersed, are slowly rotated. Biomass on the media assimilate (oxidize) the organics. Excess biomass is stripped off the media by rotational shear forces and is subsequently removed during final settling. Rotating biological contactors perform well, with reliability, unless organic loads are high or temperatures are below 13°C (55°F). Odor may be a problem, and sludge treatment and disposal is required. Additionally, facilities with large flows may incur high capital and operating costs.

A packed-bed reactor consists of a reactor that is packed with a medium to which the microorganisms can become attached. Wastewater enters the bottom of the reactor through an appropriate inlet chamber. Air or pure oxygen necessary for the process is introduced with the wastewater.

Anaerobic processes include contact, filters, fluidized-bed reactors, and lagoons. Anaerobic contact provides for separation and recirculation of seed microbes, thus allowing retention periods of 6 to 12 hours. The anaerobic

filter promotes growth of the anaerobes on a packing bed and can be designed for upflow or downflow operation. For the fluidized bed reactor process, wastewater is pumped up through a sand or plastic bed, which supports microbial growth; effluent recycle is practiced. Anaerobic lagoons are commonly used to pretreat meat-packing and other high-strength organic wastewaters. Anaerobic processes typically are reliable, but odor problems and process upsets may occur (Eckenfelder, 1989). Preference depends on waste strength, temperature, wastewater chemistry, and other factors.

CROSS-MEDIA POLLUTANTS. In selecting pretreatment options, cross-media pollutant generation must be considered. Many pretreatment facilities generate sludge that requires handling, treatment, and disposal. The treatment and disposal of sludge, especially if it exhibits hazardous waste characteristics, can be expensive and cumbersome considering the multitude of sludge and hazardous waste regulations at the local, state, and national levels. Some pretreatment processes may result in air emissions, such as off-gases from air stripping of certain industrial wastewaters, that must comply with applicable air pollution standards. Processes such as ion exchange, ultrafiltration, and reverse osmosis result in reject streams requiring disposal.

SAFETY CONSIDERATIONS. Selection of pretreatment options also involves safety considerations. Under certain conditions, electrical and mechanical equipment, if incorrectly installed, inadequately maintained, or improperly used, can cause electrical shock or other bodily injury. Wastewater gases and pathogenic microorganisms can also create health hazards. Chemicals, such as chlorine, sulfides, or ammonia, that are either present in the wastewater or added during treatment, can create noxious vapors or otherwise cause acute or chronic injuries to plant personnel or the public if control measures are inadequate.

OFF-SITE PRETREATMENT. In formulating management strategies for the pretreatment of wastewater, alternatives for off-site pretreatment should also be considered. Off-site pretreatment generally means removing all or part of the wastewater generated by a facility and pretreating it at another location so that it is suitable for disposal. An off-site pretreatment facility may or may not be a Resource Conservation and Recovery Act (RCRA) hazardous waste treatment facility depending on whether the wastes accepted meet the RCRA definition of hazardous and whether the facility is RCRA permitted. Typically, the off-site facility is nearby and designed to treat specific types of wastewater from several firms in the area, such as plating shops or printed circuit facilities, at a lower cost than comparable treatment by the individual facilities generating the waste streams. The benefit of off-site treatment is that it can eliminate the need to install a costly pretreatment system for treating what may be a relatively small waste stream. However, off-site

treatment facilities are typically only conveniently and economically available in certain metropolitan areas and may be subject to strict regulatory requirements that can result in the imposition of conditions and constraints on the wastewater-generating facility.

PROCESS MONITORING. The goal of any industrial wastewater pretreatment management strategy is to achieve cost-effective regulatory compliance by implementing waste minimization, wastewater recycling, water conservation, and wastewater treatment by the most appropriate treatment processes. To determine whether this goal is being achieved, the strategy must include a monitoring component that provides information on the effectiveness of the strategy and allows for necessary corrections. The primary purpose of monitoring is to ensure and verify that compliance with regulatory requirements, such as discharge permit conditions or categorical discharge standards, is consistently met.

However, the results from a properly designed discharge monitoring program (this includes adequate testing frequency, rapid analysis turnaround times, and analysis for the appropriate parameters) can also provide information on the efficiency of the pretreatment system and help improve the cost-effectiveness of the treatment system by offering process control data for reducing operating costs such as chemical and power usage rates.

Beside providing economic benefits, a good monitoring program is useful in assessing the effect of process or raw material changes or other waste minimization efforts, detecting potential upsets with the system that could cause discharge violations or slug discharges, and estimating loading surcharges that may be imposed by the WWTP receiving the discharge. The monitoring of the incoming wastewater also allows for improved process control, particularly in processes involving chemical addition or in the activated sludge process. Industrial facilities are increasingly using statistical process control techniques to ensure compliance.

Wastewater effluent monitoring can be performed by either the industry (self-monitoring) or the regulator with jurisdiction over the facility's discharge. Facilities with limited laboratory capabilities may enlist help from a contract laboratory for both sample collection and analysis. Industrial self-monitoring can be required by the regulator to meet reporting requirements for baseline monitoring reports or periodic reports on continued compliance required by federal regulations, as well as to ensure that the pretreatment system is operated in a compliant manner.

The results of any self-monitoring tests for regulatory purposes, whether performed in-house or by a certified laboratory, must be submitted to the regulator for review. Any violations may be subject to enforcement actions. Any self-monitoring samples collected for regulatory purposes in the U.S. must be analyzed in accordance with EPA-approved procedures. Informal self-monitoring is sometimes performed in house to facilitate the operation of

the pretreatment system and check on its response to operational changes. This can be done using test kits or other rapid analytical means as long as the results obtained are accurate. Rapid self-monitoring through the use of test kits or on-site analytical instruments can provide a quick indication of pretreatment system upsets or problems. This feedback allows for the implementation of corrective measures, including the recycling or storage of a noncompliant effluent until the pretreatment system is operating properly again to prevent discharge violations.

Results from self-monitoring using nonapproved U.S. EPA methods do not have to be reported to the WWTP unless specifically requested by the WWTP, and they do not count toward determination of compliance. However, all analytical discharge or effluent results obtained using U.S. EPA-approved methods become part of the compliance history and must be reported. The facility is subject to enforcement if these results are in violation of the limits.

An effective monitoring system is integral to the pretreatment system design and should be planned at the conceptual stage. Inclusion of properly designed monitoring points and equipment as part of the total system design can significantly reduce future monitoring costs and provide for improved pretreatment system operation.

Compliance monitoring by a WWTP or other regulatory agency represents the second type of monitoring most industrial facilities face. This monitoring can either be scheduled or unannounced. By requiring an industrial facility to install appropriate monitoring or sampling points that are continuously accessible to the WWTP, the WWTP may set up sampling equipment or obtain grab samples on either short notice to the industry or totally unannounced.

Finally, in the event of spills, slug discharges, or chronic violations, a WWTP may initiate a "demand" monitoring program against a facility in response to the problem. Once the problem has been resolved and continuous compliance is achieved, the demand monitoring program is usually rescinded and a normal monitoring schedule is resumed.

COST ANALYSIS. In developing a management strategy for the control of industrial wastewater from a facility, it is important to develop a comprehensive cost analysis for the different options under consideration. Although cost figures strongly depend on local conditions and regulatory requirements, certain elements should be incorporated into the facility's management strategy before selecting a pretreatment option. These include determining the capital cost of the pretreatment system, the operating cost (including costs of chemicals, energy, labor, compliance, and residual disposal), and maintenance costs to keep the system operating in a manner that allows for continuous compliance.

Determining which pretreatment alternative to select should include a review of return on investment goals. The selection of the pretreatment

alternative should be based on lowest life-cycle cost and highest return on investment. The performance and treatment capability of a pretreatment system will largely be driven by the regulatory requirements imposed on the discharge. In some instances, however, when the treatment of compatible pollutants is involved, it may be more cost-effective for the WWTP to treat the wastewater even though a higher user fee is charged than for the industry to pretreat its wastewater and discharge lower pollutant loads to the WWTP.

When developing a cost analysis, it is important to consider the many variables and factors in the pretreatment process, most of which will change over the lifetime of the system's operation (the life-cycle cost). An estimate of these changes, as well as the effect of any anticipated regulatory changes, residual disposal restrictions, or other applicable considerations should be incorporated into the cost analysis and, ultimately, the management strategy.

Cost information databases for pretreatment of industrial wastes are limited. This is because of the almost infinite variety of pretreatment waste streams to be treated. This variation makes it difficult to develop a large database of treatment costs. There are, however, sources of information on the more common waste streams that can be used as a starting point for the estimates, a check on order of magnitude costs, or a rough comparison of treatment options. In addition, sources of information usually exist as case studies for specific waste streams. However, these case studies typically are limited in the number of technologies compared. Industrial associations and trade groups, such as the American Petroleum Institute or the Chemical Manufacturers Association, are also a good source of information on specific waste streams because they may track and record these data for their members. It is important to use current and accurate cost and performance data because the technologies and treatment costs constantly change.

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THE POLLUTION PREVENTION PARTNERSHIP

A COLORADO VOLUNTARY PRIVATE/PUBLIC ENVIRONMENTAL INITIATIVE

Paul Ferraro, P.E., Vice President
Geraghty & Miller, Inc., Environmental Services
1099 18th Street, Suite 2950
Denver, CO 80202

ABSTRACT

It started with breakfast. In 1989 representatives from industry, regulatory agencies and public interest groups began to meet over early morning coffee. At first they sought a better dialogue between industries and regulatory agencies—turning potential adversaries into teammates. Later, this "breakfast club" evolved into the Pollution Prevention Partnership, a voluntary environmental initiative. The goal: working together to prevent pollution at its source.

By 1991, the Pollution Prevention Partnership (PPP) formed a non-profit organization. The Partnership set new standards for reducing pollution in Colorado's industries by making it easier for regulatory officials, public interest spokespeople and industry representatives to meet and forge new solutions to environmental problems.

The first major project, "SolvNet I," focused on reducing the use of 1,1,1-trichloroethane (TCA). TCA poses both health and environmental hazards. PPP set a goal for each company in the Partnership to reduce its use and release of this industrial "solvent-of-choice" by 70%. Partnership members methodically searched for more acceptable alternatives, testing over 50 compounds. By making changes in processes, products and business methods, they exceeded their goal. Pollution prevention—by reducing solvent use—reduces burdensome regulatory compliance, taxes and surcharges.

The work has not stopped there. The Partnership is reaching beyond its membership to all Colorado businesses. Members conducted technical workshops for other industry representatives. The Partnership hosted a luncheon for Colorado's top corporate executives. They worked with the Waste Minimization Assessment Center, of Colorado State University, to perform waste assessments at small and medium size industries in Colorado. Work is also under way on SolvNet II, an expanded program designed to reduce hazardous industrial waste.

This paper presents the purpose and mission of the Pollution Prevention Partnership. It discusses the SolvNet I and SolvNet II projects, gives perspectives on how companies succeeded in preventing pollution, outlines the Partnerships technical assistance activities, and gives the results of a study of pollution prevention practices and attitudes of smaller businesses in Colorado.

KEYWORDS

Pollution prevention; waste minimization; solvent; hazardous waste; regulatory compliance.

INTRODUCTION

The Pollution Prevention Partnership was not formed using an existing or theoretical model of public/private cooperation. On the contrary, it evolved over a two year period that started with discussions between two individuals concerning a difficulty in a public/private working relationship. The discussions soon expanded to several individuals meeting on a regular basis, then to informal breakfast meetings with representatives from industry, U. S. Environmental Protection Agency, Region VIII (USEPA) and the Colorado Department of Health (CDH). From the beginning the group has sought practical and measurable approaches to pollution prevention. Eventually other organizations representing the public interest joined the discussions. The League of Women Voter's of Colorado and the Colorado Public Interest Research Group (CoPIRG), an environmental research and promotion organization, now are actively involved in the Partnership. This "breakfast club", focused on shared concerns and clearly defined goals, finally formed the Pollution Prevention Partnership

BACKGROUND: THE CLIMATE FOR VOLUNTARY COOPERATION

Since the mid 1970's, public demand for environmental controls and government regulation of waste producing industries has increased in the U.S. Some business interests have complained that burdensome regulation has hurt their competitiveness and profitability. Environmental groups, on the other hand, have insisted that any weakening of environmental controls will result in long term damages and inflated clean-up costs. This conflict has affected federal, state, and local decision making. Over informal breakfast meetings, the Partnership sought common ground between public agencies and private organizations. It worked to build practical solutions. Discouraged by the confrontation, which normally existed among the organizations, Partnership members sought cooperation built on shared concerns and open discussions. This is not an easy task in the milieu of competition and hostility that often surrounds industrial and environmental concerns. Building relationships between representatives and between organizations took time and came only through a commitment to openness between member organizations. In a corporate environment often promoting secrecy, Partnership members freely shared their successes and difficulties concerning the reduction of toxins. This spirit of cooperation led to the first large scale project of the Partnership: SolvNet I, to be discussed later in this paper.

Through PPP, regulatory agencies can meet the public mandate to control hazardous and environmentally harmful substances while avoiding traditional "command and control" procedures. When pollutants are eliminated or reduced, so is the need for permitting, compliance, reporting and enforcement actions.

Industry also benefits. Companies constantly seek cost-effective ways to comply with growing regulation. Through pollution prevention they can reduce operating costs, compliance reporting and long-term environmental liabilities. The industrial partners of the Pollution Prevention Partnership were motivated to shift their environmental management practices from regulatory compliance to long-term pollution prevention.

Public interest groups strive to protect the environment from harmful substances. They encourage public awareness and strong environmental policies. Through prevention, they join a team that seeks effective and lasting answers to environmental protection.

PURPOSE AND GOALS

The Colorado Pollution Prevention Partnership is a non-profit, voluntary alliance of government, business, and public interest groups organized to develop and promote pollution prevention and waste minimization in Colorado industries.

The Partnership includes senior management representatives from the USEPA and CDH; industry representatives from Martin Marietta, Coors, Hewlett Packard, Public Service Company of Colorado (PSCO), AT&T, and Kodak; public interest representation from Colorado League of Women Voters and Colorado Public Interest Research Group (CoPIRG); and Geraghty & Miller, environmental consultants.

The goals of the Partnership are clear:

- Strengthen the working relationship between private and public sectors.
- Improve capabilities for anticipating and avoiding environmental problems.
- Pool resources and focus staff attention on the goal of pollution prevention.
- Exchange information and expertise, and help transfer it to medium and small companies and the general public.

ORGANIZATIONAL STRUCTURE

The Partnership is organized exclusively for charitable, educational, and scientific purposes under Section 501 c(3) of the U.S. Federal Internal Revenue Service Code. It consists of a Board of Directors, an Advisory Committee and a SolvNet Committee. The Board of Directors manages the affairs of the Corporation and presently consists of four members. Originally, the founders wanted all members to serve on the Board of Directors, but lawyers for the public entities indicated a possible conflict of interest. The League of Women Voters of Colorado was the only public entity that joined industry on the Board of Directors. The Advisory Committee, appointed by the Board of Directors, guides the Board's decisions through advice and recommendations. The Advisory Committee has eleven representatives. The SolvNet committee has representatives from the groups represented on the Board and Advisory Committee. It implements the Partnership's goal in pollution prevention. Other committees are formed as needed.

PPP activities are funded through corporate donations. As a non-profit entity the Partnership also qualifies for some grants through USEPA and other environmental concerns. Member companies agree to commit to the goals of PPP, to accountability in reaching those goals, and to share in Partnership expenses in an equitable manner. Currently, PPP has a budget of approximately $65,000 of in kind donations from member companies and approximately $30,000 in actual expenditures. Companies typically donate $5,000 annually to pay for project costs.

The Partnership membership list remains relatively small in order to facilitate a flexible, result oriented approach to problems rather than a rigid, bureaucratic approach. However, prevention programs are not limited to member companies. The Partnership maintains an active outreach and mentoring program for small and medium size companies. In this way the Partnership addresses both large and small prevention and waste minimization problems.

PRACTICAL SOLUTIONS AND MEASURABLE SUCCESS

In the SolvNet I project, four original member companies committed to significantly reducing use of 1,1,1- trichloroethane (TCA). TCA is widely used in industry as a solvent to clean products and metal surfaces before further processing. It is also a major ozone-depleting chemical. Companies in the SolvNet I group wanted to cut their combined TCA use 70% by December 1991. They used 1988 as their base year. The pollution prevention measures used were:

- Process modification - eliminating the need for TCA.
- Chemical substitution - finding safe alternatives.
- Revised operating practices - reducing use at the source through education and management practices.

Colorado Public Interest Research Group analyzed TCA use and emissions for the base year, 1988 and for 1991. The PPP companies provided data from SARA Title III Right to Know reports on a questionnaire. As part of their responsibilities to the Partnership, CoPIRG provided SolvNet results during the fall of 1992. The four companies reduced annual use of TCA by a combined total of 1,128,100 pounds, representing a 90% reduction from 1988.

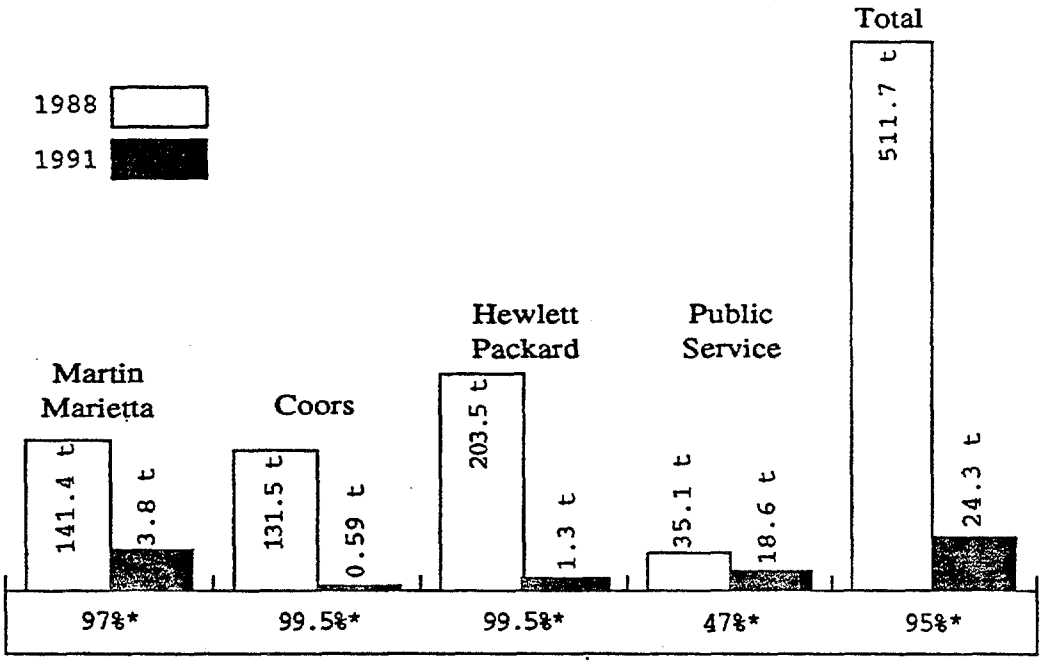


FIGURE 1 SolvNet I results:
Reduction in 1,1,1-TCA use for PPP member companies
* Indicates percent reduction from base year

TCA REDUCTION

The companies in SolvNet I reduced TCA use by modifying processes and substituting cleaners. Intensive research revealed that it could be effectively replaced with various aqueous (water-based) cleaners that are environmentally safe. Through preventative substitution the four companies reduced toxic air emissions and the volume of liquid waste generated. They cut solvent and disposal costs. They also eliminated future liabilities related to TCA use.

Martin Marietta chose aqueous and semi-aqueous based cleaners and modified several production processes to reduce TCA use including the use of alcohol spray precision cleaning of space craft components and CO_2 cleaning of large space system structures. Coors eliminated the use of TCA at its aluminum can plant and glass bottle plant by using citrus-based solvents and other substitutes. Hewlett Packard eliminated TCA in the manufacturing of printed circuit boards by using sodium carbonate. PSCO had the challenge of reducing TCA use at their decentralized facilities where it was an ingredient in cleaning fluids. They achieved reductions primarily through using alternative cleaning products and employee education.

Reducing TCA use was expensive. Coors estimates about $100,000 in staff time and $10,000 in analytical costs using in-house expertise and equipment. But benefits have offset costs. At Coors, for example, the company estimates $250,000 savings per year in reduced purchasing and disposal costs, not to mention reduced impact on the environment and increased safety in the workplace. Other companies in the SolvNet I Project reported similar benefits and financial savings.

CONCLUSIONS FROM SOLVNET I

SolvNet I succeeded because companies eliminated TCA before use rather than attempting to recycle or dispose of it after use. The companies developed safer substitutes—greatly reducing the threat to worker and public health. And because TCA is an ozone destroying chemical requiring special disposal procedures, eliminating its use also significantly benefits the environment while reducing overall costs.

Although the U.S. Clean Air Act of 1990 mandates that all U.S. companies eliminate the use of TCA by the year 2000, this project shows that other companies can follow the Pollution Prevention Partnership's lead and eliminate the use of TCA much faster.

GETTING THE WORD OUT ABOUT POLLUTION PREVENTION

Word is spreading about the Pollution Prevention Partnership. Its commitment and results spark interest from public and private organizations. By anticipating and avoiding environmental problems, achieving measurable reductions in pollution through prevention and sharing information and technology, PPP wants to make pollution prevention the new industry standard. To keep spreading the word, the Partnership developed a Technical Assistance Program.

Business helping business is generally recognized as a very effective way to facilitate technology transfer of pollution prevention strategies. So far, the Partnership's Technical Assistance Program has completed several exchanges. A CEO luncheon introduced PPP to the industrial community. Dr. Harry

Edwards of the Waste Minimization Assessment Center, Colorado State University, completed two on-site waste assessments at local companies. Next, member companies gathered for a technical interchange regarding solvents. Coors and Martin Marietta sponsored workshops to exchange other technical information. Also, PSCO included pollution prevention information in two mailings to business and residential customers. In addition, PPP sponsored several workshops with the Colorado Department of Health. Many people also heard of the Partnerships efforts through a slide presentation given at national conferences and meetings including: Eco World '92 in Washington, DC, Federal Restorations Programs 1992 Annual Conference in Washington, D.C. and the Hazardous Materials Control Annual Conference in Washington, DC. The Greater Denver Chamber of Commerce in 1993 awarded the Pollution Prevention Partnership a "Milestone Award" citing the Partnership's "significant contribution through its creation of a voluntary initiative to reduce environmental pollution."

BUSINESS TO BUSINESS

A luncheon for influential CEO's of Colorado's significant industrial users and emitters of ozone-depleting chemicals gave new legitimacy to pollution prevention in Colorado. Sponsored by the Pollution Prevention Partnership, hosted by Peter Coors and Del Hock, and addressed by Colorado Governor Roy Romer, the luncheon was attended by over 75 guests from 31 companies. At the gathering, the Partnership sought to motivate Colorado's business executives to show leadership by taking voluntary action to improve Colorado's environment through pollution prevention.

Former USEPA Deputy Administrator Hank Habicht, Del Hock of PSCO and Robert McMullen from the PPP explained the benefits of prevention to the environment and to industry. They shared case studies and challenged all companies to initiate prevention programs that would reduce use of harmful solvents. The Partnership offered its assistance and invited other companies to participate in its goals.

As a service to the community, the Partnership paid for two waste assessments performed by the Waste Minimization Assessment Center, at Colorado State University. Dr. Harry Edwards' team visited a manufacturing shop which makes cabinets from sheet metal and an integrated circuit manufacturer. The team suggested changes in process and cleaning which would reduce hazardous waste by an average of 55% and cut solvent air emissions by an average of 84%. Several of the solvent waste streams have been reduced or eliminated by the two companies.
Technical Interchange

TECHNOLOGY TRANSFER WORKSHOPS

During the summer of 1991, the Partnership hosted two technology transfer workshops open to Colorado companies. The first—regarding metal finishing—was held at Martin Marietta and attended by almost 40 people representing 10 companies. Coors hosted the second workshop on refrigerant recycling. Both workshops allowed member companies to share their pollution prevention successes and failures. Non-member companies gained valuable information including waste minimization strategies, recycling, and process alterations. They could begin to use pollution prevention technologies without lengthy and costly research.

The Pollution Prevention Partnership also co-sponsored two workshops with the Pollution Prevention and Waste Reduction Program at the Colorado Department of Health. The first addressed alternatives to the use of toxic solvents for industrial cleaning processes. The second was also co-sponsored by the Automotive Services Association of Colorado. The two workshops attracted an average of 60 participants and were very well received. More joint ventures are planned in the future.

SOLVNET II

Building on the successes of SolvNet I, PPP is looking ahead to more hazardous waste reduction through voluntary prevention in SolvNet II. Since each member company uses different hazardous materials, reduction goals needed to be customized. In SolvNet II each company chose chemicals to reduce over the next 3 to 5 years. They will reduce emissions or use by one-quarter to two-thirds through pollution prevention measures. The companies targeted chemicals for reduction based on any of the following criteria:

The chemical had strict reporting procedures under SARA.
The chemical was likely to be targeted for federally mandated reductions.
The chemical had possible long term environmental consequences.
The chemical posed a possible threat to worker or public safety.

SolvNet II member companies submitted reduction plans to the PPP Advisory Committee, and all have begun implementing their plans. Reduction goals for three companies are included here.

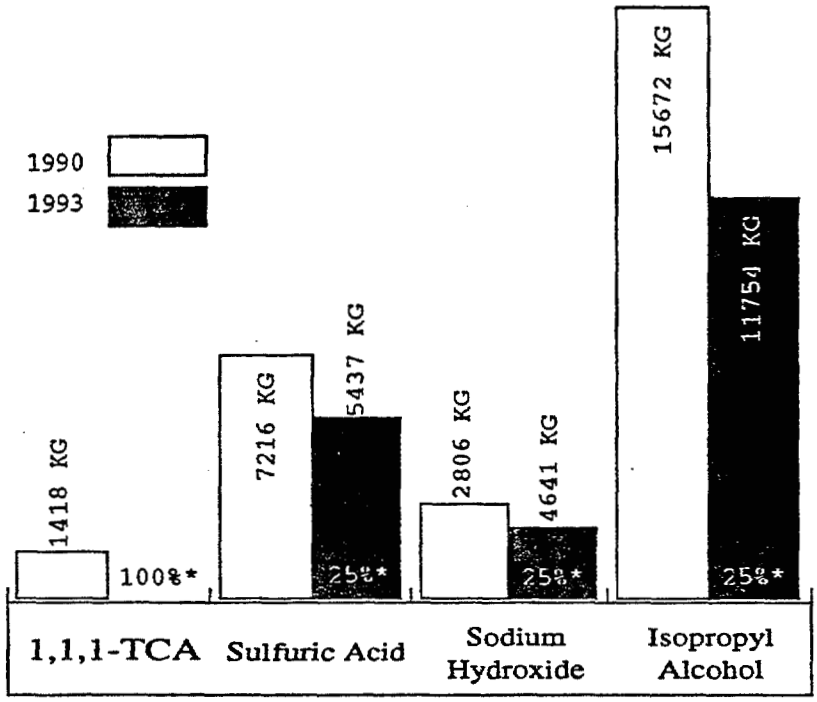
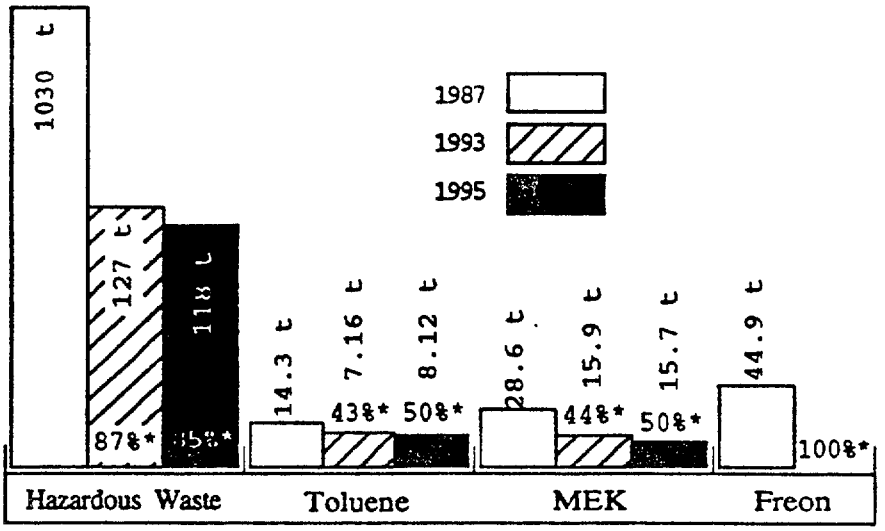
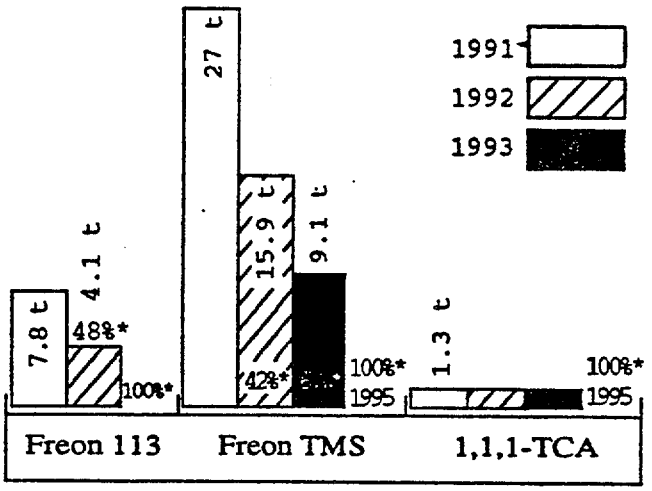


FIGURE 2 SOLVNET II proposed reductions
*Indicates percent reduction from base year



Martin Marietta Proposed Reductions



Hewlett Packard Proposed Reductions

FIGURE 2 (continued) SOLVNET II proposed reductions
*Indicates percent reduction from base year

SolvNet II companies also plan to continue helping smaller companies implement pollution prevention. The member companies would like to "mentor" companies with similar processes through short, process specific, discussion meetings. SolvNet II also includes a study of 300 smaller companies to gather information concerning their pollution prevention needs and resources.

In keeping with the business to business mentorship philosophy, the Partnership has again hired the Colorado State University Waste Minimization Assessment Center to conduct four on-site assessments of small businesses and then develop a waste minimization plan for each firm. The businesses are extremely diverse, ranging from screen-printing to chromium plating and various auto repair services. The Partnership will then sponsor workshops for similar and related industries to share the findings. This method allows many small businesses facing similar waste problems to receive sound technical advise without the high cost of individual assessment. It also encourages small business owners to seriously consider waste minimization by demonstrating in the workplace both the processes and the benefits.

RESULTS OF A STUDY OF POLLUTION PREVENTION PRACTICES AND ATTITUDES

This study investigated the pollution prevention practices and attitudes of Colorado's smaller businesses. The study attempts to answer several broad questions:

- **How well do Colorado's small and medium-sized businesses understand pollution prevention?**
- **What pollution-reducing behaviors are Colorado's smaller businesses currently practicing?**
- **Where do Colorado's small and medium-sized businesses go for the information they need?**
- **What barriers prevent smaller businesses from engaging in pollution prevention?**
- **What incentives would motivate small businesses to increase their pollution prevention efforts?**

To answer these general questions, the Partnership contracted with the CSU Center for Research on Writing and Communication Technology to do a random phone survey of 300 small and medium-sized businesses across Colorado. For the purposes of this study, "small and medium-sized businesses" are defined as having fewer than 500 employees.

The sample consisted of businesses from the following 14 industries:

Furniture manufacturing
Printing and publishing
Rubber and plastic manufacturing
Fabricated metal manufacturing
Electrical machinery manufacturing
Instrument manufacturing
Dry Cleaning
Pulp and paper manufacturing
Chemical manufacturing
Primary metal manufacturing
Machinery manufacturing
Transportation manufacturing
Photo finishing
Auto maintenance and repair

The results of the study provided some interesting answers to the Partnership's research questions.

- **How well do Colorado's small and medium-sized businesses understand pollution prevention?**

  Businesses generally comprehended what pollution prevention means. Most of the respondents knew the term, and could choose a definition that fit well with the EPA definition.

  Further, many respondents provided detailed and accurate definitions of pollution prevention. However, it should also be noted that a large minority of businesses were confused about pollution prevention.

- **What pollution-reducing behaviors are Colorado's businesses currently practicing?**

  It is clear that the businesses surveyed have actively implemented pollution-reducing practices in the past year. They have engaged in a number of pollution-reducing activities, ranging from chemical substitutions to construction of new production facilities. The most common action appears to be the use of alternative solvents.

- **Where do Colorado's small and medium-sized businesses go for the information they need?**

  When given a choice, businesses contacted sources which they perceived to be particularly knowledgeable. Suppliers, other businesses and printed materials are the most frequent sources of information. When respondents were asked to compare workshops, newsletters, magazines, and site visits, they rated them all as being equally useful. Businesses indicated that they did not like information clearinghouses.

- **What barriers prevent smaller businesses from engaging in pollution prevention?**

  Businesses spoke of several barriers to the widespread use of pollution prevention. First was the perceived cost of pollution prevention. Although most of the businesses sampled felt that prevention was cheaper than waste storage or treatment, many of them noted that prevention would only save them in the long term. A second and more serious barrier was the antagonistic relationship that the companies perceived to exist between small business and the government. Survey takers noted very strong, negative attitudes toward the government in response to this survey question.

- **What incentives would motivate smaller businesses to increase their pollution prevention efforts?**

  The most frequently mentioned pollution prevention incentives were "intrinsic motivations." Essentially, these are motivations that have nothing to do with tangible rewards or outcomes. They are largely moral or ethical motives. The second most frequently mentioned incentive was government support. Respondents were very interested in having the government subsidize their prevention efforts. Business contacts mentioned grants, loans, and tax credits as ways the government could help reduce the cost burden.

The third most frequently mentioned incentive was maintaining profitability. The responding businesses indicated a desire for the government to help them bear the costs of initiating prevention measures. Surveyed businesses also wanted to be sure that pollution prevention would pay for itself, have a demonstrable effect on the environment, or improve employee health.

Based on conclusions drawn from the study, the following actions are recommended for the Partnership to support pollution prevention in small and medium-sized businesses.

- Work with the preferred information sources identified in the study. Determine the industries with the most pollution prevention expertise and work with the suppliers, consultants, trade associations and publications in those industries.

- Provide formal and informal opportunities for companies in the same industry to exchange pollution prevention information. Programs could include both interaction with large, cutting-edge companies in an industry and with "peer" companies.

- Publicly honor companies that have made strides in reducing pollution. Encourage both the public and government to recognize the pollution prevention efforts of small and medium-size businesses.

- Promote cooperative relationships between government agencies and small businesses. As a possible means of overcoming the small businesses' distrust and antagonism towards government, examples of government and business cooperation must be shown and publicized to the small businesses community.

- Work with government agencies to recommend specific government monetary incentives for pollution prevention in small businesses. These monetary incentives could be grants to help defray the cost of installing new equipment and processes, matching funds for research into cleaner technologies, and tax incentives.

- Do not create an information clearinghouse.

CONCLUSIONS

The Partnership members are pleased to have formed the first Colorado pollution prevention public/private partnership. They hope their experience and successes will provide models and impetus for other cooperative efforts. Anyone interested in learning more about the Pollution Prevention Partnership is encouraged to contact any of its members or the secretary, Paul Ferraro at (303) 294-1200, Pollution Prevention Partnership, 1099 18th Street, Suite 2100, Denver, Colorado, 80202

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THE ROLE OF COOPERATIVE EXTENSION IN INDUSTRIAL POLLUTION PREVENTION

M.F. Dahab

Department of Biological Systems Engineering
University of Nebraska-Lincoln
Lincoln, NE 68583-0726

ABSTRACT

This paper describes the results of a partnership between Cooperative Extension at the University of Nebraska and a private industry to demonstrate the role of pollution prevention in helping to rejuvenate business and industry and to illustrate how resources available at state universities could be brought to bear in demonstrating the value of pollution prevention in the private sector. The program was a complete success from the stand-points of the university; which provided valuable field training for research personnel and assistants, and the industry which was able to achieve considerable savings in waste treatment costs and improved product quality. The industrial pollution prevention program took place at an aging manufacturing facility that engaged in metal galvanizing, electroplating, painting and associated activities. The facility produces fabricated metal products for farm, commercial and industrial use including structural steel members and plates, farm gates, fencing, and livestock watering tanks, in addition to a wide variety of structural bolts, fasteners, and so on. During manufacturing, the facility performs many operations including electroplating, hot-dip galvanizing, and painting among other activities that result in the production of a variety of hazardous pollutants (gaseous, solid, and liquid) that must be disposed of in some fashion. In developing the demonstration project, emphasis was placed on areas where the impact on reducing the total pollutant load produced by this facility would be the greatest. These areas were the electroplating, hot-dip galvanizing, painting, and tubing production lines. These areas produce the bulk of the wastes with the greatest toxicity and hazard, and consequently, any improvements in these areas would result in the greatest impacts. Work plans were developed for all operations and processes. These plans emphasized a multi-media approach to strategies for pollution prevention and minimization. By design, the university recommended operational changes and process modifications to the plant to prevent or reduce waste were simple to implement, and their pay-back periods were fairly short.

INTRODUCTION

Pollution prevention encompasses all activities leading to the elimination of waste materials at the point of generation. Generally, within an industrial facility, pollution prevention programs constitute organized, comprehensive, and continual efforts to systematically reduce waste generation. By reducing the generation of wastes, industrial facilities can save money on raw material purchases, material handling fees, disposal fees, and other operating costs. In addition, potential environmental liabilities can be reduced and worker/public health and safety can be enhanced. Hazardous waste generators also can benefit from any improvements in the general quality of the environment as well as an enhanced public image resulting from their involvement in pollution prevention activities [U.S.EPA, 1990; 1992; 1993].

The effort described in this paper was designed to develop a university-based Cooperative Extension industrial pollution prevention and minimization pilot project in Nebraska. The objectives of the project were to: 1) develop and demonstrate a potential partnership for pollution prevention between a major industrial facility and Cooperative Extension which is the principal vehicle for continuing education outside traditional university-based programs at land-grant universities and 2) demonstrate that through proper management and operating practices, the total pollution produced by an industrial operation can be reduced significantly. The ultimate goal of this pollution prevention program was to improve the net worth of the industry by lowering expenditures on pollution control measures and minimizing the burden of government regulations. An aging industrial facility in the midwestern U.S. was identified as a suitable site for the implementation of the project.

The manufacturing facility engages largely in the production of fabricated metal products for farm and industrial uses. The facility is located in a predominantly agricultural area. The plant site is a 40-hectare (100 acre) area on which several buildings are located. The largest of these buildings is a 75,000 m^2 (about 19 acres) manufacturing facility and a 3,900 m^2 (1 acre) office complex. Because of the nature of its manufacturing, the facility is licensed as a hazardous waste generator. In its various manufacturing processes, the facility performs many operations including electroplating, conversion coating, cleaning, machining, grinding, impact deformation, shearing, welding, sand blasting, hot-dip coating, painting, assembly and testing. Many of these processes result in the production of a variety of pollutants that have to be disposed of in some fashion depending on their nature. For example, the hot-dip galvanizing process results in the production of rinse water, which must be treated as a hazardous substance containing heavy metals (e.g., zinc and iron). The painting processes result in the production of used industrial cleaners, acids, solvents, and chemicals used in the cleaning and de-greasing of metal components.

All process wastewaters produced at this facility are treated in accordance with stipulations of the discharge permit. The wastewater is treated by lime and polymer addition and pH adjustment before discharge. In the past, waste disposal at this facility resulted in potential problems to both surface and ground water resources in the area. The waste disposal systems at the facility constitute a major expense. The management at the facility recognized that the economic viability of the facility depended on reducing pollution control expenses and lowering or eliminating the burden of regulation the company must endure.

PROCEDURES AND METHODS

Industrial Agreement

The Nebraska Pollution Prevention Project is a program funded through the U.S. Environmental Protection Agency (EPA) to promote voluntary pollution prevention in business and industry in the state. Through this program, business and industry volunteered (or often recruited) to undergo evaluation and assessment for the purposes of starting or enhancing pollution prevention programs. The industrial facility upon which this case history is built was a volunteer in the program. Because of the size of the facility, its relative age and the magnitude of work involved, additional support was sought from the U.S. EPA Industrial Pollution Prevention Project (IP3). The industrial facility, in return, agreed to implement as many of the project findings and recommendations as possible. Once the agreement was finalized, the project was initiated. Unlike many other projects of similar nature, this

one involved university faculty associated with the engineering college as well as Cooperative Extension who served as advisors and "resource" people and two graduate students in the environmental engineering program who served as the actual project personnel. The project formed the basis for the graduate students Master of Science Theses. In addition to university faculty and students, several facility personnel of supervisory capacity (line foremen and floor manager) were enlisted to provide the needed support. Upon formation of the team, waste stream assessment and associated work plans were formulated and specific tasks were identified and timelines were established.

Waste Stream Assessment Procedures

The initial project work centered initially on an extensive waste stream assessment. The waste stream assessment and evaluation process followed procedures outlined by the EPA (U.S. EPA, 1990; 1992; 1993). Accordingly, a work plan for the pollution prevention assessment program was developed. The work plan consisted of several tasks which are summarized as follows:

1. A detailed assessment and evaluation of current practices in the areas identified above along with a detailed characterization of all wastes produced by the facility.

2. Identification and delineation of all possible pollution prevention and minimization opportunities.

3. Economic and technical evaluation of all waste prevention and minimization alternatives including short- as well as long-term impacts of these alternatives.

4. Recommendation to the management of the manufacturing facility for implementation based on economic priority in terms of greatest benefit and shortest pay-back periods.

5. Providing technical assistance, where appropriate, during the process of implementation of the recommended alternatives.

6. Review of the results and impacts on waste prevention after implementation of the alternatives.

In developing the pilot project at the industrial facility, emphasis was placed on areas where the impact on reducing the total pollutant load produced by this facility is greatest. These areas are the electroplating, hot-dip galvanizing and the painting lines as well as the tube-mill production area. As pointed out above, these areas produce the bulk of the wastes with the greatest toxicity and hazard, and consequently any improvements in these areas would result in the greatest impacts. In developing a work plan, a multi-media approach was emphasized in developing pollution prevention and minimization strategies affecting all operations and processes.

From a project management stand-point, one graduate student was assigned to work on the electroplating lines and the other one was assigned to the hot-dip galvanizing, painting, and tube manufacture lines. The students were expected to carry out the waste stream assessments, develop detailed pollution prevention plans and alternatives as well as economic analysis and provide assistance in all other facets of the project. This paper provides a summary of activities completed to date, and essentially covers the tasks identified above.

PLANT OPERATIONS

The Electroplating Systems

The manufacturing facility operates both, an automated line and a manual electroplating line. These lines are used to deposit a thin zinc film onto small items such as bolts, fasteners and nuts, which are then used in the construction of larger plant products such as farm buildings. The automatic electroplating line is a barrel system which plates about 65 kgs (145 lbs) of work per load. The barrels are moved by a conveyor chain. The automated electroplating line processes an average of 65 kgs (145 lbs) of work pieces per barrel. There are 36 stations on the line, with an approximate cycle time of 3.5 minutes at each station (about two hours per barrel). The work is first cleaned in a soak cleaner and an electrocleaning solution. It is then rinsed, pickled in a hydrochloric acid bath, and rinsed again before going into a chloride-zinc electroplating bath. After residing in the plating bath for about an hour and ten minutes (20 stations), the work is rinsed. A light yellow chromate finish is added. A short rinse (20 seconds) follows the chromating process after which the work is dried at 65°C (150°F). The electroplating solution is circulated through a filter to remove impurities. Particles removed by the filter are rinsed into the treatment system. The total rinse water use in the automatic electroplating line at this facility was estimated at 166 liters per minute (20 gpm) during 8 hours of operation daily. The manual process is more operator intensive, which requires hand moving of barrels from station to station. The barrels are bigger, but the average load of work per barrel is also 65 kgs (145 lbs). This line is used more often than the automated line, especially when small quantities need to be plated. The work is cleaned in a soak cleaning bath (no electrocleaning) for about 15 minutes. It is then rinsed, pickled in hydrochloric acid, and rinsed again before being placed in the chloride-zinc electroplating tank (stainless steel pieces are dipped in nitric acid, instead of hydrochloric acid). The work pieces are plated for an average of 1 to 1.5 hours before being removed from the tank. A short rinse precedes the chromate coating; which can be clear or yellow, depending on customer preference. After a final short rinse, the pieces are placed on a table to air dry. A more detailed analysis of these electroplating lines is given by Parr (1994) and Dahab et al. (1994)

During the wastestream assessment several recommendations for improving waste management and pollution prevention practices were made. These recommendations included: 1) changes in house keeping practices starting with a thorough cleaning of the electroplating area including all tanks and the establishment of systematic methods of maintenance, testing and record keeping; 2) drastic reductions in rinse water use to decrease the amounts of zinc and wastewater being discharged to the treatment plant through the implementations of several measures including the use of counter-current rinsing; 3) daily testing of the electroplating chemistry; and 4) measures to reduce the dragout of zinc and other contaminants between tanks, the use of trivalent instead of hexavalent chrome finish, the use of deionized water in the electroplating tanks to reduce total dissolved solids in the baths, among others.

As a result of the wastestream assessment, several recommended changes were implemented. The first recommendation to be implemented was to clean the outside and inside of all the tanks on the plating line and remove bottom sludge that had developed. Another recommendation that was implemented was the regular testing of the cleaning, acid dip, electroplating, and chromating processes to maintain chemical concentrations at their optimum levels. The third implemented recommendation was the hiring of a chemist to perform operational control testing (among other duties including the galvanizing system chemistry, as discussed below). The fourth implemented recommendation was the reducing of all rinse flows by installing flow control devices on the rinses after the alkaline cleaning

and acid dip processes to maintain flow rates at the recommended levels.

The results of the implemented changes are very encouraging. In addition to reducing the amount of wastewater produced by the electroplating lines, remarkable product quality improvements were realized. The product quality improvements are evidenced by the results of the neutral salt spray testing (as per ASTM B-117) done on bolts plated on the automated line before and after the changes were initiated (Table 1). These results show a 1,000% increase in white rust protection and a 550% increase in red rust protection.

Table 1. Results of 5% neutral salt spray tests

Parameter	Pre-Change Results	Post-Change Results	Typical Values
Hours to White Rust	16	168	96 - 250
Hours to Red Rust	48	264	200 - 350

The Galvanizing System

The galvanizing process at the facility is a five-step procedure consisting of pickling, rinsing, prefluxing, galvanizing, and final rinsing. The pickling step prepares work for galvanizing by removing oxides from the steel surface using a 10% sulfuric acid solution at a temperature of 70°C (158°F). The work pieces are dipped in the pickling acid for varying lengths of time, and then taken away to be rinsed. After pickling, work pieces are rinsed to remove the acid. The preferred rinsing method is to dip work pieces in the rinse tank, which is filled with unheated municipal water. The rinse water is agitated by moving the work pieces back and forth in the rinse tank. After the first rinsing, work pieces are placed in the preflux tank, which is a crucial step in the "dry kettle" galvanizing process. The work is coated with flux chemicals ($ZnCl_2$ and NH_3Cl) prior to entering the zinc kettle. The preflux tank is kept at 70°C. Normally, the preflux solution should be allowed to dry thoroughly before proceeding with galvanizing. Galvanizing is accomplished by immersing steel in a tank filled with molten zinc for 2 to 3 minutes. Livestock fencing, the majority of the steel galvanized at this plant, uses the wet kettle galvanizing method. This means that a flux layer is floated on top of the galvanizing kettle. A flux layer covers the kettle, and work pieces pass through it as they enter and leave the kettle. For galvanizing other materials such as building components, the kettle flux layer is skimmed to the side and not used. The work pieces are cooled by rinsing them in a second rinse booth located next to the galvanizing kettle. This final rinse is needed to cool the work to below 200°C (390°F), which stops the possible growth of a brittle zinc-steel alloy layer. Cooling also makes it easier for operators to handle the work pieces. A detailed analysis of the galvanizing system at this facility is given by Montag (1993) and Dahab et al. (1994).

Pollution prevention efforts in the galvanizing area were concentrated on reducing the volume and metal content of rinse water since this is the principal medium through which metal is lost. Rinsing in a rinse tank, instead of a rinse booth, after galvanizing was deemed the most important step in decreasing galvanizing water use. Similarly, the use of rinse tanks after pickling was also important. Furthermore, the proposed rinse tanks should be linked in a counter-current flow arrangement to

maximize water use efficiency. A rinse test was conducted to verify the usefulness of the rinse tank concept. This test successfully demonstrated the feasibility of continuous-flow rinsing. Based on the results of the rinse test, a continuous rinse water flow rate of 24 liters per minute (6.3 gal/min) will remove pickling acid adequately for two rinse tanks in series. The proposed system would use about 35 m^3 of water (or less) per day. This represents a savings of about 83%. A cost estimate associated with these changes was presented with an estimated payback period of about 10 months. Other recommendations included changes in the galvanizing chemistry to optimize the galvanizing methods used at this facility and the hiring of a chemist to conduct quality control testing, etc.

The Painting System

The painting operation at the facility is a sequential system consisting of washing, etching, oven drying, spray painting, and oven curing. The paints used at the facility are of the traditional solvent-based variety which contain volatile organic compounds (VOC's). In 1992, the painting operation was estimated to have emitted about 37,500 kg (82,500 lbs) of xylene, and 11,000 kg (24,200 lbs) of toluene. Xylene and toluene are defined as hazardous under the 1990 Clean Air Act (CAA), and will be regulated strictly in the near future. Reducing emissions of these VOC's should receive a high priority. Two major types of paint are in use at the plant. One is a solvent-based paint, which is used for painting gates, and the other is a silicone polyester paint used for painting building panels. In 1992, 74% of paint used by the automatic paint line was used in painting farm gates. In addition, large quantities of a mixture of several aromatic solvents are used for purposes such as cleaning paint supply piping. About 2,200 liters (580 gallons) of this solvent are consumed each month. A detailed analysis of the painting system at this facility is given by Montag (1993).

The only practical way to significantly reduce VOC emissions is to change paint materials and several recommendations were made accomplish this objective. One suggestion was to consider using water-base paints instead of solvent-based ones, the use of an autophoretic painting process, and to consider the use of a powder coating system. Merits of these changes as well as costs estimates were made and presented to the management. It was clearly pointed out that pollution prevention in the painting area at this plant will not be offset by significant savings in terms of reduced waste disposal costs at the present time. However, the Clean Air Act requirements will soon demand that action be taken.

The Tubing Manufacture System

A tube mill is used at the manufacturing facility to form metal pipe from coils of sheet steel. The plant makes the tubing for all its gates, and for sale to other companies. A water-based fluid coolant is used by plant for lubrication and cooling of the tube mill. About 800 liters (210 gallons) of coolant per month are consumed at a cost of about $800. The coolant flows from its application points into sumps below the components. The sumps, in turn, drain by gravity to a large collection tank. The collection tank contains an oil removal system, consisting of a plastic tube pulled through the liquid coolant. Floating oil adheres to the polyethylene tube, and is removed by a scraper. The oil removal system is not able to remove oil fast enough. The oil in the coolant originates from grease leaking out of the tube mill gearboxes. Over the years, oil and grease leaks have covered the tube mill and the surrounding area. Grease combines with the metal filings created when excess metal is scraped off the fresh welds, and together they make a black substance that fills the bottom of the sumps in about a month. The mill is occasionally shut down while operators scoop out all the grease. About two-thirds

of the coolant is lost each time the sumps are cleaned, and this is the only time coolant is discharged from the system. A detailed analysis of the tube mill system at this facility is given by Montag (1993).

Recommendations for the tube mill area at this plant are mostly concerned with changes which would minimize grease contamination of the coolant. A suitable new oil removal unit was estimated to cost less than $2,500. The payback period was estimated at less than six months assuming that the coolant's useable life is only doubled. Beyond that, the actual payback period could be even shorter. Again preventive maintenance and cleaning was identified as a principal pollution prevention strategy.

SUMMARY AND CONCLUSIONS

In this paper, the preliminary results of an extensive pollution prevention program at a metals fabricating and finishing facility are reported. The pollution prevention program was a joint partnership between a land-grant state university and a private industrial facility. The facility is large and fairly aged. The principal operations at this facility include electroplating, conversion coating, machining, grinding, welding, hot-dip galvanizing, painting, and testing of various metallic components that are being made. The discussion in this paper centered on the principal divisions that produce the bulk of wastes at this facility including electroplating, galvanizing, painting, and tube manufacturing. Additional information regarding the manufacturing facility and its processes can be found in Dahab and Montag (1993), Dahab et al. (1994), Montag (1993) and Parr (1994).

The study is an extensive and a systematic waste stream assessment and evaluation. One of the major constraints was the fact the facility was fairly old and not very profitable. Consequently, all of the recommendations for process and operational modifications resulting from the waste stream assessment had to meet critical economic payback periods.

The operations and processes at this facility result in the production of large quantities of wastewater with significant concentrations of metals that require expensive treatment. This treatment process involves lime and polymer addition followed by pH adjustment before discharge.

The pollution prevention recommendations in the electroplating system, to date, have contributed to significant reductions in the amount of wastewater that needs to treated as well as a significant increase in the product quality. The product quality increase is clearly demonstrated by the 550 % and 1000 % increase in the level of protection against white and red rust, respectively, in the neutral salt spray tests conducted on the products before and after project implementation. The plant management has been quite pleased by these results since numerous claims have been made against the facility because of corroded fasteners.

The principal modification to the galvanizing process centered on reducing in the amount of wastewater produced in this process while improving product quality. As indicated, it was apparent that rinse water use could be reduced by as much as 83 percent of what the process was using prior to the waste stream assessment. One of the changes resulting from the study was the replacement of the spray nozzles in the rinse booths by water-saving (low-flow) ones. This change resulted in an immediate reduction in the water use by 60% and savings in water and waste treatment costs of about $250 per day. The process modifications were estimated to have a payback period of about 10 months. Product quality should improve when the suggested improvements in process chemistry are implemented.

Pollution prevention in the painting line was concentrated on reducing VOC emissions which soon will be regulated under the Clean Air Act of 1990. The costs of proposed modifications probably could not be justified in terms of savings in waste reductions. Installation expenses will have to be recovered through adjustments in the pricing of products. The modifications are well justified in terms of expected regulatory requirements.

The tube mill system was associated with excessive coolant loss as well as rancidity. The proposed changes were expected to significantly reduce coolant loss with an estimated payback of less than six months by installing a better oil and grease removal system. As it turned out, the facility was able to install a suitable oil removal system for a fraction of the estimate made during waste stream assessment.

In forming the industry/university partnership, resources available at the university were combined with those of the industry for the common cause of reducing environmental pollution. As pointed out earlier, the graduate students assigned to this project gained considerable training in recognizing and dealing with pollution prevention. In addition, the project served as a significant component of their academic programs. In turn, the industry realized considerable gains in its environmental management program that lead to meaningful reductions in pollutant loads produced by the facility, as pointed out above. Additional benefits will be gained by the facility as it continues to implement additional pollution prevention measures recommended during this study.

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THE COMPLIANCE INCENTIVE EXPERIENCE IN SANTA ROSA, CALIFORNIA

By Martin Grimsrud - City of Santa Rosa - Environmental Services Dept.

SUMMARY

A general overview of the Compliance Incentive Program (CIP), implemented with the auto repair industry in Santa Rosa, California is given. This program was introduced as an alternative approach to supplement traditional enforcement practices. The centerpiece of the program is a recognizable sticker that certifies environmental compliance to the public, while at the same time recognizing businesses for their efforts in environmental protection. Attention is placed on the evolution of the design and implementation of the program and the benefits derived for the regulators, the business community, and the public.

1.0 PRE-EXISTING SITUATION WITH AUTO REPAIR SHOPS IN SANTA ROSA

Background Information - The City of Santa Rosa operates a 17 million gallon per day wastewater reclamation plant using tertiary treatment for 100% reuse of the treated water. This plant, which services four cities and two unincorporated areas, faced a possible problem meeting air quality standards applicable to Publicly-Owned Treatment Works (POTW) related to excess levels of organic solvents in the inflow to the system. The auto repair and service industry, with over 275 facilities and a customer base of over 200,000 vehicles, is the largest generator of hazardous waste in the 75 square mile POTW service area. This same industry was found to be directly responsible for the detectable levels of organic solvents at the inflow of the Santa Rosa POTW.

The Corby Avenue Auto Mall Incident - During the spring of 1990, an inflow and infiltration team of the POTW responsible for monitoring storm water infiltration into the collection system, reported that they were unable to service flow recording equipment located in a manhole on a trunk line due to the persistent presence of noxious fumes.

Team members reported headaches, jumpiness and sleeplessness after short periods of exposure. POTW inspectors determined that the trunk line served an area known as Corby Avenue Auto Mall. This location contains fifteen new car dealers along approximately one mile of roadway.

An in-depth investigation was begun to determine the sources of the pollutants involved. This year-long process included:

- review of current Wastewater Discharge Permits for local businesses
- beginning the permitting process for businesses without permits
- starting an extensive sampling program
- comprehensive inspections to determine types and sources of discharges

Businesses Struggling to Comply - For the auto shop owners involved in the Corby Avenue Auto Mall incident, requirements and expectations of the industrial waste inspectors were unclear. Upon inspection, auto shop owners would find themselves being cited for various environmental violations with minimal information on how to correct the situation supplied by the industrial waste inspectors. For example, auto shop owners' attempts to keep hazardous constituents out of the water by letting them evaporate resulted in violations of air quality standards. This was a direct result of a lack of communication between regulatory agencies.

The auto shop owners uniformly complained that the numerous inspections by the various environmental regulatory agencies resulted in confusing information on achieving compliance. As the example above illustrates, the satisfaction of the industrial waste inspectors' demands for environmental compliance led to costly fines from the air quality inspectors for environmental violations. This exclusively punitive approach by all of the environmental regulatory agencies in Sonoma County contributed to an increasing adversarial relationship between the business community and the regulatory agencies.

The auto shop owners also cited the fact that they were losing business by trying to be in compliance. Expensive equipment for cleaning up discharges to the sewer system only seemed to transfer the problem to another media, such as the air. They claimed that these increased costs associated with complying had to be passed on to customers which gave non-complying businesses a competitive advantage. This unfair competitive edge was sharpened by the fact that any business forming a relationship with the environmental regulatory agencies was more prone to be inspected, which took up valuable business operation time and often led to conflicting information from the various agencies.

2.0 NEW APPROACH: COMPLIANCE INCENTIVE PROGRAM

Shift in Philosophy - Subsequent to the Corby Avenue Auto Mall incident, the industrial waste inspectors of the Santa Rosa POTW began adopting a new approach to environmental regulatory compliance. They began to work directly with the auto shop owners to eliminate the hazardous constituent problems at the source, instead of trying to clean up the shop's discharges at the end-of-the-pipe. Information regarding the water quality of each auto shop was reported to the shop owners for quality control, instead of withholding this information from them until a violation was issued. The inspectors realized that the previous enforcement philosophy of inspections backed up by notice of violations, fines, and Cease & Desist orders was not achieving compliance goals and was leading to increased adversarial relationships with the business community. Their new approach can be summed up as "education, before litigation."

Aspects of the Compliance Incentive Program (CIP) - With the assistance of the environmental consulting firm Strategic Environmental of Sebastopol, California, the Santa Rosa POTW began to design a comprehensive compliance program to address a number of the problems that had come to light from the Corby Avenue Auto Mall incident. The CIP consists of four elements:

- Technical Assistance - information is provided to businesses for environmental compliance, including training and materials in Best Management Practices (BMP's) and Pollution Prevention.

- Regulatory Streamlining - a collaborative effort involving all environmental regulating agencies creates a unified inspection checklist for the automotive repair and service industry to streamline the inspection process. This eliminates conflicting, confusing and redundant regulation, reduces the number of annual inspections, and enhances communication among agencies.

- Recognition - a regional sticker is presented to businesses that comply with all mandatory environmental regulations. This provides businesses with the incentive to make the commitment and investment required for full regulatory compliance. The sticker provides businesses with a marketing opportunity while moving the competitive advantage away from non-complying businesses.

- Consumer Awareness - a significant pollution prevention outreach effort is initiated to educate consumers about the program and the environmental information contained in the recognition stickers. Consumers realize that by supporting environmentally-responsible businesses, they can play a meaningful role in pollution prevention.

3.0 FROM DESIGN TO IMPLEMENTATION

Changing the Regulatory System - A key component in the implementation of the CIP is the coordination and communication among the eight regulatory agencies responsible for environmental compliance in Sonoma County. These eight agencies are: Santa Rosa Industrial Waste Section, Santa Rosa Fire Services, Sonoma County Fire Services, Sonoma County Environmental Health, North Coast Regional Water Quality Control Board, Bay Area Air Quality Management District, Department of Toxic Substance Control, and Cal-EPA. Adversarial relations exist, not only between the business community and the regulatory agencies, but also among the various regulatory agencies themselves. Creating ownership for the CIP in each of the regulatory agencies is an on-going process that is critical to program success.

The CIP provided the necessary impetus to bring these different agencies together for the common goal of environmental compliance for the auto repair facilities in the POTW service area. To achieve this goal, a committee was established with representatives from each of the eight environmental regulatory agencies that have jurisdiction over air, water, hazardous waste, and environmental health. This group, known as Sonoma Environmental Quality Assurance Committee (SEQAC), meets once a month to discuss pressing environmental compliance issues, share information on non-complying businesses, and develop better channels of communication.

From the beginning, SEQAC has used the CIP as a testing ground for creating enhanced interagency relations and efficient enforcement of environmental regulations. The centerpiece of this effort has been a streamlined auto shop inspection checklist. When the eight agencies first sat down and put their individual inspection sheets on the table, there were over 48 pages of items that every auto shop was inspected on. After several meetings, those 48 pages have been reduced to 8 pages. This eliminates redundancy in the regulatory inspection process while educating every inspector on the primary areas of responsibility that each agency has.

To ensure effective cross-agency communication regarding auto shop inspections, SEQAC created an agency referral form. This form is used by the lead inspection agency, in this case the Industrial Waste Section of the POTW, to notify all involved parties of any environmental compliance issues discovered during the inspection. The referral form must be signed by the business representative and a copy is provided for corrective action. In addition, copies are sent to other regulatory agencies, such as air quality or environmental health, when the compliance issue detected falls into their jurisdiction. In the event that the violation is of a serious nature, a field citation is issued on the spot and appropriate corrective action begins immediately.

Identifying Key Players - An important part of the CIP process was identifying the key players and inviting them to meet and discuss the program before it was implemented with the auto repair industry. From a Total Quality perspective, each group was viewed as a customer with explicit needs and requirements that had to be satisfied by the CIP.

The key players invited to the meeting included: several small auto shop owners, four large auto shop owners from Corby Avenue Auto Mall, the Chamber of Commerce Directors from the cities served by the POTW, auto shop instructors from local educational institutions, and representatives from local environmental groups.

The meeting generated a consensus and the CIP was fully supported by every represented group. Many of the participants were very encouraged by the new approach to environmental regulatory enforcement adopted by the industrial waste inspectors. The business representatives, in particular, were encouraged by the CIP approach and provided constructive criticism that pointed out potential obstacles and helped prevent program delays in the future. As Keith Woods, Executive Director for the Santa Rosa Chamber of Commerce exclaimed at the end of the meeting, **"This is a wonderful idea and the business community will welcome this approach with open arms."**

Creating the Information Kit - The next critical task was providing educational material to all of the auto repair facilities in the service area. This Information Kit contained a comprehensive information booklet which included:

- Program Description
- Best Management Practices (BMP's)
- Recognition Sticker (artist's rendering)
- Vehicle Service Facility Checklist
- Vendor List

Kick-off Meeting - A CIP kick-off meeting was held in March of 1993 to introduce the CIP concept to all auto repair and service shop owners in the Santa Rosa POTW service area. Of the 275 invitations that were sent out to owners, 165 owners showed up for this meeting. The Information Kits were distributed to all attendees before the brief presentations by the industrial waste inspectors and other regulatory representatives. The meeting was designed to cover several important areas:

- Establishing Conditions of Inspections
- Bridging Adversarial Relations
- Enhancing the Role of the Inspector
- Balancing Unfair Competitive Advantage
- Marketing Benefits

An indication of shop owners' support for the CIP concept occurred when an inspector passed around a sign-up sheet for shops wanting to volunteer for an inspection. **Over 25% of the attendees signed up on the spot. In the history of the POTW, no business had ever requested an inspection.**

Inspecting the Shops - Prior to the Corby Avenue Auto Mall incident, auto repair shops were issued wastewater discharge permits but were rarely inspected for environmental compliance. Of the fifteen auto dealerships along Corby Avenue inspected after the incident, none were found to be in full compliance. This first detailed look at the automotive repair industry alerted the industrial waste inspectors to the severity of the hazardous waste discharges originating from these facilities.

In April of 1993, armed with the list of willing participants from the voluntary inspection sign-up sheet, the inspectors began visiting shops. As of this writing, over **100 inspections have been conducted and 33 shops have been found to be in full compliance.** This is an extraordinary number when one considers a zero percentage rate of compliance prior to the CIP. Of the remaining 77 shops, most will achieve compliance within 60 days of initial inspection. A small percentage of the shops have major issues, such as ground water contamination from leaking underground tanks. While these types of problems take more time to resolve, all shops have expressed their desire to qualify as a "Sonoma Green Business."

The recognition sticker symbolizes total compliance with environmental regulations and this means that a sticker cannot be issued if there are pending issues with any of the other seven regulatory agencies. It must be pointed out that compliance is still the bottom-line. The recognition sticker and the status as a "Sonoma Green Business" is a bonus to the shops. If a business owner declines to be a participant in CIP, this does not excuse them from meeting environmental regulatory requirements. The inspections will still be conducted and enforcement implemented when necessary. The CIP is merely a tool or philosophy for enhancing the relationship between the regulatory agencies and the regulated community with the added power of the consumer to help achieve compliance.

4.0 PUBLIC PARTICIPATION IN POLLUTION PREVENTION

Publics' Role in Pollution Prevention - In the traditional environmental compliance cycle, the regulatory community alone is pitted against the business sector in a constant battle to detect violations, impose fines and face possible litigation. These two groups continually overlook the primary customers of environmental quality: the public. The CIP makes use of this fact by increasing the tools available to achieve compliance through the distribution of environmental compliance information to the community.

The public wants to support businesses that practice environmental responsibility. People are the market, and the power to encourage compliance is in their wallets. The Santa Rosa CIP uses P^4, Public Participation in Pollution Prevention, to describe this powerful leverage to achieving environmental compliance.

Sticker Value - The key is getting environmental compliance information to the public so that they can use it in their purchasing decisions. That is one of the primary uses of the CIP sticker that is now known by the name "Sonoma Green Business". This recognition sticker, presented to the auto shops that are in complete environmental compliance in the Santa Rosa POTW service area, will allow the consumer to play an active role in pollution prevention by using their economic muscle in the patronizing of 'green' businesses.

Public Education - A careful strategy was developed to get information about the sticker out to the residents of the entire POTW service area. This multi-media campaign includes:

- press conferences and announcements
- radio ads
- TV public service announcements
- newspaper articles
- public transportation ads
- announcements in city billings to POTW residents
- public meetings
- school presentations

5.0 CIP BENEFITS

Increased Compliance - While enforcement remains the main tool for inspectors to insure business compliance to environmental regulations, the CIP opens the door for the use of alternative programs that support current enforcement efforts. Through the use of incentive programs such as CIP, inspectors can add the role of educator to their enforcer identity and begin to make greater strides toward achieving environmental compliance goals.

The CIP supports enforcement activities in a variety of ways. Among some of the most important are:

- Increased inspector utilization. By training inspectors in multi-media skills, the limited number of inspectors can be more broadly utilized to focus on non-complying companies.

- Shifting compliance pressure. Instead of inspectors alone always being the ones to apply pressure on companies to comply, the CIP provides a mechanism by which other companies within the same industrial category apply compliance pressure and influence any non-participating businesses to seek CIP eligibility.

- Maximizing limited agency budgets. The CIP streamlines the regulatory inspection process and increases the efficiency of agency allocations. The cooperative relationship established between various regulatory agencies makes full utilization of limited agency resources.

- Increased compliance awareness. The CIP helps create an atmosphere of trust between the agencies and the business community. This provides a solid foundation to deliver educational material to companies for environmental compliance.

Improved Relations Between Business and Regulators - The Santa Rosa POTW had never had a request by any business in its service area for a voluntary environmental inspection to determine if that business was violating any environmental regulations. **Since the introduction of the CIP, over 100 of the 275 auto repair and service facilities in the Santa Rosa POTW service area have requested voluntary inspections.**

This improved atmosphere of cooperation generated by the CIP has expanded beyond the boundaries of the auto repair industry. Several requests from business owners from other industrial sectors, such as fleet yards, printers and photo processors, have come into the industrial waste inspectors' offices.

Improved Interagency Relations & Inspector Capacity - The core concept of the CIP is total compliance with all environmental regulations. This necessitates clear communication and effective cooperation with every agency that has responsibility for environmental regulatory enforcement. In the case of Sonoma County, that means working with eight separate agencies that have a history of conflict and their own adversarial relationships.

Increased Competitive Advantage for Businesses - From the immediate response of the kick-off meeting attendees and the comments of the auto repair shop owners who have had their facilities assessed, there is wide-spread consensus that the "Sonoma Green Business" sticker will provide a distinct marketing advantage over the shops that are out of compliance and ineligible for a recognition sticker.

The shop owners are also placing a high value on the sticker because of the information that it will provide to the other regulators in the county. By having a sticker in their window they are assured that they will not suffer from repetitive, redundant, and interruptive inspections by various environmental agencies.

Increased Public Participation - Although it is too early to tell if the P^4, Public Participation in Pollution Prevention has increased, feedback from initial marketing efforts suggest that the "Sonoma Green Business" sticker will soon become a primary source of environmental information to the citizens of Sonoma County. Questions such as, " Is this information available on all businesses?", and "Why has it taken so long to do this?", are now beginning to come into the POTW.

Requests from Other Agencies - Probably one of the best indicators of the success of the CIP is in the form of requests from other regulatory agencies for the model of doing this in their communities. A more comprehensive paper was introduced to the world in April of this year at the request of the United States Environmental Protection Agency. A presentation was delivered at the Third Annual Conference on Environmental Enforcement held in Oaxaca, Mexico. Following the conference we have received requests, for program material, from over eighty (80) countries. In addition over fifty (50) local, state, and federal environmental regulatory agencies have requested information on the CIP.

6.0 Future of CIP

Regional Applications - The focus on the CIP now is to expand it downstream to all of the agencies that have environmental jurisdiction in the entire San Francisco Bay area. Many of these agencies have been contacted and enthusiasm about CIP runs very high.

The use of watersheds by some environmental regulatory agencies to establish jurisdictional boundaries makes regional application of the CIP much more effective. Watersheds help define areas by their ecological characteristics and it is those characteristics that are monitored by the regulatory agencies.

CIP builds on this ecological awareness by bringing environmental compliance information to all groups involved in the regulatory cycle: the businesses, the regulatory agencies, and the public. This simple act of increased environmental awareness will expand the level of environmental literacy for all three groups, making future dialogue about environmental concerns much more effective.

Environmental Education - Another idea being explored is a mandatory environmental school for corporations and individuals. The present concept is utilizing the environmental school for violators of environmental regulations in an effort to provide education in addition to the litigation. Fines recovered from the violations would fund the school. The environmental school concept is quickly being expanded to make the course mandatory for a company or individual applying for a discharge permit or registering as a generator of hazardous waste.

Total Public Participation - When environmental compliance information is made available to the public, market conditions that support non-compliance will rapidly disappear. The public will change from consumers, unknowingly participating in the pollution process, to customers who are aware of the environmental consequences of their actions.

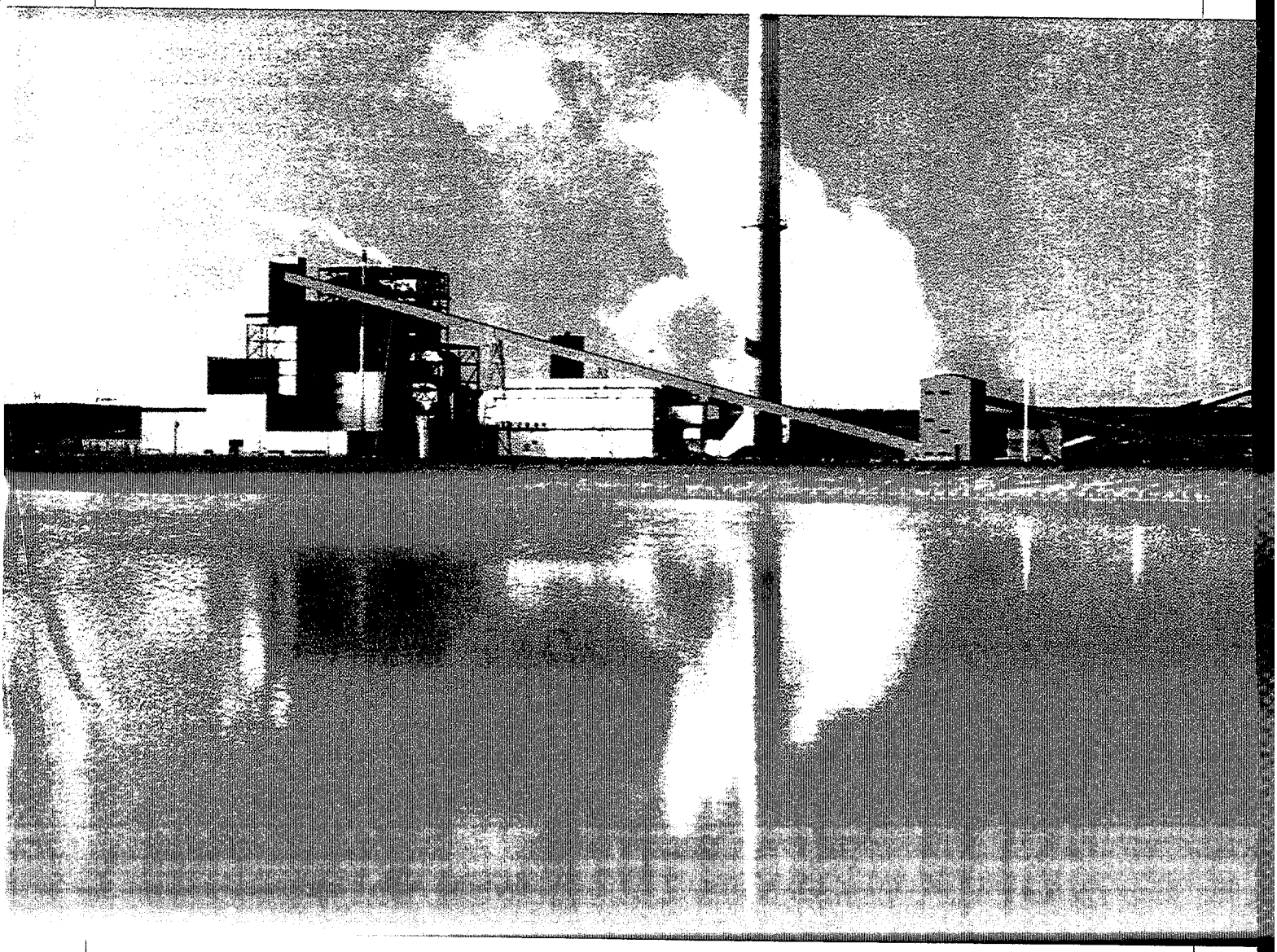
It is the absence of these customers from participation in the current regulatory process that creates the intense adversarial atmosphere that now exists between businesses and the regulatory agencies. The primary customer of the entire regulatory process, the public, is excluded from providing critical market-based feedback to the system.

By achieving P^4 in the San Francisco Bay Area through regional display of the CIP sticker, businesses upstream of the POTW will enlist their most valuable ally, the customer, in the pollution prevention process. Once that occurs, an environmentally literate, free market system will demonstrate its true role in controlling and preventing pollution.

FEATURE

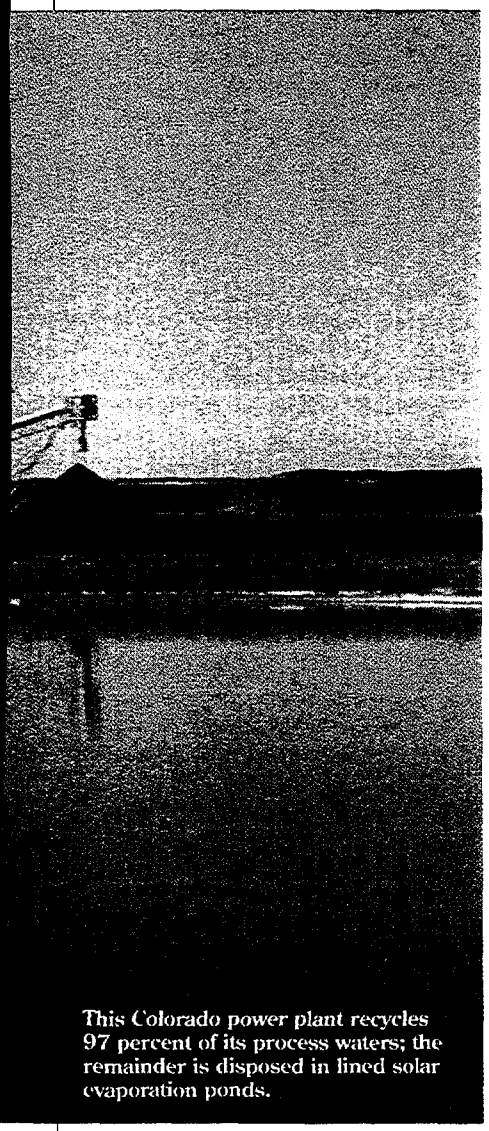
How Are You Doing?
The Importance of Environmental Auditing in the 1990s

By Rebecca P. Thomson, Charles H. Le Grand and Jeff Dresser



Environmental regulations, market forces and other factors are prompting many companies to design "greener" products, make major investments in innovative production and waste reduction programs and, most importantly, develop sound environmental management systems.

Environmental management systems include an organization's structure of responsibilities and policies, practices, procedures, processes and resources for protecting the environment and managing environmental issues. At the heart of these systems is the voluntary environmental auditing program, which is used to identify and prevent environmental problems and measure progress over time.



This Colorado power plant recycles 97 percent of its process waters; the remainder is disposed in lined solar evaporation ponds.

CH2M HILL

The risks of not developing such a program or denying the results of an environmental audit can far exceed the costs of the process itself, as the following story illustrates. (Individual and company names have been omitted and some details changed to maintain confidentiality.)

During a financial and operational audit, internal auditors noted several inconsistencies between company X's comprehensive new environmental protection policy and operations at one of its plants. Discharges to the river routinely exceeded permit limits, and the plant frequently delayed or neglected reporting these incidents to the state environmental control agency. Additionally, plant managers could not account for several 55-gallon drums of solvents. Based on these findings, senior company officials reprimanded plant managers but took no other action.

The following year, the internal audit team cited similar violations at the same plant. Auditors once again informed senior management about the potentially serious consequences of noncompliance and the need for a separate environmental auditing program. The company's general auditor also argued that the existing reporting system needed improvement because it lacked accountability and objectivity. After discussing the issue, senior management decided the plant just needed more time to implement the new environmental protection policy. They believed the cost of a firmwide environmental audit program — about $300,000 annually — would exceed the benefits. After all, they reasoned, only one of 140 plants had experienced problems during two consecutive audits.

Six months later, the state environmental control agency received a complaint from a riverfront homeowner who had noticed a yellowish foam on her children's tennis shoes after they had been playing near the river. She also noticed dead fish on the riverbank and dead birds in her yard, and the family dog was inexplicably ill. After a state inspector confirmed her story, a thorough investigation was launched. One week later, without warning, a dozen state and federal officials and members of the press arrived at the company's plant. An environmental investigation revealed a 5-acre groundwater plume of solvents, as well as soil contamination over a 12-mile stretch of the riverbed. The story was covered on national news. Total regulatory fines, legal fees and remediation costs have exceeded $20 million, and the value of lost customer confidence has been estimated at $100 million.

Environmental auditing. Environmental auditing became a popular tool in the United States in the early 1970s, with the advent of increased federal enforcement actions. From the beginning, internal auditing techniques relied on standard methodologies and involved verifying compliance against standards through the use of risk models and protocols. Although the process has evolved in terms of sophistication, objectivity, complexity and scope, there still are no uniform procedures for conducting an environmental audit. Instead, auditing programs are tailored to meet the needs of the organization and, therefore, mean different things to different people (Table 1).

EPA, for example, defines environmental auditing as: "Any systematic, documented, periodic and objective review by a firm or other regulated entity of facility operations and practices related to meeting applicable requirements." For this article, environmental auditing is defined as an integral part of an environmental management system used to determine whether an organization's controls are adequate to ensure compliance with regulatory requirements and internal policies.

In short, environmental auditing is a self-evaluation process whereby an organization learns whether it is meeting legal and internal environmental objectives. Environmental audits can be used to assess the state of an organization's

Editor's note: *This article is based on a report, "The Role of Internal Auditors in Environmental Issues," published by the Institute of Internal Auditors Research Foundation (Altamonte Springs, Fla.) and released in March.*

environmental performance. They also can be used as an ongoing tool to monitor compliance, track performance and assess an environmental management system's long-term effectiveness.

Environmental auditing assesses a facility's past performance as well as its current and future ability to meet specific, clearly stated environmental objectives. Specific functions may include:

- determining whether the organization is complying with regulatory requirements;
- evaluating the effectiveness of existing environmental management and control systems in minimizing risk;
- identifying future environmental issues and planning effective responses;
- ascertaining whether the organization is in compliance with internal policies, procedures and practices;
- meeting customer requirements or contractual obligations;
- assessing and managing the risk of receiving, buying, insuring or selling real estate, or making loans secured by real estate;
- meeting social standards adopted by the organization;
- assessing the hazardous material management practices of contracted treatment, storage and disposal operators; and
- determining that known environmental liabilities are identified and reported properly and that associated financial accruals are adequate.

The type and extent of environmental auditing a company needs depend on its objectives and the risks it faces. Generally speaking, there are seven types of environmental audits: compliance audits; environmental management system audits; transactional audits; treatment, storage and disposal facility (TSDF) audits; pollution prevention audits; environmental liability accrual audits; and product audits.

Compliance audits. Because of the potential for civil and criminal liability stemming from regulatory violations, compliance audits have become the most common form of environmental audit used by industry. In fact, any organization subject to environmental regulations should consider implementing a compliance auditing program, the scope of which would depend on the degree of risk associated with noncompliance.

Compliance audits may include a detailed, site-specific review of current operations, past practices and planned future operations, depending on the level of intensity (Table 2). Compliance audits normally are programmatic and involve a review of all environmental media a facility may contaminate, including air, water, land and wastewater. They have both quantitative and qualitative aspects and should be ongoing rather than sporadic. Generally, facilities are prioritized and scheduled for compliance audits on the basis of potential risk.

Management systems audits. Under existing laws, many organizations are faced with the expense of remediating contamination stemming from past management practices that were legal at the time. This situation has prompted many organizations to focus on anticipating future regulatory trends and incorporating them into environmental management systems. As the environmental auditing process matures and organizations become more confident about compliance, the audit emphasis shifts to environmental management systems. Specifically, these audits focus on whether systems are in place and operating properly to manage future environmental risks.

Transactional audits. Transactional audits are an environmental risk management tool for banks, land buyers, lending agencies, charitable organizations, insurers, investors and companies purchasing land on which to build a facility. They also are called acquisition and divestiture audits, property transfer site assessments, property transfer evaluations and due-diligence audits.

Transactional audits are the best method available for assessing the environmental risks and liabilities associ-

TABLE 1

Examples of Environmental Audit Functions

Type of Organization	Audit Functions
Retail, service or other nonmenufacturing industries	Identify and manage safety and health risks to employees and the public
Government or business offices	Create a waste reduction, energy conservation or recycling program or maximize the use of recycled products
Public works	Examine compliance with permits
Real estate owners, buyers, lenders, fiduciaries or charities that receive real estate	Examine existing environmental contamination on land that is part of a real estate transaction
Federal and state regulatory agencies	Self-examine for compliance with regulations; assist the regulated community in identifying and correcting noncompliance; investigate a suspected violator in an environmental enforcement action; or require a regulated entity in noncompliance to perform as part of a settlement
Manufacturers	Apply highly sophisticated risk management tools to help ensure compliance with regulations and internal environmental protection policies

ated with a particular piece of land or facility before a property transaction occurs. Transactional audits are important, because CERCLA, or Superfund, may hold landowners responsible for environmental contamination, regardless of whether they caused it. Through these audits, buyers and lenders can try to identify and quantify potential problems, including financial liability and cleanup costs that may exceed an asset's market value. Today, many banks require transactional audits conducted by third parties before making a loan secured by commercial real estate. Audit results may be reflected in the loan rating, as an indicator of creditworthiness or in the interest rate charged on the loan.

Transactional audits demand due diligence (a reasonable level of research) from the auditor; however, they cannot guarantee that a property is free of contamination.

Industry experts typically divide transactional audits into three phases, although definitions, descriptions of what constitutes due diligence for each phase and auditor qualifications are the subject of much debate.

- Phase I audits are qualitative assessments involving a review of records, including a title search and site visit.
- Phase II audits are quantitative and involve sampling and laboratory analysis.
- Phase III audits are quantitative and are performed in response to the findings of Phase II audits. They are used to confirm the rate and extent of contaminant migration and the cost of remediation.

Each phase should address all media exposures, including groundwater, surface water, wastewater, land and air, as well as all hazardous substances, materials used in operations and wastes. Most Phase II and virtually all Phase III audits require a high level of technical and scientific expertise.

A lack of formal standards has created conflict among auditors, those being audited and others involved in real estate transactions, such as banks. The American Society for Testing and Materials is in the process of developing voluntary standards for transactional audits in the United States and plans to release a final standard this year. Ultimately, however, the debate over responsibility for the environmental risks associated with property transactions likely will be resolved in the courts.

TSDF audits. Under U.S. environmental regulations, hazardous waste must be tracked from "cradle to grave" (creation to destruction), and all "owners" of these materials remain liable as long as the waste exists. This means, for example, that if a manufacturing company contracts with a transportation company to dispose hazardous waste in a landfill that later contaminates the environment, all three entities — manufacturer, transporter and landfill operator — and their officers may be financially liable for the cleanup.

For this reason, some companies conduct TSDF audits before contracting for transportation or disposal services, and many negotiate provisions for future audits into their contracts. When an organization conducts a TSDF audit on its own facility, an extensive protocol checklist covering all relevant RCRA issues must be used.

Pollution prevention audits. The purpose of a pollution prevention audit is to identify opportunities where waste can be minimized and pollution can be eliminated at the source rather than through "end-of-pipe" controls. One commonly used pollution prevention "hierarchy" suggests seven methods for handling wastes: recovery as a usable product, elimination at the source, recycling and reuse, energy conservation, treatment, disposal and release.

