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Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Industrial Audit Background Paper:

Brewery Industry

Harza Environmental Services, Inc.

The Technical Assistance Team Includes:

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Science Applications International Corp.
Harza Environmental Services, Inc.
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PREFACE/ACKNOWLEDGMENTS

This report presents the background materials for Brewery Industry prepared with emphasis on the pollution prevention/waste minimization (PP/WM) and water conservation practices for this industry. The report was prepared by Mr. Krishna Mayenkar, P.E. of Harza Consulting Engineers and Scientists (Harza), Chicago, Illinois, under subcontract with Development Alternatives, Inc. (DAI), Washington, D.C.

Efforts for preparation of this report was directed by Dr. Shawn R. Niaki, P.E., Pollution Prevention Program Director, of Harza; coordination with Dr. Usama Mudallal, Environmental Director, of the Amman Chamber of Industry (Chamber); and the member of the PP/WM Committee from the Ministry of Water and Irrigation (MWI) staff, Eng. Rania Khaleq, and the Water Authority of Jordan (WAJ) staff including Eng. Abdul Wahab Matar, Eng. Marwan Al-Tal, Eng. Nabeel Hejazeen, and Eng. Mohamad Lafi.

Special appreciation is given to Dr. Mohammed Bani Hani, Secretary General of MWI; Eng. Koussai Qutieshat, Secretary General of WAJ; Mr. Khaldun Abuhassan, Chairman of the Chamber; Mr. Walid Al-Khatib, Director General of the Chamber; Dr. Muwaffaq Saqqar, Project Coordinator; and to DAI, as represented by Edwin D. Stains, Chief of Party; for their cooperation and confidence.

BREWERY INDUSTRY
BACKGROUND MATERIALS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION PROGRAM
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

FIGURES

1.0 INTRODUCTION

This document presents the materials collected as background information for a pollution prevention, waste minimization, and water conservation audit of the Arab Brewery Company, Limited (ABC).

1.1 Background

Development Alternatives, Inc. (DAI), under a contract with the United States Agency for International Development (USAID) is performing an Industrial Wastewater Discharge Prevention Program (IWDPP) in Amman, Jordan. The IWDPP is one of the four components of the Water Quality Improvement and Conservation project, funded by the USAID. The IWDPP is being performed by DAI with full coordination between the Ministry of Water and Irrigation and the Amman Chamber of Industry. The IWDPP includes conducting audits, performing feasibility studies, and designing for demonstration activities at selected industrial facilities.

Pollution prevention and waste minimization (PP/WM) techniques are defined as any techniques to prevent or reduce waste generation by source reduction or recycling activities. These activities must reduce either the volumes or the concentrations of pollutants generated prior to treatment, storage, or disposal of the waste.

Based on a ranking methodology, the PP/WM Committee has selected ten industries with potential needs for PP/WM audits. One of these industries is the "brewery industry." Harza Consulting Engineers and Scientists (Harza), Chicago/USA, has been retained by DAI to lead the PP/WM audit for this industry.

The purpose of these audits is to assist the industries in the Amman-Zarqa Basin to assess pollution problems and the alternative solutions to achieve desired levels of pollution prevention, water conservation, and wastewater treatment under the following subtasks:

- Subtask 1.1 - Audit Coordination;
- Subtask 1.2 - PP/WM Background Materials Preparation;
- Subtask 1.3 - Pre-Investigation Meeting;
- Subtask 1.4 - Audit;
- Subtask 1.5 - Post-Inspection Meeting; and
- Subtask 1.6 - Audit Evaluation Report.

1.2 Objectives

In this document, background information has been assembled by performing a comprehensive literature review. The purpose of the literature review was to identify the available techniques and clean technologies being practiced for water conservation and PP/WM in the brewing industry. The literature review included PP/WM related articles, industry journal articles and conference proceedings, and books on pollution and controls.

Section 2.0 of this report provides an overview of the brewing industry, including a description of typical brewing processes and the wastes generated by them. Section 3.0 details the brewing processes used at the ABC. Section 4.0 describes areas for potential improvement in regards to PP/WM and water conservation. Finally, Section 5.0 lists the primary references consulted during the literature search: copies of the appropriate sections of these references are provided under a separate cover.

2.0 INDUSTRIAL OVERVIEW

Beer is a beverage of low alcoholic content (2-7%) made by the fermentation of starchy grain cereals. Beer production is typically a batch process; it begins with the cooking and brewing of grains in water, continues with fermentation and maturing of the beer, and concludes with packaging of the beer for distribution.

Large amounts of water are used in brewery processes and operations, and large amounts of solid waste and wastewaters are generated. Wastewaters are perhaps the most notorious waste from a brewery, containing very high concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS). Such contaminants, highly concentrated and released in intermittent discharges, can cause disruptive shock loadings at municipal or on-site biological treatment facilities. Solid wastes mostly consist of spent grains and yeasts: these materials have a high nutritional value and can be used as livestock feed. Air emissions are also produced at breweries, but generally are not significant and do not require emission controls except in areas with strict air quality regulations.

This section provides a description of typical brewery processes, water usages, and wastes and emissions.

2.1 Typical Processes

Beer production can be divided into four groups of processes and operations. The first three groups include the principal stages of beer production: brewhouse processes, fermentation and conditioning processes, and packaging processes. The fourth group consists of ancillary, or support, operations performed throughout the brewing facility. The four groups are described in the following subsections. A typical process diagram for beer production is provided as Figure 1.

2.1.1 Brewhouse Processes

The brewhouse is where raw materials (water, grain, malt, sugars, syrups, and hops) are transformed into unfermented beer, also called wort. The processes required for the transformation are: milling, cooking, mashing, filtration, brewing, and cooling. Each of the listed brewhouse processes is described below.

Milling. Milling reduces the particle sizes of the grain and malt to a specified gradation. The grain used is an ungerminated cereal, such as corn, oats, or rice. The malt used is a kilned, germinated cereal; typically barley. Malt is often purchased by a brewery as a kilned, germinated product; some breweries, however, produce their own malt in a steeping and germination process that requires large amounts of water.

Cooking. In this process, the milled grain is mixed with water and treated with live steam or hot water in a grain cooker to solubilize the cereal starches. Milled malt may be added to the grain cooker to prevent the mixture from becoming too viscous. The mixture is cooked for approximately ten minutes.

Mashing. After cooking, the grain mixture is introduced into mashing tubs, or tuns. There, the grain is combined with the rest of the milled malt and with malt adjuncts (cooked grain, sugars, and syrups) to be converted into a semi-liquid mixture; the product is called mash. The conversion from the grain/malt mixture to mash is accomplished by enzymes introduced by the milled malt: the enzymes convert the starches in the grain/malt mixture into dextrin and sugars. The tuns are heated to 75°C and the mixture is stirred to aid the softening and separating of the digestion process. Mashing continues until conversion ceases.

Mash Filtering. The mash is subsequently filtered to separate the insoluble spent grain from the mash liquid, which will be used directly in the beer brewing process. Filtration is accomplished in either a filter press or a lauter tun: filter presses typically occupy less space and achieve better separation than lauter tuns, which are simply false bottom vats. The filtrate is a slightly sweet liquid called wort; the spent grains have resale value, typically as cattle feed. The efficiency of the filtration process can be improved by sparging the spent grain with water at 75°C for complete recovery of all substances in solution.

Brewing. The filtered wort is boiled in a brew kettle for approximately three hours. After the first hour, hops are added to impart beer's characteristic aroma and bitter flavor (hops are dried flower cones from hop plants). Boiling not only extracts the hops' tannin and aroma, but also concentrates the wort to the desired strength, sterilizes it, destroys its enzymes, and coagulates its proteins.

After three hours of brewing, the mixture is transferred to a false-bottomed vessel, called a hop jack, beneath the brew kettle; there, the spent hops are strained from the boiling wort. As in mash filtration, spent hops can be sparged with hot water prior to disposal to recover additional wort.

Cooling. The boiled wort is passed through cooling vessels for two purposes: to cool, thus causing the protein and hop solids to precipitate, and to absorb enough air to facilitate the start of fermentation. The hot wort is first cooled to approximately 65°C in a large, shallow vessel. Some of the resins precipitate in this cooler and form a sludge-like sediment called trub. Trub is often discharged as waste, or is sometimes mixed with spent grain and sold as cattle feed.

The wort is further cooled by running it over horizontal, brine-cooled tubes or through a shell and tube heat exchanger. Wort aeration takes place during this second cooling stage, as well as a slight wort concentration due to evaporation. The air contacting the wort during this stage is carefully controlled and frequently sterilized to prevent contamination by wild yeasts.

2.1.2 Fermenting and Conditioning Processes

Fermenting and conditioning processes include those processes in which wort is fermented and aged to produce a beer product ready for bottling or kegging. These processes typically include starting, fermenting, storing, and filtering and carbonating.

Each of these is described below.

Starting. The starting process is the one in which wort fermentation is initiated: the cooled wort is mixed with selected yeasts, then placed in open-air tubs to begin fermenting.

Fermenting. After starting, the wort/yeast mixture is transferred to closed fermentation tanks, or fermentors. Fermentation transforms the sugars in the wort to carbon dioxide and ethyl alcohol. Heat is released in the process: the initial fermentation temperature is approximately 5 °C, but as fermentation proceeds the temperature rises to 15°C. The temperature is controlled by attemperators inserted in the fermentors.

The carbon dioxide rises to the top of the fermentors, bringing with it foreign substances, which are skimmed. In most larger breweries, the released carbon dioxide is collected and is stored under pressure for subsequent use in the beer carbonation process. Excess carbon dioxide can also be liquified and marketed to other industries.

Fermentation is complete after seven to ten days. At this point, most of the yeast has settled to the bottom of the fermentor; settled yeast is removed as a slurry and sent to yeast tanks for recycling and/or sale. The remaining liquid is unmatured beer.

Storing. The beer is allowed to mature, or lager, after fermentation; it is cooled to 0°C and stored in tanks for three to six weeks. The maturation process mellows the beer, that is, improves its palatability.

Initially, the beer contains a suspension of hop resins, insoluble nitrogenous substances, and yeast. During storage, however, the beer is gradually clarified. A haze may appear in the beer upon cooling; the haze can reduced by "chillproofing" the beer with chemical additives, such as polyvinylpyrrolidone.

Filtering and Carbonating. After storage, the beer is filtered and carbonated. To filter it, the beer is pumped through a pulp filter with or without a filtering aid. Carbon dioxide gas at 0°C is then injected into the beer in amounts between 0.36% and 0.45% of the weight of the beer. After carbonation, the beer is sometimes re-filtered through cotton pulp, while maintaining carbonation, to increase the brilliance of the flavor.

2.1.3 Packaging Processes

Packaging includes the processes by which the final beer product is placed in bottles, cans, or kegs. The packaging operations typically include container washing, container filling, and product pasteurizing. Each of these processes is described below for the case of bottle packaging; the packaging operations for cans and kegs are similar.

Bottle Washing. Bottle washing requires a large amount of water and creates a significant waste load. Automatic machines are available for bottle washing; the machines typically perform the following operations:

- Feed the bottles to the washing equipment;
- Pre-rinse the bottles;
- Immerse the bottles in a series of alkaline baths for washing and sterilization; the alkaline solution is typically a water and caustic soda or caustic and sodium gluconate mixture; and
- Post-rinse the bottles.

Bottle Filling. A conveyor line takes the washed bottles to a filling machine. The bottles are manually inspected to remove the defective ones before an automatic machine fills and caps the usable bottles.

Pasteurizing. Beer is pasteurized to prevent any residual yeast or harmful bacteria from developing in the packaged beer prior to consumption. Pasteurization is typically required only for bottled and canned beer; kegged beer is usually refrigerated and therefore does not require pasteurization.

Pasteurization requires heating beer to 60°C. Pasteurization is commonly performed after packaging by immersing the bottled beer in gradually hotter warm-water baths; gradual heating is required to avoid cracking the glass bottles. Pasteurization can alternatively be performed prior to packaging by "flash pasteurization": flash pasteurization is a continuous heat exchange process by which the beer is rapidly brought to at least 60°C and then cooled.

An equally effective alternative to pasteurization is biological purification by membrane filtration. This technique, also called ultrafiltration, produces so-called "bottled draft beer." Several other new procedures, including the addition of antimicrobials, produce the same effect.

2.1.4 Ancillary Operations

As stated previously in Section 2.1, ancillary brewery operations are support processes and activities carried out throughout the brewing facility. Ancillary operations include equipment cleaning and sterilizing, steam and hot water production, cooling, housekeeping, and wastewater treatment. These operations are described below.

Equipment Cleaning and Sterilizing. All equipment that comes into contact with the product must be cleaned and sterilized. Cleaning is typically performed by a mechanical cleaning-in-place (CIP) system built into the process equipment. Conceptually, a CIP system is a system in which a detergent is introduced at the top of an unclean tank by means of a fixed spray ball or a rotating gun, circulated for some time in the tank, and then discharged. Alkaline detergents, such as sodium hydroxide, are commonly used in large breweries; smaller breweries often use "built" detergents, which contain a strong alkaline agent, a wetting agent, dispersing agent, rinsing agent, and possibly a sequestering agent. "Built" detergents are more expensive, but are safer to handle than sodium hydroxide.

After being cleaned, the equipment is sterilized by use of wet heat (hot water or steam) or a sanitizing agent. Though more expensive than sanitizing agents, wet heat is a convenient sterilization method since it is safe to the product. In order for wet heat to be effective, the temperature of the surface to be sanitized must be raised to 80°C: this heating requires nearly 100°C water or steam.

Chlorine, because it is effective and inexpensive, is a commonly used sanitizing agent. The effective form of chlorine is hypochlorous acid, which is most bactericidal between pH 4 to 6. Most brewers use chlorine at pH 8: though less effective as a bactericide, it is less corrosive to stainless steel at the higher pH. Alternative sanitizing agents are quats, iodophors, and acid-ionics.

Steam and Hot Water Production. Steam and hot water are required for a number of brewery processes, including cooking, mashing, sparging, pasteurizing, and cleaning and sterilization. Steam and hot water are typically produced using a boiler, which may be fired from sources including oil, coal, or natural gas.

Cooling. Cooling is required to reduce the temperature of the wort after brewing, to control the temperature in the fermentors, and to cool the beer prior to storage. A typical cooling system consists of a water circuit including heat exchangers, cooling towers, and a make-up water connection to a water source.

Housekeeping. Floor, wall, and equipment are typically washed with hot water and degreasing agents.

Wastewater Treatment. Brewery effluent contains very high concentrations of SS, BOD, and phosphates, and therefore untreated effluent typically should not be discharged to a body of water. Most breweries in metropolitan areas can discharge their effluent to municipal wastewater collection and treatment systems: in areas without municipal systems or in cases where it is economically feasible, on-site treatment systems can be used.

Municipal treatment systems typically employ conventional biological processes, such as activated sludge. On-site treatment systems are more likely than municipal systems to employ anaerobic treatment processes; a number of anaerobic systems are effective for treating brewery wastewaters. Further discussion of wastewater treatment systems is provided in Section 4.0.

2.2 Water Usage

Though water is used either directly or indirectly in all four groups of brewery processes, the greatest volumes of water are used in the brewhouse, packaging, and ancillary operations. A brief description of water usage is provided below for each of those processes.

2.2.1 Brewhouse Process Water

All six brewhouse processes consume water: milling, cooking, mashing, mash filtering (including grain sparging), brewing (including hops sparging), and cooling.

Of these processes, hot water and/or steam is required for:

- Cooking;
- Mashing;
- Mash Filtering; and
- Brewing.

Cold or unheated water is required for:

- Milling;
- Mashing
- Mash Filtering; and
- Cooling.

2.2.2 Packaging Water

Within the packaging process, water is used for container rinsing, washing and sterilization, and product pasteurization.

2.2.3 Ancillary Operations

Ancillary operations consume water primarily as boiler feed water, cooling system water, and equipment cleaning and sterilizing water. Water is also used for general housekeeping and sanitation.

2.3 Wastes and Emissions

The following subsections list the wastewaters, solid wastes, and air emissions generated at a typical brewery, along with their primary sources. Methods of waste treatment and disposal are discussed in Section 4.0.

2.3.1 Wastewater

As stated in Section 2.0, wastewaters are typically the waste of greatest concern in a brewery: approximately 8.5 cubic meters are produced for every cubic meter of beer produced (m^3/m^3 beer). The wastewaters typically have very high BOD, COD, SS. Wastewater is generated primarily in the following processes; typical volumes are given when known:

- Brewing (1.20 m^3/m^3 beer);
- Cooling (1.40 m^3/m^3 beer);
- Fermenting (0.30 m^3/m^3 beer);

- Filtering (0.70 m^3/m^3 beer);
- Storing (0.40 m^3/m^3 beer);
- Packaging; and
- Housekeeping (0.70 m^3/m^3 beer).

Typical wastewater BOD and SS strengths are as follows:

Source	BOD_5 (mg/l)	SS (mg/l)
Trub (from Cooling)	50,000	28,000
Miscellaneous Filtrate	15,000	20,000
Filtered Yeast	150,000	800
Clarification Precipitates (from Storing)	60,000	100
Tank Rinsate	200-7,000	100-2,000
Cleaning Solutions	1,000	100
Waste Beer	90,000	4,000

Typical wastewater contaminants are as follows:

Contaminant	BOD_5 (kg/m3 beer)	BOD_5 (%)	SS (kg/m3 beer)	SS (%)
Yeast	3.71	30	2.55	30
Trub	3.21	26	1.24	14
Hops	0.39	3	0.77	9
Grain Filtrate	0.85	7	0.50	6
Drain & Rinse Effluent	2.09	17	0.85	10
Final Filter Effluent	0.50	4	1.58	19
Packaging	1.2	10	0.66	8
Miscellaneous	0.42	3	0.35	4
TOTAL	12.4	100	8.50	100

2.3.2 Solid Wastes and Sludges

The main sources of brewery solid wastes and sludges are the following:

- Spent grains from the mash filter;
- Spent hops from the hop jack;
- Trub from the wort cooler;
- Residual trub filter cake from the trub filter;
- Excess yeast from the fermentor;
- Yeast filter cake from the filters; and
- Sludges from wastewater treatment.

2.3.3 Air Emissions

The major emissions from beer making are particulates and volatile organic compounds (VOCs), primarily ethanol, from spent grain drying and particulates from grain handling. VOCs from fermentation are negligible, since the fermentors are typically closed to allow carbon dioxide collection. Other brewery processes, such as wort brewing and malt drying, are minor sources of volatile organics, ethanol, and related compounds.

Depending on the fuel source, exhaust gasses from the facility boilers may potentially contain nitrogen oxides (NO_x), carbon monoxide (CO), trace sulfur dioxide (SO_2), and particulate matter.

3.0 THE BREWING INDUSTRY IN JORDAN

The ABC is located in the old industrial area near Zarqa, along the Zarqa River and close to the Jordan Brewery Company. The ABC was originally opened in 1964, closed, and then restarted in 1971.

The ABC produces beer under a license from the German brewery Henninger. The total beer production capacity is 15 m^3/day, though current production rates are only 15-20% of capacity, or approximately 2.5 m^3/day. The working time is eight hours per day, six days a week.

3.1 Brewing Processes

The primary beer production processes at ABC, shown schematically in Figure 2, include the following:

Brewhouse Processes

- Milling of malt (with addition of water);
- Mashing (at 70°C);
- Filtration (water is added to filtered wort); and
- Boiling.

Fermenting and Conditioning Processes

- Fermenting (yeast is added);
- Lagering; and
- Filtering.

Packaging Processes

- Filling of bottles and cans;
- Pasteurizing;
- Labelling; and
- Storing.

3.2 Raw Materials and Water Usage

The available estimates of ABC's raw material and water consumption rates are given in the following sections.

3.2.1 Raw Materials

ABC's 1990 yearly consumption of chemicals and fuel oil are as given in the following table; no consumption estimates were available for beer-making ingredients:

Material	Yearly Usage
Caustic (Sodium Hydroxide)	3 tons
Detergents	1 ton
Disinfectants	50 kg
Fuel Oil	108,000 tons

3.2.2 Water

Water for ABC is supplied from a private well. Some water is deionized in an on-site ion exchanger; some soft water is also produced. Although the water consumption is not metered, it is estimated by ABC as 5,600 m^3/year, or 19 m^3/day with a production of approximately 2.5 m^3 beer/day. The water is consumed in the following ways:

- Approximately 50-75% of the water is used for cleaning the facility and its equipment;
- Approximately 15% of the water is leaving the factory in bottles and cans as beer;
- Large volumes of water are used for washing bottles;
- Some water is used for pasteurization; and
- Some water is used for boiler water.

Based on the water consumption rate of 19 m^3/day and the beer production rate of 2.5 m^3/day, water consumption is 7.6 m^3/m^3 beer. Although this figure is in line with United States (US) breweries, application of water conservation technologies has enabled some breweries to reduce this figure significantly.

3.3 Waste Discharges

ABC's main waste discharges are wastewaters and solid wastes. These are described in the following subsections.

3.3.1 Wastewater

All ABC wastewater is collected in a tank and pumped to the municipal sewer system, without pretreatment. The flow is estimated to be 66 m^3/working day. ABC has a biological wastewater treatment plant which is not used, since the quality of treated water reportedly complies with the effluent standards in force.

Total brewery effluent characteristics for ABC and for typical US breweries are given below. It is noted that the ABC BOD_5, COD, and SS values are low compared to US values; the low values may indicate that ABC process wastewater is diluted with pure water. The ABC BOD_5 value in parentheses is considered more reliable. The effluent characteristics are as follows:

Characteristic	ABC	Typical US Brewery	
		Average	**Range**
BOD_5 (mg/l)	28 (1,500)	1,718	1,622-1,784
COD (mg/l)	72	not available	not available
SS (mg/l)	22	817	723-957
pH	7.9	7.4	6.5-8.0
Temperature (°C)	not available	30	28-32

3.3.2 Solid Waste

It appears that all major solid wastes generated from operations at ABC are recycled. The two main solid wastes are wet organic wastes and glass. More specifically, the following process wastes are generated and recycled as follows:

Milling Preparation
Spent husks are sold to cattle farms.

Mash Filtering
Spent grains are sold to cattle farms.

(In total, 1,400 tons/year of wet solid waste are sold as animal fodder.)

Packaging
Broken glass is recycled at a glass factory.

4.0 AREAS FOR POTENTIAL IMPROVEMENT

Beyond assembling background information regarding beer brewing production facilities, the primary purpose of this document is to present information gathered from the literature search regarding common techniques as well as the latest advances in water conservation, pollution prevention, and waste minimization.

The subjects can be generally defined as follows:

Water Conservation. Water conservation is the reduction of process, clean-up, and domestic water use requirements of a facility.

Pollution Prevention and Waste Minimization (PP/WM). PP/WM is the reduction of volume or concentration of water, air, and solid waste discharges from a facility. PP/WM can be accomplished by implementing process improvements to actually reduce the amount of wastes generated or by developing a beneficial reuse for the waste and transforming it into a marketable by-product.

The following subsections present water conservation and PP/WM techniques potentially applicable to the ABC. Since the focus of the IWDPP project is on water, PP/WM techniques pertaining to air emissions and solid wastes are given secondary importance in the discussion. The discussion will include as much information on source reduction, in-process recycling, clean technologies, raw material substitution, and preventative maintenance as was possible to obtain through the literature search.

After the description of each water conservation or PP/WM technique, a preliminary assessment of applicability to the Arab Brewery Co. facility is provided. These preliminary assessments, based on currently available information, are provided to highlight areas with suspected potential for improvement that should be further investigated.

It is noted that water conservation techniques often provide PP/WM benefits, and vice versa. For example, reusing spent process water that is normally discharged to sewers provides water conservation, but also provides PP/WM through wastewater reduction.

4.1 Water Conservation

Water conservation can be considered from two different aspects: maximization of water reuse; and reduction of water requirements. Both aspects of water conservation, water reuse and water reduction, are addressed below.

4.1.1 Water Reuse

In-plant reuse of potential waste streams is practiced on a limited basis. Some potential areas for water reuse are described below.

Spent Hop Filtrate. The liquid remaining after spent hops are pressed can be recycled. This high-strength waste is usually discharged to the sewer system or mixed with the spent grains. However, in a few breweries the spent hop filtrate is recycled back into the brewing process, usually right after the wort leaves the brew kettle. In most cases, this can be done without having a detrimental effect on beer quality or taste.

Packaging Wastewater. Packaging wastewater is typically weaker than process and sanitary wastewater, and may be economically treated and reused. A dedicated wastewater treatment system for packaging water may prove to be economically feasible. Biological stabilization and carbon adsorption proved to be the most cost-effective treatment for packaging wastewater, in a study for a U.S. brewery.

Equipment Cleaning Water. As discussed previously, caustic cleaning solutions and several rinses are required to clean process tanks. Reuse of caustic cleaning solutions can reduce water use. Initial rinses contain high levels of SS and BOD, while final rinses are fairly clean. A significant reduction in water use can be achieved by using holding vessels to retain the final rinse of a tank and use it as the initial rinse for the next tank. Use of steam for disinfection instead of hot water can also provide savings in water use, since less quantity is required and additionally it can be condensed, captured, and reused.

Recycling of Wastewater Treatment Plant Water. Two approaches can be considered with regard to recycling treated wastewater. The first is to separate packaging water and weak rinse water from the stronger wastewater streams, and treat this water using carbon adsorption or other appropriate methods. This approach was discussed previously.

The second approach to recycling treated wastewater is to treat brewing and packaging wastewaters (excluding human wastes and cooling tower blowdown) by secondary biological stabilization, followed by activated carbon adsorption. The treated water would be suitable for use in brewhouse clean-up, cooling tower makeup, and miscellaneous uses.

4.1.2 Water Reduction

Water reduction includes all actions that lower the consumption of water required for a given amount of production. These include process optimization, good management practices, cooling system improvements, and cleaning method improvements.

Process Optimization. All processes requiring the use of water may potentially be optimized to achieve adequate product quality with minimum use of water.

Good Management Practices. Good management practices should be practiced to minimize use of water. These practices include the following:

- Generate an accurate measurement and balance of facility water use. The balance should track process waste reduction programs;
- Install flow-control valves and timers on pipes and other equipment to better control process water usage; and

- Implement a rigorous water management system that involves facility personnel, such as employee training in water use per batch of beer.

Cooling Systems Improvements. Cooling system water use can be reduced by the following methods:

- Use a closed loop cooling system, rather than wasting heated water;
- Use an alternate heat transfer liquid, such as propylene glycol and/or a water mix; and
- Recycle treated wastewater as a cooling medium (with additional treatment, as necessary).

Cleaning Method Improvements. Cleaning effectiveness is a function of washing time, temperature, concentration of solution, and intensity of application. Applying appropriate combination of these elements to each type of soil present in different process equipments can reduce water use. Typically, a hot solution is recommended in brewhouse equipment because of hop and protein incrustations. Cold wash water can be applied to clean fermentation and maturation tanks. Water can also be saved by cleaning soiled surfaces immediately after use.

4.2 Pollution Prevention/Waste Minimization

The following sections document state-of-the-art PP/WM techniques identified in the literature: the techniques include waste treatment and by-product recovery. The information focuses primarily on wastewater PP/WM.

4.2.1 Waste Treatment

State-of-the-art treatment processes for wastewater, solid waste, and air emissions are described below. The emphasis is on wastewaters, as solid wastes and air emissions are generally not a concern in the brewing industry.

Wastewater. Brewery wastewater is characteristically high in organics, solids, and volume. The combination of these factors makes disposal to natural water courses unacceptable; therefore, most brewery wastes are sent to a municipal wastewater treatment systems or are treated by on-site systems. Here, due to the high strength, the brewery waste may be only 4-5% of the total influent but 25% of the total BOD loading. Because brewery wastewaters are quite variable as to flow and strength, a municipal treatment system can experience severe shock loads.

Several advantages exist to discharging brewery waste to a municipal wastewater treatment system: first, brewery waste is organic in nature and is biodegradable, and therefore can be readily treated by a typical biological municipal plant; and second, mixing brewery waste with sanitary sewage adds nutrients that are lacking in brewery waste, and also helps to temper the variability of the brewery waste loadings.

Several different technologies for on-site treatment of brewery wastewater are available, including activated sludge, anaerobic processes, sequential batch reactors, and bioaugmentation.

Activated Sludge. Traditional on-site wastewater treatment systems are based on activated sludge processes, typically including the following operations: bar screening, grit removal, primary clarification, aeration, secondary clarification, chlorination, and anaerobic digestion (for treatment process sludges).

Anaerobic Processes. Anaerobic processes for wastewater treatment are increasingly used for treating brewery wastes. The main advantages of anaerobic processes include the following:

- Greater resistance to shock loads than a conventional activated sludge processes;
- Greatly reduced sludge generation; and
- A useable energy by-product in the form of methane gas.

Two anaerobic processes successfully used to treat brewery waste are Upflow Anaerobic Sludge Blanket (UASB) reactors and Anaerobic Fluidized Bed (AFB) reactors. There are several manufacturers with propriety UASB treatment systems that have extensive experience with the brewing industry.

Bioaugmentation. Bioaugmentation consists of adding special strains of bacteria to indigenous bacteria in biological treatment process, to improve treatment properties. In the case of brewery waste, bioaugmentation can be used to improve the treatment system's resistance to shock loadings, as well as to improve solids settling. This may avoid reseeding biological processes when disrupted by shock loadings, as well as reduce polymer demand and sludge handling costs resulting from poor solids settling.

Sequential Batch Reactors. Sequential Batch Reactors (SBRs) are aerobic biological treatment units operated in a batch treatment mode. Most conventional activated sludge systems are operated in a continuous-flow mode.

The cycle for a typical SBR tank is divided into the following five discrete periods: fill with wastewater, bioreact, settle solids, withdraw clarified supernatant, and idle to await refill. Since treatment and settling are accomplished in the same tank, SBR systems do not need separate final clarifiers and return activated sludge pumps.

The advantage of using SBR tanks to treat brewery wastewater is their tolerance to shock loads of BOD. The performance of several conventional activated sludge systems have been shown to significantly improve after conversion to SBR operation.

Solid Waste. As mentioned previously, organic solid wastes are typically processed and recycled as livestock feed or other types of food products. Broken glass is normally recycled, as are paper and plastic packaging wastes. No treatment is required prior to landfill disposal.

Air Emissions. Brew kettle vapor emissions can be removed by barometric condensation, although this method entails high levels of energy consumption. Another emissions from the brew kettle which may be significant is odor.

NO_x can be reduced either by retrofitting the burners to decrease NO_x generation, or by removing NO_x from off-gases by selective catalytic reduction or selective non-catalytic reduction.

4.2.2 By-Product Recovery

Recovery of waste solids from the different process streams is practiced extensively in the brewing industry and it appears to be the method of reducing waste loads both technically and economically. Grains, hops, trub, yeast, lost beer, and glass bottles and caps are all currently being recovered, as described below.

Spent Grains. Spent grains (barley, rice and/or corn) are recovered by all breweries large and small. The grains are removed after the starches have been solubilized and then converted to sugars. Most smaller brewers and about half of the larger ones utilize the lauter tun filter, which is a gravity filtration device, to separate the grains from the mash. A disadvantage is that it requires a large amount of water to sluice out the spent grain. Some larger plants employ a plate and frame filter, in which the grains are pressed and screened to reduce moisture content. The press liquor is frequently put in the sewer; however, it has been recycled back into the process or filtered, centrifuged, evaporated, and added to the spent grains.

Following recovery, most small breweries haul the still wet spent grains away for use as cattle feed. Large facilities dry the grains before shipment to cut down on transportation costs. In either case, the grains make an excellent and very valuable cattle feed. A study of wet brewery by-products as livestock feed indicates that an optimum moisture content is 75-80%, and that adequate protein is available in grain-yeast mixtures so no supplements are needed. More recently, spent brewers grain has been used to produce barley bran for human consumption. Some studies indicate that barley bran is twice as effective in reducing cholesterol as oat bran.

Spent Hops. Spent hops are separated from the brewing process by a hop jack filter after the wort leaves the brewing kettle. The smallest breweries usually haul wet spent hops away, while larger breweries add to the spent grains to be dried. A study has demonstrated that up to 10% wet spent hops can be added to the spent grains with no deleterious effect on voluntary uptake by cattle. The use of hop extract in the brewing process, which eliminates the hop disposal problem at the brewery, has been increasingly used in the US.

Trub. Trub is the waste from the wort cooling process, consisting mostly of insoluble proteins. Trub is sewered by nearly all small breweries and by many larger ones. The remaining larger breweries add trub to the spent grain to be used as cattle feed. Beer production results in an average trub generation of 1.16 kg/m^3 beer.

Yeast. Yeast is another very important by-product of the brewing industry that can also be used for livestock feed. It is both settled and filtered out of the brewing process after fermentation. Excess yeast is produced at a rate of about 1.3 kg/m^3 beer. Most plants sewer the yeast or haul it away in wet form. A few of the larger breweries add it to the spent grains to be dried or dry it separately. The yeast makes an excellent feed supplement: the addition of steam-killed brewers yeast to spent grains in a 1:6 ratio can increase its nutritional value without causing an undesirable tastes that would cause cattle to reject it.

Lost Beer. Lost beer can be another significant by-product of the brewing industry. It results mainly from the racking, transferring, and bottling operations. The volume of lost beer is about 6.3% of the beer produced, based on a production-weighted average. Most breweries of all sizes dispose of this beer in their sewers, but a few larger ones are recovering the beer and adding it to their spent grains for evaporation.

Glass Bottles and Kegs. Glass bottles and metal kegs often can be refilled. Where refillable bottles and kegs are used, washing becomes a major operation and requires large amounts of water and caustic. In a typical plant, washing (bottles and plant clean-up) requires 1.62 kg of caustic per m^3 of beer produced. Some larger plants recycle caustic, rather than discharging it to the sewer, and achieve significant savings in cost and resources.