Sometimes, process engineering changes are required for pollution prevention, but in many facilities, a simple commitment to more efficient practices can result in significant waste reduction. A study of recycling, reuse and recovery options — an important facet of these audits — can identify process streams amenable to recycling or reuse, areas where raw materials or wastes can be recovered and reused, and methods of altering processes to reduce the amount of waste generated. In many cases, an ongoing employee suggestion process results in pollution prevention benefits with minimal capital investment.

Liability accrual audits. The ac-

TABLE 2

Potential Levels of Compliance Auditing

Level	Description
Preliminary Assessment	A general historical look at operational practices that may provide insight into future conditions and consequences. Sometimes called a "document review" or "desk-top" audit.
Environmental Audit	Focuses on operations. Detailed. Requires a site visit to interview managers and employees, and examine hazardous waste manifests, safety data sheets, monitoring data and sampling procedures. Verifies compliance with permits and consent orders. Focuses on the validity of reports provided to enforcement agencies regarding discharges of pollutants.
Environmental Investigation/ Site Assessment	Invasive. Conducted when previous activities indicate contamination exists. Includes detailed testing, installation of groundwater monitoring wells, laboratory analyses and interpretation of laboratory reports.

*Many organizations refer to the different levels of compliance as *phases*. However, the definition of the phases may vary widely among organizations. The specialized technical expertise needed to conduct these audits increases as the level increases.

counting profession is faced with challenges in recognizing, quantifying and reporting liability accruals for known environmental issues. The parameters of "probable," "measurable" and "estimatable" — guidelines typically used to define liability — must be redefined for the environmental arena. The question of when an environmental risk becomes a financial liability also is unclear.

When an organization is subject to litigation as a potentially responsible party, a dilemma may exist, because accounting for a potential liability may be perceived legally as an admission of guilt. However, not accounting for such a liability may be perceived as a violation of the Securities and Exchange Commission's 10K reporting requirements. The Financial Accounting Standards Board and a growing group of environmental liability accrual auditors are beginning to address these issues.

Product audits. Product audits focus on ensuring that everything possible is being done to make an organization's products environmentally friendly and confirming that internal product standards and chemical restrictions are being met.

The product audit process is resulting in the development of fully recyclable products, broad changes in the use of packaging materials, and phase-out of such chemicals as CFCs, sulfates and dioxin-creating substances. Procedures for such audits vary widely, although input from customers, environmental specialists, management and employees often is helpful.

Driving Forces Behind U.S. Environmental Auditing

Generally speaking, two major forces are driving the increased interest in environmental auditing: the need to practice good environmental stewardship and increased regulatory activity.

Environmental stewardship. Several forces are prompting more and more companies to practice good environmental stewardship:

- Interest in the concept of sustainable development. According to the International Institute for Sustainable Development, sustainable development describes behavior that allows an organization to meet its current needs while protecting, maintaining and enhancing human and natural resources needed for the future. This concept is important, because it recognizes that a strong economy and a healthy environment are compatible goals. Sustainable development is more than altruism. Some organizations are concerned about their own futures if current environmental and social trends continue. Pharmaceutical companies, for example, are concerned about the health of the world's tropical rain forests, which

supply many of today's medicinal substances.

- Total quality management (TQM). TQM, the popular management philosophy credited with Japan's industrial success, focuses on integrating quality into all aspects of an organization's operations, including environmental performance. This management style, which gained popularity in the 1980s, in effect "demands" that a company practice good environmental stewardship.
- Changing customer and employee attitudes. Consumers today are increasingly aware of the environment. Demands for "greener" products and boycotts of those perceived as "anti-green" are on the rise. Likewise, employees are more interested in their employer's environmental performance and better able to recognize environmental disregard.
- Cost-cutting pollution prevention initiatives. Although some advanced pollution prevention technologies are expensive, the long-term costs of environmental damage and end-of-pipe controls may be even greater. The tangible and intangible costs of lawsuits, health insurance, environmental cleanup, loss of public trust and difficulty siting new disposal facilities are increasing. These factors must be considered when weighing the long-term costs and benefits of implementing pollution prevention techniques.
- A new focus on cooperation between environmental groups and businesses. Historically, environmental groups have relied on demonstrations, lawsuits, lobbying and buying power to "force" companies to improve environmental performance. Although these tactics are still used, environmental groups also have developed more positive strategies, including the creation of broad-based coalitions emphasizing a cooperative relationship between industry and environmentalists.

Regulatory activity. Governments, meanwhile, address pollution by passing laws, setting standards and developing and enforcing regulations, thus creating the second driving force behind increased use of environmental audits.

During its existence, EPA has created a plethora of regulations — now more than 11,000 pages — to prevent pollution and resolve existing contamination problems. According to an article in the July 6, 1992, issue of *Forbes*, EPA regulations have imposed more than $1.4 trillion (1990 dollars) in compliance costs on industry since the Agency's founding in 1970. The Agency now has more than 18,000 employees, including 96 U.S. attorneys to prosecute environmental crimes.

EPA also has had a significant impact on the U.S. economy. In 1990, for exam-

ple, the Agency estimated that complying with federal pollution control regulations costs Americans $115 billion a year, or 2.1 percent of gross national product. EPA projects that during the 1990s, compliance costs will total $1.6 trillion, excluding expenses associated with the Clean Air Act (CAA) Amendments of 1990, which could add another $25 billion to $40 billion annually.

Besides the rising cost of compliance, companies also face increasingly stiff civil and criminal penalties for environmental violations. According to EPA's Office of Enforcement, the Agency during 1992 assessed a record $62.9 million in criminal fines and $78.7 million in civil penalties.

This trend, spearheaded by the U.S. Department of Justice and EPA's Office of Enforcement, places regulated organizations, including their officers and compliance personnel, at much greater collective risk of civil and criminal prosecution than in the past. This risk is perhaps the strongest driving force behind environmental auditing in the United States.

Enforcement in the 1990s. How great is the risk of enforcement activity in the 1990s? According to EPA's strategic plan for 1992 through 1995, the Agency will continue to rely on civil and criminal prosecution as the ultimate deterrent to pollution. Although there is no way of knowing exactly who EPA will target for enforcement, the Agency's readily available policy documents and annual program implementation plans provide some insight.

The following are four major facets of EPA's plans:

- A cross-program, multimedia enforcement initiative. This approach calls for enforcing all environmental regulations simultaneously, thus putting organizations that release pollutants to more than one medium at greater risk of enforcement actions. The highest percentage of enforcement cases will come under the Toxics Release Inventory (TRI) program, and penalties are expected to increase dramatically for violations. Enforcement of CWA violations against industries and municipalities will continue to dominate enforcement activity, although EPA also intends to step up air quality monitoring and enforcement efforts as the CAA Amendments are implemented.
- Improving the integrity of the regulatory structure. EPA has developed new regional enforcement pilot projects, including a geographical information system (GIS) for Region X (Pacific Northwest). The GIS computerizes environmentally sensitive geographical information, such as maps of delineated wetlands. The system also connects with the region's numerical data files, which contain information submitted by the regulated community under various reporting requirements. The interactive process of the GIS assists enforcement by producing overlays of numerical data on a map. For example, if the region wanted to know which businesses within a mile of a wetland have a permit to handle a specific chemical, the system automatically would identify and map all companies fitting those characteristics.

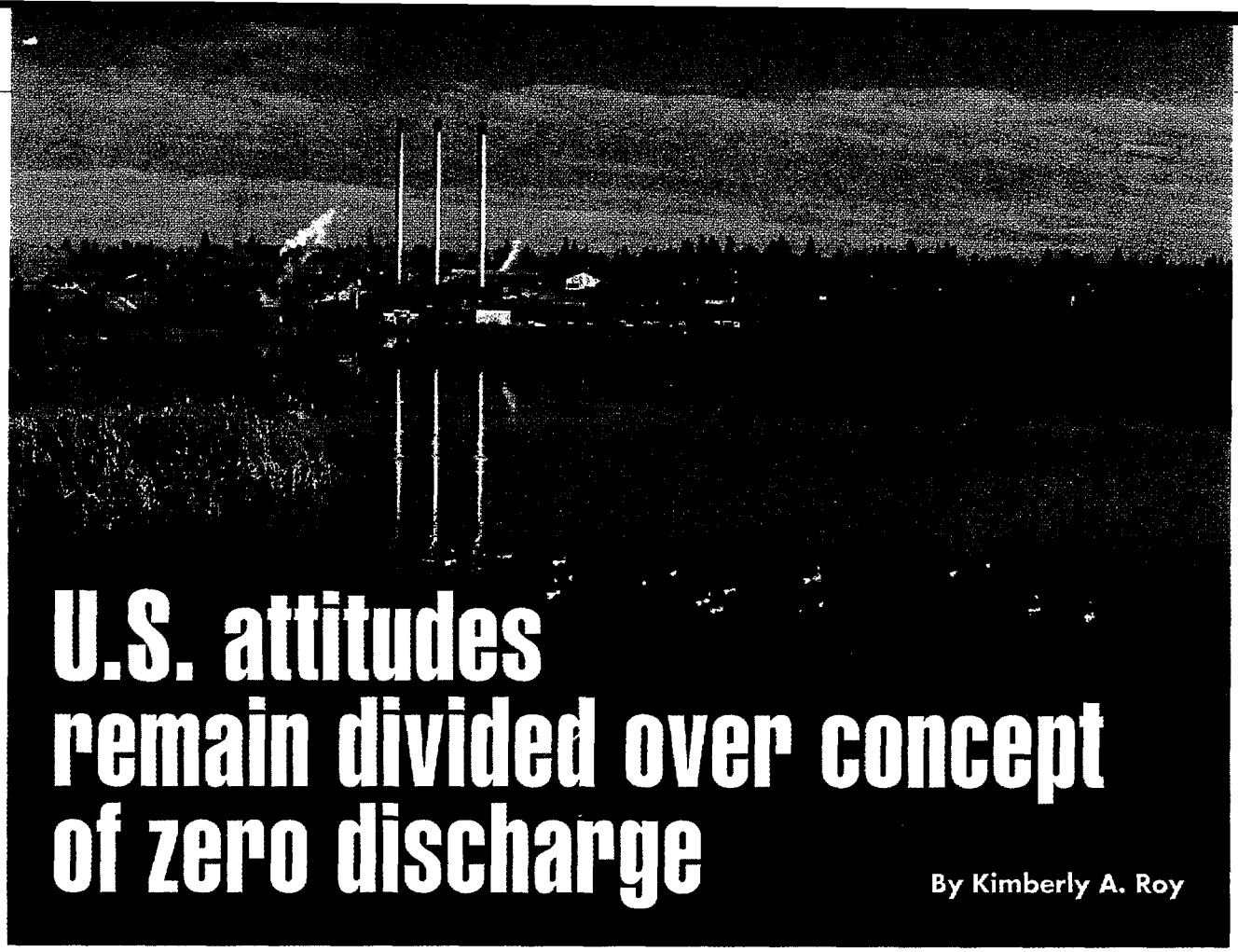
EPA also has the electronic capability to link information from its various programs and computers. This new tool, known as Integrated Data for Enforcement Analysis (IDEA), lets EPA analyze data submitted under all regulatory requirements. For example, it can compare information on a facility's TRI with its water and air discharge permits to detect inconsistencies in reporting or incidents where permit limits were exceeded.

- Compliance inspections. According to EPA, it conducts these inspections to achieve one of several objectives: reduce risk to human health or the environment; prevent pollution or minimize waste; preserve the integrity of the regulatory structure; or deter violations in an important regulated sector.
- Increased penalties. Effective enforcement actions must place violators in a worse economic position than those who comply. As obvious as that idea seems, in practice it appears to have been the exception rather than the rule. For example, a series of audits examining the effectiveness of CWA enforcement actions identified one municipality that, despite repeated illegal discharges, negotiated to reduce its penalty from $390,000 to $7,800. In fact, the EPA inspector general's audit concluded that in 46 of 69 cases evaluated, the fines paid were insufficient to outweigh the economic benefits of noncompliance. Similar practices have been observed under other regulatory programs, including RCRA. The Agency now admits such reductions are excessive and says it plans to reverse this trend.

Political influences. President Bill Clinton has said on numerous occasions that he supports tougher penalties, including longer jail terms, for environmental violations. However, the Environmental Leadership Program, initiated under the Bush administration to minimize penalties against organizations with proactive environmental management programs, apparently is gaining support under the new administration. EPA Administrator Carol Browner and other EPA officials have expressed support for the "supplemental environmental project" program, which lets companies pay a reduced fine in return for initiating pollution prevention programs, including environmental audits. The direction the Clinton administration will take to balance economic stimulation policies and environmental protection issues remains unclear.

Companies striving for successful environmental compliance in the 1990s must adopt a standard of care that takes into account the risks they face. Environmental management systems must be proactive. They must not only diagnose and respond to contamination but must be preventive, strategic, systematic and capable of providing adequate financial resources to ensure implementation. ■

Rebecca P. Thomson *is an economist in the Atlanta offices of CH2M Hill (Englewood, Colo.).* **Charles H. Le Grand** *is director of research at the Institute of Internal Auditors Research Foundation (Altamonte Springs, Fla.).* **Jeff Dresser** *is an environmental auditor in the Portland, Ore., offices of CH2M Hill.*



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U.S. attitudes remain divided over concept of zero discharge

By Kimberly A. Roy

Zero discharge continues to generate heated debate as a possible successor to today's pollution prevention strategies

Pollution prevention enjoys widespread popularity as a strategy where everyone "wins." According to this theory, pollution prevention activities result in a cleaner environment, and they help companies eliminate waste and reduce otherwise escalating disposal costs.

As the swell of support for pollution prevention continues to rise, the question looming on the horizon concerns whether the natural conclusion of this strategy is zero discharge, a controversial concept whose definition remains ambiguous.

"Zero discharge is not a new topic," notes William M. Copa, vice president for technical services at Zimpro Environmental Inc. (Rothschild, Wis.). "Ever since the passage of the Clean Water Act, the water quality profession has been debating whether our national goal should be zero discharge or zero pollutant discharge."

Today, the term typically is applied more broadly to include discharges to air and soil as well as water, but a precise definition remains elusive. Some people who take the term literally favor halting all activities that generate pollution. Others see zero discharge as eliminating the effects of hazardous substances by preventing their release into the environment in harmful amounts. This "camp" can be divided into those who believe the strategy should apply to all hazardous substances and those who would limit its application to artificial ones. Still others define zero discharge as eliminating the release of pollutants that pose a threat to human health or the environment, a strategy often referred to as "virtual elimination."

Technically, zero implies the complete absence of something. It is a point that cannot be measured or determined, only disproved. "How do we define zero discharge when you can't measure it?" asks Paul Freedman, president of LTI Limno-Tech Inc. (Ann Arbor, Mich.). "If we adopt a zero discharge policy, should we measure compliance against a detection limit, and how do we readjust as measurement technology improves? Is zero discharge the absence of parts per million, billion, trillion, or the detection of even a single atom or molecule? Further, do we establish zero discharge as an absolute requirement or a net requirement over background and intakes?"

Today, the concept of zero discharge typically applies to air and soil as well as water.

Defining zero discharge, it seems, prompts other equally important questions:

- Is zero discharge a realistic goal?
- Should it be a voluntary effort or a regulatory mandate?
- Are currently available chemical data adequate to identify problem substances?

"I certainly think it's (zero discharge) a goal, but it's not something we can hope to achieve in the foreseeable future," says Joe Turcotte, director of water and wastewater engineering at Gibbs & Hill Inc. (New York).

Christopher Day, a project scientist in Geraghty & Miller Inc.'s (Plainview, N.Y.) Raleigh, N.C., office, agrees. "Zero discharge basically is a goal, something

to try and shoot for," he says. "But realistically, for some wastestreams and certain constituents it's not going to be achievable in terms of today's technology."

Day's argument echoes throughout the halls of industry. Today's technology, say industry representatives, is not equal to the task of zero discharge, and forcing the use of innovative and often expensive techniques could be burden enough to put some companies out of business and drive others out of the country. In many cases, they say, the cost of achieving zero discharge or continuing to reduce marginal amounts of pollution is disproportionately large compared to the benefits.

According to a report written by James Lis and Kenneth Chilton and published by the Center for the Study of American Business at Washington University (St. Louis), "Over-promotion of 'win-win' pollution prevention rhetoric reinforces the public's illusion that a zero-pollution society is achievable."

Operating costs for U.S. firms "that continually commit to abating marginal amounts of pollution will undoubtedly increase," the report continues. "Higher costs translate into higher prices. In competitive, and increasingly global, markets, a firm may not be able to pass the costs of an overly ambitious prevention strategy on to the consumer. Such a firm, unless it reneges on its reduction agreement, will find itself at a competitive disadvantage."

Rather than dooming a policy of zero discharge, some experts say the potential for such circumstances to arise should be incentive for companies to take a proactive stance.

Cooperation between industry and government is the key to a successful effort, says W. Michael Joyce, director of engineering sales at R.E. Wright Associates Inc. (Middletown, Pa.). "A cooperative effort would prevent the development of unrealistic demands and ensure that scarce resources are spent in the most cost-effective way," he says. A cooperative effort, he continues, would give companies the chance to provide insight on their particular processes and wastestreams, offer input on proposed compliance schedules, and provide risk data on particular chemicals.

A successful zero discharge policy also would require a legislative and regulatory overhaul, says Libby Ford, a senior environmental health engineer

with the law firm of Nixon, Hargrave, Devans & Doyle (Rochester, N.Y.). "Until environmental laws move away from regulating each medium separately, (EPA) won't be able to mandate zero discharge," she says. "To make a workable mandate, this country would have to revamp its statutes and ... meld them into one environmental statute," an approach more common in Europe. "However," she continues, "it's such a drastic step. I don't see ... legislators having the willpower or stamina to do it, so I don't think it will happen."

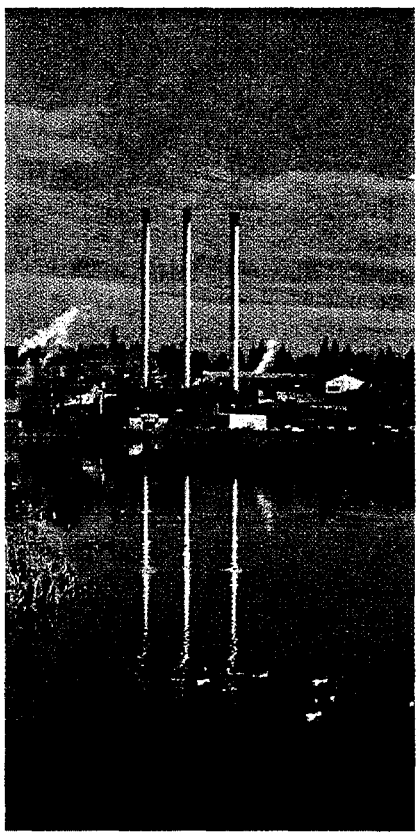
These factors — technological limitations and enforcement questions — give some people cause to advocate a voluntary effort similar to EPA's Industrial Toxics Project, also known as the "33/50" program. Under this program, the Agency asked high-polluting industries to reduce voluntarily their releases of 17 toxic contaminants 33 percent (from 1988 levels) by the end of last year and 50 percent by the end of 1995. The program gives dischargers the flexibility to select their own reduction targets and techniques. The program favors source reduction, but other methods, such as recycling and onsite treatment, also are acceptable.

"I think at least at this particular point in time, it's got to be voluntary," says Alan Rimer, an environmental engineer in the Durham, N.C., office of Blasland, Bouck & Lee (Syracuse, N.Y.). "Legislating zero discharge is the wrong approach right now."

Others, like Roger Sigler, a senior consultant with Calgon Corp. (Pittsburgh), say a volunteer effort might be more palatable but would fall far short of achieving zero discharge. Success, he says, would require more stringent discharge limits, tax breaks or other significant incentives. "We did a survey a couple of years ago, and ... no one we surveyed was looking to spend the money to retrofit just to be a good guy," he relates, noting that "today's fines usually are still cheaper than the costs of retrofitting."

According to Geraghty & Miller's Day, "Ninety-eight percent of the clients I work with are very proactive, (but) they're struggling with their own economic concerns and manufacturing processes that may be limited by currently available manufacturing technology." Most firms, he continues, fear the development of generic standards that do not take into account variations from industry to industry and facility to facility. Conversely, he says, regulatory agencies, which typically are underfunded and understaffed, tend to favor such check-list approaches, because they ease enforcement burdens.

Of course a debate on voluntary *vs.* mandatory programs assumes the country could reach an agreement on which compounds, constituents or



wastestreams to target. Two basic strategies exist. The first involves the "reverse onus" concept as advocated by Phillip Weller, former executive director of Great Lakes United, an environmental activist group. This strategy calls for industry to provide "absolute" proof that a substance is safe for human health and the environment before manufacturing or using it. Concerns about this approach center on whether any substance is absolutely safe in all circumstances, as well as the potential economic burden on industry.

The second approach calls for the "sunsetting," or phasing out, of undesirable chemicals through legislative bans. Developing a "hit list," however, could be tricky, skeptics say, because not enough data are available on individual chemicals.

"We need to spend the money to develop a database that characterizes and quantifies the chemicals being discharged, and use this information to determine risk," says Gary Fox, director of the Wastewater Management Division in Broward County, Fla.'s Office of Environmental Services. "Goals should be developed based on our understanding of the risk (associated with particular chemicals), and economics should be factored in, although some chemicals may be so dangerous that cost becomes a secondary factor."

Rather than waiting for the completion of a comprehensive database, Ford suggests the sunsetting process could begin for some well-characterized compounds. "I'm not an expert," she says, "but I sense there may be a few pollutants where the weight of evidence indicates they should be banned."

Industry experts generally agree EPA should take the lead in developing a database but acknowledge that, in light of the government's current budget crisis, such an effort is unlikely. According to Ford, this presents the perfect opportunity for companies to get involved. "If anything is ripe for a mediated or negotiated mandate, this is," she concludes. Cooperation, adds Fox, also would help alleviate protracted legal battles after regulations were passed.

Given the complexity of the issues surrounding zero discharge, its future as national policy remains uncertain. "I think the zero concepts are a little like disarmament," says Zimpro's Copa. "Total disarmament would be wonderful but probably will never happen. Likewise, there will always be a pollutant stream we must deal with. The best thing we can do as a society and as a profession is tilt the economic equation in favor of treatment, minimization and reuse." ■

Environmental Protection: The Corporate Challenge

Alan B. Nichols

In environmental affairs, the corporate culture in the U.S. is changing. A growing number of U.S. corporations has ambitious environmental policies with substantial technical staffs to oversee them. These policies, which are backed by large investments of time and money, are aimed at cleaning up the environment and preventing future pollution.

Most firms did not have environmental affairs managers 20, or even 10, years ago. In companies that did, environmental affairs offices were usually buried in human resources departments, and their directors' roles were fairly limited.

Technical assistance, environmental policy development, and overseeing site remediation are some of the responsibilities of Honeywell's office of environment, health, and safety, headed by Thomas Montag.

"There's no question that environmental regulations cost us a lot of money." —David Chittick, AT&T.

Today, however, the stature of corporate environmental affairs offices has grown in proportion to their increased authority and responsibility. These offices perform vital legal, managerial, technical, financial, and communications functions. Environmental managers are responsible for regulatory compliance, plant safety, policy, remediation, and public relations. In many of the larger firms, environmental affairs directors are corporate officers who have a direct input in major capital investment decisions.

Much of the impetus for this change can be traced to burgeoning laws and

regulations, which have been sparked to a large extent by a public that lays much of the blame for the nation's environmental problems on industry. In a relatively short time, these laws have led to a dramatic change in corporate consciousness, resulting in new thinking in many of the nation's board rooms.

That new thinking is transforming the way U.S. corporations do business and make products. Examples include source reduction process changes, chemical substitution, green labeling, and advertising emphasizing environmental responsibility. While these developments are positive, corporate environmental managers complain that environmental regulations create mountains of paperwork, are overly restrictive, and hurt U.S. competitiveness abroad. Furthermore, the fragmented administration of environmental rules creates costs that could be avoided by a coordinated national environmental policy that establishes priorities based on sound assessments of public health and environmental risk.

Industry Environmental Role Seen Expanding

"In my view the role of industry in environmental protection can be summed up in three words," said Jim Post, professor of management and public policy at Boston University. "Big, changing, and critical." By that he meant, environmental protection is a multibillion dollar investment, the balance between legal mandates and market-driven voluntary programs is changing, and there are critical problems at both the local and global levels that industry can help solve.

Post's remarks were made at a panel discussion on the role of industry in environmental protection at the 1992 Technology Literacy Conference held in Washington, D.C., in February. The panel included Robert Bringer, staff vice president, environmental engineering and pollution control, at 3M Co., and Herbert Eleuterio, director, new technology studies, at the Du Pont Company.

"Business is at the heart of this new reality for three reasons," Post elaborated. "It is the essential vehicle for economic development and technology transfer, the cleanup of our past environmental errors, and defining a new sustainable development that integrates economic and ecological principles."

Eleuterio emphasized that environmental issues are not simply technical or scientific. They are also sociological and technological, and their solution requires communicating in a language that non-technically trained people can understand. Communications rest heavily on common definitions and understanding, particularly as to the kind and extent of risks. Real and perceived risks are very different and tend to get confused in the national dialogue.

According to Bringer, chairman of the Corporate Conservation Council, the future is in "green" or environmentally responsible products produced by companies, like his own, that champion pollution prevention practices.

ENVIRONMENTALISM ON THE RISE

Once located in backwater offices several management levels removed from the top, some corporate environmental directors have gained a visibility within the corporate structure that reflects the high priority their firms give to environmental performance. Examples include W. Bailey Barton, vice president of health and environment at Borden, Inc., and Gary Olmstead, director of safety and environmental management at General Mills. Until 3 years ago, Barton reported to the president of the Plastics and Industrial Products Division of Borden, a leading producer of pasta and snack foods, wall coverings, adhesives, and wrapping film. Today, he reports directly to the CEO. Barton's staff of 31 includes environmental, chemical, and civil engineers, industrial hygienists, and hazardous-waste specialists.

"Command-and-control regulations stifle the creativity and initiative of business to meet the true needs of society for a clean environment."
—Carl Mattia, The BFGoodrich Co.

In addition to ensuring compliance with OSHA standards, the department's functions include redesigning plant systems to lower or prevent waste emissions at some 300 manufacturing sites worldwide.

Barton, who sits on the WEF Government Affairs Committee, is an engineer who obtained his law degree 10 years ago "so I could sit across from the EPA lawyers and understand their lingo." According to Barton, the primary responsibility for environmental compliance rests with the plant managers and their staffs. However, these managers rely on the technical assistance of Barton's staff.

At General Mills, a leading maker of cereals, cake mixes, and yogurt and the parent company of two large restaurant chains, including Red Lobster, Olmstead reports to the vice president of health and human services. He works closely with the company's law department to determine the company's re-

"Industry misbehaved in the past, and Congress reacted with punitive laws that require industry to lower environmental risks to a ridiculously low level." —Matthew Gross, FMC Corp.

sponsibilities under the regulations and to responde to regulation-related problems. Five years ago, manufacturing facilities had sole responsibility for their environmental compliance. Today, Olmstead's department manages a companywide environmental program that includes interpreting governmental regulations for the plants, overseeing plant environmental audits and otherwise assisting plants in compliance, and providing environmental awareness education and training for company employees. "That's [education and training] the most important part of my job," he says, adding that he also helps plant managers establish their environmental priorities and obtain money, when necessary, to accomplish specific plant objectives.

Meanwhile, at Honeywell, Inc., a manufacturer of heating, air-conditioning, and aircraft navigational systems, the corporate environment, health, and safety department reports to the vice president of corporate quality, manufacturing, and materials. Each of Honeywell's environment, health, and safety offices reports to the corporate department, headed by Thomas Montag. The department's responsibilities include developing corporate environmental policy, managing Superfund cleanup and other remediation projects, and providing technical assistance to plant sites. Another major function is to lobby directly on behalf of Honeywell or to respond to government regulations through such industry groups as American Electronics and Aerospace Industries Association.

Like many other firms, environmental performance has become a primary concern at Honeywell. In 1963, Honeywell established a safety and health department of which environmental affairs was a small part. In response to the Clean Water and Clean Air acts, the company in 1972 established a corporate environmental office that reported to the medical director who reported to the vice president of human resources. That chain of command continued until 1988, when environment, health, and safety was moved into operations, a change, Montag says, that greatly increased the department's authority and responsibility.

David Schlaudecker is director of environmental affairs at Owens Corning Fiberglas Corp., makers of underground storage tanks and home products including insulation. His staff of 26 includes chemical engineers, biologists, groundwater specialists, environmental scientists, and training specialists. Schlaudecker reports to the vice president of health, safety, and the environment, who reports to the senior vice president of human resources.

"We've [the department] grown 25% in the last 10 years," Schlaudecker says, adding that an "attitude shift" at the company 5 years ago created new authority and responsibilities for environmental affairs. "Our responsibilities go far beyond responding to regulations. We are now an integral part of all major decisions of the corporation."

According to Schlaudecker, this cultural change did not occur because of "laws being shoved down our throats, but because senior management recognized how important it was."

COMPETING GLOBALLY

Corporate environmental affairs directors preside over their companies' response to a host of regulations that fall under some seven major statutes including the Clean Water and Clean Air acts, RCRA, and Superfund. Many also have responsibility to make sure their companies conform to OSHA standards.

No one contests the goal of a clean environment.

To carry out these responsibilities, companies spend an enormous amount of time and money. When asked how much environmental regulations affect the cost of their products, those surveyed replied that it was virtually impossible to develop information to that degree of specificity.

"There's no question that environmental regulations cost us a lot of money, but it's difficult to say how much," says David Chittick, environment and safety engineering vice president for AT&T. "AT&T has dozens of autonomous business units, and simply collecting and reporting the data the federal and state governments require is extremely expensive. But taking one slice of that cost and saying how much it increases the price of a given product isn't possible."

Without documentation, how does he support his claim that environmental regulations hurt U.S. companies in the world market? "The U.S. has some 80,000 environmental regulations," he replies, "and the sheer volume of these regulations means that someone has to read and analyze each one and apply it to our company's operations. You don't have to be a genius to know that this costs money. Outside the U.S., we don't have the same regulatory burden, though our people are held to the same standards of environmental performance as here in the U.S."

"A command-and-control regulatory approach affects our ability to play on a level field," agrees Carl Mattia, vice president of environment, health, and safety management systems at The BFGoodrich Company. "That approach stifles the creativity and initiative of business to meet the true needs of society for a clean environment."

"We are not always cost competitive," echoes Schlaudecker, "and one reason is the cost of environmental regulations."

"The U.S., for more than 2 decades, has had a shotgun approach to environmental protection," declares J. Thomas Robinson, president of Nyacol Products in Ashland, Mass. "The use of legislation to blast away at regulating solutions has ignored the potential benefits of a coordinated policy. I firmly believe that unless we as a nation come to our senses, the U.S. will be globally non-competitive within the next decade."

What's the solution? Robinson says the U.S. should change the tax code to include accelerated depreciation or tax credits for anti-pollution investment, adopt market incentives and give plant managers leeway to determine the best way to achieve emission targets, create business-government partnerships based on pollution prevention and not end-of-pipe technologies, and establish national priorities based on the most serious risks to human health and the environment.

If most environmental managers anticipate a future of U.S. non-competitiveness, Chuck Bennett, director of environmental affairs at Adolph Coors Co., does not. "I attended an international conference of brewers last year and came away with the feeling that if the global playing field is not level, at least it is not too bumpy," he offers.

THE REGULATORY BURDEN

No one contests the goal of a clean environment, but these industry leaders are critical of government's approach to regulating the environment. As to specific charges, inadequate staffs and lack of coordination among different departments at state and federal environmental agencies cause administrative delays and create unnecessary work for companies trying to comply with regulations. Also, regulatory standards in many cases are unrealistic, designed to provide a margin of public health pro-

U.S. Overregulated, Industry Managers Say

The comments of industry environmental managers follow those expressed in a recent survey conducted by the Bureau of National Affairs and the National Association of Environmental Management (NAEM). Over 120 NAEM members representing manufacturers, retail businesses, educational organizations, and environmental consulting firms were surveyed on the subject of environmental regulations. A majority expressed discontent with government's approach, contending that regulations are excessive, needlessly redundant, and politically motivated. Furthermore, they undermine the ability of U.S. companies to compete abroad.

Many environmental managers object to the tendency of government to say to industry, "Here are the rules, you figure them out." One said, "The weight of these [rules] is crushing U.S. industry."

Other respondents agreed that regulations are unbalanced, hard to interpret, and unscientific. As Freeman Bartz, manager of manufacturing administration with Baldor Electric Co. in Fort Smith, Ark., said, "[R]egulations are inadequate for major pollution sources, and excessive for minor sources."

tection that is not warranted by science.

Are government environmental regulations irksome? "Let's say they are very challenging," says Barton, adding, "Regulations are developed with less than highly technical capabilities." For example, he says, when it first came out, the categorical pretreatment limit of 19 µg/L for phenol for the organic chemicals, plastics, and synthetic fibers industry created problems for many companies because it was not technically feasible. The problem, Barton explains, was that the standard was based on EPA's evaluation of the newest plants, not the typical, older plants, as is required by the regulation. To meet the standard, companies would have had to retrofit many of their plants to the industrial equivalent of tertiary treatment, and this would have been technically prohibitive, according to Barton. In a legal challenge, the court agreed and remanded the rules to the agency for further development.

Richard Dennis,
American Cyanamid.

According to Matthew Gross, director of health, safety and environmental affairs at FMC Corp., the Chicago-based producer of chemicals and machinery for business, agriculture, and government, industry "misbehaved in the past, creating an atmosphere of chemophobia in the nation. Congress reacted with punitive laws that require industry to lower environmental risks to a ridiculously low level." As a result, he adds, "We are held to standards that are far lower than in other areas of risk." Gross claims Superfund site cleanup standards are unrealistic. But he predicts that "in the end cooler heads will prevail to prevent the economy from being bled dry to clean up every site to the last molecule."

A second problem associated with the administration of regulatory programs is that the Clean Water Act allows NPDES-delegated states to establish standards that are more stringent than the federal government's, according to Barton, who says that when states like California or New Jersey make their NPDES permit limits more exacting, "We sometimes face a second wave of rulemaking which requires a time-consuming response." In addition, he says, the company's long-range plan to reduce the total emissions to all media is based on Borden's best guess as to what approach regulations will take. Such guesswork is "like riding a horse, shooting at a moving target. It's easy to miss."

Meanwhile, General Mills' Olmstead speaks about the high cost and inefficiency that results from regulatory fragmentation. In a case of the left hand's not knowing what the right hand is doing, Olmstead says it is common for a state air program to order a particular technology to capture air pollutants without regard for the impact of that technology on other media. For example, he says, one of General Mills' plants was required to install scrubbers to capture dust. The technology was effective at reducing air pollution but created a water pollution problem because the contaminated scrubbing water had to be discharged into the public sewers. "The single, best solution," Olmstead says, "is to have a coordinated administrative effort that looks at the total environment."

Regulatory fragmentation has another unfortunate side effect, according to Olmstead, who says that different plants that manufacture the same products can require different pollution controls. Unfortunately, he notes, regulations tend to be rigid, requiring controls across the board without regard for individual plant differences. Also, in today's political climate, environmental laws, like the Clean Air Act, are enacted amidst great ballyhoo. Industry jumps to comply to what he calls "the regulation du jour," putting off strategies and plans that, in the long run, might be more beneficial.

Gary Olmstead,
General Mills, Inc.

Goodrich's Mattia adds that "When the command-and-control approach is used by people who don't understand efficiencies, you hurt the environment." He says that the philosophy of command and control as evidenced in Eastern Europe has been a disaster for the environment, because it completely eliminated the desire for efficiency. He adds that, in the U.S., mandatory environmental controls should be replaced by negotiated voluntary approaches such as the successful Responsible Care Program of the Chemical Manufacturers Association and EPA's 33/50 Program.

As an example of how government rules impede efficiency, Mattia says that his company has a quality philosophy that aims to ultimately convert 100% of its materials into value-added products. Since 1988, as a result of source reduction, Goodrich has reduced its RCRA Section 313 releases by about 50%.

Mattia adds, "We plan to do even better; however, when faced with process- and chemical-specific requirements that give no thought to technology from a total systems view, the financial re-

sources needed to meet mandated regulations, because of an ill-conceived environmental strategy, leaves few dollars to really solve the problem the right way through source elimination." He adds that in spite of the company's success in source elimination, Goodrich will still have to install costly end-of-pipe treatment systems, even though the total output of materials to the environment continues to drop.

Like Borden's Barton, Mattia's message to government is, "Take a look at the successes we are having with programs now in place and give us a chance. Don't keep changing the targets on us."

Meanwhile, for AT&T's Chittick and the Norton Company's Mark Rollins, the paperwork connected with regulatory compliance strangles initiative while creating unnecessary costs. Citing the emissions reporting requirements under SARA Title III (Community Right to Know law), Chittick says that each state requires submission of data on its own reporting form.

AT&T has spent several million dollars on an environmental database, but he says that a computer system that would "spit out data suitable for each form would be very costly." According to Chittick, adopting a single form would improve internal data management and therefore compliance by business and industry. "I am not making a plea for no regulation," he says, "but for avoiding wasteful, expensive, and redundant requirements that cost the public a lot of money but don't help the environment one iota."

Rollins, corporate administrator for environmental health and safety at Norton, a Massachusetts-based manufacturer of abrasives, ceramics, and plastic and metal parts for industrial applications, claims inadequate agency staffs create administrative bottlenecks that hurt industry needlessly. For example, he says, the diesel tank of a delivery truck ruptured, spilling fuel. Under state Department of Environmental Protection orders, the company cleaned up the spill but had to wait 32 days to get a permit to dispose of the contaminated soil. "That sticks in my craw," Rollins exclaimed. "That permit should have taken a week at the most."

Rollins also says that the time has come for government to start cracking down on the small companies whose hazardous waste and chemical emissions volumes are below most state regulatory thresholds. Because they are understaffed, government agencies tend to limit their inspections to the larger companies, leaving smaller "mom and pop" operations underregulated. "I have given talks to industry groups in the state, and when I mention a federal or state environmental rule, the plant managers and owners of small companies tell me they have never heard of it," he says, suggesting that the agencies might better reach the small companies through entities like the Small Business Administration.

PROCESS CHANGES

Criticisms of environmental regulations notwithstanding, laws have sparked industry to take dramatic steps to lower their pollutant emissions. Recycling, raw materials substitution, and various source reduction process changes are several of the changes many companies have made to improve their environmental performance and to save money.

All of the companies that participated in this article have formal environmental policies that stress responsible environmental stewardship. One is American Cyanamid, a research-based biotechnology and chemical company in Wayne, N.J.

Several years ago, in an unprecedented move, company President Albert Costello was given oversight responsibility for environmental issues. A company employee publication that included an interview with Costello noted that the chemical industry had a negative image partially reinforced by its "aversion to communicate with plant communities, the public at large and the media."

American Cyanamid admits to a bad reputation for pollution which, it says, stems from the company's practice of deep-well injection of chemical wastes at its Fortier plant in Westwego, La. Though it claims this practice is entirely safe, the company says it will pursue steps to reduce chemical disposal in this manner. On January 28, 1992, the company announced plans for capital projects totalling $50 million aimed at reducing by 80% the company's total releases reported in the 1990 Toxic Release Inventory under Title III.

Included in these initiatives is a project at the Fortier plant, where several chemical recovery plants are being built to recover 54×10^6 kg (120×10^6 lb) of sulfuric acid and other SARA chemicals, 5.4×10^6 kg (12×10^6 lb) of acetonitrile, and 0.45×10^6 kg (1×10^6 lb) of hydrogen cyanide that had been deep-well injected. The company plans to use the recovered sulfuric acid in the manufacturing process or sell it for use in car batteries and gasoline refining.

Also, according to a company news release, a waste-gas-to-steam generator now under construction is designed to destroy all organic vapor releases emanating from the acrylonitrile manufacturing process at the Fortier plant. In addition, says the release, the company plans to replace the stripper column in the acrylonitrile facility, a move that will improve operations and reduce the volume of process wastewater and effluent discharge to the deep wells by 258×10^6 kg/yr (570×10^6 lb/yr).

At the same time, Cyanamid research and development efforts are producing innovative technologies, which could turn Superfund wastes into viable products. For example, at its Bound Brook, N.J., plant, scientists are working on making a liquid fuel blend out of millions of gallons of tar now collected in lagoons. The blend can be used to make cement in kilns whose high temperatures burn the fuel, thereby making this technique a safe disposal method.

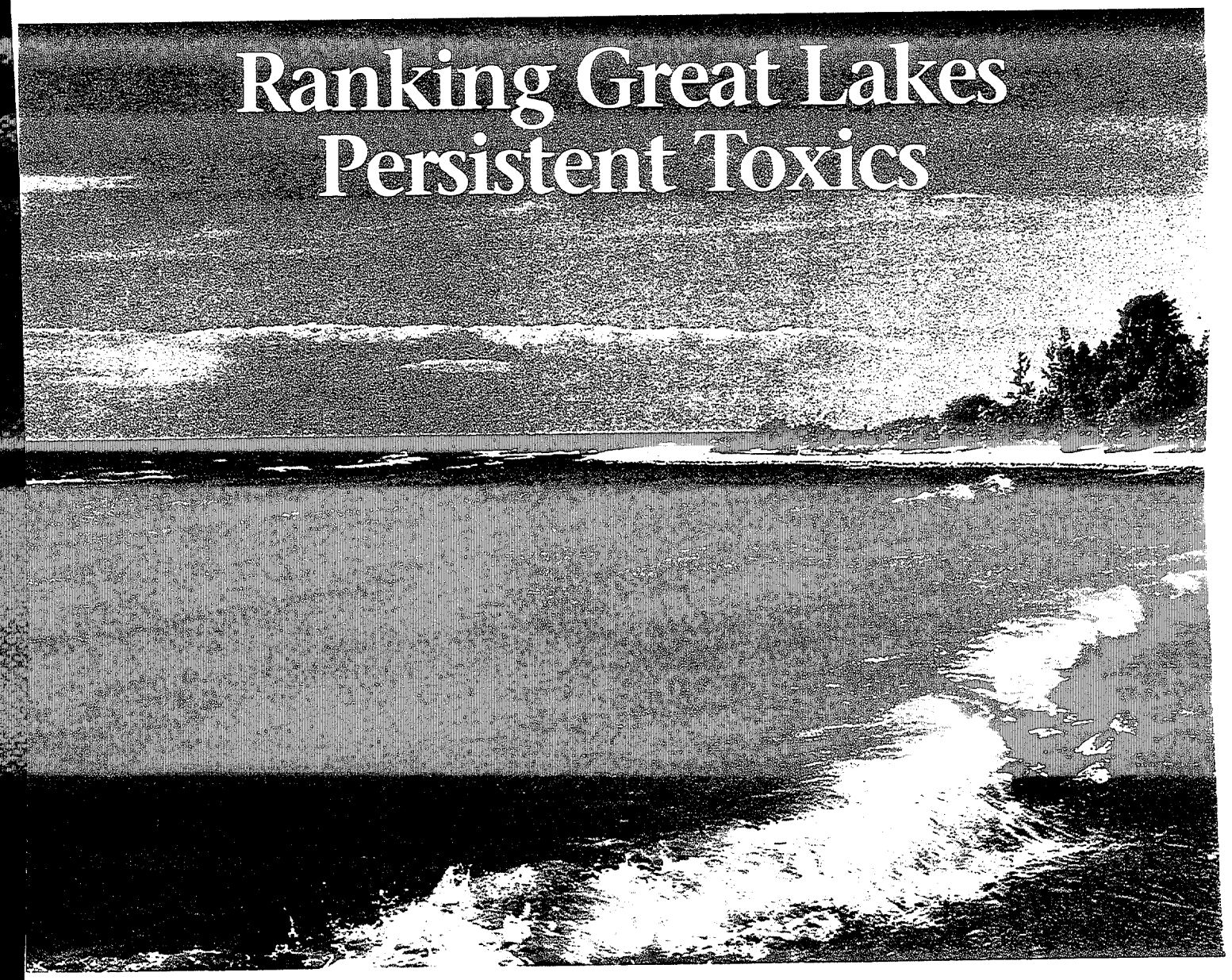
Meanwhile, according to Barton, Borden has a very ambitious long-range environmental plan to eliminate virtually all waste streams. He explains, "We don't look at air, water, or hazardous waste as categories. We look at the total system, like a chemical engineer looks at a black box. We don't care which numbers go to zero, as long as the total net volume of pollutants is reduced." A plant may therefore choose to increase its solid-waste disposal costs if it means lowering total emissions to all media, for example.

Also, the company looks at every pollutant as a potential product, either to be reprocessed in manufacturing or converted into a marketable good. For example, at many food processing plants, starch, which used to be discharged in the wastewater, creating high levels of BOD, is now sold to bakeries and other buyers. And, phenol wastes have been lowered at plants that make phenolic formaldehyde for the forest products industry. Instead of being discharged to the environment, the wastes are used to "fine tune" the chemical mixture of water, phenols, and formaldehyde in the polymerization kettles. In addition, flush water used to clean the kettles is recycled.

As a major part of its environmental and economic strategy, Borden is building a number of "hyperplants" to achieve greater economies of scale. Built to state-of-the-art production and environmental design, these facilities will enable Borden to increase its production using fewer production facilities, while meeting the firm's goal of zero waste discharge to one or more media. ■

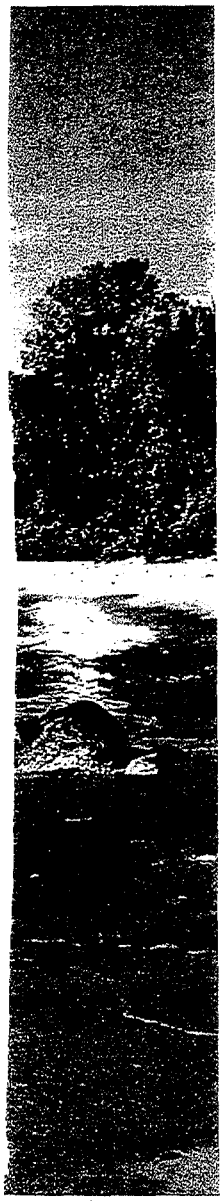
Alan B. Nichols is senior staff writer of Water Environment and Technology.

Ranking Great Lakes Persistent Toxics



Industry moves to protect the ecosystem

Daniel J. Bicknell



Lake Michigan. With a pollution prevention plan in place, the release of toxic substances to the Great Lakes should be eliminated.

Courtesy of the Michigan Travel Bureau

Toxicity Constants

Slope factor. A chemical-specific plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual's developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.

Reference dose. A chemical-specific estimate of daily exposure to the human population—including sensitive subgroups—that is likely to be without an appreciable risk of deleterious effects during a lifetime.

The International Joint Commission (IJC)-Great Lakes Water Quality Board recommends the virtual elimination of persistent toxic (PT) substances to the Great Lakes Basin ecosystem. Consistent with this initiative, the automobile industry and the Michigan Department of Natural Resources (MDNR) developed a pollution prevention action plan for the Great Lakes to prevent the generation and release of PTs (see Box *Defining Persistent Toxics*) that may significantly impact the Great Lakes. The plan requires the determination of those PTs that are of greatest risk to the quality of the Great Lakes system as one step toward fulfilling the final objectives. Therefore, General Motors developed a system that uses toxicity, persistence, and fate factors to rank PTs.

Defining Persistent Toxics

The International Joint Commission suggests that persistent toxic (PT) substances are those chemicals having a bioconcentration factor greater than 100 to 250 and a half-life greater than 8 weeks. In parallel with this concept, the pollution prevention plan defined PTs as toxic substances that have accumulated to levels that significantly impact the Great Lakes system, as evidenced by direct measurement.

RANKING PARAMETERS

A methodology was developed using parameter-specific tables, which partition PTs into weighted groups for the three variable risk factors of toxicity, fate, and persistence. Each PT is given a cumulative score by multiplying the individual factor group weight values. These individual PT scores may be normalized to construct a relative ranking that identifies which PTs are of the greatest concern to the ecosystem. To understand how a PT score is established, each component factor should be examined.

TOXICITY FACTOR

Toxicity constants (see Box *Toxicity Constants*), such as carcinogenic slope factors (SFs) and noncarcinogenic reference doses (RfDs), were used as a measure of toxicity. Toxicity factor groups were generated for oral carcinogenic SFs and noncarcinogenic RfDs by identifying the ranges of toxicity and apportioning those ranges into equal groups (Table 1). The more toxic the group, the higher the group number and group weight. The table segments PTs according to toxicities, but does not correlate carcinogenic and noncarcinogenic PTs.

Relative toxicity of carcinogenic and noncarcinogenic chemicals may be standardized by calculating acceptable fish ingestion exposure levels under a typical residential adult fish ingestion scenario for each SF and RfD toxicity group. The SF and RfD toxicity groups are then interfaced by matching common acceptable exposure levels (Table 2). Using acceptable exposure levels as a common end point, the carcinogenic and noncarcinogenic PTs may be categorized jointly, even though they have different toxicological impacts.

Acceptable fish ingestion exposure levels are developed using EPA risk assessment methodologies that link chemical exposure and toxicity to characterize public health risk. Carcinogenic risk may be expressed by Equation 1. An acceptable carcinogenic exposure level may be calculated by establishing risk, exposure intake, and toxicity parameters. A typical fish exposure intake value is derived by Equation 2.

Substituting Equation 2 for the exposure intake value in Equation 1 gives Equation 3. If all other parameters are

Equations

$$\text{Risk} = \text{toxicity} \times \text{exposure intake} \qquad \text{(Equation 1)}$$

$$\text{Intake} = \frac{CF \times IR \times FI \times AF \times EF \times ED}{BW \times AT} \qquad \text{(Equation 2)}$$

where
CF is the chemical concentration in fish (mg/g);
IR is the ingestion rate (g/d);
FI is the fraction ingested from contaminated source;
AF is the absorption factor;
EF is the exposure frequency (d/yr);
ED is the exposure duration (years);
BW is the body weight (kg); and
AT is the averaging time (days exposed).

$$\text{Risk} = \text{toxicity} \times \frac{CF \times IR \times FI \times AF \times EF \times ED}{BW \times AT} \qquad \text{(Equation 3)}$$

$$CF = \frac{\text{risk} \times BW \times AT}{\text{toxicity} \times IR \times FI \times AF \times EF \times ED} \qquad \text{(Equation 4)}$$

$$HI = \frac{\text{exposure intake}}{RfD} \qquad \text{(Equation 5)}$$

$$CF = \frac{RfD \times BW \times AT}{IR \times FI \times AF \times EF \times ED} \qquad \text{(Equation 6)}$$

$$\text{PT ranking score} = \text{toxicity value} \times \text{persistence value} \times \text{fate value} \qquad \text{(Equation 7)}$$

Examples

$$CF = \frac{\text{risk} \times BW \times AT}{\text{toxicity} \times IR \times FI \times AF \times EF \times ED} \qquad \text{(Example 1)}$$

$$CF = \frac{1.0 \times 10^{-5} \times 70\text{ kg} \times 365\text{ d/yr} \times 70\text{ years}}{5.0 \times 10^{-1}(\text{mg/kg}\bullet\text{d})^{-1} \times 23\text{ g/d} \times 0.2 \times 1 \times 365\text{ d/yr} \times 9\text{ years}}$$

$$CF = \frac{17.885}{7555.5} = 0.00237\text{ mg/g or } 2.37\text{ mg/kg}$$

$$CF = \frac{RfD \times BW \times AT}{IR \times FI \times AF \times EF \times ED} \qquad \text{(Example 2)}$$

$$CF = \frac{5.0 \times 10^{-4}(\text{mg/kg}\bullet\text{d}) \times 70\text{ kg} \times 365\text{ d/yr} \times 9\text{ years}}{23\text{ g/d} \times 0.2 \times 1 \times 365\text{ d/yr} \times 9\text{ years}}$$

$$CF = \frac{114.975}{15{,}111} = 0.00761\text{ mg/g or } 7.61\text{ mg/kg}$$

known, Equation 3 may be reorganized to identify an acceptable carcinogenic chemical exposure level to give Equation 4.

Acceptable exposure levels for noncarcinogens are, however, not based on an acceptable level of risk, such as 1×10^{-5}, rather on an exposure level that does not produce an adverse impact to human health. For this, a hazard index (HI) should be developed to determine if a RfD has been exceeded and, consequently, if there may be a potential adverse public health impact (Equation 5).

A noncarcinogen's acceptable level of exposure is determined by setting the HI at 1.0, substituting in the intake equation for intake, and solving for the chemical concentration (Equation 6).

Equations 4 and 6 can be used to generate acceptable exposure values for carcinogenic and noncarcinogenic PTs for the typical residential adult fish ingestion exposure scenario, assuming that a carcinogenic risk of 1×10^{-5} and a HI of 1.0 are "acceptable" levels to protect the public health. Michigan Part 4 Rules, Water Quality Standards, establish an acceptable carcinogenic risk from the ingestion of fish at 1×10^{-5}. To illustrate this process, acceptable exposure values are generated for a carcinogenic PT with a SF of 5.0×10^{-1} $(\text{mg/kg}\bullet\text{d})^{-1}$ and a noncarcinogenic PT with a RfD of 5.0×10^{-4} (mg/kg•d).

To obtain a carcinogenic exposure level for a SF of 5.0×10^{-1} $(\text{mg/kg}\bullet\text{d})^{-1}$, all parameters in Equation 4 were established at the appropriate values corresponding to a typical residential adult fish ingestion scenario and the equation was solved for the chemical concentration (Example 1).

To develop a noncarcinogenic acceptable exposure level for a RfD of 5.0×10^{-4} (mg/kg•d), all parameters in Equation 6 were established at the appropriate values corresponding to a typical residential adult fish ingestion scenario and the equation was solved for the chemical concentration (Example 2).

As evidenced in the above two examples, a carcinogen with a SF of 5.0×10^{-1} $(\text{mg/kg}\bullet\text{d})^{-1}$ and a noncarcinogen with a RfD of 5.0×10^{-4} (mg/kg•d) have approximately the same acceptable level of exposure.

The standardization of the PT toxicity factor is based on the correlation between calculated acceptable carcinogenic and noncarcinogenic exposure end points. This relationship links oral SF and RfD toxicity groups. Specifically, from the above examples the oral SF Toxicity Group III, 9×10^{-1} to 1×10^{-1}, and the oral RfD Toxicity Group V, 1×10^{-4} to 9×10^{-4}, have approximately the same average acceptable ingestion exposure levels—2.37 mg/kg and 7.61 mg/kg, respectively.

SF Toxicity Group III and RfD Toxicity Group V were linked under the Standardized Toxicity Group V since these two groups have approximately the same acceptable exposure values (see highlighted area in Table 2). Similarly, the other SF toxicity groups and RfD toxicity groups were equated and placed into a standardized toxicity group in Table 2. The acceptable exposure level for the carcinogens was at a 1×10^{-5} risk and noncarcinogens at a HI of 1.0 for illustrative purposes. If different acceptable carcinogenic or noncarcino-

Table 1—Toxicity Factor

Oral carcinogen

Group	Group weight	Range of slope factors $(mg/kg \cdot d)^{-1}$
VII	7	$> 1 \times 10^{3}$
VI	6	9×10^{2} to 1×10^{2}
V	5	9×10^{1} to 1×10^{1}
IV	4	9×10^{0} to 1×10^{0}
III	3	9×10^{-1} to 1×10^{-1}
II	2	9×10^{-2} to 1×10^{-2}
I	1	$< 9 \times 10^{-3}$

Noncarcinogen, chronic

Group	Group weight	Range of reference doses (mg/kg•d)
VII	7	$< 9 \times 10^{-6}$
VI	6	1×10^{-5} to 9×10^{-5}
V	5	1×10^{-4} to 9×10^{-4}
IV	4	1×10^{-3} to 9×10^{-3}
III	3	1×10^{-2} to 9×10^{-2}
II	2	1×10^{-1} to 9×10^{-1}
I	1	> 1

genic protection values are used the carcinogen and noncarcinogen toxicity groups will form different standardized toxicity factor groups.

Table 2 presents the oral carcinogenic and noncarcinogenic standardized toxicity groups from which the toxicity factor parameter value is selected for the PT ranking system. The toxicity factor value is obtained by matching the PT-specific oral SF or RfD to the appropriate standardized toxicity group and observing the group weight. If a PT has both a SF and RfD, both values must be matched to the appropriate standardized toxicity group and the higher of the two toxicity group weights selected as the toxicity factor value.

Table 2—Standardized Toxicity Factor[a]

Group	Group weight	Slope factor $(mg/kg \cdot d)^{-1}$	Reference dose (mg/kg•d)
X	38.4	$> 1 \times 10^{4}$	$< 9 \times 10^{-9}$
IX	25.6	9×10^{3} to 1×10^{3}	1×10^{-8} to 9×10^{-8}
VIII	17.1	9×10^{2} to 1×10^{2}	1×10^{-7} to 9×10^{-7}
VII	11.4	9×10^{1} to 1×10^{1}	1×10^{-6} to 9×10^{-6}
VI	7.6	9×10^{0} to 1×10^{0}	1×10^{-5} to 9×10^{-5}
V	5.1	9×10^{-1} to 1×10^{-1}	1×10^{-4} to 9×10^{-4}
IV	3.4	9×10^{-2} to 1×10^{-2}	1×10^{-3} to 9×10^{-3}
III	2.3	9×10^{-3} to 1×10^{-3}	1×10^{-2} to 9×10^{-2}
II	1.5	9×10^{-4} to 1×10^{-4}	1×10^{-1} to 9×10^{-1}
I	1.0	$< 9 \times 10^{-5}$	$> 1 \times 10^{0}$

[a]Table is based on an acceptable carcinogenic risk of 1.0×10^{-5} and HI of 1.0.

PERSISTENCE

Chemical half-lives in surface water are indicators of persistence. A long surface water half-life equates to a slowly diminishing concentration and long residence time in the Great Lakes system. This factor was selected to account for natural removal processes, such as phase transfer, chemical and biological transformation, once the PT is in the aquatic system. The range of half-lives were segregated into six groups with a greater weight given to a more persistent group (Table 3). Surface water chemical-specific half-lives are published for most PTs; however, there is significant variability in reported values among reputable sources. Also, not all PTs and distinct classes of PTs, such as metals, have established half-lives. In cases where there is no surface water half-life value for a PT,

Table 3—Persistence Factor

Group	Group weight	Range of half-life values (days)
I	1	< 0.9
II	2	1.0 to 7.9
III	4	8.0 to 30.9
IV	8	31.0 to 120.9
V	16	121.0 to 364.9
VI	32	> 365.0

Table 4—Fate Factor

Group	Weight	Range of log P values
I	1	< 0.9
II	2	1.0 to 1.9
III	4	2.0 to 2.9
IV	8	3.0 to 3.9
V	16	4.0 to 4.9
VI	32	5.0 to 5.9
VII	64	> 6.0

Table 5—Persistent Toxics Rankings and Water Quality Criteria Values

	Toxicity			Persistence		Fate				Water quality criteria[b]	
Persistent toxic	slope factor	reference dose	group weight	half-life	group weight	log P	group weight	Score	Rank	fish ingestion	rank
Pesticides											
DDT	0.39	5 × 10-4	5.1	56.0	8	6.02	64	2,611.2	2	0.59 ppt	3
Heptachlor	4.5	5 × 10-4	7.6	1.0	2	5.38	32	486.4	4	0.21 ppt	2
Lindane	1.3	3 × 10-3	7.6	8.0	4	3.75	8	243.2	5	63.0 ppt	7
Toxaphene	1.1	—	7.6	2.0	2	3.30	8	121.6	6	0.75 ppt	5
Halogenated hydrocarbons											
Hexachlorobenzene	1.6	8 × 10-4	7.6	0.3	1	6.42	64	486.4	4	0.74 ppt	4
Hexachloroethane	0.014	0.001	53.4	1.1	2	4.61	16	108.8	7	8.9 ppb	7
PCBs	7.7	7 × 10-6	11.4	365.0	32	6.25	64	23,347.2	1	0.045 ppt	1
Tetrachloroethylene	0.051	0.01	3.4	1.0	2	3.02	8	54.4	9	8.9 ppb	7
Trichloroethylene	0.011	—	3.4	1.0	2	2.27	4	27.2	10	81.0 ppb	10
Nonhalogenated hydrocarbons											
Benzene	0.029	—	3.4	1.0	2	2.12	4	27.2	10	71.0 ppb	9
Benzo(a)pyrene	11.5	—	11.4	0.4	1	6.05	64	729.6	3	31.1 ppt	6
Di-n-butyl phthalate	—	0.1	1.5	—	4[a]	4.62	16	96.0	8	12.0 ppm	11
Diethyl phthalate	—	0.8	1.5	—	4[a]	2.50	4	24.0	11	120.0 ppm	13
2,4-Dinitrotoluene	0.68	—	5.1	0.4	1	2.00	4	20.4	12	9.1 ppb	8
Ethylbenzene	—	0.1	1.5	1.5	2	3.32	8	24.0	11	29.0 ppm	12
Isophorone	0.004	0.2	2.3	<1.0	1	2.21	4	9.2	13	490.0 ppm	15
Toluene	—	0.2	1.5	0.2	1	2.79	4	6.0	14	300.0 ppm	14

[a] Group weight based on structure activity relations with diethylhexyl phthalate.

[b] Water quality criteria for fish consumption only values from EPA WQC Summary Table 1991. Recalculated values used when possible.

chemical structure activity relations may be used to categorize the PT.

FATE

Bioaccumulation is a governing mechanism for the ecological movement and fate of a persistent chemical. PTs, in part because of their chemical structure, may readily bioaccumulate to toxic levels in biological systems. The logarithm of the octanol-water coefficient, log P, is a common predictor of bioaccumulation in the oils of fish and the fat of animals. A log P value is usually used as a surrogate for a bioconcentration factor (BCF), although a measured BCF is more representative of potential bioaccumulation in the ecosystem. There are more accepted log P values than BCFs in the scientific literature for PT chemicals. Log P values were segmented into weighted groups to incorporate the bioaccumulation process into the PT ranking system (Table 4).

ESTABLISHING PT RANK

After PT-specific toxicity, persistence, and fate group weight values are selected, a PT can be ranked using Equation 7. Table 5 illustrates the PT ranking system using some organic PTs that have water quality criteria for fish consumption only values. In cases where there are many congeners for a PT, either the most toxic congener

Table 6—Ranking of Great Lakes System Persistent Toxics[a]

Rank	PTs score[b]	Persistent Toxic[c]	Risk
1	78,643.2	TCDD & TCDF	H
2	23,347.2	PCBs	H
3	5,836.8	Mirex	H
4	2,918.4	Aldrin	H
5	2,611.2	DDD & DDT	H
6	1,945.6	Chlordane	H
7	1,459.2	Dieldrin	H
8	870.4	Diethylhexyl phthalate and mercury	H
9	729.6	Benzo(a)pyrene	H
10	652.8	Benzo(k)fluoranthene and DDE	H
11	486.4	Heptachlor, hexachlorobenzene and indeno(1,2,3)pyrene	H
12	243.2	Benz(a)anthracene and lindane	M
13	217.6	Beryllium and hexachlorobutadiene	M
14	163.2	Pentachlorobenzene	M
15	121.6	Toxaphene	M
16	108.8	Chrysene, hexachloroethane and selenium	M
17	96.0	Butylbenzyl phthalate and dibutyl phthalate	M
18	81.6	Tetrachlorobenzene and trichlorophenols	M
19	54.4	Dichlorobenzenes and tetrachloroethylene	M
20	45.6	Copper and ethylene dibromide	M
21	40.8	Cadmium, lead and nitrobenzene	M
22	36.8	Acenaphthene, fluorene and pyrene	M
23	27.2	Benzene, naphthalene and trichloroethylene	L
24	24.0	Anthracene, diethyl phthalate, Ethylbenzene, nickel and phenanthrene	L
25	20.4	Arsenic, 2,4,-dinitrotoluene and silver	L
26	18.4	Acenaphthalene and zinc	L
27	9.2	Antimony and isophorone	L
28	8.0	Dimethyl phthalate	L
29	6.8	Chromium and methyl chloride	L
30	6.0	Toluene	L
31	4.6	Methylene chloride	L
32	3.0	Phenol	L

[a] Structure activity relations were used to generate organic PT half-life values, if no supportable values existed in the literature. The secondary PT ranking methodology was used to place metals into the PT ranking system.

[b] EPA toxicity constants and MDNR log P values were used in the scoring of the PTs. These are conservative values, which may overestimate actual values.

[c] Because of a lack of scientific data the following PTs have not been scored by the PT ranking system: nonachlor, octachlorostyrene, oxychlordane, and terphenyl.

should be selected for ranking, such as 2,3,4,5-PCB for polychlorinated biphenyls and 1,2,4,5-tetrachlorobenzene for tetrachlorobenzene, or the average toxicity should be used for the set of congeners.

The ranking of DDT highlights the necessity to consider environmental factors in addition to chemical toxicity. As evidenced in Table 5, DDT would be ranked as a mid-level PT based solely on toxicity, because DDT has a standardized toxicity factor group weight of 5.1. However, incorporating the long half-life and high bioaccumulation of DDT justifies the conclusion that DDT is a high-hazard PT.

Water quality criteria for surface waters have been developed by EPA to protect human health. The PT ranking correlates extremely well with the conventional water quality criteria ranking across the wide spectrum of organic chemicals, as seen in Table 5.

The PT ranking method requires that a PT have an oral SF or RfD, half-life, and log P value to construct a total ranking score. For metals, however, a PT total score cannot be crafted because of the lack of established half-life values. To address this limitation, only toxicity and fate parameter group weight values can be linked to develop a secondary PT ranking score. This secondary PT ranking associates well with the PT ranking; however, omitting the persistence of a PT in the secondary PT ranking system eliminates a pivotal ecological process. Thus, a secondary PT ranking should be used to determine the general position only of a PT in the proper PT ranking methodology for metals.

All the PTs identified in the auto industry/MDNR plan were ranked (Table 6). However, uncertainty about the validity of toxicity constants, half-lives, and log P values for some PTs diminishes the accuracy of a PT ranking score. Accordingly, the PTs were grouped into high-, medium-, and low-risk categories. For those PTs with well-founded factor values, a more precise conclusion may be drawn about their relative standings.

PT ranking indicates that halogenated polycyclic hydrocarbons, such as many pesticides, PCBs, and TCDD, are the greatest concern to Great Lakes water quality. These particular PTs have three common features—medium to high toxicity, long half-lives, and high bioaccumulation values; a PT with all of these features readily amasses to toxic concentrations in the ecosystem.

PT ranking shows that typically chlorinated aromatic solvents, such as trichloroethylene, are more toxic and thus a greater concern than nonchlorinated aromatic solvents, such as toluene. Alternatively, the ranking demonstrates that the more chlorinated members of a chemical family such as hexachlorobenzene-pentachlorobenzene-dichlorobenzene or tetrachloroethylene-trichloroethylene usually present a higher threat because they have a higher potential to bioaccumulate.

In summary, this ranking system uses toxicity and exposure factors to establish a joint ranking of carcinogenic and noncarcinogenic PTs by using common acceptable exposure levels. ■

Daniel J. Bicknell is a senior project engineer at General Motors Corporation in Warren, Mich.

The Next Generation: Reducing Toxic Pollutants

H. Stephen McDonald, Jamel Demir, Cheryl F. Creson, Mary Sanna James, Wendell H. Kido

During the next 10 years, publicly owned treatment works (POTWs) will have to meet strict discharge requirements for toxic pollutants (see Box *New Toxics Regulatory Requirements*) as a result of 1987 the Federal Clean Water Act (CWA) amendments. These amendments require all states to adopt specific numeric water quality objectives for EPA priority pollutants.

The next generation of wastewater treatment facilities must respond to a regulatory environment much different than we now know. While the regulations are shifting to toxic pollutants, and to water quality-based effluent limits, the discharge standards will be established through studies that will define what is appropriate for site-specific discharge situations.

POTWs can use the opportunity of the standards-setting phases to improve toxics reductions through source control and waste minimization programs. The best approach is to reduce toxics discharges to POTW effluents, thus reducing the need for costly end-of-pipe treatment.

However, strategic planning dictates that POTWs prepare to meet stricter regulations if source control and waste minimization programs fall short. Sacramento, Calif.'s, wastewater treatment master plan (see Box *Master Plan*) provides a cost-effective sequence of levels of end-of-pipe treatment to meet a broad range of possible situations. The associated costs projected for the different levels provide stark benchmarks as POTWs prepare for the future. The plan evaluates the ability of the Sacramento Regional Wastewater Treatment Plant (SRWTP) to meet the new water quality-based effluent limits through source control in combination with state-of-the-art end-of-pipe toxics treatment (see Box *SRWTP Processes*). The plan provides a phased construction program for wastewater treatment and disposal facilities to meet public health needs and to protect the environment through the year 2010.

New Toxics Regulatory Requirements

Two recent and significant changes now drive regulatory requirements governing the discharge of effluents by POTWs. The first change is a shift in regulatory emphasis from conventional pollutants, such as organic materials and suspended solids, to toxic pollutants, particularly heavy metals and trace organics. The second change is a shift from technology-based requirements to water quality-based effluent limits. With water quality-based standards, conditions in ambient receiving waters and the characteristics of the waste discharge determine the effluent limits.

These policy shifts were prompted by the 1987 Clean Water Act ammendments, specifically Section 303 (c)(2)(B), which require states to adopt water quality criteria for the Section 307(a) priority pollutants.

These new regulations establish compliance schedules for controlling toxic pollutants in effluent. Although these requirements will be difficult to meet, they will be enforced and are expected to be met through phased implementation programs.

Specifically, California's inland surface waters plan (ISWP) establishes a 10-year compliance schedule, begun in April 1991. The first 5 years of the schedule allow for studies to improve source control and waste minimization efforts, to reduce toxics discharged to the sewer system and, to develop site-specific water quality objectives. Depending on the success of these studies, the remaining 5 years provide time to implement "end-of-pipe" tertiary treatment for toxics reduction.

TOXICS ACTION PLAN

Sacramento's plan organizes studies on improved source control-waste mini-

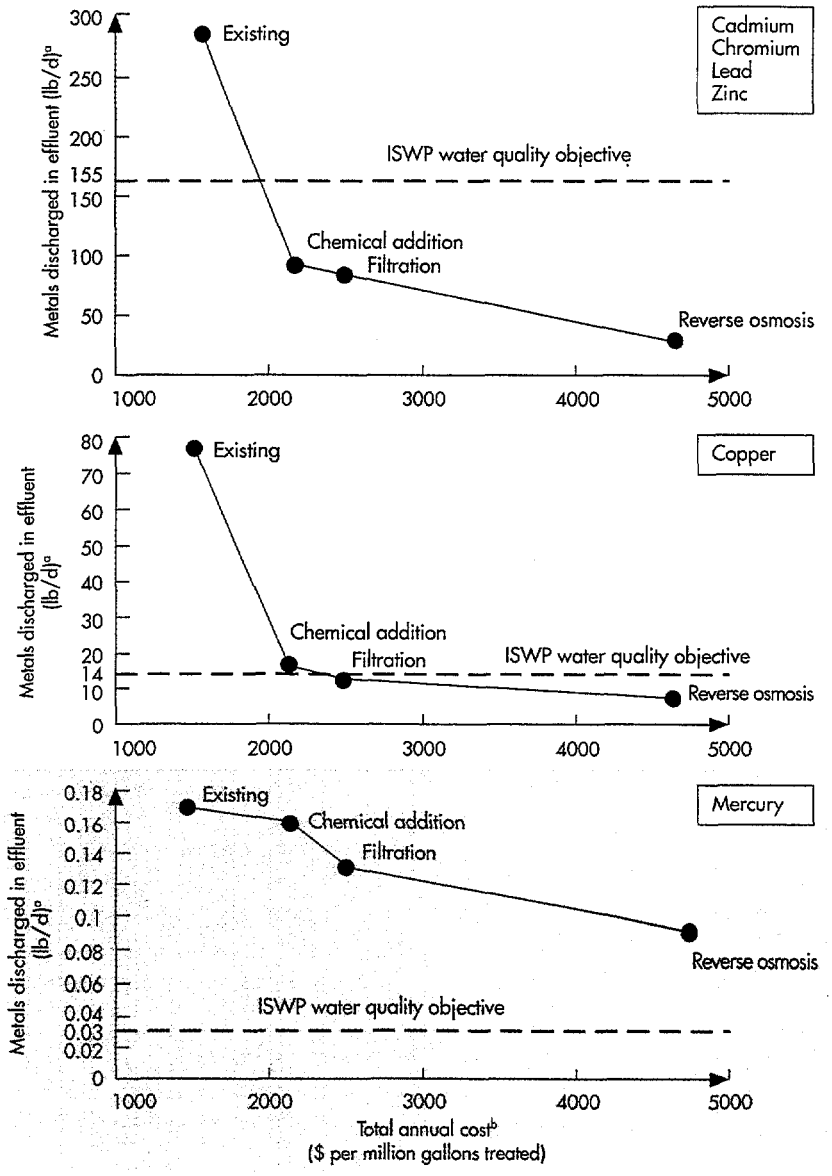
mization and the development of scientifically-defensible discharge standards into a toxics action plan (TAP). The TAP is a key component of the overall master planning strategy for wastewater treatment and will establish the extent to which end-of-pipe treatment for toxics will be required.

It is less expensive to reduce the amount of waste generated (waste minimization) and to treat a smaller, more highly concentrated waste stream at the source (source control), than it is to implement end-of-pipe treatment. Therefore, a major element of the TAP

Master Plan

California's Sacramento Regional County Sanitation District (SRCSD) recently formulated a long-range strategic approach to source control and advanced treatment alternatives to meet the new requirements as part of a major wastewater treatment master plan. This plan is one of the first in the U.S. to address 1987 Clean Water Act ammendment toxics regulations and to set forth a strategy for, and cost implications of, a range of future possibilities.

Figure 1—Metals Removal versus Costs



[a] Pounds based on projected average day annual flow of 259 mgd in year 2010.

[b] Total annual cost includes amortized capital cost (20yrs., 4%), and operations and maintenance costs for master planned facilities.

Table 1—Metal Concentrations and Removals[a]

Metal	Concentration, µg/L		Metal removal, percent[b]	
	Influent	Effluent	Existing	Required
Cadmium	2	1	50	67
Chromium	35	18	50	69
Copper	120	36	70	95
Lead	25	5	80	95
Mercury	0.2	0.08	60	94
Zinc	240	108	55	75

[a]These are reasonable maximum concentrations based on current data from January 1988 through June 1991.

[b]Based on influent concentrations shown, assuming the required discharge concentration is equal to the water quality objectives adopted in California's inland surface waters plan.

Table 2—Achievable Metals Removal

Treatment process combinations[a]				Overall percent removals, cummulative					
Existing secondary	Chemical addition	Filtration	Reverse osmosis	Cadmium	Chromium	Copper	Lead	Mercury	Zinc
X				50	50	70	80	60	55
X	X			78	87	94	97	63	85
X	X	X		85	89	95	98	70	86
X	X	X	X	96.2	95.0	97.4	98.9	79	95.8

[a] "x" denotes the processes that are combined to give the overall percent removals.

is a community-wide source control/waste minimization program to reduce the discharge of toxic pollutants to the sewer system to the maximum extent practicable.

Source control-waste minimization alone, however, cannot be expected to result in compliance with the effluent limits based on statewide objectives contained in California's Inland Surface Waters Plan (ISWP). Therefore, the TAP includes studies to verify that the EPA national water quality requirements are scientifically valid for the Sacramento River, technologically attainable, and equitably applied to all priority pollutant sources throughout the Sacramento River watershed. These studies will ensure that the SRWTP's water quality-based effluent limits reflect the most cost-effective basin-wide approach for achieving receiving water quality objectives.

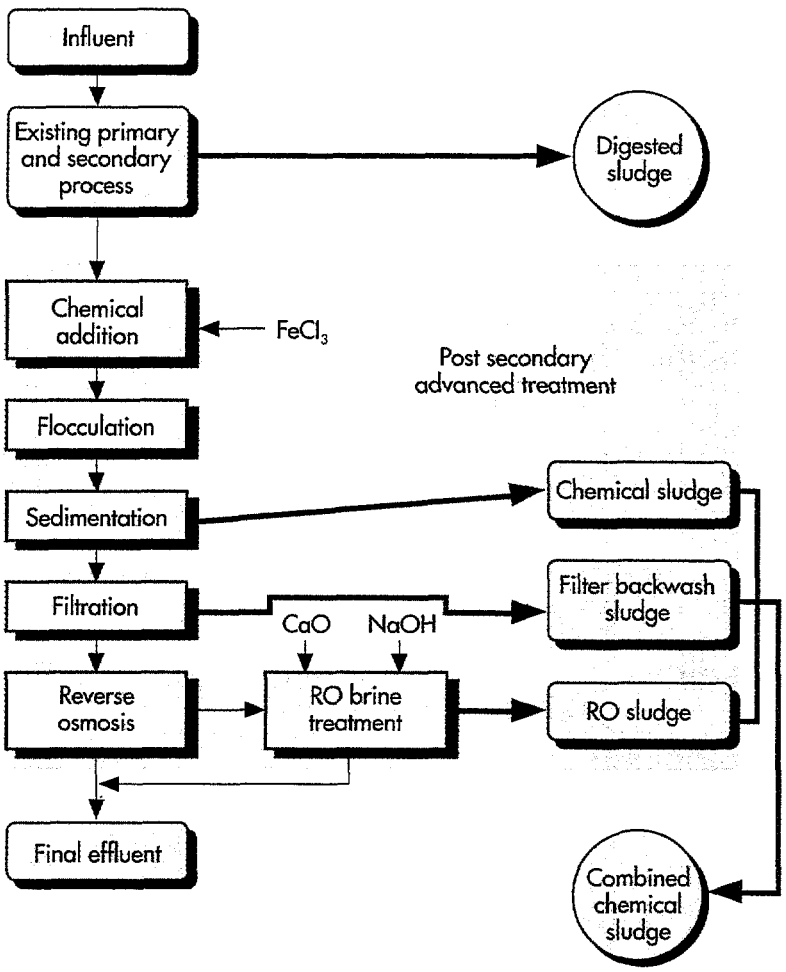
The TAP also provides for the development of a waste load allocation on the Sacramento River to allocate the discharge reductions necessary to achieve water quality objectives on the Sacramento River in the most equitable, scientifically-defensible, and cost-effective manner possible. The plan also identifies viable end-of-pipe treatment technologies to reduce toxic heavy metals to meet the new regulations.

SRWTP Processes

The Sacramento Regional Wastewater Treatment Plant (SRWTP) currently treats approximately 6 m^3/s (140 mgd) of primarily domestic wastewater and serves most of Sacramento County. The 518 km^2 (200 mi^2) service area includes approximately one million residential users, and many commercial and industrial users.

Currently, the SRWTP discharges secondary treated and disinfected effluent through a multiport diffuser to the Sacramento River. Secondary treatment is accomplished through the high-purity oxygen activated sludge (HPOAS) process. Sludge treatment and disposal involves anaerobic digestion followed by solids storage basins and on-site dedicated sludge disposal.

Figure 2—Post-Secondary Treatment Metals Removal



Treatment Scenarios to Meet Possible Regulatory Requirements

Scenario 1—Secondary Treatment and Source Control Improvements

This is the minimum required to meet existing treatment requirements. It accommodates future wastewater flows at the existing levels and includes costs to implement a toxics action plan.

Scenario 2—Intermediate Metals and Ammonia Reduction

This scenario continues secondary treatment, and includes post-secondary chemical addition and filtration for metals reduction and nitrifying trickling filters for ammonia reduction.

Scenario 3—Advanced Metals Reduction

In addition to secondary treatment, this scenario includes post-secondary chemical addition, filtration, and reverse osmosis (RO) for metals reduction, but does not include ammonia reduction facilities.

Scenario 4—Advanced Metals and Ammonia reduction

This scenario includes secondary treatment, post-secondary chemical addition, filtration, and RO for metals and ammonia reduction.

These scenarios for tertiary treatment are not mutually exclusive. Instead, they are compatible with one another and provide for increasing levels of treatment for metals and ammonia removal if the anticipated benefits of increased source control and the development of site-specific objectives are not realized.

DEVELOPING TERTIARY TREATMENT ALTERNATIVES

Because the outcome of efforts to establish water quality-based discharge standards for toxic pollutants is unknown, specific requirements for tertiary treatment to reduce toxics cannot be recommended at this time. Therefore, the master plan presents a compliance strategy with a wide range of potential requirements using tertiary treatment technologies. These technologies are further combined to develop future treatment scenarios that provide increasing levels of toxics reductions, which may be required pending the outcome of the TAP (see Box *Treatment Scenarios to Meet Possible Regulatory Requirements*).

Treatment alternatives for metals reduction were evaluated and screened based on their applicability to large treatment plants, proven ability to meet potential discharge requirements, and flexibility in implementation. The viable alternatives were further evaluated to determine their compatibility with one another and the most cost-effective implementation sequence.

The alternatives were screened based on their ability to remove heavy metals to the levels required to meet the ISWP numeric water quality objectives. Heavy metal removals required were selected based on a review of existing data and on additional limited sampling and testing studies (Table 1).

Once the choice of metals reduction technologies was narrowed to those with proven applicability to large-scale operations, a review of existing literature and a survey of existing operating facilities was conducted to determine the achievable level of metals removal (Table 2).

Size and future space requirements for tertiary treatment facilities were determined based on the design-standby criteria.

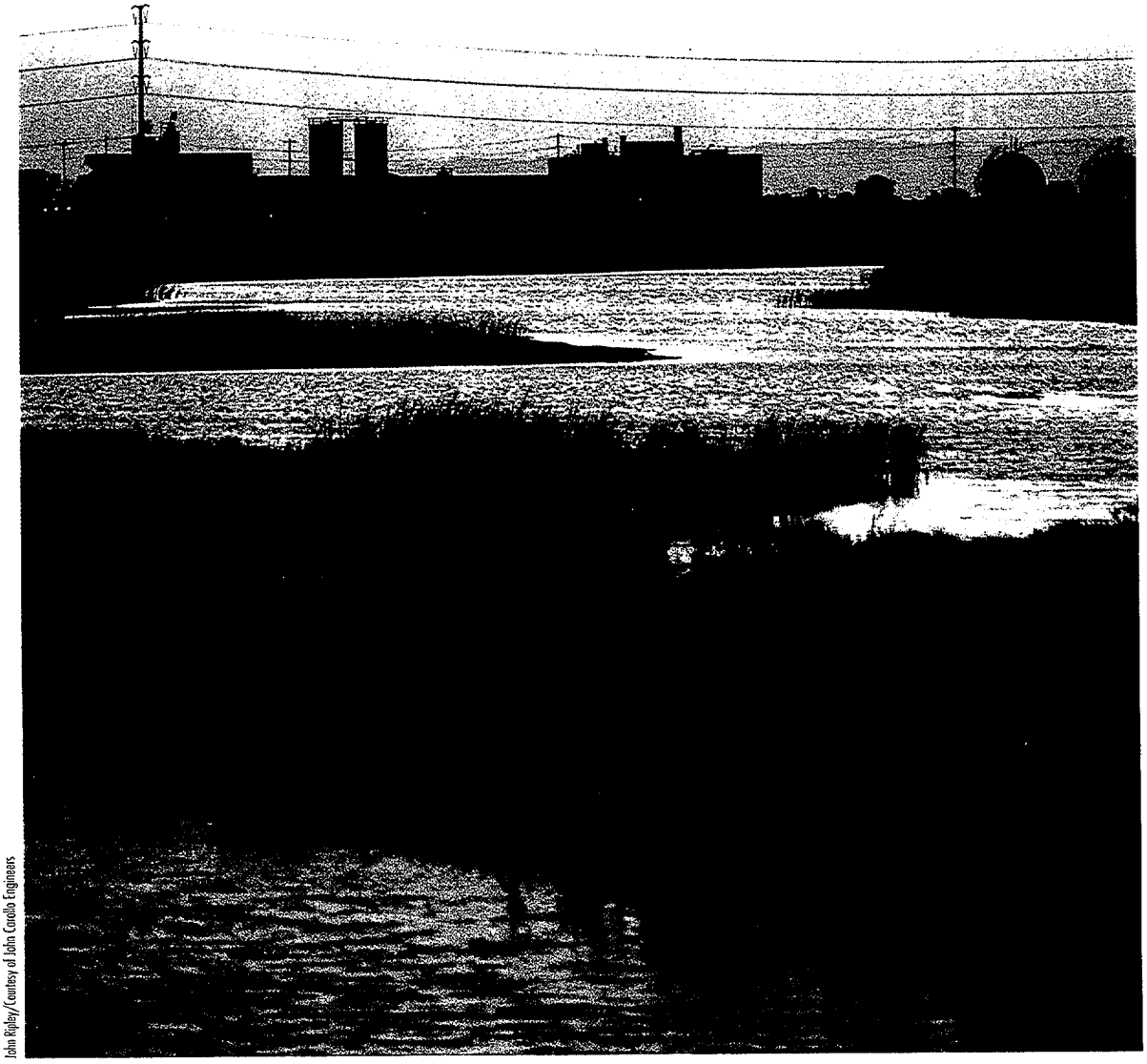
METALS REDUCTION TECHNOLOGIES

Three tertiary treatment technologies were selected and compared based on metals removal and costs (Figure 1). The recommended sequence of implementation is based on process compatibility and cost-effectiveness. This sequence and addition of facilities provides the maximum removal of toxic pollutants for the least cost.

The first process to be implemented for tertiary treatment is post-secondary chemical addition. When compared to other possible coagulants, using ferric chloride generates less sludge while removing more metals from the effluent.

Chemical addition facilities include flash and rapid mix tanks followed by

High-purity oxygen-activated treatment plant in Sacramento, Calif., coexists with sensitive marshlands.



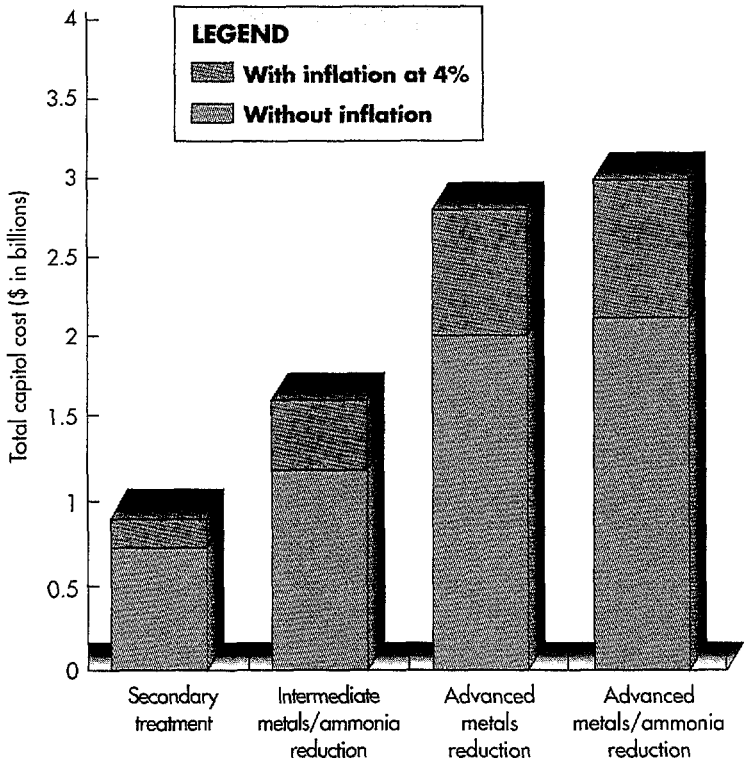
John Ripley/Courtesy of John Carollo Engineers

Table 3—Projected Annual Operations and Maintenance Costs, million dollars

	1995		2000		2005		2010	
Scenario	Current	Inflated[a]	Current	Inflated[a]	Current	Inflated[a]	Current	Inflated[a]
1	43.6	54.3	49.9	78.5	60.4	120.1	72.1	181.4
2	43.6	54.3	96.7	199.7	113.8	220.8	133.2	328.5
3	43.6	54.3	177.3	266.8	205.5	392.7	237.8	580.2
4	43.6	54.3	180.8	271.9	209.5	401.2	242.2	590.8

[a] assuming 4% inflation.

Figure 3—Capital Funding Requirements



three-stage flocculation basins and sedimentation. Chemical storage tanks and feed equipment for ferric chloride and polymer are also needed.

Filtration is the second tertiary treatment identified to achieve required metals reductions. This treatment would follow the chemical addition process and possibly, along with chemical addition, would achieve the required metals reduction.

If not, reverse osmosis (RO) is necessary. RO is a proven technology effective for separating heavy metals and inorganic constituents from water and wastewater. However, its high cost makes it the least desirable treatment when compared to the minor improvements in metals reduction achieved.

A major factor to consider when using RO is the disposal of the process's waste brine. In Sacramento, on-site treatment of the brine stream is required with blending of the treated brine effluent and RO product water.

CROSS MEDIA IMPACT CONSIDERATIONS

While the three processes considered for tertiary treatment achieve the required metals reductions, they impact sludge quantity: they result in nearly double the amount of sludge produced compared to conventional secondary treatment.

The increased sludge volume affects the treatment facilities in several ways. First, a separate chemical sludge handling system is needed to transport the sludge to a common sludge thickening process. Here, the chemical addition, filter backwash and RO sludges are combined, thickened, and either stored for eventual reuse or disposed of. If the sludge is disposed of off-site, it would need to be dewatered to a minimum of 50% solids before disposal. If the sludge is disposed of on-site, loading rates would probably be the same as for conventional secondary treatment harvested sludge (100 dry tons/ac•yr). This approach would essentially double the land area required for on-site sludge disposal.

Tertiary treatment sludge should be relatively low in volatile solids and therefore would have little need for stabilization, which essentially precludes its being mixed with digested sludge. High ferric chloride and lime concentrations could also have adverse impacts on solid storage basin algae growth and overall basin health.

Tertiary treatment to remove metals from wastewater affects sludge quality also because the metals are not destroyed, rather transferred to the sludge during treatment. The metal concentrations in tertiary treatment sludge for Sacramento, however, are expected to be equal to or lower than historical levels in conventional harvested and digested sludges because of the bulking effect of adding substantial amounts of inert chemical coagulants to remove minor amounts of metal.

These tertiary treatment impacts are significant because planning, testing, and implementing new or modified alternatives for sludge use and disposal in today's environmental and regulatory climate can easily take between 5 and 10 years. Alternatives to current disposal and use methods may be required even sooner, depending on the pace of expected regulatory efforts. The final promulgation of pending federal sludge regulations are expected to support the possibility of beneficial use alternatives. In fact, major regulatory trends are moving away from disposal and require recycling, reuse, and other techniques to reduce the pressure on landfills.

In light of changing regulatory, environmental, and market conditions over time, POTWs need the flexibility of having more than one on-going sludge use and disposal practice.

LEVEL OF TREATMENT VERSUS COSTS FOR TERTIARY TREATMENT

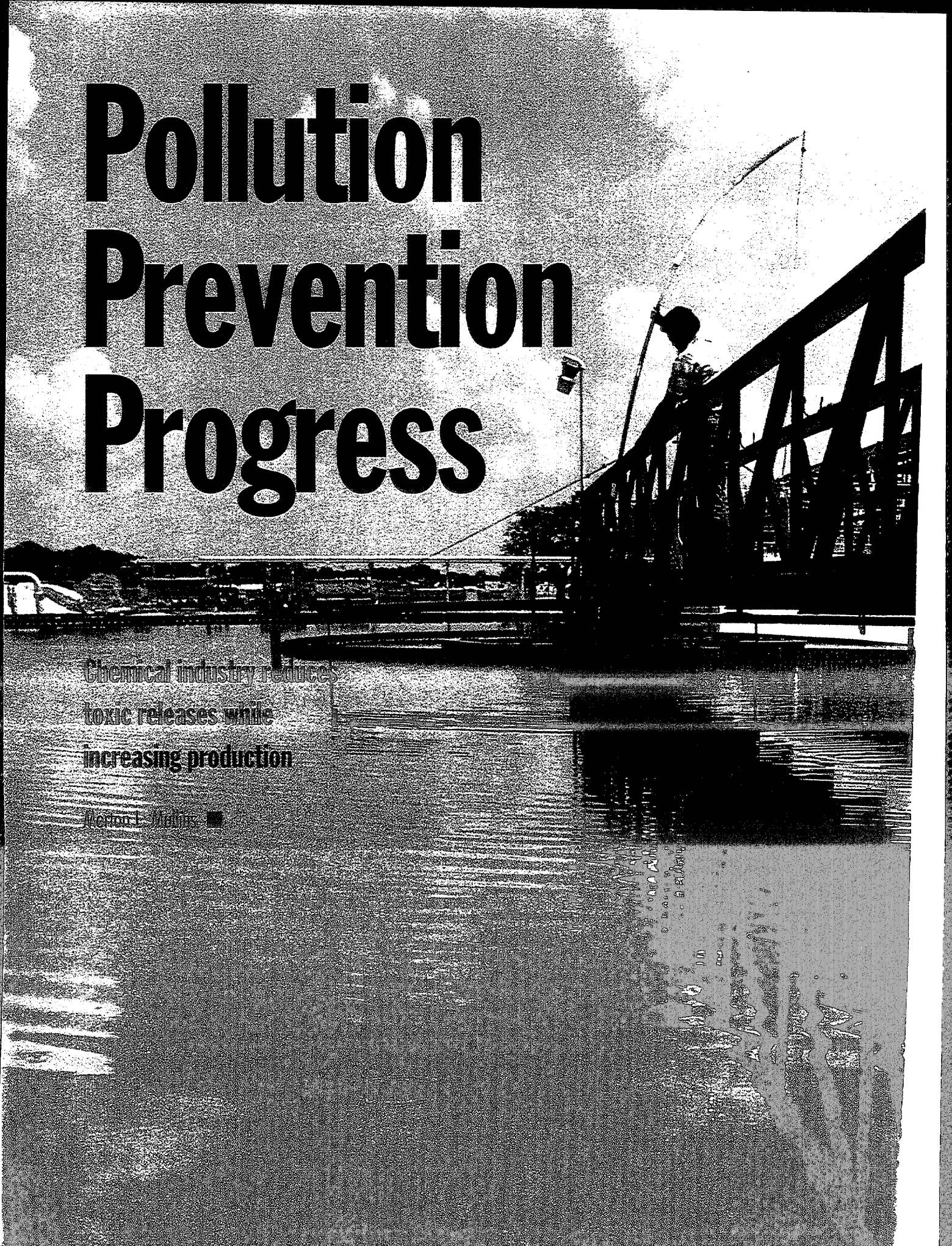
The costs for both capital improvements and operation and maintenance for each of the four treatment scenarios through the year 2010 were assessed through detailed cash flow projections in 1992 dollars. (Figure 3, Table 3).

Facilities providing the existing level of secondary treatment (Scenario 1) require capital funding of $720 million for the 20-year planning period. The second scenario's capital costs are projected to be $1162 million. Third and fourth scenario capital costs exceed $1959 million and $2086 million, respectively. Average dry weather flows are projected to increase to 10.6 m^3/s (242 mgd) by the year 2010.

The significant costs for end-of-pipe treatment for toxics demonstrate the importance of improved source control-waste minimization efforts and the development of scientifically defensible discharge standards. Should advanced treatment for metals reductions be required, however, the most cost-effective sequence of proven technologies is ready in Sacramento's master plan. ■

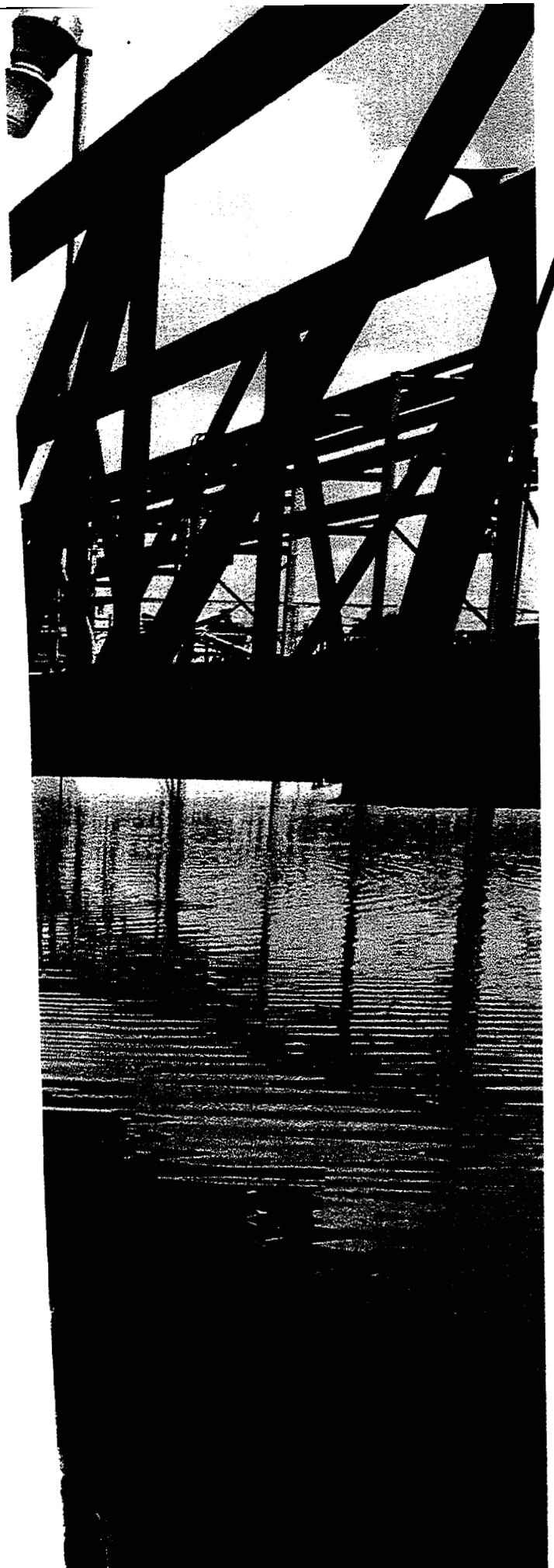
H. Stephen McDonald, and Jamel Demir are with John Carollo Engineers in Walnut Creek, California and Cheryl F. Creson, Mary Sanna James, and Wendell H. Kido are with the Sacramento Regional County Sanitation District in Sacramento, Calif.

Pollution Prevention Progress



Chemical industry reduces toxic releases while increasing production

Merton L. Mullins



When it comes to pollution prevention and chemical manufacturers, the byword is *by-products.* Since 1987, the chemical industry has focused on using by-products before they become waste. Recently published findings from the EPA Toxics Release Inventory (TRI) indicate that the U.S. chemical industry has made significant progress in reducing toxic chemical waste. According to data compiled by the Chemical Manufacturers Association (CMA) from 1553 member facilities preparing TRI reports, the U.S. chemical industry recycled or treated 93% of the 5.9×10^9 kg (13×10^9 lb) of chemical by-products produced. The remaining 7% were reported to the TRI as permitted releases to the environment.

Survey respondents included manufacturers of industrial chemicals, plastics, manmade fibers, pharmaceuticals, soaps and toiletries, paints, and agricultural chemicals. These manufacturers have invested more than $7.3 billion since 1987 in pollution control equipment.

The TRI was established by the Emergency Planning and Community Right-to-Know Act and has been used since 1987 to track toxic chemicals at manufacturing facilities. The Pollution Prevention Act of 1990 has provided additional emphasis on source reduction. The inventory documents both yearly releases and off-site transfers of nearly 320 chemicals (see Box, *Targeted "33/50" Chemicals and Carcinogens Reduced*).

In the most recent inventory, toxic releases were down 6% from 1990; and, for the fifth straight year, releases were lower across the board. Air emissions were down 29%; water discharges, down 77%; land discharges, down 35%; and deep well discharges, down 35% from the base year, 1987. Chemical facilities also reduced off-site transfers of toxic chemicals for treatment and disposal by 37% (see Tables, *1991 Toxic Release Inventory* and *1991 Toxic Releases and Transfers by Media*).

Discharges from the wastewater treatment plant at the Dow Chemical Company's Plaquemine, La., facility account for the smallest portion of their Toxic Release Inventory report.

1991 Toxic Release Inventory[a]

Year	1987	1988	1989	1990	1991	%Change
	Millions of pounds[b]					
Releases to land, air, or water	1307	1249	1085	899	848	–35
Transfers for off-site treatment or disposal	451	410	361	331	285	–37
Totals	1758	1659	1446	1230	1133	–36

[a] Chemical Manufacturers Association (1993) "Toxic Release Inventory Declines for Fifth Straight Year," *Pollution Prevention Fact Sheet*, p. 1.

[b] lb × 0.453 = kg.

Targeted "33/50" Chemicals and Carcinogens Reduced

The chemicals identified in EPA's Toxic Release Inventory vary widely in toxicity and in the amount released. However, release does not equal exposure. According to EPA, each release scenario has its own unique characteristics. Dilution may render exposure concentrations so small as to be of no concern. On the other hand, some environmental transformations lead to by-products of even greater concern than the original release. To set priorities, EPA and industry have used two measures: targeted pollutants and carcinogens.

EPA asked industry to cut releases of 17 large-volume chemicals by 33% voluntarily from 1988 to 1992 and by 50% in 1995. These are known as the "33/50" chemicals.

The Chemical Manufacturers Association (CMA) endorses the program because it is compatible with the goal of "responsible care," the industrywide initiative in health, safety, and the environment. Participating CMA member companies are 1 year ahead of EPA's goal, having achieved a 35% reduction in releases and transfers by the end of 1991.

Carcinogenicity, or the potential to cause cancer, is the other measure used by industry and EPA to set priorities for release reduction. Less than 5% of toxic releases and transfers from CMA core chemicals are considered carcinogens. From 1987 to 1991, releases of these chemicals have been reduced by 45% and off-site transfers are down 20%.

KEEPING OUTPUT UP AND RELEASES DOWN

The key for chemical manufacturers has been to find ways to cut chemical waste without sacrificing production. One prime example is the 889-ha (2200-ac) Monsanto Company plant in Pensacola, Fla., which produces nylon for carpets and industrial tires. The plant was one of the largest releasers of TRI chemicals in Florida, even while running at less than capacity during the base year, 1987. In 1988 and 1989, as production increased, so did releases. However, in 1990 and 1991, production continued at increased levels, but reportable releases were cut by 74%. The Pensacola plant achieved these reductions with several process changes.

A process change in 1989 reduced the amount of ammonia required to neutralize nitric acid, a by-product of nylon production. This, in turn, reduced the volume of ammonium nitrate disposed through deep-well injection by 8.2×10^6 kg (18×10^6 lb). As a safety measure, a new ammonia storage tank that reduced air emissions was also installed.

Additional process modifications and operational changes at the Monsanto plant from 1989 to 1991 cut releases of cyclohexane by 96%, and reduced releases of maleic anhydride, a chemical used in the fiberglass and food industries. In 1990, the plant also substituted other solvents for chlorofluorocarbons and methyl chloroform in degreasing and cleaning operations.

BUILDING A COMMITMENT TO POLLUTION PREVENTION

As a result of the Pollution Prevention Act of 1990, the TRI also now includes reporting of pollution prevention activities, such as recycling, treatment, and energy recovery at manufacturing sites. According to the TRI, chemical plants recycled 54% of the chemical by-products produced, and treated 31% in wastewater treatment units or disposed of in EPA-approved incinerators. Another 8% was recovered and consumed as energy in federally permitted boilers and furnaces. The remaining 7% was released directly to the environment (see Figure, *Percent of Chemical By-Products Recycled or Treated, 1991*). The reporting chemical facilities managed 5.5×10^9 kg (12.1×10^9 lb) of chemical by-products and released only 393.7×10^6 kg (868×10^6 lb) to the environment. Eighty-five percent of the chemicals recycled, treated, or recovered for energy use were managed at the plant site.

CMA POLLUTION PREVENTION CODE

To foster a commitment to pollution prevention among its members, the CMA adopted a Responsible Care Initiative that requires member companies to follow six codes of management practice including: *community awareness and emergency response, employee health and safety, pollution prevention, process safety, product stewardship, and distribution.* The Pollution Prevention Code is a measure designed to promote sound industry management of the residues that remain after reduction efforts. The code requires member facilities to evaluate reducing wastes and releases at their source first before evaluating recycling or treatment programs. CMA is also developing additional portions of the code that will address reviewing facility and contractor waste management practices, groundwater protection, and evaluating prior operating and disposal practices at active or inactive facilities.

POLLUTION PREVENTION SUCCESS STORIES

Pollution prevention often focuses on source reduction, and uses such techniques as in-process recycling,

process modification, improved plant operations, raw materials substitution, and changes in end-products to reduce toxic waste.

In-process recycling can close the manufacturing loop. DuPont recently introduced a new technology to recycle the catalyst within the process of making an intermediate for elastomers and spandex fibers. The catalyst replaces fluorosulfonic acid, which is hazardous.

Raw material substitution is also a pollution prevention activity that is the focus of much technical effort in the chemical industry. Substitution is usually complex, but can be as simple as using a different glue. Monsanto and 3M replaced a glue that emitted 11,340 kg (25,000 lb) of volatile organic compounds (VOCs) with a water-based glue that emitted none.

1991 Toxic Releases and Transfers by Media[a]

	Millions of pounds[b]					
Year	**1987**	**1988**	**1989**	**1990**	**1991**	**%Change**
Releases to land, air, or water						
Air	546	503	489	426	389	–29
Water	36	19	12	10	8	–77
Underground injection	677	674	548	430	420	–38
Land	48	52	37	34	31	–35
Transfers for off-site treatment or disposal						
Treatment	223	215	181	154	139	–38
Land disposal	63	52	43	36	32	–49
Publicly owned treatment works	165	143	137	140	115	–31

[a] Chemical Manufacturers Association (1993) "Chemical Industry Cuts Releases to Air, Land and Water," *Pollution Prevention Fact Sheet*, p. 2.

[b] lb × 0.453 = kg.

Source reduction techniques frequently work in tandem. In the late 1980s, PPG Industries, Inc., introduced a family of new resins for industrial paints with lower VOCs. However, the distillation step to lower the VOC content resulted in a solvent that was difficult to use or recycle. By 1991, PPG was generating 2.3 to 3.2 × 10^6 kg (5 to 7 × 10^6 lb) of the solvent annually. The company then modified plant equipment and processes to reformulate the resins and eliminate extraneous solvents. This made it easier to purify and recycle the solvent; the company was able to use 1.5 × 10^6 kg/yr (3.4 × 10^6 lb/yr) in a number of applications. Thus, to prevent pollution, PPG changed the end-products, modified processes and equipment, and recycled.

Recycling is a common pollution prevention activity. Air Products and Chemicals, Inc., recovered and recycled 272,160 kg (600,000 lb) of ammonia and ammonium nitrate from exhaust at its Escambia, Fla., plant. Air emissions were cut by 94%.

Two BASf Corp. coatings plants previously shipped solvents off-site for treatment. They began to distill the solvents for reuse in making paints, which reduced waste handling and saved $1 million/yr. In addition, residue remaining in the distillation units was used as fuel.

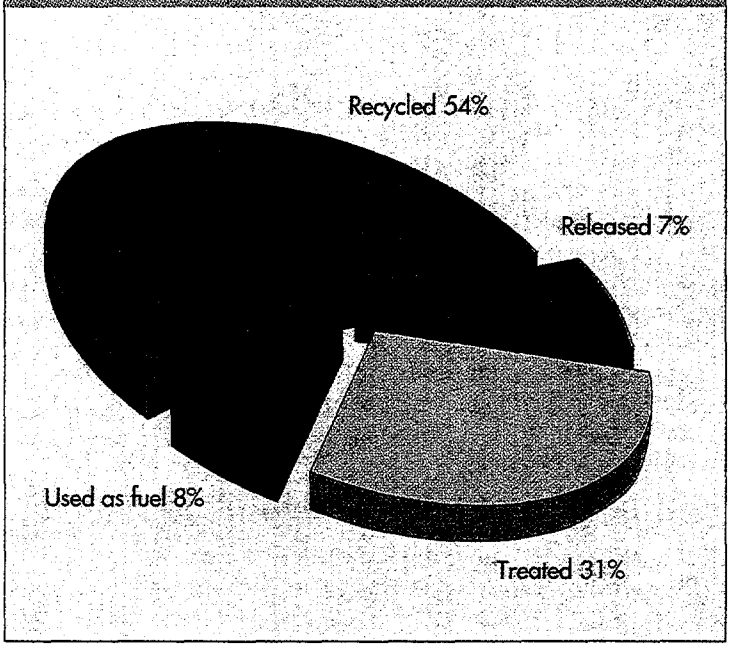
Velsicol Chemical Corp. also recovered the energy value of organic vapors from the manufacturing process at its Chattanooga, Tenn., plant. The organic vapors are burned to generate steam, thereby reducing air emissions by 95,256 kg/yr (210,000 lb/yr).

A biotank water treatment system at Georgia Gulf Corp's Plaquemine, La., plant uses naturally occurring organisms to convert contaminated water to carbon dioxide and water. Nearly 219 L/s (5 × 10^6 gal/d) of water are treated, including contaminated water from a new vapor recovery unit that reduced air emissions by 90%.

Other techniques to improve plant operations include preventive maintenance, materials handling procedures, employee training, and environmental reviews. A number of companies have improved internal and inter-industry inventory communications and control, particularly for small-volume chemicals such as those used in laboratories. ■

Percent of Chemical By-Products Recycled or Treated, 1991

The Pollution Prevention Act of 1990 added new reporting requirements to the Toxic Release Inventory to encourage source reduction. Results show that 93% of chemical by-products are recycled or treated.



Morton L. Mullins *is vice president of regulatory affairs for the Chemical Manufacturers Association, Washington, D.C.*

Be Prepared

By Manjunath A. Gokare and J. Ronald Lawson

Changes to the oil pollution prevention regulations mean many facilities will need to update their SPCC plans

Editor's Note: This is the first of a two-part series. The second half, which will address Phase II SPCC revisions, will appear in the Nov./Dec. issue.

On Jan. 2, 1988, an aboveground storage tank (AST) collapsed at the Ashland Chemical Co.'s Floreffe, Pa., facility, spilling 3.8 million gallons of diesel fuel. Approximately 750,000 gallons entered the Monongahela River; the rest was held by a secondary containment dike at the facility. This and other spills prompted Congress to form a spill prevention, control and countermeasures (SPCC) task force to review federal regulations governing oil spills and recommend improvements.

Composed of senior personnel from EPA headquarters and regional offices, and other federal agencies and state offices with significant oil spill response capabilities, the task force issued its findings on May 13, 1988. It suggested that EPA:

- change the regulatory language to clarify requirements,
- establish additional technical requirements for facilities subject to the regulation,
- expand the scope to include oil contingency planning,
- compile a list of regulated facilities and information pertaining to their oil-storage capacities, and
- strengthen the facility inspection program.

EPA responded by proposing on Oct. 22, 1991, Phase I SPCC revisions, which focus on preventive rather than reactive measures.

A facility's owner or operator is responsible for determining if it requires an SPCC plan. If so, it should be carefully organized and prepared in accordance with good engineering practices, have management's full commitment and be signed by a person with the authority to commit the necessary resources to implement and maintain the plan.

Facilities that need to create an SPCC plan or to amend an existing plan should do so immediately and establish procedures for conducting inspections and tests, and maintaining all records at the facility for five years.

The Agency estimates that approximately 435,000 facilities in the nation are SPCC-regulated.

WHAT IS OIL?

Sec. 311 of the Clean Water Act (CWA) defines oil as "oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse and oil mixed with wastes other than dredged spoil." EPA interprets this definition to include crude oil and refined petroleum products, as well as such nonpetroleum products as vegetable and animal oils.

Phase I Revisions

The proposed Phase I SPCC revisions would change the applicability of the Oil Pollution Prevention regulations, as well as the procedures for completing SPCC plans. (At press time, final Phase I SPCC revisions had not been promulgated.)

Currently, SPCC plans must be prepared within one year from the date of initial facility operations. Phase I revisions would require that SPCC plans be implemented before operations begin. They also would integrate SPCC planning with the emergency planning provisions of Title III of the Superfund Amendments and Reauthorization Act (SARA).

General requirements. Phase I revisions further explain the purpose and scope of an SPCC plan, which "should provide a written explanation of a facility's compliance with the requirements of the regulation, including equipment, manpower, procedures and steps to prevent, control and provide adequate countermeasures to an oil spill."

While SPCC plans need not follow a rigid format, the proposed revisions clarify what information must be included:

- a management approval statement,
- facility information,

- unit-by-unit storage capacity,
- type and quantity of oil stored,
- potential spill pathways,
- spill prevention and control measures,
- spill countermeasures,
- strategies for disposing recovered materials,
- a contact list with appropriate phone numbers,
- a description of the facility's physical plant, and
- a facility diagram depicting all tank locations and contents.

Notification requirements. The SPCC task force found that information about the numbers, storage capacities and locations of oil ASTs is needed for effective program administration. In response to this recommendation, EPA proposed a one-time notification requirement. Within two months of the final rule's effective date, all facilities subject to the Oil Pollution Prevention regulations would have to furnish a notification form to EPA's SPCC program office with the following information:

- owner's name,
- operator's name,
- facility name and address,
- Dun & Bradstreet number or SIC code,
- number and size of oil ASTs,
- total oil AST capacity, and
- distance to nearest navigable waters.

The final rule may require additional information, including: the facility's latitude and longitude, location of environmentally sensitive areas and potable water supplies, spill history, presence of secondary containment and leak detection equipment and alarms, ages of the tanks and adverse weather potential. (Adverse weather refers to weather conditions that make it difficult for response equipment and personnel to clean up or remove spilled oil.) This facility inventory is intended to help EPA in the Phase II SPCC revisions.

Onshore facilities. ASTs at onshore facilities would have to undergo integrity testing every 10 years and whenever material repairs are made. Integrity testing could be performed by any of the following methods: visual (photographic), hydrostatic, ultrasonic, or with X-ray or gamma radiation, helium-mass detectors or acoustic emission.

Buried piping would have to have protective coating and cathodic protection, regardless of soil conditions. All aboveground valves, piping and accessories would have to be examined monthly.

In addition, accumulated oil and oil-contaminated material would have to be removed within 72 hours of a spill event.

Contingency plan. Current regulations require only facilities without secondary containment to have strong oil spill contingency plans with written commitments of manpower, equipment and materials for spill control and removal.

According to the proposed revisions, contingency plans should be a separate section and include descriptions of response plans, personnel needs, methods of mechanical containment and removal, and the availability of sorbents, boom and other equipment. The plan could not rely, in whole or in part, on the use of dispersants or other chemicals.

Facility owners or operators would have to demonstrate that structures or equipment could not, within reason, be installed to prevent discharged oil from reaching navigable waters. The proposed revisions also clarify that contingency plans must be reviewed by the EPA regional administrator, who would have the authority either to approve the plan or require amendments.

Specific requirements. The proposed revisions also would require that:

- the entire containment system (dikes, berms and retaining walls), including walls and floors, be impervious to oil for 72 hours;
- facilities without secondary containment conduct integrity testing of tanks at least every five years;
- facilities without secondary containment conduct integrity and leak testing of valves and piping at least once a year;
- all records of inspections and all test results, along with written procedures for performing the inspections and tests, be maintained with the SPCC plan for five years (instead of the three years currently required); and
- spill prevention and control training exercises be conducted yearly and new employees be trained within their first week of work.

FOR WHOM THE BELL TOLLS

Since the Oil Pollution Prevention Act (40 *CFR* Part 112) became effective in 1974 under Sec. 311 of the Clean Water Act (CWA), the regulations have been updated three times: in 1974 to address civil penalties, in 1976 to specify procedures for writing SPCC plans and in 1990 to address the potential for oil releases from nontransportation-related onshore and offshore facilities (the Oil Pollution Act).

Nontransportation-related facilities are defined as "all fixed facilities including support equipment, but excluding interstate pipelines, railroad tank cars en route, transport trucks en route and terminals associated with the transfer of bulk oil to or from a water transportation vessel." Facilities of this description that drill, produce, store, process, refine, transfer, distribute or consume oil and oil products must prepare an SPCC plan if they could reasonably be expected to discharge into navigable waters or adjoining shorelines and have:

- a single AST capacity greater than 660 gallons,
- a total AST capacity greater than 1,320 gallons, or
- a total buried underground oil storage capacity greater than 42,000 gallons.

According to the Oil Pollution Act, the phrase "reasonably be expected" is defined as follows: "the expectation is logical, rational, sensible, justifiable, credible, plausible, etc. When examining a facility, the following factors should be considered in determining the likelihood of a spill getting into navigable water: spill history; location; drainage patterns; soil conditions; frequency and amount of rainfall."

There are more than 650,000 ASTs nationwide, according to a recent government report, and 2,000 to 3,000 spills were reported since 1982.

Certification and amendment. Under the proposed rule, SPCC plans would have to be certified by a registered professional engineer who is licensed in the state where the facility is located but is not a facility employee. Certifying engineers would have to attest that they had examined a facility and reviewed its plan, that all required testing had been completed, and that the plan is adequate for the facility.

A complete, certified copy of the SPCC plan would have to be kept at the facility and be reviewed, evaluated and updated every three years. SPCC plans also would have to be amended when:

- facility design, construction or operation is changed;
- a tank is commissioned or decommissioned;
- a tank is replaced, reconstructed or moved;
- a piping system is replaced, reconstructed or installed;
- construction or demolition might alter secondary containment structures; or
- standard operation or maintenance procedures are revised.

Coming Soon

Final Phase II revisions were published in the *Federal Register* on July 1, 1994, and became effective on Aug. 30. The Phase II rules address facility-specific contingency plan requirements for large facilities that can cause "substantial harm." (By regulating large facilities more stringently than smaller ones, EPA hopes to prevent another major oil spill like the 1988 Ashland oil spill.)

Although the Phase II rules have only recently been published, all "substantial harm" facilities were required to submit facility response plans (FRPs) to EPA by Feb. 18, 1993. SPCC plans focus on procedures to prevent and control oil spills; FRPs focus on preparedness in reacting to small, medium and worst-case discharge scenarios. FRPs must include written contractual agreements with oil spill response contractors and be approved by EPA's regional administrator. ■

Manjunath A. Gokare *is an environmental engineer in the Atlanta office of Piedmont Olsen Hensley, and*
J. Ronald Lawson *is vice president of the environmental division at the company's Greenville, S.C., headquarters.*

Making Pollution Prevention Work

By Paul S. Dickens

Electronics manufacturer adopts "design-for-environment" strategy to maximize benefits of pollution prevention and remain competitive

Environmental issues increasingly influence business decisions made by U.S. manufacturers, who must balance the growing burden of regulatory compliance with the need to be globally competitive. Successful companies reduce their regulatory burden by incorporating environmental issues into strategic plans concerning product design, customer service and manufacturing technology. These "design-for-environment" companies use pollution prevention as a tool for improving competitive strength.

What is pollution prevention? In practical terms, it is any activity that reduces or eliminates air emissions, wastewater, or solid or hazardous wastes at the source. Under the Pollution Prevention Act of 1990, it is the first priority in an environmental hierarchy that includes: 1) prevention, 2) recycling, 3) treatment and 4) disposal or release.

Unlike end-of-pipe controls, or waste management, pollution prevention enables companies to get out from under the burden of environmental regulation. Waste that is not generated does

MARC SOLOMON, COURTESY OF CAMP, DRESSER & MCKEE INC.

not need to be managed or reported. Eliminating waste also allows companies to invest in more productive activities, such as improving product quality. The ultimate goal of pollution prevention activities, therefore, is enhancing resource efficiency.

A measure of competitive strength, resource efficiency is defined to emphasize the negative impact of waste generation, which often is ignored or overlooked. A successful pollution prevention program requires that resource efficiency be given the same priority as customer service, product quality and other manufacturing concerns.

$$\text{Resource Efficency} = \frac{\text{Resource Content}}{\text{Resource Inputs} + \text{Waste Management}}$$

- Resource content is the difference between resources that go into a product and those lost to waste generation.
- Resource inputs include energy, labor, water, air, raw materials, and manufacturing chemicals and supplies.
- Waste management includes energy, labor and other materials for end-of-pipe pollution controls.

Resource efficiency is improved by reducing resource inputs and eliminating waste. To make a profit, the market value of a manufactured product must exceed the combined cost of resource inputs and waste management.

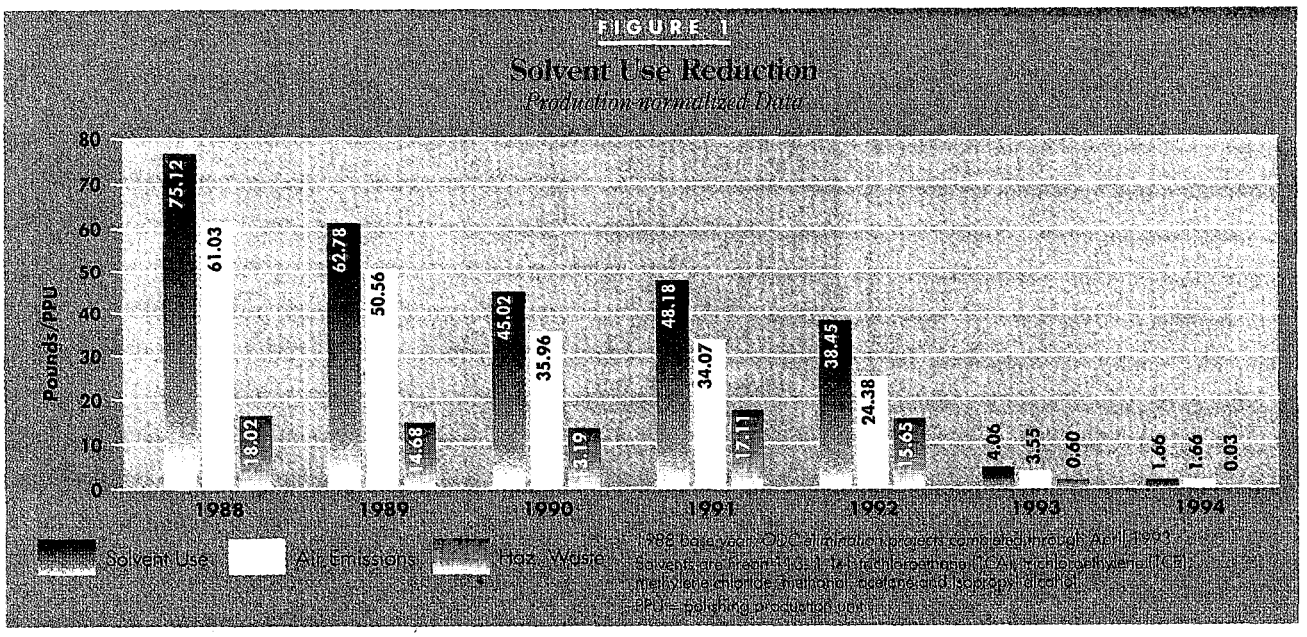
Manufacturers today face many barriers to pollution prevention, including product specifications that dictate methods and materials; inadequate capital resources for purchasing new equipment; tax codes that discourage research and investment; and environmental regulations that focus on end-of-pipe controls. The greatest barrier, however, often comes from within — company culture and the way business decisions are made.

Design-for-environment companies look at environmental issues as business opportunities that may lead to new products, services or manufacturing technology for reducing the burden of regulatory compliance.

Pollution prevention is total quality management (TQM) applied to environmental issues. It requires a commitment from all employees. Everyone must believe that pollution prevention improves competitive strength, and managers must show by example their honest support for such programs. Pollution prevention benefits come from small changes that eventually result in large reductions in emissions and other wastestreams. Although they may not be immediately apparent, the financial benefits of pollution prevention add up over time.

Integrating pollution prevention into every business decision is known as design-for-environment, a management strategy for improving resource efficiency, reducing the burden of regulatory compliance, responding to customer needs and addressing public concerns about environmental issues.

FIGURE 1



Design-for-environment companies look at environmental issues as business opportunities that may lead to new products, services or manufacturing technology for reducing the burden of regulatory compliance. Environmental issues receive the same systematic and strategic evaluation traditionally reserved for such concerns as product position and market share. Design-for-environment is effective because it transfers ultimate responsibility for environmental issues and the corresponding regulatory burden from specialized staff to senior company management.

Evolution of a program

MEMC Electronic Materials (St. Peters, Mo.) manufactures polished and epitaxial silicon wafers, the base on which microelectronic circuits (microchips) are built. The company has manufacturing plants in the United States, Europe and Asia.

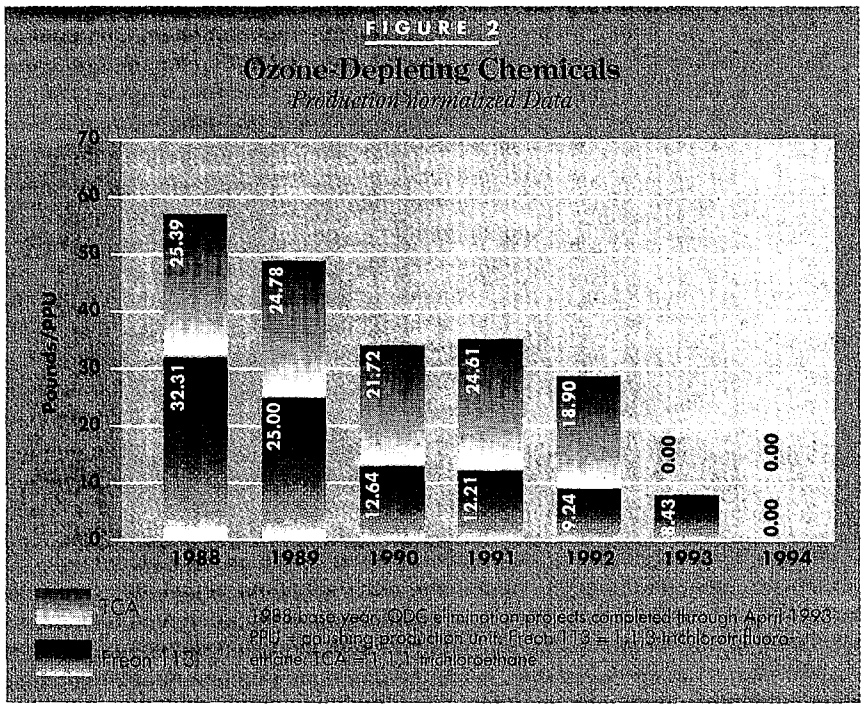
The company's approach to environmental issues has evolved over the last five years from a simple pollution prevention program to a design-for-environment strategy. The first step came in 1989, when MEMC, using 1988 as its baseline, set companywide environmental goals:

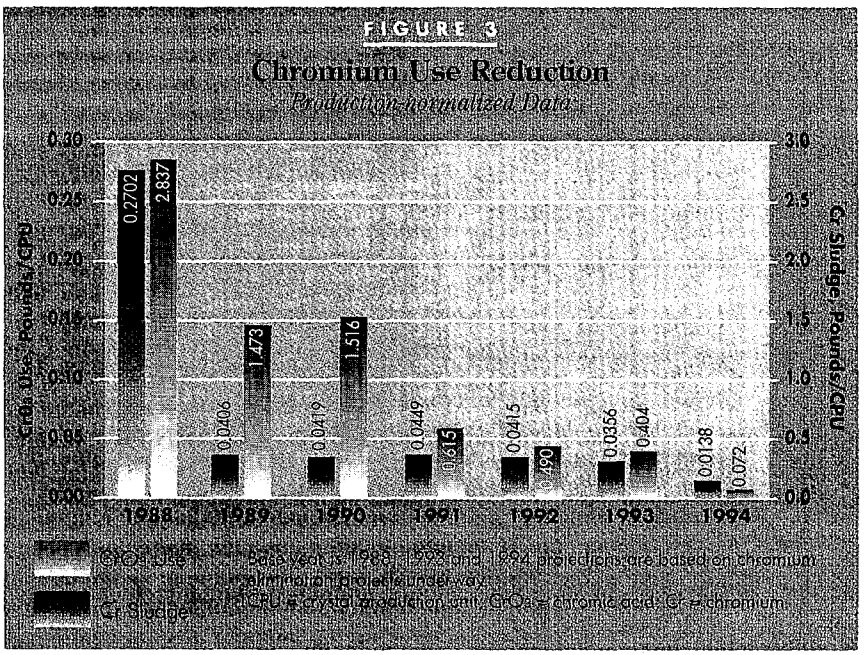
- Reduce hazardous air emissions 80 percent by the end of 1994.
- Eliminate the use of ozone-depleting chemicals (ODC) by the end of 1995.
- Reduce the generation of priority waste 50 percent by the end of 1996. (Priority waste includes hazardous waste and recyclable solid waste that is landfilled.)

Pollution prevention was selected as the preferred method for meeting these goals.

MEMC successfully completed several projects between 1989 and 1990 that provided significant cost savings and regulatory relief and, more importantly, helped convince plant-level managers that pollution prevention improves competitive strength. These early projects taught company managers that cultivating the internal culture necessary to achieve environmental goals is more important than the goals themselves. By combining environmental issues and personnel with manufacturing issues and personnel, MEMC was able to identify innovative solutions that addressed the concerns of both groups.

In 1991, MEMC developed production-based efficiency statistics to track such resources as electricity, water, chemicals and supplies, as well as emissions and waste generation. These statistics, an alternative to traditional cost accounting for measuring manufacturing performance, clearly show that product quality improvement cannot be achieved at the expense of resource effi-





ciency. True quality improvement means doing better with less.

In 1992, MEMC adopted specific resource efficiency goals targeting key resource inputs and wastestreams. It also set priorities and dates for eliminating certain toxic chemicals and hazardous wastes. Responsibility for achieving the goals was assigned to MEMC manufacturing managers. (Resource efficiency improvement goals and waste elimination projects are part of each corporate and manufacturing manager's annual performance review.)

To meet customer needs and remain competitive, MEMC must continuously improve its manufacturing technology. The phaseout of ODCs is a particularly important challenge.

The company had two options for replacing Freon 113 and methyl chloroform, also known as 1,1,1-trichloroethane or TCA, which are solvents used in the electronics industry for precision cleaning. The least disruptive and quickest way to eliminate the use of these substances is to replace them with non-ozone-depleting chlorinated solvents. After careful consideration, however, MEMC opted to replace these two ODCs with water-based manufacturing technology that eliminates the use of chlorinated organic solvents.

Waste from the new technology is nonhazardous, biodegradable and can be destroyed in conventional wastewater treatment systems. Development began in 1991, and the technology was installed in all MEMC manufacturing plants in 1992.

Between 1988 and 1990, MEMC also developed new manufacturing technology that eliminated most hexavalent chromium use and cut the generation of hazardous chromium hydroxide sludge by almost 50 percent. (Chromium hydroxide sludge is a byproduct of waste chromic acid treatment.) In 1992, the company identified additional technology that will allow it to eliminate the remaining use of hexavalent chromium and all sludge generation. Installation began early this year.

Plant-level Results

The MEMC plant in Spartanburg, S.C., in 1988 initiated several projects to eliminate unnecessary uses of ODCs and other chlorinated organic solvents. The projects included eliminating process steps, modifying vapor degreasers and other solvent-handling equipment, and tightening maintenance procedures. These efforts reduced emissions and the volume of solvent lost to hazardous waste.

In 1992, the plant installed water-based technology for polishing silicon wafers and cleaning packages. Water-based wafer polishing began in December of that year, and water-based cleaning of silicon wafer packaging began in April 1993. Since then, isopropyl alcohol has been the only organic solvent used at the plant.

Since 1988, the Spartanburg plant has eliminated 97.3 percent of production-normalized solvent air emissions and 99.8 percent of hazardous waste solvents (Figures 1 and 2). Product quality has remained constant.

Copper-based acid etchant formulas replaced chromium-based formulas at the Spartanburg plant in 1989. This manufacturing change allowed the plant to eliminate 85 percent of production-normalized chromic acid use and 49 percent of the chromium hydroxide sludge generated by treating chromic acid waste. Modified wastewater treat-

TABLE 1

Chromium Use Reduction

MEMC Spartanburg, S.C., Plant, 1988–1993

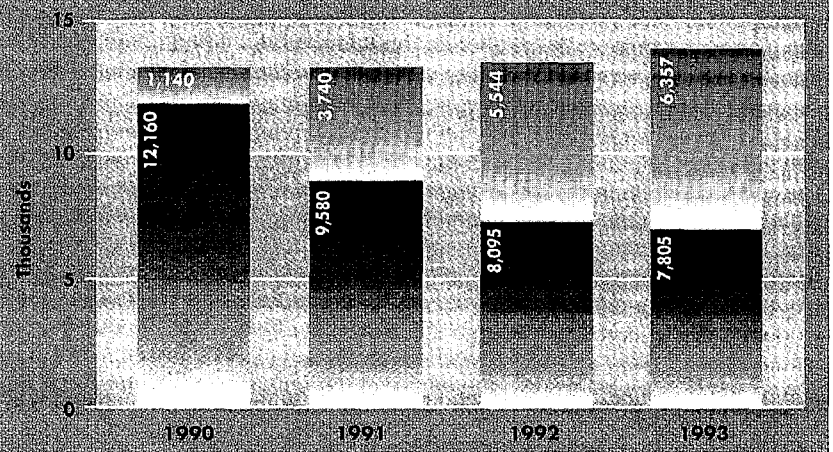
Item	Eliminated,[a] lbs/year	Percent Reduction[b] 1988 base year
Chromic acid use as CrO_3	5,060	94.9%
Hazardous chromium hydroxide sludge	54,600	97.5%

[a]Absolute data, assumes 1992 production volume and installation of chromium-free technology for manufacturing production by year-end 1993.
[b]Production-normalized data from Figure 3.

FIGURE 4

Nonhazardous Solid Waste

Annual Volume in Cubic Yards



First-quarter data expressed as annual volume-base year is 1990.
Recycled materials include office paper, cardboard, wood pallets, HDPE plastics, polystyrene, scrap metal, silicon, graphite and drums.

ment technology installed in 1991 further reduced the generation of sludge by 30 percent (Figure 3).

In February of this year, the company initiated a project to eliminate all metal salts in acid etchant formulas used for evaluating silicon crystal structure. This project will eliminate virtually all use of chromium in manufacturing operations and most of that used for quality assurance testing of silicon wafers (Table 1). The company hopes to eliminate all use of hexavalent chromium by the end of 1994.

The Spartanburg plant in 1990 also began a concerted effort to recycle nonhazardous solid waste, including office paper, cardboard, wood pallets, polystyrene, plastic packaging, scrap metal, silicon, spent graphite and used drums. Since then, it has increased recycling from 8.6 percent to 44.9 percent of total solid waste volume and reduced the volume of landfilled materials by 35.8 percent (Figure 4). Annual cost savings have exceeded $35,000, despite significant increases in landfill prices in 1991 and 1992.

Annual savings at the Spartanburg plant are expected to reach $1.63 million by the end of the year. Projected cost savings in 1994, assuming final installation of the chromium-free manufacturing technology this December, are $1.89 million (Figure 5). The payback period for capital expenditures for each of the three pollution prevention projects discussed is less than one year (Table 2).

Projected net savings in chemical costs and waste management expenses for 1994 (normalized to total production) are $34.82 per production unit. This represents a 3.48 percent reduction in total production costs since 1988.

Even more important than monetary savings, however, is regulatory relief. The reduction of ODCs and other chlorinated organic solvents cut by one-half the number of annual regulatory reports required under SARA Sec. 313. Eliminating hazardous waste solvents and substantially reducing the generation of chromium hydroxide sludge have allowed the plant to operate as a hazardous waste generator rather than a treatment, storage and disposal facility. And, when the chromium-free technology is completely installed, the plant's status will be downgraded from a large-quantity to small-quantity generator.

Eliminating chlorinated solvent air emissions has allowed the plant to avoid MACT requirements under the CAA Amendments' air toxics provision, and reducing VOC air emissions has ensured that the company will remain a minor air emission source. Of course these efforts also prevent employee exposure to toxic chemicals and byproducts and preclude the need for industrial hygiene monitoring. ■

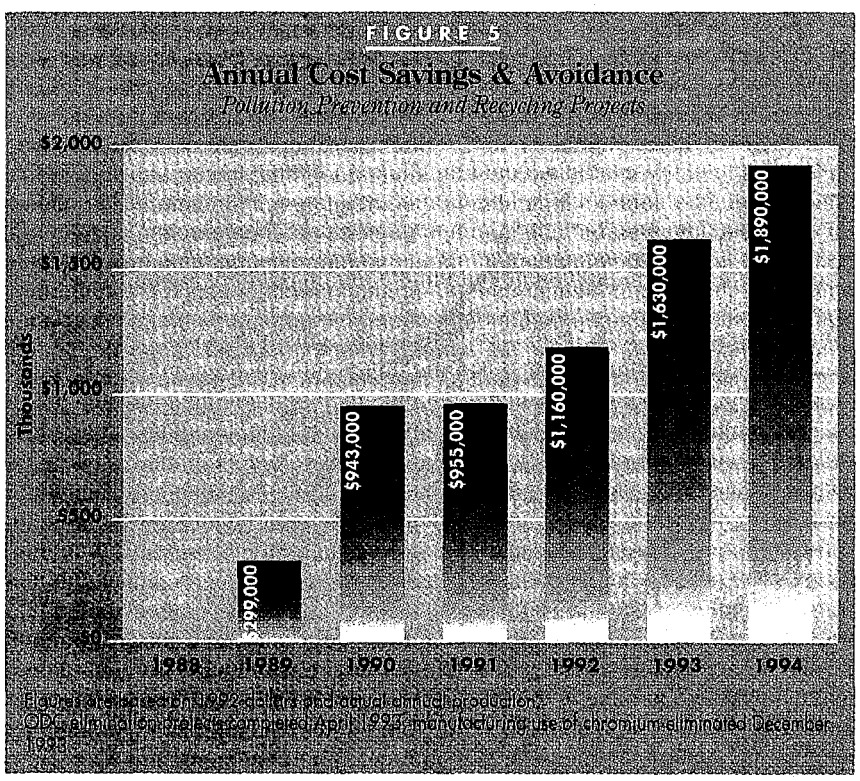
TABLE 2

Payback on Capital Expenditures for Pollution Prevention

MEMC Spartanburg, S.C., Plant, 1988–1993

Item	Total capital expenditure	Annual cost savings & avoidance[a]	Payback Period
Solvent use reduction[b]	$1,200,000	$1,610,000	0.75 years
Chromium use reduction[c]	140,000	174,000	0.80 years
Solid waste recycling[d]	20,000	52,900	0.38 years

[a]Net savings in chemical cost and waste management expense based on 1992 production volume, excluding product quality and yield improvement.
[b]Projects completed April 1993.
[c]Projects targeted for completion by year-end 1993.
[d]Projects completed first quarter 1993.



Paul S. Dickens *is a senior engineering specialist for environmental safety and health at MEMC Electronic Material's (St. Peters, Mo.) Spartanburg, S.C., plant.*

CASE STUDY

Waste Minimization and Stormwater Management Go Hand in Hand

By Andy Miller, Roger C. Ward and Rokus Euse

A cooling water recycle system and stormwater retention basin eliminate NPDES discharge and promote waste minimization at a brass foundry

A cooling water recycle system and an 18 million-gallon stormwater retention basin enabled a nonferrous metal foundry to eliminate its NPDES discharge and drastically reduce the volume of water required for plant operations, which involve the casting, milling and annealing of brass products.

Most process wastewater is treated with caustic to neutralize pH and promote metal hydroxide precipitation before being discharged to a POTW impoundment. Excluding accumulated sludge, the POTW impoundment can hold approximately 2.1 million gallons, which allows for a detention time of about two days. Effluent from the impoundment is pumped to the city sewer system at a rate of about 1 million gallons a day.

Before it was closed in 1992, the NPDES impoundment was used to treat less harmful wastestreams, including stormwater runoff and surface runoff from the immediate vicinity of the pond; cooling water from the casting shop; boiler plant waste; noncontact cooling water from the billet heaters, mills, degreasers, annealer, generator and furnaces; and minor process wastes, such as those from quench overflow pits and annealer sumps.

Caustic was added immediately upstream of the impoundment. Solids precipitated out as hydroxides before effluent discharge to a nearby creek. The 2.5 million-gallon impoundment allowed for a detention time of about 30 hours. Solids from both the POTW and NPDES impoundments were stored in a sludge impoundment.

New permit limits. Over the years, the company maintained an excellent record of regulatory compliance. In October 1989, however, state regulatory agencies issued a substantially revised NPDES permit. While previous limits were based on treatment technology standards, the new ones were based on stream quality standards. They were considerably more stringent and, the company believed, unachievable.

After ruling out end-of-pipe treatment to meet the new permit limits, the company decided to replace the NPDES impoundment with a cooling water recycle system. A facility planning study verified the feasibility of using such a system and enabled the project team to establish basic design criteria.

A sludge management plan also was developed to evaluate remediation options for all three impoundments, including whether to retrofit them for stormwater detention or close them in place. Because the compliance deadline was approaching quickly, the project team opted to construct a new stormwater retention basin.

Characterization of the existing production, pretreatment and treatment facilities began with the development of water and wastewater flow schematics for the various production areas.

Water is supplied to the facility by two sources — a well field less than a mile east of the plant site that supplies an average of 2.5 million gallons per day and the city water supply.

Groundwater is relatively hard (about 370 milligrams per liter as calcium carbonate) and has an average temperature of about 60 degrees Fahrenheit. Because of groundwater contamination (by others), the well water contains ammonia-nitrogen, benzene and trace concentrations of trichloroethene and 1,1,1-trichloroethane.

The city water supply initially provided only a small fraction of the facility's total water supply — about .18 million gallons per day. It was used primarily for sanitary supply, and small amounts were used as process water.

To improve its understanding of overall water use at the site, the project team conducted a comprehensive evaluation of both sources that considered precipitation and runoff, steam production and fate of condensate, evaporation losses, and discharge data for the NPDES and POTW basins. Flow estimates based on expected discharges agreed closely with measured flows from the two impoundments (see table).

Of particular importance in designing the cooling water system was the overall thermal load picked up by the water

stream as it flowed through the plant. Overall thermal pickup for wastewater discharged to the POTW and NPDES impoundments was calculated using historical flow data, peak monthly temperature data and measurements taken during a seven-day period. Results revealed a thermal pickup of 419 million Btu per day for the NPDES impoundment and 158 million Btu per day for the POTW impoundment. These loads were then used to make a preliminary assessment of various cooling water recycle strategies.

It became apparent that several miscellaneous wastestreams, including those from the annealing sump and quench overflow pits, were not amenable to recycling and would have to be re-routed from the NPDES impoundment to the POTW impoundment. A review of the existing facilities also revealed that cooling water from the casting area was already recycled using dedicated cooling towers, and that the past practice of discharging portions of specific cooling water streams to the picklers effectively reduced the thermal load.

Sampling and analysis revealed that total solids, pH, calcium, iron, total hardness, alkalinity and conductivity were virtually the same for the cooling and raw water streams, indicating that no significant contamination of the cooling water would occur during reuse. Sampling and analysis also re-

Overall Water Balance

Total Expected Discharge (Annual Average Basis)

Well Water	2.80 mgd
City Water	0.18 mgd
Storm Runoff	0.08 mgd
Evaporation	-0.16 mgd
	2.90 mgd

Actual Discharge (Annual Average Basis)

POTW Impoundment	0.90 mgd
NPDES Impoundment	2.00 mgd
	2.90 mgd

mgd = million gallons per day.

vealed significant solids buildup in the existing cooling towers, indicating the need for continuous blowdown in the new system. High concentrations of zinc, copper and oils meant that quench overflow pit discharge would have to be re-routed from the storm sewer to the process sewer.

Recycle strategies. After evaluating several recycling strategies, the project team decided that sending recycled water back to the water supply reservoir would be more practical than returning it to individual operations. Because the reservoir supplies both cooling and process systems, this arrangement automatically would result in a large blowdown from the recycle system, thus minimizing the accumulation of dissolved solids and scaling. The strategy also would result in a relatively simple water supply scheme, because existing production wells could feed the reservoir as needed.

To explore the strategy further, the project team conducted thermal simulations using four configurations. Based on the results of these tests, the team decided to collect individual spent cooling water streams and convey them to a new cooling tower system. This configuration was selected because it could provide cooling water at the right temperature and reliable water quality (due to grit removal in the retention basin).

The project team decided that sending recycled water back to the water supply reservoir would be more practical than returning it to individual operations.

Retention basin strategies. The only remaining question was stormwater discharge. Because the new NPDES permit limits were believed to be unachievable, the project team decided stormwater should be captured via a retention basin and slowly discharged to a proposed wastewater pretreatment system, the municipal sewer system or the new cooling water recycle loop. Because stormwater discharges usually occur when a POTW is already at peak capacity, the city would not allow direct discharge to its sewer system, nor would it allow stormwater to be combined with process water before pretreatment for dis-

charge to the sewer system. These two options, therefore, were discarded in favor of discharging directly to the cooling water recycle loop.

The basin was sized, based on a detailed hydrologic investigation, to contain runoff from a 100-year, 24-hour rainfall event. Of the basin's 18 million-gallon total volume, only 6.6 million gallons was considered to be a "useful" volume, after which stormwater would back up into the storm sewer. Concrete, clay and three synthetic liner materials, including high-density polyethylene (HDPE), Hypalon and PVC, were evaluated. HDPE was selected because of its low cost, durability and impermeability.

After installation. Construction of the cooling water recycle system began in the fall of 1991. Startup began in early winter, and the system was fully operational by March 1992. Construction of the stormwater retention basin occurred through the spring of 1992, and operations began in late June.

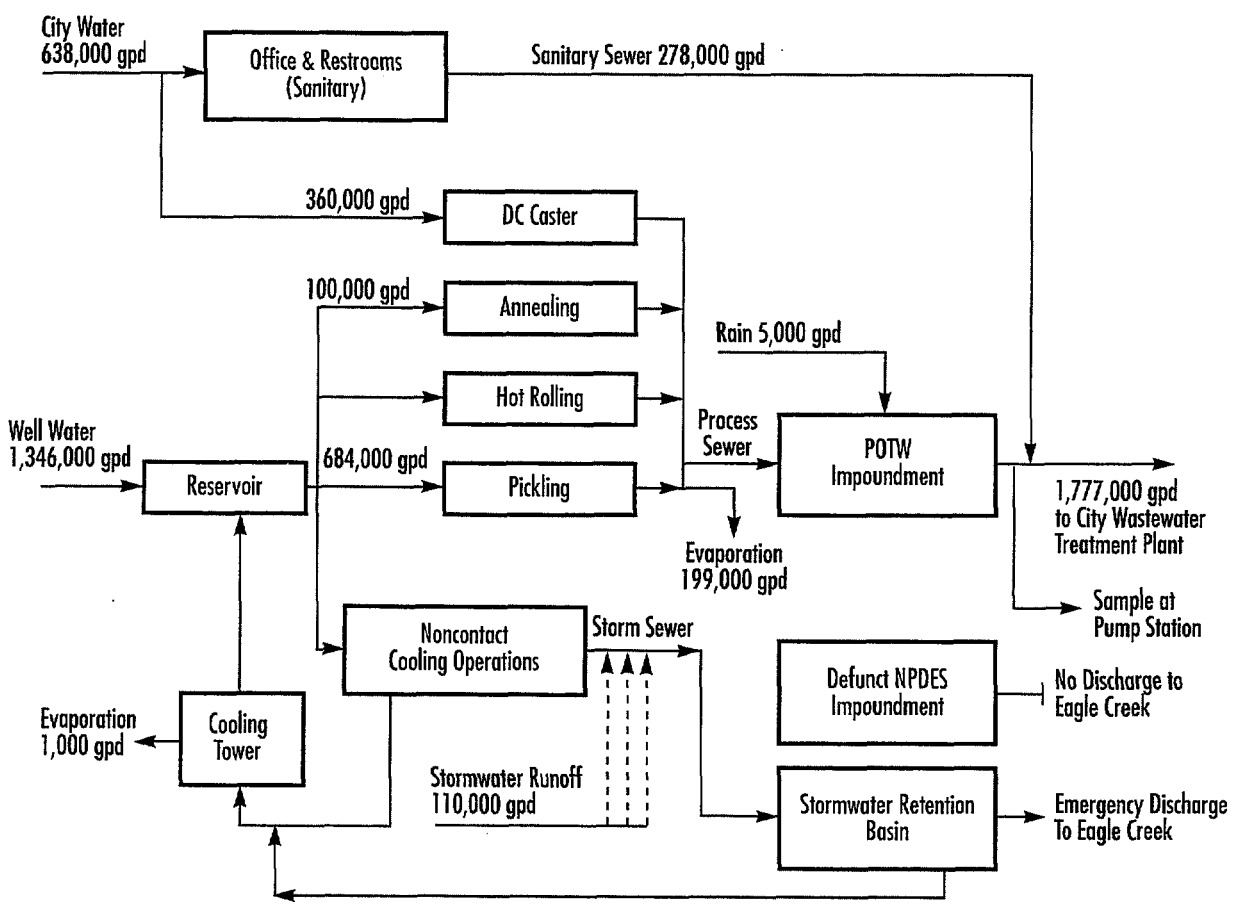
As anticipated, the cooling water recycle and stormwater reuse system has allowed the facility to eliminate its NPDES discharge and drastically reduce the total volume of water required for plant operations (see figure). Although the use of city water increased, a more dramatic decrease in the use of well water has resulted in an overall reduction of approximately 1 million gallons per day.

The company also has reduced the amount of caustic required to treat effluent. The total metals loading remained relatively constant, but decreases in well water consumption substantially reduced the amount of calcium carbonate sludge generated, which, in turn, has resulted in substantial cost savings.

Other, nonquantifiable benefits also have been realized. Stormwater reuse exempts the facility from participating in the new NPDES stormwater permitting program, and reduced caustic use has increased worker safety and reduced the potential for regulatory compliance problems due to slug discharges. Moreover, a reduction in solids has decreased the potential for future waste disposal liabilities.

Andy Miller *is a project engineer, and* **Roger C. Ward** *is vice president in the Indianapolis office of HNTB Corp. (Kansas City, Mo.).* **Rokus Euser** *was manager of environmental and energy services at the foundry. He is now retired.*

Overall Water Use and Wastewater Discharge with New Cooling Water Recycle System



The Net-Gross Issue: Who Pays To Remove Intake Pollutants?

When an industrial facility uses surface or groundwater in a process, that untreated water contains pollutants from both natural and manmade sources. Accounting for these "intake" pollutants in National Pollutant Discharge Elimination System (NPDES) permit limits has become a pressing issue—commonly referred to as the "net-gross issue." If water quality–based limits are applied on a "gross" basis to the total amount of pollutant in the discharge, point source dischargers whose operations use large volumes of water could be required to assume technical and economic burdens for pollution problems they did not create.

Dischargers required to meet water quality–based limits on a gross basis face difficulties in designing and operating an adequate treatment system, and risk permit violations. Although many treatment technologies operate effectively over a range of pollutant concentrations, dischargers need accurate information on, and the ability to control, the range and variability of intake pollutants. If intake pollutant concentrations cause the influent to the discharger's treatment system to exceed the system's capacity, a permit violation will result.

Applying limits on a gross basis also leads to economic inequities. A discharger required to meet gross limits may have to increase the size of its treatment facilities or install treatment facilities that would not be required otherwise.

Requiring point source dischargers to treat intake water may undercut pollution prevention techniques. Source reduction, one of EPA's preferred pollution prevention techniques, by definition can be applied only by the original discharger of the pollutant. Dischargers required to control intake pollutants will have to remove and dispose of these pollutants through conventional treatment methods, which could have an impact on other environmental media.

Applying limits on a gross basis also may undercut compliance with water quality standards. Because gross limits impose responsibility on some point source dischargers for treating and removing intake pollutants, pollution from other point or nonpoint sources may continue unchecked. Thus, the overall pollutant load to the water body may not decrease sufficiently to meet the water quality standard. Only when all pollutant sources are identified and regulated appropriately will it be possible to ensure the attainment of the standard.

Great Lakes Guidance May Decide Issue

The net-gross issue has come to the forefront of EPA's proposed Water Quality Guidance for the Great Lakes System. In this guidance, EPA proposes to articulate a policy on how NPDES permit writers should account for intake pollutants when setting water quality–based limits. The proposed guidance states that point source discharges are responsible for intake pollutants in their water source and can be required to remove these pollutants to attain the applicable water quality standard.

Point source dischargers may believe that a permit writer's authority to regulate effluents on a gross basis is inconsistent with the NPDES permit provisions of the Clean Water Act. These provisions apply only to the "addition" of pollutants to navigable waters from point sources. Several court cases, beginning with *Appalachian Power Company* v. *Train* (1977), support the argument that only the pollutant "added" by their own operations can be regulated.

Point source dischargers whose operations use large volumes of water could be required to assume technical and economic burdens for pollution problems they did not create.

Despite its requirement that dischargers remove intake pollutants, EPA has proposed authorizing permit writers to determine if an effluent, when evaluated on a gross basis, does not have the "reasonable potential to exceed" water quality standards and, thus, does not warrant any limit. Permit writers would make this determination only if the discharger could show that it:

- draws all of its intake water from the same water body into which the discharge is made,
- does not discharge an additional amount of the pollutant in question,
- does not alter the intake pollutant chemically or physically in a manner that would cause adverse impacts on the receiving water,
- does not increase the concentration of the pollutant at the edge of any mixing zone, and
- does not cause adverse impacts due to the timing and location of the discharge.

Dischargers that cannot demonstrate that they meet these criteria could seek relief from gross limits through other regulatory mechanisms, including the total maximum daily load and waste load allocation process, temporary variances from water quality standards, changes in the designated use of the receiving water, and site-specific criteria modifications.

EPA recognizes that not all of these mechanisms will be available in every jurisdiction, nor will they necessarily provide the relief needed. In addition to these preferred alternatives, EPA also describes other approaches to the net-gross issue. Several of these alternatives would allow permit writers to include a "credit" for intake pollutants in their water quality–based effluent limits.

The debate over EPA's net-gross proposal will be heated. It is likely, however, that EPA's resolution of the issue in the Great Lakes guidance will affect the NPDES program nationwide.

Kristy Bulleit *is a partner with the law firm of Hunton & Williams in Washington, D.C.*

WASTE ELIMINATION - CHALLENGE OF THE 1990s

Paul S. Dickens, P.E., R.E.M.
Senior Environmental Engineer
MEMC Electronic Materials, Inc.

The 1980s changed forever the management of manufacturing industry. Companies that did not adopt a focus on product quality and customer service lost in the market place. The 1990s hold similar dramatic change. Environmental issues increasingly impact business decisions. Negative public perception and increasingly stringent environmental laws will put companies that generate chemical emissions and hazardous waste at a competitive disadvantage.

This paper describes the approach of MEMC Electronic Materials, Inc. to management of environmental issues. "Waste elimination" and "resource efficiency" are discussed as tools to improve the competitive advantage of manufacturing industry. These concepts not only address timely environmental issues, but can be an important internal source of company funds. An expanded role is defined for the environmental professional working in industry. Results of MEMC waste elimination projects are discussed. The MEMC approach to environmental issues is a model for other companies considering waste elimination efforts.

WASTE MANAGEMENT AND ENVIRONMENTAL LAWS

The Resource Conservation and Recovery Act of 1976 [U.S., 1976] (RCRA) established a hierarchy for the management of solid and hazardous waste. Waste source reduction is the preferred management practice followed in order of preference by on-site waste recycling, off-site waste recycling, waste treatment, and land disposal. The 1984 Hazardous and Solid Waste Amendments [U.S., 1984] (HSWA) established new requirements that eliminate land disposal as an option for most chemical waste generated in the United States. The Land Ban provisions of HSWA [U.S, 1991a] substantially increase the cost of managing hazardous waste. The Toxicity Characteristic Leaching Procedure promulgated in March 1990 increased three-fold the volume of industrial waste defined as hazardous and subject to RCRA regulation [U.S. EPA, 1990; BNA, 1990a].

Title III of the 1986 Superfund Amendments and Reauthorization Act (SARA) requires public reporting of chemical use, chemical emissions, and hazardous waste generation at industrial plants [U.S., 1986]. The Community Right-to-Know provisions of SARA, more than any other environmental regulation, are driving United States industry to eliminate toxic chemical use. The Pollution Prevention Act of 1990 [U.S., 1990a] (PPA) requires public reporting by manufacturing industry of their effort towards chemical emission reduction and the reduction and recycling of hazardous waste. The first year for PPA waste reduction reporting is 1991. Several states have passed laws requiring industrial plants to submit plans for hazardous waste minimization and toxic chemical use reduction [Scagnelli, 1991].

Air toxics provisions of the 1990 Clean Air Act Amendments [U.S., 1990b] (CAA Amendments) require "Maximum Achievable Control Technology" (MACT) for air emissions of 189 commonly used industrial chemicals. Control requirements for emissions of volatile organic compounds (VOCs) at industries in air quality

non-attainment areas are strengthened. Enforcement of MACT and new VOC emission standards under the CCA Amendments begins in 1995. The CCA Amendments also establish a nationwide permit system for air emission sources with substantial civil and criminal penalties for violation of air emission standards. Many industrial facilities in the United States previously exempt from air quality laws will require permits and air emission controls under the CCA Amendments.

The electronics industry is a large user of chlorofluorocarbons (CFCs) and methyl chloroform (1,1,1-trichloroethane). The 1990 Clean Air Act Amendments incorporate CFC and methyl chloroform phase-out provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer [U.N., 1987]. World-wide production of CFCs will end by the year 2000. World-wide production of methyl chloroform will end by the year 2005. Production of methyl chloroform in the United States is prohibited after 2002. Meanwhile, the cost of these chemicals has greatly increased.

The management of wastewaters is also undergoing change. Section 304(1) of the 1987 Clean Water Act Amendments [U.S., 1987] has forced many industries in the United States to install new and expanded wastewater treatment facilities. Having the greatest impact are toxicity testing of wastewater effluents and revision of state water quality standards for toxic chemical pollutants. Some industrial operations will be seriously impacted by storm water discharge permits required in 1992 [U.S., 1991b]

Most industries cannot operate without access to local sanitary landfills for disposal of trash and other non-hazardous solid waste. However, many communities in the United States face a shortage of landfill capacity [Cook, 1988; Newsweek, 1989]. Reliable and affordable disposal of non-hazardous solid waste is a growing problem. Proposed Federal standards for sanitary landfills will further increase the cost to dispose of non-hazardous solid waste [U.S. EPA, 1988]. Federal laws to mandate solid waste recycling and regulate industrial non-hazardous waste disposal are proposed [U.S. House, 1989; U.S.Senate, 1989a & b]. Similar laws are already in effect in some states and local communities [Florida, 1989; South Carolina, 1991].

Public awareness of environmental issues has grown in the United States, particularly at the state and local level. Manufacturing plants perceived as "dirty" are no longer tolerated despite the jobs they create. Land use and zoning laws are increasingly used to block new industries and industry expansion. Third-party legal challenges to wastewater, air, and hazardous waste permits are common. Citizen group monitoring of industry compliance with environmental laws is on the rise. Comprehensive environmental initiatives such as California's "Big Green" [BNA, 1990b] and the Massachusetts Toxics Use Reduction Act [Massachusetts, 1989; BNA, 1991a] are gaining public support.

Expenditures on environmental protection in the United States increased from under $25 billion per year in 1972 to $100 billion per year in 1990, totaling 1.5 to 1.7 percent of the country's gross national product (GNP) [BNA, 1991b]. A large portion of this cost is borne by industry for waste management and end-of-pipe pollution controls. To fully implement existing laws, expenditures for environmental protection are expected to increase to 3.0 percent of GNP by the year 2000 with industry paying an ever larger share.

There are significant financial, regulatory, and public relation incentives for United States industry to adopt a positive action approach to environmental issues. Companies that eliminate chemical emissions and eliminate the generation of solid and hazardous waste obtain a market advantage. These companies are no longer hostage to changing environmental laws and negative public perception. These companies can devote capital to new products and improved product quality rather than to waste management and end-of-pipe pollution controls. These companies make positive contribution to both economic growth and improved environmental protection [Porter, 1991].

WASTE ELIMINATION

"Waste elimination" is the elimination of chemical emissions and the elimination of solid and hazardous waste generation by changes in product design and manufacturing technology. It is an alternative to waste management for compliance with environmental laws. Waste elimination goes by other names such as "waste minimization" and "pollution prevention" [U.S. EPA, 1991]. However, for industry the term "waste elimination" is preferred for it best describes the goal to be achieved: eliminate the generation of waste. Waste elimination is driven by two ideas: (1) waste management is an unproductive drain on company resources, and (2) companies that eliminate chemical emissions and hazardous waste obtain a market advantage.

Waste management refers to end-of-pipe systems for treating air emissions, wastewater, and hazardous waste and for disposing of solid and hazardous waste residuals generated by waste treatment. As environmental regulations become more stringent, the cost of unproductive waste management expenditures increases. Because waste management requirements are driven by environmental laws, companies have little control over waste management cost. In contrast, waste elimination avoids unproductive waste management cost. It conserves company funds for productive investment in new products and improved product quality. Waste elimination is an internal source of company funds. It is an opportunity for industry to remove itself from regulation under environmental laws. Because it conserves company funds for productive investment, waste elimination contributes to a company's competitive strength.

The relationship of waste elimination to a company's competitive strength is illustrated with the concept of "resource efficiency". Resource efficiency is the ratio of the resource content of a manufactured good to the resources used to produce that good and to manage and dispose of waste from the manufacturing process. The goal of waste elimination is to improve resource efficiency. Resources include energy, labor, water, air, raw materials, manufacturing chemicals, and supplies. Waste includes heat, wastewater, air emissions, hazardous waste, unused materials, spent chemicals, used packaging materials, and spent and unused supplies. Waste also includes the energy, labor, and materials expended for waste management and end-of-pipe pollution controls.

Resource efficiency is a direct measure of a company's competitive strength. The generation of waste is at the expense of resource efficiency. Expenditures for waste management further decrease resource efficiency. In contrast, the benefits of waste elimination are two-fold; resources are not lost to waste, and resources are not expended to manage and dispose of that waste. The 1990's require a new attitude on the part of industry towards waste. Waste must be .

viewed as evidence of lost resources. A fundamental requirement for any world-class company is to determine its resource efficiency and continuously improve it.

CULTURE CHANGE

There are many barriers to waste elimination within manufacturing industry. These include product specifications, capital resources, and environmental regulations that focus on pollution control. The greatest barrier, however, is management attitude. Management attitude refers to a company's culture and how it makes business decisions.

Waste elimination requires movement away from reliance on end-of-pipe waste management systems to comply with environmental laws. Waste elimination requires a systems approach to manufacturing management that considers environmental issues from the beginning of product design and manufacturing technology development. It requires a commitment of resources normally devoted to production. Waste elimination requires questioning product specifications that result in the generation of waste. It often results in a higher capital cost for manufacturing facilities in order to avoid waste management expense.

The goal of manufactured product quality is zero defects. This was a radical idea in 1980 that is now accepted as a requirement for the competitive survival of manufacturing industry [Deming, 1986]. The goal of product design and manufacturing technology in the 1990s should be zero waste. Negative public perception and increasingly stringent environmental laws will make zero waste a requirement for United States industry by the year 2000. The goal of zero waste may not be fully achieved, but it is a goal that should be considered in business decisions.

Waste elimination is total quality management applied to environmental issues [Bemowski, 1991; Stratton, 1991]. Like quality improvement, the power of waste elimination is in small changes that over time result in large reductions in chemical emissions and the generation of solid and hazardous waste. Like quality improvement, the financial benefits of waste elimination may not be immediately evident but build over a period of years. The key to both is continuous change. Waste elimination is a simple idea. However, its implementation within a manufacturing organization can be difficult. Successful waste elimination requires the ownership and commitment of all company employees. This ownership is the source of creative ideas for product design and manufacturing technology change. Everyone within a company must be convinced that waste elimination builds competitive advantage. Company management must show by example their honest support.

ROLE FOR THE ENVIRONMENTAL PROFESSIONAL

End-of-pipe waste management systems (and the staff to run them) evolved at most industrial plants as environmental laws were established during the 1970s and 1980s. The "end-of-pipe" approach was the most expedient way to comply with changing laws. Every United States industry established an environmental control department to manage their regulatory compliance and waste management systems. These departments are staffed with environmental professionals: engineers and scientists with backgrounds in environmental science, pollution control technology, and environmental law. Unfortunately, these departments

tend to communicate with manufacturing personnel only in response to problems or when needed to obtain environmental permits. They typically have little or no contact with marketing and research groups. The end-of-pipe approach also discourages "ownership" of waste elimination by marketing, manufacturing, and research personnel. The fact that "someone else handles it" is a barrier to their understanding of waste management problems and opportunities.

Progressive industries are dismantling vertically-integrated manufacturing, research, and marketing groups in favor of horizontally-integrated "teams." The team approach is an opportunity for the environmental professional to take an active role in promoting waste elimination efforts. These individuals have the best understanding of the sources of waste and of waste management cost. The challenge to the environmental professional is four-fold: (1) effectively communicate information on waste generation and waste management cost; (2) identify opportunities for waste elimination including the financial and environmental benefits to be gained; (3) participate in waste elimination project teams with manufacturing, research, and marketing personnel; and (4) track and provide timely reporting of waste elimination results. This role is one of educating, cheerleading, and keeping score. It requires developing a strong knowledge of manufacturing technology and product specifications. The goal of the environmental professional is to incorporate waste elimination in their company's business decisions. This occurs when the priority given to waste and resource efficiency is equal to that given issues of quality, customer service, and finance.

MEMC ELECTRONIC MATERIALS, INC.

MEMC Electronic Materials, Inc. manufactures polished and epitaxial silicon wafers. Silicon wafers are the substrate, or base, on which microelectronic circuits (microchips) are built. MEMC is a worldwide producer of silicon with manufacturing plants in the United States, Europe, and Asia. The company's 1990 sales were over $400 million. Fifty-eight percent of these sales were outside the United States. MEMC's customers are the manufacturers of logic and memory microchips used in everything from computers and consumer electronics to automobiles and airplanes. MEMC's 1990 share of world silicon wafer sales was 20 percent.

Proactive Waste Management Strategy

MEMC has evolved to a proactive strategy for managing chemical emissions and hazardous waste generated as by-products of silicon manufacturing. The focus of the strategy is waste elimination: changes in product design and manufacturing technology that reduce or eliminate chemical emissions and the generation of solid and hazardous waste. The result of these changes over time is a large reduction in unproductive expenditures for waste management and end-of-pipe pollution controls.

The MEMC waste management strategy has several components. The company has established definitive environmental goals. These are: (1) reduce hazardous air emissions by 80 percent by year-end 1994; (2) eliminate use of ozone depleting chemicals by year-end 1995; and (3) reduce generation of priority waste by 50 percent by year-end 1996. MEMC's definition of priority waste includes hazardous waste and recyclable solid waste that is landfilled. The base year for MEMC's goals is 1988. Where possible, the goals are to be

achieved through investment in manufacturing technology change rather than new end-of-pipe pollution controls.

MEMC targets efforts towards waste elimination by establishing task groups with specific waste reduction goals and deadlines. These task groups include environmental, safety, manufacturing, engineering, and research personnel. MEMC encourages ownership of environmental goals by stressing the long-term cost benefits to be gained. MEMC provides resource commitment for waste elimination by holding key manufacturing managers accountable for progress towards the company environmental goals.

Results

The MEMC manufacturing plant in Spartanburg, South Carolina has completed a number of waste elimination projects including process elimination, chemical substitution, substituting mechanical for chemical methods, modifying equipment and maintenance procedures, projects for quality and yield improvement, and solid waste recycling. Details for these projects are presented elsewhere [Dickens, 1991a & b]. The following highlights major results.

Chromic Acid. Prior to 1988, the only available acid etchants for evaluating crystal structure in silicon were based on chromic acid. Waste chromic acid and sludge from chromic acid treatment are regulated as hazardous waste. In 1988, MEMC developed a new etchant for evaluating silicon based on copper salts rather than chromium [Chandler, 1990]. The copper-based etchant does not create a hazardous waste when treated. MEMC also determined that a process called "rod etching", which accounted for 80 percent of chromic acid use, was unnecessary. Rod etching was eliminated. The copper-based acid etchant for evaluating silicon crystal structure was substituted for chromium-based etchants on all but one silicon product. An etchant with a lower chromium content was substituted for the one product still requiring chromic acid. Results are outlined in Table I. During a period when manufacturing output increased by 10 percent, 96 percent of chromic acid used was eliminated by manufacturing technology change.

Table I Chromic Acid Eliminated by Manufacturing Technology Change; MEMC Spartanburg, S.C. Plant

Item	1988	1989
Chromic acid use, lbs as CrO_3	5,490	210
Manufacturing production[a]	1.00	1.10
Chromic acid use eliminated, lbs as CrO_3		5,830

a - Manufacturing capacity is proprietary. 1988 assigned a value of 1.00 .

Chromium Treatment Sludge. Table II outlines MEMC's reduction in chromium treatment sludge generation. Manufacturing technology changes to eliminate chromic acid use allowed changes in waste treatment technology that further reduced the generation of chromium treatment sludge. Between 1988 and 1991,

the MEMC Spartanburg, S.C. Plant eliminated 53,800 lbs/year of chromium treatment sludge. This is an overall reduction of 81 percent. In addition, the chromium content of the sludge was reduced ten-fold from 47,000 parts-per-million (ppm) by weight to 6200 ppm.

Table II Chromium Treatment Sludge Reduction, 1988 - 1991; MEMC Spartanburg, S.C. Plant

Item	Value
Baseline chromium sludge generation (1988), lbs/year	66,700
Chromium sludge eliminated:	
Manufacturing technology change[a], drums/year	73
lbs/year	35,850
Waste treatment technology change[b], drums/year	42
lbs/year	17,950
Total, drums/year	115
lbs/year	53,800
Annual cost eliminated:	
Process chemicals[a]	$ 27,900
Personnel protective equipment[a]	16,800
Waste treatment chemicals[a,b]	4,800
Off-site waste transportation and disposal[c]	16,700
Off-site treatment to meet Third-Third Land Ban[c]	25,900
Hazardous waste disposal tax[d]	3,000
Total	$ 95,100

a - Elimination of Rod Etching process; substitution of copper-based for chromium-based acid etchants.
b - Modified treatment chemical recipe for mixed copper and chromium-based acid etchants.
c - Rates effective August 1990.
d - State tax effective July 1990.

Mixed Acid and HF Air Emissions. Table III outlines waste elimination results for a series of quality and yield improvement projects related to preparing silicon samples for physical and chemical property tests. The most significant project involved substituting mechanical methods for a former chemical step using a mixed acid etchant containing hydrogen fluoride (HF). This alone eliminated 76,500 lbs/year of mixed acid etchant use and acid waste generation. The quality improvement projects, together with elimination of the rod etching

process described above, eliminated 34.5 percent of plant-wide, process air emissions of HF at the MEMC Spartanburg. S.C. plant. The large reduction in HF air emissions was achieved solely by manufacturing technology change. No new air pollution controls were installed.

Table III Acid Use and Hydrogen Fluoride (HF) Air Emission Reduction, 1988 - 1991; MEMC Spartanburg, S.C. Plant

Item	Value
Mixed acid etchant use eliminated, lbs/year	101,210
HF air emission eliminated, lbs/hour	0.105
Percent of plant-wide process HF emissions	34.5
Annual cost eliminated:	
Process chemicals	$ 52,630
Waste treatment chemicals	1,430
Total	$ 54,050

Ozone Depleting Chemicals. Freon 113 (trichlorotrifluoroethane) and methyl chloroform are ozone depleting chemicals. They are common solvents used in the electronics industry for precision cleaning of semi-conductor materials and packaging. At the MEMC Spartanburg, S.C. plant, Freon 113 was used to clean containers called "tote pans." These tote pans were used for temporary storage of polished silicon wafers between cleaning and inspection steps. Freon 113 was also used to clean plastic cassettes. The plastic cassettes are a protective device used to carry silicon wafers between manufacturing steps. Methyl chloroform was used in one of several proprietary steps for cleaning raw materials associated with silicon crystal production.

Tote pan cleaning was eliminated by switching to a "just-in-time" product flow that eliminated the temporary storage of silicon wafers. The need for solvent cleaning of plastic cassettes was eliminated by changing the flow of cassettes through manufacturing steps. The cassettes are now cleaned using soap and water. MEMC developed special techniques for the clean handling of raw materials associated with silicon crystal production. These techniques eliminated the need for methyl chloroform degreasing of raw materials. An aqueous-based cleaner was substituted for the methyl chloroform cleaning step.

Table IV outlines the results of manufacturing technology change to reduce ozone depleting chemical use between 1988 and 1991. The MEMC Spartanburg, S.C. plant eliminated process steps involving 40.6 percent of Freon 113 use and 12.5 percent of methyl chloroform use. The changes reduced air emissions of Freon 113 by 42.0 percent and air emissions of methyl chloroform by 15.6 percent. The changes also eliminated generation of 5400 lbs/year of hazardous waste solvent.

Table IV Freon 113 and Methyl Chloroform Use Reduction, 1988 - 1991; MEMC Spartanburg, S.C. Plant

Item	Value
Freon 113:	
Use eliminated, lbs/year	88,300
percent of plant-wide use	40.6
Air emissions eliminated, lbs/year	85,300
percent of plant-wide emission	42.6
Hazardous waste eliminated, lbs/year	3,800
percent of plant-wide waste	23.6
Methyl Chloroform:	
Use eliminated, lbs/year	25,300
percent of plant-wide use	12.5
Air emissions eliminated, lbs/year	23,700
percent of plant-wide emission	15.6
Hazardous waste eliminated, lbs/year	1,600
percent of plant-wide waste	9.0
Annual cost eliminated:	
Process chemicals	$ 136,400
Ozone depleting chemical excise tax	100,500
Waste solvent disposal	600
Total	$ 237,500

Solid Waste Recycling. In 1990, the MEMC Spartanburg, S.C. plant experienced a a large cost increase for non-hazardous solid waste disposal due to increased sanitary landfill fees. In response, the plant undertook a solid waste study. The purpose of the study was two-fold: (1) establish a baseline generation and composition for non-hazardous solid waste generated, and (2) identify opportunities to reduce the volume of non-hazardous solid waste landfilled. Waste cardboard and office paper were found to be 30 percent of the plant trash volume landfilled. Waste wood pallets and skids were 8 percent. Various waste polyethylene and polystyrene packaging materials were an additional 8 percent. Recycling of waste cardboard, office paper, and wood pallets was implemented. These recycling efforts reduced the volume of plant trash landfilled by 31.3 percent and avoid more than $14,400 per year in landfill disposal cost. The total volume of non-hazardous solid waste landfilled (plant trash, wastewater treatment sludge, and construction debris) was reduced by 21.2 percent.