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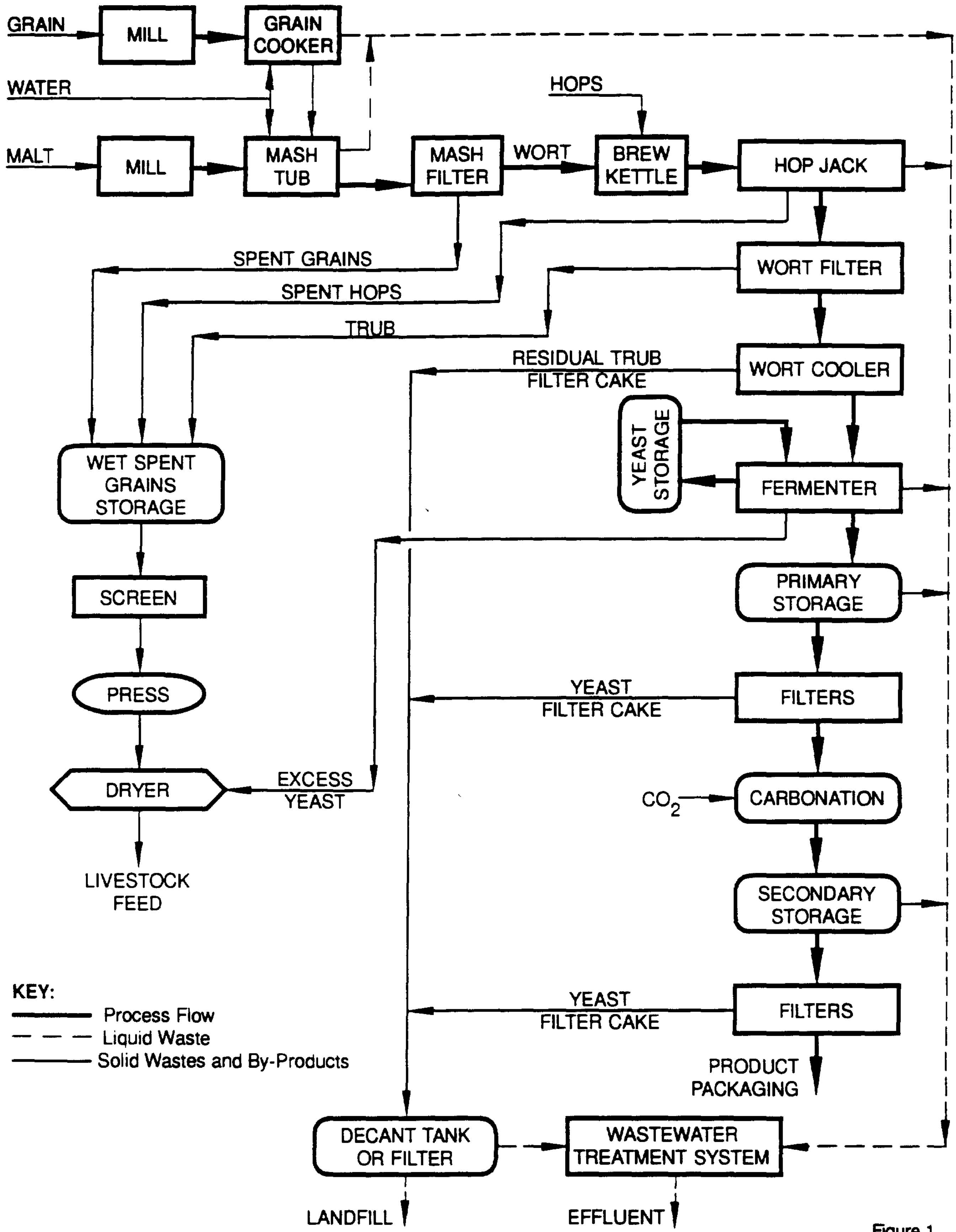

SOURCE: State-of-the-Art
Wastewater Management
in the Beverage Industry.

Figure 1

TYPICAL PROCESS DIAGRAM FOR BEER PRODUCTION

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
Amman, Jordan

HARZA *Consulting Engineers and Scientists*

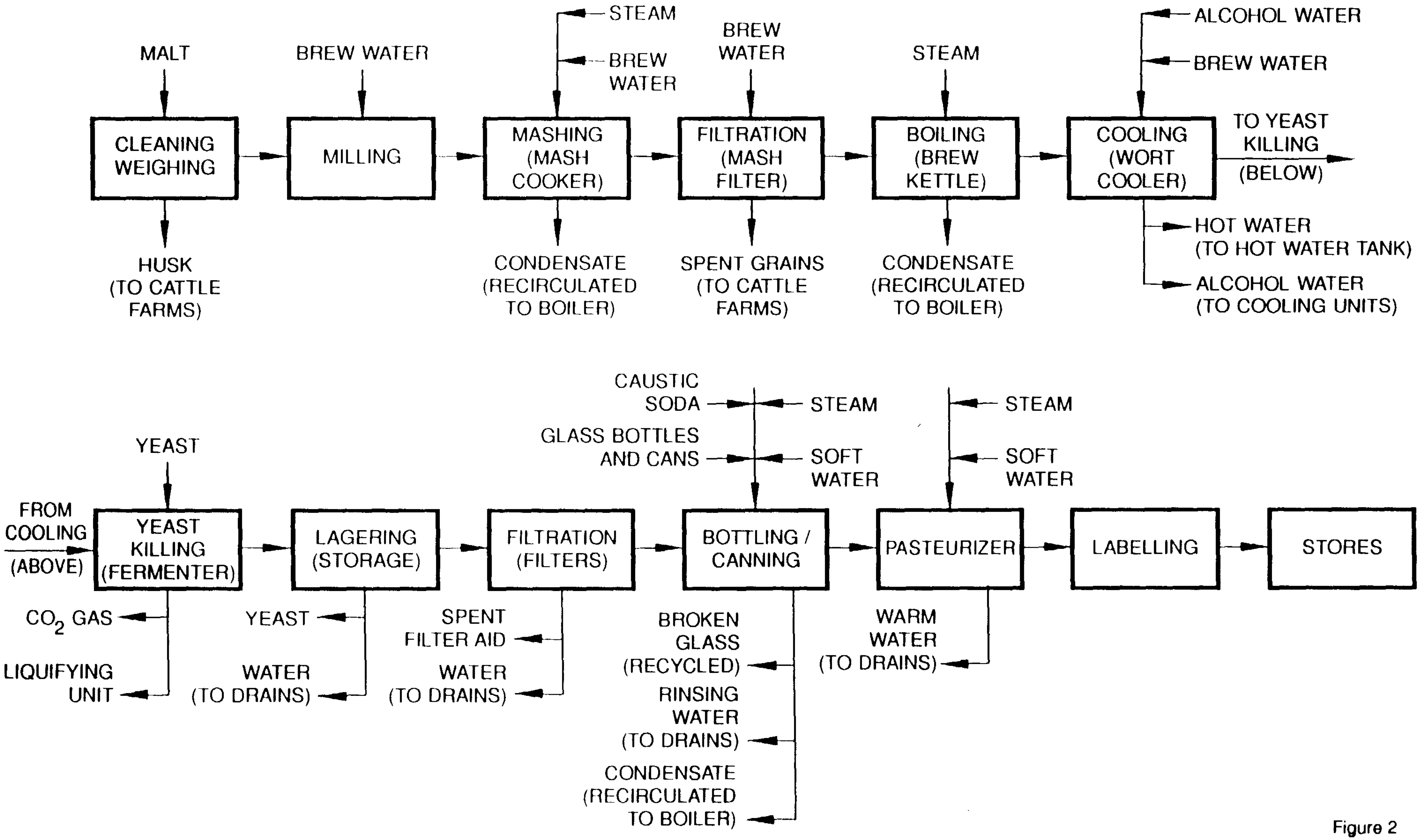

Figure 2

ARAB BREWERY COMPANY

PROCESS DIAGRAM FOR BEER PRODUCTION

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
Amman, Jordan

SOURCE: COWI Consult and RSS

HARZA *Consulting Engineers and Scientists*

BREWERY INDUSTRY
BACKGROUND MATERIALS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION PROGRAM
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan

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Technology evaluation of sequencing batch reactors

Madan L. Arora, Edwin F. Barth, Margaret B. Umphres

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The Clean Water Act (CWA) of 1977 (PL 95–217) and the Wastewater Treatment Construction Grant Amendment of 1981 (PL 97–117) include provisions that encourage the use of beneficial innovative and alternative (I/A) wastewater treatment technologies. Benefits of I/A technologies can include operations and maintenance (O & M) and capital cost reduction, and energy conservation or recovery. Other benefits may be improvement of operational reliability, toxics control, improvement in environmental benefits achieved, reclamation and reuse of water, recycling of wastewater constituents, elimination of surface discharge, and improved joint municipal/industrial treatment. The U. S. Environmental Protection Agency (EPA), in fulfilling its mandate under the CWA, developed regulations and criteria for funding projects nationwide that use an I/A technology. The underlying concept of these regulations is the provision of a basic monetary incentive: a grant increase from 75 to 85% for the design and construction of municipal treatment technology that represents an advancement of the current state-of-the-art technology with respect to meeting the stated objectives.

Since the passage of the CWA, several municipal treatment plants have received additional funding under the I/A technology program. As expected, not all plants achieved the full range of anticipated benefits after they were constructed.

This study reports the results of a post-construction evaluation of one I/A technology, sequencing batch reactors (SBR), used at several plants in the U. S. This information was collected to enable benefits of I/A technologies be realized in designing future facilities. Furthur, it is important that limitations and constraints, f any, of the I/A processes also be reported so that these can be appropriately considered during planning and design phases of a project.

SBR TECHNOLOGY

The SBR is a fill-and-draw activated sludge system. Each tank n the SBR system is filled with wastewater during a discrete period of time and then operated in a batch treatment mode. After treatment, the mixed liquor is allowed to settle for a predetermined amount of time and then the clarified supernatant is withdrawn from the tank. During treatment, sedimentation, nd withdrawal the wastewater flow is either directed to another BR tank in the system, as in a multiple tank configuration, or to a storage tank in a single SBR tank configuration where it is rawn for treatment after the supernatant withdrawal has been completed.

One modification of the SBR process, the intermittent cycle xtended aeration system (ICEAS), operates on the principle of ontinuous feed as in a continuous-flow activated sludge system, but with intermittent withdrawal as in the SBR system. With the exception, therefore, of the ICEAS, an SBR system is comprised of either a storage tank and an SBR tank or a minimum of two SBR tanks to accommodate a continuous inflow of wastewater to the treatment plant.

A lack of widely accepted design standards is the major obstacle to bringing SBR technology from the research stage to broader practical application.

Each system accomplishes treatment, sedimentation of mixed liquor solids, and withdrawal of supernatant in the same tank. Therefore, such systems do not need separate final clarifiers and return activated sludge pumps (Figure 1). Tanks in most SBR systems receive wastewater flow and discharge supernatant intermittently; this discussion, unless otherwise indicated, deals with such intermittent feed and withdrawal systems.

A cycle for a typical SBR is divided into the following five discrete periods (Figure 2): fill, react, settle, draw, and idle.[1] The purpose of each period, with the exception of idle, is evident. Idle is necessary in a multiple tank system when one tank is not yet full, perhaps at low flow, and is filling while the second tank has completed draw and is thus in idle mode.

Figure 2 shows a single tank in each of the five periods of one complete cycle. The figure also shows the percent of the maximum liquid volume and total cycle time that is typical for each period and the purpose of aeration during each period. ICEAS has continuous fill, so it has no separate fill and no idle periods. The tanks in an ICEAS always have a prereaction compartment at the influent end terminating in a baffle that permits wastewater to enter on a continuous basis without causing a significant disturbance during settle and draw. Other SBR systems may not have this separate prereaction compartment.

Irvine[1] provided an excellent discussion of the five periods in one complete SBR cycle, and included a description of the typical process equipment and hardware that may be associated with each period.

HISTORICAL PERSPECTIVE

SBR technology is not new. In fact, it preceded the use of continuous flow activated sludge technology. There are many examples of batch processes in the history of municipal wastewater treatment. Sidwick and Murray[2] outlined the evolution of batch processes into continuous-flow processes in England.

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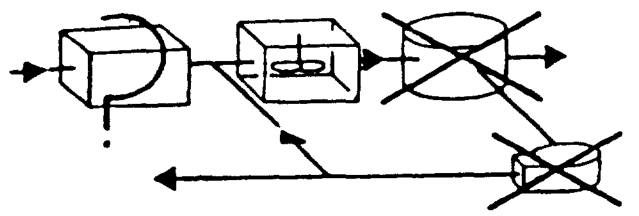

Figure 1—Comparison between SBR and a conventional activated sludge plant.

Irvine[1] and Barth[3] traced the history of SBR technology to the modern era of continuous-flow activated sludge.

The precursor to the various, now familiar, continuous-flow activated sludge processes was actually a fill-and-draw system operated in a batch process. In 1914 Ardern and Lockett[4] were among the first to show the benefit of retaining substrate-adapted organisms for efficient treatment. Working with 2.3-L flasks containing raw wastewater for Manchester, England, they showed that the batch aeration period needed to achieve nitrification could be reduced from 5 weeks to 9 hours if the sludge that accumulated from each batch were retained in the flask after decanting the nitrified liquid. They coined the term activated sludge to describe the resultant biological mass. However, many difficulties were associated with operating these fill-and-draw systems, most resulting from the process valving required to switch flow from one tank to the other and operator attention required in initiating different periods required in these batch systems. As a result of this, batch systems never became popular in large-scale municipal treatment plants. By 1920, when larger facilities were being constructed, batch systems were no longer considered viable. The birth and widespread use of continuous-low systems resulted primarily from operational considerations ind not from any process-related weaknesses of the batch sysems.

Times have changed. New hardware devices, such as motorzed valves, pneumatically actuated valves, solenoid valves, level ensors, flowmeters, automatic timers, and microprocessors or rocess controllers have been developed and are routinely available. It is important, therefore, that the application of SBR techology, abandoned because of the unavailability of these devices, e reevaluated. A series of articles[5-11] published recently provided broad overview of SBR systems and their use. In the early 980s EPA attempted to revive interest in this technology and ent considerable sums of money evaluating the process on a ll-scale basis.[12] This research examined a full-scale demonration of a two-tank SBR activated sludge treatment plant over 20-month period in Culver, Ind. Results of this project led to e use of SBR technology at several other municipal facilities.

DVANTAGES OF SBR

Proponents of the continuous-flow activated sludge systems e flexibility as one of the main reasons this process is preferred er the trickling filter process. This flexibility comes from several urces: ability to vary the return activated sludge (RAS) rate d resultantly the food-to-microorganism ratio (F/M), dissolved ygen (DO) concentration in the reactor by changing the aeron rate, and the sludge age. Such flexibility in the trickling filter process is minimal, and has been frequently compared with that of SBR systems in literature.[13-16] Among the salient points are:

- An SBR tank serves as an equalization basin during fill and therefore can easily tolerate peak flows and shock loads of biochemical oxygen demand (BOD) without degradation in effluent quality. In fact, the performance of several small continuous-flow activated sludge systems, which were not consistently producing good effluent as a result of excessive diurnal variations, significantly improved after conversion to SBR operation.[16]
- Because effluent discharge is periodic, within limits, effluent may be held until it meets specified requirements.
- During the early design life, when flow is significantly lower than design capacity, liquid level sensors can be set at a lower level, so that a fraction of the SBR tank capacity is used. In this way, the length of treatment cycles can be kept the same as design without wasting power unnecessarily by over-aeration.
- Mixed liquor solids cannot be washed out by hydraulic surges, because they can be held in the tank as long as necessary.
- No RAS pumping is required, because the mixed liquor is always in the reactor.
- Solid-liquid separation occurs under nearly ideal quiescent conditions. Short circuiting is nonexistent during the settle period.
- Because the DO concentration is zero or near zero during anoxic fill, it provides for a greater oxygen driving gradient during the react period. This could achieve somewhat higher overall oxygen transfer efficiency with the same aeration equipment.
- Filamentous growth can be easily controlled by varying the operating strategies during fill. Chiesa and Irvine[17] reported the results of a study in which sludge volume index (SVI) values were reduced from about 600 to 50 mL/g in a series of batch reactors subjected to varying, but controlled, operating strategies—percent of aerated fill time decreased successively from 100% for a SVI of 600 mL/g to 0% for a SVI of about 50 mL/g. Irvine and coworkers reported that the best operating strategy in an SBR is to have a major portion of fill unmixed

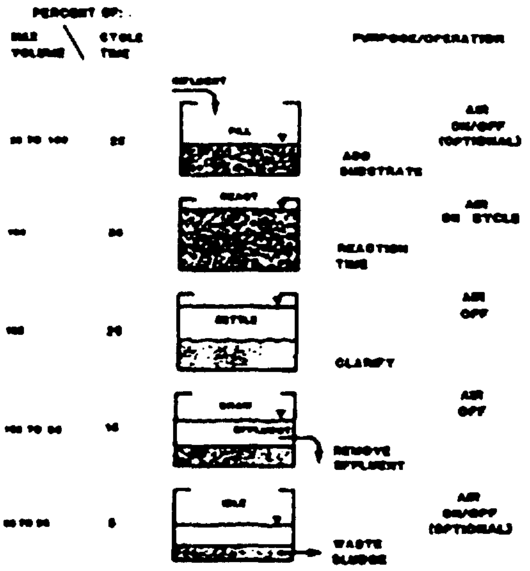

Figure 2—Typical SBR operation for one cycle.

and unaerated followed by mixing and aeration during the remainder of fill, about 15 to 30 minutes. An SBR can easily be designed to accommodate these operating strategies.

- An SBR can be operated to achieve nitrification, denitrification, or phosphorus removal without chemical addition. Nitrification can be achieved by increasing the duration of react or by increasing the duration of the mixed/aerated portion of fill, while denitrification can be achieved by increasing the length of settle and draw or both, so that near zero DO conditions are achieved during these periods. Phosphorus removal can similarly be accomplished successfully by selecting a control strategy that eliminates oxidized nitrogen and DO during fill (anaerobic conditions rather than anoxic conditions or aerobic conditions) and allows for aeration during the react period.[18] This strategy has been successfully used at Culver to reduce phosphorus to less than 1 mg/L during the last year. These variations in operating strategies are unique to the SBR systems and can be easily achieved by simple adjustments in the microprocessor settings.
- It has been reported by Irvine[18] that the ribonucleic acid (RNA) content of the microorganisms in the SBR is three to four times greater than would be expected from a conventional continuous-flow system. Because the growth rate of microorganisms depends on the RNA content of the cells, the higher content of this intracellular machinery in the SBR culture is capable of processing a greater quantity of substrate at a greater rate than is possible in a conventional continuous-flow system.

EVALUATION OF SBR FACILITIES

This study involved identifying operating SBR facilities by talking with I/A coordinators of each state, equipment manufacturers, and representatives of Canadian provincial governments. The consulting engineers responsible for designing these facilities were also identified. The engineers were contacted to obtain important design information—design flow, BOD, and National Pollutant Discharge Elimination System (NPDES) requirements. Based on a preliminary analysis of the information obtained and discussions with the EPA, all four SBR facilities operating in the U. S. were selected for post-construction evaluation. Two facilities in Canada and two facilities in Australia were also selected.

This list of selected facilities covered a range of conditions, conventional SBR and ICEAS plants, retrofits and brand new facilities, different aeration systems, and different flow capacities (Table 1). Owners of these facilities, consulting engineering firms, and regulatory agencies were contacted to establish schedules for site visits. In addition, they were requested to forward copies of the design documents, including facilities plans, NPDES permits, plans and specifications, and O & M manuals. Attempts were made to review these documents before site visits so that the visits could be effectively used to obtain supplemental or missing information.

Site visits were made with the plant operators and representatives of the consulting engineering firms on established dates. A comprehensive 30-page questionnaire was used to record the information collected during field visits. This was followed by a thorough review of the information collected. Follow-up phone calls were made to the plant operating staff to obtain additional information if it was considered necessary to complete the evaluation.

DISCUSSION

The information amassed through a review of design documents and field trips was carefully analyzed. Table 2 lists important information for each of the eight plants visited. Several comparisons and conclusions were drawn from the information in Tables 1 and 2:

- Operating staff at each of these plants indicated that the SBR process was more simple to operate compared to the conventional continuous-flow processes, activated sludge, and trickling filters that they had previously operated.
- All plants were meeting effluent requirements with the exception of Grundy Center Wastewater Treatment Facility. The problem at Grundy Center was alleged to be the result of an unsatisfactory decanter design, which permitted the MLSS to enter the decanter piping system during fill, react, and settle periods; these solids are subsequently discharged with the decanted effluent. The city is in the process of replacing the decanter.
- None of the plants, with the exception of Culver and Yamba, has primary treatment in its flow scheme. Culver and Yamba had existing primary clarifiers which they continued to use in the SBR process scheme.
- Even though the water quality objectives at the eight plants visited were essentially the same, the design criteria and the reactor sizes and power usages were not. For example, the theoretical detention time (V/Q) varied from 7.6 hours at Rivercrest to 49 hours at Glenlea. The differences in the values of F/M ratio were also of the same order of magnitude as the detention time, 0.18 day^{-1} at Rivercrest and 0.032 day^{-1} at Glenlea.
- The approach used by the design engineers in designing these plants varied from an entirely empirical approach involving sizing of the SBR reactor(s) based on somewhat arbitrarily selected detention times to an approach where sizing of the reactor(s) and aeration equipment was based on the values of organic loading, F/M ratio, sludge concentration at the end of the decant period, and durations of different periods comprising the overall cycle. Both approaches produced relatively conservative designs.
- Partial to nearly full nitrification was achieved in almost all facilities visited, although it was mandated at only two (Grundy Center and Eldora). Operators did not believe the implementation of a nitrification control strategy was difficult. One of the facilities, Culver, Ind., is currently removing phosphorus biologically to levels less than 1 mg/L without any chemical addition. This is being accomplished by adjusting the operating strategy so that an anaerobic (no oxygen and no nitrates) fill period is followed by an aerobic react period.
- The operating cycles (fill, react, settle) used at the facilities were also significantly different. For example, the react period varied from 22 hours in Glenlea to about 1.5 hours in Rivercrest.
- The operating strategy used by some operators (Rivercrest, Glenlea, and Choctaw) involved aeration during the entire fill period which, although contrary to the recommendations of Chiesa and Irvine,[17] did not necessarily encourage the growth of filaments to any significant degree.
- Because of the differences in the operating strategies, power usage at these plants was significantly different: from as low as 0.8 kWh/kg BOD applied to 22.9 kWh/kg BOD applied.
- Several types of decanter mechanisms are used at these facilities. They range from an extremely simple system that consists

Table 1—Facilities selected for post construction evaluation.

Number	Name of facility	Owner	Design average flow (L/d)	Mode of operation	Retrofit or brand new	Type of aeration system	Type of decanter system	Gravity or pumped decant	Date when operation commenced
1	Rivercrest Sewage Treatment Plant	Municipality of West St. Paul, Manitoba	90 720	SBR	Septic tank retrofit	Diffused air	Fixed single point withdrawal	Pump	August/September 1983
2	Glenlea Sewage Treatment Plant	University of Manitoba	7 560	SBR	Airogest Smith & Loveless Package Plant Retrofit	Diffused air	Fixed, single point withdrawal	Pump	1978
3	Choctaw Wastewater Treatment Facilities	City of Choctaw, Oklahoma	1.89 × 10^6	SBR	Brand new	Floating aerators	Fixed, multiple point grid (now single point)	Gravity	Since August 1983 with multiple point withdrawal grid; February 1984 with single point withdrawal
4	Grundy Center Wastewater Treatment Facility	City of Grundy Center, Iowa	3.14 × 10^6	SBR	Brand new	Jet aeration	Floating, multiple point withdrawal	Gravity	Since June 1983 with one tank; and February 1984 with both tanks
5	City of Eldora Wastewater Treatment Plant	City of Eldora, Iowa	831 600	Continuous inflow on day of visit; later changed to SBR	Brand new	Jet aeration	Fixed, multiple point withdrawal	Gravity	April 25, 1984
6	Town of Culver Wastewater Treatment Facility	City of Culver, Indiana	1.33 × 10^6	SBR	Retrofit of an overloaded activated sludge plant	Jet aeration	Floating multiple point withdrawal	Pump	From May 1980 to date. Observations cover a 20-month period commencing in May 1980 (12)
7	Westdale Sewage Treatment Works	Tamworth City Council, New South Wales	2.02 × 10^6	ICEAS	Brand new	Jet aeration	Floating, multiple point withdrawal	Gravity	June 1983
8	Yamba Sewerage Treatment Works	Shire of Maclean, New South Wales	956 340	ICEAS	Brand new	Jet aeration	Floating multiple point withdrawal	Gravity	June 1983

of one fixed vertical open-ended submerged pipe to a floating decanter. All facilities in the U. S. experienced some difficulties operating their decanter mechanisms, because these permitted at one time or another, the MLSS to enter the decanter mechanism piping during fill, react, and settle. These solids were discharged during decant, and affected the effluent quality. These problems have been corrected at some facilities and are being corrected at others. At Culver, this problem was solved by returning the effluent during the first 1 or 2 minutes of the decant period to the aeration basin through an automatic three-way valve, after which time the decanted effluent was diverted to the chlorine contact tank.

- Five of the eight plants used jet aeration in the SBR tanks, two used diffused air aeration, and one used floating aerators. There seemed to be a preference for jet aeration because it provides the flexibility to have unmixed and unaerated fill, mixed only fill, mixed and aerated fill, or any combination of these.
- At Choctaw 1 mg/L of a cationic polymer is added manually once a day; no chemicals are used to assist in settling at any other plant. Settleability of the mixed liquor at this plant seemed noticeably better than that at some of the other plants.

Decanter mechanism in use. As indicated earlier, decanter mechanisms of varying complexities have been used at these facilities and with varied success. These range from a fixed open-ended submerged pipe (Rivercrest and Glenlea) to a floating decanter (Grundy Center, Culver, Tamworth, and Yamba). The Choctaw plant has a fixed submerged pipe grid with closely spaced inlet nipples, which was later changed to a single-point withdrawal system because the original design permitted a significant quantity of MLSS to enter this piping grid during fill, react, and settle. Eldora's SBR facility is also equipped with a fixed decanter, but of a different design.

A detailed description of the different types of decanters, together with their pros and cons, is presented elsewhere.[19]

AREAS OF CONCERN

One area of concern is clear: there are no widely accepted or widely known standards for the design of SBR systems. As a result, every consulting engineer approached the design differently and obtained a different answer. The result in one case was a small reactor (detention time of less than 8 hours) and in another case was a large reactor with a detention time that was six times longer. Similar differences in other design parameters, such as F/M ratio, solids retention time (SRT), and cycle durations were also noted at these facilities.

An equally significant difference lies in the type of decanters used at these facilities. Because all these differences are reflected in the cost of facilities, comparison between this process and the continuous-flow activated sludge systems and other biological systems for wastewater treatment poses difficulties.

Differences in the operating strategies are just as significant. For example, Glenlea uses a 22-hour react period in a 24-hour overall cycle, while Rivercrest uses about 1.5 hours in a 3-hour cycle. These differences not only affect the size of the aeration equipment, as a specified amount of BOD must be satisfied during the react period, but also the operating costs of a facility.

All these variables and variations are significant in a cost-effectiveness analysis. Thus, there is a need for standardization of design and operating procedures. Standardization is also important from another point of view; it will bring technology from the research realm to the practical arena, where it would be considered a viable option by a practicing engineer designing facilities. Unless this is done most practicing engineers may continue to believe that the technology is in the developmental stages with associated uncertainties of success and that their clients may be risking their investments in using SBR for proposed projects. This would be far from the truth, because the technology is not only proven, but can also be cost-effective in several applications. Communities such as Rivercrest, Glenlea, Eldora, Tamworth, and Yamba built SBR facilities entirely out of their own funds because they believed no undue risks were associated with this technology.

SUGGESTED DESIGN APPROACH

The literature is full of methods and approaches for designing continuous-flow activated sludge systems. However, no standard and easy procedures have been developed for designing an SBR system. The following illustrates one step-by-step rational approach that can be used to design an SBR. A numerical example with practical assumptions, together with reasons for such assumptions, is presented elsewhere.[19]

1. Calculate daily BOD loading (F).
2. Assume a suitable F/M ratio consistent with the water quality objectives and calculate M.
3. Assume a suitable value of MLSS concentration expected at the end of the decant period and calculate volume occupied by the settled mixed liquor solids (M) based on the assumed concentration.
4. Select the number of SBR tanks to be used and determine the volume occupied per tank by the mixed liquor solids calculated in Step 3.
5. Decide the number of operating cycles per day and calculate the volume of liquid to be handled per decant per SBR tank.
6. Volume of each SBR tank equals the volume calculated in Step 4 plus the volume calculated in Step 5.
7. Assume a suitable SBR tank depth and calculate area required per tank; decide length and width.
8. Based on the calculated tank area, check the depth of the decanted liquid necessary to accommodate the liquid volume calculated in Step 5. Make sure that it is reasonable (1 to 1.5 m). If not, repeat the previous steps (for example, increase the area to reduce depth) until reasonable values of length, width, depth, and decant depth are obtained.
9. Based on the final value of the tank area, determine the depth of the sludge blanket necessary to accommodate the volume of sludge calculated in Step 3. Make sure it is reasonable (about half the depth of the tank).
10. Determine the daily oxygen requirement based on water quality objectives.
11. Size aeration equipment based on the calculated oxygen requirement to be satisfied during aerated fill plus react time provided in the total number of operating cycles per day decided in Step 5. This can also be done based on satisfying the expected oxygen uptake rate of the mixed liquor.
12. Size decant mechanism and piping to handle decant volume (Step 5) during the selected decant period.

These steps illustrate only a simplified approach. In a real situation, many iterative calculations may be necessary to accom-

30

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Table 2—Plants evaluation summary.

	Canada		United States				Australia	
Parameter	Rivercreet Manitoba[a]	Glenlea, Manitoba[a]	Choctaw, Oklahoma	Grundy Center, Iowa	Eldora, Iowa	Culver, Indiana[b]	Tamworth, New South Wales	Yamba New South Wales
Date of first visit	5/16/84	6/16/84	5/30/84	6/11/84	6/12/84	6/14/84	7/10/84	7/11/84
Design average flow (L/d)	90 720	7 560	1.89 × 10^6	3.14 × 10^6	83 600	1.33 × 10^6	2.02 × 10^6	958 340
Design loading								
BOD, mg/L	236[e]	251[e]	260 366[c]	200	250 120[e]	170[c,d]	260	260[e]
SS, mg/L	200[e]	152[e]	260 350[e]	—	—	150[c,d]	—	—
NH_3, mg/L	37[e]	56[e]	19[e]	15	25	20[c,d]	35 to 40	—
Current average flow, (L/d)	226 800	4 400	758 000 1.07 × 10^6 (equivalent)	3.02 × 10^6	831 600 400 680 (equivalent)	1.37 × 10^6	2.02 × 10^6	—
Desired effluent quality								
BOD, mg/L	TOC40	30	20	30	30	10	30	30
SS, mg/L	30	30	20	30	30	10	30	30
NH_3, mg/L	—	—	15	6 (summer), 11 (winter)	8 (summer), 10 (winter)			
Actual effluent quality								
BOD, mg/L	11	5	8	Not being met because of decanter problems	Data was not available Effluent appeared to be satisfactory	10	6 to 10	6 to 10
SS, mg/L	15	6	18			5	5 to 10	10 to 15
NH_3, mg/L	10	2	—			1.0	2.2	1.0
Mode of operation at design flow								
Fill time	90 minutes	22 hours	18 hours	40 minutes (without air/pumps) 120 minutes (with air/pumps)	150 minutes[e]	180 minutes	continuous	continuous
React time	45 minutes	1 hour	3 hours	60 minutes	80 minutes	42 minutes	120 to 150 minutes	150 minutes
Settle time	20 to 60 minutes	1 hour	3 hours	40 minutes	50 minutes	42 minutes	45 minutes	180 minutes
Draw time		—	—	60 minutes	45 minutes	42 minutes	45 minutes	45 minutes
Idle time	—					60 minutes Fill 30% mixed 70% aerated		

31

Important design parameters								
Detention time hours	7 6	49	48	20.4	43	16.5[e]	48	36
F/M, kg BOD/kg	0.18[c]	0.032[a]	0.037	0.078	0.06	0.08 to 0 16	0.04	0.05
MLSS			0.028[c]	0.067[c]				
SRT, days	43[c]	18 to 80[c]	Sludge wasted twice in 10 months	25 to 30[c]	Sludge not wasted in last 2 months	15 to 45[c]	—	—
Power usage kWh/kg BOD applied	0.8	22.9	2.9	0.8 to 1.3	2.2	2.1	1.9	1.5
Unit processes								
Trash rack	Yes	—	Yes (bypass)	Yes (bypass)	—	—	—	Yes
Mech. screens	—	—	—	—	Yes	Yes	Yes	—
Communitor	—	—	Yes	Yes	—	or Yes	or Yes	—
Grit removal	—	—	—	Yes, aerated	Yes, aerated	Yes	—	Yes
Equilization	Yes	Lift station wet well	Emergency holding pond	Sideline equilization	—	—	—	—
Primary treat,	—	—	—	—	—	Yes	—	Yes
SBR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Disinfection	—	—	Yes	Yes	—	Yes	Polishing lagoon	Polishing lagoon
Sludge treat,	Holding tank and land application	Agriculture farm	Holding pond and land application	Aerated sludge holding and sludge beds	Anaerobic digesters and sludge beds	Aerobic digesters and sludge beds	Sludge lagoon	Aerobic lagoon
Reasons for providing this technology	Capital cost savings and simple operation	Capital cost savings and simple operation	8.4% savings in life cycle costs	19% capital cost savings in secondary treatment process or 8% savings in overall plant cost	Capital cost savings and simple operation (100% city funding)	Full-scale study funded by EPA	Capital cost savings	Capital cost savings

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[a] Rivercrest and Glenlea data obtained from reference.[10]

[b] Culver data obtained from reference.[12]

[c] Actual operating data.