New Technology

The waste elimination projects completed at the MEMC Spartanburg, S.C. plant are modifications to existing technology. These projects are initial steps towards MEMC's company environmental goals. To achieve its goals, MEMC is developing the next generation of silicon manufacturing technology. This development is a partnership with MEMC's major customers and suppliers. Requirements for the new technology include: (1) eliminate chlorinated solvent use, particularly use of ozone depleting chemicals; (2) eliminate or reduce process related emissions to air and water; (3) eliminate one-time-use product and material packaging; and (4) improve first pass and total product yield.

SUMMARY

The 1990s require a change in manufacturing industry's attitude towards waste. Generation of waste and associated management cost are a liability. Companies that eliminate waste conserve resources for productive investment in new products and improved product quality. These companies make positive contribution to both economic growth and improved environmental protection. The role of the environmental professional working in industry is to foster a waste elimination culture. This occurs when the priority given to waste and resource efficiency is equal to that given issues of quality, customer service, and finance.

MEMC Electronic Materials, Inc. is actively pursuing waste elimination as an alternative to waste management for compliance with environmental laws. Between 1988 and 1991, the MEMC plant in Spartanburg, S.C. eliminated by manufacturing technology change:

- 96 percent of chromic acid use.
- 81 percent of hazardous chromium treatment sludge generation.
- 34.5 percent of plant-wide, process air emissions of hydrogen fluoride.
- 40.6 percent of Freon 113 use and 42.0 percent of Freon 113 air emissions.
- 12.5 percent of methyl chloroform use and 15.6 percent of methyl chloroform air emissions.
- more than $380,000 per year in unnecessary process chemical and waste management cost.

Solid waste recycling implemented in 1990 reduced the volume of plant trash landfilled by 31.3 percent. The recycling efforts avoid more than $14,400 per year in landfill disposal cost.

MEMC's waste elimination results have been a significant internal source of company funds and have gained positive recognition from the company's customers and peers. This recognition includes the 1990 South Carolina Governor's Pollution Prevention Award. The MEMC case study is a model for other companies considering waste elimination efforts.

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WASTE MINIMIZATION TO COMPLY WITH OCPSF EFFLUENT GUIDELINES

Arlen L. Bishop
Senior Engineer
E. I. du Pont de Nemours & Co.

Kenneth N. Wood
Consultant
E. I. du Pont de Nemours & Co.

SUMMARY

Ever-tightening regulations on releases to the environment from manufacturing facilities have become a major business factor for the chemical industry. Among these regulations are the new Organic Chemical, Plastics, and Synthetic Fibers (OCPSF) effluent guidelines, which were promulgated by the United States Environmental Protection Agency (EPA) in November 1987. To meet these guidelines, many companies will make a significant investment to expand or upgrade their wastewater treatment plants (WWTP). Still others, recognizing the shifting emphasis away from developing more efficient waste treatment methods to not generating waste in the first place, will choose to invest considerable energy and resources in reducing waste at the source. However, reducing waste often requires basic process or material changes, which may be difficult to identify, develop, and implement. The Du Pont Belle, West Virginia, site has accepted that challenge and is implementing a program to comply with OCPSF guidelines by placing the primary emphasis on reducing the organic load sent to the WWTP, with secondary emphasis on WWTP expansion and upgrade for more effective treatment. The program will reduce by 50% the organic load from seven processes, control priority pollutants at the source, and minimize shock loads from nine processes, contributing to the overall efficiency of the WWTP. This approach will save over $7 million of the investment that would have been required if the reduction came only from WWTP modifications. Other anticipated benefits are reduced sludge production and volatile organic emissions, as well as significantly improved product yield in one process. In this way, the program exemplifies the Du Pont belief that environmental stewardship is a win-win proposition for both the environment and industry.

BACKGROUND

The Du Pont company has operated a major chemical manufacturing complex in Belle, WV since 1926. The Belle Plant is located on the Kanawha River about 10 km above Charleston and employs 1100 people. It produces primarily agricultural products along with organic chemicals used in a variety of industries including automotive and textile manufacturing.

The plant has a long history of pollution abatement programs that have resulted in major reductions in BOD load to the Kanawha River (Hyde, 1965). The site's original wastewater treatment plant (WWTP) was commissioned in 1961 with a design capacity of 28,000 lb (12,700 kg) of BOD removal per day. An activated sludge process was employed with four parallel trains of aeration tanks and clarifiers. A major WWTP expansion was completed in 1976 which significantly increased treatment capacity and operating efficiency with the addition of a larger fifth aeration tank/clarifier system.

Today, twenty processes generate aqueous waste streams requiring treatment; of these, thirteen are continuous and seven are campaigned processes. The number and diversity of the manufacturing processes and waste constituents results in a wide fluctuation of WWTP influent conditions. Therefore, waste load variability control can be as critical to overall treatment performance as the absolute BOD load from the processes. As a first step to reducing the load and fluctuations in feed composition, three wastes that were being treated from off-site sources were discontinued in 1990.

Du Pont as a corporation is committed to waste minimization. An aggressive waste reduction program has been in place for several years and significant progress has been made. For example, hazardous waste generation was reduced by a third (indexed to production) between 1982 and 1989. Corporate goals call for similar reductions over the next decade (with even higher reductions for certain targeted materials).

PROJECTED OCPSF PERMIT LIMITATIONS

The site's current National Pollutant Discharge Elimination System (NPDES) permit expires in May 1992. Tighter WWTP effluent limits are anticipated in the new permit as a result of the recently promulgated OCPSF effluent guidelines (USEPA, 1987). To ensure continued smooth operation, the plant has set a goal to be in compliance with these lower limits when the permit is reissued. Du Pont projected what the new limits were likely to be in order to establish target goals for its compliance program. These anticipated effluent limitations were derived using guidance and examples provided by EPA's Industrial Technology Division (USEPA 1991). These were compared to the present permit limits to establish the size of the reduction necessary for the conventional pollutants (biochemical oxygen demand (BOD) and total suspended solids (TSS)) as shown in Table I.

TABLE I. CONVENTIONAL POLLUTANT EFFLUENT LIMITS (LBS/DAY)

	BOD		TSS	
	Monthly Average	Daily Maximum	Monthly Average	Daily Maximum
PRESENT	1600	4200	2200	5000
OCPSF*	890	2360	1450	4200

The projected permit limit based upon the OCPSF effluent guidelines would require a 44% reduction (from the PRESENT limit) in effluent BOD. The 34% reduction in TSS has been accomplished and compliance with the new limits has already been demonstrated through operational controls.

EPA has also established a list of compounds, under the Clean Water Act, known as priority pollutants, which are of particular concern to the Agency. A total of 56 organics from the EPA priority pollutant list are included in the OCPSF regulation in addition to the conventional pollutants. Of those, three (methylene chloride, chloroform, and toluene) are currently used or present in the waste streams at the Belle, WV plant. Du Pont has also projected what the Best Available Treatment Economically Available (BATEA) limits are likely to be for these substances and contrasted them to current permit levels (Table II).

* Includes allowance for non-OCPSF products based on "Best Professional judgement" estimates.

TABLE II. PRIORITY POLLUTANT EFFLUENT LIMITS (LBS/DAY)

	PRESENT		OCPSF	
	Monthly Average	Daily Maximum	Monthly Average	Daily Maximum
Methylene Chloride	2	4	0.7	1.6
Chloroform	2	4	0.4	0.8
Toluene	-	-	0.5	1.4

Derivation of new permit limits from OCPSF guidelines are expected to reduce the methylene chloride and chloroform allowable discharges 65% to 80% from the current conditions. Toluene will be limited for the first time in the OCPSF-based permit conditions.

ALTERNATIVES TESTED OR EVALUATED

Du Pont personnel approached the needed reductions with a two-pronged strategy: 1) identify and evaluate WWTP modifications needed to reach the lowered permit levels and, concurrently, 2) develop opportunities to reduce or eliminate waste at the process source.

1. Major WTP modifications.

The primary approaches for WWTP modification evaluated were:

- Expanding the existing aeration tank capacity (increased hydraulic residence time).
- Upgrading with additional treatment unit operations.

To assess the effect of lengthening the residence time, a full-scale field study was conducted using one of the smaller original aeration tanks and clarifiers. The feed rate was cut in half, which doubled the treatment time of the waste in aeration and the settling time in the clarifier. While the study showed projected permit limits could be met with this approach, doing so would have meant doubling the size of the WWTP to maintain needed capacity. Available land restrictions and the magnitude of investment required made this option undesirable. Therefore, other means of upgrading the treatment process were pursued.

An outside consultant was hired to study potential new types of treatment processes including the addition of powdered activated carbon or (PACT*technology) and two-stage biological treatment (with or without PACT).

The consultant conducted bench-scale treatability studies to test the effect of PACT both with single- and two-stage biological treatment units (Grey, 1989). The results showed that, while these alternatives might be effective, the amount of carbon required would have exceeded any reasonable cost. This finding put even greater pressure on the waste reduction effort. Moreover, priority pollutants could not be economically treated in the WWTP, and source reduction was the only answer. The contributing processes would have to be redesigned or raw materials changed so that the three pollutants of concern would not be present in the waste at levels greater than half of the expected permit limits in order to ensure compliance.

*Du Pont registered trademark

The laboratory evaluation of biological treatment options showed that the two-stage unit without PACT would be the most effective. The price tag for upgrading the existing WWTP to a two-stage activated sludge system was estimated to be 7 million. In addition, it was felt that a second, larger equalization tank would be required to dampen shock load variability and maintain consistent performance under the tighter effluent limits. Source control measures for priority pollutants identified by the waste reduction effort for these process chemicals would cost about $2.6 million. Using this information, the following best-case for investment under the major WWTP modifications scheme was developed (Table III).

TABLE III. BEST CASE FOR MAJOR WWTP FACILITY UPGRADE AND PRIORITY POLLUTANT SOURCE CONTROL

Project	Investment
Two-stage biological treatment without PACT	$7,000,000
Priority pollutants - source control	$2,600,000
Second equalization tank	$1,800,000
Instrumentation, air & flow distribution systems	$1,100,000
TOTAL	$12,500,000

2. Waste reduction program

In the parallel waste reduction effort, process-area personnel were asked to develop their best proposals to reduce waste in four areas:

- Organic load to WWTP by 50%.
- Control priority pollutants at the process source.
- Eliminate shock loads.
- Eliminate waste that inhibits WWTP biological activity.

Finding a way to reduce the organic load to the WWTP required following each waste component back into the process to determine its source and then focusing reduction programs to identify process, equipment, or raw material changes that would eliminate generation of the waste. It also required an extensive sampling and analytical effort. After several months of investigations, process evaluations, and engineering design effort, the waste minimization program paid off with a planned 50% reduction in organic load to the WWTP. Table IV shows changes that have been or will be made in the seven processes where organics will be reduced.

TABLE IV. SOURCE ORGANIC REDUCTIONS

Process Source	lbs/day TOC*	Investment
A. Pump seal leaks	1000	$30,000
B. Washwater incineration	600	80,000
C. Process digital control system	1000	N/A
D. Stripper overheads incineration	3000	750,000
E. Solvent incineration	700	10,000
F. Product recycle	700	40,000
G. Waste hydrolysis	3000	90,000
TOTAL	10,000	$1,000,000

*total organic carbon

Six of the process and operating changes will provide 70% of the reductions at a cost of only $250,000. The $40,000 invested to recycle product (F) resulted in an increased yield worth $100,000 a year. Process G will bring one-third of the total reduction for less than $100,000 investment; it will also eliminate a source of shock loads. Four of the seven process changes have been completed.

Controlling the three priority pollutants at the source included switching solvents (to eliminate the toluene) and discontinuing manufacture of one product with a marginal profit. The major investment for priority pollutant abatement will be in a steam distillation and incineration process for another production area.

Shock loads occur when nonroutine wastes, such as tank truck washings, are sent to the WWTP. These nonroutine wastes disrupt treatment efficiency. Similarly, wastes that inhibit the biological activity in the WWTP can also lessen efficiency. Since maximum efficiency will be required to ensure compliance with the expected limits, identifying and controlling shock loadings was an important aspect of the plant's program. The cost of eliminating shock loads at the source proved to be less than a third of that for installing an additional equalization tank to minimize their effect ($400,000 for source elimination versus $1.8 million for the new equalization tank).

3. Minor WTP modifications.

To complement the waste reduction program, a third investigation was undertaken to see what minor changes could be made to optimize operation of the existing waste treatment equipment.

As mentioned previously, the Belle WWTP has five aeration/clarification treatment trains. Flow from incoming waste and recycled sludge is split proportionally between the tanks based on relative volumes by a flow

distribution or "mix box". Field tests by the consultant indicated uneven flow to the small treatment trains and fluctuating oxygen uptake rates and dissolved oxygen. The uneven flow was corrected with a new "mix box" and sludge recirculation line valves and flow meters. The fluctuating oxygen uptake rates and occasionally deficient dissolved oxygen levels were corrected by replacing the coarse-bubble aeration systems with fine-bubble systems. In addition to more uniform air distribution, the fine-bubble aeration systems are more efficient and can maintain higher dissolved oxygen levels at lower energy levels.

Finally, the instrumentation in the waste treatment area is being upgraded to current Du Pont plant standards. Much of the WWTP instrumentation has not been replaced since the original installation in the early 1960s; in some cases, spare parts are no longer available. Additional on-line instrumentation with distributive control systems will allow more efficient monitoring of critical parameters and faster response to changing operational conditions. In addition to the general instrument upgrade, three new TOC analyzers will be installed to monitor separately the major sources of incoming waste.

FINAL COMPLIANCE PROGRAM

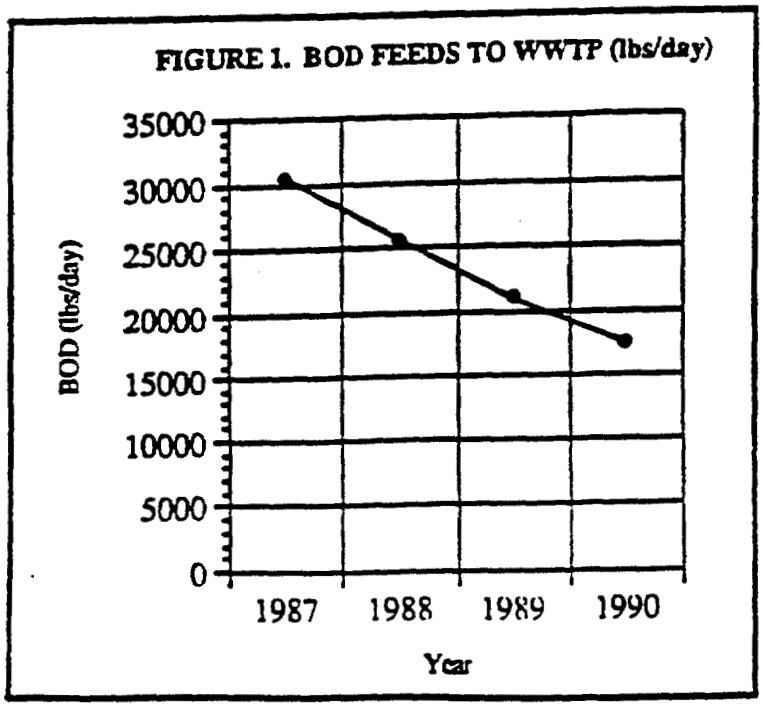
Based on the results of this approach, the following five-point strategy was pursued and is being implemented (Table V). The program has enabled the plant to prepare for the expected tighter permit limits primarily through waste reduction, with secondary projects to enhance WWTP efficiency.

TABLE V. PROGRAM CHOSEN TO MEET OCPSF LIMITS

Action	Investment
50% reduction in organic load from seven processes	$1,000,000
Source control of priority pollutants	2,600,000
Eliminate shock loads from nine processes	400,000
WWTP instrumentation, air system & flow distribution	1,100,000
TOTAL COSTS	$5,100,000

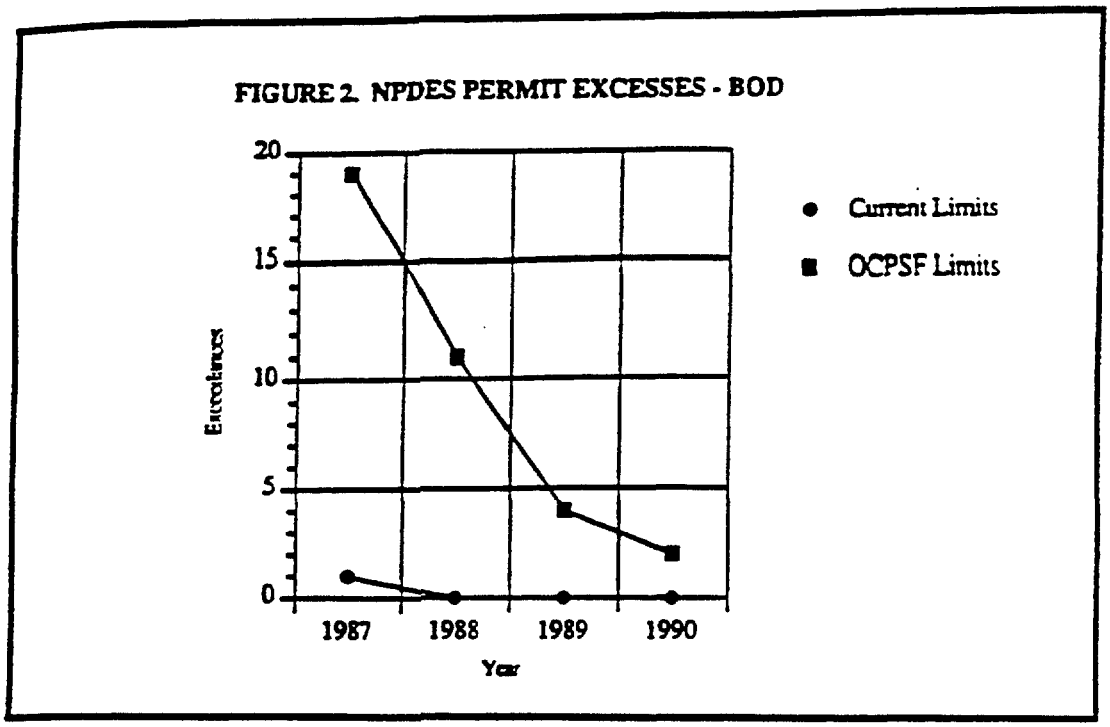
RESULTS

The effort to reduce waste generated at the source has now been in progress for over three years. Although the effort is not complete, we have seen a substantial reduction in BOD load to the WWTP over that period (Figure 1).



The plant has found that "administrative controls" are a key element to the overall waste management program. As operating personnel in the process areas became more aware of what the waste reduction goals were and of the need to maintain better controls over what they discharged to the WWTP, the organic load began to drop, even before equipment or other changes were made. Since 1987, BOD has been reduced over 40%. The final 10% reduction should be accomplished well ahead of the May 1992 target date.

Another means of evaluating our progress is in terms of projected permit noncompliances if we had been operating under the tighter limits during those four years. Figure 2 shows the permit limit exceedances that would have occurred under the more stringent OCPSF conditions.



Under the current permit, effluent limits for BOD were exceeded only once (in 1987); there were no exceedances in 1988 through 1990. Had the OCPSF guidelines been in effect in 1987, 19 exceedances would have occurred. However, as a result of the changes recently instituted, the number would have dropped to only two in 1990. Although the 1990 performance is perfectly acceptable under our current permit and demonstrates that, thus far, the program has worked, it still is not in line with our goal of zero exceedances under the OCPSF effluent guidelines. This fact continues to drive our waste reduction and permit compliance program toward the May 1992 deadline.

In addition to the primary objective of improved effluent quality, the waste minimization accomplishments will reap other anticipated benefits. These are reduced waste activated sludge production and volatile organic emissions from open tanks in the WWTP. With the investment cost savings, this program exemplifies that environmental stewardship is a win-win proposition for both the environment and industry.

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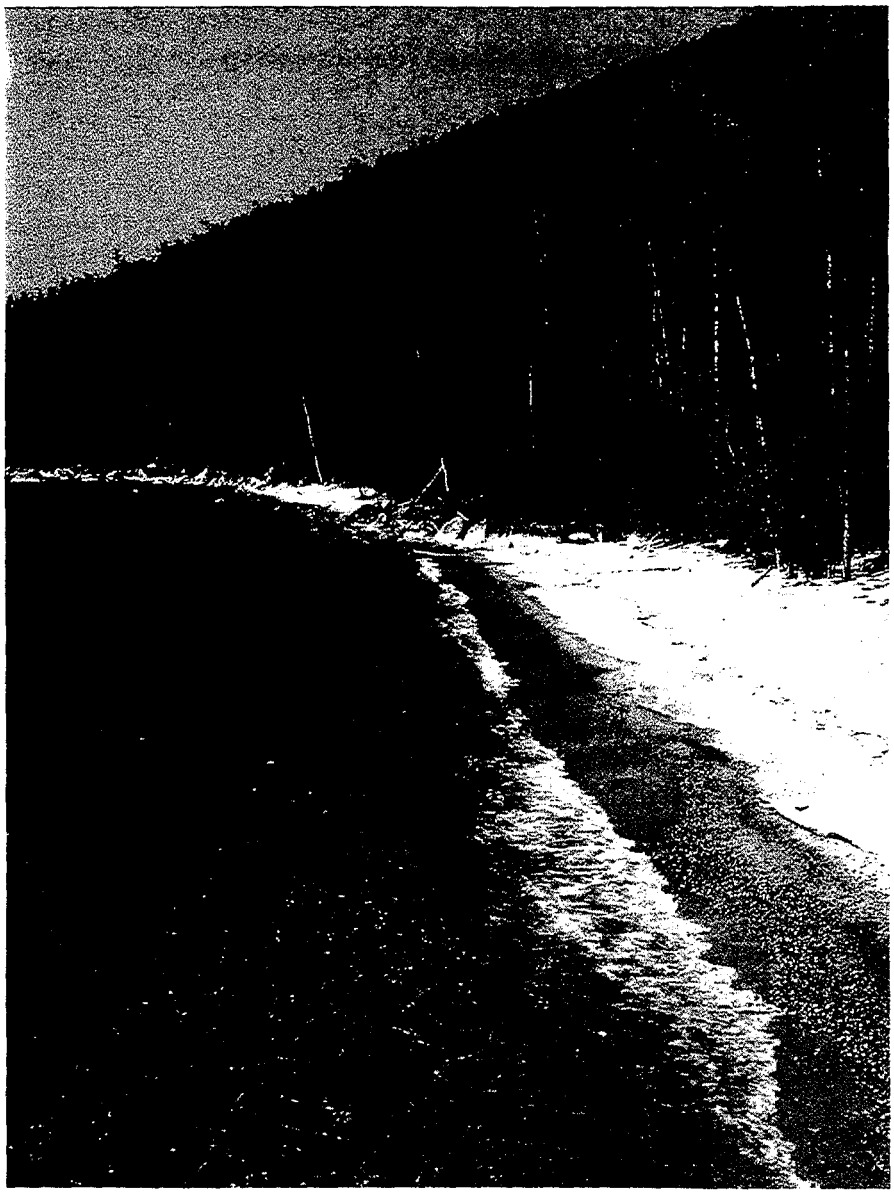
Safeguarding the World's Largest Lake



Courtesy of Boyd Norton

In 1987, the Russian Republic enacted stringent air and water quality standards for Lake Baikal, in south-central Siberia, in an effort to save the lake and its ecosystem. Lake Baikal is the world's largest (in volume), deepest, and oldest freshwater lake, and is also one of the most biologically diverse. However, it has been seriously damaged by the region's urbanization and industrialization. Recently, a joint U.S.–Russian team of engineers, planners, and environmentalists evaluated the current state of the environment in the region and recommended that Baikal-area industries improve effluent quality, reduce air emissions, and develop reuse systems.

While still a republic, Russia also created the Baikal Law, which includes guidelines for water and air quality in the Baikal region catchment basin and air shed. The newly independent country is currently pursuing designation of the lake and its watershed as a United Nations World Heritage Site. This would mean that land management and cleanup plans would be established for the area to preserve the lake for future generations.

Water Quality Is Deteriorating

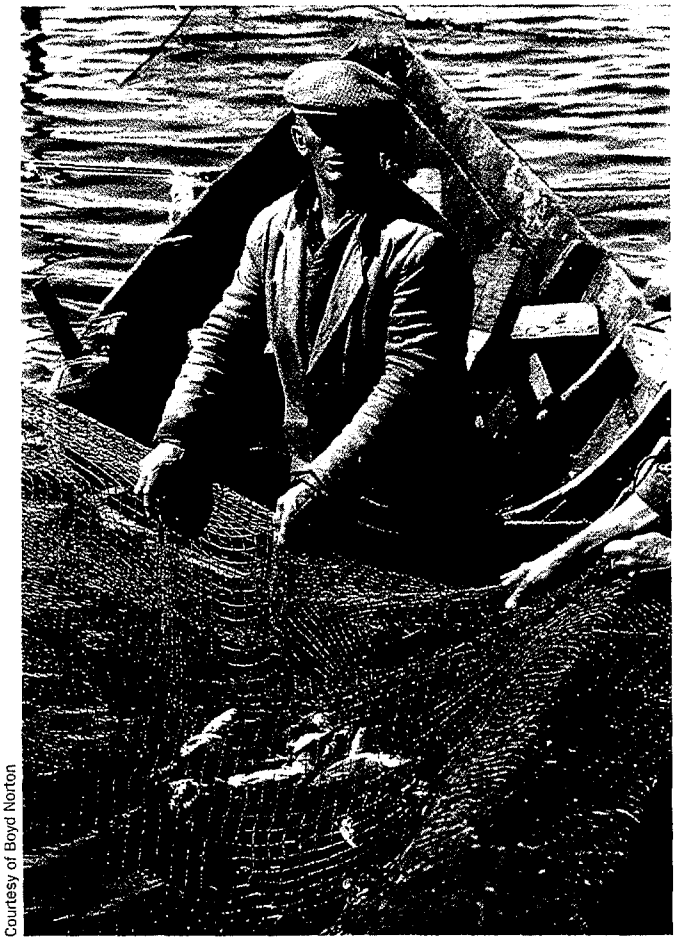
The lake's water quality is, on the whole, quite good. There are isolated areas of pollution from urban and industrial sources in the northern and southern portions of the lake. Industry, water and wastewater facilities, paper mills, and agriculture are affecting the water quality, and air pollution from many of these same sources deposits toxic and acidic materials in the watershed. Yet, compared to other freshwater lakes, Baikal is relatively clean.

While the lake has more than 300 major inlets, there is only one outlet, the Angara River near the city of Irkutsk on the southwest side of the lake.

While there are isolated areas of pollution in the Lake Baikal region, the water is surprisingly pristine. Water transparency has been reported to be 40 m in some areas.

The lake's primary inlet, the Selenga River, originates in Mongolia and flows past Ulan-Ude (an industrial city of more than 300,000) and the industrial town of Selenginsk before entering the lake's east side through a huge delta. The Selenga accounts for about 60% of the lake's freshwater influx and a substantial part of the pollutant inflow. The lake remains relatively clean because the total annual inflow is only about 0.26% of the lake's total volume. The water turnover rate is, on the average, once every 400 years, which, when combined with very cold water temperatures, means that self-purification is a slow process.

Industrial wastes. While industries in Ulan-Ude are required to pretreat their wastes before discharge to the municipal



Courtesy of Boyd Norton

The biological diversity of the Lake Baikal ecosystem is threatened by increasing air and water pollution.

Baikal: A True Natural Wonder

Lake Baikal, estimated to be about 25 million years old, contains more than 2.3 × 10^5 km^3 of water, which is equivalent to 20% of the world's freshwater supply. In surface area, Lake Baikal is the world's seventh largest lake (31,500 km^2). It is 636 km long and 48 km at its widest point with a maximum depth of 1637 m.

Known for its biological diversity, Lake Baikal has 1550 animal and 1085 plant species, two-thirds of which are found only in the area. The most notable are the Baikal seal, the only freshwater seal in the world, and freshwater sponges.

Scientists believe that the extreme clarity of the lake is strongly influenced by a microscopic crustacean (*Epishura baicalensis*), which filters large quantities of the lake water through its body.

wastewater collection system, the environmental research team observed that pretreatment facilities range from primitive and ineffective to very sophisticated and modern.

Discharges are routinely monitored by government agencies. However, the Ulan-Ude municipal wastewater treatment plant is not designed to remove industrial pollutants. The plant does have a discharge permit, but the discharge limits are not as stringent as the requirements in the Baikal Law. The team found that numerous discharge levels, including those for biochemical oxygen demand (BOD), inorganic constituents, and some heavy metals, were beyond permit limits and that most of the chemicals that exceeded limitations were probably from industrial discharges.

The improper handling and storage of industrial sludges and residuals is also probably contributing to groundwater and surface water pollution.

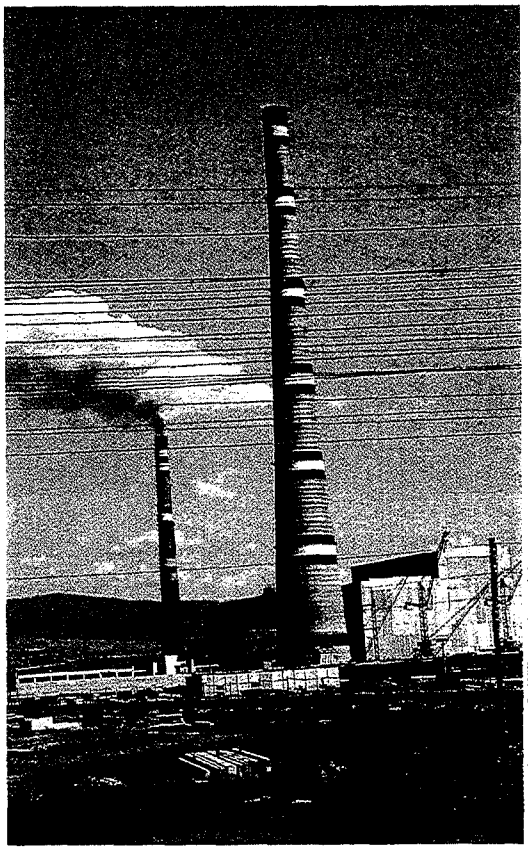
Drinking water. A number of drinking water supply wells have been shut down because of contamination. The team was unable to determine whether the contamination was from faulty well construction or groundwater pollution, or both.

Municipal waste. The quality of wastewater treatment systems in the Baikal region also varies. Rural areas generally have inadequate disposal systems. Most remote areas use low-technology waste disposal systems such as privies. Also, soil conditions in much of the region are not suitable for wastewater lagoons and septic systems.

The team visited five large municipal wastewater treatment facilities ranging in size from 1600 to 0.2 × 10^6 m^3/d (0.4 to 52.8 mgd). All facilities use some variation of the activated sludge treatment process. Effluent discharges usually do not meet the discharge limitations for Lake Baikal. These plants will require numerous modifications before their effluent meets minimum standards.

Most of the plants were treating flows well beyond their design capacity, with inadequate preventive and unscheduled maintenance programs. Solids and other residuals are typically disposed of in unlined municipal solid waste landfills, which could lead to groundwater contamination.

The Baikal Law covers particulate emissions, but most industries are not equiped to capture pollutants before they are emitted.



Courtesy of Damon S. Williams Associates

Lake Baikal Pollution Control Recommendations

- **Upgrade all municipal wastewater treatment plants with additional tertiary treatment facilities to meet the discharge standards for Lake Baikal. This may include facilities for nitrogen and phosphorous removal, chemical coagulation, filtration, and heavy metals and toxic organics removal.**
- **Explore the applicability of wastewater reclamation and reuse techniques.**
- **Implement more stringent pretreatment levels to shift the burden of industrial wastewater treatment to the individual industries.**
- **Discontinue production of all bleached cellulose products at the Baikalsk Pulp and Paper Mill and convert the plant to a zero discharge operation. Both the Baikalsk and Selenginsk mills should continue to investigate the reuse of wastewater effluent and solids.**
- **Phase out the practice of sending solids and other residuals to unlined municipal solid waste landfills.**
- **Review and revise landfill design, construction, and use regulations. All regulations should be strictly enforced, especially for industrial solids and hazardous wastes.**
- **Equip all industrial facilities and mobile sources with adequate air pollution control devices, especially pulp and paper mills and thermal and electric power stations.**
- **Set up additional air pollution monitoring facilities throughout the Lake Baikal airshed to monitor stationary and mobile source emissions.**
- **Establish a regional laboratory with more sophisticated instrumentation than is available at small facility laboratories.**
- **Implement agricultural reforms including a ban of illegal or ecologically hazardous pesticides and herbicides. Establish regional regulations with strong enforcement policies for the storage, handling, and use of agricultural chemicals. Decentralize agricultural activities, prohibit animal feedlot operations, and establish best management practices for agricultural land management.**
- **Implement stormwater runoff control and treatment measures, and control for hazardous materials transport and storage.**
- **Increase capacity at wastewater treatment facilities to prevent plant overloading.**
- **Make adjustments to combustion temperature, air-to-fuel ratios, fuels used, and equipment modifications at power generating stations to reduce air emissions and possibly lower energy costs.**

Pulp and paper mills. Two pulp and paper mills are significant sources of air and water pollution. Mill emissions have destroyed large areas of the surrounding forests. The team was unable to determine conclusively what, if any, air pollution control devices are available at the mills.

Solids disposal is a problem at the mills. Solids from the Baikalsk mill are dried in an experimental incineration process and then disposed of in a landfill. Solids at the Selenginsk mill are dried in clay-lined lignin ponds. The plant is also experimenting with composting dried solids for reuse. The clay-lined lignin ponds have vegetation growing on the bottom, indicating that the lining is probably unsound and contaminated water may be reaching the groundwater table. There are monitoring wells adjacent to the ponds, but the team was unable to determine whether pollutants had been detected.

The mills and their on-site power generation and wastewater treatment facilities have severe operations and maintenance problems. These problems could be solved with additional capacity, appropriate pretreatment facilities, upgraded maintenance programs, and pollution control devices.

Agriculture. Agriculture is an important part of the Baikal region's economy. Sources of agricultural pollution in the region range from animal farms close to the lake to improper storage of agricultural chemicals—both are a serious threat to surface water and groundwater.

Team Suggests Solutions

The joint U.S.–Russian environmental team recommended several pollution control measures and innovative technologies (see Box). As the country adjusts to a free-market economy, it may be difficult to generate the revenue necessary to implement the improvements that must be made to ensure the protection of Lake Baikal. The team suggested user fees for wastewater treatment facilities or other public works operations, permitting fees or fines for exceeding discharge limits, and joint ventures with foreign investors. The team is also developing a land use plan and map for the Lake Baikal watershed.

*—**Damon S. Williams** and **Aimée D. Conroy**, Damon S. Williams Associates, Phoenix, Ariz.*

Prognosis for R&D Funding Guardedly Optimistic

In 1993, expenditures for research and development (R&D) in the U.S. are expected to reach $162 billion, according to a forecast prepared by an international technology organization. This is an increase of $4.6 billion (2.9%) over National Science Foundation estimates for 1992.

Because part of the R&D increase will be absorbed by inflation—estimated to be just over 2% for 1993—this represents a real increase in R&D expenditures of less than 1%. This figure is considerably below the 10-year average increase of 3.1% in real R&D since 1982. The R&D growth rate has been slowing and is expected to continue to decline, perhaps even to the point of a decrease in real expenditures. A similar situation occurred two decades ago, with a very slow recovery.

Industrial financial support of research, accounting for 51.2% of the total, will continue to grow in areas related to electronics,

communications, sensors, advanced machinery, and in fields directly influenced by the need for more energy-efficient products and processes. Major changes in the traditional defense industries are forcing realignments within the industry, cutbacks in personnel, and stronger efforts toward definition of new markets—a situation not unlike the one that hit the industry in the early 1970s.

The trade imbalance and efforts to correct it as well as efforts to expand markets in response to shifts in government priorities, could spur expanded R&D. In addition, the internationalization of markets will influence R&D expenditures as U.S.-based companies attempt to accommodate the different regulatory postures and consumer behaviors in other parts of the world. Whether such initiatives will be fruitful will be influenced by the impacts of general slow-downs in worldwide economic growth and in the availability of foreign currencies.

In the recent past, an environment that permitted greater rewards for short-term financial results, rather than technological innovation, had an adverse effect on R&D investment. However, the tenor of the federal budget for 1993 and the pro-technology attitude of the incoming administration are reasons for cautious optimism.

Government to Emphasize Technology Transfer

The report predicts an increase of 2.8% in federal support for R&D, with funding expected to total $70.1 billion. This is 43.3% of the total expenditures for 1993, but is a smaller increase than originally proposed in President Bush's budget.

Prior to 1980, government was the principal funder of R&D. But industry has been the dominant source of R&D support for the past 12 years, and that trend is expected to continue in 1993 and for the next several years.

Several factors will influence federal R&D support: the continuing budget deficit, a move toward reduction or curtailment of the so-called "big science" projects, and the emphasis on technology transfer and short-term projects that have industrial applicability. The overriding concern over the deficit is expected to prompt a reduction in growth of both defense and total government R&D spending.

It is particularly noteworthy that President Clinton's proposals relative to applied research are generally consistent with those forwarded by the outgoing administration. Not surprisingly, the forecast points out, additional funds will be directed toward research aimed at technologies that will enhance industrial competitiveness over both the long and the short term. Continued concern over political changes in Eastern Europe and instability in the Middle East will also influence R&D directions. But the federal government is most likely to support research that will strengthen domestic economic growth.

While industry and the federal government provide funding for R&D in roughly equal proportions (43.3% and 51.2%, respectively), the vast majority of R&D (69.6%) is performed by industry. Industry uses almost all of its own funds either performing the R&D itself or contracting with industrial researchers. Nonprofit organizations finance both themselves and academic institutions about equally.

—***Jules Duga***, *Battelle, Columbus, Ohio.*

NPDES Stormwater Program Provides Leverage for Pollution Prevention

By Brent Larsen

Pollution prevention is the first line of defense in any attempt to improve or maintain the quality of stormwater entering our nation's waters. Without the strong emphasis EPA has placed on pollution prevention, the cost of complying with CWA's stormwater permitting program would be astronomical. Municipalities and industries using the impetus of the permitting program can leverage their limited money and resources by setting up or strengthening their pollution prevention activities. Clearly, traditional end-of-pipe treatment for all stormwater discharges would be prohibitively expensive. Water quality goals can be achieved at much less expense by a true commitment to pollution prevention measures at all levels of society, thereby saving limited federal, state, local and private dollars for situations where treatment is truly necessary.

Since CWA's passage in 1972, the mission of the NPDES program has been protection of the physical and chemical integrity of the nation's [illegible] permitting authorities [illegible] charges from [illegible]

plants. However, success in controlling these discharges has highlighted the effects of stormwater point-source discharges and nonpoint source pollution. In 1987, Congress responded to mounting evidence of and concern about the impact of stormwater discharges by adding CWA Sec. 402(p), which requires EPA to move forward with control of point-source stormwater under the existing NPDES permit program.

The new NPDES stormwater program initially affects municipal separate storm sewer systems (MS4s) serving populations of 100,000 or more, a variety of heavy and light industries, construction, stormwater discharges already covered by an NPDES permit, and discharges contributing to a water quality problem. The number of facilities is staggering — EPA estimates place the number at about 100,000. Each will have between one and literally thousands of point-source discharges.

Point-source discharge permits issued by EPA and NPDES-authorized states traditionally have relied on effluent limitations and end-of-pipe treatment requirements. Recognizing that traditional NPDES permit controls would be prohibitively expensive in the stormwater program, EPA chose to focus on pollution prevention. This strategy allows facilities to reserve costly end-of-pipe controls for those areas where pollution prevention is infeasible or ineffective.

Leverage. The principle of leverage is quite simple: With a lever and a properly placed fulcrum, a smaller amount of effort is needed to move a large object. The NPDES stormwater program uses leverage in two ways. First, the permitting framework is moving large numbers of facilities and municipalities to develop and implement pollution prevention plans. Second, the use of pollution prevention applies leverage to those resources expended in permit compliance, allowing facilities to achieve CWA's water quality goals at less overall cost.

According to CWA, permits for MS4s must effectively prohibit nonstormwater discharges into storm sewers (illicit discharges). They also must require controls to reduce the discharge of pollutants to the "maximum extent practicable." In a permit application, an MS4 is required to propose a comprehensive "stormwater management program." Such programs, which EPA expects to rely heavily on pollution prevention, must address four overlapping sources of pollutants entering a storm sewer: illicit connections and improper disposal, runoff from residential and commercial areas, runoff from industrial areas and runoff from construction sites. Once approved, the locally developed stormwater management plan becomes the heart of the MS4 permit.

With a lever and a properly placed fulcrum, a smaller amount of effort is needed to move a large object.

Industrial permits. Congress specified in CWA that stormwater discharges associated with industrial activity be subject to both technology- and water quality-based permit requirements. At the core of EPA's baseline stormwater general permits is a requirement for facilities to develop and implement a stormwater pollution prevention plan (SW3P). EPA has taken the position that SW3Ps represent the minimum technology-based "treatment" requirement for industrial stormwater. As with any NPDES permit, no further controls are needed when technology-based controls also can provide compliance with water quality standards.

An operating facility's SW3P should focus first on reducing the exposure of stormwater to pollutants. What does not get in does not have to be removed. To accomplish this goal, operators must know what is onsite and where the runoff goes. The permit requires SW3Ps to contain both operating practices and actual controls for reducing pollutants in stormwater. Good housekeeping, preventive maintenance, spill prevention and response, inspections, employee training, removal of non-stormwater discharges, sediment and erosion controls, and traditional treatment devices all play a part in a good pollution prevention plan.

Construction SW3Ps must address both short- and long-term impacts. During the design phase, both hard and soft controls can be incorporated into a project. For example, properly designed detention/retention ponds (hard controls) can add aesthetic value, in addition to controlling stormwater quality and quantity. Soft controls include greenbelt set-asides for stream corridors, impervious area restrictions, and use of grass swales instead of concrete channels.

During construction, the goal is to reduce erosion and the amount of sediment leaving the site. Industrial permits require stabilization and structural practices to reduce erosion and sediment, and compliance with local and state requirements. During construction, several options are available for erosion and sediment control, including minimizing the amount of land disturbed, protecting bare soil, leaving buffer strips to protect sensitive areas, installing perimeter and centralized sediment removal devices, such as filter fences and sediment traps, and stabilizing soil.

The SW3P requirement lets permit holders review their facilities for pollution prevention opportunities. Although it is somewhat more prescriptive than the municipal stormwater management program, the industry plan allows a facility to eliminate sources of stormwater contamination before moving on to treatment. In many cases, common sense, good housekeeping and appropriate structural and nonstructural best management practices will eliminate the need to pay for treating stormwater and disposing of residuals from the treatment process. ■

Brent Larsen, *an environmental scientist, is EPA Region VI stormwater coordinator.*

Innovations in Technology

New Stripping Technique Minimizes Hazardous Waste

By Kimberly A. Roy

With a one-two punch of heat and cold, a new stripping process removes paints and other coatings without generating toxic waste or damaging metal or composite surfaces.

The technology, known as FLASHJET®, was developed as an alternative to methylene chloride for stripping paint and coatings from aircraft at McDonnell Douglas Aerospace-East (MDA-E; St. Louis). Besides damaging the aircraft's composite substrate, methylene chloride is strictly regulated and generates hazardous waste that is costly to dispose, explains Wayne Schmitz, MDA-E's FLASHJET® program manager.

Although the company initially did not intend to develop a new technology, a review of available stripping options failed to identify a cost-effective alternative that would minimize hazardous waste, reduce maintenance time, and eliminate substrate damage and corrosion, Schmitz says.

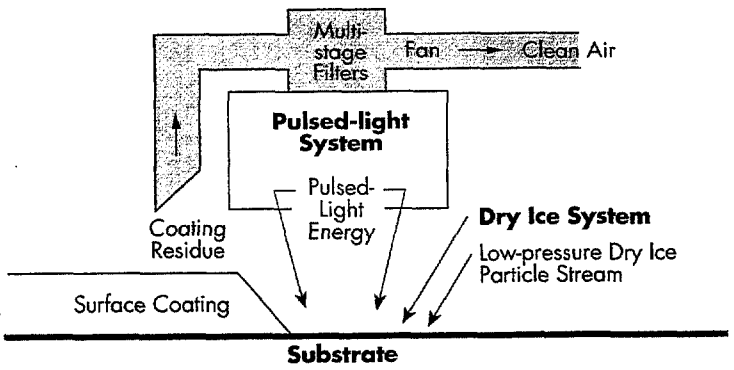
MDA-E eventually joined forces with Cold Jet Inc. (Loveland, Ohio), a developer of dry-ice blasting technologies, and Maxwell Laboratories Inc. (San Diego), an advanced technical services company and manufacturer of high-energy, pulsed-power technology and systems. The prototype, which was fabricated and tested in January 1991, "did in fact work well," Schmitz says, and the trio applied for patents later that year. Patents were pending at press time.

The FLASHJET® process uses a high-intensity flashlamp (heat) to destroy a coating's cohesive bonds and a simultaneous particle stream of dry ice (cold) to remove residue, and cool and clean the surface. Without the dry-ice stream, Schmitz says, the pulsed-light energy from the flashlamp could cause "a great deal of (structural) damage." (Using heat and dry ice together maintains surface temperature between 40 degrees and 100 degrees Fahrenheit.)

Pulsed-light energy is generated by a quartz tube filled with xenon gas, which, when electrically energized, emits a brilliant flash of light, Schmitz explains. As the paint or coating absorbs the photon energy, its temperature rises rapidly to a point at which a thin layer of paint is removed.

Dry ice, meanwhile, is produced from carbon dioxide gas, which is

Effluent Capture System



Paint Stripping Processes

Characteristics / Technology	Xenon Flashlamp/ CO_2 Pellet Blasting	CO_2 Pellet Blasting	Xenon Flashlamp	Laser	Water-Ice Blasting	Sodium Bicarbonate Blasting	Non-Phenol-Based Chemical Softener/ Water Jet	High-Pressure Water Jet 32,000 psi	Wheat Starch Blasting	Phenol-Based Chemical/ Water Rinse	Plastic Media Blasting (PMB)
Operator Safety Requirements	Ear/Eye Protection	Ear/Eye Protection	Ear/Eye Protection	Lethal Energy Level	Eye Protection	Breathing Air, Eye Protection	Chemical Burn Protection (Whole Body)	Lethal Blast Pressure	Breathing Air, Eye Protection	Chemical Burn Protection (Whole Body)	Breathing Air, Eye Protection
Aircraft Masking Requirement	Minimal	Minimal	Minimal	Minimal	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive
Aircraft Damage Potential	Low	Moderate	Minimal	Low	Low	Low	Moderate	Moderate	Low	High On Composites, Transparencies	Moderate
Paint Stripping Rate	High	Low to Moderate	Low to Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Aircraft Thru-put Rate	High	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Low	Moderate
Post Stripping Cleanup Required	None	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Media Intrusion Potential	None	None	None	None	High	High	High	High	High	High	High
Corrosion Potential	None	None	None	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjacent Component Damage Potential	None	None	None	Low	Low	Yes	Low	High	Yes	Yes	Yes
Aircraft Precleaning Required	None	None	None	None	None	None	Yes	None	Yes	Yes	Yes
Media Recycle Requirement	None	None	None	None	Yes	Yes	None	Yes	Yes	None	Yes
Media Disposal Cost	None	None	None	None	None	Low	Low	None	Low	Very High	High
Hazardous Waste Volume	Low (No Media)	Low (No Media)	Low (No Media)	Low (No Media)	Low	Low	Moderate	Low	Low	High	Moderate

Best [ ] Worst

Characteristics Rating

collected from various industrial processes, purified, converted to a liquid and compressed into tiny particles before being delivered to the paint surface in a low-pressure air stream. The pellets sublimate to a gaseous state on impact, leaving the surface clean and ready for repainting.

The carbon dioxide also acts as a shield that prevents oils or soils on the surface from igniting, thus eliminating the need to wash the surface or pretreat it before stripping. The continuous flow of dry ice also keeps the flashlamp clean, helping to ensure maximum transmission of light energy.

A self-contained effluent capture system (vacuum) is integrated with the pulsed-light and dry-ice nozzles into a common head (Figure 2). The capture system carries removed paint and coatings to a series of filters, where they are collected for incineration. Air from the filters passes through a charcoal tub-scrubber before being released to the atmosphere.

"By eliminating particulates, hazardous waste requiring disposal is reduced by 99 percent," reports Gregory Gardner, MDA-E's business development manager for the FLASHJET® program. Operators need only tinted glasses and normal hearing protection, and other technicians are free to perform maintenance on or in the aircraft while the system is operating, he adds.

While easily adaptable to robotics, the mobile system also can be controlled with a pneumatic, mechanically assisted manipulator, Schmitz says. In other words, the operator can push the system, which weighs about 50 pounds, across the surface with assistance from a color-sensing device that monitors stripping rate and provides visual feedback. If the stripping head does not contact the surface properly or is moved too slowly, the system automatically shuts down.

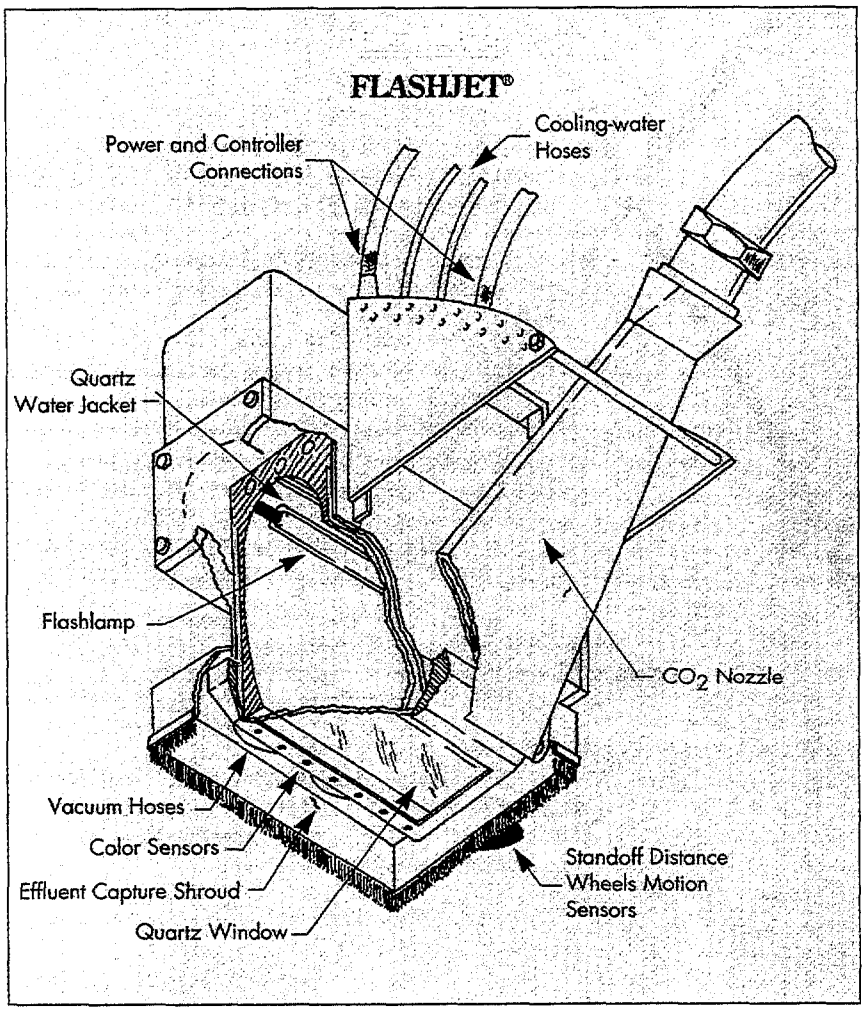
According to Schmitz, strip rates up to 4 square feet per minute are possible when stripping to primer with a 12-inch stripping head. A 6-inch stripping head also is available. (The size designation indicates the area being stripped.)

FLASHJET® also provides a high degree of control, Schmitz says, and can remove as little as one one-thousandth of an inch of coating. It can be used to remove complete finishing systems (top coats and primer) or select layers of top coat, or for chemical-free cleaning using only the dry-ice particle stream. These variations are achieved by modifying such operating parameters as pulsed-light energy density; stripping head rate of travel and distance from the surface; and dry-ice delivery pressure and nozzle angle.

To date, no limitations have been identified, Schmitz reports, adding that tests have been conducted on "all known paint and primer systems used in the aviation business, as well as all structures, including steel, aluminum, titanium and various composites."

Operating costs are estimated at $4 per square foot, compared to a minimum of $12 per square foot and a maximum of $25 per square foot for other systems, Gardner says. Capital costs have not been set.

At press time, the system was certified for use on all McDonnell Douglas aircraft and was being certified for Air Force and Navy aircraft. Certification tests were scheduled for this summer for commercial aircraft manufacturers in the United States and Europe. "We're also very interested in other applications," Gardner says, "but no special target industries have been identified at this time."



"Pollution Prevention by Reducing Antifoam Chemical Discharge"

Brian S. Johnson, Ph.D.
Nalco Chemical Company
Naperville, IL 60563

INTRODUCTION

Unwanted foaming is a serious problem in many industrial plants. Foam problems include: safety hazards, waterway pollution, process contamination, reduced process output, restricted oxygen uptake in aeration basins, and .public relation concerns. Foaming is caused by excessive turbulence, or *in situ* gas generation and can be minimized with proper plant design. While plant design can minimize foam, it does not always eliminate it, and antifoam chemical is needed. Antifoams are used in applications needing smooth flowing liquids such as industries involving: latex paints, paper making, textiles, ceramics, and lubricants. Also, industries using distillation columns such as oil refineries and alcohol producers have definite foam control needs.

With increasingly stricter environmental discharge permits, the need to reduce hazardous chemical discharge becomes more important. Formulating 'greener' products and increasing product activity reduces hazardous chemical discharge. Increased activity is accomplished by using defoaming synergisms, and reducing or using cleaner oils. Synergisms are the result of interactions between two or more defoaming chemicals to greatly increase the bubble coalescence rate. Utilizing a sophisticated feed control system is the third way to reduce antifoam chemical discharge and ensure that antifoam is only fed when chemical is required.

Pollution prevention is of concern to many governmental agencies and legislative bodies across the country. This is evidenced by pending or recent legislation, such as: the Massachusetts Toxic Use Reduction Act, The Great Lakes Water Quality Initiative, California Proposition 65, etc. Wastewater antifoam chemicals are added directly to discharge streams to control foaming on public waterways. Process streams also affect plant effluents, since process residuals eventually reach the waste treatment plant. For example, paper mills have eliminated process chemicals that contain any dioxins or dioxin precursors. Also, due to regulatory and/or environmental pressures, plants have had to change production processes to facilitate wastewater treatment. This is evidenced by paper mills changing their bleach process to facilitate ACX reduction. For these reasons the composition of added chemicals, including antifoams, is very important.

BACKGROUND

Foams are thermodynamically unstable. Energy input in the form of turbulence provides energy to keep the foam from collapsing. Impurities that stabilize the air/water interface are needed because pure water cannot foam. These impurities lower the surface tension of water. Pure water has a surface tension of 72 ergs/cm^2, where ergs is a unit of energy; therefore, to increase the surface area by one cm^2 requires 72 ergs of energy. Foaming surfactants will lower the surface tension, making it easier to increase surface area. A foaming liquid has

more surface area than a liquid at equilibrium and it takes energy to create this excess surface area. Also, the smaller the foam's bubbles, the greater the foam's total surface area. Comparing the surface area of one large bubble to the surface of many small bubbles occupying the same total volume, we see that small foam bubbles have much greater surface area.

	Single Large Bubble (radius=0.5 inch)	Many Small Bubbles (radius=0.005 inch)
Number of Bubbles	1	1,000,000
Total Volume	0.52 $inches^3$	0.52 $inches^3$
Area per Bubble	3.14 $inches^2$	0.000314$inches^2$
Total Surface Area	3.14 $inches^2$	314 $inches^2$

It takes energy to create this extra surface area, and excess surface area is excess foam. Foaming agents work because they reduce the surface tension making it easier to create foam. Less energy is needed to create the same amount of excess surface area.

Once a bubble has formed, it needs to be stabilized, since it is thermodynamically unfavorable to have the increased surface area. The natural course of events is for the bubble interface to drain and rupture. When two foam bubbles come together they drain then rupture, and finally coalesce. There are several mechanisms that stabilize foam.[1]

Air bubbles that comprise foam are created by turbulence as the liquid passes through pumps, weirs, etc. and from fermentation or neutralization processes producing gas bubbles. In many plants, the rate of bubble production is constant - due to the inherent turbulence built into the system. Expensive capital improvement is often the only way to remove the inherent turbulence. Mechanical devices can be used to reduce foam and chemical discharge. These devices function by decreasing the rate of bubble production (reduce turbulence), or by 'popping' the bubbles. To keep plants profitable, the process flow rate must be high, meaning foam generating turbulence is unavoidable and antifoam chemicals become imperative. Antifoam chemicals function by increasing the rate of bubble coalescence, reversing the effect of the foaming surfactants.

Foams develop when a foam stabilizing surfactant impedes the touching of two bubble interfaces. Without these foam stabilizing surfactants, the lamella quickly drains to the plateau border allowing the bubbles to touch and coalescence. The lamella is the liquid region between two air bubbles while the plateau border is a region between three bubbles.[2] Foams are stabilized by several mechanisms such as slow lamella drainage and lateral or 2-D diffusion of the foaming surfactant. Foam breaking is the result of lamella drainage, allowing two bubble interfaces to touch and coalesce. Lamella drainage creates a convective flux that pulls adsorbed surfactant molecules from the interface. This temporarily creates an area of reduced surfactant concentration and higher surface tension. A surface tension gradient is

formed which will oppose the flow of liquid away from the interface, that is, slowing lamella drainage. Figure 1 illustrates how this gradient drives 2-D diffusion of foaming surfactant along the interface and restores surfactant concentration or 'heals' a bubble's air/water interface. The faster a foaming surfactant can diffuse along the interface, the less time there is for bubble collapse. This is the Marangoni Effect.[3]

ANTIFOAM MECHANISMS

Common antifoam mechanisms are: bridging/lamella penetration, duplex film formation, adsorption of foaming surfactant, high contact angle particulates.[4] Various defoaming mechanisms are used by nonhazardous chemicals such as: stearic acid, polypropylene glycol, and hydrophobic particles. On the other hand, oils are very effective defoamers and removing them usually degrades performance. One reason is that foam can be stabilized by foaming surfactant micelles, blocking the lamella. These micelles form an orderly micro-structure that impedes water drainage. Oils swell these micelles, destroying the orderly micellar structure, allowing the lamella to drain.[5] This is illustrated in Figure 2.

Combinations of defoaming chemistries can be used to reduce antifoam chemical dosages. These antifoam combinations, or synergisms, exhibit greater than additive bubble coalescence rates, and can sometimes be explained using combinations of antifoam mechanisms. An oil/hydrophobic particulate defoamer can be viewed as increasing in effective particle size due to an adsorbed oil layer.[6] Lamellar penetration depth is increased, meaning that bridging between bubbles occurs faster, allowing for faster bubble coalescence. This synergism can also be used to explain why combinations of immiscible antifoam chemicals can reduce antifoam chemical usage(or increase antifoam activity). For this synergism, the two immiscible surfactants actually associate in water forming a complex with a greater penetration depth than the individual oils. This mechanism is presented in Figure 3.

ANTIFOAM COMPOSITION

Antifoam formulations are either: oil-based, water-extended (an oil-based with water replacing some oil), or water-based. Oil-based antifoams use hydrocarbon oils derived from petroleum to package antifoam actives. Advantages are quick kill and low temperature application. These formulations tend to be 'universal' antifoams - at high enough dosages. They usually work by a duplex film mechanism, and unfortunately tend to produce visible oil sheens, pollute surface waters, and increase BOD loadings to the aeration basins. Additionally, the inexpensive hydrocarbon oils used in many antifoam formulations tend to contain hazardous compounds as impurities. An example important to the paper industry is oil that contains dioxin precursors. Environmental regulations are making it difficult to justify using oil-based formulations in many processes. Unfortunately, it is difficult to remove oil from antifoam formulations without reducing performance, or increasing chemical costs, but the effect of regulations are making it increasing more expensive to use oil-based antifoams.

Water-extended antifoams are derived from oil based formulations by replacing some oil with water and adding product stabilizers. These have the advantage of quick foam kill and less

oil discharged into the environment. While a water-extended formulation discharges fewer chemicals, it still uses some oil that reduces but does not eliminate the environmental problem.

Water-based antifoams work very well from an environmental standpoint, since antifoam actives are packaged using water. Since oil is not used, the effectiveness of water-based formulations is not as universal. Water-based antifoams have a distinct environmental and commercial advantage over oil-based formulations, since the use of expensive oil is eliminated. Water-based antifoams are environmentally friendly, so fewer pounds of hazardous chemicals are discharged. Also, water-based formulations lower BOD loading to the waste treatment plant. However, there are practical problems with water-based antifoams, such as higher viscosity and limited usefulness at lower temperatures.

FEED CONTROL SYSTEMS

Dosage control systems are used to minimize antifoam chemical usage. A reliable foam detection system is required. A fouling-resistant foam probe is needed to detect foam, without giving false readings, with the detectors able to automatically control antifoam feed pumps. Feed systems consist of pumps and pipes or hoses that distribute antifoam chemical.

Adding antifoam chemical when foaming is nonexistent is another way of wasting chemical. When feasible, an automated feed control system has minimal operator involvement. With the use of automated level probes, even antifoam chemical resupply is automated. This setup has several benefits:

1) Operator time is freed for other duties.
2) Antifoam use is optimized - minimizing environmental discharge.
3) Container disposal costs are reduced.

How the feed control system applies the antifoam chemical can be another source of excess chemical use. Since antifoam chemicals tend to be water insoluble, the products have a high viscosity for increased stability. These high viscosity formulations need to be thoroughly mixed with the foaming water to be dispersed. It is very important that the antifoam is thoroughly dispersed for maximum cost-effectiveness. Otherwise, higher chemical dosages will be needed to reach the required surface or interfacial concentration.

Common antifoam application techniques are: spray directly onto the foam, drip onto the foam, drip into turbulence, or feed into a transfer pipe. The chosen method depends on physical layout and the characteristics of the antifoam formulation. An optimal application method involves applying antifoam chemical directly to the foam. To prevent foam, upstream chemical addition should be close to the foam-causing turbulence. Antifoam must be well mixed with the water to insure that the antifoam surfactants are dispersed and reach the air/water interface. Excess chemical discharge is the result of improper antifoam application and control.

This approach has minimal operator involvement, and antifoam is provided only when needed. The importance in wastewater applications is that only the minimal amount of chemical is used and discharged into the environment.

CASE STUDIES

Case I - An illustration of reduced antifoam usage is a surfactant plant in the southern United States. This particular facility produces surfactants used in household and industrial products. The foaming problem was erratic and unpredictable. Antifoam product was being supplied in drums, and plant operators needed to manually change drums. At times, the drum would run dry, and foam would become excessive, or the drums would be changed before they were empty. This led to increased disposal costs as well as wasted antifoam chemical. At this facility, antifoam usage was reduced by using a water-based product designed with a particular synergism which uses a combination of immiscible antifoam chemicals. As illustrated in Figure 4, equivalent foam control is obtained with twice the amount of a non synergism, silicon antifoam product, and 10X of a popular oil-based antifoam. By designing an antifoam without hazardous oils and using defoaming synergisms, chemical usage/pollution is minimized.

Additional chemical use was eliminated by examining the feed control system. An automated feed pump control system was installed, and a fouling-resistant probe was used to determine when excessive foam was occurring. With this system, antifoam chemical would be added only when foaming was detected. Another change was to supply chemical, in a tank, with a level gauge. This allowed operators to easily determine when the tank needed filling, eliminating erratic antifoam chemical supply as well as excessive drum disposal costs. These steps illustrate how utilizing synergisms, and automating feed systems prevents excess chemical discharge.

Case II - A surfactant facility in the Midwest illustrates the importance of antifoam application for pollution prevention. This facility produces the active ingredients found in many household detergents. Foaming was a problem, since excessive foam would spill over the aeration basin, onto a highway, creating a public hazard. This is illustrated in Figure 5. When antifoam chemical was added at the end of the aeration basin, there was little foam control, and high chemical dosages were needed. This particular antifoam chemical is not very water-soluble, and when added to water, an antifoam droplet settles to the bottom - it is not at the air/water interface. In this situation, the antifoam needed to be dispersed to control foam, by getting the defoaming chemical to the air/water interface. Adding chemical to the aerator turbulence disperses the antifoam, and acceptable foam control was possible using less antifoam chemical. Therefore, the application method can be very important in reducing chemical use/discharge.

SUMMARY

With increasingly stricter wastewater discharge regulations, the need to reduce pounds of hazardous chemical usage is more important. Wastewater antifoams can contribute to water

pollution and their composition/use needs to be examined. Fewer pounds of hydrocarbon oils are released into the environment when these oils are reduced or removed from the antifoam formulations. Defoaming synergisms can be used to minimize the antifoam chemical dosages needed for foam control. Also, utilizing antifoam synergisms reduces total antifoam pounds needed without degrading performance. This is especially beneficial when nonhazardous antifoam chemicals can work together to enhance defoaming. Finally, by controlling when and how much antifoam is used, the optimum dosage is delivered only when required. This reduces wasted antifoam product that would otherwise be discharged into the nation's waterways.

1.Johnson,B.S.(1993) Total Systems Approach to Foam Control in Industrial Wastewater. **Proceedings of the 48th Industrial Waste Conference.**,341.

2.**Foams: Theory and Industrial Applications**, J.J. Bikerman, Reinhold Publishing Corp.(1953)

3.**Interfacial Phenomena - Equilibrium and Dynamic Effects**, Surfactant Science Series **17** Miller, C.A., and Neogi, P. eds. Marcel Dekker, Inc. New York(1985)

4.**Defoaming - Theory and Industrial Applications** Surfactant Science Series **45** Garrett, P.R. ed. Marcel Dekker, Inc. New York(1993)

5.Nikolov, A.D.;Wasan, D.T. **Langmuir**, **8**, 2985(1992)

6.**Defoaming - Theory and Industrial Applications** Surfactant Science Series **45** Garrett, P.R. ed. Marcel Dekker, Inc. New York(1993)

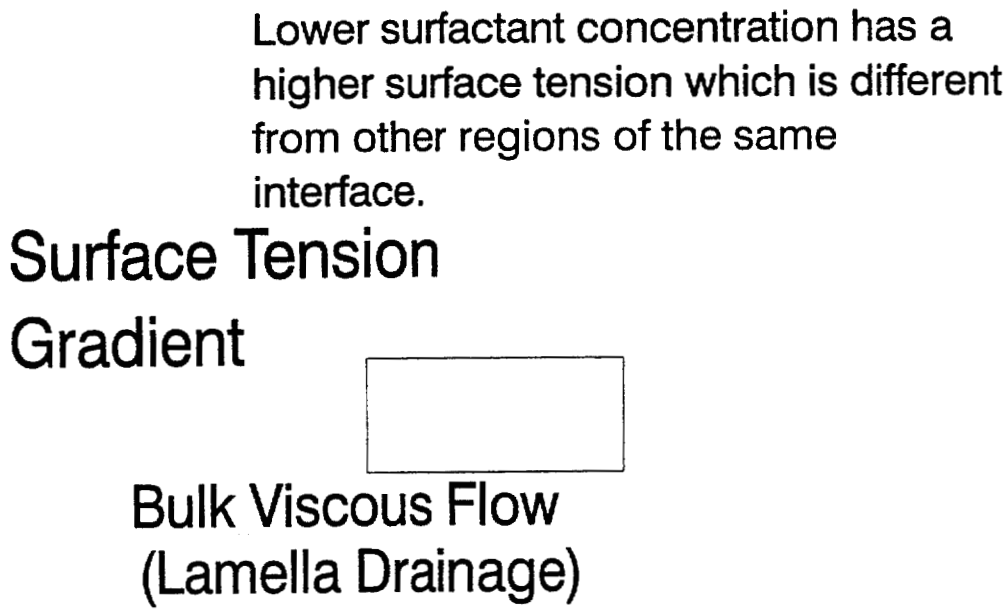


Figure 1 - The surface tension gradient opposes water flow from the lamella. Rate of lamella drainage is reduced and it takes longer for the bubbles to touch. This slows bubble coalescence.

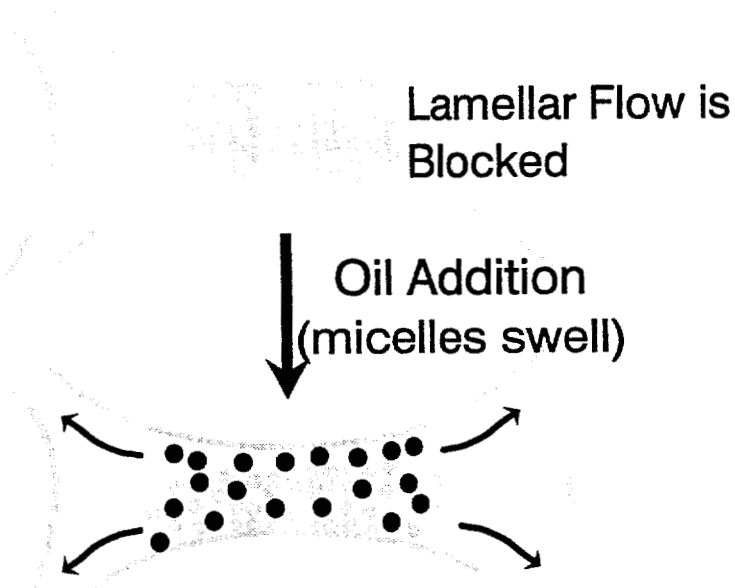
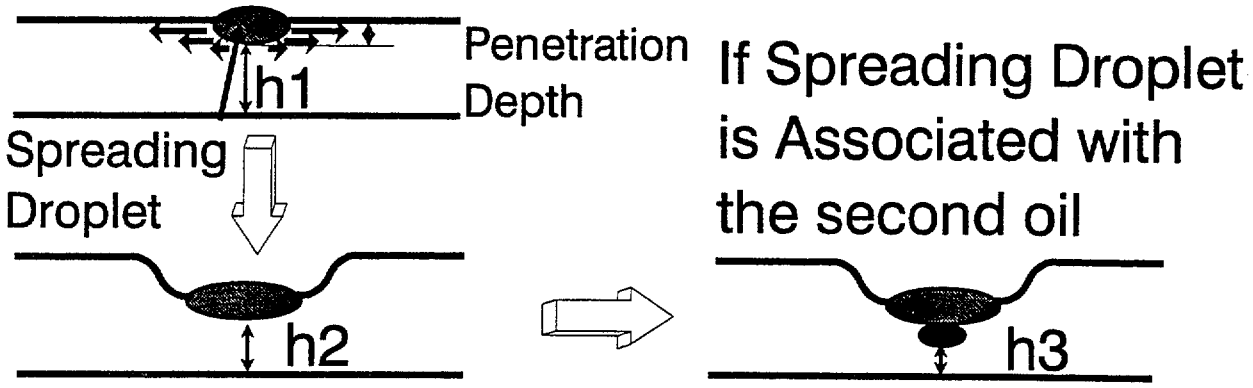


Figure 2 - Oil Swelling of Micelles Breaks up the Micelles Micro-structure.

Figure 3 - Synergism Mechanism

Reverse Maragoni Spreading drags the underlying liquid, pulling the interface down.



h3 < h2 < h1- Greater lamellar penetration depth at each stage. This reduces the time for complete lamellar bridging, increasing the bubble coalesence rate.

The Oils are not miscible. In an aqueous environment, one oil would associate with the other instead of with water, forming a large complex with greater penetration depth.

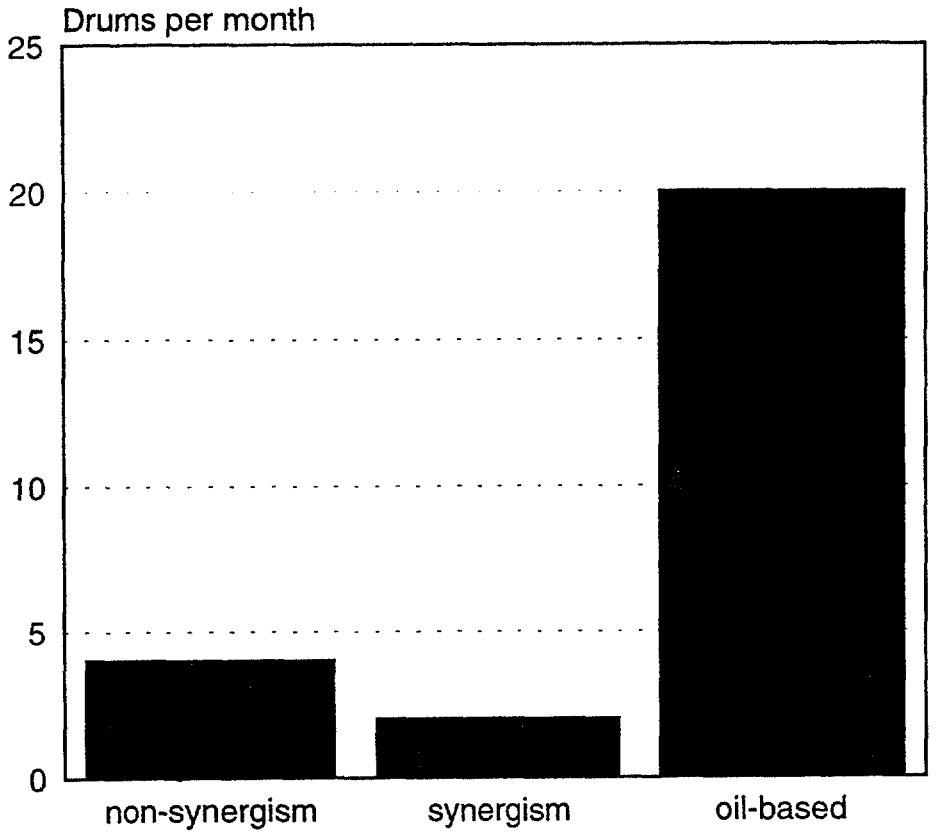


Figure 4 - Antifoam Usage Reduced Using Synergism.

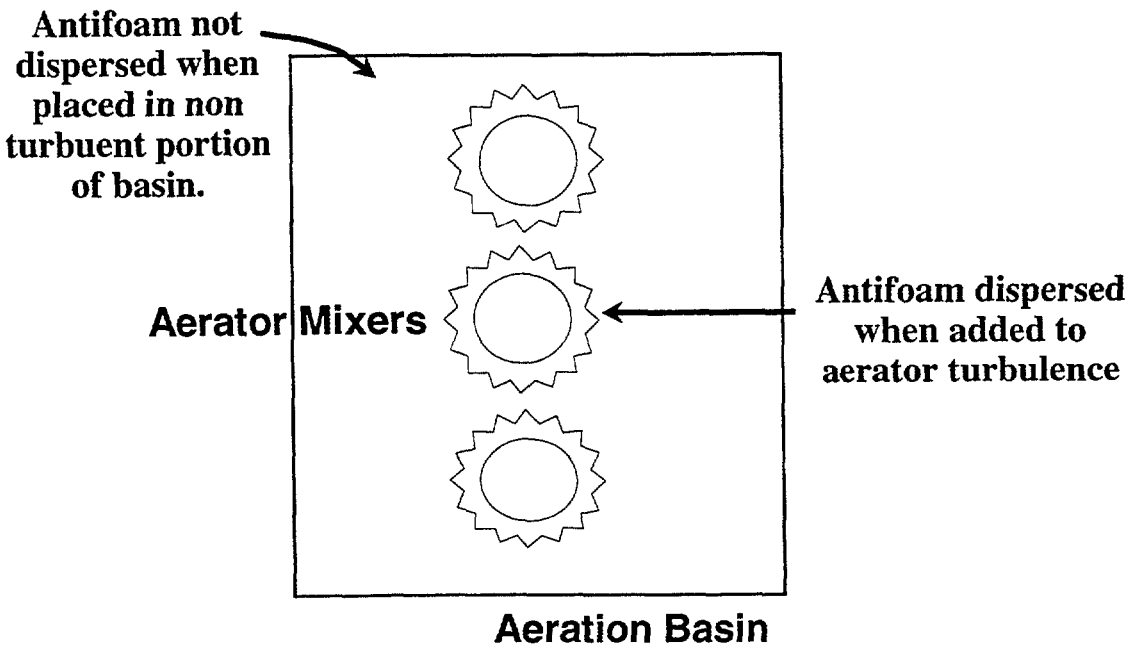
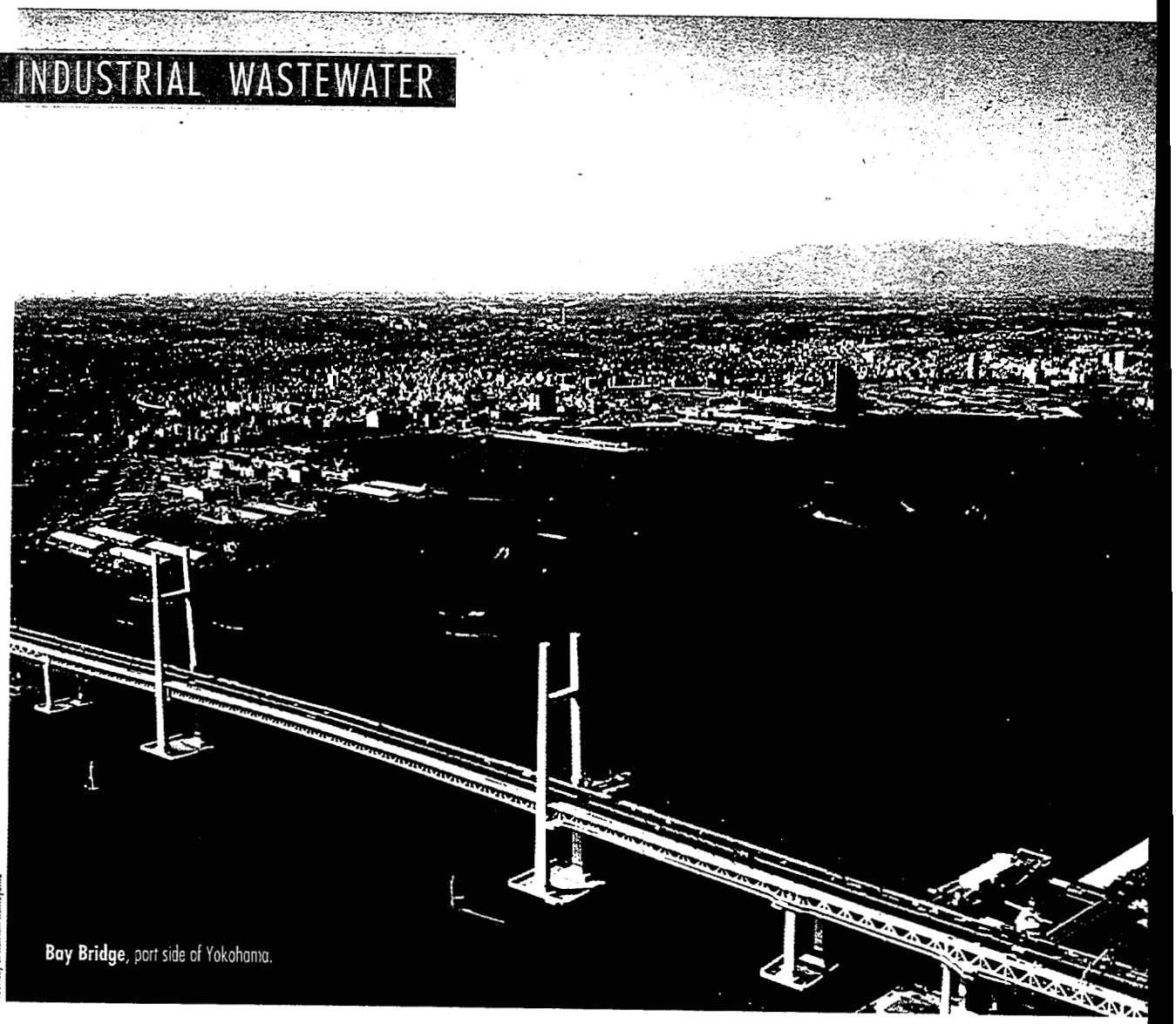


Figure 5 - Antifoam Application can affect product performance. When antifoam product is added to a quiesent part of the aeration basin foam is not controlled. Changing the application point to mix antifoam

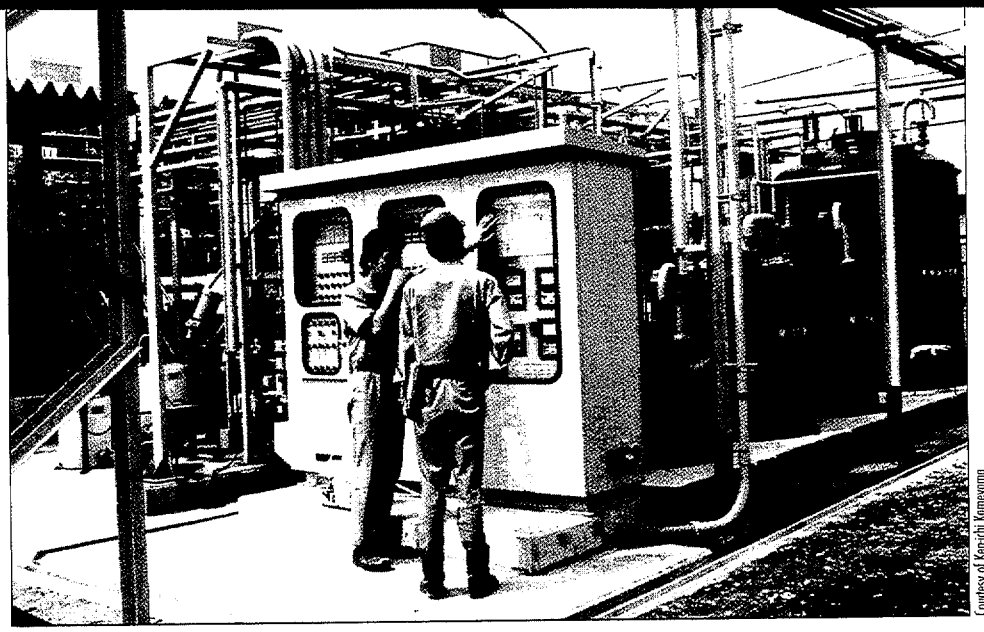


Courtesy of Kenichi Kameyama

Bay Bridge, port side of Yokohama.

REDUCING MERCURY WASTES AT HOSPITALS

Ken-ichi Kameyama



Surveillance of a factory's effluent monitoring system.

Courtesy of Kenichi Kameyama

Water quality analysis during surveillance.

Courtesy of Ken-ichi Kameyama

Mercury concentrations were found to be 93 mg/L removed by vacuum suction and 0.009 to 2.0 mg/L removed by the patient's spit.

The ideal answer to reduce the concentration of mercury discharged in amalgam would be to shift to a treatment method that does not require using amalgam; however, currently, alternatives to amalgam represent only about 30% of all filling materials. The University Hospital used a wastewater collection system to contain mercury coming from oral vacuum suction or expectoration. The mercury-containing waste was held in a special receptacle and the mercury removed by a chelating resin.

METHOD EFFECTIVENESS

Since the University Hospital and other hospitals implemented mercury reduction plans, the number of reported cases of elevated mercury levels in hospital wastewater has fallen.

The city of Yokohama periodically measures the mercury levels in effluent, sludge, sludge fertilizers, and incinerated sludge ash. The concentration of mercury in sludge fertilizers has decreased slowly over the last decade and is expected to continue to decrease as hospitals and dental surgeries improve their mercury recovery methods.

With the help of a variety of mercury-reduction methods now at hand, the city of Yokohama is steadily improving the natural marine environment, its waterways, and its man-made urban environment, and the city continues to work for further improvement in the future. ■

Water Regulations

A public wastewater system regulates factories by the Sewage Law, which is regulated under the Water Pollution Control Law. There are two types of provisions in the Sewerage Law and related ordinances: provisions to maintain sewerage facilities and provisions to maintain effluent quality of wastewater treatment plant standards.

About 2000 times a year, surveillance is conducted without prior notice at establishments requiring guidance. Major items of inspection include the quality of the wastewater discharged and the operating conditions of the pretreatment facilities. The quality of the water used in industries is measured and the production process is checked. Above all, simple on-the-spot analysis is conducted on the quality of the wastewater. If abnormalities are found or suspicion raised, a sample is taken to be officially analyzed. If a deliberate violation of the water-quality standards is found, the city authorities order an investigation of its cause and improvement of the facilities and operating methods. Official analyses are performed on about 500 samples for about 3500 items annually, but deliberate violations amount to only about 50 cases a year.

Ken-ichi Kameyama is chief of the industrial wastewater control division, maintenance and operation department, Sewage Works Bureau of Yokohama City, Japan.

Yokohama City

Construction of the city of Yokohama originated in 1858, after which Japan opened its gates to the world and took its first step toward modernization. As the trade with other countries progressed, commercial activity prospered and the Yokohama displayed all the atmosphere and color of a harbor city. Since then, Yokohama has reclaimed tracts from the sea, and on this land, the iron, ship-building, and petrochemical industries have been built on a coastal strip of Tokyo Bay connecting Tokyo, Kawasaki, and Yokohama. Thus Yokohama has an additional character as an industrial city.

Of the many industrial users of mercury, hospitals and clinics may be some of the largest. In particular, mercury compounds are found in mercurochrome, which is used as a sterilizing agent; mercuric oxide, which is used as a cell dyeing agent; damaged thermometers and blood pressure gauges; and dental filling amalgam.

About 15,800 m^3 of the 18,300 m^3 of wastewater discharged each day from medical facilities finds its way into Yokohama, Japan's, sewerage system. This volume represents about 1.2% of the total volume of wastewater treated at the city's wastewater treatment facility.

When wastewater containing mercury compounds passes directly from hospitals into the sewerage system without pretreatment or toxics recovery, treatment concentrates these toxic compounds in wastewater sludge, which may prevent the 3000 Mg/yr of sludge cake produced from being reused as fertilizer. For this reason, in 1981, the Yokohama Sewage Works Bureau conducted a survey on the use and disposal of mercury compounds in hospitals.

Before the city's hospitals were brought under the ambit of the Water Pollution Control Law (see Box *Water Regulations*), liquid and solid wastes that contained toxic substances were recovered as much as possible. In 1958, Japan required hospitals to comply with wastewater discharge requirements. Immediately after hospitals became subject to the law, the survey was conducted. The survey found that, although some waste recovery was being practiced, the mercury levels in hospital wastewater were too high. The concentrations measured would cause the treatment plant to fail to meet the law's new standard of 0.005 mg/L mercury in incinerated sludge ash for landfill disposal (leachate testing) or 2 mg mercury/kg sludge fertilizer (content testing).

Wastewater from the Yokohama City University Hospital, which was the focus of the survey, had mercury concentrations ranging from 0.16 mg/L to 0.0019 mg/L, with an average of 0.0028 to 0.0008. Particularly high values were recorded at certain outlets, such as mop sluices (see Table).

After the survey located specific mercury sources in the University Hospital, a mercury reduction plan was introduced at the hospital to try to decrease the amount of mercury released in its wastewater.

MERCURY REDUCTION METHODS

Mercury reduction at the hospital focused on reducing the amount of mercury found in examination room discharges and mop water used to clean up broken thermometers. It would have been ideal if wastewater from different parts of the hospital could have been collected and treated separately. Unfortunately, this was difficult, and the wastewater contained a variety of acids, alkalis, and heavy metals.

Several treatment methods often had to be performed simultaneously, such as neutralization, chemical clarification, oxidation reduction, adsorption, and ion exchange. It was possible to contain and separate the wastewater discharged from mop sluices and treat the waste with a chelating resin or the ferrite adsorption technique. However, because so many staff members have access to these areas, containment was difficult to control.

As part of its efforts to reduce the amount of mercury released in its wastewater, the University Hospital established a committee under the leadership of the hospital's director to ensure that a uniform approach was adopted by all departments to reduce wastes discharged from the hospital.

To eliminate the potential for mercury spills from broken thermometers, the hospital could have replaced them with thermometers that did not contain mercury. After experimenting with these electronic thermometers, the hospital decided that they were not as accurate as mercury-containing thermometers, they were too large to carry easily, and they were also rather expensive.

Two new types of mercury thermometers that do not release the mercury when broken were considered: one type is "unbreakable" and the other is coated with a plastic sheath that prevents mercury from spilling if the thermometer is broken. The University Hospital used a modification of the latter and inserted a regular mercury thermometer into a thin polyethylene sheath. Although there was an initial temperature difference of 0.2 degrees using these sheathed thermometers, after 7 minutes the sheathed thermometers gave the same reading as the thermometer without the sheath.

Another method the hospital used was to issue each patient his own thermometer on being admitted to the hospital. This relieved the nurses of carrying thermometers from room to room and reduced the need to sterilize the thermometers after each use, activities that often lead to thermometer breakage. This method was found to decrease the number of thermometers broken from 447 to 313, which subsequently reduced the amount of mercury discharged from the hospital's wastewater.

In addition to controlling mercury release from thermometers, the University Hospital prepared a manual—*Manual for the Use and Treatment of Sterilizing Agents*—to reduce the use of regulated substances containing mercury and enhance the awareness of pollution risks among the staff. Mercuric oxide used for cell dyeing was substituted with hematoxylin, a chemical that does not contain mercury.

The mercury from amalgam that finds its way into the hospital's wastewater is that part which is scaled off the amalgam during the polishing of a filling and then sucked out of the mouth and into the wastewater by oral vacuum suction equipment or spit out by the patient.

Wastewater Mercury Concentrations

Location	Concentration, mg/L
Nurse cleaning sinks	0.25 to 67
Floor cleaning sluices	1.2 to 830
Waste disposal units	1.7 to 4.1
Intensive care disposal units	0.052
Operating room catch basins	8.7
General catch basins	0.02 to 0.39

HAZARDOUS WASTE MINIMIZATION USING DYNAMIC MEMBRANE CROSSFLOW MICROFILTRATION CASE HISTORIES

Dr. Ray Groves, President and Gary Bartman, Vice President

Epoc Water, Inc.
Fresno, California

INTRODUCTION

The tightening of sewage discharge regulations has increased the application areas for membrane ultrafiltration and microfiltration technologies, particularly in the oil and grease and heavy metals industrial pretreatment markets. In many cases discharge quality requirements cannot be economically met without filtration down to the micron range. However, because of the fouling tendency of microporous membranes in these high solids and high oil and grease environments, they have not been generally successful.

The exception is the EXXFLOW crossflow microfilter which uses the principal of dynamic layers, or dynamic membranes, on permeable textile tubes rather than fixed microporus structures to achieve the 0.1 micron filtration required for many industrial pretreatment or recycle goals. This paper discusses the technical details of the dynamic membrane crossflow filter and its companion technology, EXXPRESS, which is an automatic sludge dewatering system, and reviews three case histories.

The technology is based on an innovative tubular array of woven fabric to form highly flexible tubes of either half-inch or one-inch diameter. The flexible tube microfilter system in crossflow mode can remove materials such as suspended solids, precipitated heavy metals, and oil and grease and in filter press mode, it can achieve the same dewatering characteristics as plate and frame filter presses, but is self cleaning at each cake discharge cycle.

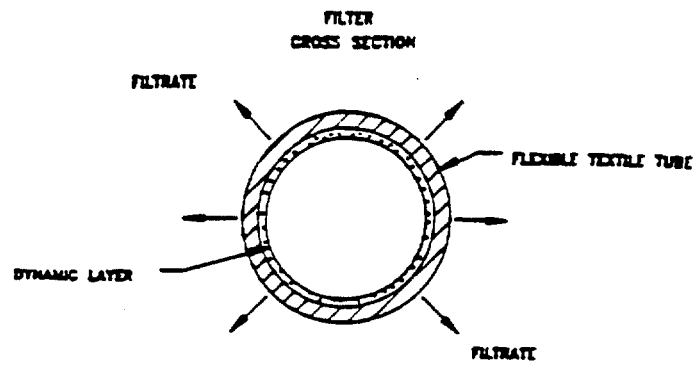
EXXFLOW CROSSFLOW MICROFILTRATION

The core technology is based upon a highly specialized woven textile tubular array and its post weaving treatment together with the formation and maintenance of dynamic layers, also called dynamic membranes. The solids in the waste water itself or additives form the dynamic layers which eliminates the cast-in-place microporous membrane requirement. Membranes or filter layers of widely different characteristics can be produced by using different pretreatment chemicals, for example, particulates or suspended matter in the feed itself, filter aid materials, metal hydroxides (Fe, Al, Ca), lime, precipitates such as calcium carbonate and powdered adsorbents such as activated carbon and ion exchange resins. The module produces a uniformly high quality permeate and removes virtually all suspended solids down to about 0.1 microns. Additionally, specialized dynamic membranes or pretreatment chemicals can be used to remove

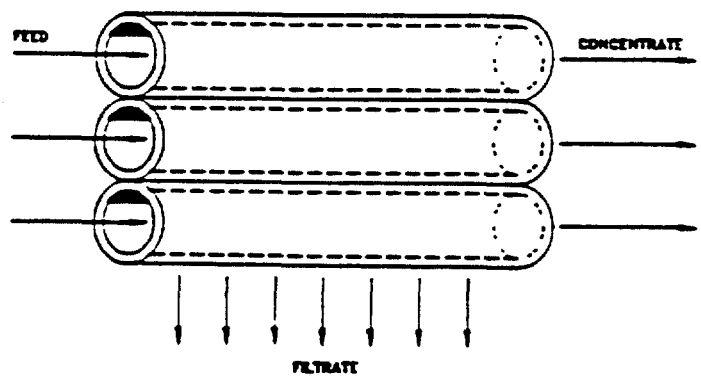
compounds such as oil, solvents, color, macramolecules, pesticides, non-volatile organics, hardness, and silica.

The microfiltration module operates with the feed being pumped longitudinally through the tubes such that the suspended and colloidal matter forms a membrane on the internal surface of each tube. The process is shown schematically in Figure 1.

FIGURE 1



EXXFLOW FILTRATION TECHNOLOGY

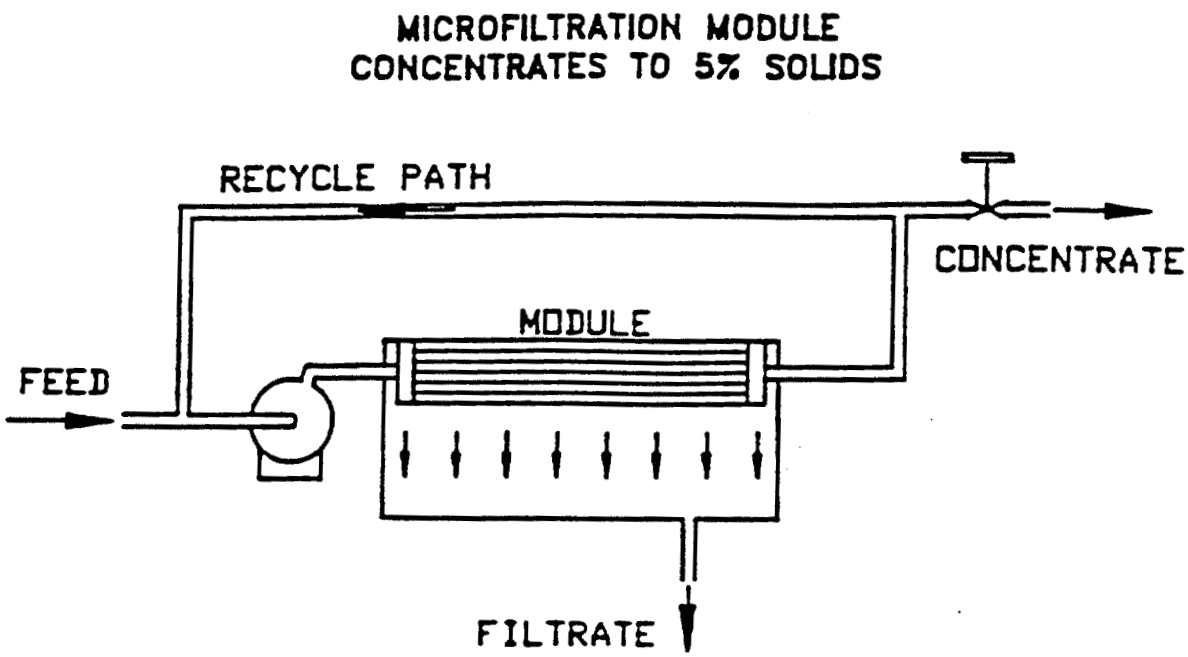


FLEXIBLE TUBE MODULE

After formation, the membrane at the liquid surface is *dynamic*, being continually formed and swept clean by the feed liquid as it flows through the module. A minimum tube reject velocity is maintained to control the thickness of the membrane layer. This is typically 3-6 fps. To become permeate (treated product water), the water filters radially through the membrane layer and out of the textile tube walls for collection at the base of each module. As the feed passes through the module, the rejected materials becomes progressively concentrated and is discharged from the module as reject or concentrate. To obtain high water recoveries, modules are operated either in batch concentration or reject concentrate recycle (feed & bleed) modes. Solids

were concentrated up to 1 - 5% w/w in the concentrate waste stream with typically 99% or more of the water recovered as high quality filtrate. A typical schematic is shown in Figure 2.

FIGURE 2

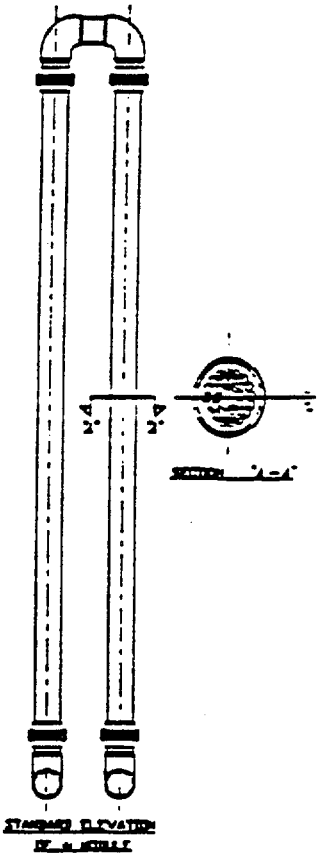


The module has excellent temperature (180°F) and pH resistant (1-14) with good chemical compatibility to strong cleaning solutions. It is a low pressure membrane process with operating pressures in the range 20-60 psi.

Module cleaning is achieved by occasional stopping and restarting the system, which causes the flexible tubes to collapse, allowing thereby allowing the membrane layer to be flushed clean. Alternately, particularly with oily wastes, the module is chemically cleaned, as applicable with acid or alkali strong detergents, and chlorine based materials.

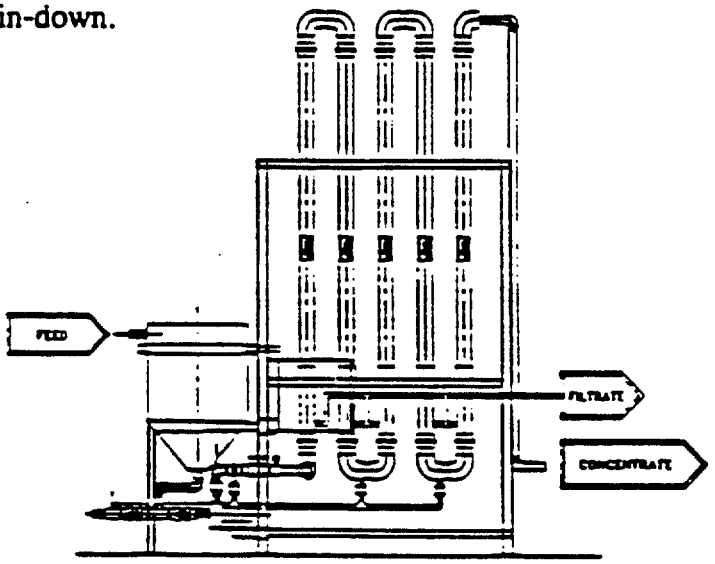
Modules are available with 70 or 21 half-inch or 30 one inch diameter tubes. Standard module lengths are 5, 10 and 20 feet. Figure 3 shows the spiral arrangement of the tubular array cloth in the module.

FIGURE 3



Modules shells are available in FRP, PVC and stainless steel. Figure 4 shows a typical arrangement. The modules are operated vertically to minimize floor space requirements and allow full drain-down.

FIGURE 4

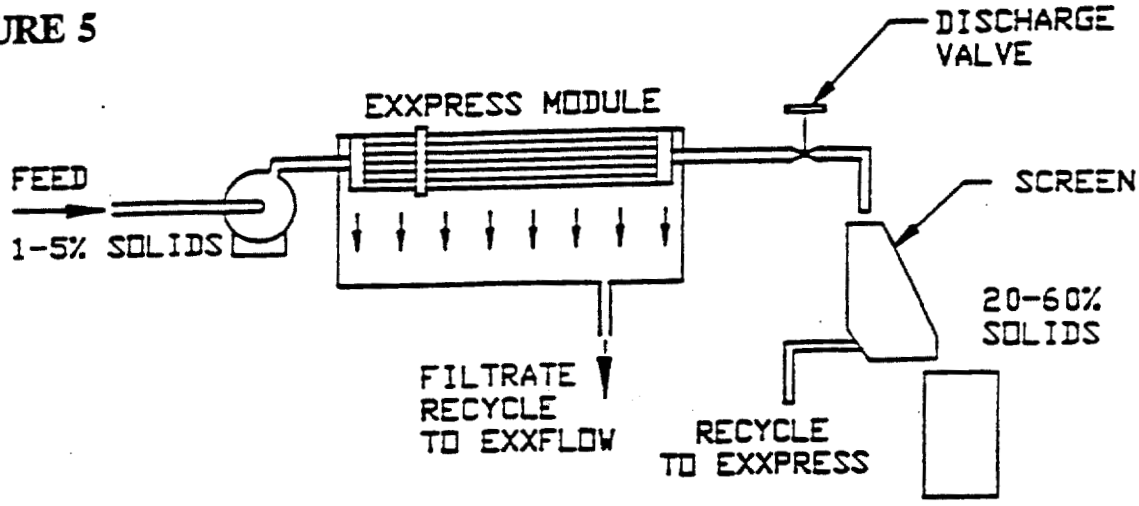


TYPICAL VERTICAL MODULE CONFIGURATION

EXXPRESS AUTOMATIC TUBULAR FILTER PRESS

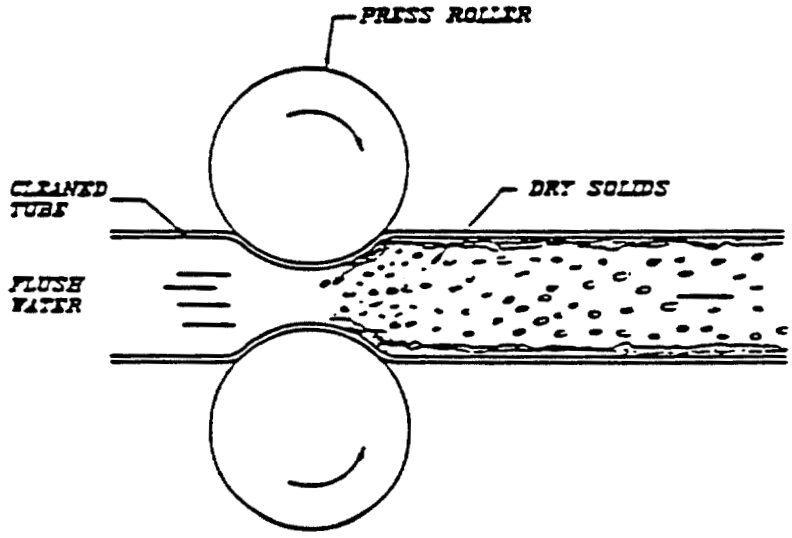
The Automatic Tubular Filter Press (ATFP) is shown schematically in Figure 5, and uses modules with the tubular array suspended as a linear horizontal bank of tubes from a support frame.

FIGURE 5



The process uses two cyclic operations of solids loading and cake discharge. In the load cycle the module operates with all tubes in parallel and in dead end mode with the reject valve closed. The solids form a thin cake layer on the internal walls of the tube. The dewatering cycle is complete when the thickness of the cake reaches a controlled thickness of about one-eighth inch. The cake discharge cycle then commences by opening the reject valve and traversing the module with rollers which disrupts the shape of the inflated tube as shown in Figure 6.

FIGURE 6



ROLLERS INTERRUPT TUBE. 40 - 60% SOLIDS ARE WASHED OUT.

This disruption causes a venturi action which simultaneously and aggressively cleans the filter cloth with incoming flush liquid and causes filter cake to chip off into the flush stream for transport out of the module. The flush liquid is the feed liquid and no other cleaning is required. The cake is deposited onto a wedge wire screen and the flush liquid returned to the feed tank for reprocessing. Thus the Exxpress module is cleaned on each discharge cycle.

The ATFP process is suitable for most types of weak sludges and concentrates containing 0.1-5% suspended and particulate matter. Significant advantages of the system include its fully automatic operation, no filter cloth washing requirement, high throughputs due to the short load cycles, operation without chemical conditioning additives such as polyelectrolytes in most cases, and excellent cake dryness on difficult to dewater sludges.

PROCESS APPLICATIONS

EXXFLOW tubular microfiltration is the most versatile microfiltration system available. Examples of successful applications are given in Table I.

TABLE I **Tubular Microfiltration Applications**

APPLICATION	REMOVES	METHOD
WATER TREATMENT		
Surface Water	Bacterial Removal	Direct
Surface Water	Taste & Odor	Ozonation
Surface Water	Organics	Powdered activated carbon
Groundwater	Fe/Mn	Pre-oxidation
Groundwater	Cr	Chemical Precipitation
Hardwaters	Ca/Mg/Si	Seeded slurry
Surface water	Nitrates	Powdered resins
Oil produced water	Oil & Solids	Adsorbents
INDUSTRIAL WASTEWATER		
Ceramics	Heavy Metals / Solids	Precipitation
Ceramics	Fine Particulates	Direct
Microchip	Fluoride	Precipitation
Circuit Board	Heavy Metals	Precipitation
Laundries	Oil & Grease / Metals	Adsorbents
Anodizing	Kerosene Wash	Adsorbents
Printing	Ink / Metals	Precipitation
Pesticide	Ag Chemicals/O&G/Metals	Precipitation
Automobile	Protective Coating	Direct
Oilfield	Oily Sludges	Adsorbents
Latex	Emulsions	Direct
PRODUCT FILTRATION		
Wine	Yeast	Direct
Wine	Lees	Direct
Grape Juice Concentrate	Solids/Yeast	Direct
Industrial Chemicals	Solids	Direct

SPECIFIC CASE HISTORIES

CERAMIC PAINT AND GLAZES WASTEWATER

This program was supported by the California Department of Health Services and Duncan Ceramics, for the commercial demonstration of a membrane filtration system using no filter aids to reduce a heavy metal laden waste water to zero discharge with 100% recycle of the waste.

The washdown water from ceramics plants contain ceramics fines, ground glass, clays, and heavy metal laden paints and glazes. Originally, this wastewater was filtered through a rotary drum vacuum filter with the use of diatomaceous earth (DE) as a filter aid. The DE addition doubled their waste volume which had to be hauled to a hazardous waste landfill. The filtrate was sewered with some of the contamination remaining.

The wastewater containing as much as 5% w/w solids and up to 6 g/l of lead and other heavy metals is now dewatered by an ATFP unit to a 50-60% w/w filter cake. The filtrate of the ATFP containing the dissolved heavy metals, is raised in pH with sodium hydroxide and becomes the feed water for the microfilter. The metals are removed and the filtrate is recycled back to the plant as product dilution water. The concentrate containing the precipitated heavy metals is returned to the front end of the ATFP unit for mixing with the solids. The filter cake consisting of heavy metals and ceramics fines is dried and vitrified. The glass-like product is returned to the plant as frit, a component in the ceramics process.

The benefit to the ceramics producer is savings of over $600,000 per year in hazardous waste disposal cost, nearly half of which had been contaminated filter aid material. The benefit to the environment is zero discharge of hazardous wastewater to the sewer or to landfill with the saving of over 2 million gallons of water per year.

The system was installed and has been in full operation since April 1990. Waste reduction and plant details are given in Table II.

PESTICIDE FORMULATION WASTE

A crossflow microfilter and ATFP system was installed in October 1989 to treat pesticide, oil, and heavy metals laden wastewater from the FMC Corporation factory in Fresno, California. The technology replaced three process steps of oil water separation by dissolved air flotation, chemical coagulation and carbon filtration.

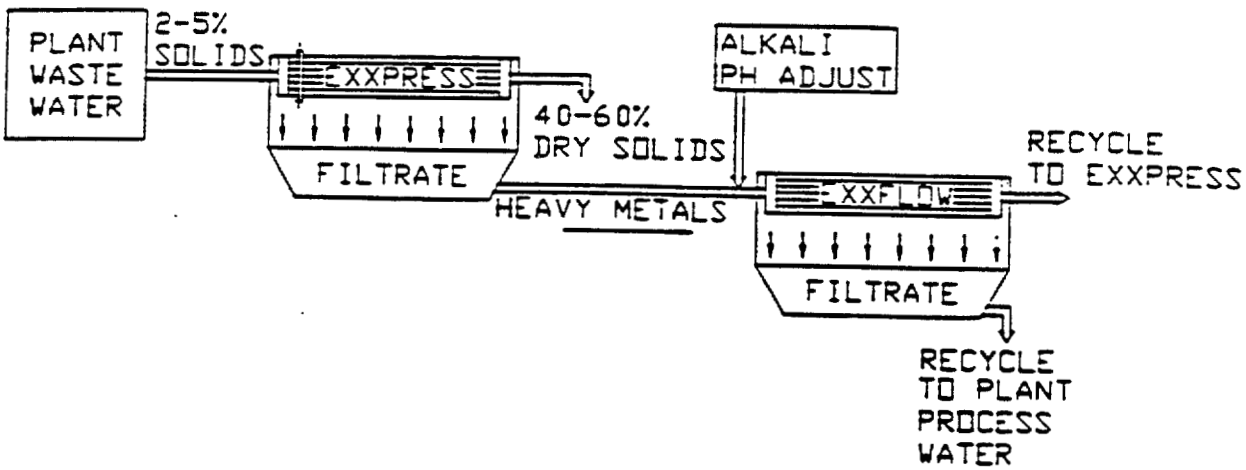
The wastewater from the formulation of pesticides and other agricultural chemicals is stored and batch treated through the EXXFLOW / EXXPRESS system. Lime is added to precipitate the heavy metals. The lime solids also form a precoat on the microfilter which effectively adsorbs the emulsified oil.

Water recovery is in the 99% range with the concentrate solids as high as 6% w/w. The filtrate water is polished with carbon and reused as rinse water and for product dilution. The

microfilter concentrate is dewatered to a 50% w/w cake by the ATFP unit. Overall, the hazardous waste volume is reduced from 30,000 gallons of liquid per batch to 50 gallons of dry cake solids. Annual savings are currently over $500,000 with zero discharge to the environment. Waste reduction and plant details are given in Table III.

TABLE II

CERAMICS PLANT

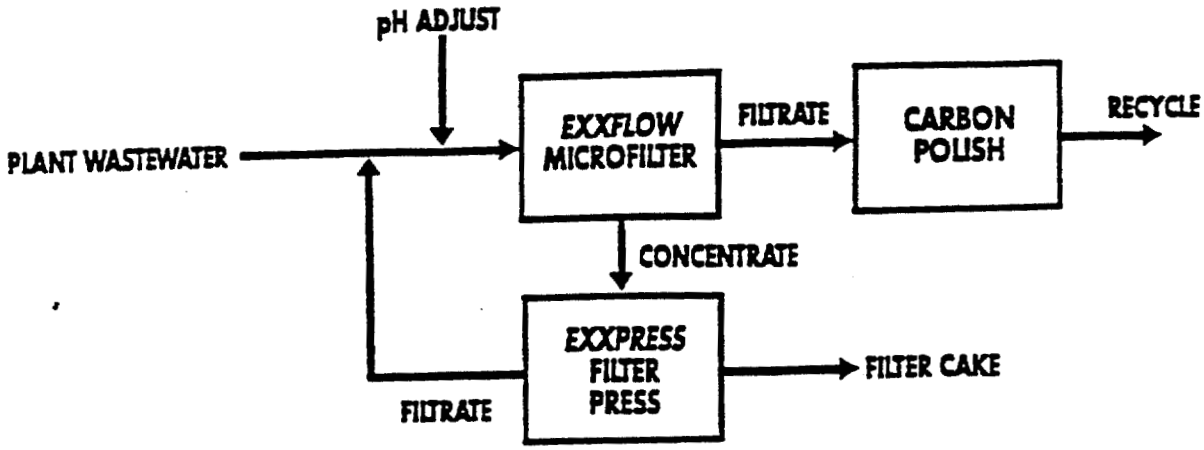


Ceramics Manufacture Waste Treatment Plant Results

		RAW FEED	FILTRATE	CAKE
Suspended Solids	(g/l)	20 - 50	< 0.01	50% w/w
Lead	(mg/l)	2000 - 6000	< 0.20	
Cadmium	(mg/l)	18	<0.05	
Cobalt	(mg/l)	21	<0.03	
Zinc	(mg/l)	295	<0.05	

Design Capacity: Exxflow 20 GPM Exxpress 3,000 lb/d

TABLE III



Pesticide Formulator Waste Treatment Plant Results

	RAW FEED	FILTRATE	AFTER CARBON
Organochlorine Pesticides (ug/l)	34,330	30.0	0.07
Organophosphorus Pesticides (ug/l)	191,360	587.3	0.30
Carbamate Pesticides (ug/l)	8,500	21.0	ND
	234,19	638.3	0.37
	(99.7% Removal)	(100% Removal)	

Metals (As, Cr, Cu, Pb, Zn) (mg/l)	23.143	0.23 (99% Removal)
Oil & Grease (mg/l)	>5,000	<25 (99.5% Removal)

Exxpress Filter Press Cake >40% w/w solids

Design Capacity: Exxflow 15 gpm; Exxpress 1 cu ft/hr.

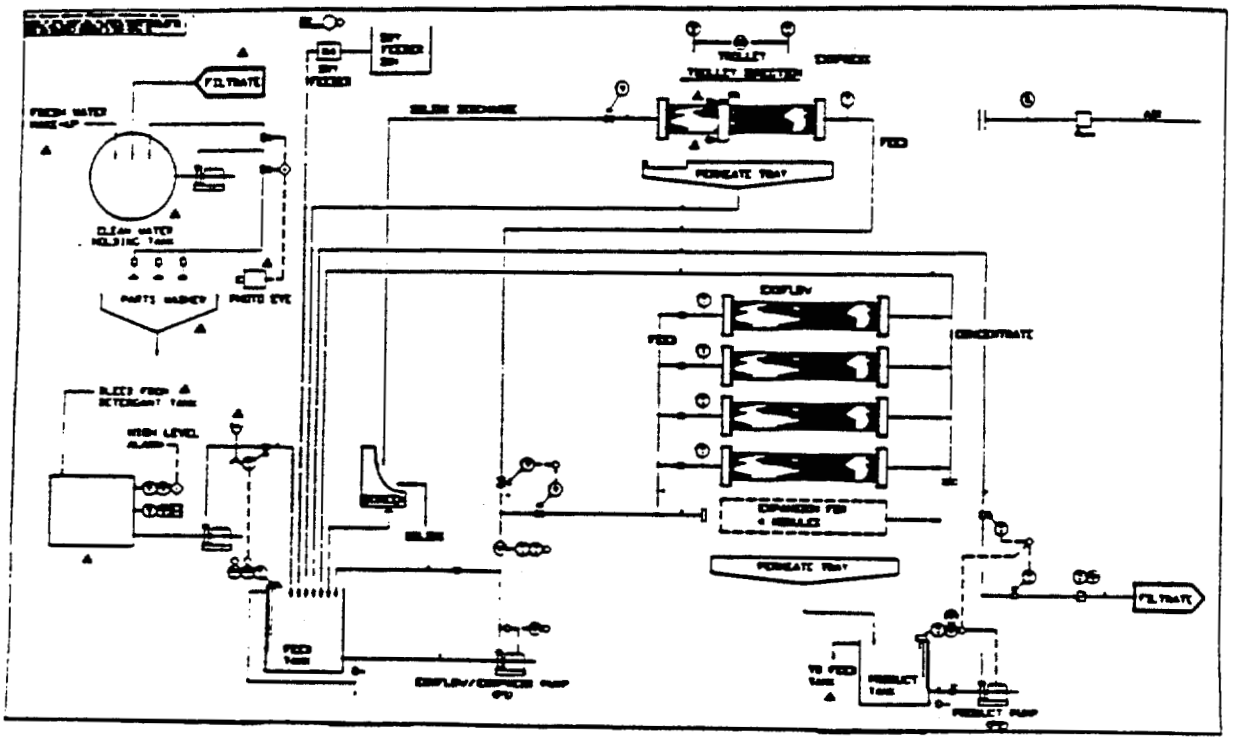
Cost Savings: $1.5 million/year vs. disposal as hazardous waste.

METAL FINISHING SEWAGE PRETREATMENT

After nearly four years of research and testing alternative wastewater treatment systems, Commercial Aluminum Cookware of Toledo, Ohio contracted for an EXXFLOW and EXXPRESS ATFP filtration system to remove kerosene, oils, and detergent from their machined parts wash line.

In the process a proprietary powdered adsorbent is introduced to the feed water. The adsorbent forms a dynamic membrane in the tubular module which removes all of the oil and grease, kerosene and detergent to below the 10 ppm discharge requirement. The water recovery is 99.9% of the feed flow with 0.1% concentrate processed by the ATFP unit to a 30 - 40% w/w solids cake. The treated water is recycled back to the parts washer. The plant has paid for itself in less than one year by recycling 40 gallons per minute of wastewater which would have previously been discharged to sewer. Details are given in Table IV.

TABLE IV



Metal Finishing Sewage Pretreatment Results

	RAW FEED	FILTRATE
Oil & Grease/Kerosene	Up to 150 mg/l	<5mg/l
Metal Fines 10-50 mg/l	ND	
Exxpress Filter Press Cake	>30% solids w/w	

Design Capacity: 40 gpm

Paycheck: Less than 3 months vs. disposal

SUMMARY

The EXXFLOW tubular microfiltration and EXXPRESS tubular filter press systems provide new technology which effectively and safely treat a wide range of waters, wastewaters and industrial wastes. The technology is a significant improvement over existing systems and the American Filtration Society has honored Epoc Water with its New Product Award for 1990. Excellent separations are achieved of particulate and colloidal matter, suspended solids, bacteria, heavy metal hydroxides, oils, fine participates and some organic materials. Enhanced separation using powdered activated carbon (PAC), powdered ion exchange resins and specialist dynamic membrane layers can be obtained in certain applications. This unique combination of dynamic membrane layer technology and a flexible tubular array support module has many exciting possibilities in a wide range of industries. It is economic and easily cleaned, it is robust and can process waters containing very high concentrations of suspended solids.

TOTAL WASTEWATER TREATMENT AND REUSE BY CLOSE LOOPING

Alex R. Keen B.E.S., President
Randy J. Sinukoff M.A.Sc., P.Eng., Senior Associate

ALTECH Environmental Consulting Ltd.

INTRODUCTION

Recent initiatives toward wastewater pollution management in the photographic processing and printing industries have been primarily directed at reducing volumes of washwater used and at removing valuable contaminants such as silver. New chemical formulations and chemical regeneration packages for processing solutions have also decreased the quantities of regulated materials being discharged down the sewer. In reality, only regeneration and recycling of processing solutions has had an impact on overall mass loading of contaminants found in sewer effluents from these industries.

ALTECH Environmental Consulting Ltd, in cooperation with Black Photo Corporation of Markham, Ontario, has thoroughly researched the mechanisms of the photographic processes, the function of all chemistry involved, and appropriate technological options to completely close loop and treat all process streams and washwater at Black's main photographic processing plant. The Black's facility is the largest photofinishing operation in Canada.

Detailed scientific and analytical studies were conducted by ALTECH to delineate the composition of each in-house process stream which was previously discharged to the sanitary sewer. All quantitative results and information discussed in this paper are the result of this work. A detailed design was conceived, tested, and implemented, incorporating membrane filtration, vacuum distillation, activated carbon treatment, ion exchange, and electrolytic silver recovery. This total system, called *System Crystal*, has been operating since June 1, 1991 to provide total water reuse and a dry process sewer.

Before System Crystal was installed, up to 70,000 USGPD of wastewater was discharged from the facility consisting of depleted photographic chemicals and once-through washwater. The closed loop process treats and recycles water, resulting in a final system byproduct of up to 200 USGPD mixed photochemistry concentrate, which is sent for incineration. Through System Crystal, Black's has achieved a 97% reduction in process water usage, the remaining 3% used to make up evaporative losses.

PROJECT STRATEGY

Based on the results of ALTECH's flow and contaminant loading study of all process streams and washwaters at the Black's facility, a strategy was conceived to develop the closed loop system. Six separate research and design areas were targeted for action as follows:

- Understand the variables affecting process chemistry to predict key sensitivities or constraints on close looping;
- Determine potential for implementing additional regeneration packages, both available and custom, for processing solutions;
- Analyze existing fixer regeneration and desilvering system for added efficiencies;
- Determine treatment options for non-regenerable solutions, including final design;
- Fully characterize washwaters and develop system flow strategy; and,
- Determine optimum treatment strategy for washwaters, including final design.

In all work performed, the quality of the final photographic product had to be maintained as the first priority.

An extensive literature survey was done to establish baseline information, such as determining the function and fate of each chemical component, and determining the impact each substance has on the photographic process. Where information was unavailable or unknown, bench-scale and pilot-scale experimentation was performed by both ALTECH and Black's to determine feasibility of theories and design. This resulted in a thoroughly researched final system particularly suited to the Black's operation, but with internal flexibility incorporated to enable ease of operation and accommodation of future process changes.

During the initial study, analysis of key parameters such as BOD, TOC, iron, silver, and halogens at source and at end of pipe determined that over 95% of mass contaminant loading originated from the 2% of the total wastewater volume attributed to high strength process solutions. From this, the treatment system was designed to handle process chemistry and washwater separately. Typical BOD values for photographic solutions and non-recycled washwater are 1500 ppm and 10 ppm respectively.

HIGH STRENGTH TREATMENT

The composition of a typical mix of depleted photographic solutions is shown in Table 1. This stream can vary significantly depending on daily plant operations and represents high strength materials which cannot be regenerated due to technology, quality, or economic restrictions. The water portion of the solution (typically above 90%) is extracted by a vacuum distillation system with a processing capacity of 2400 USGPD. The equipment operates at ambient temperature and 685 mm Hg of vacuum.

TABLE 1:
CONTAMINANT PROFILES BEFORE TREATMENT

	High Strength Stream (%) (Estimated)	Fixer Washwater (ppm)	Remaining Washwater (ppm)
Benzyl Alcohol	0.3		50
Ethylene Glycol	0.5		ND
Acetic Acid			2200
Carbonate	2.5		1080
Amines	0.3		3660
Ammonium Nitrogen	0.8	1150	1680
Chelates as EDTA	0.5		8800
Free Sodium			110
Free Potassium			420
Free Calcium			90
Free Magnesium			30
Free Iron		1	1260
Total Iron	0.7	1	1500
Total Silver		40	
Sulphite	0.5	1250	140
Sulphate	0.4	1500	560
Thiosulphate	0.7	3480	
Nitrate			90
Chlorides, Bromides	1.5		5400

All values are estimates for maximum operating conditions based on actual analytical results.

Depending on the feed composition, the aqueous distillate contains impurities of up to 0.4% ammonia, 0.2% benzyl alcohol, 0.04% ethylene glycol, and trace aromatic derivatives. The concentrate contains approximately 25% precipitated organic and

inorganic salts of glycol, EDTA, amine, halide, carbonate, and sulphate nature. The remaining concentrate liquid is approximately 40% water, 55% paraphenylene diamine derivatives (from photographic developers), 3% ethylene glycol, 1% benzyl alcohol, and remainder trace organics. This stream represents the 200 USGPD residual which is ultimately taken for incineration.

The distillate flow of up to 2200 USGPD is treated by activated carbon to remove organics and by ion exchange to remove ammonia. This enables this water to be reused as makeup for washwater and process solutions.

The ion exchange regeneration effluents were also targeted for recycling and reuse by segregating each charge of liquid to the resin bed. Residual distillate is sent back to the column feed tank, spent sulphuric acid is sent to vacuum distillation, and 85% of the column rinse water is reused for the next regeneration. It is also possible that the concentrated ammonia from the sulphuric acid regenerate can be reclaimed for chemical manufacturing by outside sources.

WASHWATER REUSE AT SOURCE

The contaminants found in washwater are the result of carryover from the preceding process baths. In photoprocessing equipment operated in a traditional manner, washwater is used on a once-through basis, resulting in a concentration of carried-over impurities which is typically in compliance with most sewer by-law parameters. In a closed-loop system such as System Crystal, a portion of the washwater is recirculated at source to increase the loading and make more efficient use of each volume of water used. This increased loading has in no way compromised the quality of photographic film and paper processed by Black's.

The decision to close loop the process was taken by Black's to ensure sewer use compliance at all times in the future and to lead the photoprocessing industry in protecting the environment. Water reuse strategies which reduce the total volume of water discharged cannot be effective in maintaining compliance unless appropriate treatment is also added. Thus it is difficult to use water in its most efficient manner without detailed analysis of the impurities in the wastewater stream and how they are generated.

WASHWATER TREATMENT

Table 1 details the maximum contaminant profiles of two separate washwater streams. All fixer washes contain silver thiosulphate complexes and are combined to pass through a nanofiltration system at 5000 USGPD to concentrate silver for subsequent electrochemical removal. The permeate stream composed of ammonium, chloride, bromide, sodium and calcium ions, is treated by reverse osmosis. Total dissolved solids content in the final treated water is typically 280 ppm as compared to Markham city water at 370 ppm. All water is recirculated to source wash baths after treatment.

The remaining washwaters from each photographic process are reused insitu to increase contaminant loading before treatment. A continuous stream from each washbath is collected and treated by nanofiltration at 2400 USGPD to remove the majority of the impurities present. The permeate stream is sent to the reverse osmosis system for final treatment and for recirculation of clean water to all processes. The concentrate streams from washwater treatment are collected as a high strength mixed process solution which is treated by vacuum distillation.

Before membrane treatment, all washwater passes through a sterilization station which uses ultra-violet light to neutralize any algae which is present. This process was installed to control algae build-up in the wash baths, which is a common problem in the photoprocessing industry. Provisions have also been made to circulate all untreated washwater through the algae destruction station during off-hours and on weekends to ensure that algae growth is controlled at all times. The algae control system has been highly successful thus far.

Evaporative and system losses are replenished with city water makeup and treated vacuum distillate. The city makeup stream constitutes approximately 8% of the daily volume of water treated, and depends primarily on the volume of water lost to the atmosphere as a result of drying the photographic paper product.

A comprehensive economic and performance evaluation of the entire system is currently underway.

INNOVATIVE ADVANCED TREATMENT SYSTEM ACHIEVES "ZERO DISCHARGE"

Dals H. Chaudhary, P.E., Vice President
Robert E. Hagadorn, P.E., Senior Vice President
Hazen and Sawyer Environmental Engineers & Scientist, New York

When PepsiCo, Inc. chose the shores of the Muscoot Reservoir in Somers, New York as the site for its new World Beverage Headquarters, it wasn't hoping for an award for innovative engineering design. Proximity to the reservoir, a New York City water supply, however, demanded that PepsiCo build a "Zero Discharge" sanitary wastewater treatment system capable of supporting a corporate facility that will ultimately employ 6,000 people.

Following environmental and treatment system design considerations were established as part of overall project planning guideline.

- Zero discharge due to proximity to the Muscoot Reservoir.
- Preserve site aesthetics and conserve space.
- Recycle treated effluent to meet 100% of the facility's non-potable water needs.
- Remaining treated effluent to recharge beds located under the parking lot.
- High quality effluent requirement including dual nutrient removal and activated carbon adsorption.
- Separate RO treatment of cooling tower blowdown to conserve water.
- Flexibility to expand in phases.

PROCESS AND DETAILED DESIGN

Since effluent is reused and a portion is discharged to a subsurface leaching system, very stringent effluent levels were established as given in Table 1:

Table-1

REQUIRED EFFLUENT LEVELS	
BOD_5 - mg/l	- 10
TSS - mg/l	- 10
TKN - mg/l	- 3
Ammonia Nitrogen - mg/l	- 2
Nitrates as N - mg/l	- 10
Phosphorus as P - mg/l	- 3

Wastewater treatment facilities are sized for the Phase I population 2,000 flow of 40,000 gpd, with provision for expansion to the ultimate population 6,000 flow of 116,000 gpd. Design influent wastewater characteristics are as given in Table-2:

Table-2

DESIGN INFLUENT CHARACTERISTICS	
Office Population	- 2,000
Wastewater Flow - GPD	- 40,000
BOD_5 - mg/l	- 430
TSS - mg/l	- 420
TKN - mg/l	- 100
Ammonia Nitrogen - mg/l	- 50
Nitrates as N - mg/l	- 7
Phosphorus as P - mg/l	- 40

The complex on-site sanitary waste treatment processes employed treat the wastewater to required levels and recycle up to 70% of the treated effluent to provide 100% of the facility's non-potable water needs. Remaining 30% of the treated effluent is discharged to groundwater recharge beds of 38,000 square feet concrete chambers located under the office complex parking lot. This effectively preserves space and site aesthetics. Recycling both reduces PepsiCo's water requirements and lessens the amount of groundwater recharge to the poorly permeable soils. Preliminary treatment processes include screening, flow equalization, primary settling, and alum addition for phosphorus removal. Next, activated sludge with single stage extended aeration substantially reduces BOD and TSS levels and provides nitrification. Denitrification is achieved in packed bed, fixed film anaerobic reactors with methanol addition and is followed by multimedia filtration and hypochlorite disinfection prior to groundwater

discharge. The treated effluent targeted for recycle receives activated carbon adsorption for color and odor control and is rechlorinated for disinfection to create an acceptable non-potable water supply as illustrated in the schematic (Figure-1). Shown on the right side of the schematic is the cooling tower blowdown, reverse osmosis treatment system which also provides for water recycle.

TREATMENT SYSTEM OPERATION AND MONITORING

Process parameters monitored include BOD_5, TSS, TKN, ammonia nitrogen, nitrates and phosphorus. In addition, activated sludge mixed liquor solids, pH and temperature levels are recorded for process control. Alum addition for phosphorus removal tends to lower the pH level requiring caustic addition to adjust pH and restore alkalinity for nitrification. Final effluent BOD is very sensitive to methanol feed in the denitrification column and close attention is required to prevent overdosing. Primary sludge and waste activated sludge is discharged to on-site sludge holding tanks and then trucked for disposal off-site.

SYSTEM PERFORMANCE TRACK RECORD

After initial start-up adjustment in process parameters, treatment system performance continues to be in compliance with all effluent parameters. Plant performance for the calendar year 1989 is given in Table-3.

Table-3

PLANT PERFORMANCE

Parameter	Influent mg/l	Effluent mg/l	Percent Removal
BOD_5	224	8	96.4%
TSS	335	8	97.6%
TKN	50	3	94%
Amm-N	27	1.2	95.6%
Nitrate-N	9	3.1	65.6%
Phosp-P	9	1.6	82.2%

Hazen and Sawyer's design of this advanced treatment system received first prize in the 1989 New York American Consulting Engineers Council's Engineering Excellence Competition for its ability to meet a complex set of environmental requirements. These included minimizing space usage and preserving the site aesthetics of the naturally wooded area, creating an effluent recycling system to accommodate limited well water supplies, poor soil permeability, and lack of a nearby public sewer system; and achieving a high quality of effluent to protect the reservoir and meet the "zero discharge" requirements of a planning agreement with the City of New York.

Due to the stringent environmental requirements of the project site, Hazen and Sawyer provided assistance in treatment process and effluent requirement negotiations with New York City and Westchester County officials; liasion activities to secure necessary project approvals and permits; and intensive post start-up serives including operator training, operations and maintenance manual preparation, and on-going system consultation.

The application of state-of-the-art technologies beyond their normal uses satisfied the aesthetic and environmental concerns that were the focus of this project. For PepsiCo, these innovative engineering solutions were tailored to help them continue their growth in an environmentally responsible manner. For the engineering profession, they provide demonstration for practical application elsewhere to alleviate similar environmental problems associated with growing land development.

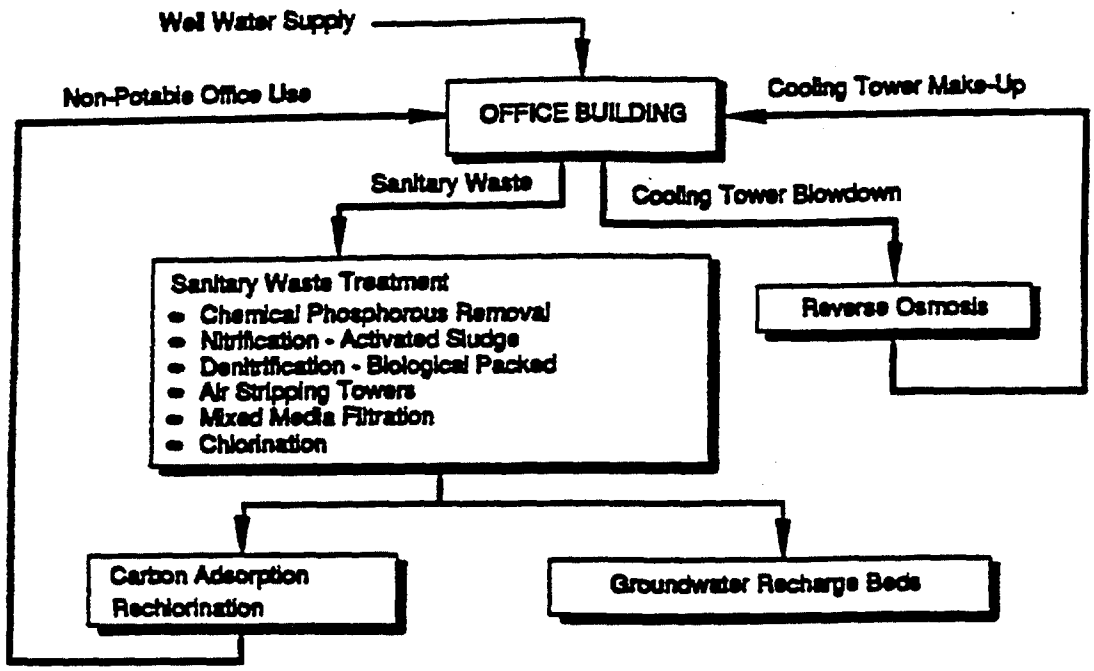

Well Water Supply
Non-Potable Office Use
OFFICE BUILDING
Cooling Tower Make-Up
Sanitary Waste
Cooling Tower Blowdown
Sanitary Waste Treatment
• Chemical Phosphorous Removal
• Nitrification - Activated Sludge
• Denitrification - Biological Packed
• Air Stripping Towers
• Mixed Media Filtration
• Chlorination
Reverse Osmosis
Carbon Adsorption
Rechlorination
Groundwater Recharge Beds

FIGURE 1

Case Studies

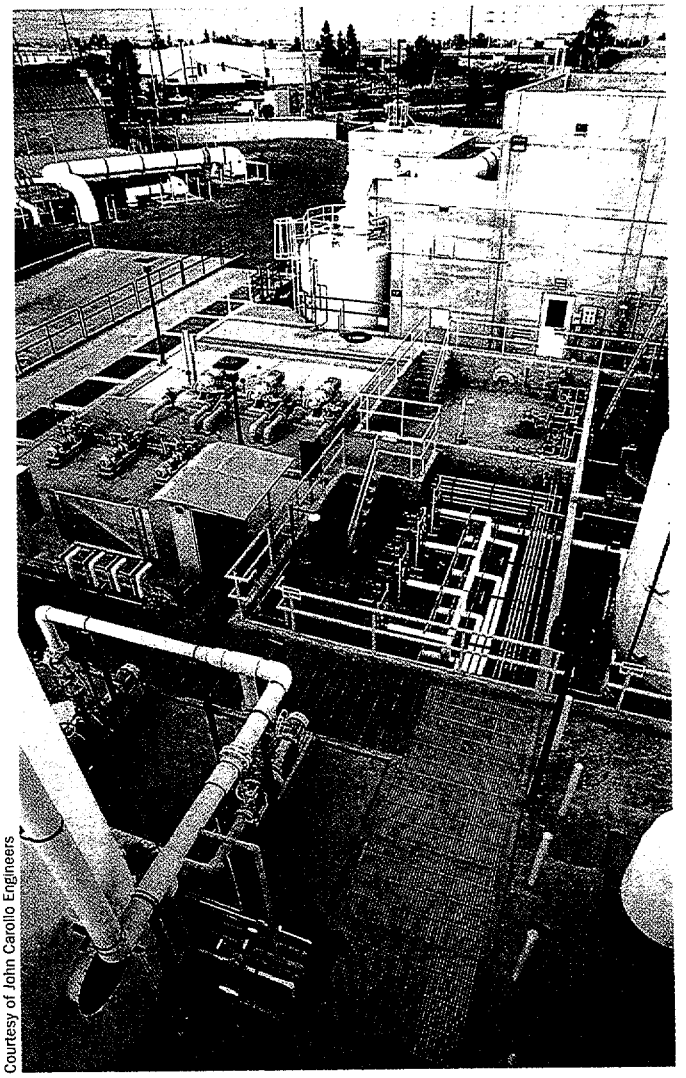
Metals Meet Their Match

The County Sanitation Districts of Orange County, Calif. (CSDOC) combine an aggressive source control program with enhanced primary treatment to reduce total suspended solids (TSS), biochemical oxygen demand (BOD), and heavy metals in wastewater discharged to the Pacific Ocean. Over the past 6 years, effluent discharge of BOD has been reduced by 8%; TSS, by 13%; and heavy metals, by 44%.

Source control and enhanced primary treatment increase heavy metals removal

Mary C. Lee
Paul J. Schuler
Blake Anderson
Robert J. Ooten

The districts own and operate two wastewater treatment plants along the Santa Ana River in Fountain Valley and Huntington Beach, collection and transfer facilities, interplant pipelines, and a 3-m-dia (10-ft-dia) ocean outfall. The facilities currently operate under a 301(h) waiver of the Clean Water Act that allows discharge of blended primary and secondary effluent to the Pacific Ocean. The districts' National Pollutant Discharge Elimination System (NPDES) permit discharge limits are based on a combination of the Clean Water Act 301(h) waiver, the 1983 California Ocean Plan, and local basin regulatory requirements of the California Regional Water Quality Control Board.



Courtesy of John Carollo Engineers

Orange County has reduced metals loadings in plant effluent by almost 86% over the last 15 years.

Removal of Metals with Enhanced Primary Treatment, 1991–92

Unit process	Percent removal						
	Cadmium	Chromium[a]	Copper	Lead	Nickel	Silver	Zinc
Plant 1 Advanced primary	46	53	52	70	33	39	57
Plant 2 Advanced primary, Side A	65	59	54	69	33	50	77
Plant 2 Advanced primary, Sides B and C	66	57	57	71	27	54	51
Final effluent[b]	74	69	73	80	36	65	72

[a] Total chromium.

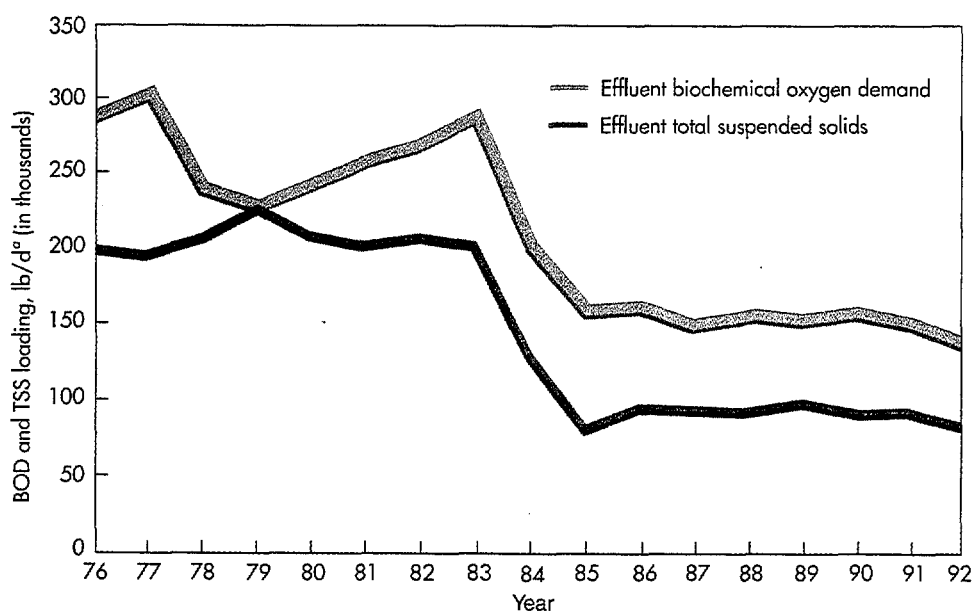
[b] Cumulative overall removal.

SOURCE CONTROL PROGRAM

The districts' approach to industrial pretreatment, as embodied in its federally approved program, focuses on the control and minimization of pollutant discharges from industrial sources by controlling them at their source. The districts currently regulate more than 1000 industries, 400 of which are deemed "significant industrial users" in accordance with the federal definition. The current approach consists of:

- a permitting program, which focuses on problem prevention by requiring careful evaluation of pretreatment and waste minimization systems before an industry is allowed to discharge. Permits issued for each discharge location contain effluent limits, monitoring schedules, reporting and notification requirements, and other management practices. To promote water conservation and place a cap on the mass of pollutants entering the sewerage system, the districts issue mass emission permit limits specified in pounds per day, in addition to issuing concentration limits.
- a field monitoring and inspection program to determine whether industries meet their permit requirements. During the last fiscal year, more than 2000 inspections were collected, and more than 25,000 laboratory analyses were performed. Compliance with requirements is also determined based on self-monitoring conducted by each industry. A downstream monitoring program supplements on-site evaluations with the collection of clandestine wastewater samples.
- an enforcement program that incorporates a progressive series of actions to deter industries from violating discharge requirements, and to bring noncompliant industries back into conformance with requirements. The available enforcement procedures

Average Effluent BOD and TSS, 1976–92



[a]lb/d × 0.453 = kg/d

Average Influent and Effluent Metals Loading, 1987–92

	Influent, lb/d[a]					Effluent, lb/d				
Constituent	87-88	88-89	89-90	90-91	91-92	87-88	88-89	89-90	90-91	91-92
Cadmium	23	18	9	10	8	8	6	3	3	2
Chromium	100	93	61	50	50	32	34	17	13	17
Copper	470	417	342	345	259	140	130	98	94	68
Lead	86	88	52	31	28	21	44	15	4	6
Nickel	120	103	85	76	73	63	66	50	48	46
Silver	39	37	40	43	32	21	18	15	15	10
Zinc	400	357	340	363	305	130	130	131	125	85
Total average	1238	1113	929	918	755	415	428	329	302	234

[a] lb/d × 0.453 = kg/d.

include written notices, probation orders, enforcement agreements, administrative penalties, permit suspension or revocation, and civil or criminal actions. The districts have joined with the state, county, city, and other local agencies to form an interagency hazardous waste strike force that investigates, identifies, and prosecutes industries suspected of cross-media environmental crimes.

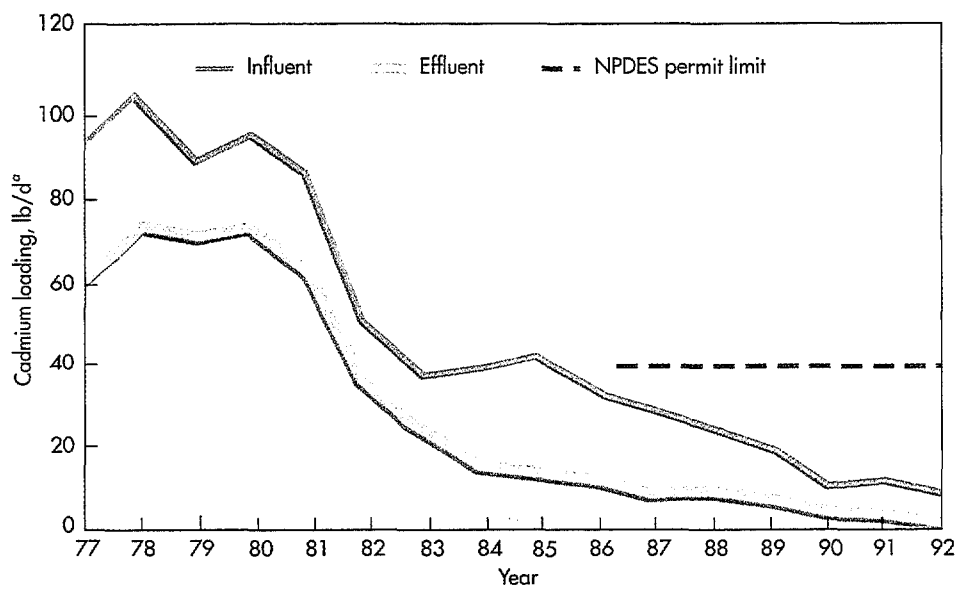
- a pollution prevention program that requires all companies that violate discharge requirements to undertake a waste minimization assessment and implement those techniques found to be technically and economically achievable. Industries are provided with guidelines on how to conduct the assessment and information on proven waste minimization techniques.
- a public participation program that cultivates the development of close ties to the industrial community, other regulatory agencies and the general public through coordinated public participation activities. These include the districts' ad hoc industrial advisory committee, which is made up of representatives from industries within the districts' service area.

Since 1976, the total mass of heavy metals discharged to the sewerage system has decreased by 77%, while the mass of metals discharged to the marine environment has decreased by 55%. This reduction has occurred despite a 25% increase in flow. The reduction in toxics by the source control program has been so effective that, for the last three years, the influent heavy metals have met the districts' NPDES discharge standards before wastewater treatment has occurred.

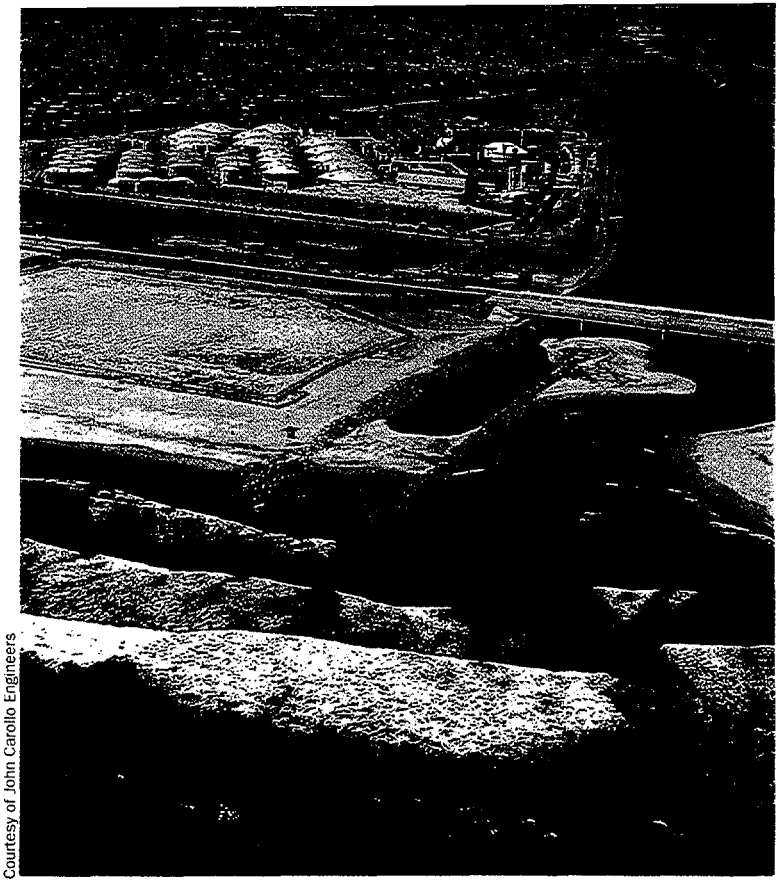
TESTS SHOW ENHANCED TREATMENT IS VIABLE

Population growth in Orange County has resulted in increased wastewater flow to the districts' facilities, and additional treatment has become necessary to

Average Influent and Effluent Cadmium, 1977–92



[a]lb/d × 0.453 = kg/d



Courtesy of John Carollo Engineers

Physical-chemical treatment facilities have improved BOD and TSS removal.

meet permit limits. The districts evaluated enhanced primary treatment (physical-chemical treatment) at the primary clarifiers to determine whether this treatment could meet permit limits without the construction of additional secondary treatment.

Adding ferric chloride and anionic polymer. The districts conducted a 7-day, full-scale study of enhanced primary treatment by adding ferric chloride and an experimental anionic polymer to the primary influent flow. A full-scale primary clarifier was constructed at CSDOC Plant 2. The treatment train consisted of a 43-m-dia (140-ft-dia) circular basin 3 m deep (9 ft deep), a rapid-mix chamber, a flocculation chamber, and multiple chemical-injection points.

Ferric chloride was added at 20 ppm, and anionic polymer at 0.25 ppm; flow proportioning pumps maintained these required dosages. Samples were collected every 4 hours from the experimental clarifier and an adjacent control clarifier and analyzed for TSS, turbidity, grease and oil, BOD, chemical oxygen demand (COD), ammonia, heavy metals, phenol, and cyanide.

Results showed that the chemical addition increased removal efficiency of the primary clarifiers. The TSS removal in the clarifiers improved from approximately 70% in the control clarifier to 84% in the experimental clarifier. The BOD removal increased from approximately 27% to 45%. Metals removal increased as follows: silver, 44%; cadmium, 27%; chromium, 16%; copper, 35%; mercury, 10%; lead, 28%; and zinc, 27%.

Comparison study. The districts also conducted a 6-week study to further investigate the feasibility of the new treatment. During normal operation, the primary clarifier system at CSDOC Plant 2 is divided into sides A, B, and C, with each side receiving approximately equal flow. Effluent from side A receives secondary treatment, side C effluent receives only primary treatment, and side B effluent is proportioned between secondary treatment and primary treatment.

During the study, wastewater flow through side B received enhanced primary treatment and side C was the control. Side A continued to receive secondary treatment.

Ferric chloride was added to the headworks splitter box in a turbulent region after the headworks pumps to facilitate mixing. The polymer was added in a turbulent area of the primary flow distribution box to facilitate mixing before reaching the clarifiers.

During the study, the chemical systems operated 24 hours per day; however, the chemicals were not flow-paced. Chemical addition was based on a dosage of 20 ppm ferric chloride and 0.025 ppm polymer at peak daily wastewater flow. Side B flow ranged from a minimum of 1360 L/s (31 mgd) to a peak of 3600 L/s (82 mgd), with an average flow of 2700 L/s (62 mgd).

Grab samples were collected four times per day and analyzed for TSS and BOD. Additional grab samples from two basins were composited on a daily basis for 1 week and analyzed for heavy metals (see Table, *Removal of Metals with Enhanced Primary Treatment, 1991–92.*

TSS and BOD removal. The clarifiers increased the removal efficiency of TSS by 9%. Effluent from the experimental clarifier contained 57 mg/L TSS, while that from control clarifiers was 73 mg/L. The experimental clarifier achieved an average influent BOD removal efficiency of approximately 41%, compared with a 26% removal efficiency in the control clarifiers.

Heavy metals removal. The experimental clarifier effluent contained lower concentrations of all monitored metals, except iron. In fact, removal of cadmium, copper, and chromium improved. The removal efficiency of the more soluble metals, such as nickel, however, was only slightly better than in the control clarifier.

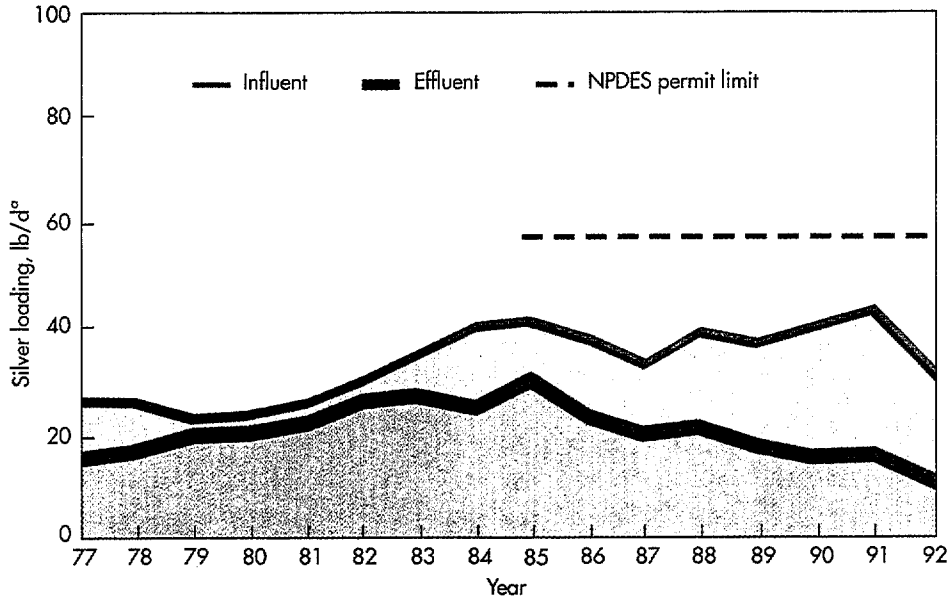
The ferric chloride solution contained 40% ferric chloride and trace amounts of other metals. Less than 2 ppb of any trace metal in the 20-mg/L ferric chloride dose contributed to the final effluent.

FULL-SCALE IMPLEMENTATION RESULTS ARE FAVORABLE

After testing, the districts constructed full-scale enhanced primary treatment facilities at both plants. Enhanced primary treatment was initially operated 6 to 12 hr/d; however, CSDOC Plant 2 has recently implemented 24-hour treatment. Effluent data show that TSS, BOD, and heavy metals removal has been effective.

TSS and BOD removal. Over an 18-year period, TSS has decreased from more than 72,600 kg/d (160,000 lb/d) to 38,600 kg/d (85,000 lb/d) (see Figure, *Average Effluent BOD and TSS, 1976–92*). Many improvements have been made during this time, including addition-

Average Influent and Effluent Silver, 1977–92



[a]lb/d × 0.453 = kg/d

al secondary treatment. Enhanced primary treatment has contributed to BOD and TSS reduction.

In 1992, effluent BOD discharge was approximately 63,500 kg/d (140,000 lb/d), which is 11% below the previous 6-year annual average daily discharge. The mass emission discharge rate of BOD decreased from more than 72,600 kg/d (160,000 lb/d) to 63,500 kg/d (140,000 lb/d) even though flow has increased.

Heavy metals removal. The concentrations of seven metals (cadmium, chromium, copper, lead, nickel, silver, and zinc) are monitored by the districts every four days at the treatment plants and used to evaluate plant removal efficiency (see Table, *Removal of Metals with Enhanced Primary Treatment, 1991–92*). The percent removal at Plant 1 is lower than at Plant 2 because of higher hydraulic loading at Plant 1. In addition, enhanced primary treatment was only used for 10 hr/d at Plant 1 during the reporting period as compared with 12 hr/d for Plant 2. Lead, chromium, copper, and zinc removal is enhanced with the chemical addition.

Since the source control program and full-scale enhanced primary treatment implementation, influent metals concentrations have decreased approximately 39%, and effluent metals concentrations have declined 44% (see Table, *Average Influent and Effluent Metals Loading, 1987–92*).

During 1991–92, effluent discharge of cadmium averaged 0.9 kg/d (2 lb/d), compared to 1.4 kg/d (3 lb/d) the previous year and the NPDES 6-month limitation of 17 kg/d (38 lb/d). During the past 5 years, influent cadmium has decreased by 65%, while effluent cadmium decreased by 75% (see Figure, *Average Influent and Effluent Cadmium, 1977–92*).

Effluent chromium discharge in 1991–92 averaged 6.8 kg/d (15 lb/d); although this represents a 0.9-kg/d (2-lb/d) increase from the previous year, this value is well below the NPDES permit limit of 86 kg/d (189 lb/d). During the past 16 years, influent chromium has been reduced by 88%, while effluent discharge has decreased by 94%.

During the past 5 years, the influent copper level was reduced by 45%, while the effluent level has decreased by 51%. Effluent copper averaged 31 kg/d (68 lb/d) in 1991–92, compared with 43 kg/d (94 lb/yr) the previous year and the NPDES limit of 258 kg/d (568 lb/d).

Influent lead decreased 67%, while the effluent was reduced by 71% during the past 5 years. Influent nickel decreased by 39% and effluent, by 27%.

Influent silver decreased 18%, while the effluent decreased 52% during the past 5 years (see Figure, *Average Influent and Effluent Silver, 1977–92*). Although the influent during the past 16 years has been variable, the effluent concentration has decreased steadily since the enhanced primary treatment program was implemented.

During the past 16 years, influent zinc was reduced 77%, while the effluent discharge was reduced 88%. In the past 5 years, influent zinc was reduced 24%, while effluent zinc was reduced 35%. ■

***Mary C. Lee** is a partner and **Paul J. Schuler** is a project engineer with John Carollo Engineers in Santa Ana, Calif.; **Blake Anderson** is director of technical services and **Robert J. Ooten** is operations director for the County Sanitation Districts of Orange County, Calif.*

San Jose Launches Pollution Prevention Program

Courtesy of Mark Niver

The slough that transports treated effluent to San Francisco Bay may soon contain lower metals levels

The city of San Jose, Calif., is implementing a program to prevent heavy metals from reaching San Francisco Bay while providing cost-savings for industrial dischargers. The agreement settles a citizen suit filed by Citizens for a Better Environment and other environmental, bay-user, and business groups. The suit was filed over dry-weather discharges of metals into south San Francisco Bay.

The program will address copper and nickel sewer contamination from sources in the 70% of Santa Clara County served by the San Jose-Santa Clara Water Pollution Control Plant. The program components generally are consistent with similar agreements addressing discharges to the Palo Alto and Sunnyvale wastewater treatment plants (*WE&T*, Sept. 1993, p. 50).

The program calls on industrial copper and nickel dischargers to the city's wastewater treatment plant to implement cost-effective pollution prevention strategies. San Jose will require pollution prevention audit studies of approximately 50 electronics and related companies that are the largest industrial discharges of copper and nickel to the wastewater treatment plant. The San Jose plant has advanced treatment for biodegradable contaminants but cannot completely eliminate metals and other persistent contaminants that pass through the plant into the bay.

Audit results will guide the design processing improvements to reduce waste, save companies money on chemical and waste disposal costs, and increase product quality. Improvements that result in significant metals waste reduction and pay for themselves within 5 years will be implemented.

The first three pilot audits of volunteer firms in the metals-finishing, printed circuit board–manufacturing, and magnetic disk–manufacturing industries have been completed by San Jose. Private engineering consultants found through audit results that companies could reduce copper and nickel discharges by 60% to 100% through pollution prevention measures that pay for themselves in 2 to 3 years. San Jose's audit consultant has found that the reduction in copper and nickel ranges from 91% to 99%.

San Jose also will establish a $2-million capital fund to help the city's small businesses invest in cost-efficient and contaminant-reducing industrial improvements identified by the pollution prevention audit studies. Expanding this repayable financing scheme to small, high-waste metal-finishing plants and printed-circuit-board manufacturers in Silicon Valley could help retain 5000 manufacturing jobs. Jobs would be retained by increasing companies' profits—and economic viability—through pollution prevention. Production improvements would result in fewer raw materials, less process water waste, fewer reject products, and increased product quality.

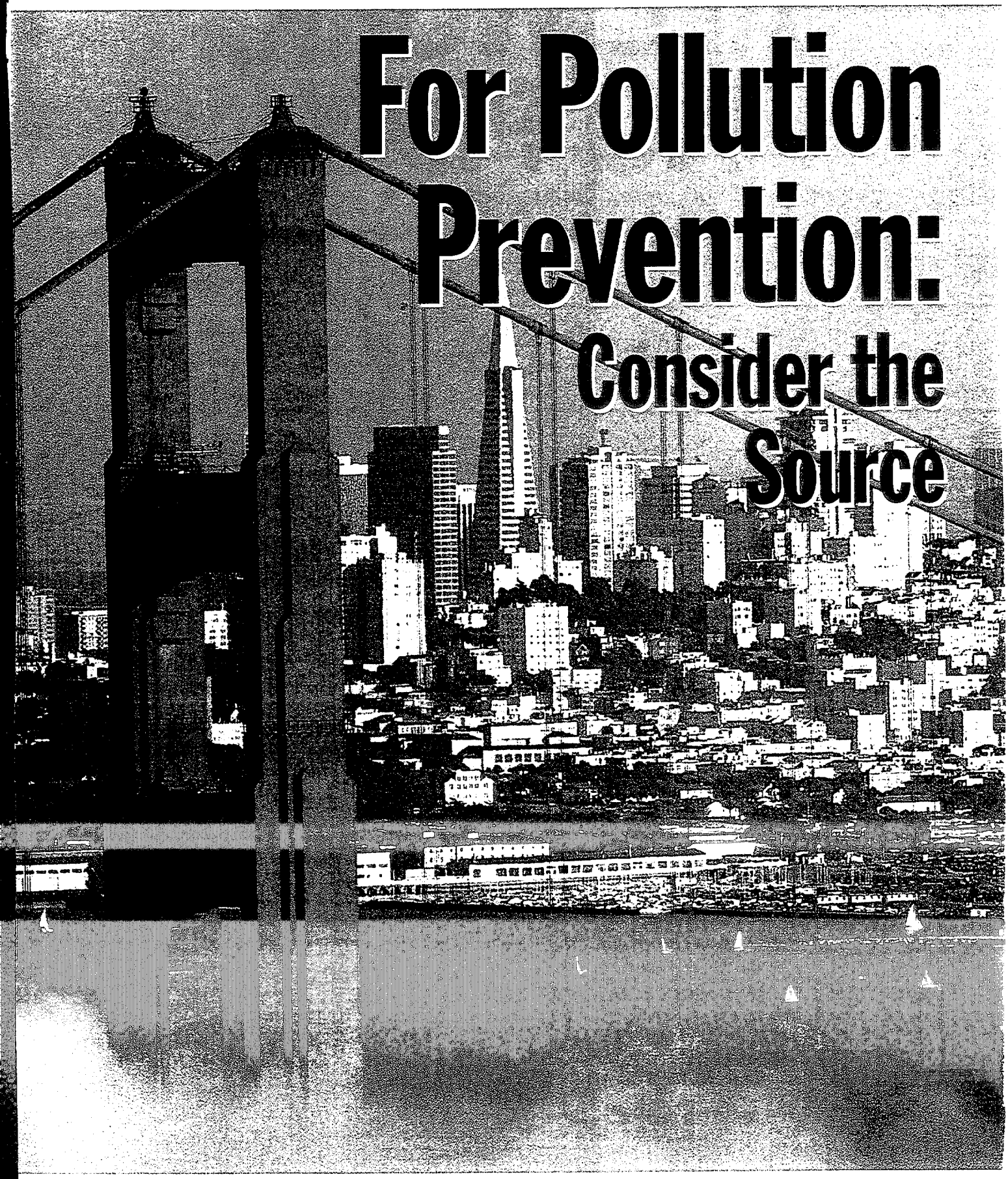
The city will spend $375,000 to open a pollution prevention center, which will be governed equally by city, environmental, and industry representatives. The center will develop additional methods to limit bay contamination from all south bay sources. San Jose will provide $375,000 in seed money for the center over the next 3 years.

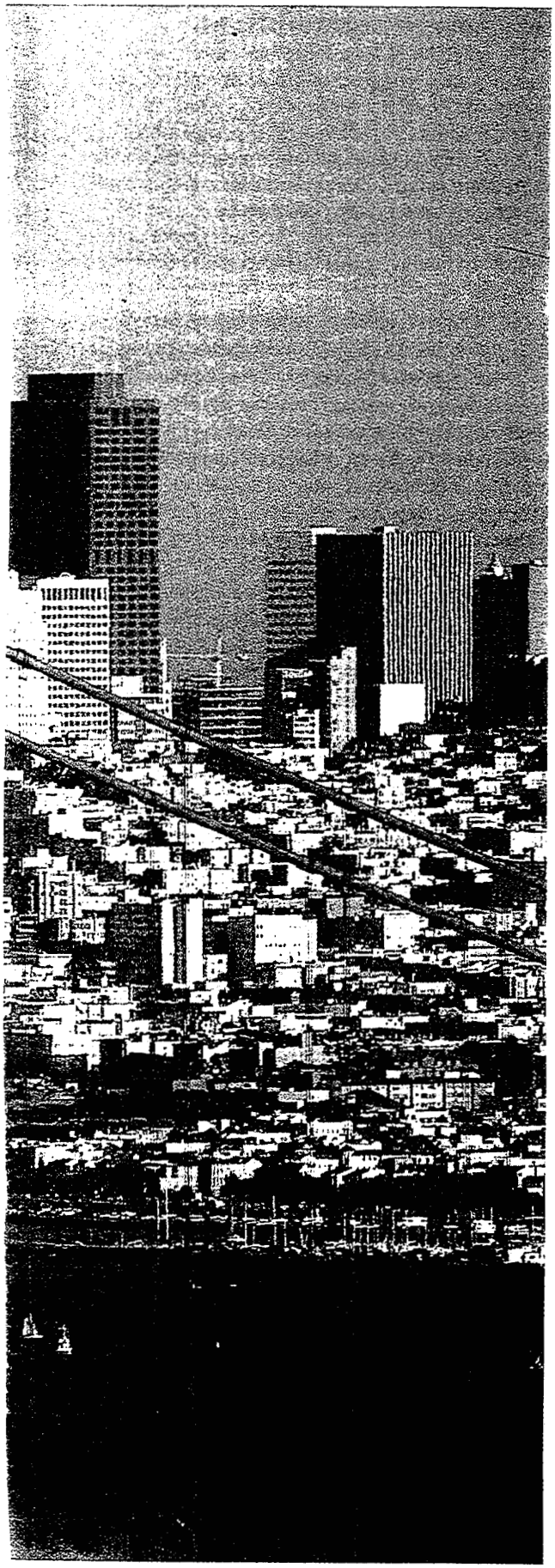
New restrictions will be placed on contaminant releases from industrial and commercial businesses into sewers. These new "local limits," which will reflect the results of pollution prevention studies and environmental goals, will reduce the total toxics flow through the wastewater treatment plant to levels that comply with the city's Clean Water Act permit restrictions on discharges to the bay. San Jose also will take actions to reduce contributions to south bay copper and nickel contamination from water-supply algicides, corrosion, consumer products, and commercial businesses.

The environmental groups have agreed to grant San Jose a 5-year grace period on strict enforcement of state and federal effluent limits while the city implements the program. Permit violations could result in $25,000 per day in fines for the city. The settlement also gives local industries a 2-year grace period before industrial compliance with new local limits is required.

—***Greg Karras**, Citizens for a Better Environment, San Jose, Calif.*

For Pollution Prevention: Consider the Source





San Francisco's water pollution prevention program reduces cross-media transfer of waste

Frank Filice
Geoff Brosseau

San Francisco, Calif., has developed a water pollution prevention program that focuses on specific industrial, commercial, and residential activities to control pollutants at their source. The program provides an integrated, comprehensive approach to source control as well as providing departmental interaction, flexibility, and efficiency, which collectively reduce the risk of cross-media transfers of waste. This program adds another focus to the city's other hazardous material–waste minimization efforts.

San Francisco has a combined sewer system that serves a sewered area of approximately 12,500 ha (31,000 ac), with a resident population of 725,000. San Francisco has modest levels of precipitation [average annual rainfall is 0.53 m (21 in.)]. Before construction of combined sewer overflow (CSO) control facilities, overflows occurred on average between 46 and 81 times/yr, depending on the drainage basin. An average of 34×10^9 L/yr (9×10^9 gal/yr) of CSO was discharged before CSO control.

The Regional Water Quality Control Board [the state National Pollutant Discharge Elimination System (NPDES) permit issuing agency] required the city to reduce the number of untreated overflows to an annual average of 10/yr in the areas where shoreline usage is predominately maritime, 4 to 8 overflows/yr in areas where water-contact recreation occurs, and 1 overflow/yr near the shellfish beds along the southeast shoreline of the city.

The city is required to achieve compliance with their CSO control requirements by January 1, 1996. A series of transport and storage boxes with overflow wiers and two baffles, pump stations, and treatment plant improvements has been designed and constructed. The system provides secondary treatment to all dry-weather flows and a combination of primary and secondary treatment for wet-weather flows generated within the city.

Direct discharge from San Francisco's combined sewer facilities contains pollutants typical of urban runoff and domestic and industrial wastewater.

A consumer product inventory showed that 35% of arsenic and 7% of chromium in the residential wastestream are associated with household products.

The NPDES permits also contain a requirement that effluent meet all existing and future water quality standards. In addition, the permits require monitoring of both effluent and receiving water for conventional and toxic pollutants. For CSO structures, no specific numerical limitations have been adopted; instead, the city must develop industrial source control programs and implement best management practices (BMPs) to minimize the introduction of toxic pollutants and monitor CSO discharges.

The city's first step was to quantify specific wet- and dry-weather pollutants of concern and their sources. Based on the results of these studies, the city's pretreatment requirements for industrial dischargers have expanded to include previously unregulated commercial and industrial dischargers. In addition, BMPs have been developed for residential activities.

DRY-WEATHER POLLUTANTS OF CONCERN

The pollutants of most immediate concern are those that may cause compliance problems with the city's wastewater discharge requirements, including:

- contaminants exceeding NPDES permit limits,
- contaminants contributing to general receiving water degradation (for example, contaminants exceeding receiving water quality objectives),
- contaminants in compliance but near permit limits,
- toxic contaminants that bioaccumulate or biomagnify, and
- contaminants contributing to sediment toxicity.

Copper and mercury concentrations currently exceed objectives of the San Francisco Bay Basin Plan, and cyanide concentrations occasionally exceed these objectives. An evaluation was performed on wastewater influent to the city's treatment plants to determine the metal loading associated with the potable water supply, as well as residential, commercial, and industrial areas (see Table, *Principal Dry-Weather Sources of Pollutants*).

Based on this influent data, processes and activities that have the potential to discharge pollutants of concern were investigated. In general, wastes from small, unregulated generators and residences are present in liquid form. These include inks, oils, and sol-

Principal Dry-Weather Sources of Pollutants

Metal	Water supply	Residential	Regulated industries	Other commercial services
Copper	Raw water supply Pipeline corrosion	Root killer products Algicides Foods	Manufacturers of electrical equipment	Auto body shops Cooling towers Commercial printers Linen suppliers
Mercury		Paints Photo wastes Auto fluids Foods (meats, vegetables, and grains)	General medical and surgical hospitals Lamp manufacturers	Paints and wallpaper Photo laboratories Auto services Metal manufacturers Laboratories Dentists
Lead	Raw water supply Pipeline corrosion	Paints Photo processors Auto fluids Home plumbing	Hospitals Radiator repair shops Linen suppliers Car washes	Sheet metal shops Auto services Equipment renters Painting services
Nickel	Raw water supply Pipeline corrosion	Paints	Metal platers Hospitals	Auto services Cleaners and laundries
Silver		Photo processors Personal care products Polishers	Photochemical suppliers Hospitals Motion picture industry	
Zinc	Corrosion prevention	Paints Auto fluids Water heaters	Hospitals Sausage manufacturers Laundries and linen suppliers	Auto services Printers
Cyanide			Silverware manufacturers and plating works	Motion picture industry Equipment renters Commercial laboratories

vents. These small quantity generators can have a significant impact on the discharge of pollutants into the combined sewer system. Field studies of several large dental facilities showed significant contributions of mercury, silver, and to a lesser degree, copper and zinc to the metals loading identified in the influent to the treatment plants.

A consumer product inventory showed that 35% of arsenic and 7% of chromium in the residential wastestream are associated with household products. Household products also account for between 0.45% and 3.83% of total silver, nickel, cadmium, zinc, mercury, lead, and copper in the residential wastestream.

Mercury. The painting industry contributes significantly to mercury discharges. Phenyl mercuric has been identified in adhesives used by painting contractors. In addition, chloromethyl propyl mercuric acetate was found in adhesives, and in some spackling pastes and paint preservatives. Compounds found in paint-related products can reach the sewer system in many ways. For example, paint mixing and equipment washing result in wastewater that contains mercury. The tool rental industry is also a significant discharger of mercury because they lease paint-spraying devices. When such devices are returned without being cleaned, the rental facility must wash them.

Dental facilities and hospitals use mercury in amalgam-filling processes and in equipment such as chest suction mechanisms. Mercury is pumped through the equipment, and when the process is complete, the mercury is decontaminated for reclamation. The potential for accidental spills exists in these facilities.

Copper. The corrosion of copper pipes contributes significantly to total copper at the treatment plant. Copper is also found in cooling tower blowdown from heating, ventilation, and air conditioning systems used in a variety of high-rise buildings, manufacturing activities, and large retail facilities.