[d] Raw wastewater.

[e] Jet motive pumps on all the time, but air on and off for 40 and 10 mts, respectively repeated three times during the 150 minutes fill and react periods.

modate several possible values of MLSS concentrations (5000, 7500, 10 000, for example), different number of operating cycles per day (4, 5, or 6), diurnal flow variations, and different decant heights (1, 1.5, and 2 m). As a minimum, it would be desirable to check if some of the more common contingencies can be accommodated during operation.

SUGGESTED MODES OF OPERATION

The SBR technology has the ability to achieve BOD removal, nitrification, denitrification, and removal of phosphorus with or without chemical addition by changing the operating strategies. A review of information contained in Table 2 indicates that no two of the plants evaluated used the same operating strategy even though their objectives were simple (removal of BOD and suspended solids) and identical. If the objectives are expanded to nitrify, denitrify, or remove phosphorus, the number of possible operating cycles will be further increased.

Nitrification can be achieved by providing a sufficiently long SRT (5 to 10 days or more) to ensure the growth of nitrifying organisms and a sufficient aerated basin volume at DO concentration adequate for nitrification (2 mg/L). For denitrification to occur, on the other hand, an anoxic basin or anoxic period in an SBR is necessary (presence of nitrates, but absence of DO). If these conditions are achieved sequentially in an SBR, nitrification will occur first and be followed by denitrification.

Phosphorus can be removed in an SBR by coagulant addition and precipitation[12] or biologically without chemical addition (as is done at Culver). Biological removal first requires an anaerobic period (the absence of DO and oxidized nitrogen), during which exogenous electron donors (the substrate) are present. This period should be followed by an aerobic period (DO present) which promotes luxury uptake of phosphorus by the sludge mass. This principle is the basis for implementing an appropriate control strategy in an SBR to remove phosphorus without adding chemicals.[20]

These principles can be used to develop different operating strategies for different water quality objectives. One suggested strategy for each of the several common water quality objectives is shown in Figure 3. Bear in mind that:

- In a given plant, fill time is a function of the plant flow rate over which the operator has no control. Fill time will be less at high flow and vice versa.
- To increase react time, overall length of the operating cycle does not necessarily have to be increased correspondingly. Longer react time required for nitrification or for the treatment of high strength waste, can often be achieved by running the aeration equipment for a portion of the fill period (fill, mixed, and aerated).
- Operating strategies for nitrification and denitrification may not necessarily be different; recognizing that nitrification must precede denitrification, identical operating strategies can be expected if the DO is reduced to less than 0.5 mg/L during settle, decant, and idle periods. Many plants are removing nitrogen to some degree even though it is not their treatment objective (Culver, Rivercrest, Glenlea).
- Because phosphorus removal requires an anaerobic period (zero DO and zero oxidized nitrogen) followed by an anerobic period (high DO), a denitrifying system is easily adaptable to phosphorus removal.

The integration of these concepts for meeting different water quality objectives into a successful operating strategy at an SBR treatment plant is not an exact science. But, this is not unique to an SBR. Continuous-flow systems face the same shortcomings. The ability of the operator to integrate these concepts into a successful strategy seems as good in an SBR plant as in a continuous-flow activated sludge system. In most cases, continuous-flow systems can only provide significant nitrogen and phosphorus reductions by major expenditures of money required for constructing additional advanced waste treatment facilities, while SBR plants can accomplish the same objectives by appropriate changes in the operating strategy.

CONCLUSIONS

- All the plants visited as a part of this study are producing effluent of acceptable quality with the exception of Grundy Center, Iowa, which is experiencing problems with the decanter mechanism.
- There are no widely accepted or widely known standards for SBR design. Consequently, there was a wide range in the design parameters, such as detention time, F/M ratio, and operating strategies at the facilities evaluated.
- Different water quality objectives (carbon, nitrogen, and phosphorus removals) are frequently achieved in an SBR by

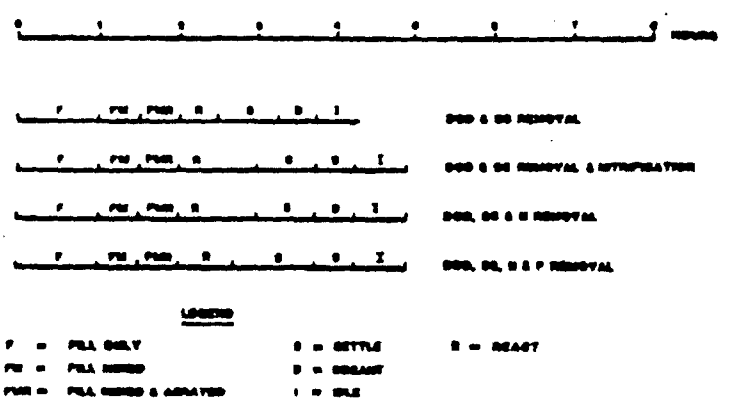

Figure 3—Suggested operating strategies for different water quality objectives.

appropriate changes in the operating strategy; such changes can be made easily by microprocessor settings at the control panel.

- SBR systems have several advantages over continuous-flow systems. These advantages include equalization, ideal settling, simple operation, compact layout, and perhaps cost savings (capital and O & M).
- All the SBR plant operators reported that these facilities are easier to operate than the conventional continuous-flow systems.
- All U. S. plants experienced some problems with their decanter mechanisms. These problems, which stem from MLSS entering the decanter piping during fill, react, and settle periods, have been corrected or are being corrected. Until a good decanter design has been developed and tested over a long period of time, it may be desirable to return the decanted effluent to the inlet end of the aeration basin during the first few minutes as done at Culver. It will be most desirable if development of different types of decanters is encouraged, because this device is crucial to the successful SBR operation.
- The floating decanter of the type used at Tamworth and Yamba in Australia seems to have a long proven history at plants in that country; however, it has not been used anywhere in the U. S. Two U. S. plants located at Tullahoma and Union City in Tennessee, currently under design or construction, plan to use this decanter. It will be valuable to monitor the performance of this device in the U. S.

ACKNOWLEDGMENTS

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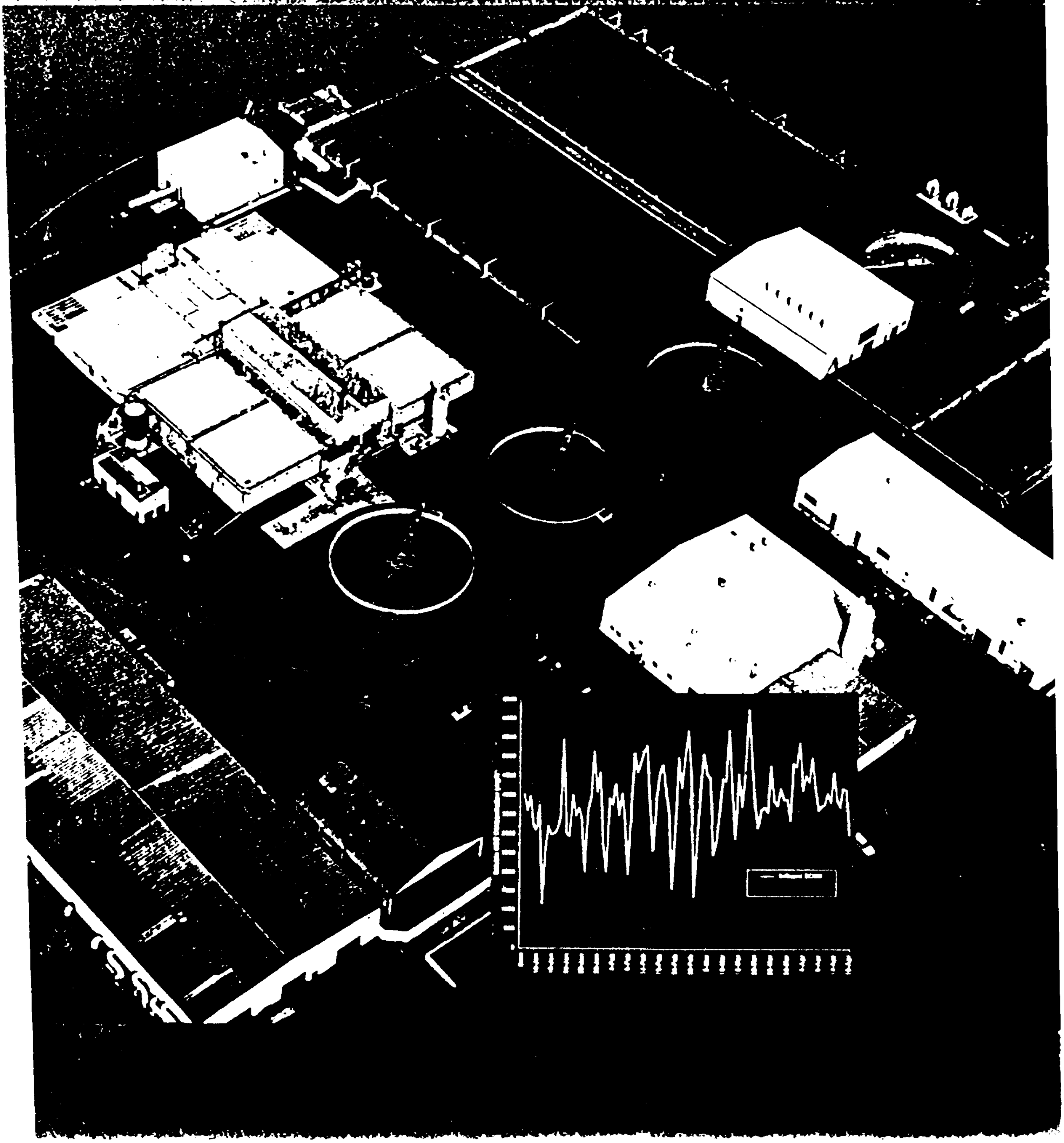


the biothane advantage

PROVEN RELIABILITY
More than one hundred industrial-scale plants now in operation throughout the world.

MAJOR REDUCTION IN BOD
Over 90% in most applications. Significantly lowers municipal surcharges and improves operating efficiency of on-site secondary treatment systems.

PRODUCTION OF USABLE ENERGY
Generates methane at approximately 0.35 cubic meter per Kg COD converted. Helps offset factory energy costs.

RAPID HYDRAULIC THROUGHPUT
Hydraulic retention time can be measured in hours. Permits responsive control of system operations.

HIGH LOADING CAPABILITY
Readily achieves 10-18 Kg COD per cubic meter of digester volume per day. Higher loadings possible as biomass adapts to specific wastewater.

QUICK SYSTEM START-UP
Full performance can be achieved in less than eight weeks with inoculation of granular biomass.

LOW SLUDGE PRODUCTION
Produces only one-tenth as much sludge as aerobic systems treating equivalent BOD load. Dramatically reduces disposal problems.

HIGHLY SETTLEABLE SLUDGE
Develops remarkable sludge granules which are characteristic of the Biothane process. Greatly facilitates biomass handling.

STABLE OPERATION
Resists upset from variety of wastewater pH, temperature and COD load conditions. System can remain dormant during factory "downtime" without affecting future performance.

COMPACT SIZE
Needs only a small fraction of equivalent aerobic space requirements. An area less than 1/3 acre can accommodate a Biothane system treating 50,000 Kg of COD per day.

ECONOMICAL OPERATION
Automated system control provides reliable, efficient operation without intensive labor costs. Digester is easy to maintain because it has no moving parts.

LONG LIFE
Attention to quality control and the use of state-of-the-art materials of construction assures a long operating life for the system components.

CLOSED SYSTEM
Sealed tank helps contain odors. Allows installation in urban areas.

VERSATILITY IN APPLICATION
Compact, self-contained anaerobic module can be easily interfaced with existing wastewater treatment systems.

COST EFFECTIVE
The bottom line. The Biothane process actually turns waste into an asset because methane recovery helps offset energy costs as wastewater treatment problems are solved.

the economics make sense

BIOGAS RECOVERY
A 1.0 MGD flow of wastewater containing a COD concentration of 6500 mg/1 can result in the generation of methane approaching 300,000 cubic feet per day (2700 therms). This can realize savings of 620,000 gallons of fuel oil in a 320-day operating year with a value of $500,000.

REDUCED SEWAGE ASSESSMENTS
An industry paying $70 per 1000 lbs BOD discharged with the aforementioned wastewater characteristics can save as much as $700,000 per 320-day operating year. Even larger potential savings can be accrued with higher-loaded wastewaters.

OPERATIONAL SAVINGS
Very low energy consumption, simplicity of operation and maintenance and the low production of biomass makes possible substantial savings relative to treatment of wastewater by on-site aerobic systems.

(cover photo) the compact Biothane system consisting of four covered digesters (left center) installed at Anheuser-Busch's Baldwinsville, New York brewery removes more than 90% of the organic pollutants contained in the high-strength wastewater prior to final polishing in the large aerobic basins and clarifiers...the inset graph highlights the excellent treatment efficiency by providing influent and effluent SCOD data through the anaerobic digesters for three months following start up of the Biothane system.

The bottom line with the Biothane process is fast payback ... two to three years for many applications.

Biothane®

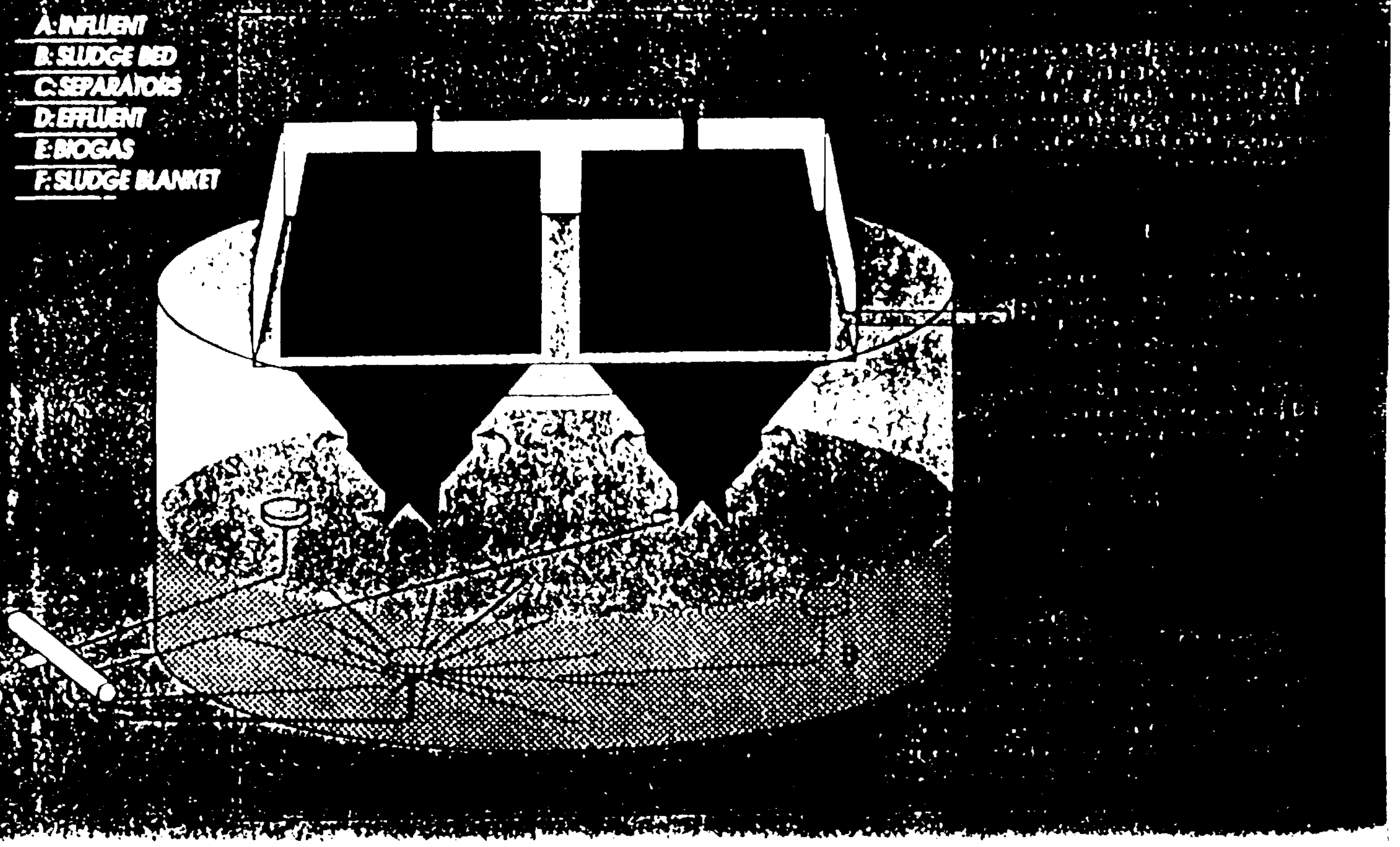
biothane, *still* the world leader in [illegible] technology

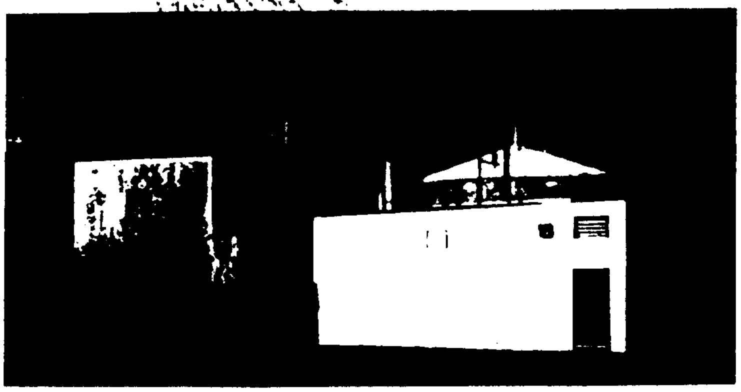
The Biothane [illegible] wastewater treatment process [illegible] United States and Canada [illegible] from Biothane Corporation of Camden, New Jersey, which owns the patent [illegible] the technology worldwide. [illegible] biological process [illegible] research and development [illegible] originated in the Netherlands and [illegible] ongoing both within Biothane Corporation and its Dutch subsidiary company, Biothane Systems International. The Biothane process has its generic origins in Upflow Anaerobic Sludge Blanket (UASB) concepts, but the incorporation of the patented three-phase separator [illegible] has enabled [illegible] into the state-of-the-art technology [illegible] treatment of wastewaters from a wide variety of food and related industries.

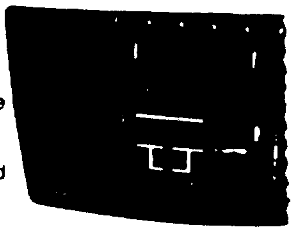
T[illegible] sludge [illegible] retained [illegible] very good [illegible] hydraulic [illegible] that [illegible] remarkable [illegible] characterize the Biothane process. Effective[illegible]

[illegible] wastewater [illegible] sludge [illegible] nature of [illegible] input. [illegible] digester [illegible] operate.

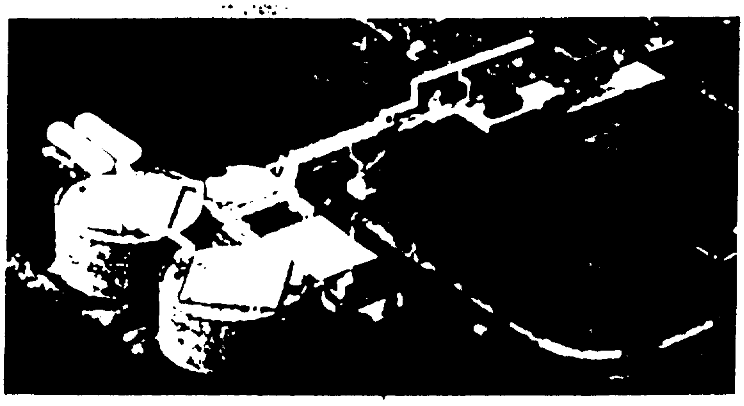
T[illegible] operation [illegible] loadings [illegible] (600 to [illegible]

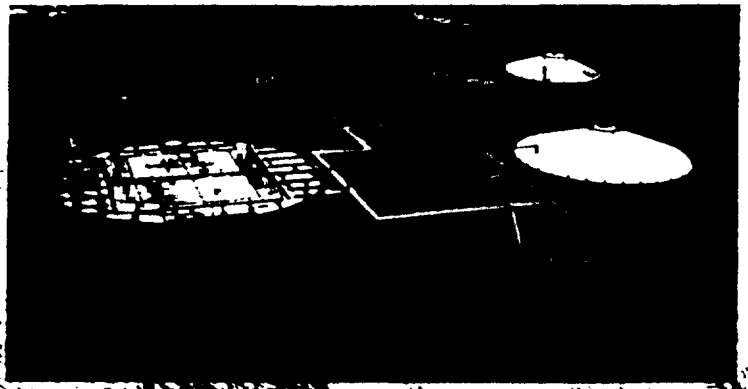






State-of-the-art microprocessor monitoring and control makes the Biothane process easy to operate and maintain and allows for fast automated response to any potential problems to insure long-term system stability.





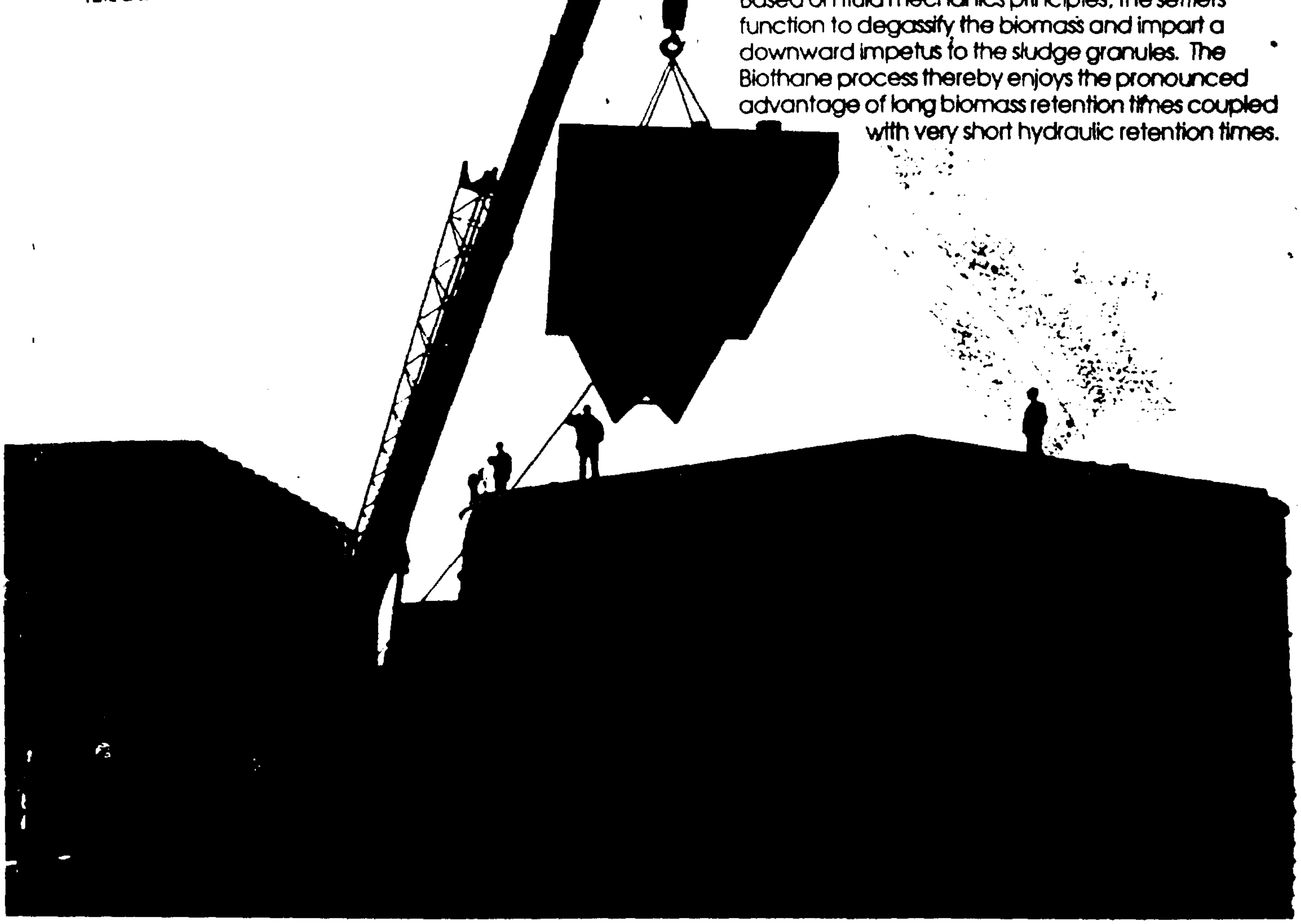
#1 Biothane systems come in various shapes and sizes. This compact concrete structure located at The J.M.Smucker Company is compartmented to contain a 600 m³ digester vessel, a 200 m³ conditioning tank, a small surplus sludge vessel, and the equipment and control building pictured towards the front right. The common wall construction is economical and practical for system users with high wastewater flow and relatively low-strength organic load. The Biothane facility at The J.M. Smucker plant is designed to treat a COD load of 5000 Kg/d contained in a flow of 0.4 MGD.

#2 The gleaming silver structure to the left of the picture is a 200 m³ Biothane package plant installed to treat wastewater from frozen yogurt production at Colombo, Inc. This package digester concept is ideal for system users who have organic loads of less than 6000 Kg/d COD. The small equipment and control building is located to the right of the digester, and the fiberglass domed roof of the upstream conditioning tank is visible in the background. The system at Colombo is designed to treat 2000 Kg/d of COD contained in a flow of 0.1 MGD.

#3 The twin 2500 m³ digesters at Eagle Yeast each treat 26,000 Kg/d of COD contained in a flow of 0.3 MGD. This New Jersey facility utilizes the generated biogas to supply a majority of the energy required in the manufacturing of its baker's yeast product. The system has been in operation since 1985 and routinely achieves a 90% BOD removal efficiency. The concept of parallel digester operation introduced so successfully at Eagle Yeast has been used subsequently in several large Biothane treatment installations.

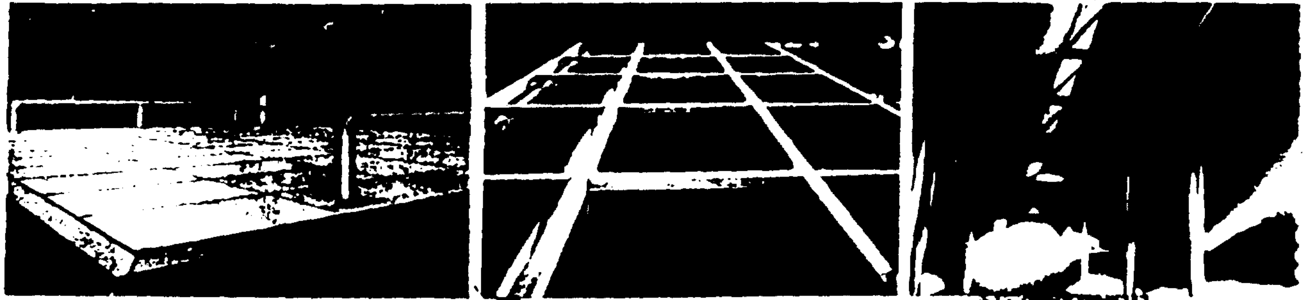
#4 The Biothane process offers significant energy savings compared to aerobic treatment systems. The generation of combustible biogas rich in methane can be utilized by the production facility, and the simple, space-efficient, process hydraulics and controls require minimal horsepower to operate and can be skid-mounted.

#5 The space compactness of the Biothane system is illustrated by the treatment of wastewater from Stone Container, a recycle paper mill. The entire system treating 7500 Kg/d COD contained in a flow of 0.3 MGD, is located on a site of less than 7000 square feet in area.



the settlers...the innovation that makes the difference

The specially designed patented internal settler sections form the heart of the Biothane digester. Based on fluid mechanics principles, the settlers function to degassify the biomass and impart a downward impetus to the sludge granules. The Biothane process thereby enjoys the pronounced advantage of long biomass retention times coupled with very short hydraulic retention times.



(top) The unique settler design results in [illegible] three-phase separation and promotes development of [illegible] biomass, here seen highly magnified through an electron microscope... (middle) A settler section is lifted into its proper position at the top of Ore-Ida Food's Biothane digester...(bottom left to right) The settler sections are sealed on top with [illegible] to retain heat and prevent escape of [illegible] of the fiberglass tubular gridwork [illegible] the settler section of a digester...The [illegible] bacteria looking upwards from inside [illegible]

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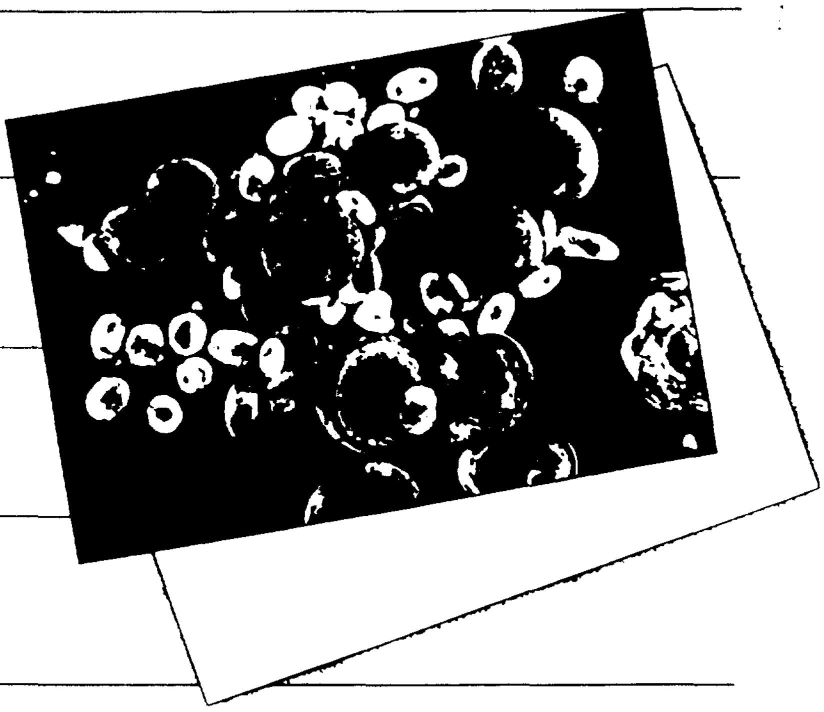
BREWERY WASTE WATER: ECONOMICAL AND TECHNOLOGICAL EFFECTIVE TREATMENT



BIOPAQ®

ANAEROBIC TREATMENT
EFFICIENT, RELIABLE, BIOLOGICAL

PAQUES

ENVIRONMENTAL TECHNOLOGY

BIOPAQ, THE TECHNOLOGY OF ANAEROBIC TREATMENT - PROVEN RELIABLE IN BREWERIES TOO, ALL ACROSS THE WORLD!

Breweries are more and more being affected by legislation requiring the improved treatment of waste water. The standards set for effluent are becoming increasingly stringent. Preconditions applying to such matters as the limitation of sludge production, energy consumption and space consumption are playing an important role. The reclamation of energy has also been demanding increasing attention. Partly as a result of practical experience in breweries, the Biopaq process has developed in a relatively short time into the world's most widely applied method of anaerobic treatment.

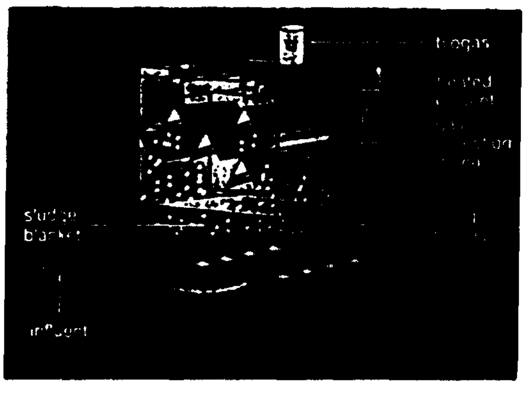
WHAT IS BEHIND THIS SUCCESS?

Through fundamental and applied research, the following hypothesis was confirmed: as a result of carefully controlled processing conditions, anaerobic bacteria can effectively break down organic impurities in brewery waste water. Biopaq technology offers the right processing conditions.

BIOPAQ: THE ANAEROBIC TREATMENT OF BREWERY WASTE WATER WITH THE BIOPAQ-UASB SYSTEM

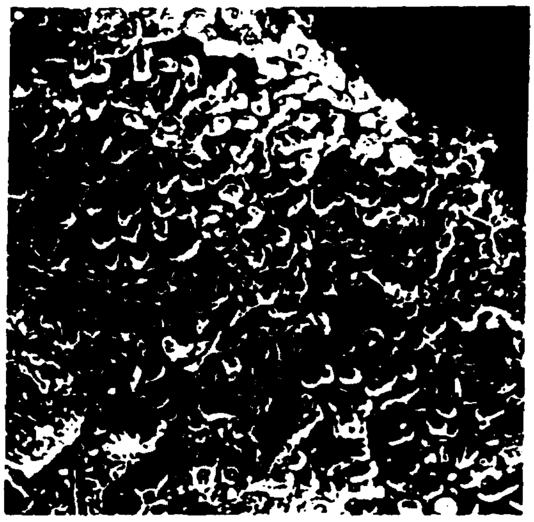
Brewery waste water is characterized by a high BOD/COD ratio (0.6-0.7) and a widely fluctuating composition. Treatment with the aid of the Biopaq system has proven to be extremely effective and reliable. Anaerobic bacteria are distinguished by a substantial capacity for removing COD. In the heart of the Biopaq installation, they reduce the fatty acids in the waste water to energy-rich methane (70-80%), carbon dioxide (20-30%) and a small amount of cell material (1-5%). In spite of the frequent influent peaks, water treated in this way has an extremely uniform quality. An important aspect

Waste water, sludge, the production of methane gas and treated water: the principle of the UASB reactor



Granulation

Aggregation of anaerobic bacteria in UASB granular sludge



BREWERY EXPERIENCE LEADS TO BIOPAQ INTEGRATED TECHNOLOGY

Since the early eighties, a tremendous amount of experience has been developed worldwide with the Biopaq process. By virtue of its ability to effectively handle the variations in COD in the waste water supplied, the Biopaq system produces an effluent of stable quality. This makes possible an exact sizing of any form of post-treatment. Moreover, the objective combination of the benefits of various systems is an important option of Biopaq integrated technology.