Copper is also found in commercial printing operations, radiator shops, root killers, and in algicides used to protect San Francisco's water supply.

Cyanide. Cyanide was evaluated by several different methods. Potassium ferricyanide is used in many different industries including film developing, which uses a bleaching solution that is partly composed of potassium ferricyanide. Unless a facility has an on-site reclamation program, the solution is discharged to the sewer system after use.

Cyanide is contained in certain dyes for ink, paints, and blueprint paper, and is also found in cleaning and laundry detergents, acrylics, and in the raw material used in manufacturing concrete.

Silver. Silver is found on film and photo paper. The silver enters the solution in the development process, and may then be discharged into the sewer. Silver is also used in dental offices, labs, jewelry making, and plating shops. The devices used to clean teeth leave trace amounts of silver in the mouth that are washed down the drain when a patient rinses. Silver may also enter the sewers during resilvering and replating.

WET-WEATHER POLLUTANTS OF CONCERN

As with dry-weather discharges, the major concern with wet-weather discharges is those pollutants that violate the city's discharge permits. Although the city's wet-weather discharges are currently in compliance, this situation may change as new water-quality objectives are

Pollution Prevention Pointers

The following best management practices (BMPs) were adopted by the city of San Francisco to reduce pollutants of concern in the aquatic environment. The BMPs are general in nature, involve sound "housekeeping" practices, and are divided into educational, regulatory, and public agency categories. These measures focus on promoting public awareness and understanding of the impacts that unregulated dischargers have on the aquatic environment.

- **Educate the public on the impacts that result when oil, antifreeze, pesticides, herbicides, paints, solvents, or other potentially harmful chemicals are disposed of in sewers.**
- **Educate the public on the proper use of fertilizers, pesticides, herbicides and other potentially harmful chemicals.**
- **Educate the public on effective "housekeeping" practices, including the use of absorbents, cleaning compounds, and oil and grease traps.**
- **Educate the public on the need to keep rainfall and runoff from contacting potential contaminants.**
- **Research, strengthen, and enforce regulations to limit the improper disposal of potentially harmful wastes.**
- **Research, strengthen, and enforce regulations to limit the improper disposal of soil, debris, refuse, or other pollutants into storm drains, sewers, and catch basins.**
- **Research, strengthen, and enforce regulations that allow the city to require oil and grease controls in areas that are significant sources.**
- **Develop and implement regulations that require landowners and tenants to provide covers to keep rain off areas that contain contaminants and to keep runoff from draining through areas that contain contaminants.**
- **Label storm drain inlets.**
- **Develop and implement programs that provide convenient means for people to properly dispose of oil, antifreeze, pesticides, herbicides, paints, solvents, and other potentially harmful chemicals.**

Principal Wet-Weather Sources of Pollutants

Constituents of concern	General wet-weather sources	Commercial and industrial wet-weather sources
PAHs[a]	Asphalt Gasoline Oil and grease Tires Wood preservatives	Auto service and repair
Copper	Algicides Brake linings Paints and wood preservatives Vehicle engine parts	Auto service and repair Electrical equipment manufacturing and metal finishing Paints, inks, and printing
Lead	Batteries Gasoline Paints Vehicle exhaust Vehicle engine parts	Auto service and repair Equipment rental
Cyanide	Animal wastes Cyanogenic insects Microorganisms Vehicle exhaust	Printing and publishing Metal finishing Silverware manufacturing
Cadmium	Gasoline Oil and grease Tires	Auto service and repair Metal finishing
Mercury	Paints	Printing and painting contractors
Nickel	Gasoline Paints Oil and grease Brake linings	Local trucking Auto service and repair
Zinc	Atmospheric fallout Galvanized iron and steel Oil and grease Tires Paint	Auto service and repair Commercial printing Equipment rental Local trucking
Chromium	Engine parts Brake linings	Auto service and repair Metal finishing

[a] polynuclear aromatic hydrocarbons

incorporated into permits as discharge limits. The city conducted studies that determined its wet-weather pollutants of concern. Based on the last three years of overflow data, pollutants of concern were divided into three tiers:

Tier 1—significant concern. Three-year mean overflow pollutant concentrations that are 10 times greater than *potential* water quality concentration objectives without dilution (PAHs, copper, lead, and cyanide).

Tier 2—moderate concern. Three-year mean overflow pollutant concentrations greater than *potential* water quality concentration objectives without dilution (cadmium, mercury, nickel, silver, and zinc).

Tier 3—little concern. Three-year mean overflow pollutant concentrations less than *potential* water quality concentration objectives without dilution (chromium and arsenic).

The primary wet-weather sources of Tier 1 and Tier 2 pollutants of concern are automobiles and automotive-related industries. Pollutants are introduced when exhaust, leaking vehicle fluids, and corrosion of parts are deposited on streets. Pollutants of concern contact rainfall or runoff and are carried into the combined sewer system. Typically these pollutants include grease and oils, heavy metals, and PAHs (see Table, *Principal Wet-Weather Sources of Pollutants*). ■

Frank Filice *is an environmental coordinator with the San Francisco (Calif.) Department of Public Works in San Francisco, and* ***Geoff Brosseau*** *is a senior project manager with Uribe & Associates in Palo Alto, Calif.*

When Less Is More

By Kimberly A. Groff, Scott T. McMillan and David Saklad

Synthetic fibers facility uses thermal evaporation technology to recover waste solvent and minimize residues

Increased production of industrial sludge and more stringent disposal restrictions have created a tremendous incentive to develop cost-effective technologies that minimize residues, many of which are highly viscous and difficult to handle.

One technology receiving increased attention is evaporation, a separation technique that relies on heat to vaporize organics, which typically are recovered via condensation, and reduce the volume of material requiring disposal.

Heat can be applied directly or indirectly. Direct heating systems, in which the heat-transfer medium — usually hot gas — comes in contact with the waste, typically are used to treat nonhazardous materials. In indirect systems, the heat-transfer medium — usually hot water, steam or oil — does not contact the waste being treated. These systems usually are used for toxic or hazardous materials and when air emissions are a concern.

Solvent recovery from waste polymer solutions. Indirect thermal processing turned out to be the technology of choice for a synthetic fibers manufacturing facility whose off-spec polymer solution was causing serious waste-handling problems.

The waste material is highly viscous and contains approximately 65 percent dimethylacetamide (DMAC). The off-spec solution is unusable and costly to dispose as a hazardous waste. It tends to harden when exposed to air, making atmospheric processing impractical. Previous attempts to recover the solvent using a combination solvent extraction and gravity separation technique were inefficient and labor-intensive.

FIGURE 1

Specific Evaporation Rate as a Function of Temperature

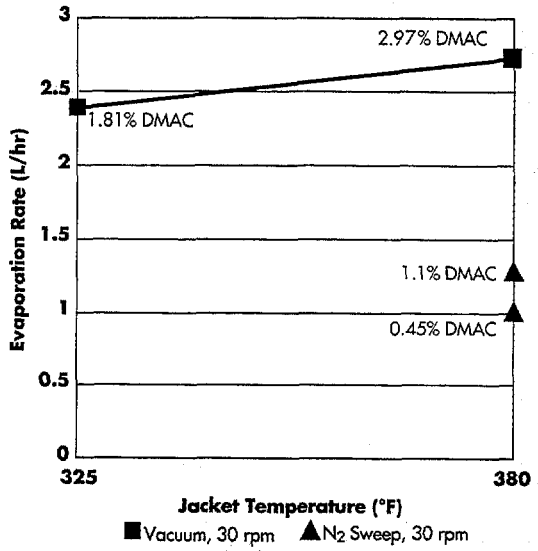


FIGURE 2

Specific Evaporation Rate as a Function of Shaft Speed

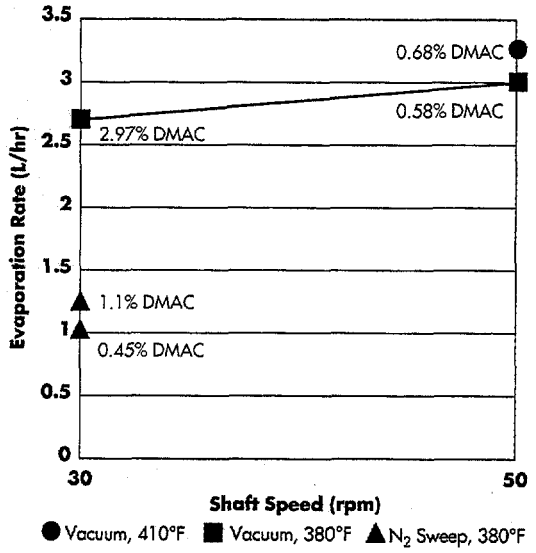


TABLE 1

Evaporation Technologies

Technology	Advantages	Limitations	Cost*
Belt Dryer	• Long retention time • Handles heat-sensitive products	• Direct contact between heating medium and product • Large volume of vapor discharge results in high cost for solvent recovery or pollution abatement • Requires large space • Only operates at near-atmospheric pressure	3
Extruder	• Very high power input • Intensive mixing • Usually operates under positive pressure	• Limited vapor disengaging space • Power cost vs. cost of other heating media • May degrade heat-sensitive products • Requires large space	1 Highest Cost
LIST Thermal Processor	• Large, self-cleaning heat transfer surface • Operates under pressure or vacuum • Good mixing, kneading • Long retention time • Large vapor disengaging space	• Improper shutdown procedures can overload drive • Foreign objects can cause mechanical damage	2
Thin-film Evaporation	• High heat transfer coefficient • Good vapor-handling capacity • Operates under pressure or vacuum	• Cannot produce dry solids • Solids adhere to high-speed rotating parts, causing unbalance • High cost of maintaining high-speed rotating equipment	4 Lowest Cost

* Cost rankings relative to competing technologies, with 1 being the most expensive and 4 the least expensive.

The goal, therefore, was to identify a process that would recover DMAC from the waste polymer solution and leave behind no more than 1 percent residual solids — the legal limit for disposing the material in a sanitary landfill.

Given these parameters, the company decided to evaluate four evaporation technologies: a belt dryer, a thin-film evaporator, a twin-screw extruder and the LIST thermal processor. (Table 1 summarizes the strengths and weaknesses of the technologies evaluated.) The LIST processor eventually was selected for a series of pilot-scale tests.

The polymer solution had a solids content between 25 percent and 35 percent and a viscosity of 500,000 centipoise. DMAC's boiling point is 331 degrees Fahrenheit under atmospheric conditions; its specific heat is 0.48 calories per gram degrees Celsius; and its heat of vaporization is 119 calories per gram.

The processor used in the tests was a horizontally agitated vessel known as the Discotherm B, or DTB, developed by Swiss engineers at LIST AG (Arisdorf, Switzerland). The technology, supplied by LIST Inc. (Acton, Mass.), is patented in the United States and Europe.

The cylindrical body has a single shaft on which are mounted disc segment blades with peripheral angled mixing and transport bars. The outer casing, shaft and blades are

TABLE 2

Trial Results Using the LIST Thermal Processor

Trial No.	Initial Solids Content (%)	Jacket Temperature (°F)	Reactor Pressure	Mixing Speed (rpm)	Final DMAC Content (%)
1	20-25	380	N_2 Sweep	30	0.45
2	20-25	380	N_2 Sweep	30	1.09
3	20-25	325	24 mm Hg	30	1.81
4	35	325	24 mm Hg	50	8.64
5	35	380	24 mm Hg	50	0.58
6	35	380	24 mm Hg	30	2.97
7	35	410	24 mm Hg	50	0.68

heated indirectly using steam, hot water or a heat-transfer fluid. The bars continuously sweep the shell surface to provide mixing in the processor. In continuous units they also transport material through the system in an effective, controlled plug flow.

Counter hooks mounted on the body shell scrape the shaft and blades. Disc segments and counter paddles interact to produce a gentle, yet intensive, mixing and kneading action that renews the product surface for optimum heat and vapor transfer and prevents product caking on heating surfaces. The ratio of heating surface to product volume is high — 10 square meters per cubic meter to 40 square meters per cubic meter. Operating under vacuum allows the process to run at less-than-atmospheric temperatures, which effectively lowers the solvent's boiling point and reduces the heat requirements.

Experimental conditions. The DTB was heated by hot oil (Therminol 66) at temperatures between 325 degrees and 410 degrees Fahrenheit. Condensate was recovered with a

tap water-cooled condenser. The unit was powered with a hydraulic drive (5 kilowatts), and the agitator was adjustable between zero and 70 revolutions per minute (rpm). Power uptake was indicated by a "J"-type thermocouple on one of the hooks. Off-spec polymer was released by gravity flow into the processor, whose fill level was estimated visually.

Seven trials were conducted, during which such conditions as mixing speed, jacket temperature, initial solids loading and fill level were varied to generate data for a full-scale unit. The system was operated at atmospheric pressure and under vacuum. The amount of solvent recovered, bed temperature and power uptake were measured as a function of batch time. The final DMAC content of the solids was measured by gas chromatograph.

During the tests, jacket temperature varied from 325 degrees to 410 degrees Fahrenheit, and agitator speed was set at either 30 rpm or 50 rpm. The reactor was run under a nitrogen sweep during the first two trials and under vacuum for the others.

Trial results. All trials produced dry, free-flowing solids with a DMAC content of 0.45 percent to 8.64 percent, indicating that this particular unit could achieve the target of less than 1 percent DMAC in the solids (Table 2).

Bed temperature and condensate volume were recorded as a function of time. Bed temperature stabilized at the boiling point of DMAC after approximately 50 minutes, signifying the beginning of the evaporation phase. Temperature during the evaporation phase decreased significantly during vacuum operation, which increased the temperature differential between the bed and jacket. Theoretically, this means that operating the system under vacuum would increase the evaporation rate.

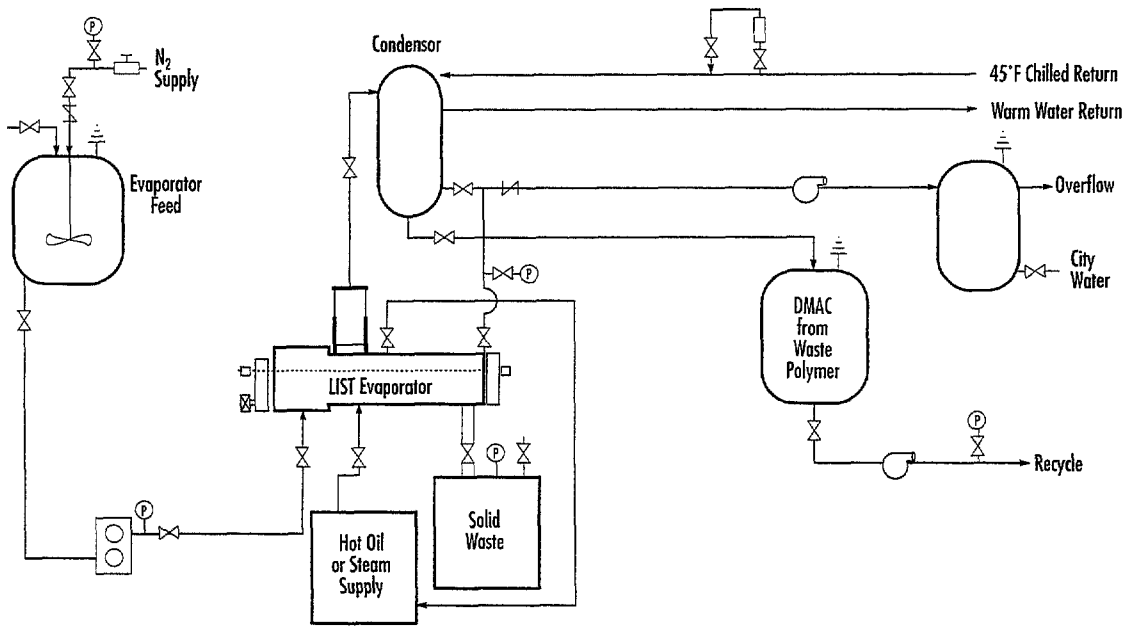
TABLE 3

Process Scale-up

Description	Value
Hot Oil Heating Temperature (°F)	380
Steam Heating Pressure (psig)	175
Feed Solids (%)	35
Feed Rate (lb/hr)	85
Guaranteed Feed Rate (lb/hr)	54
Solvent Evaporation Rate (lb/hr)	55
Residence Time (hr)	1
Discharge Rate (lb/hr)	15
Solvent Concentration in Solids (%)	<1

FIGURE 3

Full-scale Thermal Evaporation System



Hydraulic pressure was measured to provide an indication of power uptake on the agitator. Hydraulic pressure varied between zero and 30 pounds per square inch during the trials and typically peaked during the transition from viscous material to dry solid (pasty phase).

Trials 3 and 4 were run at 325 degrees Fahrenheit to simulate the temperature that would result if 80 pounds of steam were supplied as the heat-transfer medium. This temperature proved insufficient to reduce the DMAC content of the solids to less than 1 percent.

The purpose of trials 5, 6 and 7 was to determine the influence of jacket temperature and agitator speed on the DMAC content of the final product. Trial 5 was run at a jacket temperature of 380 degrees Fahrenheit and an agitator speed of 50 rpm. Trial 6 was carried out at the same temperature and an agitator speed of 30 rpm. Hydraulic pressure was higher at 50 rpm, and solids analysis revealed that the DMAC concentration was lower for Trial 5 (0.58 percent) than for Trial 6 (2.97 percent).

During Trial 7, jacket temperature was raised to 410 degrees Fahrenheit, and the agitator speed was set at 50 rpm. These conditions did not reduce the final DMAC content of the solids (0.68 percent), but a lower peak hydraulic pressure was recorded during this trial, probably because the material was less viscous.

Specific evaporation rates were estimated for each trial based on the volume of solvent recovered, the batch time and a heat transfer area of 0.31 square meters in the processor. Specific evaporation rates ranged from 1 liter per hour to 3 liters per hour.

Temperature had a dramatic effect on evaporation rate, which increased at higher temperatures and nearly doubled when the system was run under vacuum (Figure 1).

The evaporation rate also increased as the agitator speed increased (Figure 2), but temperature had a more dramatic effect, indicating that the process is heat-transfer limited.

Full-scale plant. The measured evaporation rates from Trial 5 were used to scale up the system to the desired feed rate of 30 pounds per hour. Estimates indicated that a 40-liter DTB has more than enough capacity to handle this feed rate (Table 3).

A flow diagram for the full-scale system is shown in Figure 3. Waste is fed to a continuously stirred heating tank blanketed with nitrogen before being pumped to the jacketed evaporator, which is heated with steam to approximately 380 degrees Fahrenheit. Free-flowing solids are discharged continuously under vacuum to a waste hopper, and vaporized solvent is condensed and recovered. The unit features intensive mixing and surface cleaning, which help maximize heat transfer.

The full-scale system, which has been on-line since October 1993, consistently produces a residue whose DMAC content is less than 1 percent.

Based on solvent recovery and a reduction in disposal costs associated with rendering the solid residue nonhazardous, pay back on capital investment is estimated to be 2.5 years. The unit has dramatically reduced the amount of operator attention and downtime associated with the solvent recovery process. ■

Kimberly A. Groff *is director of environmental technology, and* **Scott T. McMillan** *is vice president at LIST Inc. (Acton, Mass.).* **David Saklad** *is a process engineer at Globe Manufacturing Inc. (Fall River, Mass.).*

Dynamic Pollution Prevention Program Provides Results

By Adriana Renescu
and Margaret H. Nellor

Industrial case studies showcase pollution prevention success stories in Orange County, Calif.

The County Sanitation Districts of Orange County, Calif., recently initiated the final phase of a program to control and reduce the quantity of toxic materials discharged by industrial users to its sewer systems. The first phase, in effect since 1982, has relied on enforcement requirements mandating the implementation of pollution prevention by industrial dischargers. The final phase expands the program to consider cross-media and nonindustrial pollution prevention options and create a partnership with industry.

The agency provides wastewater treatment for more than 2 million people in 23 cities and unincorporated areas of Orange County. It treats more than 225 million gallons per day of residential, commercial and industrial wastewater at two regional treatment plants that discharge to the Pacific Ocean. More than 1,000 companies are regulated under the agency's federally approved pretreatment program. Of that number, 450 are considered significant industrial users as defined by EPA. The agency's pretreatment program includes industrial permitting, inspection, monitoring and enforcement actions to ensure protection of public health and the environment.

Activities for preventing toxics from entering the sewer system include aggressive source control, and the promotion of pollution prevention and continuing education programs directed at promoting safe industrial and household waste disposal practices. These activities are part of the agency's 30-year plan, *2020 Vision*, which integrates research, facilities planning, environmental analysis, toxics control, water conservation and reclamation, sludge reuse and other innovative programs into a unified strategy. In May 1992, the agency received an EPA National Pollution Prevention Award in recognition of the program's outstanding contribution to environmental protection through pollution prevention.

In the beginning. The history of the agency's source-control activities can be traced back to 1970, when the Industrial Waste Division — now the Source Control Division — was established to issue permits, set flow and quality limits, and monitor industrial discharges to the sewer system. During the program's inception in the 1970s and throughout the early 1980s, the agency regulated discharges of heavy metals, oil and grease, organic materials, dissolved solids, suspended solids, phenolic compounds, radioactive wastes, combustible materials and other contaminants with the potential to degrade the wastewater treatment processes or the marine environment.

A formal pollution prevention program began in 1984, when the agency implemented a policy to control and reduce the quantity of toxic materials discharged by industrial users to the sewer system. This program was developed in response to a new philosophy favoring source control and waste minimization over end-of-pipe treatment.

To encourage wastewater reduction and water conservation and prevent companies from relying on dilution to achieve compliance, the agency adopted mass emission rates for each permitted industrial discharger. Mass emission rates were calculated on the basis of an analysis of samples taken from a facility and its average water usage. These rates then were compared to permit limits. As part of this initial effort and subsequent enforcement of mass emission rate limits, facilities were required to install flow restrictors or control valves to regulate

and limit the flow of wastewater to the sewer. In addition to routine monitoring and inspections, industrial facilities are checked at least annually for water conservation control equipment.

Another important element of the program during its early stages was the advocacy of waste minimization techniques as tools whereby companies could achieve compliance with discharge standards. Companies discovered that waste minimization practices, such as waste segregation, counter-current rinses, drag-out tanks and flow restrictors, reduce waste volume and lower pretreatment costs and sewer-use charges.

In September 1989, as part of the revisions to its sewer-use ordinance, the agency included provisions establishing pollution prevention requirements. In essence, these provisions required all industrial users to develop pollution prevention plans, investigate new technology, provide inventory control, implement educational and training activities, and take any other steps needed to minimize waste.

Today's program. Today, enforcement actions are still the agency's primary method for encouraging pollution prevention. Pollution prevention requirements are incorporated into enforcement actions taken against noncompliant companies through written orders and compliance schedules. In response to an action, companies must conduct pollution prevention assessments and implement any economically feasible methods or techniques that will ensure long-term compliance. Descriptions of proven waste minimization techniques, their application and benefits, and a waste minimization checklist are provided to assist companies in their evaluations. Companies also must prepare written operating procedures and provide operator training. As part of this approach, an engineer is sent to each facility to review its manufacturing processes and, through permitting and compliance activities, assess pollution prevention opportunities. In addition to these enforcement-related activities, the agency also participates in technical outreach efforts for the industrial community by sponsoring and attending workshops on waste reduction and pollution prevention.

In the program's second phase, which was initiated at the end of 1992, an extensive effort is being made to "market" pollution prevention and champion the incorporation of pollution prevention "ideals" into each discharger's way of doing business. Through informational and educational

FIGURE 1

Total Heavy Metals Concentrations in Raw Sewage

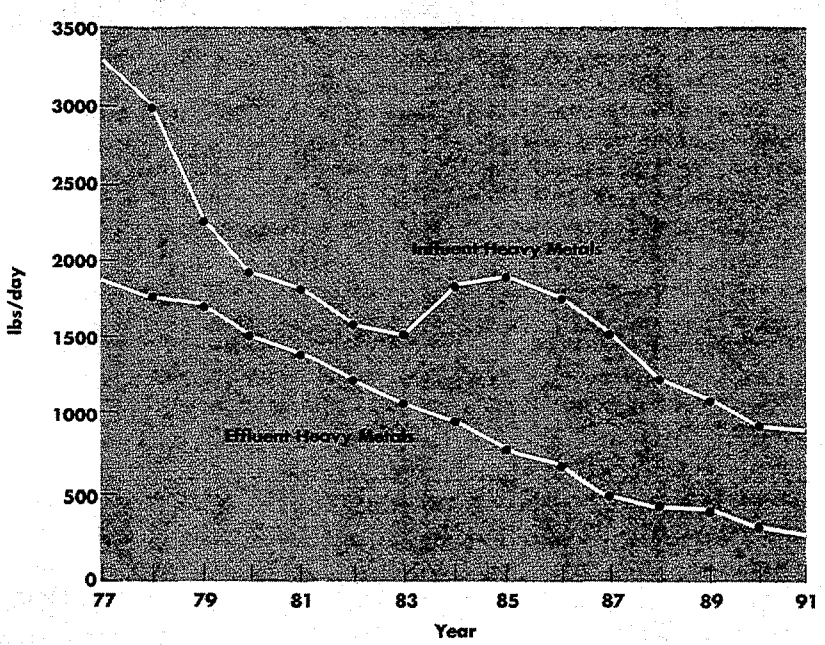
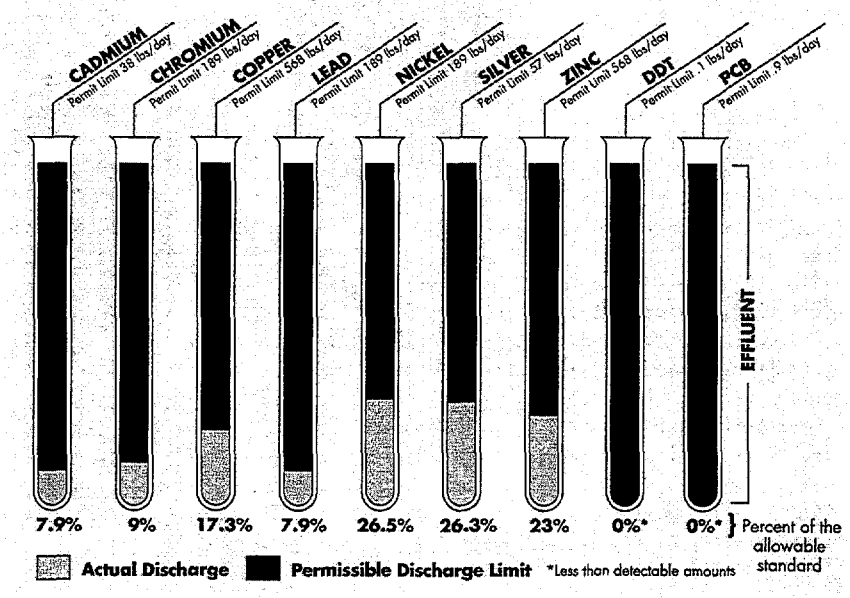


FIGURE 2

Beating the Standards



outreach, the agency is promoting pollution prevention as the preferred alternative to all other control methods. The Pollution Prevention Task Force, which includes agency officials and industry representatives, was established to discuss pollution prevention and other topics of interest to industry.

The first step of this second phase was an extensive survey to determine the extent of industry's pollution prevention efforts. Of the 247 companies that received the survey, 54 percent responded and indicated they had implemented some type of pollution prevention measure. Except for a small number, most respondents said they had implemented at least two pollution prevention techniques, mostly technical modifications. Small industrial sources and commercial dischargers also are being brought into the program.

Results. Since the program began, 95 percent of metal finishers and other federally regulated industries have installed flow restrictors or control valves to reduce wastewater usage, or have implemented various measures to reduce the volume of hazardous waste and wastewater discharged to the sewer system. Significant environmental improvements have been achieved. In the past five years, total heavy metals in the agency's raw sewage has been reduced approximately 50 percent, and greater reductions have been achieved for specific constituents (Figure 1). For example, cadmium has been reduced by 90 percent, chromium by 86 percent, copper by 62 percent, lead by 82 percent, nickel by 66 percent and zinc by 74 percent.

The overall reduction in toxics has been so effective that, for the past three years, heavy metals concentrations in incoming raw sewage have met the agency's NPDES discharge standards (Figure 2).

Case Studies

These case studies illustrate distinctive waste management practices for different types of facilities; demonstrate the technical and economic feasibility of implementing pollution prevention techniques; and demonstrate the availability and utility of such options for similar industrial facilities. All three companies are classified as significant industrial users.

Organic chemical industry. Company A, which employs 31 people, blends a variety of industrial and household cleaning products and places them in aerosol containers. Production involves a batch process; each formulation contains a specific blend of water, organic solvents and anhydrous compounds. Organic solvents used in the formulation are methylene chloride, 1,1-dichloroethene and 1,1,1-trichloroethane. Alcohols and glycol ethers also are used.

Before the implementation of pollu-

FIGURE 3

Pollution Prevention Modifications
Organic Chemical Company

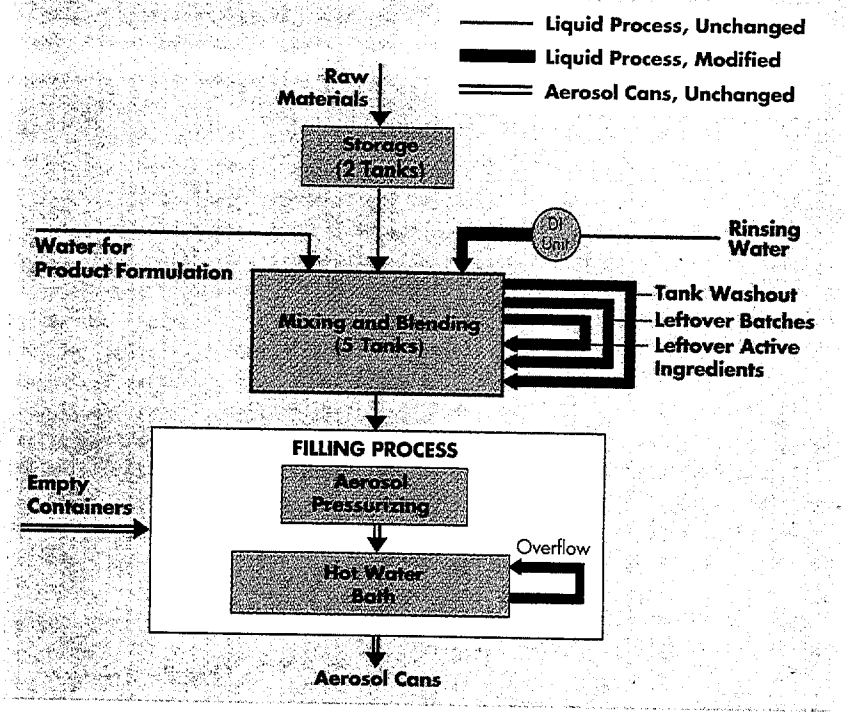
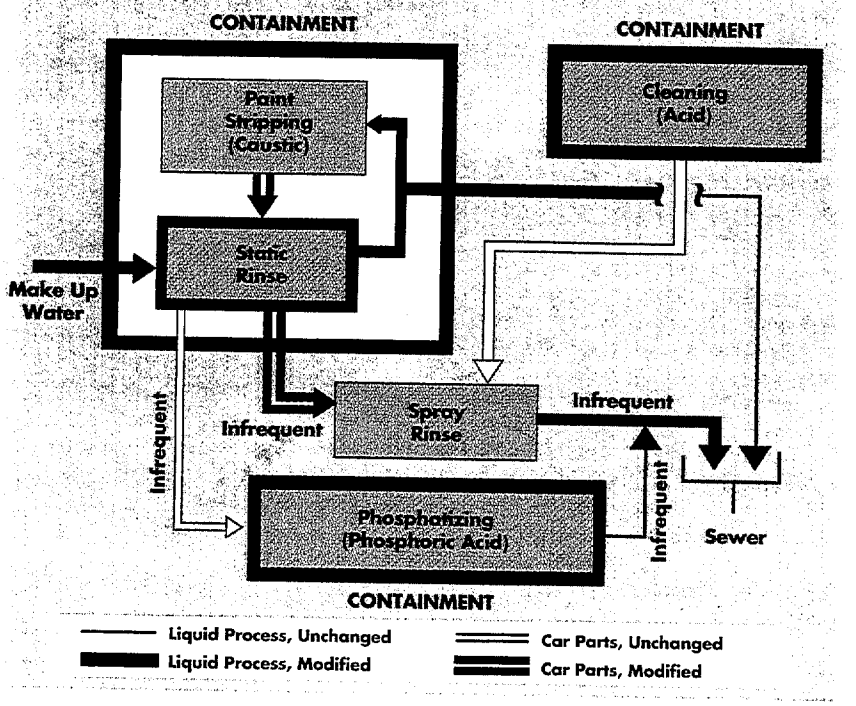


FIGURE 4

Pollution Prevention Modifications
Paint Stripping and Metal Finishing Company



tion prevention techniques, organic chemicals from two storage tanks were sent to one of five tanks, where products were mixed in batches. Mixed products then were pumped to the aerosol line used to fill containers. Full cans were taken to a "gassing" room, where they were injected with propellant. Pressurized cans then were taken to a hot water bath, where they were tested for leaks.

Wastewater was generated primarily during formulation, batching and rinsing of the mix tanks; there was little wastewater discharge from the filling process. However, there was potential for the leak-testing procedure to generate waste, because leaking material remained in the bath, which overflowed to the waste discharge system. Wastewater discharges from the facility ranged from 800 gallons per day to 3,600 gallons per day, depending on the production level. Wastewater passed through a clarifier before being discharged to the sewer.

After significant violations of its discharge permit, the company was given a probation order requiring it to assess and resolve its noncompliance problem. In response, the company evaluated its processes and identified three waste management options:

- install an end-of-pipe treatment system;
- install and implement pollution prevention techniques, such as process changes, operational modifications, partial recycle and reuse of wastes, and installation of a small pretreatment system; or
- implement pollution prevention techniques to create a closed-loop system that would provide 100 percent recycling and reuse of materials.

After a technical and economic evaluation, the company decided the third option, a closed-loop system, was the most cost-effective alternative. The new system includes the following features (Figure 3):

- All water phases of the product formulation process are batched in the same tank, thus precluding the need for washouts between batches.
- Leftover formulations are saved for the next batch.

- Deionized water is used for tank washouts when a formula change is required. (The washout also is saved for the next batch.)
- Leftover active ingredients are saved for the next batch.
- The schedule for batching and formulation rotates compatible products to maximize the reuse of leftover washouts and active ingredients.

These modifications have enabled the company to eliminate discharges to the sewer. By implementing changes that involved relatively low first-time costs, the company also has been able to realize savings in operating expenses.

Paint stripping and metal finishing. Company B, which employs only three people, strips paint off old automobiles by using basic metal-cleaning and paint stripping techniques and prepares the surface for repainting.

Before pollution prevention measures were implemented, paint was stripped in a 9,500-gallon tank containing a caustic solution heated to between 110 degrees and 120 degrees Fahrenheit. Car parts were submerged in the tank, drip-dried over trenches and rinsed again in a separate area. The facility also had a pickling tank containing a 20 percent solution of muriatic acid, which removed oil, dirt and oxide from metal parts. Parts pickled in acid were rinsed in the same spray area as those dipped in caustic. After being stripped and cleaned, parts were immersed in a bath of 15 percent phosphoric acid, which provided a good surface for paint bonding. Caustic cleaning was the main operation; muriatic and phosphoric acid treatment were intermittent.

None of the facility's tanks was contained; all drippings and spills were wasted to the sewer. Spent caustic and acid solutions were discharged to trenches, where they neutralized each other. Accumulated solids were removed manually from the trenches. Rinses contained chromium, zinc and, on occasion, high levels of lead from paints. Wastewater discharges ranged from 3,000 to 7,000 gallons per day; no treatment was provided prior to discharge.

Noncompliance at the facility was attributed primarily to the lack of a waste management plan for reducing the level of heavy metals in rinsewater discharged to the sewer. The company was directed through a probation order to assess and resolve its noncompliance problem.

To attain compliance, the company had to conduct an industrial waste survey and implement a pollution prevention plan. The company evaluated its processes and identified two waste management options:

- install an end-of-pipe pretreatment system to treat approximately 5,000 gallons per day of wastewater containing heavy metals; or
- install and implement pollution prevention techniques.

After conducting an economic and technical evaluation, the company chose the second option (Figure 4). Key aspects of the pollution prevention measures were as follows:

- A 6,000-gallon static rinse tank was added as an intermediate step before spray rinsing.
- Spray rinsing is performed only if needed after rinsing in the static tank.
- Spent rinsewater recirculates to the hot caustic tank as makeup.
- Tanks are contained to capture drippings and spills. Liquid captured in the contained area is recycled to the solution tanks.

In addition to the obvious environmental benefits, this small company has been able to avoid the cost of designing, constructing and operating a pretreatment system and the concomitant compliance liabilities. ■

Adriana Renescu *is a source control engineer for the County Sanitation Districts of Orange County (Fountain Valley, Calif.).* **Margaret H. Nellor** *is the agency's source control manager.*

CONVERSION OF PAPER MILL SLUDGE INTO PAPERMAKING PULP AND FILLER PRODUCTS

John V. Maxham, Ph.D., P.E.
Paper Science Department
University of Wisconsin - Stevens Point

ABSTRACT

Prime Fiber Corporation of Appleton, WI, produced and sold 1,922 AD metric tons of high quality, bleached market pulp made exclusively from paper mill sludge. This sludge was obtained from six paper mills located within a 60 km radius of the Prime Fiber pulp mill. Paper mills supplying sludge hauled their sludge to Prime Fiber at their own expense and paid a tipping fee.

Sludges were examined from 33 North American pulp and paper mills. Based on that investigation, it was estimated that about 30% of the 4,200,000 OD metric tons of paper mill sludge generated annually in the U.S. has sufficient pulp yield to be economically processed.

After the long fiber pulp has been extracted from paper mill sludge, a fiber fines/clay remnant remains. The drainage characteristics of this remnant were considerably improved by an acid treatment possibly making it suitable for inclusion as a filler in paperboard products.

KEYWORDS

Pulp, Sludge, Recovery, Reuse, Paper Mill, Recycle, Filler

INTRODUCTION

Prime Fiber Corporation (now defunct) owned and operated a market pulp mill located in Appleton, WI, USA, with a nominal pulp production capacity of 40 air dried (AD) tons per day. The mill produced a high quality papermaking pulp from either paper mill sludge or 100% post consumer white office wastepaper (PC-WOW). The mill was operated by Prime Fiber from April 1990 until December 1992 and is now owned and operated by Repap, a Canadian corporation.

Prime Fiber held three U.S. patents (Maxham, 1991a, 1991b, and 1992a) on process technology that converted the long fiber fraction of paper mill sludge into a papermaking pulp product. Prime Fiber successfully applied this sludge processing technology at its Appleton pulp mill from April 1990 until August 1991. 1,922 metric tons of AD market pulp were produced exclusively from paper mill sludge and sold to Wisconsin paper companies during that time. Afterwards, Prime Fiber used predominantly PC-WOW as raw material to make a high brightness, low dirt count, 100% post-consumer market pulp.

National Science Foundation (NSF) Small Business Innovative Research (SBIR) Phase I and II grants were used to develop process technology to produce a papermaking filler product from paper mill waste solids after the long fiber pulp fraction had been extracted. Results of that R&D effort were presented in a report by Maxham (1992b) to the NSF. The production of a papermaking filler product in addition to a long fiber pulp product would significantly increase the total amount of sludge solids that could be recycled into papermaking raw materi-

als. The yield of long fiber pulp from paper mill sludge would be in the range of 40 to 60%. Production of a filler product in addition to a pulp product would increase total yield to over 90%.

PULP AND PAPER MILL SLUDGE CHARACTERISTICS AND AMOUNTS

Prime Fiber received sludge samples from thirty-three North American (thirty-two U.S. and one Canadian) pulp and paper mills interested in investigating alternatives to their current sludge disposal practices. These samples were tested in order to determine whether the long fiber fraction could be economically removed from the sludge and converted into a high quality market pulp. Important considerations included the amount of long fiber present as a percentage of oven dry (OD) solids, the bleachability of the long fiber, and the nature of the chemicals, dirt and debris contained in the sludge.

After a sludge sample was received, the consistency, ash, Canadian Standard Freeness (CSF), and Bauer-McNett fiber length distribution (% of OD solids retained on 14, 28, 48, 100 mesh screens) were measured in accordance with TAPPI test methods (TAPPI, 1991). Usually, three to four sludge samples were received from a particular mill. In some cases, however, only one sample was received.

Mill personnel collected the sludge samples that were representative of the sludge generated. The data was averaged when separate samples were tested from a particular mill.

TABLE I

CHARACTERISTICS OF RAW DEWATERED SLUDGES FROM 33 PULP AND PAPER MILLS

	CONSISTENCY (%)	ASH (%)	FREENESS (ML)	BAUER-MCNETT FIBER CLASSIFICATION % VOLATILE SOLIDS RETAINED ON 100 MESH SCREEN	BAUER-MCNETT FIBER CLASSIFICATION % TOTAL SOLIDS RETAINED ON 100 MESH SCREEN
AVERAGE	31.6	25.9	186	43.8	33.0
STD DEV	7.0	14.4	146	15.8	14.9
HIGH	48.6	55.7	672	75.5	59.3
LOW	16.1	2.3	50	12.9	5.6

Table I presents the results of this pulp and paper mill sludge study. The average consistency of all sludges was 31.6% with a range of 16.1% to 48.6%. The sludge consistency was dependent on the type of dewatering equipment used and the type of sludge solids being dewatered. A screw press normally produced the driest sludge cake with a belt press producing a drier sludge cake than either a vacuum filter or centrifuge. The majority of mills used belt presses for dewatering sludge. Sludges that contained appreciable amounts of biological solids and fiber fines were difficult to dewater regardless of the type of dewatering equipment used.

The average ash content was 25.9% with a range of 2.3% to 55.7%. The ash content of a sludge was dependent on the type of product the mill produced and the raw materials employed to produce that product. A deinking mill sludge normally had a high ash content because its raw material, wastepaper, had a much higher ash content than virgin pulp. A coated paper mill sludge also had a high

ash content because significant amounts of inorganic pigments were added to the paper as fillers or coatings.

The average CSF was 186 with a range of 50 to 672. CSF varied according to the nature of the sludge solids, in particular, the nature of the organic or volatile fraction. High percentages of long fiber and large woody debris in a sludge normally yielded a high CSF value. Large amounts of biological solids and gelatinous fiber fines in the sludge caused the CSF values to be low. If the long fiber was highly refined, its freeness was also low.

The Bauer-McNett apparatus determined the size of solids contained in sludge samples. Screen mesh sizes 14 (1.19 mm opening), 28 (0.595 mm opening), 48 (0.297 mm opening) , and 100 (0.149 mm opening) were used to fractionate the sludge solids. Solids retained on the screens were predominantly long fiber plus small amounts of debris and ash. Sludge samples from integrated Kraft pulp mills sometimes contained appreciable amounts of large woody debris and shives that were usually captured on the 14 mesh screen. Fiber that passed through the 100 mesh screen was arbitrarily considered to be a fiber fine.

The Bauer-McNett results given in Table I show that as much as 75.5% and as little as 12.9% of the OD volatile fraction in the raw sludge samples received from thirty-three mills were retained on screens up to 100 mesh. On the average, 43.8% of the volatile fraction was retained. As little as 5.6% and as much as 59.3% of the total OD solids were retained on screens up to 100 mesh. On the average, 33.0% or about one-third of the total OD solids were retained.

TABLE II

YIELD OF MARKET PULP FROM PAPER MILL SLUDGE

YIELD (OD PULP/OD SLUDGE)	% OF MILLS WITH YIELDS GREATER THAN
0.0	100
0.1	97
0.2	76
0.3	60
0.4	30
0.5	15
0.6	0

The total % of OD solids retained on Bauer-McNett screens up to 100 mesh can be assumed to be equal to the expected yield of a sludge processing facility recovering long fiber pulp from paper mill sludge. (The actual fiber yield at the Prime Fiber mill was accurately estimated using this assumption.) Table II shows that 30% of the 33 mills whose sludge was examined had an estimated long fiber yield greater than 40%: 15% of the 33 mills had a long yield greater than 50%. Yield is a very significant factor determining the economics of fiber recovery from paper mill sludge. Maxham (1992b) showed that if the yield is much less than 40%, it is unlikely that fiber recovery can be economically justified, even when the recovered fiber quality is good. Therefore, it is estimated that 30% of U.S. mills have sludges where fiber recovery may be economically attractive compared to other sludge disposal alternatives.

Miner and Unwin (1991) in a NCASI survey showed that on the average between 55 to 60 kg of dry waste solids are generated per metric ton of paper or paperboard produced. Taking 57.5 kg per ton as the average, it can be calculated that the pulp and paper industry annually produced about 4.2 million OD metric tons of waste solids in 1990 since 72.9 million metric tons of paper and board were produced in 1990 (American Paper Institute, 1991).

Table III gives estimates on the total amounts of paper mill sludge generated in the United States during 1990 and the amounts of recoverable long fiber and filler. The estimates are based on the following assumptions:

- The average consistency of wet sludge is 31.6% and the ash content of the OD solids is 25.9%.

- On the average, 5.8% of the paper produced in the U.S. is converted to OD sludge solids of which 33% is potentially convertible to long fiber.

TABLE III

ESTIMATED QUANTITIES OF PAPER MILL SLUDGE COMPONENTS
PRODUCED IN THE UNITED STATES IN 1990
(METRIC TONS)

WET:	13,200,000
OVEN DRY:	4,200,000
RECOVERABLE LONG FIBER:	1,400,000
FIBER FINES, ASH, AND DEBRIS:	2,800,000
ASH:	1,100,000
FIBER FINES AND DEBRIS:	1,700,000

Of the estimated 4.2 million OD metric tons of paper mill sludge generated in 1990, about 1.4 million OD metric tons of long fiber could have, in theory, been recovered. The remaining 2.8 million OD metric tons were fiber fines, ash, and debris of which 1.1 million OD metric tons were ash.

TABLE IV

ESTIMATED FIBER AND FILLER THAT COULD BE PRODUCED ANNUALLY FROM
U.S. PAPER MILL SLUDGES WITH LONG FIBER YIELDS GREATER THAN 40%

AMOUNT OF FIBER:	600,000 METRIC TONS
POTENTIAL VALUE OF FIBER:	$240 - $360 MILLION
AMOUNT OF FILLER:	500,000 METRIC TONS
POTENTIAL VALUE OF FILLER:	$25 - $50 MILLION

Table IV gives estimates on the amounts and potential value of long fiber and filler that can be produced annually from paper mill sludges with long fiber yields greater than 40%. The value of the recovered pulp was assumed to be between $400 - $600 per OD metric ton: the value of the filler was assumed to be $50 - $100 per OD metric ton. Of the 33 mills whose sludges were examined, 24% had yields which were greater than 36% and also had a potential fiber recovery greater than 7.0 metric OD tons/day. These mills would be considered possible candidates for fiber recovery from sludge. Of the 33 mills whose sludges were

examined, 12% were considered excellent candidates for fiber recovery from sludge in that the quality of the recovered fiber was good in addition to having high amounts and yields of recovered fiber. Based on these observations, about 40% of the amounts of fiber and filler given in Table IV come from mills where fiber recovery has excellent economic potential.

THE PRIME FIBER EXPERIENCE IN PRODUCING MARKET PULP FROM PAPER MILL SLUDGE

Description of Paper Mill Sludges Processed by Prime Fiber

From April 1990 to August 1991, Prime Fiber successfully produced market pulp exclusively from paper mill sludge. During that 17 month period, many changes in processing equipment and operation took place. These changes allowed Prime Fiber to increase product quality and tonnage while accepting poorer quality sludges. The sludges from six paper mills were processed during that time.

Prime Fiber accepted almost all of the sludge generated by Mill 1 from April 1990 to August 1991. The sludge from this mill contained little ash and had a relatively high percentage of OD solids potentially recoverable as OD long fiber (45.5%). It was estimated that 1.2 metric tons per day of OD long fiber could be produced from this source. Some of the sludge obtained from Mill 1 was mined from a landfill located adjacent to their wastewater treatment plant. This sludge had been buried for approximately 3 years and visually looked about the same as the fresh sludge. However, the landfilled sludge was odorous and contained less recoverable long fiber than the fresh sludge (28.1% compared to 45.5%). Furthermore, the landfilled sludge contained copious amounts of gravel and other debris that created problems with the pulping and cleaning equipment. Mill 1 landfilled sludge was used from July 1990 to March 1991.

Mill 2 was an non-integrated mill producing high quality rag content bond, ledger, index bristol and other fine papers from virgin pulp and cotton fibers. Though the amount of sludge generated was small, the recovered fiber was of high quality and was relatively easy to bleach. The Appleton Pulp Mill accepted all of the sludge generated by Mill 2 from April 1990 to August 1991. It was estimated that 0.6 metric tons per day of OD fiber could be produced from this source. The yield of OD fiber was 39.8%.

Mill 3 was an integrated pulp and paper mill producing tissue products (sanitary, towel, and napkin stock) from bleached hardwood sulfite pulp (produced on site) and purchased market pulps. This sludge contained appreciable pulp mill solids that overloaded the capacity of the Prime Fiber screening and cleaning system. Dirt counts rose dramatically whenever this sludge was used. Another problem was that the sulfite pulp exhibited serious brightness reversion. Noticeable pulp yellowing would occur within one day. These problems proved so severe that mill 3 sludge was accepted only in January and February 1991. It was estimated that 9.2 metric tons per day of OD fiber could be produced from this source. The yield of OD fiber was 37.6%.

Mill 4 was an non-integrated paper mill producing tissue type products (facial and bathroom tissue, toweling, disposable diapers, etc) primarily from bleached virgin market pulps. This sludge would have made an excellent furnish for pulp making if it weren't for the fact that the sludge was screw pressed. This made the sludge difficult to defiber and caused the ash to penetrate deeply into the fiber lumens. Deflaking proved only moderately effective in defibering

and releasing the ash from the fiber. Nevertheless, considerable quantities of this sludge were accepted by the Appleton pulp mill (from April 1991 to August 1991). It was estimated that 2.5 metric tons per day of OD fiber could be produced from this source. The yield of OD fiber was 46.6%.

Mill 5 was an non-integrated paper mill producing cotton fiber bond, ledger, bristol, and other fine papers from predominantly virgin pulps. This sludge was also an excellent furnish for pulp making except for a few problems. One was the fact that secondary biological sludge was combined with the primary solids creating an odor problem whenever the sludge was stored for significant time periods. The fiber also contained dyes that were difficult to bleach using a single stage hypochlorite bleaching process. This, in turn, lowered the overall brightness of the market pulp product. This sludge was used in July and August 1991. It was estimated that 2.5 metric tons per day of OD fiber could be produced from this source. The yield of OD fiber was 41.4%.

Mill 6 was an non-integrated paper mill producing glassine, greaseproof, wet strength and other papers. The amount of long fiber (51.4%) in this sludge was higher than any other source. Unfortunately, the fiber proved difficult to bleach due to the presence of unbleachable dyes and unbleached fiber and could not be used in appreciable quantities. It was estimated that 1.7 metric tons per day of OD fiber could be produced from this source. This sludge was used from April to July 1990, October to November 1990, February 1991, and May 1991.

The total estimated amount of pulp that could be produced from all of these sources was 17.7 OD metric tons/day (19.7 AD metric tons/day). This was still considerably below the hoped for 45 AD metric tons/day production level. Though many other paper mill sludges were examined within a reasonable distance of the Appleton mill, these sources proved unsuitable to produce a high quality papermaking pulp for a variety of reasons: either the pulp recovery yield was below what would have been economically feasible, the fiber could not be bleached to an acceptable brightness, or the sludge contained too much dirt and debris for the Prime Fiber screening and cleaning system. Therefore, during September 1991 it was decided to focus on the use of PC-WOW to make market pulp.

TABLE V

PRIME FIBER CORPORATION INCOMING SLUDGE METRIC TONNAGES
(APRIL 1990 - AUGUST 1991)

TOTAL WET TONS:	13,512
TOTAL OVEN DRY TONS:	4,120
TOTAL VOLATILE TONS:	3,604
TOTAL ASH TONS:	516
TOTAL TONS (90% SOLIDS):	4,577
PREDICTED OD FIBER TONS:	1,674
ACTUAL OD FIBER TONS:	1,645
ACTUAL OD PULP TONS:	1,730

VOLATILE YIELD (OD PULP/OD VOL SLUDGE):	45.6%
TOTAL YIELD (OD PULP/OD SLUDGE):	42.0%

Table V gives the tonnages of paper mill sludge processed by Prime Fiber during the 17 month period. Sludge trucks were weighed before unloading to

determine tonnage. At the same time, a technician would grab a sample such that ash, consistency, volatile solids, and Bauer-McNett fiber length distribution could be determined. The Bauer-McNett test predicted that 1,674 metric tons of fiber would be recovered from 3,604 metric tons of volatile solids entering the mill as paper mill sludge. This prediction was about 2% higher than the 1,645 metric tons that were actually recovered.

The six mills that disposed of their sludge at Prime Fiber were charged a tipping fee. The tipping fee was typically set at a level such that the mill's total cost of sludge disposal was the same or slightly less than landfilling.

Description of Prime Fiber Process Technology

Dewatered paper mill sludge was hauled to the Prime Fiber mill in a variety of different sludge trucks at the sludge generator's expense. Prime Fiber personnel used an articulated front-end loader to handle the sludge after it had been unloaded on the tipping floor. The sludge was defibered (i.e. the individual fibers were untangled from fiber bundles) at about 4% consistency in 22.7 m^3, unbaffled, 304 stainless steel tanks. Agitation was provided by 11.2 kW agitators. Provision was made such that steam could be injected directly into the tanks to raise the temperature into the range of 40 to 50 ^{o}C. Usually no pulping chemicals were added to the defibering tanks. Normally one hour or less was sufficient to completely defiber a sludge. Problems were encountered in defibering screw pressed sludge where the fibers were pressed tightly into fiber bundles by the high mechanical forces encountered in a screw press. Therefore, a deflaker was installed to assist in defibering this type of sludge. Eventually, the defibering tanks were replaced with a standard 3 OD ton lobed hydrapulper when Prime Fiber pulped wastepaper instead of sludge.

After defibering, the furnish was pumped to a rectangular grit tank to remove high density large materials. This chamber was cleaned periodically by hand. The stock then flowed to a 22.7 m^3 consistency control tank to be diluted to about 1% consistency. Initially the diluted stock was pumped to a bank of 0.15 m diameter Bauer hydrocyclones with stock savers. These cleaners removed fine grit before the pulp went to screening. Eventually these Bauer cleaners were replaced by a cleaning system that included both coarse (a Hymac with 2.0 mm diameter holes) and fine (a Voith with 0.25 mm slots) pressure screens and a forward three stage 0.075 m diameter Bauer hydrocyclone system. This equipment enabled dirt counts in the range of 5 - 20 ppm to be obtained whenever sludges were processed from mills 1, 2 and 6 (plus landfilled sludge from mill 1).

After the cleaning steps, the long fiber was separated from the fiber fines/clay by a screening device. Initially vibrating screens were used. These screens, however, had severe hydraulic capacity limitations and were replaced by sidehill screens in June 1990 that had a much higher hydraulic capacity. Unfortunately, the sidehill screens were easily plugged. By December 1990, a Black Clawson Double Nip Thickener (DNT) was installed at the Appleton Pulp Mill to replace the sidehill screens. The DNT did an excellent job in separating the fiber fines/clay from the long fiber and thickening the long fiber to up to a 12% consistency.

After screening, the long fiber pulp entered a low consistency (4%) bleaching tank identical to the defibering tank. Hypochlorite was used as the bleaching agent. Steam was directly injected into the tank to raise the temperature

into the range of 40 to 50 °C. After the DNT was installed, hypochlorite bleaching was instead performed in a medium consistency (10 - 12%) bleaching tower. After bleaching, the stock was diluted with bleach killer added. The stock was then dewatered on a belt press to a consistency in the mid 20's. The dewatered stock was stacked on pallets by hand and shipped to customers. In December 1990, the belt press was replaced by a wet lap machine capable of producing standard size sheets of wet lap pulp at a consistency in the high 30's.

All effluents were at first clarified by gravity sedimentation type clarifiers. These clarifiers, however, proved relatively ineffective as the waste solids had a strong tendency to float. Therefore, the gravity clarifiers were replaced by a dissolved air flotation (DAF) system. The DAF was very effective in removing the waste solids from the effluent which was recycled. The waste DAF float solids were landfilled after thickening by a rotary drum screen and dewatering by a FKC screw press.

Tables VI, VII and VIII presents Prime Fiber pulp tonnage and quality data. A total of 1,730 OD tons and 1,922 AD tons of pulp were produced exclusively from paper mill sludge during that time period. The overall yield of pulp from the sludges was 42.0%. Pulp samples from each truck load (about 18 metric tons of wet lap pulp) were taken and CSF, burst, brightness, dirt count, and ash measured. Monthly average values are presented in Table VII. In Table VIII, Bauer-McNett fiber classification data were taken on what were monthly composite samples from March 1991 to August 1991. Values for virgin hardwood bleached Kraft (HWBK) and softwood bleached Kraft (SWBK) pulp samples are presented in Tables VII and VIII for comparison purposes.

The freeness of unrefined virgin hardwood pulp (740) and softwood pulp (790) was considerably greater than the recovered sludge pulp (358). The principal reason for the low pulp freeness was that the sludge fiber was highly refined. It was not necessarily true that the freeness was low because the sludge pulp contained high quantities of fiber fines. The freeness averaged 434 from March 1991 to August 1991 after much of the new processing equipment had been installed.

Table VIII presents Bauer-McNett fiber classification data on sludge pulp composite samples. The total amount of fiber retained on a 100 mesh screen (72.7%) was about the same as for virgin hardwood pulp (74.2%). A virgin softwood pulp had a much higher long fiber fraction (93.6%).

The ash content of the sludge pulp (5.1%) was significantly higher than the virgin pulps tested (0.2%). However, customers did not consider an ash content of 3 to 4% for a secondary fiber pulp to be unreasonable. After March 1991, the ash content averaged 3.4%.

The brightness of the sludge pulp was typically in the high 70's to low 80's. The brightness could normally be increased or decreased by adjusting the bleach dosage. Problems with unbleached fiber, recalcitrant dyes and brightness reversion were encountered with some sludges.

The dirt count averaged 42.0 ppm over the 17 month period. This average was skewed by two months where the dirt count was 103 and 324 ppm respectively. During the first 10 months of mill operation, the dirt count was less than 20 ppm. There were three months when the dirt count averaged less than 10 ppm.

TABLE VI

PRIME FIBER CORPORATION PULP METRIC TONNAGES
(APRIL 1990 - AUGUST 1991)

TOTAL WET TONS:	5,557
TOTAL OVEN DRY TONS:	1,730
TOTAL OD LONG FIBER TONS:	1,645
TOTAL ASH TONS:	85
TOTAL AIR DRIED TONS (90% SOLIDS):	1,922
VOLATILE YIELD (OD PULP/OD VOL SLUDGE):	45.6%
TOTAL YIELD (OD PULP/OD SLUDGE):	42.0%

TABLE VII

PRIME FIBER CORPORATION PULP PROPERTIES
AVERAGE MONTHLY VALUES
(APRIL 1990 - AUGUST 1991)

	SOLIDS WT%	METRIC DRY WT TONS	CSF (ML)	BURST (kPa)	BRGT (%)	DIRT (PPM)	ASH (%)
AVERAGE	31.4	102	358	125	78.4	42.0	5.1
STD DEV	5.6	34	64	29	2.8	74.4	2.1
HIGH	38.4	170	463	188	82.5	324.3	8.1
LOW	24.5	33	260	85	71.5	5.5	2.3
VIRGIN HWBK			740	45	84.0		0.2
VIRGIN SWBK			790	139	80.0		0.2

TABLE VIII

PRIME FIBER CORPORATION PULP PROPERTIES
VALUES OF MONTHLY COMPOSITE SAMPLES
(MARCH 1991 - AUGUST 1991)

	SOLIDS (%)	ASH (%)	CSF (ML)	BAUER-MCNETT FIBER CLASSIFICATION: % VOLATILE SOLIDS RETAINED ON 100 MESH SCREEN	BAUER-MCNETT FIBER CLASSIFICATION: % TOTAL SOLIDS RETAINED ON 100 MESH SCREEN
AVERAGE	38.5	3.4	434	72.7	70.2
STD DEV	0.7	0.6	26	3.7	3.2
HIGH	39.1	4.1	470	76.5	73.6
LOW	37.1	2.4	390	65.0	63.5
VIRGIN HWBK		0.2	740	74.2	74.1
VIRGIN SWBK		0.2	790	93.6	93.4

Though the quality of the pulp produced from paper mill sludge was not as high as virgin pulps, the market demand was nevertheless strong. Prices were near virgin hardwood levels.

CONVERSION OF FIBER FINES/CLAY INTO A PAPERMAKING FILLER

The principal focus of NSF SBIR Phase I and II research was to convert the fiber fines/clay fraction of paper mill sludge or PC-WOW into a papermaking filler product after the long fiber had been extracted. A relatively uncontaminated stream of fiber fines/clay was contained in the underflow or filtrate of the Black Clawson DNT. Table IX gives the characteristics of those solids when the Prime Fiber mill was using PC-WOW as a raw material to make market pulp.

TABLE IX

CHARACTERISTICS OF 19 SAMPLES OF DNT FILTRATE SOLIDS
COLLECTED WHEN PC-WOW WAS USED TO PRODUCE PULP

	CONSISTENCY (%)	ASH (%)	BAUER-MCNETT FIBER CLASSIFICATION % TOTAL SOLIDS RETAINED ON 325 MESH SCREEN
AVERAGE	0.088	33.5	6.8
STD DEV	0.012	2.9	1.9
HIGH	0.113	37.1	12.5
LOW	0.059	24.9	4.2

A total of 19 samples were collected from November 1991 to February 1992 (approximately one sample per week) and the consistency, ash, and Bauer-McNett retention measured. The average consistency was 0.088% and the average ash was 33.5%. The DNT had an approximately 100 mesh wire through which the filtrate solids passed. Even so, only 6.8% of the DNT filtrate solids were retained by a 325 mesh screen on a Bauer-McNett apparatus. Though brightness was not measured on these particular samples, nine other DNT samples were collected within this same time period. The average brightness of those samples was 63.1 with a low value of 56.2 and a high value of 67.5. The brightness was affected by the presence of very fine ink particles. Attempts to brighten the fiber fines/clay by bleaching the ink particles or ink removal by adsorption onto a solid surface or flotation were unsuccessful.

TABLE X

CHARACTERISTICS OF 5 SAMPLES OF DNT FILTRATE SOLIDS
COLLECTED WHEN PAPER MILL SLUDGE WAS USED TO PRODUCE PULP

SAMPLE NO.	CONSIS. (%)	ASH (%)	BRGT (%)	R (Tm/kg)	R_o (Tm/kg)	m	r
3	0.268	16.1	36.4	5.56	0.391	0.378	0.963
4	0.322	13.9	37.8	4.23	0.685	0.306	0.951
5	0.292	40.2	68.6	3.21	0.328	0.297	0.956
6	0.266	24.7	58.3	8.78	1.887	0.130	0.874
7	0.312	51.9	63.6	1.75	0.402	0.207	0.997

From March to August 1991, samples of DNT filtrate solids were collected when paper mill sludge was used to make market pulp at the Prime Fiber mill. Many experiments were performed on these samples with the goal to increase the brightness and decrease the specific resistance to filtration. Table X gives the consistency, ash, brightness, and specific resistance of these 5 samples.

A simple test was developed where both brightness and specific resistance could be measured on DNT filtrate solids. This involved filtering under vacuum 30 g of a 3% consistency slurry through a Gooch crucible containing a glass microfiber filter. By recording the time to collect the filtrate, it was possible to calculate the specific resistance to filtration (R). During the test a plaque of fiber fines/clay formed on the filter pad. The plaque was placed on the aperture of a brightness meter to have its brightness measured. Since the plaque was moist, its brightness was less than the brightness measured by a TAPPI standard procedure (1991). However, the moist brightness measurement correlated well to the dry standard TAPPI brightness measurement (Maxham, 1992b).

The goal was to achieve a fiber fines/clay solids brightness greater than 80 and a specific resistance less than 1.0 Tm/kg. Values of R less than 1.0 Tm/kg (Tm = 10^{12}m) are also considered to be desirable in dewatering unit operations for wastewater treatment plant sludges. Difficult to dewater sludges (e.g. raw biological sludge) can have a specific resistances as high as 100 Tm/kg and must be conditioned with ferric chloride, lime, and/or polymers before dewatering. The DNT filtrate solid samples had a specific resistance of 1.75 to 8.78 Tm/kg (see Table X). This meant they were moderately difficult to dewater in a vacuum filter apparatus. Since paper machine wires dewater the furnish by gravity and vacuum filtration mechanisms, it was anticipated that adding raw fiber fines/clay mixtures to papermaking furnishes would cause drainage problems unless the specific resistance of those solids were decreased.

For DNT filtrate solids obtained from paper mill sludge, the brightness could be significantly increased by bleaching with hypochlorite. Even so, the results of bleaching experiments were somewhat disappointing in that rather heavy dosages of hypochlorite were often required to achieve modest brightness increases. A typical brightness gain was 1.0 to 1.5 points for every 1% hypochlorite added (based on OD DNT solids) at dosages less than 15%. Much greater success was achieved in improving the specific resistance. Experiments were performed where the DNT filtrate solids were reacted with 15% hypochlorite at room temperature for 24 hours at the pH levels of 3, 5, 7, 9, and 11. The data were correlated by the following exponential equation:

$$R = R_o * e^{(m*pH)}$$

where:

- R - specific resistance of the cake (Tm/kg)
- R_o - a constant (Tm/kg)
- m - a constant (1/pH unit)
- pH - reaction pH level
- r - correlation coefficient

Table X gives the values of R_o, m, and r for the experiments performed on DNT samples no. 3 - 7. R_o can be considered the value of R after the DNT filtrate solids were reacted at a very low pH. The values of R given in Table X were the specific resistances of the DNT solids before chemical treatment and

where the pH was approximately neutral. Referring to Table X, it is seen that the value of R_o was about an order of magnitude less than R for every sample. Therefore, reacting the fiber fines/clay at a low pH greatly improved the specific resistance. On the other hand, reacting the solids at a high pH caused the specific resistance to greatly increase. Further experimentation showed that reacting the fiber fines/clay samples at a low pH caused the solids to drain well even if the pH was later increased. Also, it was not necessary to add hypochlorite bleach in order to improve specific resistance.

The ability to decrease the specific resistance of fiber fines by lowering the pH was a significant and unexpected result and a patent application was filed. This technique only required that the DNT slurry be thickened and reacted at ambient temperature with sufficient acid to significantly lower the pH. Lowering the pH to 5.0, in fact, seemed adequate. The amount of acid that needed to be added was in the range of 0.06 to 0.12 g H_2SO_4/g OD DNT solids to obtain a pH of 5.0.

Though a significant improvement in fiber fines/clay specific resistance was achieved by an acid treatment, improving brightness was much more difficult, particularly for samples containing many ink particles. Therefore the fiber fines/clay suspensions will only be suitable as fillers for paper and paperboard products where a low brightness is acceptable.

ACKNOWLEDGEMENT

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EFFLUENT COMPLIANCE THROUGH POLLUTION PREVENTION AT INGERSOLL-RAND

Daniel P. Reinke, P.E.*
Capsule Environmental Engineering, Inc.
1970 Oakcrest Avenue, Suite 215
St. Paul, Minnesota 55113

Robert Smith
Ingersoll-Rand Company
Davidson, North Carolina

ABSTRACT

The Ingersoll-Rand manufacturing facility in Davidson, North Carolina, developed and implemented a cost-effective method to comply with stringent zinc discharge limits (0.05 milligrams/liter) proposed by the control authority. This paper addresses the methods used to identify and quantify all sources of zinc in the wastewater, segregate industrial from sanitary wastewater, reduce process flows, and change certain raw materials and material handling practices. Compliance with the zinc limits was achieved and has been maintained through these pollution prevention techniques, rather than treatment.

Operations at the facility include machining, cleaning, painting and equipment testing. The wastewater modifications were completed in conjunction with a total facility realignment which increased product quality and reduced manufactured costs.

Initial activities included simple colormetric analyses of all wastewater sources. This work identified certain compressor lubricants, a galvanized screen over a trench, nuts and bolts dropped into the trench, and accumulated sludge in an oil/water separator that could contribute zinc to the wastewater. In addition, a new segment of incoming galvanized pipe was found to supply water with elevated zinc levels. The significance of each source was estimated and options were identified to minimize or eliminate each source.

The selected options were implemented in 1992 and the facility has been able to maintain compliance with effluent zinc levels since that time. This case study effectively demonstrates the benefits of utilizing source reduction principles to cost effectively achieve environmental compliance.

KEYWORDS

Wastewater, Zinc, Pollution Prevention

INTRODUCTION

The Ingersoll-Rand plant in Davidson, North Carolina, is a state-of-the-art, just-in-time manufacturing center, producing rotary and reciprocating air compressors and snow making machines. The facility is ISO 9001 quality certified.

Facility operations include assembly, welding, product testing and packaging. The facility also houses repair operations for compressors sent in by customers. These repair and rebuild operations include aqueous cleaning, simple machining and painting.

In the 1980s, wastewater was generated from a number of operations at the site. At that time, compressors were assembled, tested, cleaned using a manual pressure washer, and painted using a solvent-based paint in a water wall paint booth. During the compressor testing process, there would be occasional leaks of the compressor lubricant/coolant. This lubricant would drain into trenches which were connected to an oil/water separator. The test cells would be regularly cleaned with water which also drained through the trenches. The trenches were covered with galvanized metal screen material to catch dropped bolts and other small parts. Cleaning in the rebuild area was accomplished using petroleum distillate soak cleaners in which parts often had to sit overnight to loosen stubborn carbon deposits, oils and greases. Process wastewater was generated from the compressor test cells, discharge of water from the wet paint booths and general floor cleaning. Site wastewater discharges averaged 11,000 gallons per day of a mixed process and sanitary flow.

In the midst of a major redesign of the products and manufacturing process, Ingersoll-Rand was notified by the local control authority that the zinc discharge limits in the discharge permit were to be significantly reduced from 0.42 milligrams per liter (mg/l) to 0.05 mg/l to accommodate a lack of zinc loading capacity at the publicly owned treatment works (POTW). Ingersoll-Rand retained Capsule Environmental Engineering to assist in identifying zinc sources within the facility and to jointly develop a plan to attain compliance through pollution prevention rather than expensive end-of-pipe treatment.

METHODOLOGY

The strategy for effluent compliance through pollution prevention included the following steps:

* Source sampling and analysis
* Data evaluation
* Strategy development
* Pilot testing
* Final design
* Implementation and training
* Continuous improvement

The activities taken under each step are described below.

Source Sampling and Analysis

This initial task included evaluating all wastewater sources to determine the contribution of each process to the overall facility wastewater loading. To get an accurate evaluation of the sources, multiple samples were collected and analyzed for zinc and chemical oxygen demand (COD) from the following areas:

* Incoming water at several locations
* Trench water
* Oil/water separator effluent
* Floor cleaning water
* Compressor lubricants

Sample analysis was completed using colormetric test kits to allow for immediate test results. Select samples were also sent off site for laboratory analysis.

Data Evaluation

The data collected was evaluated to determine the relative significance of the various wastewater sources. There were several interesting findings.

The first finding was that the compressor lubricants contained significant levels of zinc and that when the lubricants were mixed with water, the water would pick up zinc at levels above the discharge limits.

A second finding was that a new, more biodegradable compressor lubricant that was being used had a specific gravity of 0.99, which was too high to allow effective removal through an oil/water separator. Fluid suppliers were contacted and it was found that low levels of zinc were added to the materials to increase lubricity. While reformulation may have been possible to eliminate this source of zinc, the more logical approach was to eliminate the discharge of any lubricants to the wastewater. This strategy was consistent with the product and process redesign activities which were aimed to eliminate all machine leaks and rework processes.

A third finding was that while incoming zinc levels were significant, 0.03 to 0.06 mg/l, in one area of the building where there had been extensive remodeling, the incoming water was found to contain 0.56 mg/l of zinc. We suspected that galvanic action was causing erosion of new galvanized water supply piping where it was connected with older copper lines. This piping was immediately replaced with copper piping.

A fourth finding was that the water from the trenches and the oil/water separator contained especially high levels of zinc at the beginning of the day. What we determined was that dropped galvanized fasteners were dissolving in the trenches, releasing zinc into

the wastewater. We also found that there was a buildup of sludge in the oil/water separator which also contained high levels of zinc and released this material into the wastewater. Levels were highest in the morning at startup and decreased through the day. The trenches and the oil/water separator were cleaned out, lowering zinc levels in the discharge. Regular cleaning of the trenches and the oil/water separator was added to the facility preventative maintenance program to prevent further buildup.

Strategy Development

Based on this evaluation, which included calculations of total mass loading of contaminants from industrial processes, a strategy was developed to meet POTW loading requirements. This strategy was developed in conjunction with the local control authority which was very supportive of Ingersoll-Rand's desire to address the issue through pollution prevention rather than extensive end-of-pipe metals removal equipment. The strategy was as follows:

1. Segregate industrial flows from sanitary flows and reduce the permit flow limit from 14,000 gpd to 5,000 gpd.

2. Increase zinc limits on a concentration basis to reflect the lower permit flow rate.

3. Eliminate lubricant leaks and discharges wherever possible through improved product and process design and increased employee awareness.

4. Perform regular cleaning of trenches and the oil/water separator to reduce sludge buildup.

5. Purchase a non-chelated cleaner for use in floor cleaning.

6. Investigate the use of plastic screens over the trenches to eliminate the galvanized material. The trenches were later eliminated in the redesign of the compressor test cells.

7. Investigate the use of an ultrafiltration system to remove any oil and high COD contaminants that would come from the compressor test cells, floor cleaning and new aqueous cleaning systems.

As part of an overall objective to reduce the environmental impact of the Ingersoll-Rand manufacturing operations, the facility tested and purchased several high pressure cabinet washers for use in rebuild and manufacturing operations. These washers significantly reduced the amount of time and labor required in these operations, reduced the generation of hazardous waste from the facility and reduced employee exposure to hazardous chemicals.

Another significant change was the elimination of painting operations through the use of prepainted parts. The use of prepainted sheet stock gives a better product appearance and also allows these sheets to be coated more efficiently, reducing manufacturing costs. The elimination of all production painting at the facility also reduces the impact of air permitting requirements, reduces the generation of hazardous waste and reduces employee exposure to chemical solvents. All of these items reduce the cost of manufacturing at the facility.

Pilot Testing

Testing the impact of the procedural changes was completed by thoroughly cleaning out the trenches and oil/water separator, and repeating the source sampling and analysis. Operators were trained to prevent the discharge of compressor lubricant to the drains. These changes were found to effectively eliminate zinc contributions from the test cell operations.

While the procedural changes alone may have been able to maintain regular compliance, facility management personnel were concerned that there was no effective system to remove lubricants from the wastewater. Since the new, more biodegradable fluid had a specific gravity close to water, the oil/water separator was not able to reduce the oil and grease and COD loadings that would result from a compressor leak in the test cells. Membrane technologies were tested, first on a bench scale and later with a pilot scale system, to determine the potential of this method to reduce these loadings.

The bench and pilot testing showed that ultrafiltration was effective in reducing COD loadings of wastewater containing compressor lubricant by approximately 80 percent. Since these fluids also contain low levels of zinc, it was expected that this technology could reduce zinc loadings from any fluid leaks. Pilot equipment performed well, and facility personnel were able to easily maintain the system with minimal labor requirements.

Final Design

Based on the results of the pilot testing, a final design for installing an ultrafiltration system was submitted to, and approved by, the local control authority. Due to a lack of adequate space in the existing oil/water separator area, a new building was designed to house storage tanks and the ultrafiltration system. This new building included secondary containment for spill protection and a sprinkler system.

Implementation and Training

The product and process redesign involved a total revision of the manufacturing facility layout. Quality teams assisted in improving the designs to simplify the manufacturing process. New test cells were built and the old trench system was eliminated.

The ultrafiltration system was installed in 1992 and has allowed the facility to remain in compliance with the new discharge standards. One process modification was made to bubble air through the wastewater holding tank to prevent the buildup of anaerobic bacteria. Prior to this modification, the smell from the stagnant water would build up, especially over weekend shutdown periods.

Continuous Improvement

The facility is dedicated to a total quality management program that stresses continuous improvement in all of the operations. This program has had a measurable impact on product quality and manufactured cost.

RESULTS

Since implementation of the process changes, the facility has been in full compliance with effluent discharge limits, including the zinc discharge limits. Average process wastewater flows are 2,000 gallons per day. The most recent effluent analysis gave the following results:

BOD	83 mg/l
TSS	8 mg/l
Zinc	0.01 mg/l

CONCLUSION

Pollution prevention techniques were successful at Ingersoll-Rand in addressing stringent zinc discharge limitations proposed by the local control authority. While some treatment was necessary to assure COD loadings would be within standards, the product and process modifications that were completed successfully kept zinc out of the wastewater. These modifications, which were initially developed to reduce manufacturing costs and improve product quality, had the following environmental impacts:

* Significantly reduced generation of hazardous waste, to below small quantity generator limits.

* Effectively eliminated the volatile organic compound (VOC) emissions from the facility, reducing air permitting requirements.

* Effectively eliminated employee exposure to solvents.

* Allowed compliance with stringent zinc discharge limits without the investment in a major end-of-pipe treatment system.

POLLUTION PREVENTION OPPORTUNITY ASSESSMENT FOR A MAJOR INDUSTRIAL CLIENT

Alex, Gregg S.; Engineering-Science, Inc., 406 West South Jordan Parkway, Suite 300, Salt Lake City, UT 84095 (801)572-5999.

ABSTRACT

A pollution prevention (P2) opportunity assessment was conducted for a major industrial client. Approximately 250 different waste generating processes were studied to find P2 opportunities. The P2 opportunities were developed to assist the client in reducing the amount of hazardous materials used and hazardous wastes generated by their industrial processes.

The study consisted of five distinct tasks: 1) process assessment, 2) determination of possible P2 options, 3) technical feasibility analysis, 4) economic feasibility analysis, and 5) preparation of a options list ranked according to ability to accomplish the client's goals. Through these tasks, each P2 option was evaluated for its potential effectiveness. The highest ranking options were recommended to be a top priority.

The processes involving the maintenance of vehicles are a major contributor of wastes at the facility. This paper focuses on the five tasks discussed above, using the vehicle maintenance processes as examples throughout the paper.

Keywords: Pollution prevention, waste minimization, opportunity assessment, process assessment, hazardous waste, air emissions, waste water.

INTRODUCTION

P2 is becoming more than just a way for industries to save money, reduce potential liability, and improve public perception. There are now regulations that require waste minimization programs to be in-place. In 1990, Congress emphasized the importance of waste minimization in the Pollution Prevention Act (PPA). The PPA established a national policy to reduce pollution at its source rather than practice traditional "end-of-pipe" approaches. Storm water general permit regulations (40 Code of Federal Regulations (CFR) 122.26) require pollution prevention (P2) plans to be developed. The US Environmental Protection Agency (EPA) issued guidance (58 Federal Register No. 31114) on Section 3002(b) of the Resource Control and Recovery Act (RCRA), which requires generators to certify on their manifests that they are conducting a waste minimization program at their facility. In the near future, many more regulatory mandates and guidelines for P2 can be expected as EPA implements its Source Reduction Review Project (SRRP). Under this project, EPA will evaluate P2 alternatives during all regulatory review and development processes.

In May 1992, Engineering-Science, Inc. (ES) was asked to develop a pollution prevention (P2) implementation plan for a major industrial client. The client was interested in a plan providing P2 options that 1) would assist them in complying with regulatory requirements, 2) achieved substantial reductions in use of ozone depleting substances (as defined in the Clean Air Act, Sect. 602(e)) , EPA's 17 Target Compounds[1], and other potentially hazardous substances, 3) could be easily implemented, 4) were cost effective, and 5) would reduce the generation of hazardous waste, waste water, and regulated air emissions. To achieve these objectives, ES performed five distinct tasks:

- facility-wide process assessment;
- determination of potential P2 options;
- technical feasibility analysis;
- economic feasibility analysis; and
- preparation of an options list ranked according to ability to accomplish the client's goals.

This paper is organized chronologically by the tasks listed above. The application of these tasks to vehicle maintenance operations is used as an example throughout the text.

PROCESS ASSESSMENT

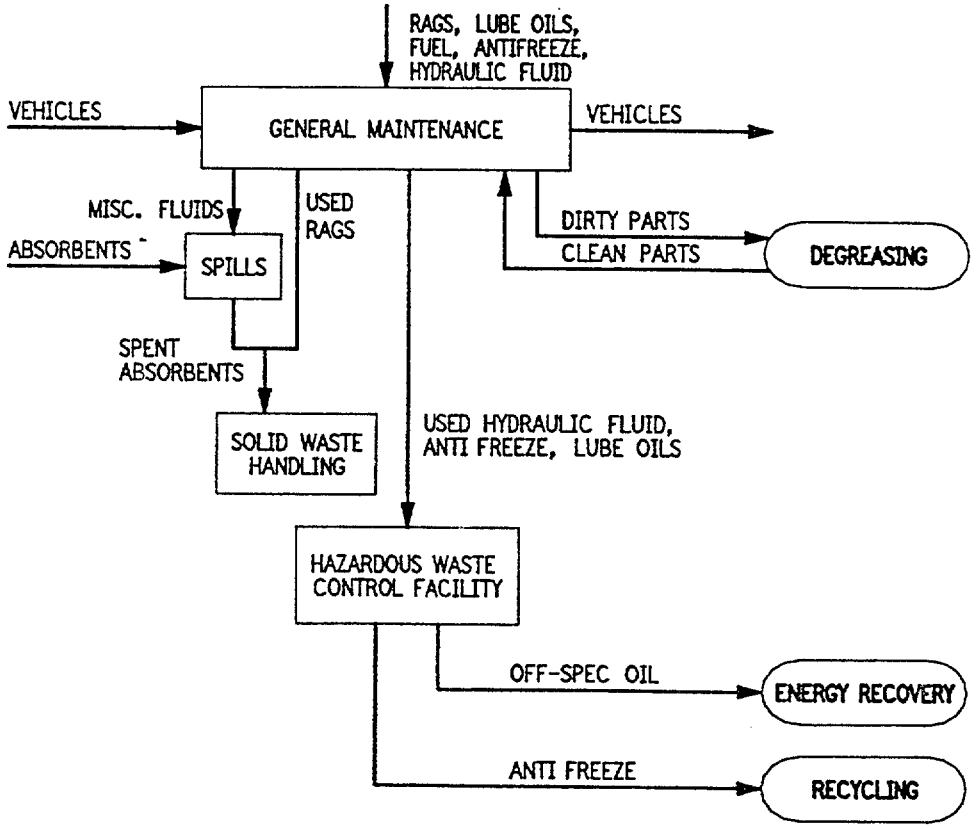
The investigation of 250 different waste producing locations began at RCRA

[1]- The EPA 17 Target Compounds are defined under EPA's 33/50 Voluntary Program established in 1988 (see Table II).

satellite hazardous waste collection sites. Based on the wastes collected at each site, a determination of the contributing processes was made. A set of worksheets was prepared to describe each of the these processes. Operators and managers at each location provided most of the information necessary to complete the worksheets, and based on their working knowledge offered specific ideas for P2. Additional sources of process information included in-house databases used by the client to track hazardous material usage, and hazardous waste generation and characterization.

For each process observed, ES developed a general flow diagram (see Figure 1) and calculated a best estimate of input materials used and waste products generated. Other information collected to complete the worksheets included: 1) the types of equipment used, 2) in-place pollution controls, 3) material and waste handling procedures, and 4) industrial hygiene information, such as hours of exposure to input materials and level of personal protective equipment (PPE) required.

FIGURE 1
Vehicle Maintenance Flow Diagram



ES completed the worksheets for each of the 250 process sites. The process sites were then organized into 29 "process groups" as shown in Table I. The groupings were based on the nature of activities, types of input materials, and types of wastes associated with each process. Hazardous material and waste totals are shown in Table I for each process group. The Vehicle/Machinery Maintenance and Repair group (VEH) consumed

an estimated 544,000 kilograms of potentially hazardous materials such as diesel fuel, hydraulic fluid, and antifreeze. Used oils, spent solvents, and old asbestos brake pads were some of the wastes that contributed to the 177,000 kilograms produced by VEH; although used oils are not classified by RCRA to be a hazardous waste, they were assumed to be hazardous for this part of the study.

TABLE I
Process Group Ranking[2]

CODE	PROCESS GROUP DESCRIPTION	HAZ. MATL'S (kg/yr)	HAZ. WASTE (kg/yr)	RANK	RANK DISTRI-BUTION[3]
ANO	Electroplating (Anodize)	14,966	2,721	7	T
BAT	Battery Testing	43,991	38,549	14	M
BON	Bonding	16,327	726	17	B
DAQ	Parts Cleaning/Degreasing-Aqueous Cleaners	3,039	2,857	11	M
DEF	Defueling/Refueling	2,993,197	7,710	9	M
DSH	Parts Cleaning/Hand-Wipe Degreasing with Solvents	90,703	31,293	5	T
DST	Parts Cleaning/Degreasing-Tank w/ Stoddard Solvent, etc.	10,431	8,617	8	M
DSV	Parts Cleaning/Degreasing-Vapor Degreaser	95,238	20,862	4	T
ECD	Electroplating (Cadmium)	590	726	16	B
ECN	Electroplating (Silver/Cyanide)	680	181	18	B
ECR	Electroplating (Chromium)	26,304	9,070	6	T
ERC	Electronics Assembly/Repair/Cleaning	6,349	2,132	15	B
ETC	Etching (Acid/Alkali)	16,327	726	17	B
JER	Jet Engine Repair and Maintenance	90,703	26,757	7	T
JET	Jet Engine Testing	1,723,356	6,349	10	M
LAB	Laboratory Testing	3,175	3,311	13	M
MET	Metal Working/Welding/Grinding	7,710	8,617	21	B
NDI	Non-Destructive Parts Inspection	6,803	5,896	12	M
PES	Pesticide/Herbicide Application	2,404	0	21	B
PHO	Photo/Microfilm Development	6,349	45	20	B
PNE	Pneudraulics/Hydraulics	5,896	86,168	10	M
PPG	Painting/Corrosion Control-Paint Guns	163,265	108,844	3	T
PRB	Paint Removal-Media Blasting/Abrasive	0	498,866	11	M
PRC	Paint Removal-Chemical Stripping	263,039	77,098	2	T
PRT	Printing	544	227	22	B
PSC	Painting/Corrosion Control-Spray Guns	1,361	1,587	19	B
REC	Recovery of Solvents/Hydraulic Oils/etc.	0	2,812	8	M
VEH	Vehicle/Machinery Maintenance and Repair	544,218	176,871	1	T
WAS	Vehicle/Aircraft Washing (Wash Rack or Steam Cleaner)	8,617	0	16	B

2 - Based on April 1991 - April 1992 data.
3 - T= top 1/3rd, M=middle 1/3rd, B=bottom 1/3rd

Most of the hazardous materials for the VEH group such as fuels, are consumed in the process and others (i.e. antifreeze) are recycled before becoming waste. This accounts for most of the 350,000 kilogram per year difference in the inputs and outputs.

The process groups were then ranked was based on a quantitative evaluation of input materials and wastes generated. Some of the factors considered during input materials evaluation include 1) total weight used, 2) OSHA permissible exposure limit (PEL), 3) worker exposure time, and 4) vapor pressure. For instance, 1,1,1-trichloroethane (TCA) received 12 vapor pressure points of a possible 15 for having a vapor pressure of 135 (mm Hg at 70°F). Generated wastes were evaluated on total weight produced and their reportable spill quantities (RQ) as defined in RCRA 40 CFR 302.4. For example, the RQ for spent TCA is 454 kilograms per year; this resulted in 4 points out of 10.

The total points produced by all input materials used and wastes generated were totaled within each process group. The process groups were then sorted in descending order according to total points received and then assigned a rank (1 to 22) as shown in Table I (note that several processes received the same number of points and therefore the same rank). For evaluation purposes, these were further broken down into a distribution within the top, middle, and bottom 1/3rd of the ranking. For example, groups with a ranking from 1 to 7 are in the top 1/3rd.

The results of this ranking were used to assist in determining which processes had the greatest potential for hazardous material and waste reductions, and to assist in developing a P2 implementation strategy (see Table III).

In addition to process group ranking, waste generation data were used to document the release of ozone layer depleting substances (OLDs) and EPA's 17 Target Compounds. Gross estimates by medium (air, hazardous waste, and waste water) were completed as shown in Table II. These data were also used in developing a P2 implementation strategy (see Table III).

DEVELOPMENT OF P2 OPTIONS

Once the origins and causes of waste generation were understood, ES identified and evaluated a comprehensive set of P2 options for the processes. A final list of 152 potential P2 options was produced. P2 option ideas were provided by a variety of sources including process operators and managers. They often had the greatest understanding of facility operations and processes and were able to provide some potential options. For instance, a vehicle maintenance shop manager recommended the use of equipment that blends used oil with diesel fuel; this would eliminate all disposal costs associated with used oil and reduce diesel fuel consumption. Further research showed special equipment was available and the blended mixture could (at the time of the study) be used as fuel legally in all states in the country except California.

TABLE II
Fate of EPA's 17 Target Compounds and
Ozone Layer Depleting Substances

Target Chemical	Air Emissions (kg/yr)	Hazardous Waste (kg/yr)	Waste-water (kg/yr)	Consumed by Process (kg/yr)	Recycled (kg/yr)
Benzene	100	73	0	104,308	0
Toluene	20,862	3,492	0	104,308	0
Xylene	1,769	590	0	104,308	0
TCA	27,211	49,887	0	0	12,245
Methylene Chloride	73,016	31,293	1,905	0	0
MEK	32,200	6,803	9	0	0
MIBK	9,070	1,179	0	0	0
Chromium	0	1,723	16,327	11,791	0
Cadmium	0	104	27	118	0
Lead	0	16,780	0	9,524	68,934
Nickel	0	227	204	816	0
Cyanide	0	200	771	0	0
TCE, PCE, Carbon tetrachloride, Chloroform, Mercury	0	0	0	0	0
Freon 113	4,989	9,524	0	0	6,213
Other CFCs[4]	816	2,313	0	0	0
Totals	170,032	124,186	19,243	335,175	87,392

4 - Does not include most refrigerants or halons.

Other sources of ideas came from literature research, equipment vendors, and brainstorming sessions among ES personnel and with facility environmental managers. Some additional options developed for the VEH process group included:

- adding "by-pass" oil filtering systems to all combustion engines to extend the useful life of the oil;
- replacing clay-type (kitty litter) oil absorbents with organic, combustible, and compostible absorbents;

- using test equipment to monitor the quality of lubrication fluids so that fluid changes are performed only when necessary;
- switching to alternative fuels such as natural gas, methanol, ethanol, etc.; and
- installing in-line filters in parts cleaning solvent tanks.

TECHNICAL AND ECONOMIC FEASIBILITY

Each of the 152 proposed options were evaluated for technical feasibility based on factors such as 1) P2 potential, 2) material compatibility, 3) commercial availability, 4) anticipated costs and 5) space requirements. For example, alternative fuels were not considered technically feasible for the VEH process group at the time because studies had not proven which fuel had better overall environmental benefit. Natural gas was known to reduce generation of VOCs, but it was thought to increase releases of nitrogen oxides (NOx) and potentially harmful greenhouse gases (Popular Science, July 1992).

Also during the Technical Feasibility analysis, two other factors were evaluated to assist in developing an implementation strategy: 1) Option Hierarchy and 2) Ease of Implementation. The option hierarchy deals with whether the P2 option was considered to be source reduction, reuse/recycling, or treatment/disposal. The client wanted more emphasis placed on source reduction with the least amount of credit going to treatment/disposal options.

The Ease of Implementation was also evaluated and each option was put in one of three categories: a) only personnel or procedural changes required, b) equipment needed is off-the-shelf, or c) option requires further research and testing. This evaluation was important to "weed out" options that would take years to actually get operating and highlight those that could be implemented quickly with few hassles.

Finally, the options determined to be technically feasible were evaluated for economic feasibility. This economic analysis was based on a detailed comparison between costs of business-as-usual ("status quo") and the costs of implementing the P2 option. An economic life of 10 years was used and the net present value as well as payback period was calculated. The economic analysis showed for example, blending used oil with diesel fuel would generate about $77,000 net annual operating savings, while replacing clay-type oil spill absorbents with organic Peat Sorb® would generate a net annual loss of $300.

Another important factor in the economic evaluation was the economic stability of the option. The economic stability of the option was determined by changing one or more of the economic assumptions to see how it would effect the result. For example, in evaluating whether the client should run their vehicles on synthetic oils to decrease the number and cost of required oil changes, it was assumed that synthetic oils would last twice as long as conventional. The validity of this assumption was unknown at the time, so it was changed several ways to see how sensitive the net present value was to oil

change frequency. Net present value was the current worth of implementing the option over ten years. If the net present value was considered sensitive to assumption changes (i.e. cost savings were uncertain), the P2 option was considered to be economically unstable.

IMPLEMENTATION STRATEGY

After technical and economic analysis, the potential list of P2 options was narrowed to 109. To develop the implementation strategy, each of these options was assigned points based on an evaluation in several categories such as ease of implementation, payback period, and amount of reduction in waste water generation (see Table III). Using this scheme, the results of the scoring process for the top five options showed a net present value of eleven million dollars (based on an economic life of 10 years) with the predicted payback of each less than five years (see Table IV). The potential estimated reduction in RCRA hazardous waste generation for these 5 options approaches 40,000 kilograms per year. Also shown in Table IV are evaluation results for 3 VEH P2 options.

Intangible factors were also identified for each option to highlight aspects of each option that could not be otherwise quantified. For example, improvements in long-term worker health and safety, reductions in potential liability, and possible space limitations were all factors considered to be intangible. For this project, these factors helped the client differentiate between options that received equal points in the ranking. In addition, the facility will take these into consideration when they evaluate options for implementation.

TABLE III
P2 Options Evaluation Scheme

CHARACTERISTIC OF OPTION	2 POINTS	1 POINT	0 POINTS
Type of Option	Source reduction	Reuse/recycling	Treatment or disposal
Ease of Implementation	Personnel or procedural changes	Off-the-shelf equipment needed only	Requires further testing
Payback Period (PB) and Net Present Value (NPV)	PB≤2 and NPV>0	2<PB≤5 and NPV>0	PB>5 and/or NPV<0
Option Economic Stability	Very stable	Moderately stable	Unstable
OLDs Reduction	100%	50-99%	<50%
EPA 17 Target Compounds Reduction	>454 kg	45-453 kg	<45 kg
Air Emission Reduction	>454 kg	45-453 kg	<45 kg
Waste water Reduction	>189 m3	38-188 m3	< 38 m3
Hazardous waste Reduction	>454 kg	45-453 kg	<45 kg
Ranking of Process Group[5] for which option applies	Top one-third of the ranked list	Middle one-third of the ranked list	Bottom one-third of the ranked list

5- See "Process Assessment" Section.

Many of the P2 options identified in this can be implemented by simply purchasing and installing presently available equipment. Some options require simple training exercises for facility personnel. Still other options require further research to determine implementability. Based on the data collected in this assessment, the client is currently considering several options including 1) using plunger cans to dispense solvents used for hand-wiping, 2) recycling isopropanol (used as a cleaning solvent) by distillation, 3) using oil pans to reduce material spills (dragout) when transferring parts from dip tanks to parts racks, and 4) blending used oil with diesel fuel.

The client was able to use the ranked list of P2 options and intangible factors as an implementation strategy guide. ES did not recommend any options directly. We provided the ranked list, a discussion of its development and limitations, and let them determine which options they wanted to implement. We did recommend the client pay special attention to the options receiving the most total points.

TABLE IV
Implementation Strategy Guide

PROCESS GROUP CODE	OPTION DESCRIPTION	OPTION HIERARCHY	EASE OF IMPLEM.	PAY-BACK PERIOD (yr)	NET PRESENT VALUE ($)	OPTION STABILITY	OLDs REDUC-TION (%)	TARGET CMPND REDUCT. (kg/yr)	AIR EMISSION REDUCT. (kg/yr)	WASTE WATER REDUCT. (m3/yr)	HAZ. WASTE REDUCT. (kg/yr)	TOTAL POINTS
DSV	Use aqueous cleaners and make equipment changes	Source Reduction	Requires Further Testing	0.4	2,216,400	Very Stable	100	0	47,619	56,775	16,327	16
DSV	Use less hazardous solvents and make equipment changes	Source Reduction	Requires Further Testing	0.5	1,120,400	Very Stable	100	0	47,619	56,775	10,884	16
ECR	High velocity oxygen fuel process	Source Reduction	Requires Further Testing	0.6	6,059,000	Very Stable	NA	7,710	4,535	12,112	6,349	16
PPG	Employ more efficient paint application practices	Source Reduction	Personnel/ Procedural	0	1,908,600	Moderately Stable	NA	6,349	2,222	0	3,265	15
DSH	Train operators to use less solvents	Source Reduction	Personnel/ Procedural	2.2	105,600	Moderately Stable	10	2,041	2,585	NA	2,630	15
VEH	Conduct lube oil tests	Source Reduction	Off-the-Shelf Equipment	0.7	9,600	Moderately Stable	NA	NA	NA	NA	NA	7
VEH	Use by-pass filters	Source Reduction	Off-the-Shelf Equipment	11	27,875	NA	NA	NA	NA	NA	NA	7
VEH	Blend OFS oil with diesel fuel	Treatment	Off-the-Shelf Equipment	0.2	504,000	Very Stable	NA	NA	NA	NA	NA	7

ESTABLISHING BASELINES

Before implementing any P2 options, it is important to develop a hazardous material and waste production baseline so that P2 success can be measured quantitatively. Based on data collected during the process assessment, this baseline was created using an ES customized computerized database. Data collected during future process assessments will be compared to these original baseline figures.

CONCLUSIONS

This pollution prevention opportunity assessment was successful in:

- producing a list of P2 options that would accomplish the goals established by the client;
- giving managers a better understanding of their waste producing processes; and
- providing a hazardous materials and hazardous waste baseline for use in measuring the success of P2 programs.

As the client implements the options recommended by this study, future process assessments should show a substantial reduction in waste generation compared to the 1992 baseline. As a result of these efforts, the client should be able to improve their public image, decrease potential liabilities, save money, and be better prepared to meet regulatory challenges.

DIRECT COPPER PLATING WITHOUT THE ELECTROLESS COPPER SOLUTION

By

Jane H. Tran
Associate Engineer
County Sanitation Districts of Orange County

Margaret H. Nellor
Director of Technical Services
County Sanitation Districts of Orange County

In the manufacturing of printed circuit boards, electroless copper plating is utilized to metalize the entire board with a thin deposit of copper to render the board conductive for subsequent through-hole electroplating. The disadvantages of this electroless plating process are: (1) the chelating agent creates difficulties and interferes with wastes/wastewater treatment, (2) the reducing agent, formaldehyde, is a human health hazard, and (3) the instability of the electroless copper bath creates difficulties in process control. There is an alternate process which uses tin-stabilized colloidal palladium dispersion to deposit a film of palladium particles on surfaces of the circuit board prior to electroplating. This new process eliminates the electroless copper solution and offers advantages in process control, productivity, pollution prevention, and pretreatment.

TRADITIONAL ELECTROLESS COPPER PLATING PROCESS

Why Electroless Copper Is Needed Prior To Electroplating

There are two kinds of copper plating in the manufacture of printed circuit boards: electroless copper plating and acid copper electroplating. Acid copper electroplating plates copper only on a conductive surface via electrochemistry method whereby electrons are obtained from a direct current power source to reduce metal ions to the metallic state. In electroless plating, the mechanism is similar but the source of electrons is a chemical reducing agent. Hence nonconductive surfaces may be metalized by employing electroless baths, since the baths contain their own source of electrons. Electroplating baths cannot be used for nonconductive surfaces because the electrons cannot flow.

Figure 1 shows a cross section of a hole after a drill operation. The hole walls represent the dielectric portion of a circuit board, which is nonconductive. The exposed material may be made of phenolic-resin, polyester, or epoxy fiberglass. Therefore, electroless copper plating is needed to render the board conductive for subsequent through-hole electroplating.

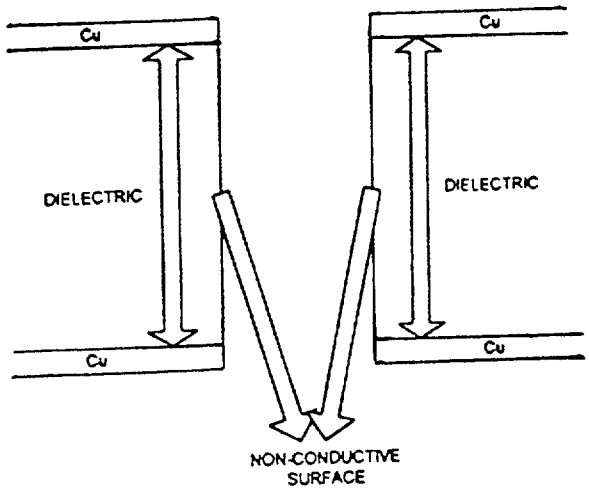


Figure 1. Cross Section Of A Hole After Drill

Mechanism of Electroless Copper Solution

The electroless copper solution consists of the following elements:

1. Copper sulfate - source for copper.
2. Formaldehyde - reducing agent.
3. Caustic - basic medium.
4. Chelating agent (amines, gluconates, glucoheptaonates, various EDTAs, and tartrates) - governs the plating rate and has a marked influence on the properties of the deposit and the bath stability.

As shown in the chemical reaction below, with the presence of palladium as a catalyst and under a strongly basic medium, electrons are obtained from the reducing agent, formaldehyde, to reduce the cupric ions to metallic copper.

$$2Cu^{+2} + HCHO^{-} + 3OH^{-} \xrightarrow{Pd} 2Cu^{+} + HCOO^{-} + 2H_2O$$

$$2Cu^{+} \rightarrow Cu^{o} + Cu^{+2}$$

However, the reduction proceeds through a cuprous state. An excess of cuprous oxide formation will cause the reduction reaction to proceed out of control. To inhibit the formation of cuprous oxide, air is bubbled slowly through the electroless copper solution and small complexing agents are added to the solution. The presence of these complexing agents turns the electroless copper bath into a chelated solution.

Furthermore, in order for the reaction to progress, certain concentration levels of copper sulfate, formaldehyde, sodium hydroxide, and chelating agent, and the correct chemical ratios of these chemical components must be maintained. The electroless copper bath must be analyzed at least every four hours to make sure optimum concentrations and ratios are maintained. Replenishment of copper sulfate, formaldehyde, sodium persulfate, and chelating agent must be provided as needed. Constant monitoring and maintenance are required to properly operate the electroless copper bath.

When "plate-out" occurs (e.g., the copper starts to deposit on the tank walls), it is very much likely that the bath is out of control and has to be replaced with a new bath. In order to strip the copper plated on the tank walls, strong micro-etch solutions, such as ammonium-persulfate or sodium-persulfate, must be used. For quick copper stripping, nitric acid is usually employed. This stripping process generates copper-rich spent solutions that must be pretreated to meet permit limits prior to discharge to a local sewerage facility or to a local receiving water.

Process Description of the Traditional Electroless Copper Plating Line

Table I describes the step-by-step process of a traditional electroless copper plating line. The two processing steps prior to the catalyst solution are for surface preparation to promote cleanliness and better adhesion and to prevent the copper peeling effect. Catalyst, a mixture compound of tin and palladium, is then deposited on the hole walls. Palladium will not attach to the hole walls directly. Tin is required as an intermediate to initiate the catalyst deposition. The panel is then rinsed to remove catalyst residues. After this step, the accelerator solution is added to remove all tin particles because copper will not deposit on tin; it is the chemical activity of palladium that is needed to initiate the copper deposit. The panel is rinsed, and then the copper is plated. The final steps are for removal of any remaining electroless copper residues, and prohibition of oxidation.

TABLE I - PROCESS FLOW CHART OF A TRADITIONAL ELECTROLESS COPPER PLATING PROCESS

Solution Identification	Solution Type	Process Function
Cleaner/Conditioner	Alkaline	Removes organic contaminants from copper surface
Counterflow Rinse	Water	Removes cleaner residues
Micro-Etch	Acidic	Removes any inorganics; promotes good adhesion
Counterflow Rinse	Water	Removes etchant residues
Predip	Acidic	Protects catalyst solution from contamination

TABLE I - PROCESS FLOW CHART OF A TRADITIONAL ELECTROLESS COPPER PLATING PROCESS (Cont.)

Solution Identification	Solution Type	Process Function
Catalyst	Acidic	Deposits catalyst particles (a combination of palladium and tin) on the hole walls
Counterflow Rinse	Water	Removes catalyst residues
Accelerator	Acidic	Drops tin from the catalyst and leaves the palladium
Counterflow Rinse	Water	Removes accelerator residues
Electroless Copper	Alkaline	Deposits copper on the hole walls
Counterflow Rinse	Water	Removes electroless copper residues
10% Sulfuric Acid	Acidic	Neutralizes the alkalinity of the electroless copper
Counterflow Rinse	Water	Removes any remaining electroless copper residues
Anti-Ox	Neutral	Prohibits oxidation
Counterflow Rinse	Water	Removes any anti-ox residues

There is an alternate process that uses tin-stabilized colloidal palladium dispersion to deposit a film of palladium particles on non-conductive surfaces prior to acid-copper electroplating. The film of palladium is so stable that it gives sufficient conductivity for subsequent electroplating without the electroless copper. A case study describing this process is summarized below.

CASE STUDY

Multi-Fineline Electronics (M-Flex) is a flexible printed circuit board manufacturer located in Anaheim, California. The company discharges industrial wastewater into the County Sanitation Districts of Orange County's sewerage facility under a Class I Industrial Wastewater Discharge Permit. The company experienced to chronic violations of its permit limits for copper (daily maximum discharge limit of 3.00 mg/L; monthly average limit of 2.07 mg/L) despite having an ion-exchange pretreatment system. The non-compliance problems were caused by the chelated wastestream generated by the electroless copper plating process. The resin type used in their existing ion-exchange pretreatment system could not handle the chelated copper wastewater. In order to achieve compliance, the company needs to implement one of the following options:

1. Provide treatment for the chelated copper wastestream by installing an additional anion resin column to the existing ion-exchange unit to break the copper chelated bond; or

2. Eliminate the electroless copper solution which was the source of the copper chelated wastestream by implementation of product or process substitution.

After conducting a comparison study between the two options, M-Flex's final decision was to substitute the old electroless copper plating with a non-electroless copper plating process called the "Ardrox N.E.P. system". The decision was made based on the advantages the new process offered in process control, pollution prevention, environmental safety, and wastewater treatment. To convert to the new process, only minor modifications were needed including heater placement and installation of an indirect heat source for the activator step. The existing process equipment was easily adapted to the new process.

M-Flex operates the N.E.P system in accordance with the process flow chart described in Table II. Process steps prior to the activator solution are used to enhance surface cleanliness and condition the nonconductive surface to ensure void-free hole coverage. The activator steps contain the tin-stabilized palladium dispersion. Process steps after the activator solution are for either solidifying the bond between the printed circuit board and the palladium deposition or removing the film from areas where it is not wanted.

TABLE II - PROCESS FLOW CHART OF ARDROX N.E.P PROCESS

Solution Identification	Solution Type	Process Function
Microetch	Acidic	Removes chromate conversion film and micro-etches copper surface
Counterflow Rinse	Water	Removes microetch residues
Pre-Conditioner	Alkaline	Conditions the drilled through-holes
Counterflow Rinse	Water	Removes preconditioner residues
Cleaner/Conditioner	Alkaline	Conditions the drilled through-holes and removes organic soils from copper surface
Counterflow Rinse	Water	Removes cleaner/conditioner residues
Predip	Acidic	Extends and protects the life of the activator solution, and conditions surfaces for proper adsorption of the activator
Activator	Acidic	Contains the tin-stabilized palladium dispersion; it provides an activator surface on dielectric substrates for subsequent electroplating
Counterflow Rinse	Water	Removes activator residues

TABLE II - PROCESS FLOW CHART OF ARDROX N.E.P PROCESS (Cont.)

Solution Identification	Solution Type	Process Function
Accelerator	Alkaline	Contains two chemical components: an alkaline accelerator to optimize the activator activity on glass and other dielectric materials that lower the resistance or increase the conductivity of the treated surface; and an acidic copper activator to enhance the platability of tin-palladium coating
Counterflow Rinse	Water	Removes accelerator residues
10% Sulfuric Acid	Acidic	Neutralizes alkaline residues and conditions surface for acid-copper electroplating
Counterflow Rinse	Water	Removes remaining residues

The new process was designed with a stabilized activator and an alkaline accelerator to provide a palladium film that stays so stable on the hole walls that the surfaces have enough conductivity for subsequent acid-copper electroplating.

ADVANTAGES OF THE NON-ELECTROLESS COPPER PROCESS

Process Control and Productivity

The non-electroless copper process eliminates carbon or insoluble adhesion failures; and improves adhesion of plated deposit in the hole, which means no post-separation and no barrel cracking. By eliminating the unstable electroless copper bath, process control of the new process becomes easier. Less laboratory time is spent for chemical analyses and there is no more electroless copper "plate-out".

Total processing time of the new process line is 30% less compared to the traditional electroless line. Additionally, the plating operator also saves time that used to be spent to monitor, maintain, and clean-up the electroless copper bath.

Pollution Prevention and Pretreatment

The non-electroless copper process offers a true pollution prevention solution by eliminating following wastes: chelated electroless copper solution and its associated rinses, copper stripping solutions (strong micro-etchant and nitric acid), and hazardous chemicals such as formaldehyde and cyanide compounds usually present in electroless copper solution.

By eliminating heavily chelated spent electroless copper solution and its associated rinses, the new process provides the following advantages in terms of utilizing pretreatment equipment:

1. With hydroxide precipitation systems, in order to successfully remove copper generated from the electroless copper line, addition of chelate breakers such as sodium sulfide or DTC are commonly used to break the copper chelated bond prior to hydroxide precipitation. With the new process, due to the absence of electroless copper solution and its associated rinses, there is no need to add any chelate breakers.

2. With ion-exchange pretreatment system, an anion resin column is used to break the chelated bond prior to copper cation exchange taking place in the cation resin column. The new process eliminates the chelated copper wastestream and therefore an anion resin column is not required.

3. In order to optimize the treatment process of wastestreams containing chelated waste and wastewater, segregation of chelated wastestreams from non-chelated wastestreams is necessary. Segregation sometimes requires complicated piping and construction especially for older or existing facility. The non-electroless copper process simplifies the system by eliminating the need for waste segregation.

4. With a batch treatment system, by eliminating the electroless copper solution, the wastewater operator no longer needs to treat either spent electroless copper baths or copper-rich stripping solutions.

Cost Comparison

Although the cost of processing boards using the new process is approximately the same as the traditional electroless, M-Flex has realized appreciable savings in waste disposal. The new activator is three time more expensive than the old catalyst, but it never needs replacement; whereas, the old catalyst bath must be replaced once a year. Furthermore, the rate of copper contamination found in micro-etch and cleaner/conditioner baths is slower compared to rates observed with the traditional electroless line.

CONCLUSION

In conclusion, this process substitution is a unique pollution prevention system because it eliminates the electroless copper solution and its associated drag-out wastes and rinses, while offering quality assurance, increased productivity, and pretreatment advantages.

ACKNOWDLEGEMENTS

Credits

Henry H. Li, Manager of Wet Processes of M-Flex provided process information of the Ardrox N.E.P. system which was installed and successfully operated at M-Flex facility.

Disclaimer

Mention of chemical manufacturers in this paper does not constitute endorsement by the County Sanitation Districts of Orange County as to the use and/or performance of the process mentioned.

References:

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Schiller, Harold, and Gallegos, Dan, and Pittman, Kevin, (1993) Electroless-Copper Alternatives, Printed Circuit Fabrication, Vol. 16, pg. 46, 48.

Text Citation:

"Metallize the entire board (Coombs) with a thin deposit of copper to render the board conductive for subsequent through-hole electroplating."

"Electrons are obtained (Coombs) from a direct current power source to reduce metal ions to the metallic state. Electroplating baths can not be used for nonconductive surfaces because the electrons can not flow."

"An excess of cuprous oxide (Coombs) formation will cause the reduction reaction to proceed out of control."

"Governs the plating rate (Coombs) and has a marked influence on the properties of the deposit and the bath stability."

"Uses tin-stabilized colloidal palladium dispersion (Schiller, Gallegos, and Pittman) to deposit a film of palladium particles."

"Heater placement (Schiller, Gallegos, and Pittman) and installation of an indirect heat source for the activator step."

"Either solidifying (Schiller, Gallegos, and Pittman) the bond between the printed circuit board and the palladium deposition or removing of the film from areas where it is not wanted."

Plumbing the Depths of Waste Minimization

By Eric Trauner and James Bilgo

Manufacturing facility uses management and engineering strategies to minimize process wastewater

It is not often that less of something is good, but Kohler Co. (Kohler, Wis.) was quite pleased when its main manufacturing facility cut daily process wastewater flow by 66 percent.

Kohler's largest manufacturing facility, located at its corporate headquarters, employs about 5,500 people and produces small engines and a variety of plumbing fixtures, including toilets, sinks, tubs and faucets. Until its national pollutant discharge elimination system (NPDES) permit expired in 1986, the facility had been treating most of its wastewaters in settling lagoons and discharging clarified wastewater to the Sheboygan River. Solids were dredged from the lagoons every few years and landfilled.

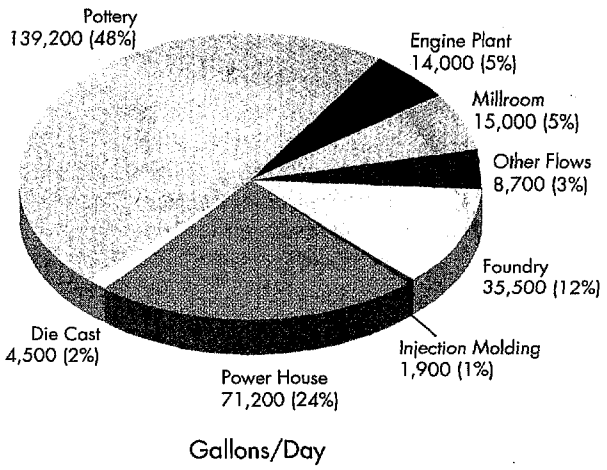
Then, when the Wisconsin Department of Natural Resources issued Kohler a new NPDES permit in 1989, the company discovered that its process wastewater scheme could not meet the state's new water quality regulations. The company needed a new strategy.

Kohler hired a consultant to help determine the most cost-effective way to comply with wastewater regulations, reduce the liability and exposure associated with an NPDES permit and preserve natural resources. They began by looking at the sources of the facility's process wastewaters: wet air scrubbers, water curtain spray booths, electroplating baths and rinses, metal finishing operations, quench waters (contact cooling water), product testing, wet analytical laboratories, cooling tower blowdown and general washwaters.

Based on this evaluation, Kohler decided to segregate process wastewaters

FIGURE 1

Average Daily Process Wastewater Flows (Sept. 1, 1991—Feb. 29, 1992)



( ) = percent of total facility flows.

from high-volume clear waters, such as noncontact cooling water, drinking fountain discharge and stormwater, before treating them in a new central pretreatment facility. Pretreated wastewater would be discharged along with sanitary wastewater from plant restrooms and showers to the local POTW. Other streams, such as electroplating wastewater (already pretreated by hydroxide precipitation) and cooling tower blowdown, would be discharged directly to the POTW.

A dedicated sewer would convey process wastewaters to the central pretreatment facility. The company would use the existing storm sewer system and settling lagoons to manage noncontact cooling water, clear water and stormwater, which would continue to be discharged to the Sheboygan River.

With this strategy in mind, Kohler officials began to develop a plan. The new wastewater treatment scheme was divided into three phases:

- design and construction of a dedicated process wastewater sewer and use of telemetry to track wastewater output from each production area;
- collection of flow data and implementation of wastewater minimization projects; and
- characterization of the combined wastewater and design, construction and startup of a central pretreatment facility.

Because the central pretreatment facility's costs would be proportional to wastewater flow, a comprehensive monitoring system was installed to establish baseline wastewater flows and monitor reductions (Figure 1). Flow data were used to justify and track wastewater minimization efforts.

To encourage maximum wastewater minimization, company managers decided to make the operating divisions financially responsible for the central pretreatment facility's construction and operation by billing them based on their share of total wastewater output. Upon learning this, the operating divisions initiated wastewater minimization programs involving both managed and engineered solutions. The pottery division, whose 500 employees manufacture vitreous china plumbing fixtures (Figure 2), reduced its wastewater discharge 75 percent — from 140,000 gallons per day in 1991 to 31,000 gallons per day by late 1993.

FIGURE 2

Wisconsin Pottery Production Processes

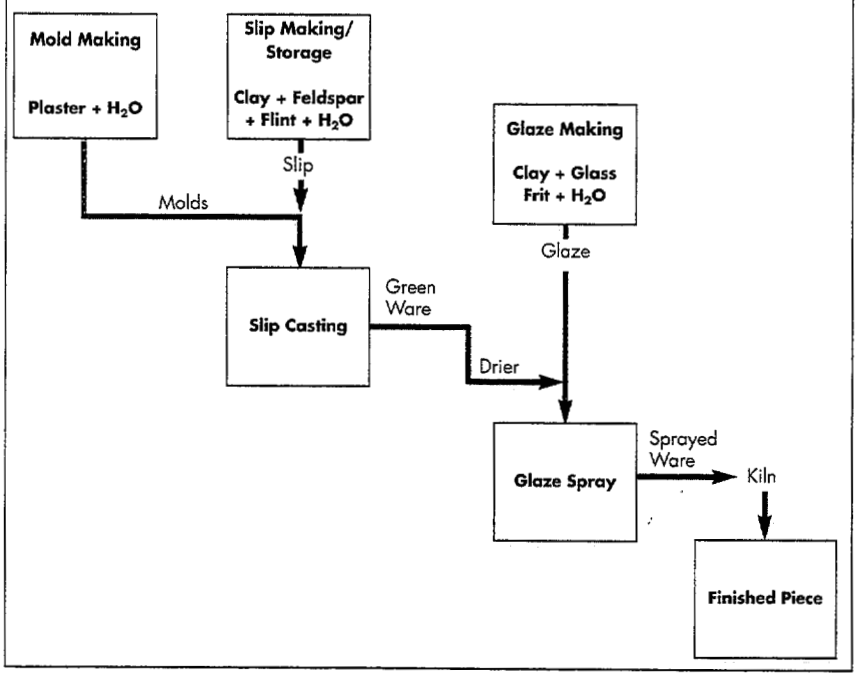
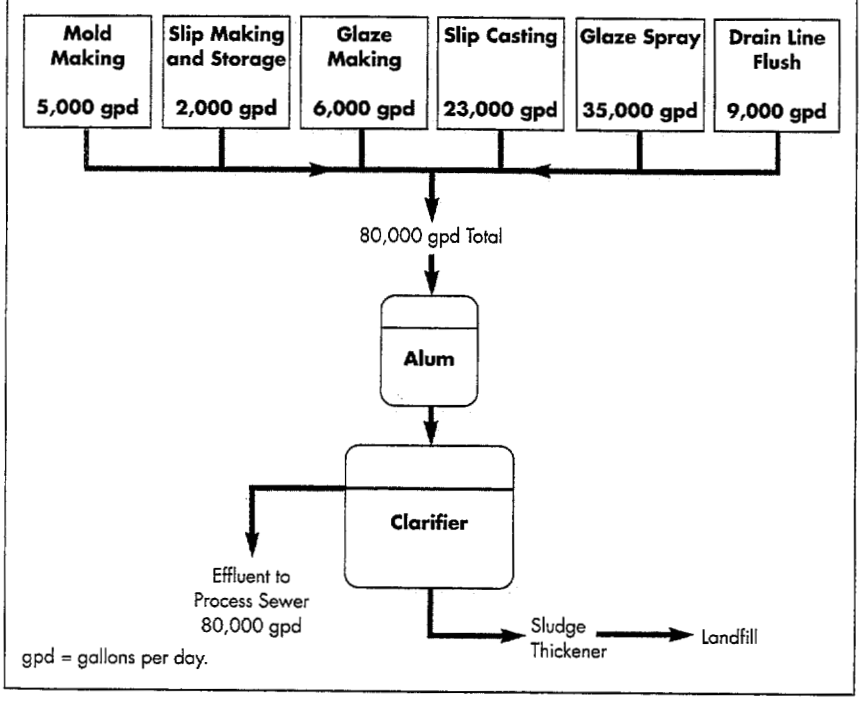


FIGURE 3

Wastewater Flow Before Recycling System and After Management Initiatives



gpd = gallons per day.

Pottery's Wastewater System

Most of the the pottery division's process wastewater originally was drained by gravity to an old clarifier; glaze spray wastewater flowed to a sump before being pumped to the clarifier. Alum (aluminum sulfate) was injected into the main wastewater drain pipe upstream of the clarifier.

Suspended solids that settled in the clarifier were pumped to a sludge thickener, where sludge was stored until it was landfilled. Clarified wastewater overflowed the clarifier and ran through a V-notch weir, where an ultrasonic flow meter regulated the addition of treatment chemicals.

Environmental engineering and safety personnel planned to reduce wastewater through management efforts and, if economically viable, further reduce discharges by designing and installing engineered systems.

Management Reductions

Management efforts and minor hardware modifications reduced the pottery division's wastewater flows from 140,000 gallons per day in 1991 to 80,000 gallons per day in 1992. These efforts and modifications included:

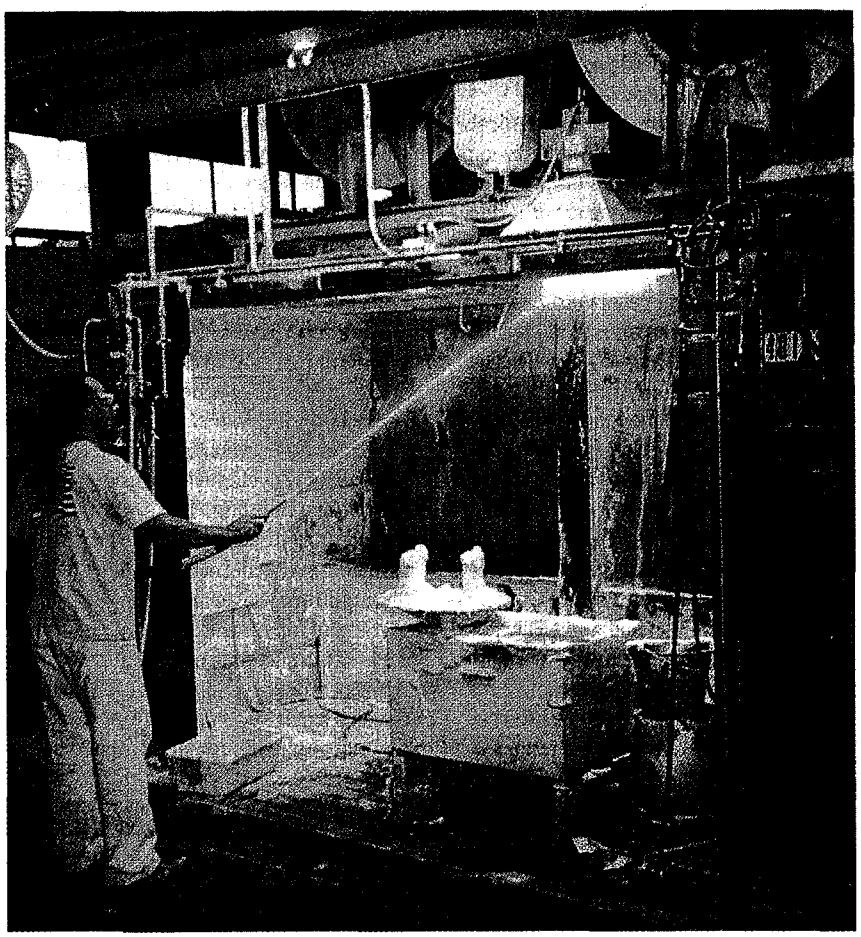
- teaching employees to shut off hoses and sinks when not in use,
- installing motor-run clocks on wastewater sump pumps in the glaze spray area to track daily wastewater output from a large wastewater source and
- installing spring-loaded valves on especially "troublesome" sources.

Despite these efforts, the pottery division remained the largest contributor to the central pretreatment facility, because the other manufacturing divisions also were reducing wastewater. (Figure 3 illustrates the results of management efforts to minimize wastewater in each production area.) In fact, the pottery division's percentage of the site's overall process wastewater flow actually increased (Figure 4).

Engineering Reductions

A review of the pottery division's production operations indicated that several wastewater sources used potable water where it was not required. By installing a system of tanks, pumps, piping and controls to recycle clarified wastewater from the existing clarifier to areas that did not require freshwater input, the division expected to reduce wastewater discharge from 80,000 gallons per day to about 50,000 gallons per day.

Installing the new recycling system allowed the planned central pretreatment facility to be downsized, resulting

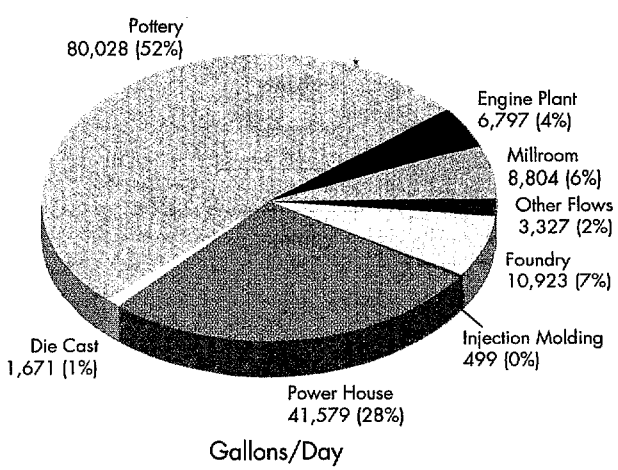


KOHLER CO.

Clarified wastewater is recycled for uses that do not require potable water, such as cleaning this wet spray booth.

FIGURE 4

Average Daily Process Wastewater Flows
(Aug. 1, 1992—Nov. 30, 1992)



( ) = percent of total facility flows.

in a net capital savings of $200,000. It also would save $22,000 per year in potable water and sewer fees and $10,000 per year in treatment chemicals and sludge disposal costs. Management approved the recycling system, which was completed in the summer of 1993.

In the new system, clarified wastewater flows from the existing clarifier into a new recycling reservoir tank, which serves as both an added clarifier and temporary storage (Figure 5). The reservoir tank exceeds the total capacity of all sumps and wet spray booths in the building to prevent recycling pumps from running dry or cavitating.

Connected to the reservoir is a pump station that includes two centrifugal pumps and a cylindrical pressure tank whose water level controls the pumps. As recycled water is used and the water level in the pressure tank drops, pressure in the system's piping is maintained by a "blanket" of compressed air over the water in the pressure tank. When the pumps turn on and the pressure tank fills with water, a pressure relief valve releases compressed air.

One of the centrifugal pumps operates continually to maintain a constant level in the pressure tank; the other is available to meet peak demand. Both are equipped with motor-run clocks that help identify potential problems. For example, a sudden increase in a pump's "on" time without a corresponding increase in demand could indicate mechanical problems or careless use of recycled water.

A new dedicated piping system transports recycled water throughout the pottery building. The system required more than 3,400 linear feet of pipe and more than 400 fittings, such as tees, elbows, valves and couplings.

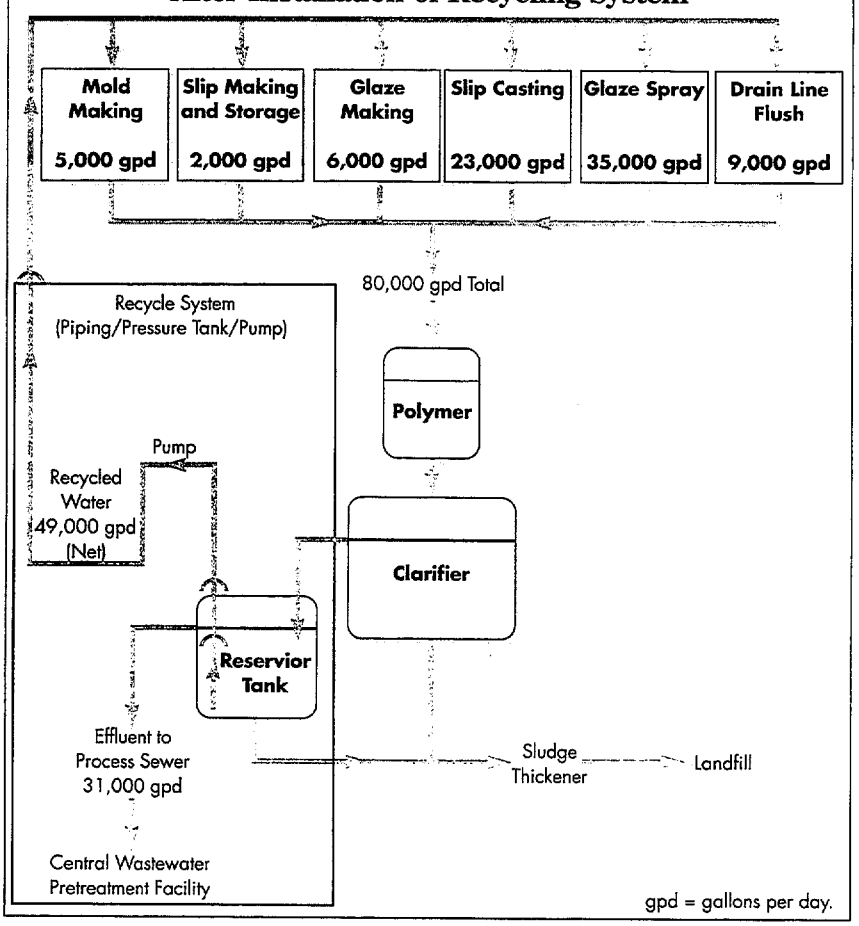
Several electronic sensors and associated alarms also were installed to monitor the recycling system. These devices track such parameters as system pressure, pump performance and reservoir water level. Each alarm is routed electronically to a pottery division office staffed 24 hours a day.

The recycling system is not a closed loop. Fresh water enters the system throughout the day from sources that do not receive recycled wastewater, such as the slip casting sinks, which means wastewater still overflows from the pottery division to the central pretreatment facility. Actual discharge is determined by an outlet pipe flow meter. (Slip casting sinks do not receive recycled wastewater because management determined that too many were in remote areas to justify the expense of extra piping.)

A failure in the recycling system could put some areas out of production or damage certain equipment, so a backup water source was included in the design. Specifically, the recycle system is cross-connected to Kohler's well water system, which typically is used as a source of process water. (Potable water is supplied by the city.)

FIGURE 5

Pottery Process Wastewater Flow Diagram After Installation of Recycling System



Construction Issues

Installing the recycling system hardware in a 70-year-old building while operations continued necessitated weekly coordination meetings among production personnel, the contractor and the in-house construction manager. The first meeting was held before a contractor was even chosen.

Besides restrictions imposed because of continuing production, the contractor also had to understand the building's physical limitations, such as elevators, doorways and hallway turns. The reservoir tank, for example, had to be fabricated in predetermined pieces at the contractor's shop before final on-site assembly.

Startup Issues

The recycling system was first activated in August 1993. Pottery's wastewater discharge was immediately reduced from 80,000 gallons per day to about 31,000 gallons per day, unexpectedly exceeding the original goal of 50,000 gallons per day.

Several minor pieces of hardware, such as check valves, were found to be inadequate and were changed shortly after startup. The most serious difficulty involved treatment chemicals. For years, the pottery division used alum (aluminum sulfate) to clarify its process wastewater, because alum was effective

and inexpensive. Alum is a mild acid, however, and its buildup in the recycling system caused the water's pH to drop steadily. Eventually, pH values reached less than 5, which, in the long term, would devastate system hardware.

To alleviate acid buildup, pottery personnel changed from alum to a proprietary polymer from Betz Industrial Inc. (Trevose, Pa.) that maintains a neutral pH. Analysis has revealed that the wastewater's total metal content has remained relatively constant. Crystal-clear recycled water has remained somewhat elusive, however, because the wastewater's variable solids loading makes it difficult to regulate polymer feed. Without careful addition, polymer also tends to build up in the recycle system, reaching concentrations at which it acts as a dispersant.

Kohler continues to work on improving the appearance of its recycled wastewater. Fortunately, the effectiveness of the central pretreatment facility downstream of the pottery division makes this an issue of aesthetics and maintenance rather than compliance.

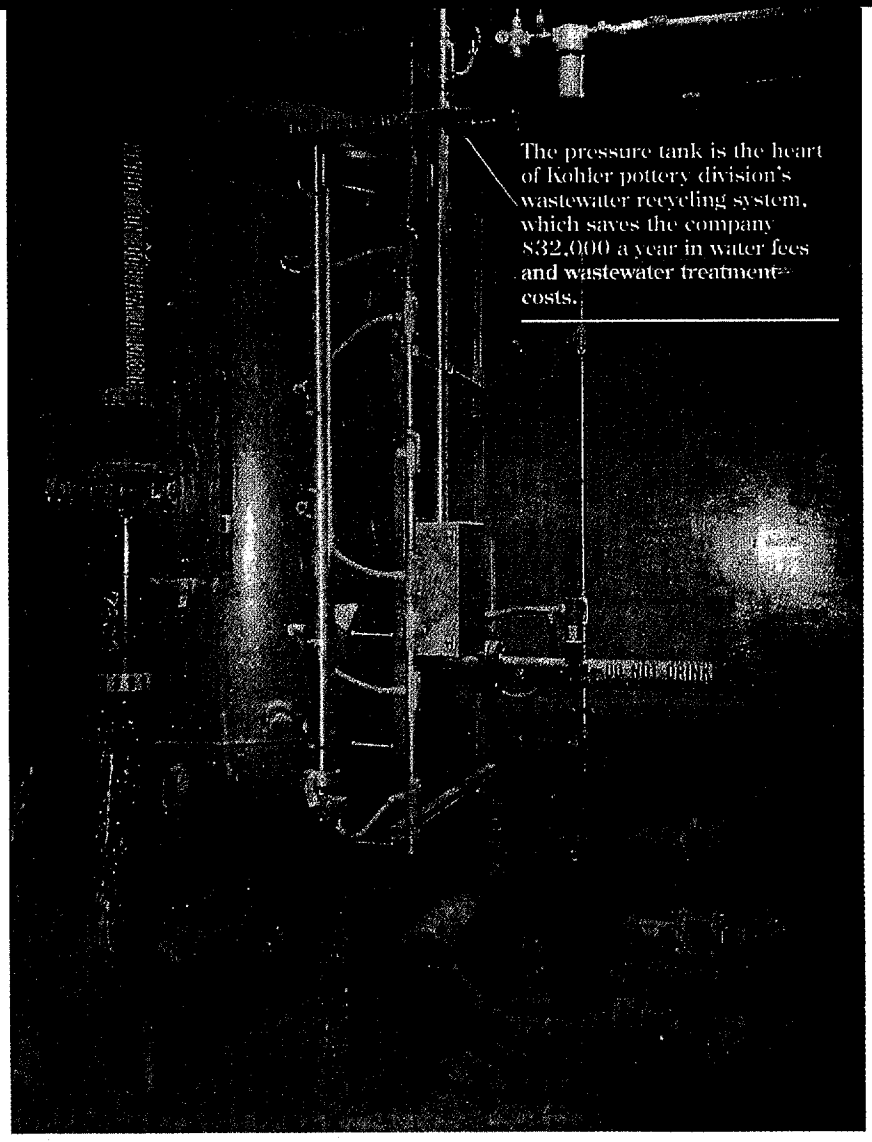
Employees required to use recycled water adapted quickly to the new system because of education through special meetings and in-house newsletters. Educating maintenance personnel about the new system was especially important to prevent cross-connections of recycled water piping with other piping networks. (Anyone considering installing a dedicated recycling system should be sure pipes are labeled as soon as possible after installation.)

Figure 6 charts wastewater flows from each Kohler manufacturing area after the pottery process wastewater recycle system was completed.

This project moved Kohler significantly closer to its corporate wastewater management goals. Managers attribute its success to two critical components: using comprehensive flow monitoring to track wastewater reductions and allocating costs for the new treatment facility based on waste contribution. ■

Eric Trauner *is a project civil engineer, and* **James Bilgo** *is supervisor of wastewater compliance at Kohler Co. (Kohler, Wis.).*

Editor's note: This article was based on a paper given by Trauner at the 49th Purdue University Industrial Waste Conference.

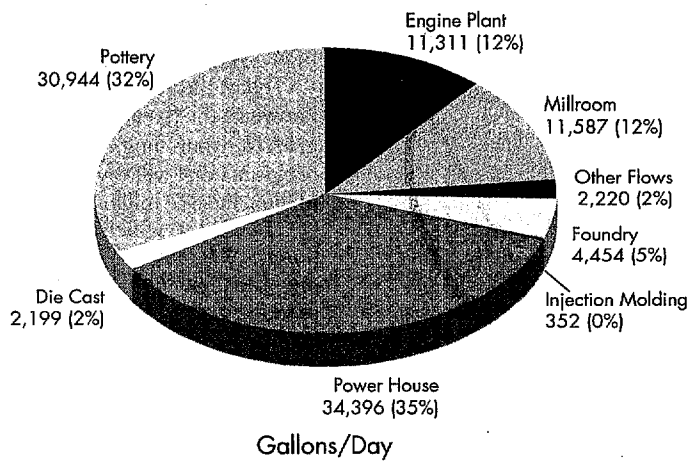


The pressure tank is the heart of Kohler pottery division's wastewater recycling system, which saves the company $32,000 a year in water fees and wastewater treatment costs.

KOHLER CO.

FIGURE 6

Average Daily Process Wastewater Flows
(Nov. 1, 1993—Feb. 28, 1994)



( ) = percent of total facility flows.

"A SOURCE CONTROL PERMIT PROGRAM FOR WASTE MINIMIZATION AT METAL FINISHING FACILITIES," Lewis Jones, East Bay Municipal Utility District, PO Box 24055, Oakland, CA 94623.

The East Bay Municipal Utility District (EBMUD) supplies water and provides wastewater treatment for parts of Alameda and Contra Costa Counties in the San Francisco Bay Area. The wastewater treatment plant serves a 83-square mile area, 611,000 residential customers, and 20,000 business and industrial users. The EBMUD Source Control Division regulates a total of 386 significant industrial users, including 36 metal finishing facilities that discharge process wastewater.

The District's waste minimization program for metal finishers requires a discharger to assess its waste minimization opportunities and to submit an implementation schedule of selected actions. This successful program has caused the 36 metal finishers in the District's jurisdiction to make significant process and other changes to reduce the generation of pollutants.

The District developed the program in response to new discharge and emission requirements now facing the EBMUD wastewater treatment plant. Several new regulations are impacting the treatment plant: air pollution requirements limit the emission of volatile organic compounds; pending sludge and compost regulations could result in increased efforts to reduce the amount of heavy metals in the plant influent; bioassay monitoring of the plant effluent for toxic and chronic effects could also increase source control activities; and in the Bay Area, the control agency has assigned total mass discharge limits to several POTWs.

These requirements lead to the necessity of additional source control actions to further reduce the influent loading for an expanded list of constituents. The District is therefore extending its source control program for non-residential dischargers to include a broad range of previously unregulated businesses. The District is also augmenting its program for regulated facilities by encouraging waste minimization.

The District incorporates conditions into new and old permits that encourage businesses to follow the waste minimization concept of operating processes so that no waste is generated. The District's goal is to continue to develop a program that encourages dischargers away from end-of-pipe treatment toward non-generation of wastes. This approach can result in cost and environmental benefits to a facility, the District, and the public. A waste minimization alternative to pretreatment is not

always possible, of course, but the District's strategy is to develop permits that lead dischargers away from the generation of pollutants that need disposal.

EBMUD has developed programs for both newly and traditionally regulated businesses. This paper will briefly discuss the newer permits before describing the waste minimization program for metal finishers.

Newly Regulated Industries

The newly regulated businesses for which the District has instituted waste minimization permit programs are photo finishers, radiator shops, dry cleaners, and auto repair facilities.

The District's program for photo finishers is designed to minimize the discharge of silver from the photo-developing process. The permit requires a facility to use the best available technology to capture silver for recycling. Forty-five facilities are covered in the program with a compliance rate of 94%.

The District program for radiator repair shops prohibits the discharge of untreated process wastewater. The program was developed because of non-compliant high concentrations of heavy metals in the shops' discharge. The permit program mirrors the current best technology standard for this industry of closed loop operation with no discharge. All radiator repair shops in the District's wastewater service area have made process changes to eliminate their discharge and comply with the prohibition.

The District has also prohibited the discharge of process wastes from dry cleaners. This permit program was introduced to reduce the amount of perchloroethylene entering the treatment plant. Perchloroethylene is recyclable, and the District's program encourages dry cleaners to recycle. The program applies to 110 dry cleaners and has resulted in a 75% reduction in the amount of perchloroethylene. One facility disregarded the prohibition and continued to flagrantly discharge perchloroethylene. This action resulted in District enforcement action and an administrative fine of $27,000.

The District is also implementing a waste minimization program for over 900 auto repair facilities. This program prohibits the untreated discharge of process wastes which can contain concentrations of oils, greases, volatiles, and metals which violate the District's Ordinance. The District will encourage the use of best available technology to maximize the recycling and reuse of auto shop wastes such as coolants, oils, and solvents. Facilities that wish to continue a wastewater

discharge must obtain a more expensive permit which requires best available technology treatment and involves a full monitoring program. Recycling of wastewater from water based processes such as steam cleaning and vehicle cleaning is encouraged to reduce the amount of wastewater needing treatment.

The District is also considering waste minimization programs for other commercial and small industrial facilities. Business categories included are printing, medical, dental, and laboratories.

Traditionally Regulated Businesses

The District has also reviewed existing permits for waste minimization opportunities. Among long-standing permit holders, metal finishers offered the best possibility for waste minimization. Factors that make metal finishers receptive to waste minimization include: their facilities tend to have aging pretreatment systems that require a continuing and growing investment to keep them operational; costs for disposal of sludges from pretreatment systems are rapidly increasing; ongoing expenses for chemicals to treat the wastes is costly; and operation and maintenance costs are a sizeable, perpetual addition to overhead expenses.

Some metal finishers feel that the continuing large business investment in a system that results in the costly disposal of a hazardous waste could perhaps be better channeled into modification of processes to minimize the generation of waste. An ongoing expense could be turned into a short-term expenditure with pay-back possibilities.

An investment in waste minimization results in cost and environmental benefits for metal finishers and a reduced influent-loading benefit for the District. Wastewater discharge permits that encourage waste minimization provide a useful means of gaining pollutant reductions beyond those achieved through pretreatment.

The District chose the metal finishing industry for this program for several reasons: the industry contributes a large percentage the mass of metals in the influent of the District's treatment plant; metal finishers have experience with wastewater regulation which is a situation that can aid implementation of a new program; much research on the feasibility of waste minimization practices has been done on the metal finishing industry; and, in general, the industry has many possibilities for becoming a more efficient and more environmentally positive process.

Permit Program for Metal Finishers

The District's permit program required each metal finishing facility to conduct a waste audit of its processes, evaluate waste minimization alternatives for each waste, develop a plan for instituting selected actions, and submit an implementation schedule. The findings and documentation were submitted as a Waste Minimization Opportunity Assessment Report (WMOAR).

The first step was to identify the pollutants of concern at a facility. Each facility reviewed the source for each pollutant and developed a breakdown of how the pollutant was released to product, wastewater, and other environmental media. The permit did not require a mass balance for a pollutant because the intricate calculations were not essential to a "big picture" understanding of the source and destiny of pollutants.

The second step required the facility to evaluate the waste minimization approaches that are available for each pollutant or process. The WMOAR report was to describe what approaches were technically feasible and economically practical at the facility. The waste minimization approaches to be considered were input change, operational improvement, production process change, and product reformulation. The permit required that the facility also document rejected alternatives.

The final part of the WMOAR was an implementation schedule for selected waste minimization actions with both milestone and completion dates. The report was to provide a quantification of the expected effectiveness of the proposed actions. The final WMOAR was to be certified by the individual directly responsible for the processes.

Relation to Other Regulations

The District waste minimization program for metal finishers parallels California's waste minimization regulations. Senate Bill 14 (SB14), The Hazardous Waste Source Reduction and Management Review Act, requires waste minimization reports from industries that generate more than 13 tons of hazardous waste per year. SB14 applies to metal finishers, even small facilities, because the weight of the water entering the pretreatment system is counted towards the 13 tons. SB14 requires an eligible facility to create a report that documents past waste minimization achievements and projects future actions.

SB14 allows small businesses, such as many metal finishers, to achieve compliance by using a waste minimization checklist created for their industry by the State of California Alternative Technology Division of the Department of Health Services and also recommended by the Waste Minimization Committee of the Metal Finishers Association. The checklist for metal finishers is a comprehensive workbook of about 48 pages. A metal finisher who

conscientiously uses the checklist will make a thorough review of its processes and be led through a concrete examination of waste minimization alternatives. The checklist process also leads to a prioritization of waste minimization changes that can be made.

The District's program allows a discharger to file one report for both the District's requirement and for the requirements of SB14. EBMUD stipulated that compliance with the District could be achieved by using the Checklist, by filing a separate report, or by becoming a zero discharger of process wastewater. Any one of the three alternatives also meets the SB14 requirements.

Nether SB14 nor the District's requirements are not based upon the traditional "command and control" method. The "command and control" method typically would require a facility to reduce waste by a certain percentage and would establish an enforcement program. The approach associated with waste minimization, on the other hand, gives the responsibility to each individual business to evaluate opportunities and to make a decision on what actions to take and at what schedule. The burden is on an industry to put together an effective enough set of actions to convince the public that a new "command and control" requirement and enforcement structure is unnecessary.

The public, via access to a facility's waste minimization report, will determine if the approach selected by a business is effective and meets the generally accepted standards for the environment. The success or failure of an industry's efforts will thus influence future regulations. If the generation of waste is reduced, there will be no need for further regulation. If little change occurs, a return to command and control can be anticipated. If new regulations are developed, however, the waste minimization experience of an industry can help determine the scope of those regulations.

The District's waste minimization program allows metal finishers the opportunity to help determine their own future. The District only requires metal finishers to identify opportunities for waste reduction. The next step of deciding on and taking actions is up to the individual facility.

Results of the Metal Finishing Program

The District's waste minimization requirement applied to 36 metal finishing facilities. The requirement was made in the fall of 1990 with a submittal date of March 1, 1991.

The result of the program has been a serious review by most metal finishers of their waste generating processes. Many facilities reported changes either accomplished or scheduled for implementation.

Of the 36 facilities, 27 filed either reports or checklists. Two plants went out of business for unrelated reasons, and one became a zero discharger. The six remaining facilities, all of which are part of a large federal facility, were granted an extension until September 1, 1991 to prepare one comprehensive report.

Most businesses reported that the experience of conducting a waste minimization opportunity assessment was useful. One facility commented, "Completing the Checklist was helpful in bringing to my attention the numerous opportunities to minimize our facility's waste streams and the exposures related thereto. The Checklist identified certain items which could be implemented with nominal expense and time invested. We intend to follow-up and make the appropriate changes."

The District reviewed the submittals only for seriousness of effort. One report was returned for preparation of a resubmittal, but this facility decided to become a zero discharger instead.

Seven businesses reported planned or accomplished decreases in mass loading through water-use reductions without a change in pollutant concentration levels. One facility claimed credit for reducing water use from >30,000 gpd to the current ~200 gpd.

Four facilities said that they planned to change plating solutions to reduce pollutants. One facility replaced a cyanide bath. Another was able to convert from chrome-6 to chrome-3. An alodining firm and another facility each replaced a solution containing chrome.

Nine facilities wanted credit for significant waste minimization actions had taken in the past.

Ironically, one business reported the installation of a larger pretreatment unit as their waste minimization action.

Among the significant actions reported as a result of this program were:

- Installed photo-sensing spray rinses, with a pay back from water savings in 4 1/2 months.
- Introduced control measures on raw products resulting in an improvement in sludge quality.
- Began using cooling water in rinse tanks.

- Instituted longer dwell-times over plating tanks reducing dragout.
- Set up an evaporation system to reduce discharges.
- Discontinued a vapor degreaser.
- Set up static rinse tanks.
- Set up counter-current flow rinse tanks.
- Put in flow restricters on water outlets.
- Installed a refrigerated cooling system on a degreaser to minimize TCA volatilization.
- Provided polypropylene balls on heated tanks to reduce evaporation and water use.
- Improved double containment and leak detection.
- Provided drain boards for baths.
- Incorporated waste minimization awareness into training program.
- Incorporated waste minimization into written procedures.
- Established procedures to conduct an annual waste minimization audit.

Other Aspects of the Program

The District's regulatory program for waste minimization is supplemented by educational and public activities which include a library, mailings, workshops, funding, and participation in waste minimization committees.

The District has developed a library of pollution prevention materials that can be used by permittees and the public. The library consists of books, manuals, studies, a computer data base, visual aids, videos, and files of clippings and articles.

The District has held a waste minimization workshop for metal finishers. The District also conducted a meeting for representatives of the photo processing industry and attended meetings of the dry cleaning trade association. Meetings to discuss future regulatory measures are now being scheduled with the auto repair industry. Two mailings on waste minimization grant programs have been mailed to over 3000 businesses.

The District has contributed funds to the League of Women Voters to produce waste minimization videos for household hazardous waste and for small businesses. The District also distributes an "information wheel" on household hazardous wastes.

District staff serve on two regional waste minimization committees. A staff person is vice-chairman of a waste minimization advisory committee to the Regional Water Quality Control Board, the regulatory agency for POTWs in the Bay Area. Another staff person is an elected officer of the Bay Area Hazardous Waste Reduction Committee, a regional multi-agency, multi-media information coordinating committee.

APPENDIX

^F1^
Account No. ^F8^

COMPLIANCE REPORTING CONDITIONS

^F1^ shall submit by March 1, 1991 a WASTE MINIMIZATION OPPORTUNITY ASSESSMENT REPORT containing an audit and plan for pollutants released from your facility in discharges or emissions to wastewater, sludge, or air. The report must include at a minimum the following elements:

- Identification of each pollutant in measurable concentrations in the wastewater discharge. The description of each pollutant must include a description of the source, the generating process(es), the breakdown of the annual quantities released to water, land, and air, and the annual quantity contained in product.

- Evaluation of waste minimization approaches available for each source and process. The evaluation must consider at least all of the following source reduction approaches: input change, operational improvement, production process change, and product reformulation.

- Description of and rationale for the technically feasible and economically practicable waste minimization measures to be implemented. The Report must document the rationale for rejection of any available waste minimization approach.

- Schedule for implementation of the selected waste minimization measures.

- Quantification of the expected effectiveness of the selected waste minimization measures.

The Report must be certified by a registered professional engineer, by a registered environmental assessor, or by the qualified individual who is directly responsible for the processes and operations.

NAS ACCOUNT NUMBERS

NAS	MP	188-00015
NAS	25	771-95511
NAS	5	778-95511
NAS	360	773-95511
NAS	32	774-95511
NAS	24	777-95524
NAS	14	772-95511
NAS	372	779-95511
NAS	397	781-95511
NAS	41	775-95511
NAS	113	784-95511
NAS	162	776-95511
NAS	166	777-95511
NAS	400	782-95511
NAS	530	783-95511

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CASE STUDY

Metals Removal Plane and Simple

Aircraft maintenance center uses sulfide precipitation to remove heavy metals from wastewater, meet new discharge limits

By Daniel F. Seidel and Neil Demon

United Airline's maintenance center at San Francisco International Airport provides depot-level overhaul services for the company's entire fleet of aircraft.

COURTESY OF KENNEDY/JENKS CONSULTANTS

United Airlines operates a major aircraft maintenance center at San Francisco International Airport that provides depot-level overhaul services for the company's entire fleet of aircraft.

In an average year, the 40-year-old center services 1,200 aircraft and 1,500 turbine engines, performs 80 paint jobs and overhauls more than a million components. It employs more than 15,000 people and has a complete range of shops for engines, landing gear, tires and brakes, metal plating, machining, airframe repair, instruments, electronics and interior work.

Industrial wastewater from the center, which sits on 147 acres adjacent to San Francisco Bay, is pretreated to remove oil and suspended solids before being discharged to the airport's industrial wastewater treatment plant (WWTP).

The airport WWTP, however, cannot treat heavy metals, so when the state lowered the site's heavy metal discharge limits in 1987, the maintenance center was required to upgrade its pretreatment processes.

At the time, copper, lead, cadmium and nickel were the center's principal concerns, although chromium, phenol, cyanide and detergents also were factors. More recently, toxicity to fish and other aquatic organisms has become an issue.

To address these concerns, the maintenance center decided to minimize waste, isolate wastestreams and improve pretreatment processes. Specifically, the strategy included:

- eliminating cyanide stripping solution wherever possible,
- batch treating and recovering metals from spent plating solutions,
- reducing chromium and hydroxide precipitation,
- batch treating phenol and metal-bearing paint-stripping wastes, and
- reducing the frequency of aircraft washing.

At the same time, the center also focused on reducing atmospheric emissions of volatile organic compounds (VOCs), primarily from solvents. However, reducing the number of solvent-based cleaners increased the use of water and detergents, which resulted in greater loading on the wastewater treatment system. The center also installed a 0.6 million-gallon stormwater retention basin to intercept the first half inch of runoff from the aircraft parking areas and washrack. Collected runoff is routed to the oil-water separation plant.

The center began addressing end-of-pipe treatment needs in 1988 by performing source monitoring and characterization studies to identify major pollutants and their sources. (This information also was used for waste minimization planning.)

Reducing the number of solvent-based cleaners increased the use of water and detergents, which resulted in greater loading on the wastewater treatment system.

These sources included all major sumps and wet wells in the industrial sewer system, the aircraft washrack, stormwater holding basin, plating shop sumps and the paint-stripping wastewater treatment unit.

Analyses were performed for heavy metals, oil and grease, suspended solids, pH, phenol, cyanide and detergents. (Table 1 shows the maximum daily concentration allowed for each constituent, the number of samples exceeding the standard, and the range and average values of those constituents.) Average dry-weather flow is 300 gallons per minute (gpm), with a peak wet-weather factor of two.

The key heavy metals were cadmium, chromium, copper, lead and nickel. Oil and grease were not a problem, although the existing oil-water separator eventually

was replaced with a larger unit.

Besides laboratory and bench-scale treatability tests, subsequent studies involved testing specific equipment to identify processes that would meet the discharge limits.

A screening process eventually led the project team to select iron sulfide precipitation to precipitate or coprecipitate heavy metals.

Hydroxide precipitation could not meet the limits for cadmium, chromium or nickel. Membrane and ion-exchange processes also were rejected because they required extensive pre-conditioning and were not cost-competitive.

Process development. Bench-scale studies verified that sulfide would precipitate the metals, but using flocculation and sedimentation to remove fine precipitate posed a significant problem. Inorganic coagulants and various cationic, anionic and nonionic polymers were tested until a cationic/anionic combination was found that worked.

A one-month pilot test using a solids contact reactor/clarifier unit was performed to evaluate process performance and obtain on-line design data. The unit was rated at 100 gpm for water treatment applications but could handle only 50 gpm for sulfide precipitation because of the light floc that formed.

Four problems were identified during pilot tests:

- uncontrolled discharge of batch-treated paint-stripping water, which contained high concentrations of heavy metals and phenol, caused process upsets;
- wastewater temperature variations caused thermal stratification and short-circuited treatment units;
- flow and waste variability interfered with consistent performance; and
- nickel was the critical heavy metal, even when everything was working well.

After investigating these problems, the project team concluded that the treatment process for paint-stripping wastewater required better control, equalization was needed to overcome composition and temperature variations, and nickel would be a continuing problem. It also decided to place the filter units ahead of the carbon contactors to minimize plugging.

Team members then visited two comparably sized industrial WWTPs that use sulfide precipitation processes. These

TABLE 1
Oil Separation Plant Effluent

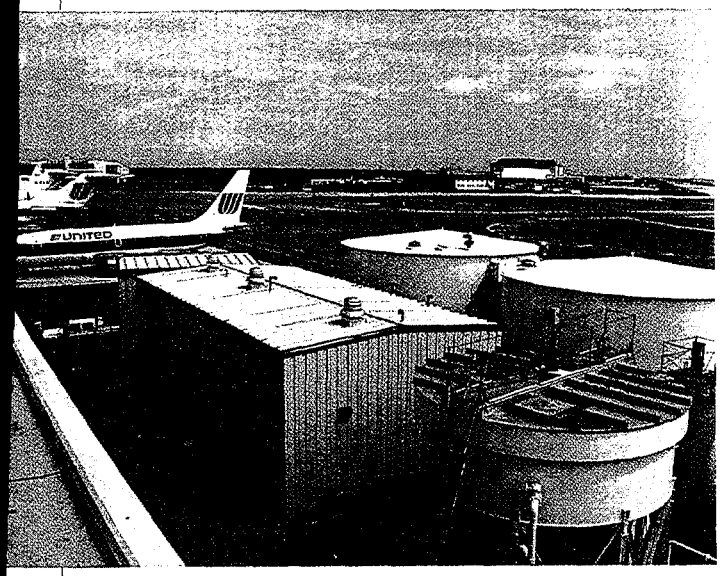
Constituent	New Standard Daily Maximum Concentration (mg/L)	Number of Samples Exceeding Standard[1]	Statistics for Samples Exceeding Standards	
			Range (mg/L)	Average (mg/L)
Metals				
Arsenic	0.20	0	—	—
Cadmium	0.03	26	0.04–0.17	0.078
Chromium	0.11	27	0.13–0.80	0.32
Copper	0.20	7	0.22–0.33	0.26
Lead	0.056	10	0.06–0.48	0.19
Mercury	0.001	0	—	—
Nickel	0.071	28	0.12–0.77	0.32
Silver	0.023	0	—	—
Zinc	0.58	0	—	—
Nonmetals				
Cyanide (Total)	0.1 average 0.2 maximum	4	.26–1.79	0.77
MBAS[3]	4.5	28	5.0–34.6	13.9
pH (unit)	5 to 9	1	10.9[2]	10.9
Phenol	1.5	7	1.7–6.2	3.7
Oil & Grease	120	0	—	—
Settleable Matter	0.5	0	—	—

Notes:

[1] Semimonthly 24-hour composite samples, from December 1986 through January 1988. Number of analyses is 28.

[2] Caused by spill.

[3] MBAS: Methylene blue active substance; anionic surfactants that react with methylene blue to form a blue chloroform-soluble complex; the intensity of color is proportional to concentration.



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The new metals removal plant, shown here near the end of construction, began operating in 1992.

visits confirmed both the viability of sulfide precipitation and the value of flow equalization.

The culmination of this testing and research effort is a system that includes screening, flow equalization, dissolved air flotation, and heavy metals precipitation using ferrous sulfide in a reactor/clarifier. The plant has a nominal operating capacity of 300 gpm, with a peak hydraulic capacity of 700 gpm.

Effluent is filtered through anthracite coal and partially treated with granular activated carbon (GAC). Oily sludge is dewatered in a rotary drum vacuum filter and incinerated; sulfide sludge is dewatered in a filter press; and metal sludge is disposed in a Class I landfill or hauled to a smelter for metals recovery.

Pilot tests and the original system design were based on a process developed for and patented by the U.S. Air Force, but high royalty charges for a process license led the project team to select a similar but less costly alternative.

Specifically, the team was interested in the sulfide precipitation stage of Permutit's Sulfex process, in which ferrous sulfide is injected into the wastestream along with cationic and anionic polymers to precipitate, flocculate and settle out heavy metals. (The first stage of the process — hydroxide

TABLE 2

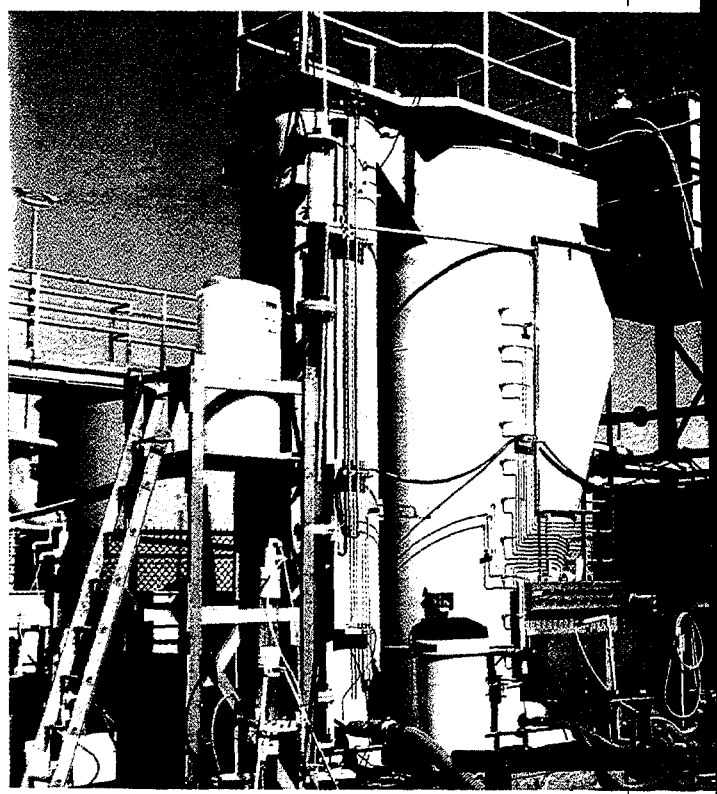
San Francisco Metals Removal Plant Performance Summary

Constituent	Permitted Daily Maximum Concentration (mg/L)	Influent		Effluent	
		Range (mg/L)	Average (mg/L)	Range (mg/L)	Average (mg/L)
Metals					
Arsenic	0.20	0 – 1.4	.07	0 – .02	.005
Cadmium	0.03	0.2 – 1.9	.24	0 – .04	.008
Chromium	0.11	.12 – 9.9	2.0	0 – .37	.065
Copper	0.20	.09 – 1.8	.54	0 – .08	.025
Lead	0.056	0 – .78	.18	0 – .13	.019
Mercury	0.001	0 – 0.001	0	0 – 0.001	0.0
Nickel	0.071	.05 – 3.1	.52	0 – .68	.11
Silver	0.023	0 – .12	.02	0 – .04	.005
Zinc	0.58	.08 – 2.2	.55	0 – .85	.12
Nonmetals					
Cyanide	0.1 ave./0.2 max.	.02 – 3.0	.31	.01 – 3.0	.12
MBAS*	4.5	2.2 – 46	14	.06 – 13	2.6
pH (unit)	5 to 9	2 – 13	8.9	6.4 – 11	8.8
Phenol	1.5	.19 – 10	1.5	.13 – 6.1	1.0
Oil & Grease	120	17 – 380	130	3 – 46	18
Settleable Matter	0.5	0 – 38	6.0	0 – .09	.02

Notes:

These data are based on semimonthly 24-hour composite samples taken from June 1992 through May 1993 (24 samples).

*MBAS: Methylene blue active substance; anionic surfactants that react with methylene blue to form a blue chloroform-soluble complex; the intensity of color is proportional to concentration.



The pilot system featured a Densadeg metals precipitation unit manufactured by Infilco-Degremont (Richmond, Va.). The unit contains three compartments: a two-stage, back-mixed tank, a recirculating reactor containing a turbine mixer, and a clarifier/thickener with tube settlers.

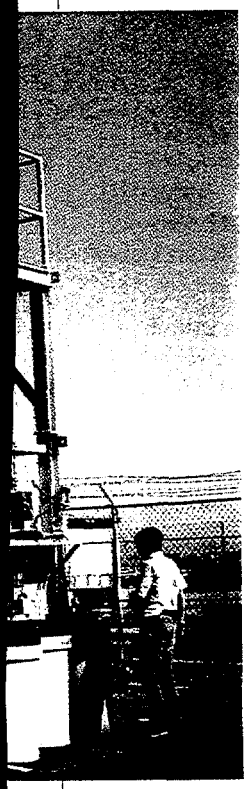
precipitation — was ineffective on the wastewater's low initial metals concentrations.)

Typically, the sulfide precipitation stage occurs in a solids-blanket reactor/clarifier, but because of space restrictions, the maintenance center's process is a hybrid that uses the second stage of the Sulfex process with a modified equipment configuration and flow regime.

Instead of the Sulfex solids-blanket reactor/clarifier, the system features a Densadeg unit manufactured by Infilco-Degremont (Richmond, Va.). This metals precipitation unit is a three-compartment apparatus consisting of a two-stage, back-mixed tank, a recirculating reactor containing a turbine mixer, and a clarifier/thickener with tube settlers.

The plant is fully confined in a containment basin to protect against accidental spills. Instruments measure flow, pH, turbidity, sludge blanket level and streaming current. All process units are computer monitored and controlled, with dual programmable logic controllers and dual terminals. Special covers, vents and flame arresters were installed on the inlet works, equalization tanks, dissolved-air flotation unit and oily sludge storage tank to comply with new air emission regulations for VOCs.

Operating experience. After the first year of operation, several process changes were made:



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- Ferrous sulfide batching difficulties caused by chemical impurities were resolved with metered batching and the use of non-caking granular ferrous sulfate.
- GAC plugging caused by bioslime was reduced with periodic caustic soda treatment.
- Foaming caused by the wastewater's high detergent levels was reduced by better controlling washrack operations and adding water sprays at foam-producing locations.
- Toxicity of the undiluted effluent was reduced by switching to non-toxic detergents and cleaners.
- Nickel discharges in excess of treatment capability are being addressed by tighter material inventory control, source controls and reduced use of cyanide and other chelating agents.
- Process upsets from accidental spills in the main facility were addressed by improving communication among the center's various operating areas.

Efforts are continuing to improve plant performance, reduce chemicals costs and isolate sources of problem contaminants that can result in process upset or cause the plant to exceed its discharge limits.

Overall process performance has been generally satisfactory (Table 2). Occasions when discharge limits have been exceeded typically involved a short period of time and were the result of an uncontrolled discharge in the center. The system reduces total heavy metal concentrations (nine metals) 91 percent, from 4.1 milligrams per liter to 0.36 milligrams per liter.

Initial characterization and treatability studies were performed in 1988, the first year of a five-year drought. As water conservation efforts were implemented, constituent concentrations increased, so when the treatment plant began operating in 1992, it received a more concentrated waste than anticipated.

During the winter of 1992-1993, an above-average rainfall thoroughly flushed accumulated solids from the collection system and greatly increased the mass loading on the plant. As a result of these changing conditions, operating the facility has been a continuing challenge. As operations return to a more predictable routine, performance should become more reliable and economical. ■

Daniel F. Seidel *is a senior project manager at Kennedy/Jenks Consultants (San Francisco).* **Neil Denton** *is a staff engineer at the United Airlines Maintenance Operations Center at San Francisco International Airport.*

Research

USING A HAZARDOUS MATERIAL CELL MODEL IN POLLUTION PREVENTION OPPORTUNITY ASSESSMENTS

Dale A. Rice*, P.E., Engineering-Science, Inc., Melvin R. Hockenbury, P.E., Engineering-Science, Inc.

Engineering-Science, Inc., 10521 Rosehaven Street, Fairfax, VA 22020

ABSTRACT

Pollution prevention (P2) opportunities can be best identified when a manufacturing operation is divided into component processes, and all material inputs and outputs for each process are carefully scrutinized. A conceptual model ("Hazardous Material Cell Model") is proposed which can be used as a framework for predicting hazardous material loss to each medium (e.g., air, wastewater, hazardous waste). Quantities are assigned to individual "cells," and the entrance to each cell can be estimated using simple rate equations. An example production process, a description of its various media cells, and respective loss equations are presented in this paper. The primary focus of the example is centered on release to the aqueous media. By identifying the most significant cells, P2 plans can be strategically implemented.

KEYWORDS

Pollution prevention, hazardous material control, multi-media

INTRODUCTION

With the passage of the Pollution Prevention Act of 1990, a new precedent in national environmental policy was formalized. The emphasis in subsequent environmental regulations would make reduction or elimination of pollutants at the source the highest priority. For example, the Water Pollution Prevention and Control Act of 1993 (Senate Bill 1114) as proposed would require the EPA to develop a list of key pollutants to be targeted for reduction, mandatory reduction of these pollutants by industry, and preparation of specific P2 plans by industrial discharges as a part of the permit process. Other pending amendments to environmental legislation, e.g., the Resource Conservation and Recovery Act, will undoubtedly have strong P2 overtones. As a result, a broader section of industry will be required to consider P2 in a more concerted fashion.

EPA's stated P2 hierarchy, with the highest priority as hazardous material source reduction, is a mandate away from traditional treatment approaches and toward identifying methods to eliminate or reduce hazardous materials in a production process. With this environmental evolution, new techniques will be needed to assist the environmental manager in understanding and tracking a plant's use of hazardous materials. Others (e.g., Morris and Robertson, 1993) have demonstrated mass balance approaches for waste minimization at the macro level. A conceptual model is proposed in this study which can help the user track the fate of hazardous materials as they leave an individual process and are "lost" to one or more media. This model, the Hazardous Material Cell Model (HMCM), is a simplistic attempt to conceptualize these material losses. By understanding the

mechanisms by which these losses occur, the HMCM may be used to determine the relative magnitude of the losses.

METHODOLOGY

A typical process will require a number of chemicals and other materials in the manufacture of a product. The amount of each chemical used is summarized in the following expression:

$$M_u = M_t - L \qquad (1)$$

Where

M_u = net mass of a material used productively, kg
M_t = total mass of material procured for the process, kg; and
L = mass of material lost from the process, kg

A loss is defined here as that amount of material that is no longer immediately usable in the process. Losses from the process occur to one or more of the following media: air, wastewater (WW), hazardous waste (HW), and solid waste (SW). For each medium, one or more mechanisms govern the loss rate from the process to the medium. For example, the transfer rate of a volatile organic compound (VOC) from an aqueous solution (where no free solvent layer exists) to the atmosphere may be approximated by the following (Tchobanoglous and Schroeder, 1985):

$$r_c = -K/h\,(C - C_s) \qquad (2)$$

Where

r_c = rate of evaporization, g/m^2hr
K/h = coefficient of mass transfer, m/hr
C = concentration of VOC, g/m^3; and
C_s = saturation concentration of VOC, g/m^3

Figure 1 depicts a matrix of loss terms attributed to various media. This matrix is easily set up in spreadsheet format and can be tailored to accommodate a specific process. Each "cell" contains a loss rate with a value determined from an appropriately assigned rate equation governing the transfer of an individual chemical from the process to a specific medium. Note that separate loss rates are calculated at various manufacturing stages (storage through post process). Some cells may be left blank where a medium is not entered by the chemical of concern (e.g., transfer of a non-volatile metallic salt from an aqueous phase to vapor phase).

LOSS TERMS:

MEDIUM	STORAGE	PROCESS	PROCESS MAINTENANCE	POST PROCESS
Air				
Area	$A_{a,s}$	$A_{a,p}$	$A_{a,m}$	$A_{a,x}$
Stack	$A_{s,s}$	$A_{s,p}$	$A_{s,m}$	$A_{s,x}$
Fugitive	$A_{f,s}$	$A_{f,p}$	$A_{f,m}$	$A_{f,x}$
WW				
Batch	$W_{b,s}$	$W_{b,p}$	$W_{b,m}$	$W_{b,x}$
Continuous	$W_{c,s}$	$W_{c,p}$	$W_{c,m}$	$W_{c,x}$
HW				
Batch	$H_{b,s}$	$H_{b,p}$	$H_{b,m}$	$H_{b,x}$
Continuous	$H_{c,s}$	$H_{c,p}$	$H_{c,m}$	$H_{c,x}$
SW	S_s	S_p	S_m	S_x

WW = Wastewater; HW = Hazardous Waste; SW = Solid Waste

Figure 1 - Hazardous Material Loss Term Matrix

To set up the HMCM, the process to be addressed is carefully examined to identify where losses of chemical products can occur. Typical examples of how losses can occur in manufacturing processes are presented in Figure 2. A separate spreadsheet is established for each chemical of concern. Physical mechanisms, taken from process engineering studies or other sources, are selected for each applicable cell. In the case where a process has a reaction involving the chemical of concern, a much more rigorous set of rate equations may be needed.

An example process, nickel electroplating, is presented to demonstrate the HMCM. Nickel, the key component of the process, is one of the EPA 17 Industrial Toxics Project Chemicals and is selected as the chemical targeted for the model below. Information concerning the example process is given in Table I.