Aerobic? Anaerobic? Usually both - since brewery waste water is relatively easy to decompose. The anaerobic reactors can achieve high yields, a capacity which makes subsequent aerobic treatment relatively easy and inexpensive. Moreover, it is well known that anaerobic preliminary treatment substantially eliminates the familiar bulking sludge problem. This simplifies the aerobic post-treatment of the effluent.

Bavaria brewery

A PRACTICAL EXAMPLE

At a brewery with a production capacity of 1 million hl/year the COD load is about 6 tons per day. Traditional treatment of waste water requires 275 kW of power for aeration. The amount of sludge produced by this traditional treatment is very high: 2000 kg of dry material per day, corresponding to a volume of some 200 m3 and after mechanical thickening, to about 100 m3 (thus 6000 kg of well dissolved and readily degradable material is converted to 100 m3 of difficult-to-dispose-of sludge).

Anaerobic treatment, combined with aerobic post-treatment results in substantially better values:

- a total of only 40 kW of power is needed for aeration;
- a methane gas production results in about 150 kW of power or some 18 tons of steam per day;
- the residual sludge (from the anaerobic reactor) is reduced by 90%, to about 200 kg/d.

A SPECIFIC KNOWLEDGE OF THE BREWING PROCESS PROVIDES THE BASIS OF THE CORRECT TREATMENT CONFIGURATION

Built into every Biopaq system are the years of experience in a broad range of breweries. No two breweries in fact operate under exactly the same conditions. A specific knowledge of brewing processes combined with a specific knowledge of treatment technology results in optimum systems. PAQUES has built up so much experience in the brewing world that pilot research is not usually necessary. But since brewing processes can be considerably specialized, and waste water can vary substantially in composition, pilot studies are of course regularly conducted at many breweries. The choice of on-the-spot pilot studies and/or research only in the laboratories is important.

The fact that PAQUES provides a whole range of treatment technologies assures that the highest degree of objectivity is used to develop the recommendations resulting from the pilot studies. In this way, a PAQUES analysis report becomes a management tool of the first order.

THE WORLD'S TOP COMPANIES USE BIOPAQ TREATMENT but small producers of special beers have also learned to profit from this PAQUES technology.

In mid-1992, more than 30 brewery concerns had Biopaq treatment systems. Well-known quality brands set the trend while smaller specialist breweries likewise recognized the possibilities and advantages. Example: for the production of about 60 million hl/year PAQUES has realized more than 35,000 m3 of reactor volume, with a combined capacity of 6000 m3/hr.

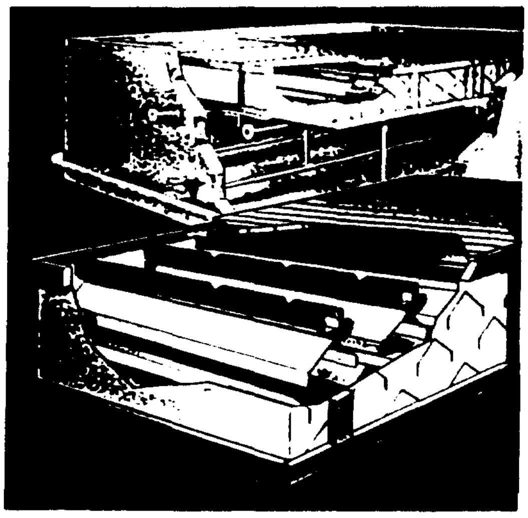
Polar brewery - Caracas, Venezuela

Pipe lines at Francaise de Brasserie

BIOPAQ INSTALLATIONS FOR BREWERIES: MODULAR SYSTEMS WITH OPERATIONAL RELIABILITY

Of course, success does not depend only on the process, but also on the way that process is applied in practice. The flow diagram of the anaerobic Biopaq installation is adjusted to this. This approach ensures optimum operational management and at the same time leads to lower running expenses.

Modular system - BIOPAQ-UASB reactors



The modular system guarantees a maximum flexibility of construction. In other words, for every production capacity, Biopaq technology offers the right treatment capacity.

The flow diagram below is a universal model. Conditions differ at every brewery, but three elements are always present.

1. Solids

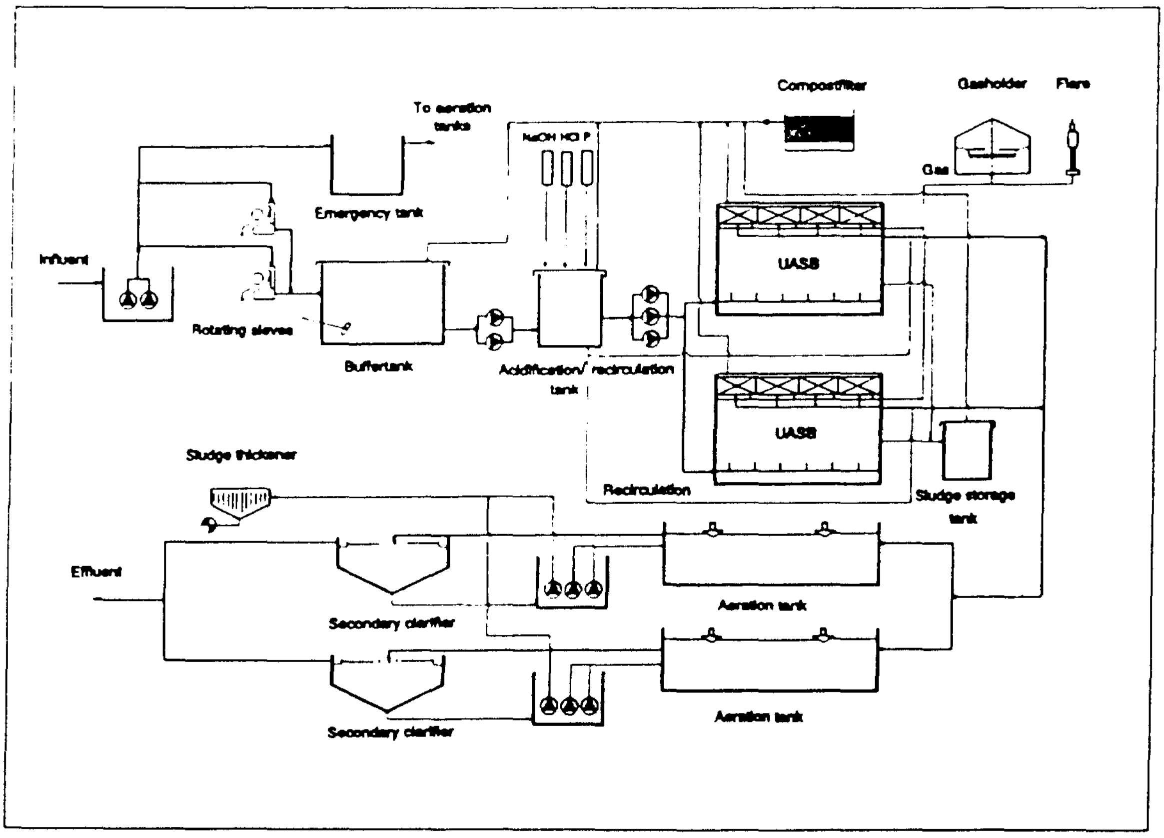
Biopaq anaerobic treatment is effective in removing COD. A preliminary treatment, however, is sometimes necessary to remove excessive amounts of solids. A careful analysis of the treatment of solids at the brewery (yeast, trub, spent grains) determines the preliminary treatment needed to avoid unnecessary primary sludge formation.
An integral application of biotechnology!

2. Pre-treatment

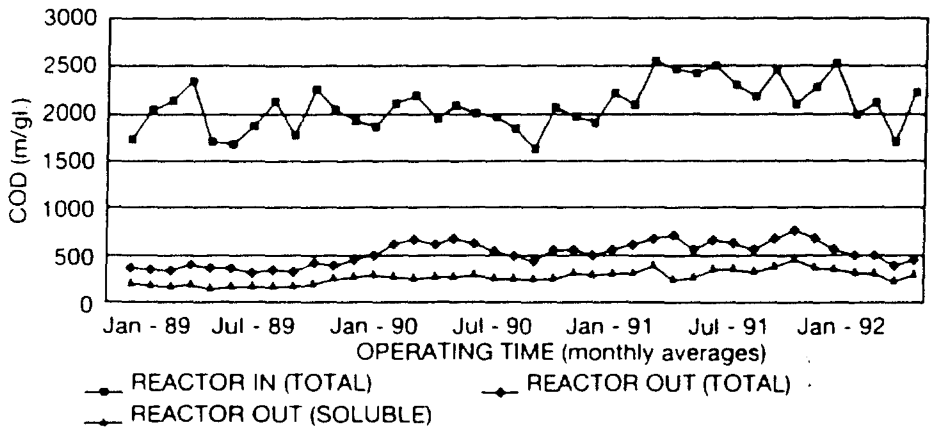
Part of the organic compounds must be converted to fatty acids in advance. An analysis of factors such as beer losses, the cleaning agents used and pH fluctuations is essential for determining the correct pre-treatment retention times.

3. Methane Formation

The practice-based development of the Biopaq process in breweries has shown that our procedure for the treatment of diluted waste water (low COD: 1000-1500 mg/l in a temperature range of 18-25°C) also achieves good efficiences.



Flow diagram, the principle of a Biopaq System. Clearly shown is the UASB reactor.



Monthly averaged COD concentrations in the UASB reactor influent and effluent for the period January 1989 - March 1992

Specific brewery indicators for the anaerobic treatment of wastewater with Biopaq.

organic load	1.5-2.0 kg COD/hl
surface needed	150-250 m2/million hl
energy production	15-25 Mj/hl
sludge production	10-15% of aerobic treatment
energy consumption	10-15% of aerobic treatment
number of reactor modules per million hl	9-11 modules/million hl.

CONVERSION OF EXISTING SYSTEMS

The rate at which breweries are being compelled to modify or completely replace their old treatment systems continues to accelerate. We regularly convert other existing anaerobic systems or replace them with a Biopaq installation.
(Note - a major reason for this is the fact that the Biopaq-UASB reactor is not subject to corrosion).

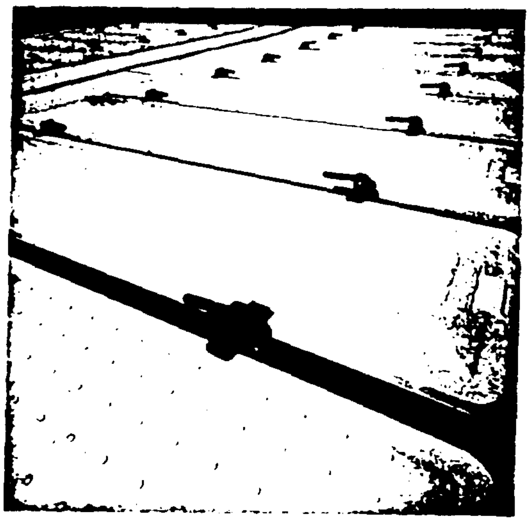
SERVICE AND BIOPAQ

Brewing processes demand a high degree of reliability at all levels - hence in the waste water treatment phase as well. This is why our customers are glad to know that they can count on the excellent service provided by PAQUES and its licensees. At all times, everywhere, worldwide. Buyers of a Biopaq system are making an investment in the security of a reliable system and a reliable supplier.

THE LIFE SPAN OF A BIOPAQ SYSTEM

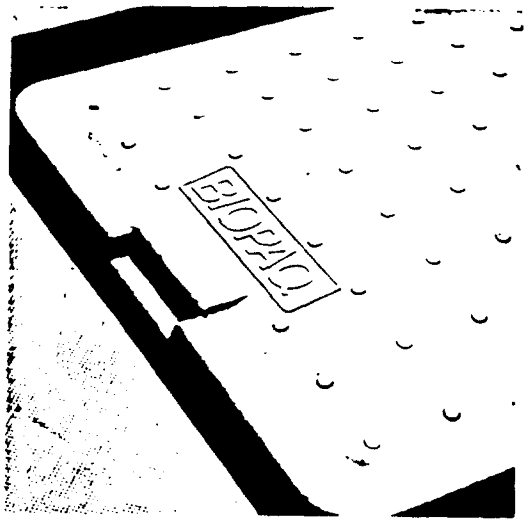
Biopaq systems derive their economic value from their COD reduction capacity and working life. Thus, the life span of our UASB reactors exceeds that of traditional steel reactors many times over!

Practical experience has resulted in the Biopaq system being constructed primarily of synthetic materials which are virtually unaffected by anaerobic conditions.



Corrosion-free long-lasting seal for BIOPAQ reactors

Biopaq - visible quality on the outside too



PAQUES - THE PEOPLE BEHIND BIOPAQ

PAQUES occupies an important place in the world of environmental technology and engineering. Underlying this leading position is a clear philosophy.

The environment in focus

All our dealings are based on the following mission statement: 'PAQUES aims at serving its customers and the environment through the development and realization of profitable and high-grade treatment engineering'.

In achieving this objective, the company has been successful on an international scale. A cohesive network of licensees - the people we see as our partners - has been built up and PAQUES engineers can regularly be found on location. There is an ongoing program of training projects for licensees and their employees.
A relatively large number of our personnel has a university or comparable education. This top level training, combined with our realistic approach is highly regarded by our customers.

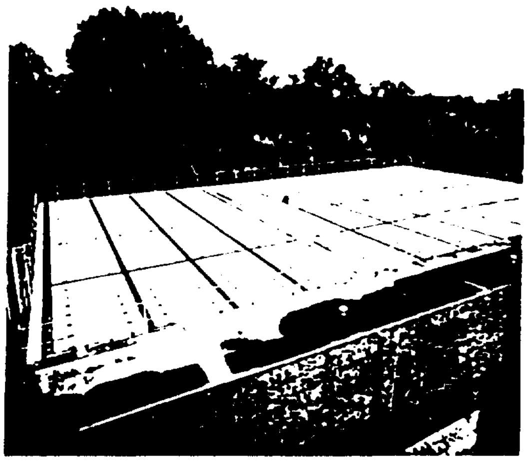
Waste water treatment at Heineken Brewery 's Hertogenbosch (BIOPAQ-IC installation)

Turnkey Experience

The turnkey projects that PAQUES has designed and implemented, particularly in the Benelux and France, have provided a wealth of valuable know-how.

To this end, of course, PAQUES has invested considerable sums in research and development. This too contributes to the success of Biopaq.

PAQUES BV is engaged in the further development and marketing of Environmental Technology and Environmental Systems. We maintain close contacts with various Universities and research institutes. Indeed, teamwork in the broadest sense of the word is the key to achieving our goals.



Bavaria brewery; waste water treatment

BIOPAQ

Mr. Omar Godoy Paolini, corporate manager of special projects, Polar brewery, Caracas, Venezuela

"The Polar brewery was obliged to select a technology that not only was capable of efficiently treating it's wastewater, but could also be erected in a limited area located in metropolitan Caracas. Several technologies were evaluated and only after extensive research and travel to Europe and the USA Paques B.V. was selected to participate in the project.

Paques engineers and biotechnologists collaborated with the Polar technical department in an harmonious and ethical manner to develop a suitable waste treatment concept. The technical support supplied after start-up was instrumental in resolving problems and assuring the stable operation of the waste water treatment plant.

Taking into account several factors associated with UASB reactors such as the low operating costs, small area requirement and minimal sludge production, we consider that the combination of UASB pretreatment and aerobic post-treatment of brewery wastewater offers many economic and operational benefits. For these reasons we are recommending this treatment combination for the expansion of our existing aerobic treatment facilities at our other three breweries.

In conclusion we affirm that the Polar brewery in Caracas is very proud to display as an example to the Industrial community and the Environmental authorities an industrial wastewater treatment plant that succesfully complies not only with the technical expectations but also presents a clean and neat appearance without bad odors or excessive noise."

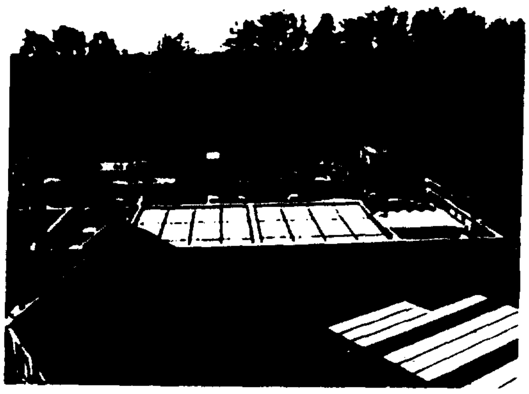
Caracas 18-08-'92

M. Gerstner, brewery director, Francaise de Brasserie, Mons en Baroeul, France

"Our wastewater treatment plant was started up in the spring of 1992.

The brewery of Francaise de Brasserie is situated in the urbanized area of Lille (France) and our process water contains relatively much sulphate (250 mg/l). For these reasons we required an odourless installation, and anaerobic effluent without sulphide to avoid nuisance when discharged.

The combination of a BIOPAQ anaerobic UASB-reactor with PAQUES' sulphide technology enabled us to treat our wastewater on site and discharge the effluent on the municipal sewer system."



THE BIOPAQ SYSTEM AT WORK:
POLAR BREWERY, CARACAS (VENEZUELA)

One of the four Polar breweries was founded in 1951, in the area of Los Cortijos, Caracas, Venezuela.

Today, this brewery is situated in the middle of a highly urbanized area, capable of producing over two million hl/yr of Venezuela's most popular beer. Due to the lack of area available the brewery's wastewater (6 m^3/hl beer bottled) was not yet being treated anaerobically, unlike the other three Polar breweries in the country.

The wastewater was discharged from the brewery into a main sewer, which joined a river crossing the city.

In the development of anaerobic technology for low concentrated wastewaters by a high rate process, Polar saw a solution to change the existing situation, and decided in 1986 to use this new technology in Venezuela.

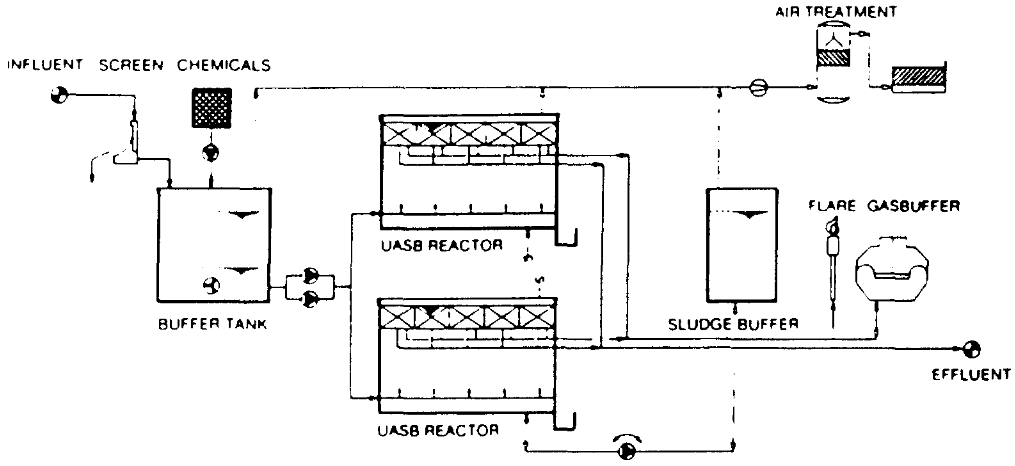
The BIOPAQ® process enabled the brewery to pre-treat their wastewater, removing the bulk of organic material instead of discharging it into the environment.

The successfull cooperation between Polar and PAQUES resulted in a unique conclusion to the project. Polar carried out a major part of the construction of the plant themselves, assisted by PAQUES' technicians. PAQUES was responsible for design, engineering and technological aspects, and for delivery of the major important items of the plant.

The plant is highly automated and operation is controlled by the brewery PLC, using monitors with light-pen, situated at various points in the brewery.

The two reactors are anticipating future expansion of the brewing capacity.

The little area available was used efficiently by placing (off-) gas- handling equipment, rotating sieve and flare on top of the preacidification tank. The compact set-up used just 825 m2 for treatment of 6.100 m3/d. Special care was taken for treatment of off-gasses to avoid any nuisance by the plant.



		Design
Wastewater		
COD load	kg/day	17,690
COD concentration	mg/l	2,900
Flow	m^3/d	6,100
UASB reactors		2
Volume	m^3	1118+950
Loading rate	kg COD/m^3. day	8,6
COD reduction anaerobic	%	80
HRT	hrs	8.4
Temperature	°C	30-35
Gas		
Production	m^3/d	5,800
Composition	% CH4	85

THE BIOPAQ SYSTEM AT WORK:
GROLSCH BREWERY, GROENLO (THE NETHERLANDS)

In 1615 the guild master Peter Cuypers founded the original Grolsch Brewery. Today, Grolsch has production facilities in Groenlo and Enschede and is among the best-known major beerproducers in the Netherlands.

The company's annual production of up to 1.750.000 hl of beer includes about 750.000 hl from the Groenlo operation.

For every hl of beer produced, some 3-4 hl of wastewater is produced which results in a total pollution load equivalent of a population of 12.000 people.

The wastewater of Grolsch Groenlo was treated in the municipal treatment facilities but the levies were high. In particular, the sudden modification of the Dutch Model regulation on Pollution Levy, January 1986, caused a steep increase in the company's wastewater costs.

Because quality is a guiding principle at Grolsch, the company was determined to find the best possible solution to their wastewater problem. Initial contacts between Grolsch and Paques had been made in 1984. Following the levy increase, Grolsch decided to install a Paques 3 m^3 reactor pilot plant. This six month trial showed that the wastewater from the brewery (Grolsch has no softdrink production and no malting facilities) was very well anaerobically biodegradable. Based on this result a final design for the full-scale plant was made.

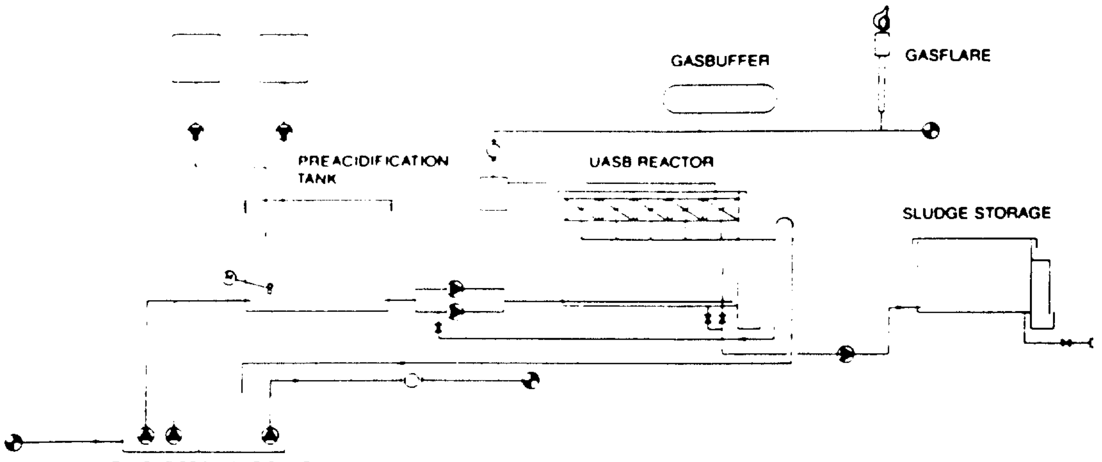
The plant was ordered for completion towards the end of 1986. Although basic and detailed engineering began immediately, actual production could only start in August 1987, because of delays by local government procedures.

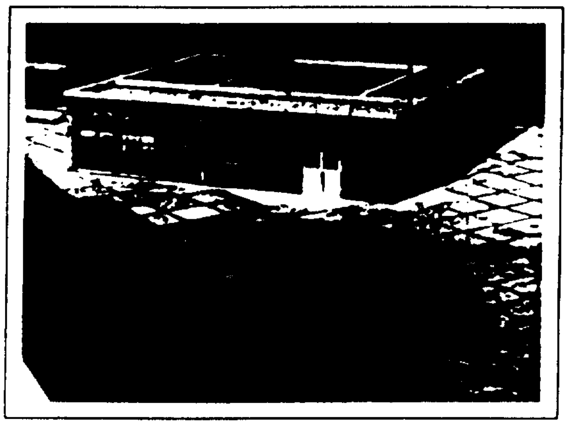
Upon completion of the construction, the plant was started-up and commissioned during the summer of 1988.

The rectangular Biopaq modules are used in this plant. Together with the rectangular shaped pre-acidification tank, sludge buffer tank and service building they form a neat "bungalow" treatment plant, housing all the relevant parts.

As an existing voluminous sewer was used as a buffer to cope with hydraulic and COD shock-loads, only a 200 m^3 mixed pre-acidification tank was required. The 300 m^3 Biopaq anaerobic reactor with a rectangular Biopaq modules has a volumetric loading rate of 7 kg COD/m^3.d. The incoming COD load of 2.050 kg can be biodegraded with at least 75 per cent efficiency.

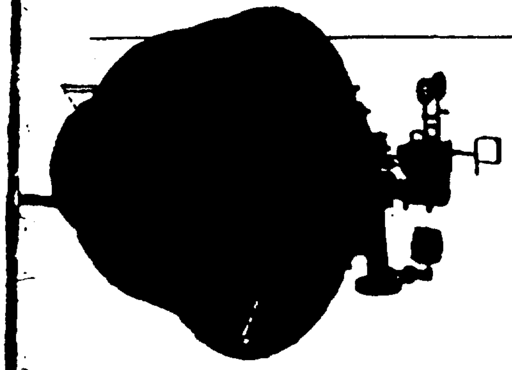
The 100 m^3 surplus sludge tank is equipped so that future pollution increases of up to 35 per cent could easily be handled by installing two Biopaq modules to convert it to a reactor.

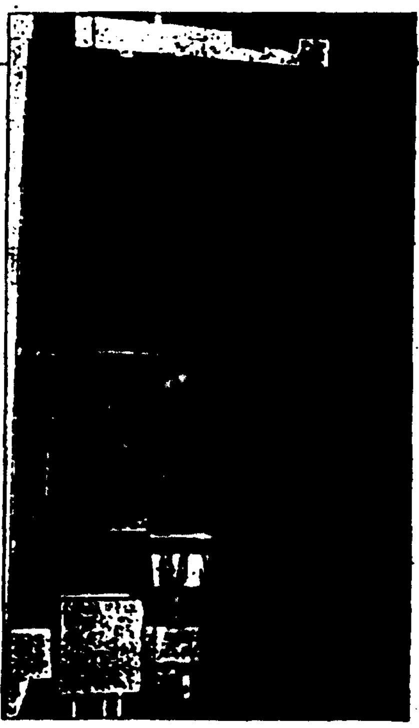




		Design
Waste-water		
COD-load	kg/day	2.050
COD-concentration	mg/l	1.500
Flow	m^3/d	1.350
UASB reactor		
Volume	m^3	300
Loading rate	kg COD/m^3 day	7
COD-reduction	%	77
H.R.T.	h	5.3
Temperature	°C	25-35
Gas		
Production	m^3/d	360
Composition	%CH_4	80

Year of realization 1988





The Variflame burner (above) has allowed the steam-generating furnace at right to be fed with up to 35% recycled fluegases. NOx emissions remain below the limits set forth in the new statute

Six boilers will meet a NOx limit of 30 ppm this year

BURNER RETROFITS REDUCE BREWERY EMISSONS

In 1988, the South Coast Air Quality Management District in California (SCAQMD) tightened its grip on industrial emissions of nitrogen oxides (NOx). The new statute, Rule 1146, mandates a 75% reduction in NOx emissions over a five-year period ending this July.

Anheuser-Busch Inc.'s second-largest brewery in Van Nuys fell under the new law's jurisdiction. The plant's six natural-gas-fired boilers, which produce 460,000 lb/h of steam for the brewing process, were the first to get attention. Three units, installed in 1953, have capacities of 50,000 lb/h. One, installed in 1964, produces up to 60,000 lb/h, and the other two, installed in 1980, can supply 125,000 lb/h each.

Under the new law, the maximum allowable NOx emission must be reduced from 120 to 30 ppm for the two largest boilers. There were two alternatives: either prevent its formation inside the boiler, or remove it from the offgases via selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR). Prevention was chosen, because the NOx-removal technologies are unproven in the U.S. on natural-gas-fired boilers. In addition, it was not known whether SCR or SNCR could respond to the wide swings in boiler demand. At any given time, loads between 30 and 100% of capacity would be required from the boilers.

The brewery retrofitted the 125,000-lb/h boilers with Variflame burners supplied by Todd Combustion Inc. of Stamford, Conn., based upon an earlier retrofit at Anheuser-Busch's Merrimack, N.H., brewery. Although that facility was not subject to strict NOx limits, the Merrimack facility had seen considerable fuel savings.

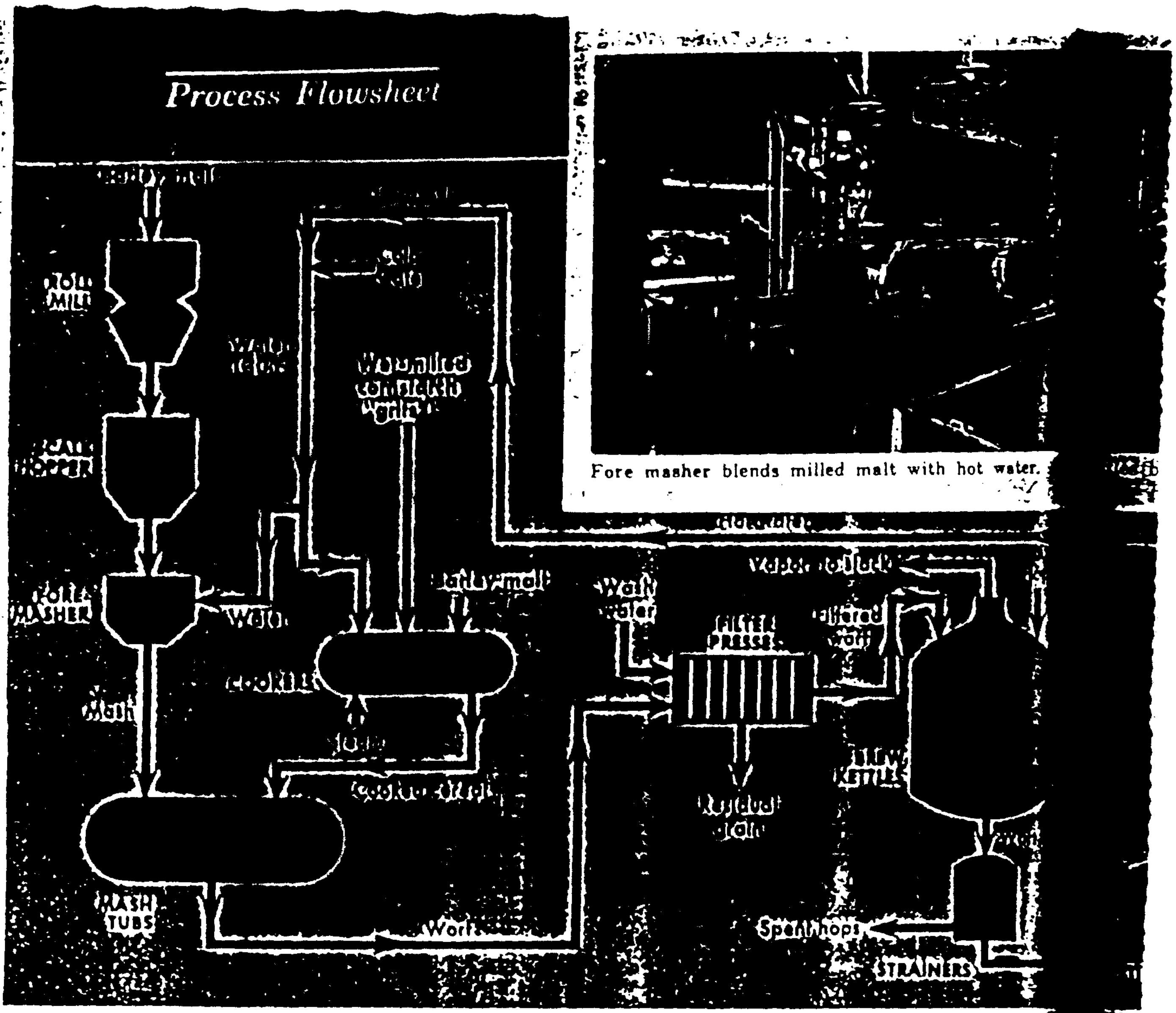
The Variflame burner has a venturi-register design that adds fuel and air to the flame in stages along the length of the burner. In conventional burners, fuel is added directly to the flame, where turbulence provides the necessary mixing. This causes uneven and very high flame temperatures — above 2,600°F — at which the majority of NOx is formed. In the new burner, the flame temperature stays between 2,400 and 2,600°F, just below the threshold temperature for NOx formation. In addition, the burner's flame stability reduced the boiler's excess-air requirement and allowed the increased use of recycled fluegases.

Conventional boilers typically require at least 20% excess air for efficient operation, due to poor mixing of the air and fuel. The improved mixing resulting from these burners allows the boilers to operate with 10% excess air, hence more efficiently.

Similarly, conventional boilers usually have problems when the amount of recycled fluegas exceeds 20%. However, recycled fluegas quenches the flame, decreasing its temperature and the amount of NOx formed. With the new burners, the boilers operate with 35% recycled fluegas.

One problem found after startup was the emission of high levels of carbon monoxide. Rather than coming from the burner, the emissions were traced to fluegas leaking from the furnace up into the tube bank. This occured when the tubes, which were supposed to touch, moved apart due to thermal expansion. Unburned fuel rose between the tubes and out the stack. The problem was solved by welding the tubes.

Monitoring of the retrofitted boilers revealed NOx emissions of 27 ppm. The 60,000-lb/h boiler will be retrofitted next. The three small boilers will present a challenge because they contain refractory insulation. These units hold in more heat than the others do, so that they have higher temperatures and higher NOx emissions.—*Todd Combustion, Inc., Stamford, Conn.* 448 ■


Process Flowsheet

Fore masher blends milled malt with hot water.

What's Doing in Beer Brewing

Grain products, hops and water combine in this gleaming brewery to yield a popular, long-honored thirst quencher.

N. P. CHOPEY, *Assistant Editor*

Though often not thought of as such, beer brewing is a genuine, full-fledged branch of the chemical process industries.

One successful representative of this field is the F. M. Schaefer Brewing Co., Brooklyn, N. Y. Long a marketer on the Atlantic Coast, the company has recently extended its coverage by starting to market in Ohio as well.

Annual output of Schaefer's brewery in Brooklyn is close to 2.7 million bbl./yr. (83.7 million gal./yr.). Most of this is sold in bottles or cans, the rest in kegs; the only process difference being that the small-container be pasteurized during packaging.

Unfold →

Beer brewing consists of four major First, kilned germinated grain (called ma well as a nongerminated cereal produc treated with hot water. This dissolves and allows enzymes, introduced by the m convert the starches to dextrins and malt

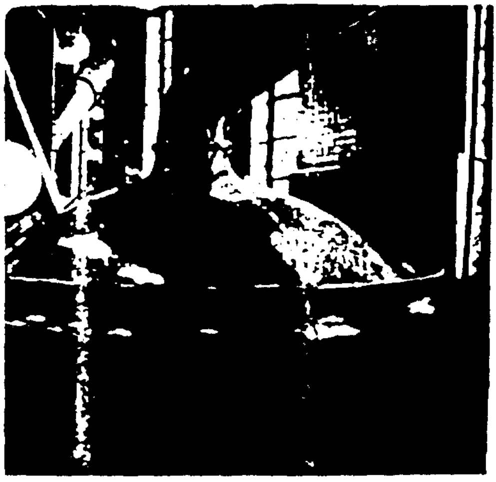
The resulting solution, called wort, is with hops, which impart beer's charact flavor and aroma. Then, the boiled wort is combined with yeast, and allowed to fermen ing fermentation, the yeast converts the sugars to alcohol and carbon dioxide.

Finally the beer goes to storage for la or maturing. It is carbonated either dur after storage, and then packaged.

Here are the specifics of how Schaef ries out this operation at Brooklyn.

▶ Making Wort—Typical of U. S. brewing pr

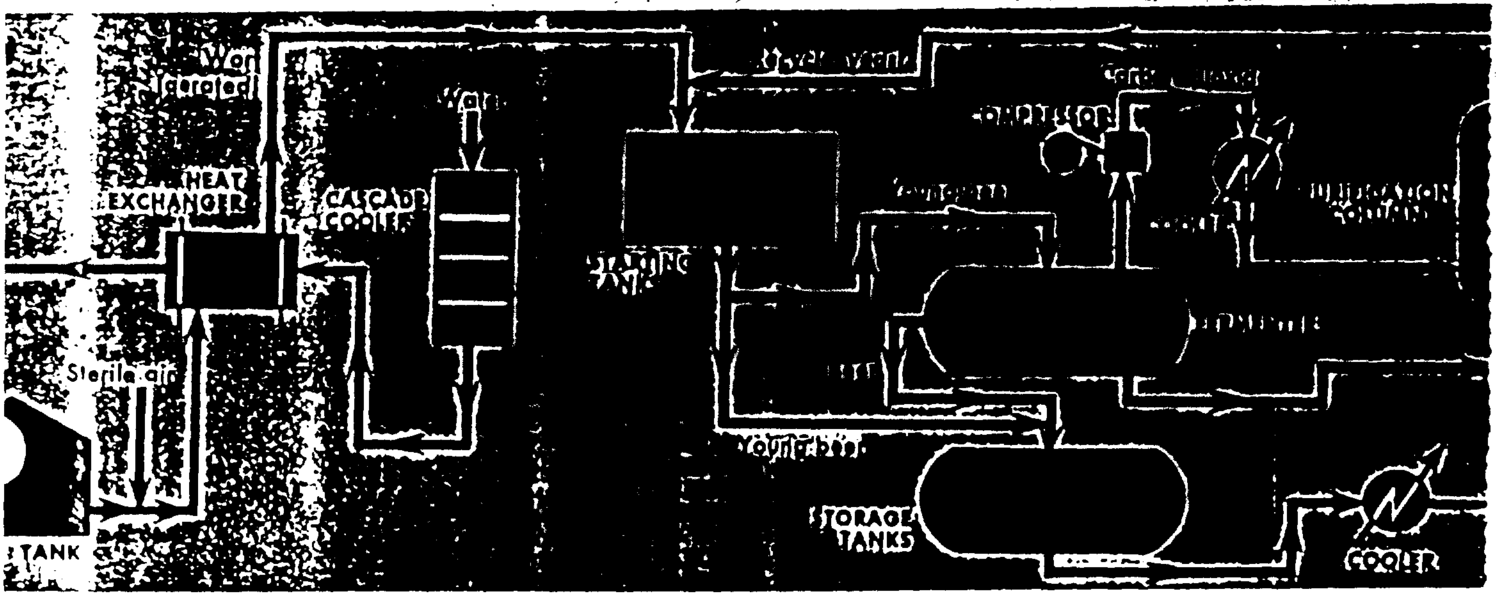
JUNE 25, 1962 • CHEMICAL ENGINEERING • PAGES 94-96



hops and wort together.

Starting tank is where the fermentation begins.

Fermentation tanks yi



ıklyn plant processes barley malt. This
ds to a roll mill similar to a flour mill and
x rolls. Particle distribution of the milled
uch that 10% is retained by a 14-mesh
ıd 30% by a 30-mesh screen, the rest
ıoth screens.

ıtch of milled malt mixes with 130 F.
ıd the mixture drops into a horizontal
ıl vessel known as a mash tub or tun.
ıwhile, wet-milled cornstarch, called
ırewers' grits," feeds to a similar cooker
ere it combines with 130 F. water and
ıund malt; purpose of the latter is to
he mixture from becoming too viscous.
ərators introduce live steam, and the
boils for about 10 min. to dissolve the
Resulting solution enters the mash tub.
, a helical, ribbon-type mixer agitates
ure. Then the latter rests for about
ear 160 F., allowing the enzyme-induced
ı to occur and produce wort.

g **Wort**—After this conversion, the mash
ate-and-frame filter presses that separate
ısolved grain constituents.

The brewery has four of these presses, each containing 58 chambers. Many brewers carry out this filtration in false-bottomed vats called lauter tubs. Schaefer uses the filters because of plant space limitations, but also believes that the filters achieve better separation and higher yield. Though they incur greater manpower costs at present, the situation will be alleviated next year when the brewery automates the filtering operation.

The spent grain is sparged with water; then the wort goes to one of six brew kettles, having an average capacity of 18,600 gal., that contain steam coils and also a steam-heated percolator.

To brew a batch, operators first introduce water to the kettle and apply heat through the coils. Then the wort is gradually added and the percolator turned on. Hops also feed to the kettle, and the mixture brews for about 5 hr. at roughly 212 F. and a pH of 5.3.

This brewing sterilizes the solution, inactivates the enzymes, extracts flavor from the hops, and completes the reactions of the malt sugars and malt proteins.

Hot wort next passes through one of a pair of strainer vessel
which contain an
tains spent hops
Strained wort the

▶ **Fermentation**—
wort is line-blen
through a shell-
cools the solution
12% dissolved ext
line-blends with
goes to one of a
These each h
tain the mixture
mentation to star
fermenters, leavin
proteins and hop

The closed
about 35,000 gal.,
control. Ferments
to six days, its p
beer's specific gra

Carbon dioxic
to a purification ar
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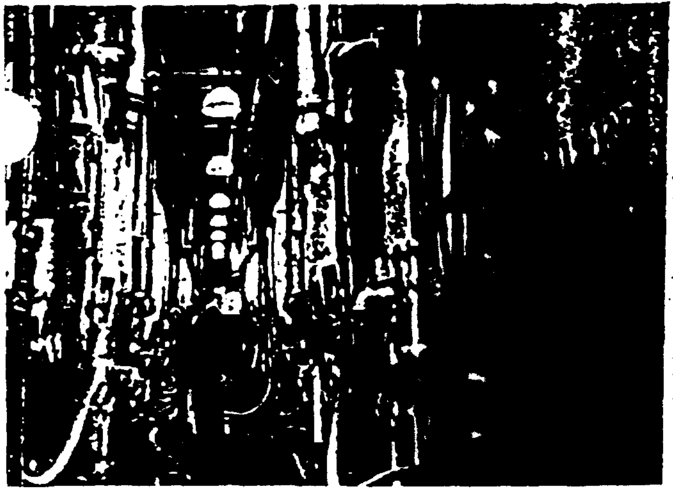
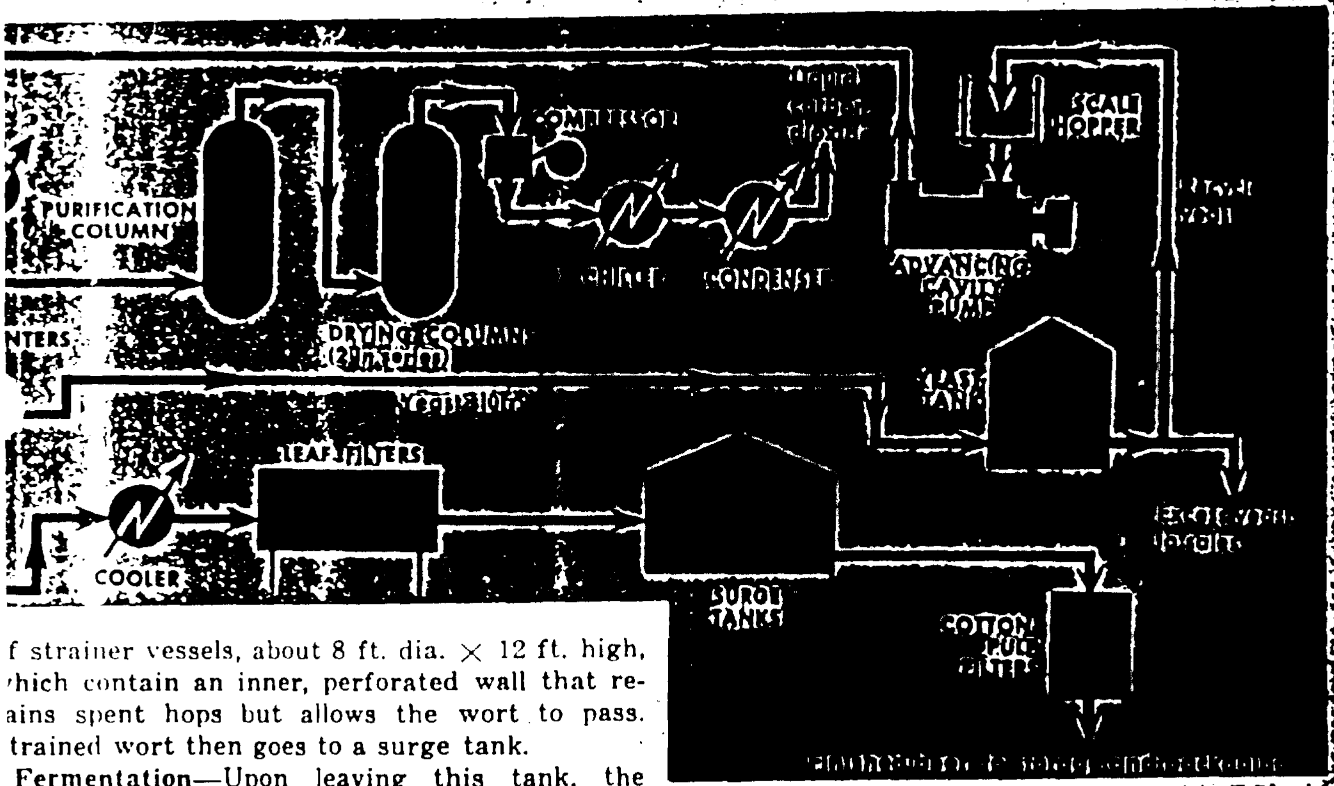


mentation tanks yield beer ready for mellowing.



f strainer vessels, about 8 ft. dia. × 12 ft. high, hich contain an inner, perforated wall that reains spent hops but allows the wort to pass. trained wort then goes to a surge tank.

Fermentation—Upon leaving this tank, the ort is line-blended with sterile air, then sent hrough a shell-and-tube heat exchanger that ols the solution to about 50 F. Containing some 2% dissolved extract at this point, the wort next ne-blends with yeast slurry, and the mixture oes to one of a series of open "starting tanks."

These each hold about 50,000 gal. They conin the mixture for up to 18 hr., allowing ferentation to start. Then the beer goes to closed rmenters, leaving behind a residue of coagulated roteins and hop petals, called trub.

The closed fermenters, typically holding out 35,000 gal., have brine coils for temperature ntrol. Fermentation takes place in them for up six days, its progress being indicated by the er's specific gravity and temperature.

Carbon dioxide comes off overhead and goes a purification and liquefaction system. Schaefer now modernizing this operation, installing a water-scrubbing column to replace four large spray-injector tanks. The carbon dioxide has many uses around the brewery because it provides a valuable inert atmosphere as well as a means for final adjustment of carbonation.

After fermentation is completed, the beer is decanted from the yeast and sent to storage. The yeast stream comes off the bottom. Fermentation produces a fivefold increase in yeast, so part is withdrawn for sale as animal feed while the rest recycles.

▶ **Storage**—The beer is mellowed by storage for 3-5 wks., in cylindrical glass-lined steel tanks, or in rectangular concrete ones that are lined with microwax. The tanks have an average capacity of 31,000 gal.

Schaefer is one of the few large breweries in the U.S. to carbonate its beer "naturally" during storage. This process, called Kraeusening, is accomplished by introducing a small portion, under 20%, of new beer directly from the starting tanks; as the new beer ferments in the storage tanks, it carbonates the batch. Batch temperature in storage starts around 43 F., then rises during the fermentation. For the last portion of storage, it is lowered to about 32 F.

The beer is finished for packaging by cooling to 29 F., then being passed successively through a leaf filter, a tank and a cotton-pulp filter.

Schaefer's brew kettles are of copper, as are the lines for handling in-process beer. The plate-and-frame wort filters are cast iron. All other plant equipment, including the finished-beer lines, are stainless steel.

SECTION III

S.I.C. 2082 MALT LIQUOR

Industry Description

The malt liquor industry in the United States is the world's largest with total sales of 17.4 million m^3 in 1973 worth $4.3 billion. Per capita consumption was 112 l/yr in 1973. The brewing industry is a very heavy user of water with about 100 facilities discharging in excess of 230 million m^3 of wastewater/yr (67).

Breweries are scattered through the United States with most large facilities located in or near large urban areas. In recent years, the southern states as a geographical area have shown the greatest percentage increase in production but the north central states still account for 45 percent of the total U.S. brewing capacity. Table 1 gives geographic distribution of U.S. breweries.

TABLE 1. GEOGRAPHIC DISTRIBUTION OF BREWERIES AND CAPACITY, 1974 (39)

Region	Plant Numbers	Percent	Total Year Capacity 10^6 m^3 (10^6 bbl)	Percent
Northeast	30	30	3.67 (31.3)	20
North Central	30	30	8.34 (71.1)	45
South	25	25	4.69 (40.0)	25
West	15	15	2.03 (17.3)	10
TOTALS	100	100	18.70 (159.7)	100

In recent years, the trend has been toward more production with fewer facilities. In 1967, 185 breweries produced about 12.7 million m^3 of beer and by 1973 129 breweries produced 17.4 million m^3. This trend will likely continue. As a whole, the industry is projected to grow at a rate of 6.7% per year making shipments worth $7.3 billion by 1980 (67). This growth will result from an increased number of people in the 18-44 age group.

Production Methods and Wastewater Sources

The basic processes and raw materials used to make beer are quite standard throughout the industry. A general outline of these procedures and the resulting wastes is given below. A process diagram is shown in Figure 1.

The brewing of beer is a batch process. First, the cereal grains (rice or corn) are cooked to solubilize the starches. Then, the grains are mixed with malt to allow the malt enzymes to convert the starches to sugars. This mixture of malt and grains is referred to as the "mash." The mash is sent to the mash filter press to remove the spent grain which is a valuable by-product. The remaining clear liquor (wort) is sent to the brew kettle where hops are added for flavor. The mixture is boiled to coagulate the undesirable protein (trub). Then, the hops are strained out in the hop jack and the wort is pumped to the wort cooler where the trub is removed as a sludge-like sediment. Frequently, the cooled wort is filtered with diatomaceous earth to remove any residual trub. The clear wort is sent to the fermentor where yeast is added to convert the sugars to alcohol and carbon dioxide. After the fermentation is complete, the excess yeast is removed and the beer is cooled and placed in primary storage. After sufficient aging in primary storage, the beer is filtered, carbonated, and placed in secondary storage to await packaging. The filters remove the residual yeast. The beer may be filtered again just prior to packaging. The product is sold in bottles, cans, or barrels.

Figure 2 gives a summary of the raw materials used to make a cubic meter of beer and Table 2 gives a breakdown of water usage within the brewery.

TABLE 2. WATER USAGE WITHIN A BREWERY (2)

Process	Water Usage (m^3/m^3 beer)	
Cooling Water	1.42	13%
Process Water	3.6	33%
Bottle Washing	2.9	26%
Misc.	3.1	[illegible]
	[illegible]	

Wastewater Characteristics

Although there may be large temporal variations in production, most breweries operate throughout the year. Generally, breweries combine all the individual waste streams except cooling water into a single stream. Brewing effluents are high in soluble organics, low in nutrients and high in temperature. Table 3 lists some of the characteristics of a brewery's total effluent and Table 4 shows the differences in effluent

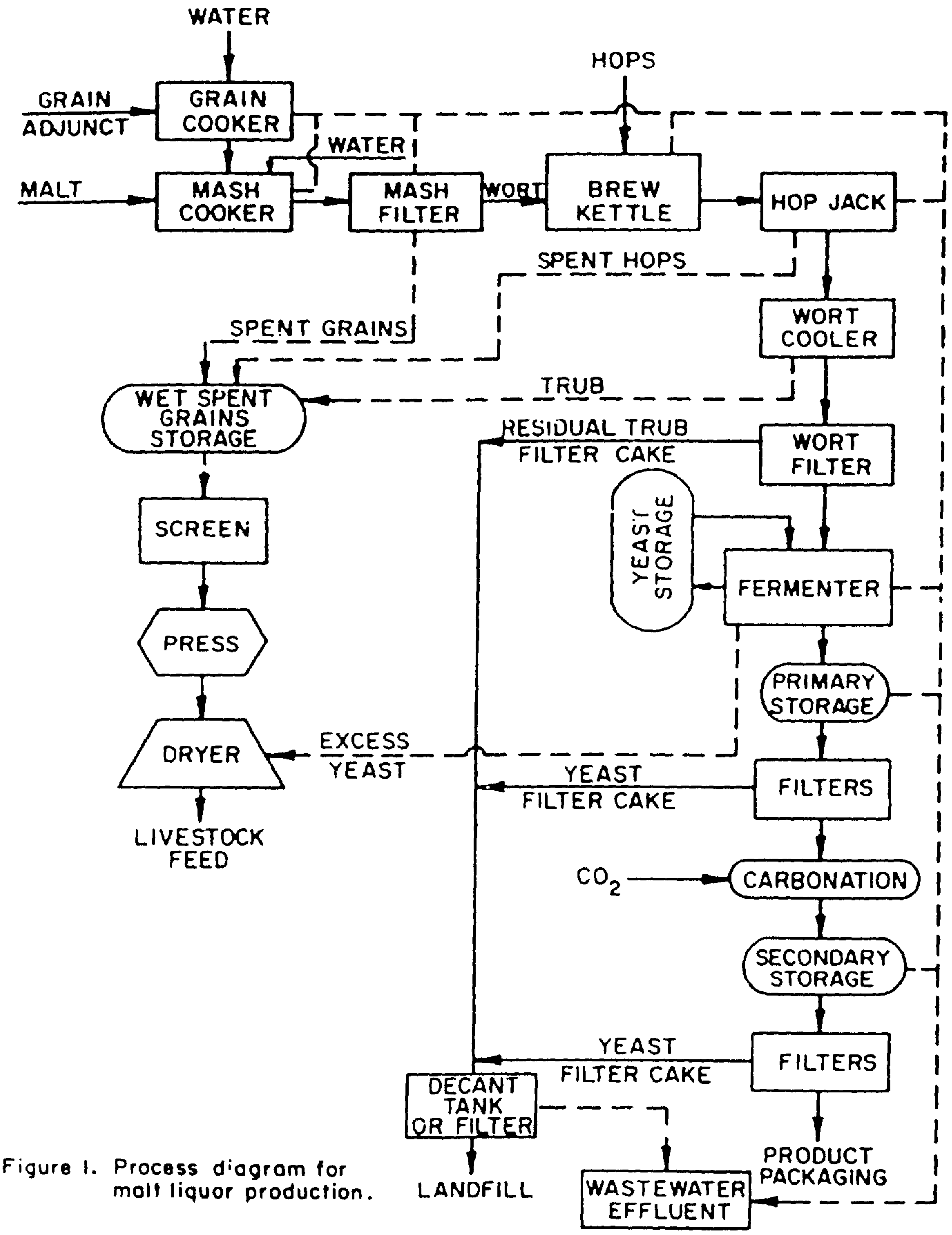


Figure 1. Process diagram for malt liquor production.

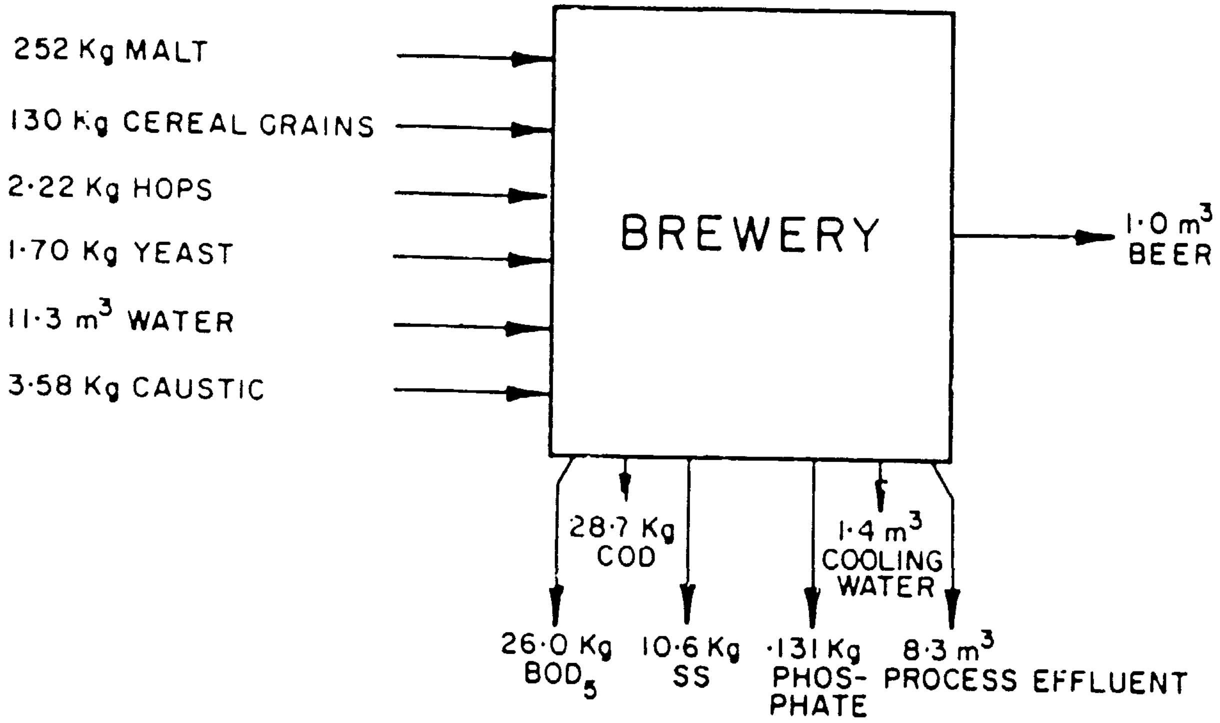


Figure 2. Brewery input-output characteristics (2).

characteristics for different classes of breweries. Discrepancies in flow and wastewater characteristics are due to different sources of information.

A breakdown of individual process effluents is given in Tables 5-8. Spent yeast and trub are major sources of pollutants accounting for about 56% of the total BOD_5 and 44% of the SS assuming no recovery (30).

TABLE 3. BREWERY TOTAL EFFLUENT CHARACTERISTICS (2, 37, 72, 58)

Characteristic	Average	Range
BOD_5 (mg/l)	1718	1622-1784
(kg/m^3 beer)	10.4	9.43-11.8
SS (mg/l)	817	723-957
(kg/m^3 beer)	4.18	3.83-4.79
pH	7.4	6.5-8.0
Temp. (°C)	30	28-32
Process Effluent Volume (m^3/m^3 beer)	6.9	5.5-8.3

TABLE 4. EFFLUENT CHARACTERISTICS FOR DIFFERENT CLASSES OF BREWERIES (58)

	Brewery Classification							
	New Large		Old Large		Effl. Limited		Other	
Characteristic	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
BOD_5 (kg/m^3 beer)	10.5	3.01	18.8	2.13	1.74	--	8.47	7.46
SS (kg/m^3 beer)	3.86	1.58	7.34	2.51	1.08	--	3.63	3.75
Process Effluent Volume (m^3/m^3 beer)	5.41	--	11.03	--	1.62	--	7.71	--

TABLE 5. SOURCES OF POLLUTANTS FROM A BREWERY (30)

Source	BOD_5 (kg/m^3 beer)	BOD_5 (%)	SS (kg/m^3 beer)	SS (%)
Yeast	3.71	30	2.55	30
Trub	3.21	26	1.24	14
Hops	0.39	3	0.77	9
Pressed Grain Liquor	0.85	7	0.50	6
Drain & Rinse	2.09	17	0.85	10
Filter Effluent	0.50	4	1.58	19
Bottling	1.20	10	0.66	8
Misc.	0.42	3	0.35	4
TOTAL	12.4	100	8.50	100

TABLE 6. PRINCIPAL WASTE STREAMS FROM THE BREWING PROCESS (4)

Source	BOD_5 (mg/l)	SS (mg/l)
Washings from kettles, cookers and grain separators	200-7,000	100-2,000
Screen and press liquor	15,000	20,000
Trub	50,000	28,000
Yeast	150,000	800
Clarification precipitates	60,000	100
Spent filter aid	--	--
Beer	90,000	4,000
Cleaning solutions	1,000	100

TABLE 7. RAW WASTE CONTRIBUTIONS FROM IN-PLANT SOURCES (2)

Source of Raw Waste	Brewery Industry Mean Raw Waste Volume (m^3/m^3 beer)
Cooling water	1.40
House cleaning	0.70
Aging	0.40
Filtration	0.70
Fermentation	0.30
Brewing	1.20
Malting	--
Other	3.60
TOTAL	8.30

TABLE 8. TYPICAL CONCENTRATIONS OF WASTES DISCHARGED FROM SPECIFIC BREWERY OPERATIONS (36)

Brewing Operation	SS (mg/l)	BOD_5 (mg/l)
Cereal cooker	300	700
Mash tun	300	2,000
Lauter tun	3,000	10,000
Spent grain tank (or press)	10,000	15,000
Brew kettle	100	300
Hot wort tank (inc. trub)	5,000	10,000
Wort cooler	20	30
Fermentation tanks	2,000	5,000
Ruh chiller	30	700
Ruh tanks (primary aging)	20,000	30,000
Primary filtration	30,000	40,000
Aging tanks	600	10,000
Final filtration	500	100
Finished beer tanks	200	50
NON-RETURNABLES		
Rinser	3	20
Pasteurizer	--	50
RETURNABLES		
Prerinse	200	500
Final rinse	10	10
Pasteurizer	20	30

TABLE 8. TYPICAL CONCENTRATIONS OF WASTES DISCHARGED FROM SPECIFIC BREWERY OPERATIONS (36) [Continued]

Brewing Operation	SS (mg/l)	BOD_5 (mg/l)
KEGS		
Prerinse	100	1,000
MISCELLANEOUS WASTES		
Bottle and can filler drip	--	50,000
Conveyor lube drip	1,000	5,000
Spray tunnel drip	40	3,000
Floor hosedown	--	--

Wastewater Management

The nature of the brewing industry and the resulting wastewater present some special management problems. As previously described, the wastewater is characteristically high in organics, solids, and volume (a large brewery may discharge in excess of 4 million m^3/yr. The combination of these factors makes disposal in natural watercourses unacceptable; therefore, most brewing wastes are sent to municipal treatment systems. Here, due to the strength, the brewery waste may be only 4 percent or 5 percent of the total influent but 25 percent of the total BOD loading. Because brewery wastewaters are quite variable as to flow and strength, a municipal system can experience severe shock loads.

Most beer is produced in large metropolitan areas so a high capacity municipal system is available for wastewater disposal. Recently, there has been a tendency to build new breweries in smaller cities and towns. This situation will require brewery-owned treatment plants or expansion of the existing municipal facilities.

Recycling

In-plant recycling of potential waste streams is practiced on a limited basis. The glass bottle is the most important container used for retail sales and the major portion of these bottles are the refillable type. In fact, a Senate committee has considered a bill to make all beer and soft drink bottles refillable as is the case in Oregon (56). Washing of refillable bottles is a major operation in a brewery and is likely to remain so. The large metal containers (half-barrels, quarter-barrels, etc.) are also recycled and must be washed. This container washing plus plant clean-up requires an average of about 1.62 kg of caustic per m^3 of beer produced (2). Most breweries put the cleaning caustic directly into the sewer, however, 10 percent of the very large production breweries do recycle it. For a brewery producing hundreds of thousands or even millions of barrels per year the cost savings and waste reduction could be very significant.

The liquid remaining after the spent hops are pressed can also be recycled. Customarily, this high strength waste is put in the sewer or, in a few large facilities, it is mixed with the spent grains. However, a few breweries (abour 10 percent) recycle the spent hop liquid back into the brewing process; usually right after the wort leaves the brew kettle (2). One particular article (36) in the literature discusses several alternatives open to a brewery facing increasing sewer surcharges including: no changes, implement a rigid water-conservation program, treat and reuse the packaging wastewaters and treat all brewing and packaging wastewaters by secondary biological stabilization and carbon adsorption. Of these alternatives the authors suggest that treating the packaging wastewater using carbon adsorption is the most economical with increasing surcharges as more municipal plants incorporate secondary treatment. Using this system only the weak packaging wastewaters which are about 50-75 percent more voluminous than the process effluents will be treated and reused within the brewery. This will reduce sewer charges and water costs which can be very large for a brewery.

By-Product Recovery

Recovery of waste solids from different process streams is practiced extensively in the brewing industry and it appears to be the best method of reducing waste loads both technically and economically. Grains, hops, trub, yeast, and lost beer are all currently being recovered (14).

Spent grains (barley, rice and/or corn) are recovered by virtually all breweries large and small. The grains are removed from the brewing process after the starches have been solubilized and then converted to sugars. Most smaller brewers and about half of the larger ones utilize the lauter tun filter, which is a gravity filtration device, to separate the grains from the mash. A disadvantage is that it requires a large amount of water to sluice out the spent grain. Some larger plants employ a plate and frame filter which is showing increased use. The grains are screened and pressed to reduce the moisture content. The press liquor is frequently put in the sewer; however, it has been recycled back into the process or filtered, centrifuged, evaporated and added to the spent grains (17).

Following recovery, most small breweries haul the spent grains away wet for use as cattle feed. Large facilities dry the grains before shipment to cut down on transportation costs. In either case the spent grains make an excellent and very valuable cattle feed. A recent study of livestock feeding of wet brewery by-products indicated that an optimum moisture content is between 75 percent and 80 percent and that adequate protein is available in grain-yeast mixtures so no supplements are needed (30).

Spent hops are separated from the brewing process by a hop jack filter after the wort leaves the brewing kettle. The smallest breweries usually haul wet spent hops away and the largest add them to the spent grains to be dried. A study (30) has demonstrated that up to 10 percent wet spent hops can be added to the spent grains with no deleterious effect on voluntary uptake by cattle. The use of hop extract in the brewing process, which eliminates the hop disposal problem at the brewery, has been on the increase with 17 percent of the plants employing it in 1971 (2).