MEDIUM	STORAGE	PROCESS	PROCESS MAINTENANCE	POST PROCESS
Air				
Area	Storage area vent	Process area VOC emissions	Emissions from waste-water	Product loss (airborne)
Stack	NT	Solvent emissions	Paint booth cleanup	NT
Fugitive	Bulk solvent volatili-zation	Valve, pipe leakage	Equipment leaks	Product loss (airborne)
WW				
Batch	Spill cleanup	Plating bath replacement	Tank cleanout	Product loss cleanup
Continuous	NT	Parts rinsing	Oil/water separator effluent	NT
HW				
Batch	Shelf-life exceedence	Tank bottoms	Spent solvent	Product contamination
Continuous	NT	Sludge generation	Solvent purging	NT
SW	Floor spill residual	Dry paint filters	Cleaning residuals	Off-spec product waste (non-hazardous)

NT = Not Typical; WW = Wastewater; HW = Hazardous Waste; SW = Solid Waste

Figure 2 - Examples of Chemical Losses From Various Media

Table I - Nickel Electroplating Example Process Data

Plating tank capacity, V	5,000 L	Rack interval, i	1 min
Bath makeup		Dragout, D	0.1 L
Nickel chloride	45 g/L	Rinse flow, Q_r	20L/min
Nickel sulfate	330 g/L	Tank maintenance interval, M	6 mo
Boric acid	40 g/L	Maintenance residual, R	.01
Additives	3.5%	Off-spec product ratio, z	.005
pH	4.0	Density plated nickel, d	8.91 g/cm^3
Molarity (Ni)	1.4m/L	Plating area/rack, P	$4 \times 10^3 cm^2$
Tank sequence		Average plating thickness, p_t	10^{-2}cm
(1) Nickel plating bath			
(2) Rinse tank			
(3) Rinse tank			

In the example, parts are mounted on racks, electroplated in a nickel bath containing nickel anodes and plating solution, and then rinsed in a series of two countercurrent rinse tanks (Figure 3). The rinses overflow to WW treatment at flow rate Q_r where they are neutralized with sodium hydroxide. Losses of nickel from the process will occur primarily from plating solution drag-out which clings to the parts and racks as they enter the rinses. Losses via air media are negligible. Some storage losses could occur, e.g., exceeded shelf-life of nickel sulfate or nickel chloride. A loss of nickel will also occur in process maintenance when the plating bath becomes contaminated and is either treated in the WW treatment system or disposed off-site as a HW. Post process nickel losses can occur with product rework (failure to meet specifications) where nickel plated parts must be recycled. To simplify the example, the loss from splashing caused by plating tank aeration or from accidental spills is not addressed here.

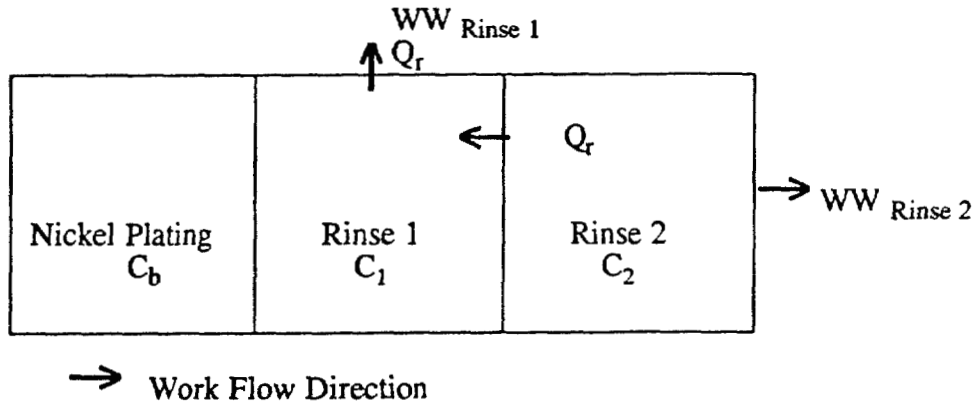

Figure 3 - Example Nickel Plating Process Configuration

Assuming equilibrium nickel concentrations and complete mixing of drag-out with the rinse, the following relationship has been proposed by Lowenheim (1978):

$$C_n = C_b(D/iQ_r)^n \qquad (3)$$

Where

C_n = nickel concentration in dragout after the nth tank, g/L;
C_b = nickel concentration in plating bath, g/L;
D = estimated volume of drag-out per rack, L (assumed constant);
i = time interval between racks entering bath, min; and
Q_r = rinse flow into and out of tank, L/min.

The loss of nickel from the plating system of Figure 3 occurs at two points: the overflow of Rinse 1 and the dragout from Rinse 2. The rate loss equation from Rinse 1 having nickel concentration C_1 is approximated as $Q_r C_1$, or substituting from Equation (3):

$$WW_{Rinse\ 1} = C_b (D/i) \qquad (4)$$

Note that in Equation (4) the loss of nickel from drag-out into Rinse 2 can be ignored where $Q_r \gg D/i$. The drag-out loss from Rinse 2 is defined as follows:

$$WW_{Rinse\ 2} = C_2 (D/i) \qquad (5)$$

Substituting Equation (3) into Equation (5) and combining terms, we have:

$$WW_{Rinse\ 2} = C_b (D/i)^3 Q_r^{-2} \qquad (6)$$

Equations (4), (5), and (6) are expressed in g/min. Note, however, where $Q_r \gg D/i$, $WW_{Rinse\ 1} \gg WW_{Rinse\ 2}$. Since this is the case in the example, the nickel loss from Rinse 2 can be ignored and $W_{c,p} \approx C_b(D/i)$.

Plating tank maintenance is performed semiannually in the example process. This operation typically involves draining the tank contents to a temporary storage tank for bath purification and cleaning out accumulated residues from the plating tank. The rate of nickel loss from the process tank can be estimated as:

$$W_{b,m} = 2.3 \times 10^{-5}\ VC_bR/M \qquad (7)$$

Where

$W_{b,m}$ = nickel loss rate (WW batch - maintenance), g/min;
V = volume of plating tank, L;
R = fraction of nickel remaining as tank residual;
C_b = nickel concentration in bath, g/L; and
M = maintenance interval, mo.

Since the example includes product loss, the rate loss of nickel as off-spec material must be estimated. Although the substrate material is typically recyclable, the nickel-plated layer will likely be wasted. The loss rate during the process operation is estimated as:

$$S_x = Pp_pdz/i \qquad (8)$$

Where

S_x = nickel loss rate (SW- post process), g/min;
P = average plating area/rack, cm^2;
p_t = average plating thickness, cm;
d = density of nickel metal, g/cm^3;
z = fraction of material off-spec; and
i = rack interval, min.

RESULTS AND DISCUSSION

The appropriate loss equations (4, 7, 8) were configured into the HMCM as shown in Figure 4. Note that all other matrices are assumed to be not applicable or insignificant. Using Table I process data, rate losses were determined for the example process as shown in Figure 5.

LOSS EQUATIONS (g/min):

MEDIUM	STORAGE	PROCESS	PROCESS MAINTENANCE	POST PROCESS
Air				
Area	$A_{a,s} = 0$	$A_{a,p} = 0$	$A_{a,m} = 0$	$A_{a,x} = 0$
Stack	$A_{s,s} = 0$	$A_{s,p} = 0$	$A_{s,m} = 0$	$A_{s,x} = 0$
Fugitive	$A_{f,s} = 0$	$A_{f,p} = 0$	$A_{f,m} = 0$	$A_{f,x} = 0$
WW				
Batch	$W_{b,s} = 0$	$W_{b,p} = 0$	$W_{b,m} = 2.3 \times 10^{-5} VC_b R/M$	$W_{b,x} = 0$
Continuous	$W_{c,s} = 0$	$W_{c,p} = C_b(D/i)$	$W_{c,m} = 0$	$W_{c,x} = 0$
HW				
Batch	$H_{b,s} = 0$	$H_{b,p} = 0$	$H_{b,m} = 0$	$H_{b,x} = 0$
Continuous	$H_{c,s} = 0$	$H_{c,p} = 0$	$H_{c,m} = 0$	$H_{c,x} = 0$
SW	$S_s = 0$	$S_p = 0$	$S_m = 0$	$S_x = P_R\, dz/i$

Figure 4 - Hazardous Material Cell Model for Example Nickel Plating Process

LOSS RATES (g/min):

MEDIUM	STORAGE	PROCESS	PROCESS MAINTENANCE	POST PROCESS
Air				
Area	0	0	0	0
Stack	0	0	0	0
Fugitive	0	0	0	0
WW				
Batch	0	0	0.02	0
Continuous	0	8	0	0
HW				
Batch	0	0	0	0
Continuous	0	0	0	0
SW	0	0	0	1.8

Figure 5 - Hazardous Material Cell Model Solution for Nickel Plating Process

For the example process, only three nickel rate losses were calculated for a total nickel rate loss of approximately 10 g/min during operation of the process. Obviously, the rinses account for the greatest loss of nickel from the process. The greatest P2 opportunities are not likely with the other cells in this example. Efforts to minimize loss, therefore, should be focused on the rinsing of parts. A number of technical approaches can be used to minimize the transport of nickel into the rinses or to recover the nickel from the rinses. These techniques include reducing drag-out from the plating bath by better positioning parts on the racks, allowing additional time for the racks to drip over the plating bath before entering the rinses, or by modestly spraying the parts with a fresh rinse as they come out of the plating bath. Nickel recovery can be accomplished via ion exchange or evaporative recovery. Waste minimization efforts in the electroplating field have been documented (Graham and Patry, 1992).

The HMCM is intended to be a potential tool to allow the user to identify specific points where and at what relative magnitude HMs are exiting from a process. A matrix set up along the lines of environmental media and different stages of the production process enable the compartmentalization of individual losses.

CONCLUSIONS

A conceptual model, HMCM, has potential application in P2 studies. The HMCM has been demonstrated for an example process from the surface finishing field. The model was used to predict the loss rates of nickel metal from an electroplating process. The HMCM can be tailored for a specific process by identifying applicable expressions which approximate the loss rates of a material from the process. Future work with the HMCM could entail modeling other example processes and linking costs to the cells in the matrix.

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Authors. Dale A. Rice is the Hazardous and Industrial Waste Department Manager with Engineering-Science, Inc., Fairfax, Virginia and Melvin A. Hockenbury is Vice-President, Eastern Operations of Engineering-Science, Inc.

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University of Michigan to Develop Pollution Prevention Modules

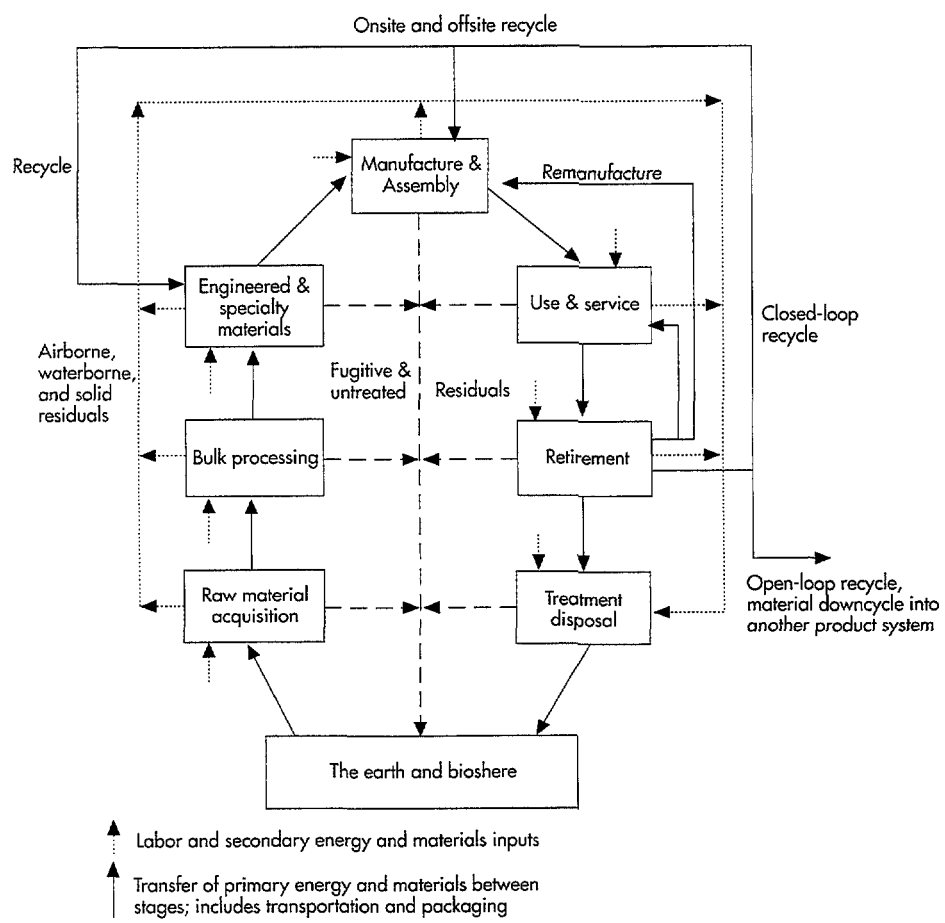
The newly organized EPA Office of Pollution Prevention and Toxic Substances (OPPTS), formerly the Office of Toxic Substances, has entered into a cooperative agreement with the University of Michigan to establish a national pollution prevention center. Under the agreement, EPA will contribute $320,000 and the university will contribute $161,000 to fund the first 3 years of the center. The university has already begun a fund-raising effort to fund the center beyond the 3-year grant period.

The center will develop pollution prevention curriculum modules for the schools of engineering, business, art and architecture, and natural resources and will disseminate these materials to universities nationwide. The administration of the center will be located in the school of natural resources with participation by the other three schools at the university. Beginning next year, the center will offer short courses (2 days to 1 week) in each of the schools.

In the meantime, other universities and industries are being solicited for input into the development of the modules. These modules were chosen for development because they can be adapted readily to existing courses at other universities. The modules will include instructor's guides, lecture materials, case studies, open-ended problems, small-group problem solving exercises, and videos.

Development of the center's education modules will be based on a product life cycle framework (see Figure). This framework is a systematic approach to pollution prevention that considers each stage in the life of the product from raw materials to finished product, use, resource recovery, and disposal. Analyzing a product in terms of its life cycle helps identify environmental impacts and risks associated with its manufacture and use.

The Product Life Cycle



The life cycle viewpoint will be used in the development of the business and engineering modules to address hidden environmental costs and liabilities now overlooked by companies. The center assumes that engineering education is crucial to the development and implementation of pollution prevention strategies.

Each of the engineering disciplines, including chemical, civil, and environmental engineering, will have greater emphasis on pollution prevention. For example, engineering design has traditionally been guided by such factors as costs, aesthetic considerations, and regulatory constraints. To achieve environmental risk reduction, design must stress pollution prevention criteria over end-of-pipe controls.

Reducing pollution at the source entails a change in traditional business and management approaches. Environmental costs and liabilities need to be clearly identified and policies established so that managers and planners can pursue pollution prevention.

Education of future business managers will focus on changing attitudes and values in a way that makes it easier for them to factor pollution prevention considerations into their decision-making. Areas of business focus will include finance, marketing, and op-

erations management.

Meanwhile, according to agency literature, pollution prevention and life cycle analysis need to be grafted onto business and engineering curricula. To achieve the greatest reduction in environmental risk, the design of new products must include pollution prevention criteria. Environmental costs and liabilities need to be added to notions of efficiency and other traditional business considerations. Ultimately, pollution prevention needs to become part of the business manager's ethic and a basis of corporate policy.

The center will also sponsor an internship program. One graduate student in the School of Business is already working as an intern with the Ford Motor Co. on pollution prevention and waste minimization processes.

The center's manager Greg Keoleian stressed that the center will be truly national in character with as much participation by the business, industry, and academic communities as possible. He says the center will be a strategically important educational institution that produces students who are equipped to face future environmental challenges.

OPPTS project manager Karen Hoffman adds, "Students completing the curriculum will not only be up to speed on such things as regulatory matters, they will be industry's leaders in this important field."

"Students completing the curriculum will not only be up to speed on such things as regulatory matters, they will be industry's leaders in this important field."

The center represents another major initiative in the implementation of EPA's pollution prevention strategy, which Administrator William Reilly has designated as among the agency's top priorities.

Looking to identify critical areas that were not being addressed by current pollution prevention activities, OPPTS staff met in January with industry representatives, including IBM and Shell Oil, to discuss the types of pollution prevention programs industry groups would likely support. Four options emerged from these talks: curriculum development, technology transfer, clearinghouse functions, and pollution prevention training. The agency eventually settled on curriculum development and dissemination.

—Alan B. Nichols, senior staff writer

Additional Information

For Further Information Contact:
National Pollution Prevention Center for Higher Education
University of Michigan
Dana Building 430 East University
Ann Arbor, MI 48109-1115
Telephone: (313) 764-1412
Fax: (313) 936-2195

CONVERTING AUTOMOTIVE PAINT SLUDGE TO ACTIVATED CARBON

B. R. Kim*, E. M. Kalis, and I. T. Salmeen
Ford Research Laboratory, P.O. Box 2053, Drop 3083/SRL, Dearborn, MI 48121

Carl W. Kruse, Ilham Demir, Stephen L. Carlson, and Massoud Rostam-Abadi
Illinois State Geological Survey

Abstract -- The pyrolysis of a paint sludge, six dried paints (simulated paint sludges), and a coal (a potential additive) produced nine chemically activated chars. These chars were characterized by surface areas, ash contents, and adsorption capacities. The primary findings are 1) activated black-paint chars showed surface areas and adsorption capacities comparable to those of commercial activated carbons, and 2) the activated paint-sludge char showed an adsorption capacity approximately 20% (total weight based) and 50% (ash-free weight based) of commercial activated carbons. Other findings are: 1) activated white-paint chars showed substantially smaller surface areas and lower adsorption capacities than activated black-paint chars probably due to the white pigment, titanium dioxide and 2) coal could be added to paint sludge to improve the quality of the resulting char.

Key Words -- Paint Sludge, Adsorption, Activated Carbon, Pyrolysis, Automotive Wastes

INTRODUCTION

Automotive painting operations generate various wastes: exhaust spray-booth air that contains volatile organic compounds (VOCs); spent spray-booth scrubber water that contains VOCs; and paint sludge. An integrated approach has been investigated at Ford to reduce all of these wastes by using existing spray-booth scrubbers. The study reported herein explores the possibility of recycling paint sludge as part of the integrated approach.

One of the major factors that affect the costs of handling and disposing of paint sludge is the volume of the sludge. In order to reduce sludge volume, some automotive assembly plants have been drying the sludge. This reduces transportation and disposal costs and may make it possible to reuse the dried sludge for filler or to make low-quality paints (Berghoff, 1993).

Another process that could be used for volume reduction is pyrolysis. The pyrolysis of paint sludge not only results in a smaller volume than that achieved by drying, but also could produce a char. The char could be put back into the scrubber water as an adsorbent to remove VOCs (especially nonpolar VOCs) from the exhaust booth air (Kim and Pingel, 1989).

The objectives of this study were to determine whether paint materials (a paint sludge and several dried paints) could be pyrolyzed to produce carbon-based adsorbent

materials (chars) and to compare adsorption capacities of the resulting chars in comparison with those of commercially available activated carbons.

METHODOLOGY

Materials

The adsorbents used in this study, their base materials (coal, paint sludge, and paints), and the sources of the base materials are listed in Table I. Black paints were selected to represent low-ash paints whereas white paints were selected to represent high-ash paints. The black paints contained carbon black as a pigment whereas the white paints contained titanium dioxide as a pigment.

The paint sludge was obtained from an assembly plant in a dry form. In that plant, overspray paint materials were captured using a wet scrubber, detackified using organic polymers, collected through flotation, and dried using a thermal dryer.

The coal was a Herrin (Illinois No. 6) coal from lot IBC-109 (a low-sulfur Illinois coal) in the Illinois Basin Coal Sample Program (Harvey and Kruse, 1988). The coal char served as a control with which to compare properties of chars made from the coal/paint mix, the dried paints, and the paint sludge and also those of commercially available activated carbons. The coal/paint-mix char was prepared by mixing the Illinois coal with a solvent-borne white paint (manufacturer B) prior to pyrolysis.

p-Nitrophenol (99+%) was obtained from Aldrich Chemical Company, Inc. (Milwaukee, WI). p-Nitrophenol has been frequently used as a model adsorbate by many researchers in the environmental field (Snoeyink et al., 1969; Kim et al., 1976; Fritz and Schlünder, 1981; Kim and Cognata, 1990).

Reagent-grade potassium hydroxide (85.0% minimum assay) was from EM Science (A Division of EM industries, Inc. and an Associate of E. Merck, Darmstadt, Germany). The weight ratios, which were used for KOH activation, were based on the total reagent weight, not its KOH content.

Deionized water was used in all adsorption experiments.

Analytical Methods

The surface areas of the chars were measured with a Quantachrome Monosorb Surface Area Analyzer manufactured by Quantachrome Corporation (Syosset, NY). The Monosorb uses the single-point BET method for calculating the surface area from the amount of nitrogen adsorbed at −196°C by a sample that had been degassed at 130°C under vacuum prior to introduction of the adsorbate nitrogen.

A Cahn TG-131 thermogravimetric analyzer (The Cahn Corporation, Cerritos, CA) was used to determine the volatile matter and ash contents of the samples.

Table I Adsorbents Used in This Study

Adsorbents		Base Materials	Sources
Name	Type		
Calgon BL	PAC[1]	Bituminous Coal	Calgon Corp.
Calgon F-400	GAC[2]	Bituminous Coal	Calgon Corp.
IBC-109	Coal Char	Bituminous Herrin (Illinois No. 6) Coal	Southern Illinois preparation plant
Coal/Paint Mix	Coal-Paint Mix Char	A Mixture of Illinois No. 6 Coal and Dried Solvent-borne White Paint	Southern Illinois preparation plant/Paint Manufacturer B
Paint Sludge	Paint-Sludge Char	Dried Paint Sludge	An Automotive Plant
WBBP-B	Black-Paint Char	Dried Water-borne Black Paint	Paint Manufacturer B
SBBP-B	Black-Paint Char	Dried Solvent-borne Black Paint	Paint Manufacturer B
SBBP-A	Black-Paint Char	Dried Solvent-borne Black Paint	Paint Manufacturer A
WBWP-B	White-Paint Char	Dried Water-borne White Paint	Paint Manufacturer B
SBWP-B	White-Paint Char	Dried Solvent-borne White Paint	Paint Manufacturer B
SBWP-A	White-Paint Char	Dried Solvent-borne White Paint	Paint Manufacturer A

1 Powdered Activated Carbon
2 Granular Activated Carbon

The concentration of p-nitrophenol was measured using a Lambda 6 UV/visible spectrophotometer (The Perkin-Elmer Corporation, Oakbrook, IL) at a wavelength of 317 nm. An ion analyzer (Model 960, Orion Research, Cambridge, MA) was used to measure pH.

Experimental Methods

Preparation of Base Materials for Pyrolysis. Each paint was separately dried by heating it at approximately 50°C in a hood for several weeks until most of the paint solvents evaporated, and then placing it in an oven at approximately 110°C for several days. The paint was crushed and further dried under vacuum. The coal was ground to a 60-mesh particle size in a mill (Model 500, Holmes Brothers Inc., Danville, IL). Neither the coal nor the paint sludge required vacuum drying.

Pyrolysis and Activation. Pyrolysis was carried out in a continuous-feed charring oven (CFCO), which was patterned after one described by Kruse and Shimp (1981) and Kruse et al. (1988) for thin bed charring of coal. The CFCO was used to produce all activated chars from the coal/paint mixtures, the paint sludge, and the dry paints.

Chemical activation was used to increase the surface area of the resulting chars. Except for the coal/paint mix, each base material was mixed with KOH at a weight ratio of 1 to 1 prior to pyrolysis. The weight of KOH was based on the total weight of KOH pellets, not their assayed content. The addition of water and a small amount of detergent facilitated mixing. The mixture of KOH and a base material was dried at approximately 100°C for two days under reduced pressure and pyrolyzed at 600°C for 30 minutes in a nitrogen atmosphere in the CFCO. The pyrolyzed paint/KOH mixture was washed with warm deionized water, soaked in 5-N HCl for 15 hours, and washed again with deionized water. The chars were dried at approximately 110°C and stored in a desiccator prior to use.

The procedure for preparing a coal/paint-mix adsorbent involved two mixing steps prior to pyrolysis. A paint/KOH mixture and a coal/KOH mixture were prepared separately and then mixed to yield a coal-to-paint ratio of 9 to 1. The paint/KOH mixture was 1 part solvent-borne white paint (manufacturer B) with 1 part KOH, whereas the coal/KOH mixture was 1 part coal with 1.5 part KOH.

Adsorption-Isotherm Experiments. Isotherm experiments were conducted in 250-mL or 125-mL amber glass bottles with Teflon-lined caps. Predetermined amounts of an adsorbent were placed in the bottles which were then filled with a p-nitrophenol solution of a known concentration. The bottles were then packed into paint cans which were placed on a roller apparatus (Bellco Glass, Vineland, NJ) for mixing. After at least four days of mixing for equilibration, the bottles were centrifuged prior to analysis to remove adsorbent particles using a Sorvall RB-5C Superspeed Centrifuge (DuPont Instruments, Newtown, CT).

All isotherm experiments were conducted at room temperature (21 to 25°C) and at a pH less than 4 to ensure that p-nitrophenol was in the neutral form. A dilute H_2SO_4 solution was used for pH control.

RESULTS AND DISCUSSION

Physical Characteristics of Activated Chars

The surface areas of the activated chars were calculated on both a total weight basis and an ash-free weight basis. The results are shown in Table II with data on Calgon carbons. The Calgon carbons had higher surface areas than those of the chars prepared for this study including the two made from the Illinois coal (IBC-109 and coal/paint mix). The black-paint chars had substantially higher surface areas than the white-paint chars. This was expected because the main pigment used in the white paints is titanium dioxide. Titanium dioxide was not expected to form a porous material although there was the possibility that this oxide might in some way enhance carbon porosity. Two black-paint chars, WBBP-B and SBBP-A, showed a surface area close to that of coal-based char (IBC-109) despite the differences in ash contents. The chars produced from manufacturer B's black paints contained substantially higher ash content than those of IBC-109 and the Calgon carbons. The ash content of SBBP-A was less than 2%. The high ash contents of manufacturer B's black-paint chars (21% for WBBP-B and 59.3% for SBBP-B) were somewhat surprising because the major inorganic ingredient of paints was thought to come from pigments and the carbon-black pigment of the black paints should not be part of the ash. On the other hand, the ash contents of the white paints were high (over 80%), as expected, because of the white pigment, titanium dioxide.

The particle-size distributions of the chars were not determined. However, the black-paint chars were visually powdery and black and were similar to a typical powdered activated carbon, whereas the white-paint chars were mostly powdery and grey but contained some granular materials which were generally smaller than the sizes of a typical granular activated carbon such as Calgon F-400.

Adsorption of p-Nitrophenol on Activated Chars

Adsorption isotherms are frequently described with the Freundlich isotherm equation as shown below:

$$X = K\, C_{eq}^{\frac{1}{n}} \qquad (1)$$

where X = the amount of p-nitrophenol adsorbed (mg p-nitrophenol/g adsorbent);
C_{eq} = equilibrium concentration of p-nitrophenol (mg/L); and
K and n = coefficients.

Table II Surface Areas and Ash Contents of Activated Chars and Calgon Carbons

Adsorbents	Surface Area (m^2/g)		Adsorption Capacity at 100 mg/L of p-Nitrophenol (mg/g)		Ash Contents (%)
	Based on Total Weight	Based on Ash-Free Weight	Based on Total Weight	Based on Ash-Free Weight	
Calgon BL[1]	1,000-1,100	1,100-1,200	278	303	8.5 max.
Calgon F-400[2]	1,050-1200	-	311	-	not available
IBC-109	761	773	277	284	2.5
Coal/Paint Mix	576	627	206	224	8.1
Paint Sludge	205	594	49.6	144	65.5
WBBP-B	707	752	134	169	21.0
SBBP-B	236	580	61.6	151	59.3
SBBP-A	767	783	223	228	< 2[3]
WBWP-B	64	323	7.10	35.9	80.2
SBWP-B	83	565	16.7	114	85.3
SBWP-A	124	756	24.6	150	83.6

1 Calgon Technical Bulletin
2 Calgon Activated Carbon Product Bulletin
3 Estimated. The ash content of this sample was not determined. However, a different, but similarly prepared sample showed an ash content of 1.7%.

The coefficient, K, is the amount adsorbed at C_{eq} = 1 mg/L [the intercept of the plot of Eq. (1)] and 1/n is the slope of the lines on a log-log plot of C_{eq} versus X.

The Freundlich isotherm equation is strictly empirical and does not converge to Henry's law at low equilibrium concentration. Nevertheless the Freundlich equation is useful for data analysis. For example, K in Eq. (1) gives a measure of adsorption capacity of an adsorbent, and 1/n is a measure of adsorption intensity (Adamson, 1967). In other words, higher values of K and 1/n indicate higher adsorption capacity and adsorption energy, respectively.

The results of the isotherm experiments on the activated chars are shown in Figure 1 with those of the Calgon carbons. The isotherm for a granular activated carbon, Calgon F-400, was obtained from the literature (Kim and Cognata, 1990).

All isotherms were fitted to the Freundlich equation as shown in Figure 1. As mentioned earlier, the coefficient, K, is frequently used as a measure of adsorption capacity. However, the concentration of 1 mg/L, at which the values of K are determined, was not within the range of p-nitrophenol concentration studied here, and therefore the amounts adsorbed at 100 mg/L were used instead to compare adsorption capacities of the adsorbents. These values were obtained from Figure 1 and are listed in Table II for both the total weight and the ash-free weight of each adsorbent. Several observations can be made on the results shown in Figure 1 and Table II.

1. The adsorption capacities of the Calgon carbons (BL and F-400) and IBC-109 char were comparable (see Figure 1 and Table II), despite a surface area of IBC-109 that was much smaller than those of the commercially available Calgon carbons. A possible explanation is that the measurement of surface area was based on nitrogen adsorption and cannot be directly applicable to the adsorption of p-nitrophenol. The Calgon carbons may have more micropores (<20 Å diameter) and a sizeable fraction of the surface area in the micropores may not be accessible to p-nitrophenol molecules. However, the surface area remains a useful parameter for making a rough comparison among adsorbents.

2. The adsorption capacities of all the paint chars were lower than those of the Calgon carbons and IBC-109 char. This might be related to the smaller surface area and high ash content. One black-paint char, SBBP-A, had a high adsorption capacity, approximately 80% of the Calgon carbons.

3. The adsorption capacities of the black-paint chars were higher than those of the white-paint chars. The white-paint chars had smaller surface area and higher ash content than the black-paint chars. The low adsorption capacity of the white-paint chars indicates that the pigment, titanium dioxide, did not appreciably participate in the adsorption of a compound such as p-nitrophenol. It remains to be seen whether this is also true for the adsorption of more hydrophilic compounds such as alcohols.

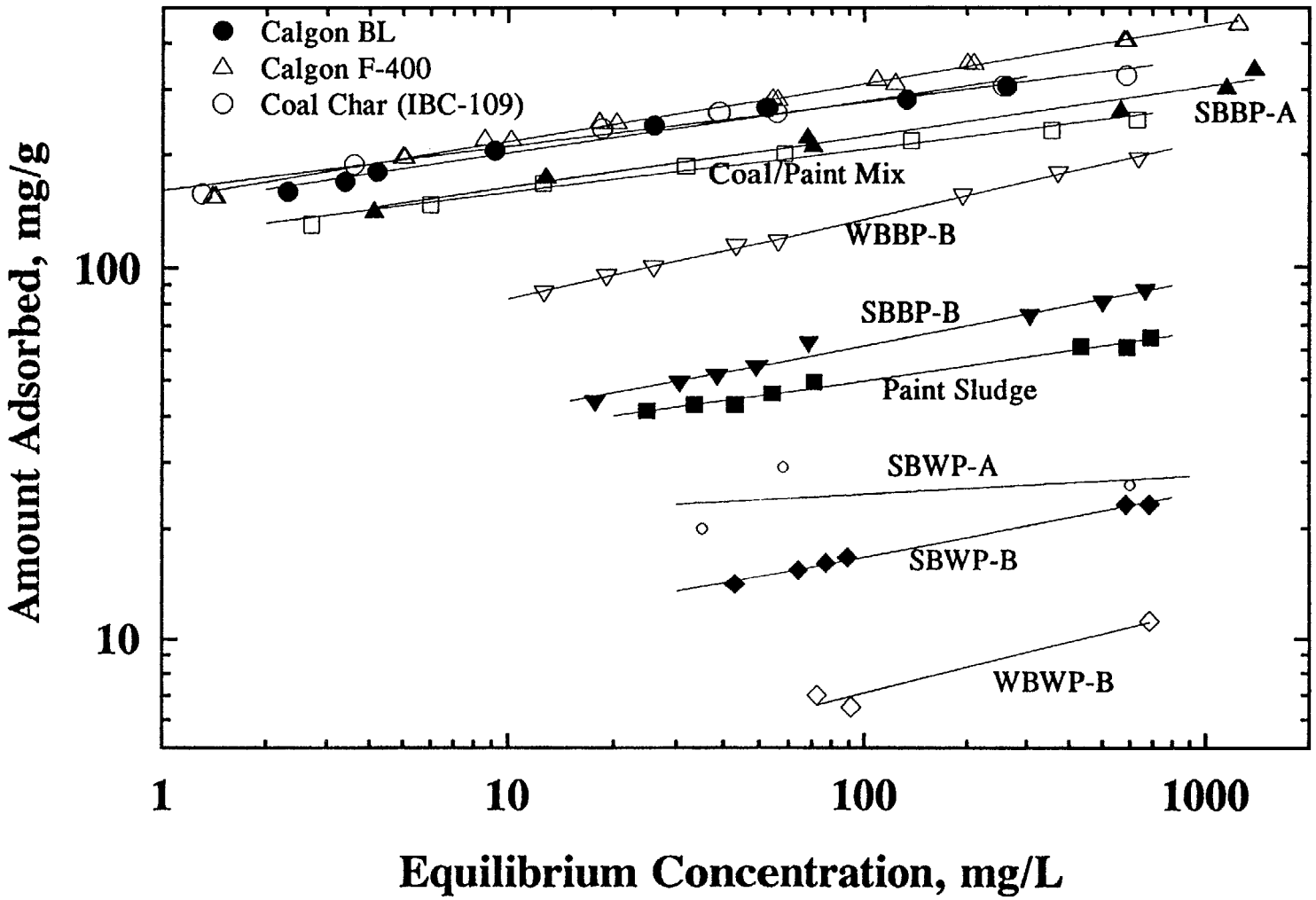


Figure 1 Adsorption of p-Nitrophenol on Activated Paint Chars and Activated Carbons

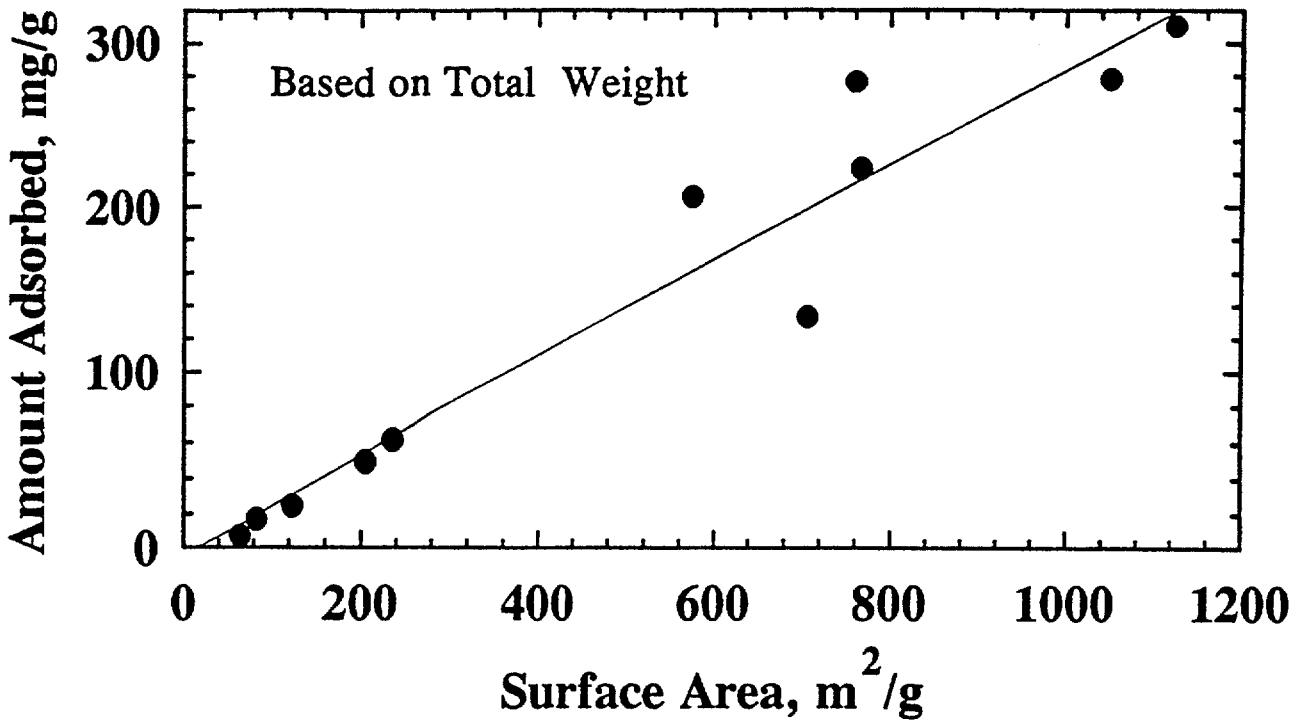
4. It is quite interesting to note that the paint-sludge char, which was produced from a paint sludge collected at an automotive assembly plant where a variety of paints was used, showed an adsorption capacity which was between those of the black-paint chars and those of the white-paint chars. The ash content of the paint-sludge char was also between those of the two groups of the paint chars. This seems to support the idea that black paints would produce adsorbents with relatively high adsorption capacity among a variety of paints whereas white paints would do the opposite. The adsorption capacity of the paint-sludge char is approximately 18% (total weight based) and 48% (ash-free weight based) of that of Calgon BL, respectively. This adsorption capacity is still substantial, and the idea of putting a paint-sludge char back into a scrubber for capturing paint VOCs from the spray-booth air seems promising.

5. Coal/paint mix showed a high adsorption capacity indicating that the addition of coal to improve the quality of the resulting char and to reduce ash content is feasible. As mentioned earlier, the char was produced from a mixture of coal and the solvent-borne white paint (manufacturer B). Based on the ash contents of IBC-109, coal/paint mix, and SBWP-B, coal/paint mix should be composed of 7% SBWP-B and 93% IBC-109. The calculated adsorption capacity of coal/paint mix, derived from the calculated composition and the adsorption capacities of SBWP-B and IBC-109, is 259 mg/g (total weight based) which is higher than the experimental value, 206 mg/g. The difference might have been due to some blockage of pores by the titanium dioxide.

6. The slopes of all the paint-char isotherms (or 1/n) are close to those of the Calgon carbons and are relatively flat (i.e., n is much greater than 1). This means that the adsorption capacity of a paint-sludge char can be efficiently used even at relatively low concentrations. In addition, the similar slopes indicate that the Calgon carbons and the paint chars have similar surface characteristics with respect to their affinity for p-nitrophenol because the slope roughly represents the adsorption energy.

7. The adsorption capacity at 100 mg/L of p-nitrophenol, which is listed in Table II, is plotted against surface area in Figure 2. Both the amount adsorbed and the surface area in the top figure are based on total weight of an adsorbent, whereas those in the bottom figure are based on ash-free weight of an adsorbent. The solid lines are linear regression lines. The results show that the adsorption capacity generally increases linearly with the N_2-BET surface area.

With regard to the possibility of implementing this pyrolysis process at an automobile assembly plant, one major factor is the amount of paint sludge available at the plant for conversion to activated char. The amount of sludge available might be too small to justify a dedicated facility for each assembly plant for making activated carbon. If so, it might be more economical to build a relatively large, centralized facility to which several assembly plants could send their paint sludges. This might be particularly true for the southeast region of Michigan where many assembly plants are located. In addition, blending the sludge with coal as feed to this centralized facility could be an attractive option to improve the adsorption capacity of the resulting char. In this case, the location



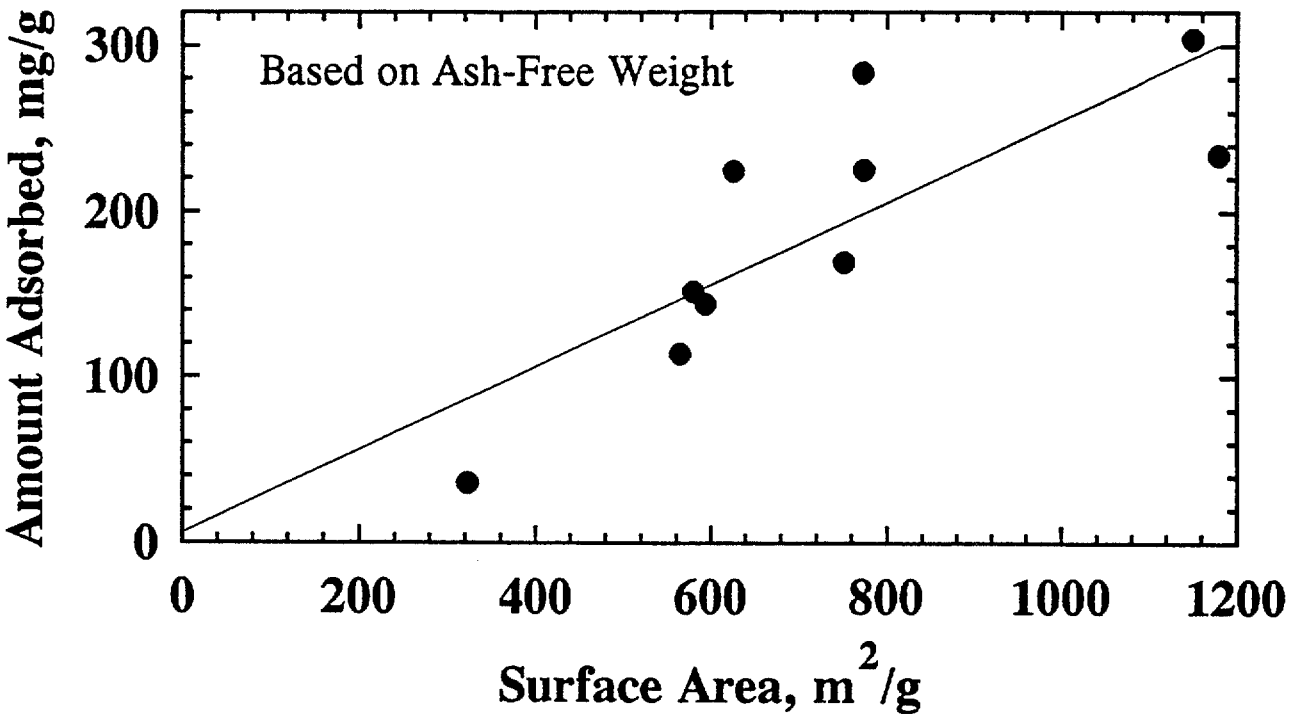


Figure 2 Effect of Surface Area on the Adsorption Capacity at 100 mg/L of p-Nitrophenol

of the facility will depend on the amount of coal to be used, the transportation cost of coal from a coal source, and the transportation cost of paint sludge from assembly plants.

SUMMARY AND CONCLUSIONS

The technical feasibility of producing activated carbon from real and simulated paint sludge was examined. The primary findings are as follows:

1. The black-paint chars showed substantially larger surface area than the white-paint chars, probably due to the white paint pigment, titanium dioxide, which is not expected to form a porous adsorbent material.

2. The black-paint chars, produced from manufacturer B's paints, showed unexpectedly high ash contents (21% for WBBP-B and 59.3% for SBBP-B) for a paint using carbon black as pigment.

3. The ash content of the white-paint chars was very high (over 80%), as expected, because of the white pigment, titanium dioxide.

4. The adsorption capacities of the Calgon carbons (BL and F-400) and IBC-109 char were comparable and were higher than those of the paint chars.

5. The adsorption capacities of the black-paint chars were higher than those of the white-paint chars indicating that the white pigment, titanium dioxide, did not participate appreciably in the adsorption of p-nitrophenol or in making the carbon structure more active.

6. The paint-sludge char showed an adsorption capacity and an ash content that were between those of the black-paint chars and those of the white-paint chars, as expected from the fact that the sludge was formed from a variety of paints. The adsorption capacity of the paint-sludge char was found to be a little less than 20% (total weight based) and 50% (ash-free weight based) those of the Calgon BL.

7. The fact that coal/paint mix showed an adsorption capacity that was proportional to the fraction of coal in the mix suggests that there is no synergism between the white paint's titanium dioxide and coal for producing additional surface area or adsorption capacity. However, it was found that coal could be added to paint sludge to improve the quality of the resulting char and to reduce ash content.

8. The slopes of the paint-char adsorption isotherms were close to those of the Calgon carbons and were relatively flat (i.e., n is much greater than 1), indicating that the adsorption capacity of a paint-sludge char could be efficiently used even at relatively low concentrations of p-nitrophenol.

9. The adsorption capacity at 100 mg/L of p-nitrophenol was found to increase linearly with surface area.

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Technical assistance and advice provided by Anthony Lizzio of the Illinois State Geological Survey on many aspects of producing and characterizing the chars described herein are gratefully acknowledged. The Illinois Hazardous Waste Research and Information Center (Champaign, IL) and Ford Research Laboratory (Dearborn, MI) provided funds that made this work possible.

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THE TOXICS REDUCTION EVALUATION PROCEDURE IN PENNSYLVANIA AN INDUSTRIAL CASE STUDY

Mr. Charles T. Young* Mr. Ashutosh Gupta Dr. William L. Lowe, Ph.D., P.E., DEE Ms. Judith A. Delconte, P.E.
Roy F. Weston, Inc. 1 Weston Way West Chester, PA 19380-1499

Mr. Thomas J. Wildoner, Jr.
Tobyhanna Army Depot, Attn: SDSTO-EM, Tobyhanna, PA 18466-5086

Mr. David Drucker
U.S. Army Corps of Engineers Baltimore District, Attn: CENAB-EN-HM,
City Crescent Building - 10th Floor, 10 South Howard Street, Baltimore, MD 21201

ABSTRACT

Tobyhanna Army Depot (TOAD) performs numerous industrial operations including plating, photofabrication, and fabrication of electronic equipment. TOAD's NPDES permit required compliance with stringent water quality-based effluent limitations for the wastewater treatment plant effluent for seven heavy metals, cyanide, phenols, and chloroform and the performance of a Toxics Reduction Evaluation (TRE). The TRE study consisted of the review of current operations and wastewater management practices, verification of the sources and extent of the constituents, and the identification and screening of wastewater management and treatment practices necessary to achieve compliance. Extensive wastewater sampling was performed, sources were ranked in terms of their relative contributions, and potentially applicable control measures were identified. This structured approach for identifying contributing sources, wastewater management practices, and treatment technologies provides a framework for industrial dischargers to determine the priorities and costs associated with modifying or adding those treatment processes required to comply with stringent effluent limitations.

Keywords: Wastewater, Heavy Metals, Compliance, Effluent Limits

INTRODUCTION

Tobyhanna Army Depot (TOAD) is a U.S. Army Materiel Command installation located 35 miles east of Wilkes-Barre, Pennsylvania. TOAD performs a variety of industrial operations including plating, photofabrication, depot maintenance, overhaul, rebuilding, modification, repair, inspection, technical assembly, and fabrication support for prototypes for electronic and communication equipment. Process wastewaters from plating and photofabrication operations are pretreated in an Industrial Wastewater Treatment Plant (IWTP). The IWTP uses the soluble sulfide precipitation process to remove the metals from the wastewater. The IWTP effluent combines with other wastewater flows (including domestic wastewaters, other process wastewaters, and boiler blowdown) for further treatment in the wastewater treatment plant (WWTP). Both IWTP and WWTP effluents are regulated by a National Pollutant Discharge Elimination System (NPDES) permit issued by Pennsylvania Department of Environmental

Resources (Pennsylvania DER). The IWTP effluent is monitored as an internal outfall with metal finishing industry categorical effluent limitations for Best Available Technology (BAT) specified at 40 CFR 433. The WWTP effluent is discharged to a small, first order stream, Hummler Run, which is designated "High Quality - Cold Water Fish" by the Commonwealth of Pennsylvania. Beginning 22 August 1994, TOAD was required by the NPDES permit to comply with stringent water quality-based effluent limitations at the WWTP outfall for the following parameters: cadmium, hexavalent chromium, copper, lead, nickel, silver, zinc, free cyanide, phenols, and chloroform. Because the WWTP effluent dominates the stream flow under low flow conditions, minimal instream dilution occurs and, at the relatively low hardness of 40 mg/L (as $CaCO_3$), the WWTP effluent limitations for the divalent metals obtained by Pennsylvania DER's modeling range from 1 μg/L for cadmium to 54 μg/L for nickel. Permit limits are shown in Table I.

TABLE I

MONTHLY AVERAGE EFFLUENT LIMITATIONS (in mg/L)

Parameter	Industrial Wastewater Treatment Plant	Wastewater Treatment Plant
Total Cadmium	0.26	0.001
Total Chromium	1.71	Not detectable by EPA Method 218.4*
Total Copper	2.07	0.003
Total Lead	-	0.006
Total Nickel	2.38	0.054
Total Silver	0.24	Not detectable by EPA Method 272.2
Total Zinc	-	0.022

* Chromium (VI)
- No limitation applied

In order to identify the structural and/or non-structural wastewater management practices necessary to achieve compliance with these effluent limitations, TOAD was required by Pennsylvania DER to conduct a Toxics Reduction Evaluation (TRE). The U.S. Army Corps of Engineers, Baltimore District (USACE), tasked Roy F. Weston, Inc. (WESTON) to perform a TRE study according to the Pennsylvania DER's guidelines for conducting such studies (Pennsylvania DER, 1993). The Commonwealth of Pennsylvania's TRE process differs from the U. S. Environmental Protection Agency's Toxicity Reduction Evaluation procedure which relies on the use of toxicity testing to isolate and identify sources of unknown toxic constituents in wastewater discharges. The Pennsylvania TRE process utilizes chemical tracking methods, among other techniques, to identify sources of selected constituents at a facility for the purpose of minimizing the concentrations of those constituents in effluent discharges and ensuring compliance with water quality-based effluent limitations. The TRE process emphasizes the development of in-plant control and end-of-pipe treatment methods including pollution prevention measures such as source reduction via equipment and/or process modifications, good housekeeping practices, and alternative waste management practices.

METHODOLOGY

The TRE study consisted of four major tasks: (1) Review of current TOAD operations including industrial processes, chemicals and reagents, as well as current waste management practices, (2) verification of the presence of the TRE constituents in TOAD wastestreams, (3) determination of the sources of these constituents, and (4) identification, screening, and evaluation of wastewater management and treatment practices necessary to achieve compliance.

An initial project kick-off meeting was held at TOAD with representatives from WESTON, USACE, TOAD environmental personnel, and foremen from the major industrial shops at the facility. Briefing topics included the importance of successfully conducting the TRE study and implementing corrective actions to attain compliance with the pending discharge limits, project components, and schedule. Specific emphasis was given to reassuring the shop foremen that every effort would be made to minimize interference with production during sampling activities and to enlist the cooperation of their staff in identifying sources of the constituents of concern. This team building initiative was instrumental in obtaining valuable information from shop personnel on potential sources and the operating and maintenance (O&M) procedures affecting wastewater discharges from the various shops.

In order to locate specific sources of the TRE constituents, an extensive review (over 5,000 in number) of the facility's Material Safety Data Sheets (MSDSs) was conducted. The products containing the TRE constituents were identified along with the location of their use at the installation. Complexing agents and surfactants were also identified in the MSDS review due to their ability to sequester metals and potentially interfere with treatment processes. In addition, historical wastewater data and previous engineering reports were reviewed.

Wastewater sampling was performed to verify the extent and determine the sources of TRE constituents in the wastewater collection and treatment system. An additional goal of the sampling program was to assess the effectiveness of the existing treatment units by comparing the influent and effluent concentrations of various TRE constituents. Sampling was performed in two phases. During the first phase, extensive chemical characterization sampling and flow monitoring was performed at wastewater collection/conveyance system and industrial process area locations. Information from existing reports, plans, maps, operating logs, analytical data sheets, MSDSs, and interviews with facility personnel was used to identify and prioritize sampling locations for this phase of the sampling.

Three rounds of sampling were performed during the initial phase at 10 process locations and 20 locations in the wastewater collection/conveyance system. Sampling for the batch processes involved taking grab samples prior to the discharge of the wastewater to the sanitary sewer system. For the continuously discharging processes, all samples were composited over an 8-hour period except for the WWTP samples which were composited over a 24-hour period. Composite sampling was performed using ISCO® (Models 2700 and 2710) automated composite wastewater samplers. The samplers were programmed to acquire a fixed volume of sample at 15 minute intervals over the sampling period. In addition, one round of flow monitoring and confirmatory flow-proportioned sampling was performed at 10 selected locations within the wastewater collection/conveyance system. For the flow measurements, a portable combination weir, manufactured by Thel-Mar Company, was used in conjunction with ISCO® Model 3230 bubbler flow meter. The flow meter converted head to flow by means of a weir

characterization table contained on a Programmable Read-Only Memory (PROM) chip.

Analysis of the Phase I data indicated several previously unidentified sources contributing TRE constituents to the WWTP. These sources were subsequently sampled during the Phase II TRE sampling effort. Unlike the Phase I sampling where all samples were analyzed for the entire range of TRE constituents, samples collected during Phase II were analyzed for selected TRE constituents.based on the Phase I results. In addition, the Phase II sampling included analysis of oil and grease in selected wastestreams for evaluation of the potential treatability of those wastestreams and analysis of sulfide residual and total/soluble metal fractions to evaluate IWTP treatment effectiveness.

All samples were analyzed using the methods specified at 40 CFR Part 136 for the determination of pollutant concentrations in wastewaters. Analytical laboratory quality control and quality assurance (QA/QC) procedures included method blanks, blank spikes, and blank spike duplicates. Field QA/QC samples included rinsate blanks to verify the decontamination procedures used on the sampling equipment, and blind replicate samples.

Upon completion of the Phase I and II sampling efforts, the concentrations of the TRE constituents from each of the identified sources were converted to a mass basis. Although the pending effluent limits are based on the concentration of a constituent in the effluent rather than the total mass discharged over time, the mass contributed by individual sources at the facility influences the concentration in the combined WWTP effluent. Concentrations of the TRE constituents in the WWTP discharge are determined by the mass of a constituent influent to the WWTP, the effectiveness of removal, and the total flow. By evaluating the sources on the basis of mass contribution, the comparative and absolute significance of large, dilute flows and small, concentrated flows with respect to WWTP loading can be estimated. Conversion to a mass basis was performed using mean concentrations of the constituents and known or estimated flows from the individual processes. This allowed the comparison of the contribution from each of the unit processes as a fraction of the total mass of each constituent from identified sources at the facility. A total mass estimate for the TRE metals, based upon mean concentration data from identified sources, does not account for wastestream variability and contributions from other sources. However, this method permitted the known sources to be ranked for purposes of prioritizing control measure implementation. Potentially applicable control measures were identified based on waste characteristics and EPA guidance documents on waste minimization and wastewater treatment systems and technologies (EPA, 1982, 1990, and 1991). Order-of-magnitude capital and annual O&M costs for the control options were estimated. By comparing the costs associated with treating specific wastestreams with their relative loading to the WWTP, priorities for implementing control options can be established by TOAD.

RESULTS

The TRE study identified two principal types of sources for the TRE metals at TOAD: (1) specific industrial sources resulting from particular operations, and (2) systemic sources of certain metals, arising within the water supply/distribution system. Each of these types of sources has the potential to cause violations of the water quality-based effluent limits.

The results of the TRE sampling effort indicated that although the IWTP has historically been able to

meet the metal finishing categorical limits specified at 40 CFR 433, it is still a major contributor of metals to the WWTP. The concentrations of metals in the IWTP effluent are high enough that additional treatment may be necessary to allow the WWTP to meet its pending effluent limits. The IWTP is the largest single source of cadmium, nickel, and zinc and the third largest fraction of lead among all identified sources at the facility. Analytical determination of residual sulfide revealed that concentrations were below the design criterion of 1 mg/L, and that modifications to existing electrode maintenance and calibration practices might provide improved metals removal. In addition to the IWTP effluent, several process wastewaters which are not currently pretreated at the IWTP were found to have the potential to contribute significantly to exceedences of the pending permit limits. For example, the relatively small volume (740 gallons/day) of wastewater from ultrasonics cleaning of metal parts contained high enough cadmium and copper concentrations to potentially cause exceedences without any additional contributions from other sources at TOAD. Average metal concentrations of metals in selected process sources and the relative source ranking by mass contributions are shown in Tables II and III, respectively.

TABLE II

AVERAGE METAL CONCENTRATIONS IN SELECTED SOURCES (in mg/L)

Parameter	IWTP	Photofabrication	Ultrasonics Cleaning	Water Supply	Floor Cleaning	Steam Cleaning
Cadmium	0.399	ND	0.740	ND	0.953	0.504
Chromium (VI)	0.180	ND	0.210	-	-	0.019
Copper	0.285	0.586	2.097	0.109	1.155	0.241
Lead	0.068	0.028	0.889	0.005	5.427	0.444
Nickel	0.422	0.050	0.259	-	0.239	0.181
Silver	0.005	0.083	0.040	-	0.022	0.006
Zinc	0.756	0.360	1.864	0.054	13.120	1.914

TABLE III

RELATIVE MASS CONTRIBUTIONS FROM SELECTED SOURCES

Parameter	IWTP	Photofabrication	Ultrasonics Cleaning	Water Supply	Floor Cleaning	Steam Cleaning
Cadmium	1	ND	2	ND	3	4
Chromium (VI)	1	ND	2	-	-	ND
Copper	3	2	4	1	5	6
Lead	3	2	5	4	1	6
Nickel	1	2	3	-	4	5
Silver	2	1	3	-	4	5
Zinc	1	6	5	2	3	4

- Not analyzed
ND Not detected
Sources ranked from 1 through 6 in order of decreasing mass of the constituent contributed to the wastewater treatment plant

The source ranking also revealed that the primary source of lead discharged to the WWTP is the washwater generated by floor cleaning machines. Although it was anticipated that the floor cleaning discharge would be a minor contributor of metals to the WWTP relative to the other processes identified at the facility, this process was included in the Phase II sampling effort because of the variety of machining, milling, sanding, stripping, and painting operations.

The TRE study also demonstrated the presence of systemic sources of some TRE constituents besides the industrial sources. Sampling and analysis of the drinking and process water indicated that the water distribution system is a significant source of copper and lead to the WWTP. As shown in Figure 1, copper levels upstream of the industrial area (sample point 11E) and in residential areas of the facility where no significant industrial activities exist (sample point 17) show levels of copper above the pending permit limit. In addition, zinc was found systemically in the wastewater collection system (and in subsequent Phase II TRE samples of raw groundwater) at levels which may exceed pending permit limits. The aggressive nature of the water supply may make it difficult for TOAD to meet the water quality-based limitations in the receiving stream. A corrosion control study mandated by the Lead and Copper Rule (40 CFR Part 141) is currently being performed at TOAD. This study is intended to identify methods of controlling copper and lead concentrations to meet human health-based standards. The TRE study concluded that the corrosion control study should be conducted with the additional objective of meeting the pending NPDES limits which are lower than the Safe Drinking Water Act concentration limits.

COURSE OF ACTION

Based on the findings of the TRE study, sources of the TRE constituents in TOAD wastewaters can be classified into two different categories: systemic sources and specific sources. The water supply system is a systemic source of copper, lead, and zinc which are contributed to the WWTP by both domestic and industrial wastewater flows. Based upon available information, this appears to be a result of the aggressive groundwater supply acting upon the distribution system piping. TRE constituents (including, in some cases, copper, lead, and zinc as well as other constituents) are derived from specific industrial process sources (e.g. silver from photographic processing operations; lead from battery maintenance operations). These two categories of sources will require different control methods.

TOAD has developed a planned program to address each of these categories. Key components of this program with examples of specific actions designed to achieve compliance with the pending effluent limits will include:

Systemic Sources

Corrosion control study - Performing the study mandated by 40 CFR Part 141 with the additional objective of minimizing water distribution system contributions of copper and lead.

Industrial Sources

Housekeeping - Modify existing practices including dry sweeping of facility floors to

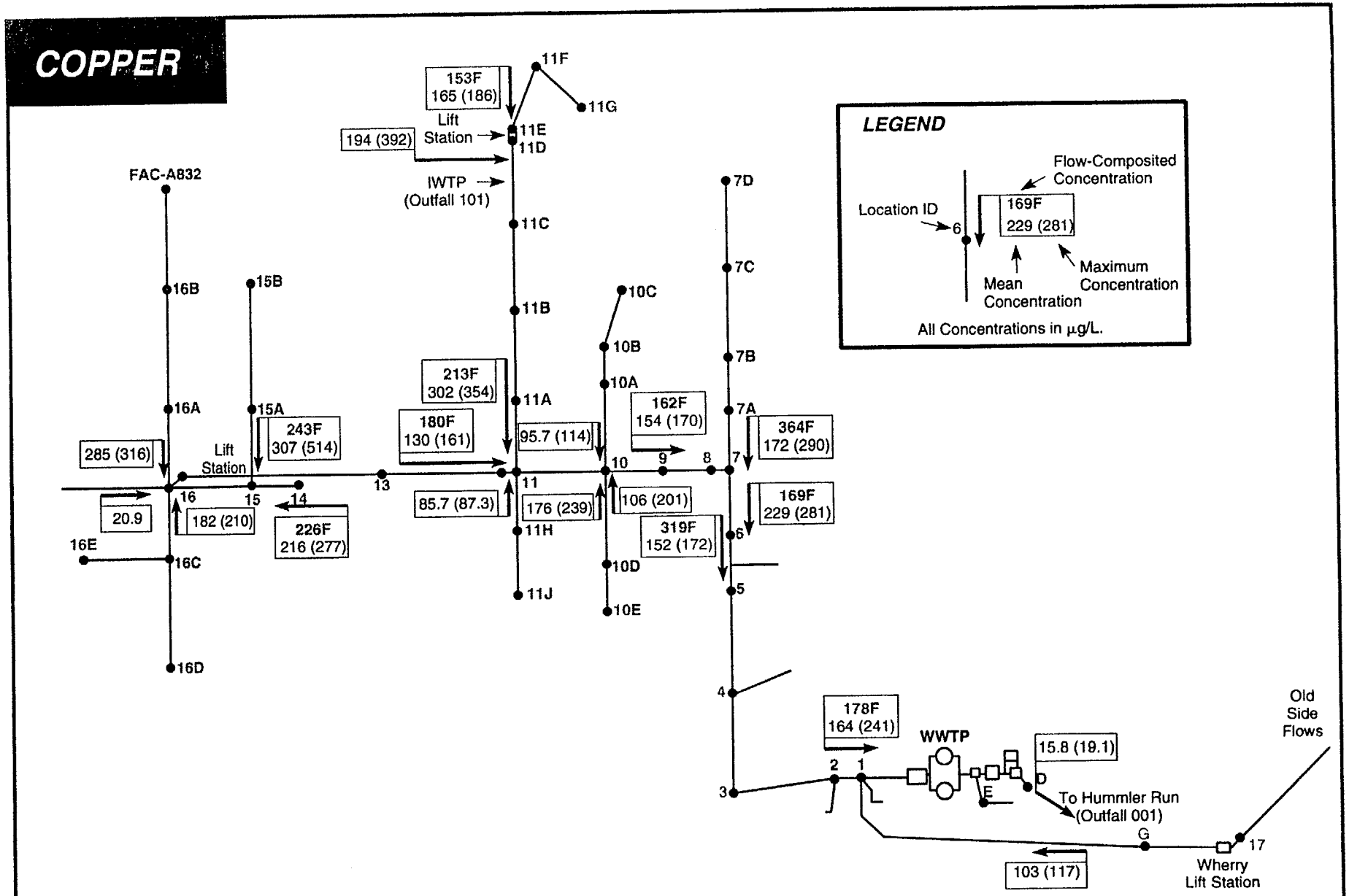

FIGURE 1 WASTEWATER COLLECTION/CONVEYANCE SYSTEM COPPER CONCENTRATIONS

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minimize metals concentrations in floor cleaning washwater.

Process modification - Optimize sulfide addition at the IWTP to maximize metals removal.

Alternate waste management practices - Off-site treatment and disposal of sludge from ultrasonics cleaning operations and spent fixer from photographic operations. Addition of silver recovery units for photographic rinsewaters.

Additional treatability studies - Testing of pretreatment requirements and compatibility of steam and ultrasonic cleaning wastewater treatment at the IWTP.

Additional evaluation of source control needs and methods - Monitoring improvements resulting from the implementation of source controls and identifying additional measures necessary to achieve compliance.

A number of these recommendations are presently being implemented such as silver recovery at the photographic shop and the cessation of unnecessary operations. TOAD will continue to pursue reduction in total levels of these constituents. In addition, the results from the study will be used in the design of an integrated wastewater management system for a proposed new industrial operations facility at TOAD. The potential control options evaluated for the various sources of the TRE constituents at TOAD are shown in Table IV.

TABLE IV

SOURCE EVALUATION AND SCREENING OF CONTROL OPTIONS

Source	Constituent	Fraction of Total[1]	Options
IWTP	Cd	0.79	(1) Reduce usage of complexing agents in plating/photofab processes at source.
	Cr	0.96	(2) Reduce dragout/spillage at source.
	Cu	0.14	(3) Optimization of sulfide addition.
	Pb	0.17	(4) Perform equalization of influent wastewaters.
	Ni	0.81	(5) Ion exchange/Reverse osmosis polishing.
	Ag	0.07	(6) New IWTP.
	Zn	0.36	
Process/Drinking Water	Cu	0.53	(1) Enhance water treatment system to reduce aggressiveness.
	Pb	0.12	
	Zn	0.31	

TABLE IV

SOURCE EVALUATION AND SCREENING OF CONTROL OPTIONS (CONTINUED)

Source	Constituent	Fraction of Total[1]	Options
Floor Cleaning	Cd	0.04	(1) Dry sweep floors prior to washing.
	Cu	<0.01	(2) Segregate dilute and concentrated wastewater.
	Pb	0.31	(3) Contract disposal of washwater.
	Ni	0.01	(4) Discharge to IWTP.
	Ag	<0.01	(5) Discharge to the proposed cold vaporization unit.
	Zn	0.14	
Photofabrication Shop	Cd	<0.01	(1) Discharge to IWTP.
	Cu	0.24	(2) Ion Exchange units to remove copper.
	Pb	0.24	(3) Pretreat feedwater to Photoresist stripping machines.
	Ni	0.06	(4) Install/improve silver recovery unit.
	Ag	0.88	(5) Upgrade spent fixer silver recovery unit.
	Zn	0.01	(6) Fixer solution disposal to commercial recovery firm.
			(7) Install additional inner sump pump.
Ultrasonics Cleaning	Cd	0.06	(1) Airblasting of parts before cleaning.
	Cr	0.04	(2) Dispose of vacuum sludge as hazardous waste.
	Cu	0.04	(3) Discharge to IWTP.
	Pb	0.09	(4) Discharge to the proposed cold vaporization system.
	Ni	0.02	
	Ag	0.02	
	Zn	0.02	
Auto Shop Trench Drain	Cd	0.01	(1) Transfer some cleaning operations to the proposed cold vaporization system.
	Cu	<0.01	(2) Discharge to IWTP.
	Pb	0.03	(3) Discharge to the proposed cold vaporization system.
	Zn	0.03	

TABLE IV

SOURCE EVALUATION AND SCREENING OF CONTROL OPTIONS (CONTINUED)

Source	Constituent	Fraction of Total[1]	Options
Administration Building Photo Shop	Ag	0.02	(1) Upgrade fixer solution silver recovery unit. (2) Silver recovery unit for developer. (3) Fixer solution disposal to commercial recovery firm.
Boiler Plant	Cu	0.02	(1) Influent water treatment. (2) Modification of water treatment system/chemicals at the boiler plant. (3) Blowdown treatment (Ion Exchange).
	Pb	<0.01	
	Zn	<0.01	
Battery Charging Area	Cd	<0.01	(1) Discharge to IWTP. (2) Discharge to the proposed cold vaporization unit.
	Cu	<0.01	
	Pb	0.03	
	Zn	<0.01	
Auto Shop Lead Acid Battery Neutralization	Pb	<0.01	(1) Operation being discontinued.
Power Washing	Cd	0.06	(1) Discharge to IWTP. (2) Discharge to the proposed cold vaporization system.
	Cu	<0.01	
	Pb	0.14	
	Ni	0.07	
	Ag	<0.01	
	Zn	0.06	
Steam Cleaning	Cd	0.03	(1) Discharge to IWTP. (2) Discharge to the proposed cold vaporization system.
	Cu	<0.01	
	Pb	0.04	
	Ni	0.01	
	Ag	<0.01	
	Zn	0.03	
WWTP	TRE Metals	--	(1) Add ion exchange polishing. (2) Add reverse osmosis polishing.

[1] Fraction of total estimated contribution from all identified sources sampled during TRE.

As a consequence of the TRE study, the Pennsylvania DER has granted a time extension to comply with the water quality-based effluent limitations by revoking the existing permit and reissuing a new amended permit which requires that TOAD continue to monitor and report the concentrations of the TRE constituents. This time extension will give the facility an additional two years to implement certain of the above-mentioned control measures and to track improvements in the WWTP effluent quality. Given the number of individual sources of the TRE constituents at TOAD and the uncertainties associated with the extent to which these sources are amenable to treatment, this extension will allow TOAD to remain in compliance with the NPDES permit while performing the necessary treatability studies, implementing appropriate control measures, and evaluating the effects of the modifications to their wastewater management practices on the discharge.

APPLICABILITY OF THE TRE METHODOLOGY

The methodology used in this study for source identification and determination of the significance of the identified sources may be useful at other industrial facilities that are subject to stringent water quality-based numerical effluent limits for particular parameters rather than whole effluent toxicity-based limitations. This structured approach to the identification of contributing sources, wastewater management practices, and treatment technologies provides a framework for determining the priorities and costs associated with modifications, enhancements, and new treatment process additions necessary for achieving compliance. The TRE methodology is especially applicable to industrial dischargers with diverse operations and wastestreams.

ACKNOWLEDGEMENTS

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APPROACHES TO WASTE MINIMIZATION IN THE COMMERCIAL SECTOR

M.F. Dahab, Ph.D., P.E.,
Associate Professor
University of Nebraska-Lincoln, USA

H.C. Johnson
Research Associate
University of Nebraska-Lincoln, USA

Introduction

Waste minimization involves implementing source reduction and/or recycling methods to reduce the amount or toxicity of waste generated, stored, treated, or disposed. Examples of source reduction activities include process modifications, improved housekeeping and management practices, substitution of raw materials, and recycling within a process. Any operational change which decreases or eliminates waste production within a process is a source reduction activity.

A general example of a recyclable waste product is one that can be used as a raw material by a different industry or business, reused in the same type of processing, or reclaimed by treating the waste to remove impurities. Waste products can be recycled both on-site where they were originally generated or off-site.

While a waste minimization program involves a strong commitment on the part of a business or industry in terms of planning, education, and often capital investment, the benefits usually outweigh the costs. Reducing waste production can result in lower disposal and operating costs, as well as decreased liability. Other benefits may include increased worker safety and an improved public image (U.S. EPA, 1987; University of Pittsburgh, 1989; University of Tennessee, 1989).

This paper discusses the results of waste reduction assessments conducted on several types of businesses in Nebraska's commercial sector. The initial project focused exclusively on businesses located in Lincoln, Nebraska. Support received from the U.S. Environmental Protection Agency (EPA) allowed the project to be extended in May 1990 to include establishments in other Nebraska communities.

Waste Minimization Assessments

Generally, a waste minimization assessment has four distinct phases which can be described in the following manner (U.S. EPA, 1988; University of Tennessee, 1989):

1. Phase One involves identifying the major waste streams generated by a business or industry and selecting certain waste streams for further evaluation.

2. During Phase Two, data concerning the chosen waste streams are collected (quantities, cost of disposal, market price, etc.) and several alternative methods of waste reduction are developed and assessed.

3. During Phase Three, the chosen waste reduction alternatives are evaluated as to whether they are technically and economically feasible.

4. Phase Four involves setting priorities among waste reduction alternatives as to their technical and economical feasibility and developing a plan for implementation.

Both the Lincoln and the U.S. EPA-funded programs concentrated on the completion of the first three phases of waste minimization assessments. During both projects, assessments were conducted on businesses which volunteered to participate and were not required to implement any of the waste minimization recommendations (Dahab and Andersen, 1991). Phase Four was deemed beyond the scope of both projects due to time limitations.

Assessment Categories

During the Lincoln Project, ten types of businesses were audited. The establishments were chosen to represent a cross-section of the business activities occurring in Lincoln. These businesses were:

1. Wholesale Outlet with Fleet Service.
2. Manufacturing Facility (Non-food items).
3. Office Complex.
4. Snack Food Processor.
5. Educational Facility.
6. Printing and Photography Business.
7. Small Quantity Hazardous Waste Generator (Pharmaceuticals).
8. Hotel with Restaurant Facilities.
9. Discount Department Store.
10. Health Care Facility.

While the Lincoln Project concentrated on business activities in a large community, the EPA assessment categories were chosen to emphasize the rural nature of the state. The assessment categories reflect the types of businesses which can be found in small communities with limited access to recycling markets and waste minimization technical assistance. These assessment categories include:

1. Farm Co-ops.
2. Food Processors.
3. Office Complexes.
4. Pesticide Applicators.
5. Retail Establishments.
   a. Department Stores.
   b. Drug Stores.
   c. Grocery Stores.
   d. Restaurants.
6. Small Quantity Generators.
   a. Dry Cleaning Establishments.

b. Metal Plating Facilities.
c. Photography and Printing Facilities.
d. Vehicle Maintenance Facilities.

7. Trucking Companies.

To date, assessments have been performed on nearly all types of these businesses. Additional assessments will be completed during the remainder of the project.

Research Goals and Objectives

While the Lincoln Project was aimed at increasing environmental awareness among its participants, the EPA Project is aimed at achieving a significant reduction in the amount of waste produced by Nebraska's commercial sector. The Lincoln Project's main objectives included (Dahab, et al., 1990):

1. Demonstrating that waste minimization assessments are effective and easily conducted,

2. Demonstrating that waste reduction programs can benefit an establishment by reducing waste disposal costs, and

3. Extending the useful life of the Lincoln Landfill.

The EPA project objectives were more focussed on obtaining data that could be used to establish a waste minimization technical assistance program in Nebraska. Because many of the business categories have not been studied extensively, little is known about the types of waste generated and the barriers which might exist in implementing waste minimization methods. The EPA Project's principal objectives are:

1. Identification of waste streams and releases produced by specific types of businesses,

2. Development of multimedia-oriented recycling and source reduction methods, and

3. Development of methods for measuring progress towards pollution prevention, among others.

Example Case Studies: The Lincoln Project

The following examples summarize the results of assessments conducted on three Lincoln businesses. While it was estimated that these businesses were already recycling or reusing 25 - 70% of their waste streams, several recommendations were made that could possibly reduce waste production further (Dahab and Andersen, 1991).

<u>1. Discount Department Store</u>

This establishment is part of a nation-wide chain of discount department stores. At the time

of the assessment, the store had already formed a pollution prevention task force, and was recycling or reusing about 70% of the waste generated. The store was divided into four departments (administrative services, shipping and receiving, merchandise display area, and the snack bar) for the purpose of identifying waste streams.

The store was recycling corrugated cardboard, aluminum beverage containers, high-grade office paper, computer paper and used cooking oil. Items which were reused included packing materials and non-returnable clothing (i.e., given to charitable organizations). It was determined that most of the facility's landfilled waste consisted of packaging materials and food waste (Dahab and Andersen, 1991).

Most of the specific information requested by the assessment team was estimated while touring the facility since most waste quantities were not known. Several recommendations were made to improve the store's waste minimization program. These recommendations included (Dahab and Andersen, 1991):

1. Using permanent dinnerware in the snack bar to replace polystyrene, plastic, and paper containers.

2. Increasing the amount of cardboard recycled by the store. Significant quantities of cardboard were observed in the waste container during the assessment. It was recommended that salvaging procedures be reviewed regularly.

3. Minimizing paper waste by using both sides and posting employee memos in a central location.

4. Minimizing packaging waste by purchasing items which are packaged using recycled or recyclable materials and which are not excessively wrapped.

5. Choosing an employee to be the pollution prevention coordinator as part of his/her regular responsibilities.

2. Manufacturing Facility

This facility manufactures water quality monitoring equipment and employs approximately 215 people. It was estimated by the management that 65% of the total waste stream was recycled at the time of the assessment. The company was divided into six departments (administrative services, shipping and receiving, offices, engineering, production and customer service, and the cafeteria) for the purpose of identifying waste streams generated by each area.

The company was recycling some computer paper, acrylonitrile-butadiene-styrene (ABS), polypropylene (PP), stainless steel, ferrous metal, brass, and corrugated cardboard. Used solvent was also collected and distilled using on-site distillation equipment. It was determined that most of the company's landfilled waste consisted of paper, non-returnable containers, packaging materials, and food scraps.

Several of the recommendations made to the company were similar to the ones listed previously. This included recommendations concerning the minimization of paper and packaging waste, the appointment of a pollution prevention coordinator, and the use of permanent dinnerware. Other recommendations included providing a desk-side paper receptacle for employees who generate considerable amounts of waste paper, using reusable shop towels instead of disposable paper ones, and purchasing non-aerosol cleaning and lubrication products (Dahab and Andersen, 1991).

3. Snack Food Processor

This company manufacturers snack foods made primarily from popped corn and employs approximately 110 people. At the time of the assessment, the management estimated that 25% of the waste generated was recycled. The company was divided into four departments (administrative services, product manufacturing/packaging, shipping and receiving, and the break-room area) for the purpose of identifying waste streams generated by each area.

Prior to the assessment, the company was recycling some corrugated cardboard, polystyrene packing materials, aluminum cans, and some computer paper. The company also collected edible waste food product for use as animal feed and used an adhesive to reduce the amount of stretch wrap needed to package products for transportation. Most of the company's landfilled waste consisted of packaging materials, cardboard, and contaminated product.

The recommendations made to this company also included appointing a pollution prevention coordinator, procuring items with minimal or recyclable packaging, minimizing paper waste, and using permanent beverage containers. Other recommendations specific to this business included increasing the amount of waste product sold as animal feed by improving housekeeping and processing operations and increasing the amount of cardboard recycled. It was observed that significant amounts of recyclable materials were being discarded for landfilling in the compactor container (Dahab and Andersen, 1991).

Business Category Results: The EPA Project

To date, assessments on three business categories (drugstores, grocery stores, and vehicle maintenance facilities) have been completed and the final recommendations submitted to the participating businesses. During the assessments, quantities of wastes were determined by collecting samples for sorting and weighing when possible and by contacting refuse services and recycling organizations.

1. Drugstores

There were two drugstores which volunteered to participate in this project. One store was located in a community with a population of less than 5,000, and the other in Lincoln. Both stores generated low quantities of waste on a weekly basis (i.e., four to five cubic yards per week) and had difficulty in implementing recycling programs due to the small quantities of recyclables produced and lack of markets for the materials.

The drugstores reused polystyrene packing materials and small cardboard boxes for wrapping gifts and used both sides of computer paper before discarding it. The only type of recycled waste was aluminum beverage containers generated by employees at the store. Other types of recyclable waste which were identified included corrugated cardboard, glass and plastic medication bottles, and computer paper. One recommendation made to the stores was to use permanent coffee mugs instead of disposable polystyrene or paper cups. Recycling the small quantities of items generated was not found to be cost-effective for the stores due to the cost of hauling materials to a recycling center and the lack of markets in the smaller community. The low cost of landfilling waste did not encourage waste minimization.

2. Grocery Stores

There were five grocery stores that participated in this project. Four of the stores were located in Lincoln and one in a community with a population of less than 7,500. The sizes of the stores varied widely with the square footage ranging from 17,000 to 70,000 square feet. The services offered to customers also differed as two of the stores were of the warehouse-type which offered discounted prices, but fewer customer services (e.g., sacking merchandise and hauling groceries to vehicles).

Corrugated cardboard was found to be the largest waste stream generated and the most cost-effective material to recycle. Analysis of the assessment data suggested that typically cardboard makes up 50% to 70% of the total waste stream. In all cases, balers or compactor containers were needed to prepare cardboard for recycling. Table I illustrates the payback periods for balers (Grocery Stores A, B, and C) and compactor containers (Grocery Stores D and E) used to collect cardboard. Grocery Store A received approximately $18 per ton for baled cardboard while the other stores received $10 per ton.

Table I. Payback Period for Cardboard Recycling Equipment.

Grocery Store	Income from Cardboard Sales ($/year)	Savings on Disposal Services ($/year)	Capital Investment	Equipment Payback Period
A	$4,450	Unknown	$4,000	< 1 year
B	$ 650	$5,400	$3,000	6 Months
C	$1,050	$3,000-$5,000	Unknown	Unknown
D*	$2,200	$1,750	$15,000	3.8 Years
E	$5,450	$4,400	$16,500	1.7 Years

* Values are based on estimates if cardboard recycling was implemented.

Grocery Store D does not currently recycle cardboard so the payback period was calculated using information received from local recycling organizations, refuse services, and equipment dealers. The capital investment for Grocery Store D reflects an average cost of a 42-cubic yard compactor container since the management had previously expressed interest in purchasing one for

the separation of paper waste. As shown in the Table, all of the payback periods were less than four years. The payback period for Grocery Store C was unknown since cardboard had been baled for 17 years and the price of the baler was unavailable. According to EPA, a three- to four-year payback period is usually considered acceptable for low-risk investments (U.S. EPA, 1988). The results of the analyses indicate that cardboard recycling is justified based on economic considerations as well as environmental concerns.

Other items which were recycled or reused by one or more of the project participants included meat trimmings, newspapers, used cooking oil, office and computer paper, plastic films and grocery sacks, aluminum beverage containers, and wooden pallets. Several items were also donated to charitable organizations or sold at a reduced cost to customers to minimize waste. These items included edible damaged products, day-old bakery items, and substandard produce.

Source reduction methods were often difficult to implement since the amount of waste generated depended on the methods used by suppliers when packaging products. The warehouse-type stores generated greater amounts of waste when comparing the number of square feet used for selling space since they tended to sell higher volumes of products. Many of the source reduction methods which were identified relied on the customer reusing an item or the manufacturer reducing the amount of packaging on a product. The identified methods included customers reusing paper grocery sacks and refilling plastic containers with juice and water. Stores also were able to decrease waste by using both sides of office and computer paper, reusing waxed paper to line baking pans, reusing plastic bags to cover baked goods, and by eliminating paper towel waste with the use of cloth roll hand towels.

Based on the assessments performed on grocery stores, the participating stores recycled as much waste as was possible. Cardboard was the only recyclable material generated that would significantly reduce the amount of landfilled waste if removed from the waste stream, as well as lower disposal costs. The majority of the landfilled waste consisted of non-recyclable packaging materials (e.g.,stretch wrap, soiled plastic films, waxed cardboard, wooden crates, polystyrene meat trays, aluminum foil) and organic waste (e.g., vegetable peelings, spoiled produce, fish).

Other recommendations that were made by the assessment team included purchasing products with minimal or recyclable packaging, and purchasing products for in-store use in concentrated forms or reusable containers.

3. Vehicle Maintenance Facilities

There were three automobile dealerships that volunteered to participate in the Project. All three facilities were located in Omaha, Nebraska. As shown in Table II, the number of maintenance bays and employees varied. Two of the establishments had auto body repair and painting departments.

Extensive data were collected at each of the dealerships regarding quantities of raw materials purchased and discarded each month. Used solvent, carburetor cleaner, used petroleum-based fluids, and batteries were picked up by companies for recycling. Aqueous detergent, spent antifreeze, and radiator flush were typically diluted and disposed of to the sanitary sewer since they

are compatible with the local wastewater treatment system.

Table II. Number of employees, general maintenance bays, and vehicles serviced by project participants.

Automobile Dealership	Number of Employees	Number of General Maintenance Bays	Number of Vehicles Serviced (1990)
A	8	5	4,691
B	11	26	13,590
C	20	28	9,600

Several waste minimization methods currently being used were identified during the assessments. These methods included:

1. Using a high-pressure transport system to control the amount of engine oil, transmission fluid, and lubricant grease released and to minimize dripping,

2. Recycling freon on-site using distillation equipment,

3. Segregating scrap metals for recycling through a local firm,

4. Reusing absorbent several times before disposal, and

5. Using brake cleaning equipment to minimize the loss of solvent to the environment instead of spraying parts with solvent in an aerosol form.

In order to determine the types of waste which were discarded, the contents of two trash receptacles were randomly collected from each automobile dealership. The contents of each of the six receptacles were sorted into four groups (cardboard/paper, metals, plastics, and non-recyclables) and weighed. The results of the waste classification activity are shown in Table III.

Table III. Composition of solid waste at vehicle maintenance facilities.

Auto Dealer	Metals (%)		Plastics (%)		Cardboard & Paper (%)		Non-recyclables (%)	
	1	2	1	2	1	2	1	2
A	37	2	13	23	17	6	33	69
B	44	61	21	2	13	13	22	24
C	26	34	15	16	15	7	44	43

As shown by the non-recyclable column in Table III, over 50% of the solid waste collected was classified as recyclable. As a result of this study, the feasibility of implementing a recycling

program at such repair facilities currently is being examined.

Discussion

The approaches used by the participating businesses to minimize waste were dependent on whether they were a retail establishment, a manufacturer, or a service-oriented business. The retail establishments (department store, grocery stores, and drugstores) needed to focus on recycling opportunities since they had no control over the methods of packaging used by manufacturers. Most of the stores' waste was generated while shelves were being restocked.

While manufacturers also recycled several items, they appeared to be more concerned with increasing the efficiency of operations and decreasing the amount of packaging used on products (i.e., source reduction methods). The service-oriented businesses, such as automobile dealerships, also needed to focus more on source reduction methods since they could control the amount of products used when repairing or maintaining vehicles.

Most of the participating businesses had implemented several waste minimization methods prior to the assessments. Because of this fact, some problems were experienced when attempting to obtain information regarding waste quantities and market prices for recyclables. There are several reasons behind the unavailability of this data. They include:

1. Management did not want to release information concerning the revenue generated and/or spend the time obtaining the information.

2. Managers were sometimes preoccupied with business matters and were unable to devote sufficient time to the study.

3. Because prices paid to businesses for recyclable materials often varied depending on quality and quantity, the recycling centers were reluctant to release specific information.

4. Managers were reluctant to involve employees in the study although they were not aware of the amount of waste generated in a particular area of an establishment. In some cases, the assistant managers were not informed that the establishment was participating in the project.

It is important that businesses involve their employees in the assessment process since they are generally more familiar with day-to-day operations than the management. During site visits by University personnel to various businesses, managers often answered the majority of questions without consulting employees. Information which could not be supplied during the meeting was typically provided at a later date (i.e., after the management had consulted employees) or not at all if the manager had other responsibilities at that time. Assessments were completed in a shorter time period and more detailed information was obtained when managers allowed the Assessment Team to confer with personnel in their respective departments. Due to the lack of employee involvement and insufficient information, the economic evaluation of recommendations was often hindered or prevented.

Conclusions

Based on the information presented above, several conclusions can be made about the value of waste minimization in the commercial sector and the different ways businesses approach the subject. These include:

1. Significant quantities of recyclable materials are generated by the commercial sector. Actual reductions in the amount of waste landfilled were often limited by the markets for materials in the community.

2. Due to low landfilling costs and waste generation rates, some establishments (such as drugstores) may not benefit greatly from a recycling program.

3. While most of the participating businesses could achieve a significant reduction in landfilled waste by segregating and recycling particular types of materials, it was often more difficult to implement source reduction methods. This was particularly true for the retail establishments (grocery stores, drugstores, and department stores) that cannot control the amount or types of packaging materials used by manufacturers.

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