Table 10. COORS BARLEY MALT PROTEIN (18)

	Percent
Protein	50
Fat	10
Fiber	2
Nitrogen Free Extract	29
Carbohydrates	31
Ash	3
Moisture	6
Amino Acids	
Lysine	3.25
Histidine	1.74
Ammonia	3.06
Arginine	5.60
Asportic Acid	5.62
Threonine	4.10
Serine	3.98
Glutamic Aicd	24.56
Proline	11.56
Gylcine	3.62
Alanine	5.38
Half Cystine	0.99
Valine	4.63
Methionine	1.88
Isoleucine	2.44
Leucine	7.05
Tyrosine	4.05
Phenylalanine	6.45
	100.00

TABLE 11. LOADING AND EFFICIENCY OF CITY TREATMENT PLANTS CONTAINING BREWERY WASTES (4)

City	Flow (m^3/day)	% of Flow Contributed by Brewery	Treatment Plant Influent Strength (mg/l)	Efficiency (%)
Merrimac, NH	12,000 (Design 18,925)	100	BOD_5: 1200-5000 SS: 200-400	90
Frankenmuth, MI	2271-2650	50	BOD_5: 1400-1500	BOD_5: 90-95 SS: 50-85
Belleville, IL	25,170	20	BOD_5: 400-500 SS: 275-350	94

Two U.S. breweries own and operate their waste treatment facilities: Pabst Brewery in Perry, Georgia, and Coors in Golden, Colorado. In 1970, the Pabst Brewery at Perry, Georgia went on line in a rural area about 6 miles from Perry where no municipal treatment facilities were available. The brewery was designated for an initial production capacity of 1.76 million m^3/yr. The receiving stream was unpolluted and had a minimum flow of about 1000 l/sec which dictated an efficient treatment system to maintain the water quality.

Preceeding the treatment plant is an extensive in-plant by-product recovery and waste collection system. The brewery recovers the spent grains, spent hops, trub and yeast using techniques similar to those described in the previous section. Several separate waste collection systems exist at the brewery. All uncontaminated cooling water is collected and put in the storm sewer. Cooling tower and boiler blowdown containing corrosion inhibitors and biocides are discharged directly to the polishing lagoon. Sanitary sewage is collected and treated separately in a packaged extended aeration unit which eliminates the need for chlorinating the brewery's entire effluent. The diatomite filter backwash is decanted to remove solids and then added to the process sewer. The high strength process waste is collected separately, put in holding tanks and metered into the treatment system. The spent caustic cleaning solutions are treated similarly which helps control the pH of the influent.

Figure 3 is a flow diagram for the Pabst treatment facilities and Table 12 gives the design unit loadings. A complete description of the system is given in the literature (37). Table 13 is a summary of the treatment plant's performance.

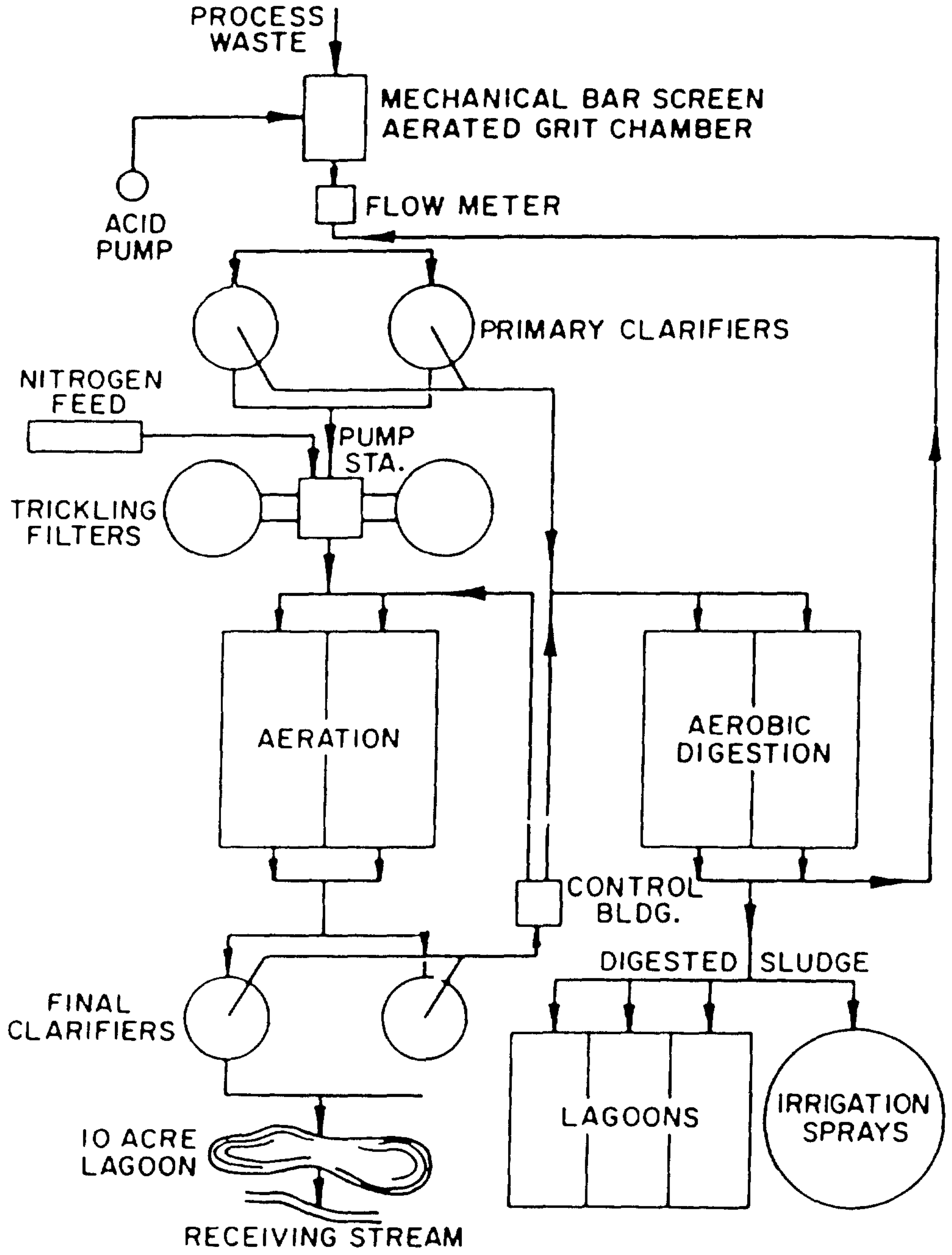


Figure 3. Flow diagram for Pabst waste treatment facility (37).

The Adolph Coors brewery produces 1.23 million m^3 of beer per year. ollution control efforts began in 1951 with an inplant water conservation ogram and construction of a waste treatment facility. An extensive y-product recovery program is used to recover the spent grains, hops, rub and yeast. A plate and frame filter is used to filter out the spent rains because it uses subsequently less water than the conventional auter tub. The spent grain liquor is centrifuged to remove solids and hen recycled back into the process. The trub is handled like the spent iquor. The benefits of the water conservation program are shown in able 9. The treatment scheme as shown in Figure 4, utilizes a high rate ctivated sludge system. Flow equalization and pH adjustment are used o provide for optimum performance.

Table 14 gives a summary of performance. A complete discussion of he Coors facility is given in the literature (17).

ABLE 12. TREATMENT PLANT DESIGN LOADINGS FOR PABST BREWERY, PERRY, GEORGIA (37)

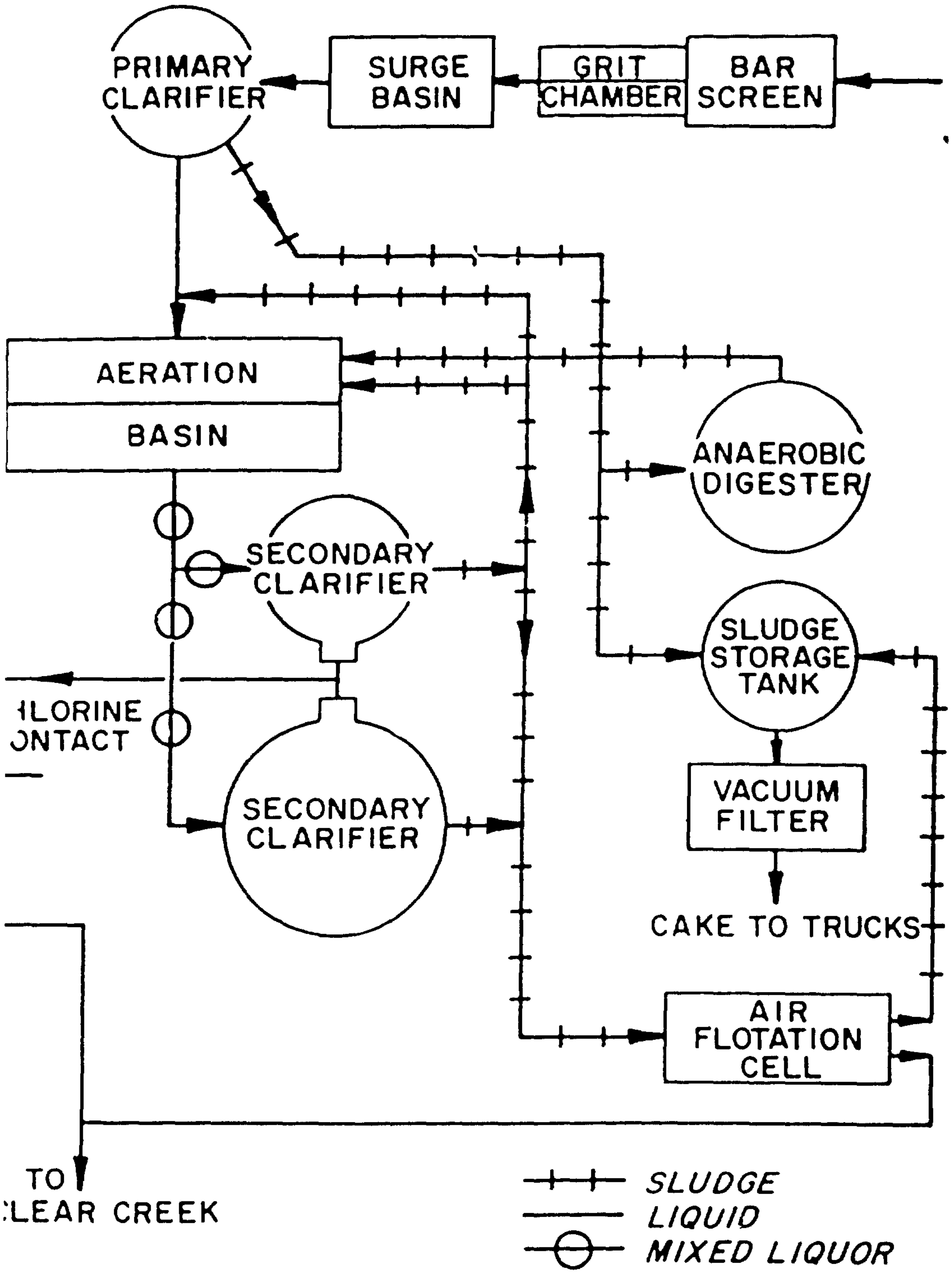
reatment	Metric	English
rimary Clarifier		
Surface loading	27.1 m^3/m^2 day	665 gpd/ft^2
Weir loading	72.2 m^3/m day	5820 gpd/ft
Detention	1.9 hours	1.9 hours
rickling Filters		
BOD_5 loading	4.8 kg/m^3	300 $lb/1000\ ft^3$
Hydraulic loading including recirculation		
Minimum	.68 $l/sec\ m^2$	1 gpm/ft^2
Maximum	1.36 $l/sec\ m^2$	2 gpm/ft^2
ctivated Sludge		
BOD_5 loading	1.60 kg/m^3	100 $lb/1000\ ft^3$
Aeration capacity	1.5 kg O_2/kg BOD_5	1.5 lb O_2/lb BOD_5
Return sludge ratio	50%	50%
BOD_5/MLSS ratio	0.38	0.38
MLSS concentration		
Contact basin	4.9 hours	4.9 hours
Reaeration basin	14.5 hours	14.5 hours
inal Clarifier		
Surface loading	20.7 m^3/m^2 day	509 gpd ft^2
Weir loading	73.9 m^3/m day	5950 gpd/ft
Detention	3.7 hours	3.7 hours

TABLE 12. TREATMENT PLANT DESIGN LOADINGS FOR PABST BREWERY, PERRY, GEORGIA (37) [Continued]

Treatment	Metric	English
Polishing Lagoon		
BOD_5 loading	60.5 kg/day/ha	50 lbs/day/acre
Detention	15 days	15 days
Aerobic Digestion		
Solids retention	10 days	10 days
MLSS concentration	15,000 mg/l	15,000 mg/l
Sludge Spray Disposal		
Liquid loading	2.54 cm depth/appl.	1 in depth/application
Solids loading	0.5 kg/m^2/appl.	0.1 lb/ft^2/application
Application interval	1 to 7 weeks	1 to 7 weeks

TABLE 13. PERFORMANCE OF PABST BREWERY TREATMENT PLANT (39)

Characteristic	Units	Raw Waste	Effluent	Percent Reduction
Flow	m^3/day	48.45		
	(MGD)	(1.28)		
	m^3/m^3 beer	5.48		
	(gal/bbl)	(1.70)		
BOD_5	kg/day	88405	252	97
	(lb/day)	(18530)	(556)	97
	mg/l	1740	58	97
	kg/m^3 beer	9.55	.27	97
	(lb/bbl beer)	(2.47)	(.07)	97
SS	kg/day	3470	208	94
	(lb/day)	(7650)	(459)	94
	mg/l	716	40	94
	kg/m^3 beer	3.94	0.23	94
	(lb/bbl beer)	(1.02)	(0.06)	94



ure 4. Flow diagram for Coor's waste treatment facility (17).

TABLE 14. COORS RAW WASTE AND EFFLUENT PARAMETERS (17)

Parameter	Raw Waste	Treated Effluent	Percent Removal
Flow	12490 m^3/day (3.3 MGD)	--	--
BOD_5	825 mg/l	34 mg/l	96
Suspended Solids (SS)	280 mg/l	29 mg/l	90

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Volume 9

BREWERY OPERATIONS

TRANSCRIPTS FROM THE 1992
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Chapter 15.

SOUND ENVIRONMENTAL BREWING PRACTICES, PART 3

Will Kemper,
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VIRTUALLY ALL BREWERIES in the United States are located in cities and discharge their liquid wastes into municipal treatment systems. Air emissions, both in gaseous and vapor form, are discharged into the atmosphere and directly impact the surrounding area. Solid waste can become a foul and wretched mess. It is as incumbent on the brewer to address and competently manage the brewery's impact on the environment as it is to make professional-quality beer.

Liquid Waste

In determining the necessary approach to liquid wastes, the primary considerations are:

- the brewery's effluent quantities and profile,
- the community's acceptable standards—often determined by statutes.

Individual brewery operations and their consequential environmental impacts differ, and the various community attitudes and restrictions for those impacts differ as well. A technical understanding of both areas is often critical for establishing a work-

ing solution.

Any discharge to *navigable waters* (a federal definition which in essence includes all liquid effluents) has to conform to quality standards that are specific, applied nationally, and enforceable by the U.S. Department of Justice. Sewage plants that ultimately discharge effluent have to comply with those standards. How this is done depends on the community and the treatment scheme used. Each treatment plant has a particular capacity with differing operational techniques. A small plant might be able to accept a more concentrated discharge than that of a much larger plant, or a plant might not permit treatment of brewery waste without pretreatment to an acceptable quality.

It is essential to work with the necessary governmental or private agencies (not all treatment plants are governmentally owned) in dealing with brewery sewage waste. Before a brewery or brewpub opens, it is logical to assume that everyone with a jurisdictional stake in its operation has been notified; if not, the less informed will quickly be enlightened. For many in our population, the term "brewery" conjures up images of huge, industrial plants bellowing out smoke. Additionally, there can be political and social groups opposed to anything having to do with *any* brewery. If individuals with jurisdictional interests have no idea of what is involved in a brewery, they will naturally take the most conservative or negative approach. Brewers should take an informed approach in order to allay fears and assist treatment operators.

The quality and quantity of allowable industrial waste discharges are determined by the treatment facility's system capabilities. For example, the most recent Department of Public Works restrictions for the city of San Francisco include the following parameters:

Pollutant/pollutant property	Limit
pH	6.0 min.; 9.5 max.
Dissolved sulfides	0.5 mg/liter max. (0.5 ppm)
Temperature	125 degrees F (52 degrees C)
Chromium (Total)	5.0 mg/liter max. (5.0 ppm)

Other restrictions are also in effect for grease and oils, arsenic, heavy metals, zinc, phenol, and cyanide. Most of these areas are not pertinent for brewery operations.

The main sources of concern for breweries are the following:

- *Biological or biochemical oxygen demand (BOD).* The loss of oxygen in solution over a five-day period from a closed sample held at 65 degrees F (18.3 degrees C).
- *Chemical oxygen demand (COD).* Measures the dissolved organic material by boiling with potassium dichromate and concentrated sulfuric acid. The excess remaining dichromate is neutralized with ferrous ammonium sulfate using as indicator ferrous 1, 10-phenanthroline; COD: BOD is 1.65 - 1.00: 1
- *Suspended solids (SS).* The weight difference of a preweighed glass fiber filter before and after a known volume of filtrate.
- *Total flow.* Total wastewater treated. Based on a metered amount or factored from water supplied.

Representative municipal treatment costs are as follows:

Location	Flow/1000 gal	COD/lb	SS/lb
San Francisco	$5.413	$0.0494	$0.2467
Frankenmuth, Mich.	$0.7071	$0.1024(BOD)	$0.0462
L.A. Calif. (1973)	$0.083	$0.00475	$0.011

Obviously, there can be a great disparity among treatment plants with regard to specific costs. One thing for certain is that costs will continue to rise.

Waste effluent from breweries ranges from a minimum of four barrels of waste per barrel of beer produced by large breweries with sophisticated means of water treatment and reuse to greater than ten barrels of effluent per barrel of beer produced. Before 1970, it was common to use more than ten barrels of water per barrel of beer produced. With extreme waste (especially for cooling), up to *sixty* barrels of waste were produced for every barrel of beer. With a general regard towards conservation—even with no treatment in place, a 10 to 1 estimate is reasonable.

The average urban sewage flow is estimated at 120 to 180 gallons per capita per day. On the low end, one can expect for the 120 gallons (1,000 pounds) figure, 0.2 pounds of BOD [200 parts per million (ppm)] and 0.23 pounds SS (230 ppm). In comparison, production of 1,000 barrels of beer per year (producing 10,000 barrels of effluent) yields the equivalent flow of seven people per day, 3,200 pounds of BOD (equivalent to forty-four people per day), and 2,200 pounds of SS (equivalent to twenty-five people per day).

A brewery of 30,000 barrels production per year yields the BOD equivalent of 1,320 people daily. A regional brewery such as Rainier or Genesee (at 2,000,000 barrels per year) is the equivalent for 88,000 people, and Coors Brewing Company in Golden, Colorado, potentially yields the equivalent of 880,000 people. Because of this potential, Coors quite likely has the most extensive reuse and treatment operations within the industry today; it is more sophisticated than most municipal treatment facilities.

Brewery effluent contributions from the different sources are as follows:

Waste From	BOD (ppm)	SS (ppm)	Comments
Kettle	300	100	Wort residue
Lauter tub	10,000	3,000	Mash residue
Hot wort tank (trub)	42,000	28,000	Wort & protein residue
Fermenters	66,000	unknown	Beer, protein & yeast
Finishing tanks	3,400	unknown	Beer, fine organic trub
Keg washing	1,120	100	Beer, misc solids
Primary aging	30,000	20,000	Beer, misc solids
Finished beer	90,000	unknown	
Waste yeast	130,000	unknown	

The strongest and most troublesome product is spent yeast. It continues to grow and use oxygen in its life process. The impact of yeast in brewery effluents tends to make that effluent twenty to forty times stronger in SS and ten to seventy-five times stronger in BOD than municipal waste. The impact of brewery effluent is significant considering normal domestic sewage evaluation is as follows (in ppm):

Constituent	Strong	Medium	Weak
SS, total	500	300	100
BOD (5 day)	300	200	100

Approximately 28 percent of the BOD in brewery wastewater is accounted for in brewhouse operations, 60 percent from cellars and fermentation processes, and the remaining 12 percent from packaging. It is apparent that these percentages vary from brewery to brewery depending on the different operational schemes used. Combining trub and yeast and other solids with spent grains dramatically reduces BOD and SS levels, but the facility has to consider storage, bacteria, and space problems as well. As a final thought, one bottle of beer spilled on the floor would require sixty gallons of water to dilute it to the BOD level of municipal waste.

Solid Waste

Solid waste is virtually all a result of spent grains and the portions added thereto. Good housekeeping and punctual removal of grains are required as wet grains quickly mold and turn rancid. For brewpubs, plastic, fifty-five gallon drums with lids—filled three-quarters full—can conveniently be handled. Dumping wet grains with other garbage can create problems as those containers cannot generally be adequately flushed. If a small brewery is lucky enough to find farmers to take its grains, quick and timely removal is necessary. A worse-case scenario would find mycotoxins adversely affecting the stock that had eaten the spent grains. Mycotoxins are secondary metobolites produced by fungus under stress conditions and have harmful biological effects in man and animals.

Air Pollution

Steam venting from the brewkettle is the major discharge that breweries make into the air. If removal is necessary, condensation is the only realistic option. Because much energy is associated with a phase change (gas or vapor to liquid), a high proportion of condensing capability (by refrigeration power or cooling water supply) is necessary.

Within the Chemical Process Industries a barometric condenser has been used for a century as the most efficient means to condense steam. It is based on water as the condensing medium for steam. Close to 100 percent steam condensation can occur with the resulting condensate stream five to ten degrees below boiling temperatures. The key aspect is venting the non-condensables. A draft is created from a boiling kettle whereby non-condensables are carried with the steam and tend to create a back pressure for many condensation systems.

Assume that a ten-barrel brewlength evaporates 7 percent of its volume in ninety minutes and uses water at 70 degrees F (21 degrees C) for condensation. If the exiting condensate has to conform to the discharge temperature imposed by the treatment facility—for example, 125 degrees F (51.5 degrees C)—a mass/energy balance will show that 421 gallons of water will be needed. For every gallon of steam condensed, approximately twenty gallons of cooling water will be used.

In the Future

Water and waste treatment prices will likely double by the year 2000. Besides inflation there will be more demands upon the treatment systems, and replacement for many systems is becoming necessary. Breweries will be required to continue to look for and use schemes to reduce discharge levels both in quantity of total discharge and concentration of pollutants. Effluent standards will become more strict and pre-treatment—besides becoming more economically justified—may become a requirement. If breweries don't conform to established standards, authorities have all the necessary jurisdiction to stop production at those non-compliant facilities.

Will Kemper, of Lansdowne, Pennsylvania, has been involved with microbrewing and pubbrewing operations full time since 1984. Previously, he was a consultant for the federal Environmental Protection Agency, working in inspection and emergency response. He is a member of the MBAA and the Institute of Brewing in London. He holds a degree in chemical engineering from the University of Colorado in Boulder, Colorado.

Pergamon

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RESEARCH ON THE CHARACTERISTICS OF START UP AND OPERATION OF TREATING BREWERY WASTEWATER WITH AN AFB REACTOR AT AMBIENT TEMPERATURES

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ABSTRACT

The purpose of this study was to evaluate the efficiency and feasibility of treating brewery wastewater with an Anaerobic Fluidized Bed(AFB) reactor at ambient temperatures of about 25°C. Results from nearly one year of tests have demonstrated that the reactor has a volumetric loadings rate of 27-30kgCOD/m³.d with 2.5 h of hydraulic retention time (HRT). The COD removal rate can reach 85% or more under stable operating conditions. The average production rate of biogas was 0.45m³/kgCOD removed, of which the CH_4 content was 72%. In addition, the formation mechanism of the biofilm was analyzed, the measures of rapid start up of the reactor was investigated. The operational characteristics of the AFB reactor were also discussed.

KEYWORDS

r wastewater; wastewater treatment, ambient temperature; anaerobic fluidized bed; biofilm

INTRODUCTION

the rapid development of industry, a lot of high strength organic wastewater, such as brewery waste, is g unceasingly generated. At the same time, the problem of a world wide lack of energy becomes more us. Thus, the conventional aerobic processes in the field of wastewater purification cannot meet the tive need because of their higher energy consumption and lower efficiency. Therefore, it is necessary to lop some new types of biotechnology with lower energy consumption and higher efficiency. Since the s, a series of modern anaerobic biotechnologies of higher efficiency have been invented. One of them is naerobic Fluidized Bed (AFB) process. AFB was initially used to treat organic wastewater with the ning of denitrification by Jens and Owens in 1974. Since then, it has been found to be well suitable for ng high strength organic wastewater. Up to now, AFB has been successfully employed to treat a variety gh strength organic wastewaters on lab/pilot scale, but only a few full scale AFB reactors were in tion abroad, and few studies about it were in China. Because the AFB system is still at an early stage of opment, especially in China, more research effort is needed to gain better insight into the complex of the system and to develop a more rational design and control procedure. The objective of this study assess the feasibility of using the AFB reactor for the treatment of brewery wastewater and waste y recovery, from which settleable solids have been removed by a primary clarifier, at ambient ratures. This paper reports and discusses the results of a laboratory investigation.

MATERIALS AND METHODS

Experimental system of AFB reactor

Figure 1 shows the experimental system for the AFB reactor. The [illegible] B reactor with a conical bottom used in this investigation was 150 cm in [illegible] diameter of [illegible] mm in the fluidized zone. The AFB reactor has a total working volume of [illegible]5 [illegible] which include [illegible] enlarged section installed at the top to facilitate the separation of liquid and particles. Seven sampling ports were installed along the column length to obtain bed samples. The wastewater was introduced at the bottom of the column in a downward and then upward fashion to ensure uniform [illegible] of [illegible] particles. The AFB reactor was maintained at approximately 25°C during the experimental period.

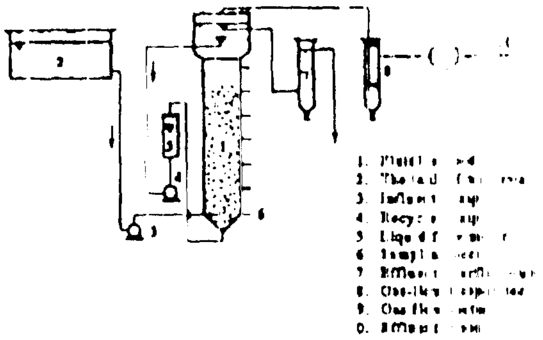


Fig. 1 Schematic diagram of a laboratory-scale [illegible] reactor.

Wastewater

The AFB reactor was fed with the brewery wastewater, both saccharifying and [illegible]ing, from Beijing Brewery. This wastewater exerted a COD of 2000-3000mg/l. No trace element was added. Nitrogen and phosphorus were added according to COD:N:P of 200:5:1 in order to meet the nutrient need of bacterial growth. Total alkalinity was over 600mg/l as $CaCO_3$ by means of Na_2C[illegible] added [illegible].

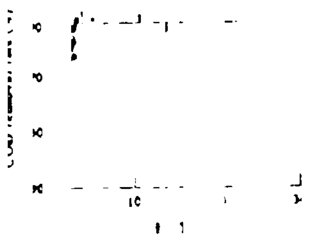
Growth support material

Both polyvinyl chloride (PVC) and ceramsite with a mean diameter of 0.6 mm (range from 0.5-0.71 mm) were selected to be growth supporters. Their density was 1.10 and [illegible]51 g/cm^3 respectively, and their porosity was 41.7% and 48.5% respectively. Because of the differences between the two material surface charges and other factors, such as a coarse surface, the adherence test of the biofilm formed on the supporter showed that PVC was an invalid carrier of AFB reactor during the 70 day start up period. In contrast ceramsite was a valid carrier on which biofilm formed quickly in 35 days at ambient temperatures. Finally, ceramsite instead of PVC was adopted as the carrier for the AFB reactor in this experiment.

Seed sludge

The seed was flocculent sludge obtained from a sludge digester of a municipal wastewater treatment plant. Both methanogenic activity and settleability were poor. The ratio of VSS to SS was only 0.55. The sludge had some adherent properties. Since the sludge included some odds and ends, it was necessary to filter it with a sieve of 1.25 mm x 1.25 mm before it was added to the reactor for seeding purposes.

[illegible]



[illegible]

[illegible]

[illegible]

[illegible] AFB [illegible] The results of [illegible] using the AFB [illegible] the capability of the [illegible] B reactor for [illegible] day [illegible]

[illegible]

Following [illegible] with increased [illegible] loading rate [illegible] particles [illegible] increasing diameter. Table 3 [illegible] the variation [illegible] It seems that fairly thick [illegible] film can be obtained in the AFB reactor. Thereby biomass concentration [illegible] 0gVS/l can be reached. The improved biomass activity can be seen from Fig. [illegible] which shows [illegible] difference in methanogenic activities throughout the reactor. From this it is clear that very high volumetric purification capacities become possible in the AFB reactor. As can be seen from the broken lines in Fig. 6, it seems that the distribution of both biomass concentration and biofilm mass per unit density along the height of the reactor tended to be uniform with the development of biofilm. The control of the biofilm thickness may be possible through turbulence created only by wastewater flow and biogas flow in the reactor. Thus, the diameter varies from 0.8mm to 2.0mm in a defined biofilm thickness. The density of the bioparticles is [illegible]3g/cm^3 at the latter stage.

udy have demonstrated that the AFB reactor is feasible and highly efficient for th wastewater and mixing wastewater from a brewery at ambient temperatures. Th reactor at stable operation is significantly better than that so far achieved in othe ents with similar conditions

ormance and relatively high efficiency of the AFB reactor are ensured mainly ma ntration combined with the recycle, which means high pumping costs. The high ne mixed degree is. The optimum value can be reduced to 4.7-5 in this experimen vidence that phase separation had occurred, and the bed expansion of 25-30% wa d upflow and biogas overflow. Moreover, the restart of the reactor after a shor very quick, the loading rates applied before the shut-down could be resumed

lopment of biofilm can be divided into four steps. Among them, sub-biofilm and primary biolayer formation is also important

luring the period of stable operation of the AFB reactor is within the range of 0.8 as good methanogenic activity. The constant biofilm thickness can be maintained ogas flow in the reactor.

r is very suitable for the treatment of medium strength wastewater (COD = 2000 rewery waste in this investigation. It is an attractive treatment system due to the h rate of digestion, methane produced, and high resistance to shocks etc. Based on study, it appears that AFB technology can indeed fulfil the promised advantages ic technologies. Therefore, it seems reasonable to expect that the AFB technology idespread technology in a possible short time.

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NCES

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Boulder, Colorado USA

fringe benefits. Other costs such as advertising and taxes are added, and our total controllable expenses are roughly $26,000.

Noncontrollable costs include rent at $200 a month for 200 square-feet (included as a brewery cost even though we own the space the brewery occupies, a mortgage on our brewing equipment, and a 6 percent administrative fee. These bring our total noncontrollable costs to $8,100. In six months' operation, charging seventy dollars a keg, we have made a profit of $1,100 in the brewery.

I hope that I have helped you by giving you a look at some of McGuire's figures. I want to reiterate that the bar and restaurant business is highly competitive and demands professional management skills and long hours. But with dedication, I believe that you can succeed.

McGuire Martin, Pensacola, Florida, opened his McGuire's Irish Pub in 1977 and moved it to its present location in Pensacola in 1982. He has a long history in the food business, including managing the food service operations of Saga Food Service, which provides food for college cafeterias.

Chapter 9.

PRACTICAL BREWERY SANITATION

Dr. Michael Lewis
University of California, Davis

Sanitation is one of the essential basics of brewing and the brewer's art. I call it the "brewer's lifeline." If you are wearing a "life line" of sanitation, then you have a good chance of being successful in the enterprise on which you have set sail, that is, the manufacture of good beer. For making good beer, I advocate a "quality triangle": quality materials, consistent processing, and rigorous sanitation. If you pay attention to that triangular relationship, you won't go far wrong in making good beer. Sanitation helps to assure beer quality, minimize complaints about poor beer, and prevent legal penalties for spoiled beer. Curiously enough, when we talk about brewing, we rarely mention the laws at the federal, state, and local levels that govern the sanitary production of food. Your brewery is, in fact, a food company, and you must obey the food laws or you will feel the penalities of the law.

Sanitation procedures fall into two general parts: the first I call protectability, and the second is cleanability. A brewer must make beer in a place that is protected from the environment, a place where he may safely do business. Second, a brewer must have equipment that is cleanable. If he has cleanable equipment in a protectable

place, then he has something that makes sense. We call it a brewery.

Let's talk first about the protectability of the brewery. I think of a brewery as being a fortress because a fortress offers very limited access. The drawbridge is up, and the gate is down. A moat surrounds it. There are cannons on the rampart to discourage anyone who would violate this protected territory. The brewer's flag is flying at full staff at the top of the operation, and a sign says "buzz off" to insects and other pests. But through mismanagement, the protectability of the brewery and the brewing process can be badly compromised, and often is, especially in a brewpub setting. When the defenses break down, we are, in effect, putting out a sign that says, "Welcome all." We provide windows and doors where people and other pests can enter, and by insanitation, we may encourage flies, mice, and even rats. This creates an unsafe place for brewing. When you look at your brewery, please think of it as a fortress, and therefore as a place where only authorized personnel may go perform authorized duties, to the exclusion of everyone else. This will allow you to protect your brewing process in the way

it should be protected. A brewery is a professional workplace, and you must make sure that it has those qualities.

Location of the equipment has sanitary implications. Avoid putting vessels where the process can be compromised. Avoid cross contamination. For example, don't put open fermenters beside the malt mill. In one brewery I visited, the open whirlpool was under a cold water pipe. After the wort cooled down, you could look into it and see your face reflected in the wort; then the reflection was shattered by water dripping into it from the cold water pipe upon which the steam was condensing. This washed spider eggs, dust, and worse down into the wort. It was an intolerable situation.

The brewery operations should be physically divided into at least four parts so that there is a very real division between raw materials handling, the brewing operation, fermentation and conditioning, and finally bottling or kegging. Without this order, a brewery is a cross-contamination problem waiting to happen. Be sure that you have control over the flow of people, dust, air, heat, and moisture between these very different kinds of operations in the brewery. Furthermore your access to the outside world should be carefully located among these divisions. Proper plant layout is the basis of a successful operation and must be addressed in the planning stages with special regard for access and cross contamination. If an operation is poorly laid out and the process stream is poorly planned, then you will not succeed in establishing the kind of protectable environment you need and want for your process.

The ability to clean — whether it is a manual cleaning process with a bucket and a brush or a mechanical cleaning-in-place (CIP) system — must be built into the brewing equipment. Before you reach the manufacturing stage, while you are still in the design process, you must think about how you are going to clean your equipment. Don't be fooled into thinking that just because you spend a good deal of money on a CIP system you can forget about cleaning. A manual cleaning process or a CIP system both need to be managed and maintained, and you must provide that management even though you have paid for expensive equipment.

A CIP system should contain a sanitary loop. This is a connection of pipes and hoses that circulate hot water, hot cleaning solution, and hot sanitizer around the loop by means of sanitary connections that deliver it back to the tank where it originated. The product usually travels in only part of this loop. The loop should be able to be disassembled for inspection, and should drain adequately. To clean properly, a piping system must have adequate pumping power. You must have enough pumping energy to push the liquid through the piping system, and even uphill if need be, while maintaining adequate velocity.

A CIP system is conceptually a simple process whereby the cleaning solution enters the tank at the top by means of a fixed spray ball or a rotating gun; the solution is circulated for some time and then discharged. The problem is that tanks always have cleaning shadows, for example an area underneath the temperature probe or especially underneath the manhole door, that cannot be cleaned by the spray ball. These areas must be cleaned manually before the full CIP cleaning process is started. There are many cleaning areas of a brewing system that are non-CIPable and that must be cleaned by hand.

Cleaning technology is always "clean first and then sanitize." That is a practice you should not alter unless you have a reason. Why should you always clean first? Because in the process of cleaning, you remove both soil and bacteria. Cleaning first greatly reduces the microbial population, and therefore also reduces the population that will have to be killed by the sanitizer. In cleaning, we also remove the soil that harbors and protects the bacteria from the sanitizer. If soil is present during the sanitizing process, it will

react with the sanitizer and reduce its effectiveness. But if soil is removed first, the sanitizer will work at its maximum efficiency.

Soil is not held by magic to the surface of equipment. Soil is held to a surface energetically (by energy), and the strength of the attraction depends on the nature of the soil itself and the nature of the surface. The removal of soil therefore always requires energy input. When you clean, you must think of it as applying energy in one (or more) of three ways: physical energy such as scrubbing with a brush; heat energy using hot water; or chemical energy such as using cleaning agents. All three of these modes of applying energy are often used at once. They function very well to lift the soil off the surface and suspend it so it can be washed away.

In the brewery, you don't have to clean everything with the same intensity. You can relate the intensity of cleaning to the amount and kind of soil present. For example, bottle washing is very different from cleaning a bright beer storage tank, which is different from a kettle where wort and hops have boiled, which is different from a fermenter that has contained yeast and fermenting wort. If you are going to use the same cleaner to wash all of these items, you will want to make a stronger solution (3 to 4 percent) to clean the bottles, a somewhat less strong solution to clean brewhouse equipment and fermenters (1 to 2 percent), and a mild solution to clean wet beer tanks or serving tanks (0.5 percent). You may similarly choose a level of physical energy and heat suitable to the cleaning task at hand. Gauge the amount of soil on a surface and don't hit everything with the same very powerful cleaning solution. Cleaning chemicals and procedures can and sometimes do damage equipment.

Clean a soiled surface immediately after use. Don't wait two or three days to clean a vessel or pipe system, but clean it immediately after use so that the soil doesn't become more closely associated with the surface. Don't let the soil dry out. Cleaning technology always follows the same process whether you are cleaning the egg off your plate in the morning or cleaning a brewing tank at work. Always rinse first to get rid of the bulk of the soil, then clean with the cleaner, and then rinse away the cleaning material.

Alkaline detergency is the backbone of cleaning in the food, dairy, and brewing industries. The most common and cheapest source of what we call "active" alkalinity, is sodium hydroxide ($NaOH$). Big breweries use this as a cleaner, but I do not recommend it for small breweries. It is too dangerous. It is soda, or lye, and if it splashes on your face, it will take your nose off in a moment. Highly alkaline cleansers are excellent dissolvers of soil; they are also excellent dissolvers of people.

Instead, choose a "built" detergent. A "built" detergent contains strong alkalinity, a wetting agent, dispersing agent, rinsing agent, and possibly a sequestering agent. These are mixed by the manufacturer for special purposes, which is why these products cost more than sodium hydroxide. But they are well worth it. Sources of alkalinity may include sodium metasilicate or chlorinated trisodium phosphate. The dispersing or rinsing agents may be polyphosphates or wetting agents. Control for "stone" (a mineral deposit on surfaces) may be EDTA or sodium gluconate. I urge you to establish a relationship with a local representative of a major corporation involved in cleaning technology and draw on their expertise. Buy few products and learn to use them well.

After cleaning comes sanitizing. The purpose of sanitizing is to kill the bacteria remaining on a piece of equipment after cleaning it. Sanitizing is always done on a previously cleaned surface, i.e., after the bulk of the microbes has already been removed by washing. The important thing to remember is this: do not automatically sanitize your equipment immediately after you have cleaned it. Sanitize it immediately before you are ready to use it; the interval between cleaning and sanitizing may be a few hours or a few days. Clean, and then before use, just sanitize.

Sanitizing agents often contain chlorine. It is effective, cheap, and when diluted, it is safe. Alternatives are quats, iodophors (which are popular), and acid-anionics (which are not). My preference is chlorine as a household bleach. The effective form of chlorine is hypochlorous acid ($HClO$), which is most bactericidal between pH 4 and 6. Most brewers, however, prefer to use $HClO$ at pH 8. It is less effective at that pH, but it is much safer to use because in an acid environment, chlorine becomes corrosive to stainless steel; chlorine on the alkaline side is the better choice. Because domestic chlorine bleach is an alkaline solution, it is convenient to use.

Chlorine as bleach contains approximately a 5 percent solution of sodium hypochlorite, or about 50,000 parts per million (ppm or mg/L) of chlorine. But about 50 ppm chlorine is sufficient in a brewery setting, on a surface that has been previously cleaned. To make a dilution, think of it this way: 500 ppm is a 1:100 dilution, or a liter of bleach in a hectoliter, or about a quart of bleach in a barrel. One-tenth of this concentration, or three to four ounces in a barrel of water, is sufficient to sanitize a clean surface.

Brewers prefer to sanitize with wet heat, i.e., hot water or steam. Wet heat is a very useful sanitizing agent because it is so safe for the product, but it is expensive. For wet heat to be effective, you must raise the temperature of the surface you are sanitizing to 180 degrees Farhenheit. This does not meaning spraying 180-degree water into a big, cold stainless steel tank for a few minutes! If you were to try to heat the surface that way, you would have to spray it for a long time with 210-degree water, which would be expensive and impractical in most microbreweries. If you use hot water to raise the temperature of a surface, you must allow sufficient time of circulation to achieve the required temperature. When using steam as a sanitizer, you must also allow enough time to heat the

Economics of Water Reuse in a Brewery

By J. E. McKee and A. B. Pincince

ABSTRACT

It is prudent for each brewery to make a balance sheet of its total costs for both water supply and wastewater disposal with the intent of minimizing such costs.

This paper delineates the water requirements and wastewater characteristics (volume and quality) of a typical, but ypothetical, brewery. It demonstrates the average costs of services under conventional methods of operation. It examines the economic feasibility of reduction of demands and wastewater flows and strengths by inernal housekeeping methodology; plus advanced treatment f various types of effluents and the recycling of treated aters for reuse in certain brewery operations. With such euse, the savings in water bills, wastewater surcharges, and proportionate share of construction costs might justify es-ntially complete recycling in certain localities.

SINTESIS

Es prudente hacer un balance para cada cervecería de sus costos totales para suministros de agua y desecho de aguas de residuo con el objeto de minimizar dichos costos.

Este trabajo delinea los requerimientos de agua y las características del agua de desecho (volumen y calidad) de una cervecería típica pero hipotética. Demuestra los costos promedio de dichos servicios bajo métodos convencionales de operación. Después examina la facilidad económica de reducir las demandas de agua y los flujos y potencia del agua de desecho por metodología casera interna; además de tratamiento avanzado de varios tipos de efluentes y el reciclado de agua tratada para el reuso en ciertas operaciones cerveceras. Con dicho reuso, los ahorros en los costos de agua, recargos en agua de desecho y una cuota proporcionada de los costos de construcción deberán justificar esencialmente el reciclado completo en ciertas localidades.

INTRODUCTION

Most breweries in the United States are located in ties and discharge their liquid wastes to public sewers. ntil recently, this arrangement was generally satisfacry unless the brewery wastes constituted too large a oportion of the combined municipal wastes, such that e public sewage treatment plant was overloaded or im-lanced with respect to carbon-nitrogen ratios. Brew-ies have traditionally paid for municipal sewer service rough *ad valorem* taxes related to the assessed value the brewery property and/or through sewer service arges generally based on the quantity of water used or ste discharged.

Now the situation is changing as a result of Public w 92-500, entitled the "Federal Water Pollution Con-l Act Amendments of 1972." This act and subsequent propriations enable the federal government to conbute up to 75% of the construction cost of expansions improvements to municipal wastewater treatment plants, trunk intercepting sewers, and effluent discharge facilities. Some states add to this largesse such that the total financing from federal and state sources can reach 90%.

Before approving grants for any project for any treatment works, the Administrator of the Environmental Protection Administration (EPA) must first have determined that the applicant sewerage entity

> (a) "has adopted or will adopt a system of charges to assure that each recipient of waste treatment services within the applicant's jurisdiction, as determined by the Administrator, will pay its proportionate share of the costs of operation and maintenance (including replacement) of any waste treatment services provided by the applicant;" and (b) "has made provision for the payment to such applicant by the industrial users of the treatment works, of that portion of the cost of construction of such treatment works (as determined by the Administrator) which is allocable to the treatment of such industrial wastes to the extent attributable to the Federal share of the cost of construction;" see Section 204(b)(1).

. McKee is a Director and Dr. Pincince is a Vice sident of CDM Inc., Pasadena, California, a subsidi of Camp Dresser & McKee, Environmental Engirs, Boston, Mass.

Moreover, Section 310(b)(1)(B) specifies that by 1 July, 1977, publicly owned treatment work must comply with effluent limitations based on secondary treatment, e.g., over 85% removal of biochemical oxygen demand (BOD). This provision means that municipal plants presently providing only primary treatment (sedimentation) must be upgraded to biological treatment by trickling filters or the activated-sludge process, or by some other means providing equivalent treatment. To be eligible for 75 to 90% government grants for such upgrading, publicly owned plants must meet the provisions related to industrial wastes, as described above. Rare indeed will be the public sewer agency that will go to secondary treatment without a huge government grant.

The Administrator of EPA has issued guidelines to local agencies relative to the payment of industrial waste treatment costs, including model systems and rates of user charges. Many municipalities and other local sewerage agencies have already promulgated industrial waste "surcharges" that augment the conventional *ad valorem* property taxes for operation and maintenance costs.

An example of this annual surcharge is the formula used by the Sanitation Districts of Los Angeles County (SDLAC) in "An Ordinance Regulating Sewer Construction, Sewer Use and Industrial Wastewater Discharges," 1 April 1973, *viz*

$$\text{Surcharge} = a(V) + b(COD) + c(SS) + dM(P) - TAX$$

where:

Surcharge = Net annual industrial wastewater treatment surcharge in dollars. No refund will be made if a negative number results.

V = Total annual volume of flow, in millions of gallons.

COD = Total annual discharge of chemical oxygen demand, in thousand lbs.

SS = Total annual discharge of suspended solids, in thousand lbs.

P = Peak discharge rates over a 30-min. period, occurring between the hours of 8:00 a.m. and 10:00 p.m. and determined by averaging a maximum of 10 substantiated peak flow rate measurements of the accrual year in gal./min.

M = A multiplying factor accounting for increased Districts' costs from high ratios of industrial discharger peak-to-average flow rates (P/A), such that $M = 2.50 \log_{10}(P/A)$.

a,b,c&d = Unit charge rates adopted annually by the Districts based upon the projected annual total costs for wastewater collection, treatment, and disposal, per unit.
In 1973:—
a = $83.25/million gal.
b = $4.75/1,000 lbs. COD
c = $11.00/1,00 lbs. S.S.
d = $22.00/gpm

TAX = The annual *ad valorem* taxes paid to the Districts on the land or property utilized for generation of industrial wastewater.

This formula will be used later in this paper as an example of an operating and maintenance surcharge for a hypothetical brewery. To this surcharge, however, must be added the charges assessed to industry for the construction costs for secondary treatment. Finally, in any recycling effort, one must also consider savings in the costs of purchased or locally pumped water supplies.

It is the purpose of this paper to investigate the feasibility of treating, recycling, and reutilizing all or part of the wastewater effluent from a typical, but hypothetical, one million bbl-per-year brewery (Brewery X) in order to eliminate or at least minimize the surcharge for operation and maintenance, the assessment for the construction cost for secondary treatment, and the cost of water supply. Conceivably under certain circumstances the cost of constructing, amortizing, and operating a "bottled-up" system would be less than the charges and surcharges resulting from PL 92-500.

The concept of treatment, recycling, and reuse of industrial wastewaters is not new. It was utilized successfully by the corn-starch-process industry in the 1920's.(1) The Kaiser Steel plant at Fontana, California, has treated, recycled, and reused its wastewaters(2) and at the Lever Bros. plant in Los Angeles County, wastewaters laden with fatty acids from the cleanup of tanks used in edible-oil production are processed through colloidal-air flotation units.(3) Many other examples of treatment, recycling, and reuse could be cited.

QUALITY AND QUANTITY OF BREWERY WASTES

Several investigators have reported on the quality and quantity of the total wastewater effluent from breweries, but data on the wastes discharged from various operations inside breweries are less abundant. The information available on discharges from various operations is generally limited to analyses that determine gross parameters of pollution, e.g., suspended solids, BOD, COD, etc. Data on the volumes or rates of flow from specific processes are scarce indeed.

Table I shows typical values for analytical data from the waste discharged from individual brewery units.

TABLE I
Typical Concentrations of Wastes
Discharged from Specific Brewery Operations

BREWING OPERATIONS	Suspended Solids (mg/l)	BOD (mg/l)
Cereal cooker	300	700
Mash tun	300	2,000
Lauter tub	3,000	10,000
Spent grain tank (or press)	10,000	15,000
Brew kettle	100	300
Hot wort tank (inc. trub)	5,000	10,000
Wort cooler	20	30
Fermentation tanks	2,000	5,000
Ruh chiller	30	700
Ruh tanks (primary aging)	20,000	30,000
Primary filtration	30,000	40,000
Aging tanks	600	10,000
Final filtration	500	100
Finished beer tanks	200	50
NON-RETURNABLES		
Rinser	3	20
Pasteurizer	—	50
RETURNABLES		
Pre-rinse	200	500
Final rinse	10	10
Pasteurizer	20	30
KEGS		
Pre-rinse	100	1,000
MISCELLANEOUS WASTES		
Bottle and can filler drip	—	50,000
Conveyor lube drip	1,000	5,000
Spray tunnel drip	40	3,000
Floor hosedown	—	—

ese values were taken from the literature and from eering reports on the treatment of brewing wastes. e I also shows that the brewing operations (which purposes of this paper include fermentation, filtra- and aging) produce most of the high-strength es, while the wastes from packaging generally are tantially less concentrated. This fact is significant use it allows for a convenient way of segregating es for treatment. Further segregation of waste ces could be attained, especially for breweries under gn, but in existing plants the simple division into major categories might be more reasonable.

hile data on flows from individual operations are ce, flow data distributed according to general loca- have been presented by LeSeelleur[4] and are re- luced herein as Table II. This table shows that about -quarter of the wastes by volume are produced in wing and that packaging produces about one-half of wastewaters. The remainder of the wastewaters re- to domestic and cooling uses. In terms of strength, tes from brewing predominate. Typical averages for wing waste strengths are in the neighborhood of 3,000 /l for suspended solids and 5,000 mg/l for BOD. On other hand, packaging wastes have strength in the er of 50 mg/l for BOD and suspended solids.

able III summarizes these findings using values in le II for the estimates of flows. These values are also ended in Table III to show total flow and mass emis- n rates of BOD and suspended solids in mg per liter roduct. The values shown do not apply to any one ticular brewery, but they are within the ranges shown the literature. The contents of Table III should be sidered as illustrative only, and are presented to ve as an example. In-plant surveys would have to be ducted at any specific brewery where it might be irable to apply the concepts in this paper.

TABLE II
Probable Geographical Distribution of Liquid Effluent*
(Bbl./bbl. beer)

ction	Location	High	Low
wing	Brewhouse	1.5	1.2
nenting	Fermentation room	0.4	0.2
ering	Carbonating room	0.2	0.2
ng	Storage cellar	0.2	0.2
kaging	Bottleshop	4.04	3.6
nestic	Offices and miscellaneous area	0.35	0.30
ling	Power house	2.57	1.24
otals		9.26	6.94

rom Reference (4)

TABLE III
Mass Emission Rates for SS and BOD From A Typical Brewery

				Mass Emission Rates (mg/l product)	
ation	Suspended Solids (mg/l)	BOD (mg/l)	Flow (water product)*	Suspended Solids	BOD
wing	3,000	5,000	2.3	6,900	11,500
kaging	50	50	4.0	200	200
ling Blowdown	20	10	2.6	52	26
Total			8.9	7,152	11,726

e.g., bbls wastewater per bbl beer produced.

Brewery X separates spent grains and excess yeast for disposal or sale, but discharges the filter backwash waters to the sewer. Most modern breweries do indeed remove grain and yeast from the wastewater, but discharge of backwash water to the sewer is by no means universal.

BOD values are shown in Tables I and III because most publications present the results of this test rather than those of the COD test. COD values for brewing wastes are approximately 1.66 to 2.0 times the BOD values.[5,6] The characteristics of the wastes from individual operations may differ considerably from these ratios, but, for simplicity and in cognizance of the approximations inherent in Table III, a ratio of 2:1 for COD to BOD is used in this paper.

The maximum rate of waste production occurs while packaging operations are being conducted. An estimate of about 1.5 to one for the ratio of peak flow to average flow, as obtained from data presented by Armitt, Dargusch, and Healy,[7] is used in this paper.

OPTIONS OR ALTERNATIVES IN WASTEWATER MANAGEMENT

Assume that Brewery X is located in Los Angeles County and it discharges to sewers of the SDLAC. Assume, moreover, that it recovers spent grains and excess yeast for disposal or sale, but it discharges filter backwash waters to the sewers. Let the total mass emission rates for SS and BOD conform to Table III and let the COD rates be twice those of BOD. On that basis, the quantities involved are as follows:

Product = 10^6 bbl/yr = $31\text{x}10^6$ gal/yr = $117\text{x}10^6$ liters/yr.

Wastewater = 8.9 x product = $276\text{x}10^6$ gal/yr = 0.756 mgd (avg)

Peak wastewater flow = 1.5 x 525 gpm = 788 gpm

SS = 7152 mg/l x $117\text{x}10^6$ l/yr = $839\text{x}10^9$ mg/yr = $839\text{x}10^3$ kg/yr = $1{,}880\text{x}10^3$ lb/yr = 5150 lbs/day (avg)

BOD = 11,726 mg/l x $117\text{x}10^6$ l/yr = $1375\text{x}10^9$ mg/yr = $1375\text{x}10^3$ kg/yr = $3076\text{x}10^3$ lb/yr = 8420 lb/day (avg)

COD = 2 x BOD = 6150 x 10^3 lb/yr.

Brewery X may wish to consider the following options or alternatives to minimize its total cost of waste management:

A. Continue its present discharges to the sewer, i.e., do nothing except monitor its wasterwaters and pay the SDLAC surcharge.

B. Establish a rigid program of internal economies to reduce the quantities of water used for tank clean-up purposes, package washing, and general hosedowns. Such a program would include counter-current use and reuse of caustic cleaning solutions, recycling of weak rinse waters, increased use of steam instead of water, reduction of blow-down water from cooling towers, and a general program of water economy.

C. Treat by carbon adsorption and reuse the packaging wastewaters and possibly some of the weak rinse waters from the brewhouse, but continue to discharge concentrated brewing wastes to the sewer.

D. ~~Blend all brewing and packaging wastes (but with clusion of domestic sewage and cooling~~-tower blow-own) and subject the blend to secondary biological abilization followed by advanced treatment using acvated-carbon adsorption columns. Reuse such highly eated waters for all purposes except those that incororate water in the product (i.e. use for brewhouse ean-up, packaging operations, and cooling-tower makep).

Let us consider each of these alternatives in turn.

Option A. Continue to pay the present surcharge and ture increases thereof. In areas where industries have aid for municipal sewer service through *ad valorem* xes without an industrial waste surcharge, or with only nominal surcharge, breweries have generally *not* reised their operating procedures to decrease the disharged waste.(8) Modifying present procedures would enerally increase labor and equipment operating costs; ence breweries have usually found it to be less expenve to purchase more water and to pay a nominal surharge than to attempt to conserve water. The imposion of sizable surcharges and portions of the construcon costs for municipal secondary treatment under PL 2-500, however, may increase the monetary burden fficiently that many breweries should investigate war conservation, treatment, recycling, and reuse.

In Los Angeles County in 1973, the SDLAC surcharge r Brewery X is calculated as follows:

olume = \$83.25/mil. gal x 276 mil. gal/yr = \$23,000
OD = \$4.75/1000 lbs x 6,150 = 29,200
S = \$11.00/1000 lbs x 1,880 = 20,700
eaking = \$22.00/gpm x 788 gpm x 2.5 $\log_{10}$ (1.5) = 7,600

Total = \$80,500
Less estimated SDLAC ad valorem tax = 10,000

Net = \$70,500

Under PL 92-500 and the 1972 ocean discharge reuirements of the State of California, however, SDLAC ill have to construct a secondary biological treatment lant and new sludge handling facilities. In a recent echnical report,(9) SDLAC has estimated the cost of onstruction, amortization, and yearly operation and aintenance (O&M) as shown in Table IV. It is not nown yet how these expenditures will modify the constants (a, b, c, & d) in the surcharge formula; but if the yearly O&M for SDLAC increases from \$3.2 million to \$20.0 million, the annual surcharge to Brewery X might well increase by a factor of 6.25. It would then amount to \$80,500 x 6.25 = \$500,000 less \$10,000.

In addition, however, each industrial discharger will be required to pay its proportionate share of the yearly amortization of new construction costs, totalling \$23.5 million per year in Table IV. The proportionate shares based on mean daily flow, suspended solids, and BOD would be as follows:

	SDLAC	*Brewery X*	*Proportion*
Mean daily flow, mgd	400	0.756	0.00189
Suspended solids, lbs/day	1,760,000	5,150	0.00293
BOD, lbs/day	1,230,000	8,420	0.00683
Mean			0.00388

In lieu of a future complete analysis and assessment by SDLAC, let us use the mean of the foregoing tabulation. On this basis the annual cost to Brewery X would be \$23.5 million x 0.00388 = \$91,300. Coupled with the O&M surcharge of \$490,000, the annual assessment to Brewery X would be \$581,300, a staggering amount. In the opinion of the authors of this paper, however, the cost estimates in Table IV may be excessively high and final costs might well be 50 to 75 percent of those shown. Even then, if SDLAC goes to secondary biological treatment, it will certainly behoove Brewery X to consider other options of wastewater management.

Option B. Implement a rigid water-conservation program. Table II shows what could be considered as typical ranges for waste production from various locations in a brewery. Let us assume that, by instituting a program to reduce the volume of water used, waste production could be reduced from the high range in Table II to the low range. Such a program could reduce the water usage and waste production, excluding domestic wastes from 8.9 to 6.6 bbl. per bbl. of beer. This reduction and the similar reduction in peaking rate would reduce the SDLAC surcharge by less than \$2,000 per year at the current SDLAC surcharge rates. On the other hand, the water bill, at \$0.20 per 1,000 gal. would be reduced by about \$14,000 per year.

TABLE IV
Sanitation Districts of Los Angeles County* Joint Water Pollution Control Plant Cost Summary[1]
(Million of Dollars)

	Capital Expenditure	Yearly O&M	Yearly Amortization[2]	Present Worth[3]
Existing Plant	\$ 34.9[4]	\$ 3.2	\$ 0.6	\$ 43.7
Improvements Schedule for Completion by 1975[5]	15.0	3.4	1.3	54.0
Secondary Treatment Biological Treatment Facilities	249.0	12.0	21.7	387.0
Sludge Dewatering & Disposal[6]	6.0	1.4	0.5	21.8
(Secondary Treatment plus Solids Processing)	(\$270.0)			
TOTALS		\$20.0	\$24.1	\$506.5

[1] All costs in January, 1973 dollars
[2] Amortization at 6%, 20 years
[3] 6%, 20 years
[4] Total investment at the JWPCP, as of January, 1973
[5] Grit Chambers 5 and 6, Digester Cleaning Treatment Systems, and Solids Processing Facilities
[6] Assuming trucking to landfill
* Based on Table V-14 of Reference 9, with modifications to show yearly amortization instead of total annual cost (amortization plus O&M)

s not clear if such a reduction would offset the in- d labor and equipment costs associated with a ram to reduce wastes. It appears, nevertheless, that possibility of saving about $16,000 per year in the r bill and in the industrial waste surcharge merits stigation, conducted on-site at a brewery.

ption C. Treat and reuse the packaging wastewaters. removal of residual suspended solids, COD, and D from wastewater effluents already quite low in such utants has been demonstrated by English *et. al.*,(10) by other operating installations utilizing adsorption ranular activated carbon. Such treatment is capable roducing a polished effulent with less than 10 mg/l D, 1.0 mg/l SS, 3 units of color, and 1.0 unit of tur- ty. Such effluent is suitable for reuse in bottle or can eg rinsing, pasteurizing, and other processes in the kaging plant. No chemicals are added during waste- er treatment, but the mineral salts from caustic and rgents in the rinsing operations will accumulate ex- ively in the recycled water unless about 20 percent be treated water is bled off at each cycle.

ssume, as per Table III, that Brewery X uses 4.0 of water per bbl. of product in the packing plant and this plant operates 250 days per year. Then the n water use is 496,000 gpd or 345 gpm, and the total ual flow is 124 mil. gal. Based on summaries of many ats published by the Advanced Waste Treatment earch Laboratory of the Environmental Protection ncy in Cincinnati, the total costs for amortization, ration, and maintenance of an activated-carbon treat- nt plant of a mean capacity of 496,000 gpd will be ut $0.40/1,000 gal. Hence for Brewery X the cost per r would be $49,600.

low much could be saved by such an installation? By present SDLAC surcharge rates, the savings based 80% recycling and 20 percent bleed-off would be:

Volume	$ 8,250
COD	480
SS	568
Peaking factor	2,660
Total	$11,948

Brewery X would also save in its purchase of city ter at $0.20 per 1,000 gal. This annual savings for 80% 24 mil. gal. would be $19,800. Hence the total savings surcharge fee and water bill would be $31,748, which ess than the annual cost for activated-carbon treat- nt.

f SDLAC goes to secondary biological treatment, wever, the pendulum will swing the other way. The charge might well increase by a factor of 6.25 and n the savings in surcharge fee alone would amount $74,600 per year. When this saving is added to the luction of the water bill ($19,800) and a proportion- share of the amortization of the SDLAC biological nt, the overall savings will be more than twice the nual expense of activated carbon treatment.

It can be concluded that treatment, recycling, and use of packaging wastewaters at Brewery X is not economically feasible at present, but may become so when SDLAC installs secondary treatment.

Option D. Treat all brewing and packaging wastewaters by secondary biological stabilization, followed by polishing with activated-carbon adsorption, for use in brew-house clean-up, packaging, and cooling-tower make-up. Human wastes should be excluded from this system for reasons of public health and cooling-tower blow-down should be excluded because of toxic additives that would upset biological treatment.

Based on Table III, such a treatment plant should be designed to handle a mean flow of 780,000 gpd (543 gpm), a peak flow of 1,170,000 gpd (813 gpm), a SS loading of 5,150 lbs/day, and a BOD loading of 8,400 lbs/day. The plant would probably compromise primary sedimentation, preliminary biological treatment by high-rate trickling filtration, secondary biological treatment by activated sludge with probable adjustment of the carbon-nitrogen ratio by addition of ammonia, final sedimentation, and adsorption of residual organics in activated-carbon columns. We estimate that the construction cost for the secondary biological treatment plant (exclusive of carbon columns) will be $4,200,000 and the amortization (20 years @ 8%) will be $428,000 per year. Operation and maintenance costs are estimated at $300,000 per year, bringing the total annual expense to $728,000 for the biological treatment plant. Activated-carbon adsorption is estimated at $0.35 per 1,000 gals. for operation, maintenance, and amortization, or $100,000 per year (365 days). The total annual cost for biological treatment and carbon polishing is then $828,000.

As noted under Option A above, the future total assessment to Brewery X for an O&M surcharge and a proportion of the SDLAC amortization for secondary biological treatment is not likely to exceed $581,000 and might well be 50 to 75% of this amount. On that basis, Option A is preferable to Option D, and indeed the almost bottled-up brewery (Option D) does not appear to be economically feasible.

SUMMARY AND CONCLUSIONS

In compliance with PL 92-500, public sewering agencies are adopting surcharges for industrial wastewaters discharged to such systems. For brewery wastes, these surcharges are already substantial and are bound to increase markedly as public agencies are forced to install secondary biological treatment. A hypothetical Brewery X of one million barrel per year capacity in Los Angeles County would have to pay a surcharge of about $70,000 under 1973 conditions. This assessment might well escalate to over $500,00 per year if and when L.A. County installs secondary treatment.

Under present conditions, Brewery X can reduce its surcharge somewhat by good-housekeeping measures, recycling of weak rinse waters by counter-current use, and other programs of water economy. While such measures will reduce the surcharge and the water bill, it is not clear whether or not the cost of introducing and maintaining them will exceed the apparent savings.

Thorough two-stage biological treatment of all brewing and packaging wastewaters for Brewery X, followed by adsorption of residual organics on activated-carbon columns, and the reuse of such highly polished waters in brew-house clean-up, packaging, and cooling-tower make-up—in effect an almost bottled-up brewery—does not appear to be economically feasible even if the L.A. County assessment escalates to $500,000/year.

It may be feasible, in the future, however, for Brewery X to treat its packaging wastewaters by activated-carbon adsorption and to reuse 80% of such polished water in the packaging operation. Annual savings will accrue not only from a reduction in the surcharge but also from a decrease in the annual cost of purchased city water. This option does not appear to be economically feasible in 1978, but it will become attractive if and when L.A. County constructs secondary biological treatment.

It behoves every brewery that discharges wastewaters to public sewers to make an economic feasibility study of alternative options for minimizing industrial-wastes surcharges imposed as a result of *PL* 92-500.

QUESTIONS AND ANSWERS

Q. Do the figures for packaging waste BOD include filler wastage?

A. The figures in Table III for packing operations do not include bottle and can filler drip. This item is shown under "Miscellaneous Wastes" in Table I, with a BOD of 50,000 mg/l. In our hypothetical brewery X, we expected that the filler wastage would be segregated from the rinses and pasteurizing water, with the filler waste being discharged to the sewer under Option C.

Q. Would it benefit a brewer to only consider secondary treatment, without polishing by activated carbon adsorption and without extensive reutilization?

A. The answer depends on the location of the brewey and the final disposition of the effluent. If the brewery discharges to a river or large lake, Public Law 92-500 will require that the equivalent of secondary treatment be provided and that stringent effluent guidelines be met. On the other hand, if the brewery discharges to the Los Angeles County sewer system, then under Option D the total annual expense for secondary treatment is calculated to be $728,000. There would still be a SDLAC surcharge based on the total volume and peaking; but with reduced charges for COD and suspended solids. Moreover, without reutilization of a polished effluent, there would be no savings in the cost of purchased city water.

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Air Pollution Engineering Manual

AIR & WASTE MANAGEMENT
ASSOCIATION
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SINCE 1907

Edited by
Anthony J. Buonicore
Wayne T. Davis

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New York

ertight enclosure. Accumulation of dust and moisture inside the control panel can cause short circuits in the solenoid valves for the pulse jet system, ultimately leading to system failure. To avoid such problems, general baghouse operation and maintenance practices should be routinely applied at grain handling and processing facilities.

Generally, emissions from multiple operations at grain handling and processing facilities are controlled by a single air pollution control system. If the ventilation system that connects these sources is not properly designed and operated, excess fugitive emissions are generated at the source. References 35 and 36 provide excellent information on designing, operating, and maintaining balanced ventilation systems.

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FERMENTATION

Joseph A. Mulloney, Jr., P.E.

Fermentation as an industrial process is currently employed primarily in the manufacture of beer, alcoholic spirits, wine. and fuel-grade ethanol (ethyl alcohol). Minor applications include a wide variety of food (including enzyme and amino acid), pharmaceutical, and industrial processes. In the past. fermentation processes were used to produce a variety of chemicals that are currently derived from petroleum feedstocks. Future petroleum prices or availabilities may spur renewed interest in these processes. Additionally, the potential of biotechnology may result in both improvements to current processes and totally new processes and products from industrial fermentations.

With respect to characterizing the air emissions from distilleries, breweries, and wineries, a distinction is necessary between a distillery that produces concentrated volatile organic streams (e.g., ethanol and fusel oil) similar to the fuel-grade ethanol facility described below and breweries and wineries where the volatile compounds are always present in solution or associated with water vapor. While ethanol is the major VOC, there are many other VOCs present, such as isoamyl alcohol, ethyl acetate, isopropyl alcohol, and *n*-propyl alcohol, that contribute to beverage bouquet and taste but constitute only 1% or less of the amount of ethanol. Emissions of beverage alcohol are primarily from spillage and breakage in packaging operations and secondarily from processing operations. A typical brewery will lose 3% of liquid volume after fermentation where the VOCs are formed) as processing and packaging losses that primarily run to sewers, but also partially leave the premises as evaporate.

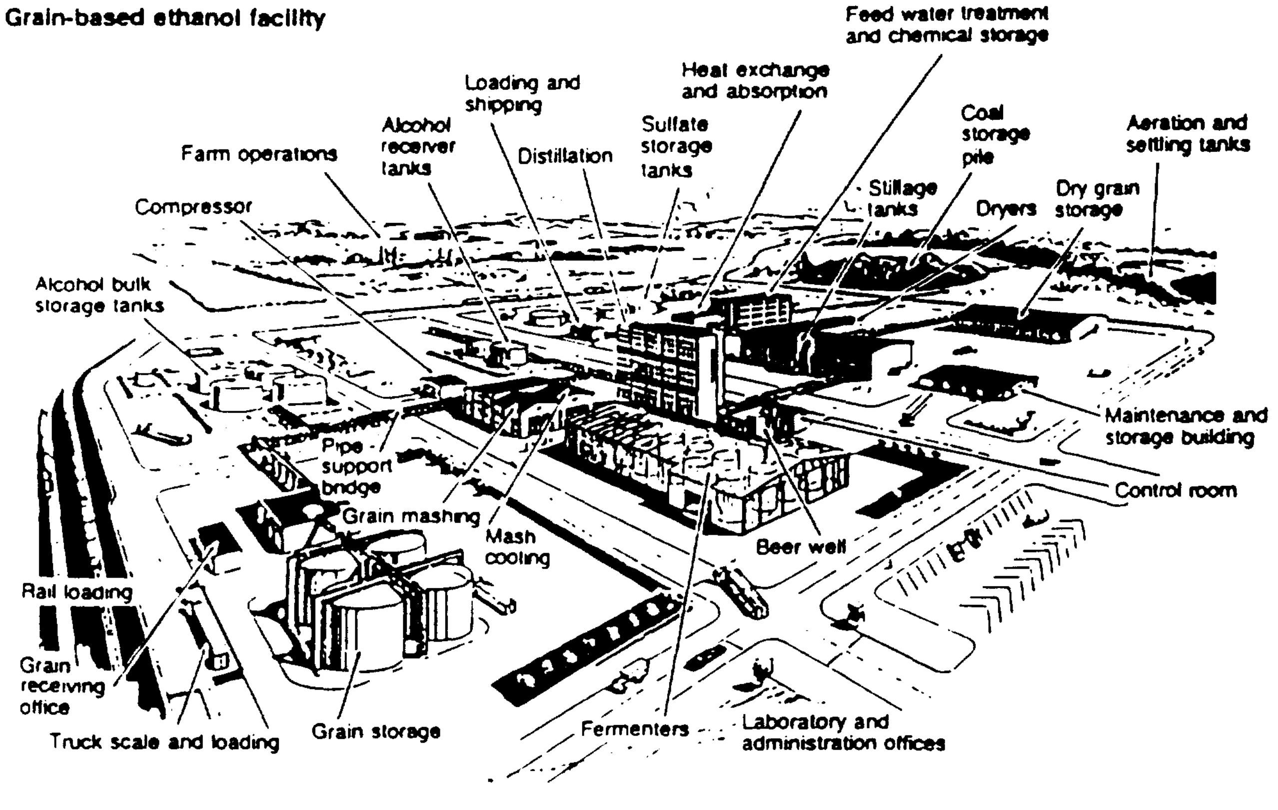
In 1989, approximately 800 million gallons of fuel-grade ethanol were produced, as well as 200 million barrels of beer (200 million gallons ethanol), 1200 million tax gallons of distilled spirits (600 million gallons ethanol), and 475 million gallons of still wines (50 million gallons ethanol).[1]

PROCESS DESCRIPTION

The base case alcohol fermentation plant is designed to produce 50 million gallons per year of 99.5 vol % (199 proof) fuel-grade ethanol from corn. In addition, it will produce 177,111 tons per year of Distillers' Dark Grain (also known as Distillers' Dried Grain with Solubles or DDGS), a commercial animal feed. The plant is assumed to be located in central Illinois, close to a source of Illinois No. 6 coal, which is used as fuel.

The alcohol plant, designed by Raphael Katzen Associates,[2] Cincinnati, Ohio, generally uses existing process technology currently employed in grain alcohol plants. A drawing of the facility is presented in Figure 1. The plant operates as a continuous-flow process, except for the fermentation and fungal amylase sections, which are operated in a continuous batch mode. The distillation system employs a two-pressure concept currently utilized in industrial and beverage alcohol production and in other chemical processing fields. The process also utilizes several heat economy measures that result in a total steam usage of 31.7 lb/gal of ethanol. The distillation system uses 21.4 lb/gal of steam, of which 2.8 lb/gal is obtained as flash vapors from mash cooking. Feedstock to the plant will consist of shelled corn at a rate of 58,900 bushels per day. No distress corn (e.g., corn contaminated with aflatoxins, pesticides, etc.) is contemplated for use in this facility; No. 2 shelled corn (less than 15.5% moisture content) will be used.

All the utility requirements, with the exception of electricity, are produced within the boundaries of the plant. Water is obtained from a well field located close to the plant. The boiler burns relatively low-cost, high-sulfur coal. The plant is designed effectively to utilize most of the waste streams, with final disposal in an environmentally acceptable manner. Flue gas from the boiler is used to dry the stillage residue to yield Distillers' Dark Grain as a by-product. Wastewater is treated in a two-stage, activated sludge treatment facility. The resultant sludge is dewatered and fed to the boiler. Cooling water from the various con-



Source: Solar Energy Research Institute (Golden, Colo.)

FIGURE 1. Plan of 50-Million-Gallon-per-Year Grain-Based Ethanol Facility

PROCESS FLOW

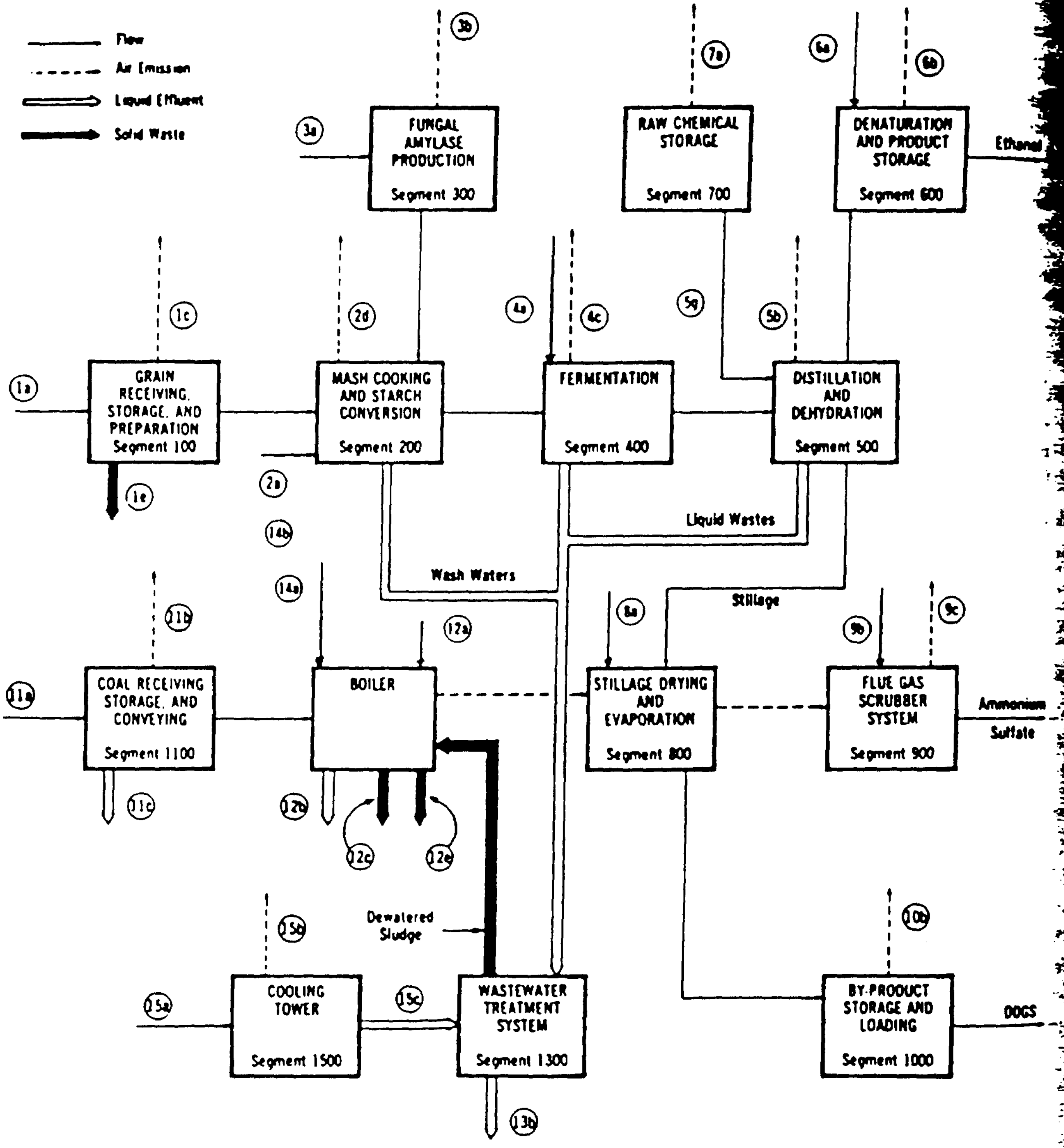


FIGURE 2. Grain-Based Ethanol Fermentation Facility Process Flowchart

densers is recycled through a two-cell cooling tower. A flue gas scrubbing system employing ammonia is utilized to remove particulates and sulfur dioxide emissions, producing ammonium sulfate. The latter could be utilized as a rtilizer.

AIR EMISSIONS CHARACTERIZATION

Air emissions from an ethanol plant arise principally from three sources:

- Combustion of conventional and unconventional fuels
- Feedstock preparation and by-product processing operations
- Overall process schemes employed, such as the distillation/dehydration systems, flash coolers, evaporators, and cooling towers.

Figure 2[3] presents the process flowchart for the facility and should be reviewed in conjunction with Table 1,[3] which provides data on the resources used and products produced. Table 2,[3] also to be reviewed in conjunction with Figure 2, presents the facility's annual releases of air and water pollutants and solid wastes.

Most of the plant air emissions are associated with the combustion process used to supply steam and electricity to the plant. The type of fuel used and the degree of combustion will dictate the nature of these emissions. For example, uncontrolled emissions from coal- or biomass-fired boilers will be greater than those from facilities using natural gas or residual oil. The degree of local impact of emissions from facilities using solar energy or process waste, such as bagasse, would be considerably different from that of a conventional fuel source. These air emissions, therefore, are not inherently coupled to the biomass-to-ethanol process.

Particulate emissions, sulfur oxide (SO_x) emissions, and, to a lesser extent, nitrogen oxide (NO_x) emissions associated with coal combustion are likely to constitute the primary air-related environmental problems for most facilities. Polycyclic organic matter (POM) emissions from some of these sources are also significant. In a test performed by

TABLE 1. Resources Used and Products Shipped

Code No.[a]	Resource	Annual Usage[b]
	Feed materials	
1a	Corn	544×10^3 tons
	Fuel	
11a	Coal	97.9×10^3 tons
	Water	
2a	Process water	330×10^6 gallons
14b	Raw water makeup	83.1×10^6 gallons
5a	Cooling tower makeup	280×10^6 gallons
	Processing materials	
3a	Air input to amylase production	223×10^3 tons
4a	Yeast	396 tons
	Iodine sterilizing solution	7.92×10^3 gallons
5g	Hydrocarbon solvent	9.03×10^3 gallons
6a	Denaturant	1.00×10^6 gallons
8a	Air input to dryer	652×10^3 tons
9b	Anhydrous ammonia	3.04×10^3 tons
12a	Air input to boiler	1.10×10^6 tons
14a	Water treatment chemicals	
	Sodium chloride	396 tons
	Lime	792 tons
	Sludge polymer	7.9 tons
	Land	50.0 acres
	Personnel	
	Operation	159 workers

Product	Annual Production
Primary	
Ethanol (199 proof)	50×10^6 gallons
By-products	
Distillers' Dark Grains	177×10^3 tons
Dry ammonium sulfate	10.4×10^3 tons
Fusel oils[c]	760 tons

[a] See Figure 2.

[b] Assumes a 90 percent capacity factor

[c] Fusel oils are usually mixed with the grain ethanol product prior to blending with gasoline.

TABLE 2. Annual Releases of Air and Water Pollutants and Solid Wastes

Code No.*	Environmental Residuals	Annual Quantities Released
	Air Pollutants	
1c	Particulates from grain cleaning	163 tons
2d	Emissions from starch conversion	Negligible
3b	Emissions from enzyme production	Negligible
4c	Emissions from fermentation:	
	Ethanol	1.80×10^3 tons
	Water vapor	2.48×10^3 tons
	Carbon dioxide	170×10^3 tons
5b	Distillation/dehydration pollutants:	
	Carbon dioxide	$2..81 \times 10^3$ tons
	Water vapor	41.2 tons
6b	Emissions from product handling	Negligible
7a	Emissions from raw chemical storage	Negligible
9c	Scrubber emissions:	
	Sulfur dioxide	947 tons
	Particulates	104 tons
	Nitrogen oxides	726 tons
	Water vapor	120×10^3 tons
10b	Exhaust from DDGS handling	5.31 tons
11b	Fugitive dust from coal handling	49.0 tons
15b	Cooling tower evaporative drift losses	242×10^6 gallons
	Water pollutants	
11c	Water runoff from coal storage	Not quantifiable
12b	Boiler blowdown	7.92×10^6 gallons
13b	Wastewater effluent to river	363×10^6 gallons
15c	Cooling tower blowdown	38×10^6 gallons
	Solid wastes	
1e	Grain cleaning rejects	54.4 tons
12c	Boiler bottom ash	3×10^3 tons
12e	Boiler fly ash	4.75×10^3 tons

*See Figure 2.

TRW Environmental Engineering Division (Redondo Beach, Calif.), the POM emission factors for coal and, especially, for wood were found to be extremely high, approximately 13.8 mg/kg and 484 mg/kg respectively.[4] In the study, dibenz[a,h]anthracene, a carcinogen, was identified, and the presence of other carcinogens, such as benzo[a]pyrene and benzo[g,h,i]perylene, was also indicated. For this reason, particulate emissions, especially respirable particulates, and associated POMs from wood and wood residue combustion are of concern.[5]

Stack emissions from burning corn stalks or bagasse are primarily in the form of particulates and NO$_x$ since there is very little sulfur present. Little analysis of the chemical composition of these emissions has been done. On the basis of experience with burning bagasse in the sugar industry, the particulates can be expected to be lightweight and high in unburned carbon content.[6] The moisture content of these residues will determine the feasibility of their use as fuel sources. At 50% moisture content, most of the agricultural residues are good fuel sources. At higher percentages, however, the moisture causes some problems, limiting combustion.

Several types of trace elements also will be present in the boiler flue gas from conventional coal and oil combustion. Besides chlorine, the elements of greatest concern appear to be aluminum, barium, beryllium, chromium, lithium, nickel, phosphorus, and silicon.[3] Again, the amount of these emissions will depend largely on the type and grade of fuel and on the type of boiler and stack emission controls.

Other sources of emissions are the fermentation and enzyme-producing and distillation and dehydration sections, as well as ethanol denaturing, storage, and handling operations. The principal pollutants of concern from these operations are VOC emissions. Vents from the fermentation vats, flash coolers, enzyme-producing reactors, and distillation and dehydration columns produce the highest levels of VOCs. The VOC emissions generated during chemical storage are relatively small.

Fermentation facilities generally produce large amounts of carbon dioxide (CO$_2$). For example, in the ethanol facility reviewed above, for each molecule of sugar fermented, two molecules of ethanol and two molecules of CO$_2$ are produced. Carbon dioxide from annually renewable feedstocks is not generally considered a net contributor to atmospheric CO_2. The CO_2 is often recovered and sold as liquified CO_2 where the local market conditions are favorable.

AIR POLLUTION CONTROL MEASURES

The emissions most likely to require controls are SO_x and particulates. Control of NO_x is possible with boiler design and operating parameters; where NO_x emissions are not regulated, no control is likely to be employed. Generally, the controlled emissions of air pollutants from fuel combustion are expected to be within regulated limits in most states.[7]

Grain-handling or feedstock-preparation operations within an ethanol plant generate emissions similar in amount and characteristics to those from other grain-handling operations, such as grain elevators and milling activities. Particulate emissions are the main pollutant from grain-processing facilities; they are generated in an ethanol plant by grain receiving and unloading, cleaning, and conveying, as well as by storage and milling operations. The majority of these emissions arise principally from cleaning and milling operations. Stillage (residual mash remaining after distillation) drying or by-product processing will also generate particulates; their amounts may be greater than those from grain-milling operations. Although these emissions are fugitive, control by conventional techniques is both possible and feasible.

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FISH, MEAT, AND POULTRY PROCESSING

William H. Prokop, P.E.

This chapter discusses the application of odor control technology to various agricultural operations which consist of the production and processing of fish, meat and poultry. For a comprehensive discussion of odor sensory measurement and a brief discussion of odor control methods, refer to Chapter 5 on odors.

This chapter is divided into four sections. These subjects are of sufficient importance to merit individual discussions of the pollution problems and the control technology associated with these agricultural activities.

LIVESTOCK PRODUCTION AND MEAT PROCESSING

Livestock production is a major activity in the United States. The raising of cattle, hogs, and sheep for meat production is an important food source. Feedlots for beef cattle and hog production have become major operations where large herds of animals are concentrated in a single location. For example, more than half of the beef cattle raised in the United States are located in feedlots containing more than 10,000 head. As a result, the collection, storage, transport, treatment, and disposal of manure has resulted in major odor problems. These emissions and their control are discussed in detail later in this chapter.

Cattle and hog slaughter operations are becoming more concentrated into fewer and larger companies, with only three major companies currently accounting for more than 60% of the annual total beef slaughter, estimated at approximately 35 million head. Less than five years ago, six or seven companies accounted for the same percentage of the total.

A typical beef slaughter operation includes receiving cattle in holding pens, stunning the animals and draining their blood at the kill floor, removing their hides, and evisceration and trimming. Each animal's carcass is separated into edible parts for human consumption and inedible by-products, which are processed in rendering plants. Choice fatty parts from the cutting operations are processed into edible fats by a special rendering process. Manure is collected from the holding pens and paunch manure is *fourth edition*

CHEMICAL PROCESS INDUSTRIES

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The water in 95% alcohol is rem al methods: (1) Dehydration by *distillation with a third co* which forms a minimum constant-boiling mixture in the system, boiling at a lower temperature than the 95% alcohol (78.15°C) or the water. Here (*a*) the minimum is a binary one, of which water–ethyl ether is an example,[24] or (*b*) the minimum is a ternary one, of which alcohol-water-benzene is an example. In such instances anhydrous alcohol is obtained at the bottom of the distilling column, because its vapor pressure is relatively lower than that of the constant-boiling mixture removing the water. (2) Dehydration by *countercurrent extraction*,[25] usually also in a continuous column with a third component which depresses the vapor pressure of water more than it depresses the vapor pressure of alcohol, e.g., glycerol, ethylene glycol, glycerol or glycol with dissolved salts, and a molten eutectic mixture of sodium and potassium acetates. Anhydrous alcohol comes out at the top of the extraction column.[26]

The basic principle of the process using benzene as a withdrawing agent is illustrated[27] in Fig. 31.3. There are three binary minimum constant-boiling mixtures in the system, two homogeneous ones and one heterogeneous one (between water and benzene), and a ternary minimum constant-boiling mixture which is the lowest-boiling composition in the system, boiling at 64.85°C. In Fig. 31.3 the composition of the ternary minimum constant-boiling mixture is represented by point *F*. In order that the removal of the constant-boiling mixture from the starting mixture may leave anhydrous alcohol in the still, the starting composition must lie on the straight line *CF*. If the starting mixture is to be made up by adding benzene to 95% alcohol, the starting composition must also lie on the line *EB*. Therefore the intersection *G* represents the starting composition. If enough benzene is added to 95% alcohol to bring the total composition to point *G*, continuous distillation gives the ternary constant-boiling mixture (bp 64.85°C) at the top of the column and absolute alcohol (bp 78.3°C) at the bottom of the column in a simple distillation.

An important[28] feature of the process is separation of the condensate into two liquid layers, represented in Fig. 31.3 by points *M* and *N*. The ratio of the top layer *N* to the bottom layer *M* is equal to *MF*/*FN*, or 84:16. The compositions involved are shown in Fig. 31.4, which also illustrates how this process functions. These same principles of distillation in multicomponent systems, involving constant-boiling mixtures, are used for dehydrating other organic liquids, such as propyl alcohol, and for removing the water formed in sulfonations (benzenesulfonic acid) and esterifications (ethyl acetate).[29] The fundamentals of distillation are presented here because of the extensive data on alcohol that are available.

BEERS, WINES, AND LIQUORS

The making of fermented beverages was discovered by primitive humans, and has been practiced as an art for thousands of years. Within the past century and a half it has evolved into a highly developed science. A brewer has to be an engineer, a chemist, and a bacteriologist. In common with other food industries, the factors taste, odor and, almost, individual preference exist, to force the manufacturer to exert the greatest skill and experience in producing palatable beverages of great variety. In the last analysis, the criterion of quality, with all the refinements of modern science, still lies in the human sensory organs of taste, smell, and sight.

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[23] This third component is frequently called a *dehydrating* or *withdrawing agent* or simply an *entrainer*. See ECT, 2d ed., vol. 2, pp. 839-859, 1963 (references) and Tassios (ed.), Extractive and Azeotropic Distillation, ACS, 1972.

[24] Othmer and Wentworth, Absolute Alcohol, *Ind. Eng. Chem.* 32, 1588-1593 (1940). Here the water is removed overhead by ether, the system being under 100 lb of pressure.

[25] Othmer and Trueger, Recovery of Acetone and Ethanol by Solvent Extraction, *Trans. AIChE*, 37, 597-619 (1941).

[26] The use of a solid dehydrating agent, such as quicklime or calcium sulfate, may be looked upon as an extreme case of the method, though usually run in a discontinuous manner because of the solid involved.

[27] A somewhat similar procedure is the ether pressure system of Othmer and Wentworth, *op. cit.*

[28] Guinot and Clark, Azeotropic Distillation in Industry, *Trans. AIChE* (London), 16, 189 (1938).

[29] Consult Perry, sec. 13, on distillation, for a rigorous and fundamental treatment of this important unit operation.

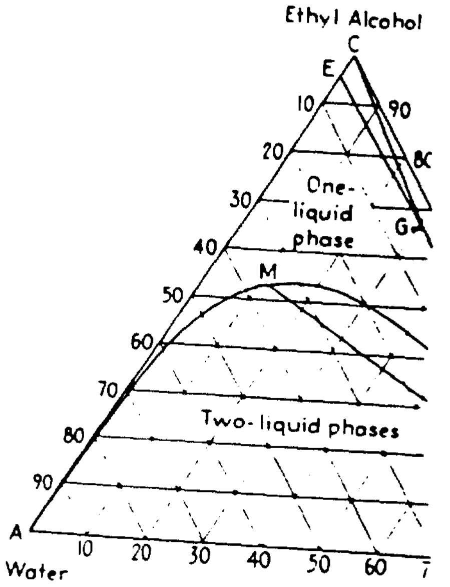

Fig. 31.3 Ternary diagram of the liquid system water-al

USES AND ECONOMICS As Table 31.3 ages are manufactured in the United States e. increasing rapidly in recent years.

RAW MATERIALS Grains and fruits su The variety of grains and fruits employed is wide to beverage. Russia ferments potatoes and by di of the maguey in Mexico yields pulque; but the cereals, corn, barley, and rice, and grapes.

MAKING OF BEER[30] Beer and allied prod made by brewing various cereals with hops, usual control the fermentation that follows. The cereals sary enzymes and the desired flavor, as well as n used in Germany, and rice and millet in China.

TABLE 31.3 *U.S. Production of Alcoholic Beverage Fiscal Years 1965–1980 (In thousands)*

Beverage	*1965*	*1972*	*198*
Still wine, gal	197,257	599,000	800
Sparkling wine, gal	6,358	20,400	30,
Rectified, proof gal	92,923	120,907	150,
Beer, bbl	108,015	143,000	200,

Source: U.S. Treasury, Internal Revenue Service. *19 a estimated. Note: 1 bbl contains 31 gal.

[30] Shearon and Weissler, Brewing, *Ind. Eng. Chem.* 43, 126. 2d ed., vol. 3, p. 297, 1964.

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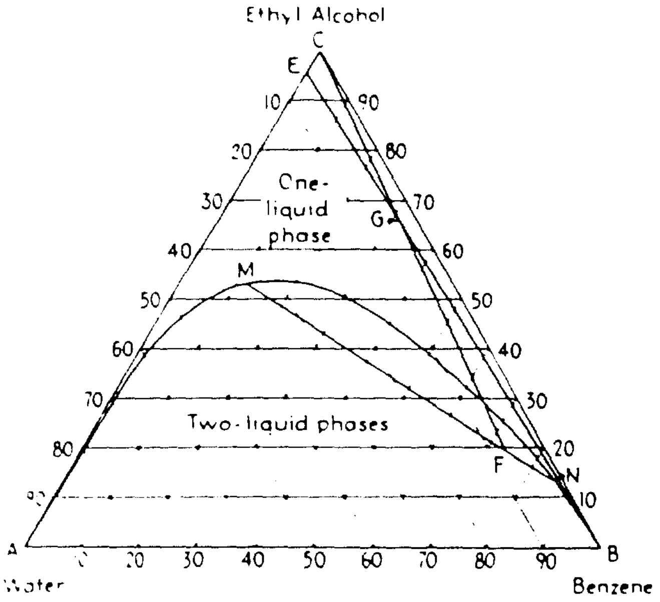

Fig. 31.3 Ternary diagram of the liquid system water-alcohol-benzene.

USES AND ECONOMICS As Table 31.3 indicates, many millions of barrels of alcoholic beverages are manufactured in the United States each year. The amount of wine production has been increasing rapidly in recent years.

RAW MATERIALS Grains and fruits supplying carbohydrates are the basic raw materials. The variety of grains and fruits employed is wide, changing from country to country or from beverage to beverage. Russia ferments potatoes and by distillation obtains vodka; similar treatment of the sap of the maguey in Mexico yields pulque; but the world's chief raw materials for fermentations are the cereals, corn, barley, and rice, and grapes.

MAKING OF BEER[30] Beer and allied products are beverages of low alcoholic content (2 to 7%) made by brewing various cereals with hops, usually added to impart a more-or-less bitter taste and to control the fermentation that follows. The cereals employed are barley, malted to develop the necessary enzymes and the desired flavor, as well as malt adjuncts: flaked rice, oats, and corn; wheat is used in Germany, and rice and millet in China. Brewing sugars and sirups (corn sugar, or glucose)

TABLE 31.3 *U.S. Production of Alcoholic Beverages, Fiscal Years 1965–1980 (In thousands)*

Beverage	*1965*	*1972*	*1980**
Still, wine gal	197,257	599,000	800,000
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Source: U.S. Treasury, Internal Revenue Service. *1980 is estimated. *Note:* 1 bbl contains 31 gal.

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[30] Shearon and Weissler, Brewing, *Ind. Eng. Chem.*, 43, 1262 (1951) (many excellent pictures, tables, and diagrams); ECT, 2d ed., vol. 3, p. 297, 1964.

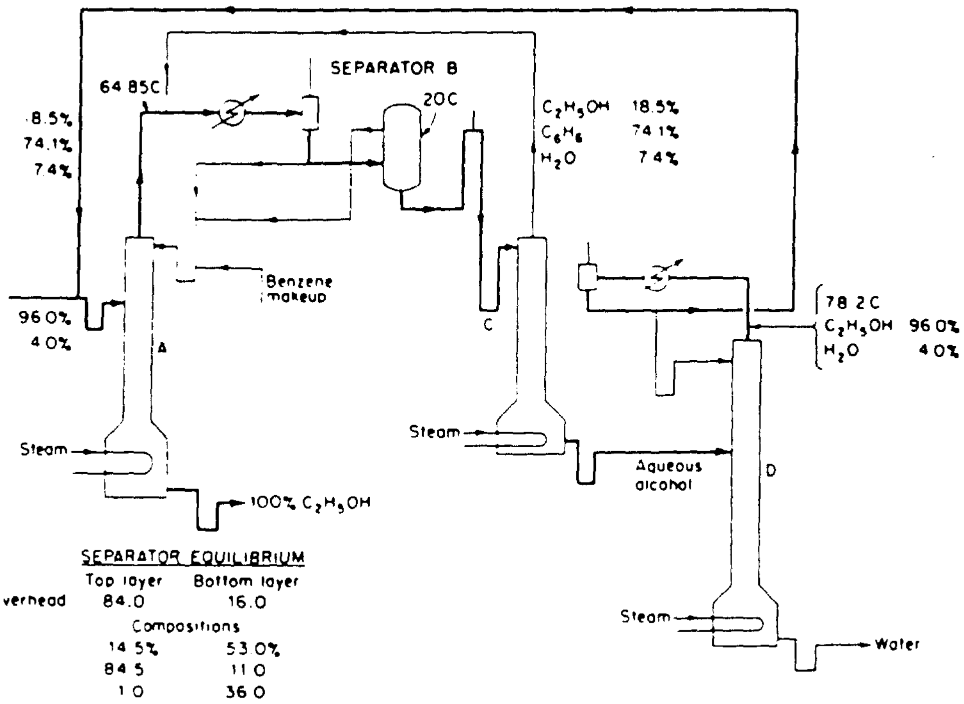

Fig. 31.4 Dehydration of 96% ethanol to absolute alcohol by azeotropic distillation with benzene at 1 atm. 96% alcohol is fed into column *A*. The ternary azeotrope is taken overhead in this column, and absolute alcohol is obtained as a bottoms product. The overhead vapors are condensed and passed to a separator (decanter) *B*, in which two liquid layers form. The upper layer, rich in benzene, is returned to column *A* as reflux, and the lower layer is fed to column *C*, which produces the ternary azeotrope as the overhead product and benzene-free aqueous alcohol as the bottoms product. This latter product is fed to column *D* which produces by ordinary distillation an overhead product of 96% alcohol and a bottoms product of nearly pure water. The overhead from column *D* is recycled to column *A* for removal of the water. The benzene is recycled continuously in this system, and it is necessary only to make up the benzene losses from the system. This withdrawing agent is used over and over again with a loss that should not exceed 0.5% of the volume of the anhydrous alcohol produced. [*Perry, p. 13-42; Chem. Eng.* (N.Y.), 67(10), 129 (1960).]

and yeast complete the raw materials. For beer the most important cereal is barley, which is converted into malt by partial germination.[31]

The barley is steeped in cold water and spread out on floors or in special compartments and regularly turned over for from 5 to 8 days, the layers being gradually thinned as the germination proceeds. At the proper time, when the enzymes are formed, growth is arrested by heat. During growth, oxygen is absorbed, carbon dioxide is given off, and the enzyme *diastase* is formed. The last-mentioned is the biological catalyst that changes the dissolved starch into the disaccharide maltose which, after transformation into the monosaccharide glucose by *maltase*, is directly fermentable by yeast.

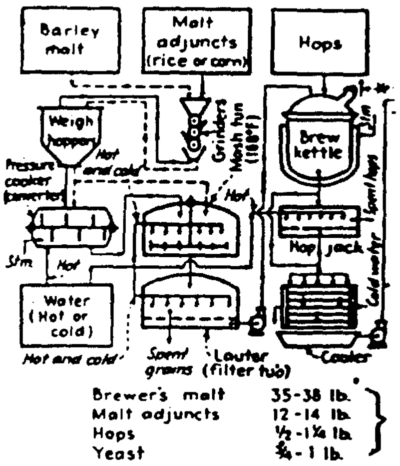

Fig. 31.5 Flowchart for the manufacture of beer

The flowchart for beer manufacture in Fig. 31.5 may be divided into three groups of procedures: (1) brewing of the mash through to the cooled hopped wort, (2) fermentation, and (3) storage, finishing, and packaging for market. *Mashing* is the extraction of the valuable constituents of malt, malt adjuncts, and sugars by macerating the ground materials with 7.5 to 9 bbl of water per 1,000 lb of materials listed in Fig. 31.5 and treating with water to prevent too high a pH, which would tend to make a dark beer. In the pressure cooke
the soluble malt starch into dextrin and r
the rest of the malt in the mash tun, raisin
wort.[32] This is carried out in the *mash* t
from the brewing materials, the entire ma
straining tub, where the wort is separat
bottom and run into the copper wort coo
spray of decarbonated water at 165°F is

The wort is cooked for approximate
purpose of boiling is to concentrate the w
stroy all the enzymes, to coagulate certai
extract the hop resins' tannin and aroma :
At the end of the 3 h the spent hops are s
bottom in the hop jack or strainer under
of wort per 100 lb of hops, they should

The cooling step is not only to red
enough air to facilitate the start of ferm
cipitated. The hot wort first may be cool
certain of the resins precipitate. The wor
of the open Baudelot cooler or through a
place. Slight concentration, due to evapo
conditions to prevent contamination by

The cooled wort is mixed with sele
¾ and 1 lb of yeast being used per barrel
but, as the fermentation proceeds, the te
that the conversion of the sugar to car
generates 280 Btu/lb of maltose conver

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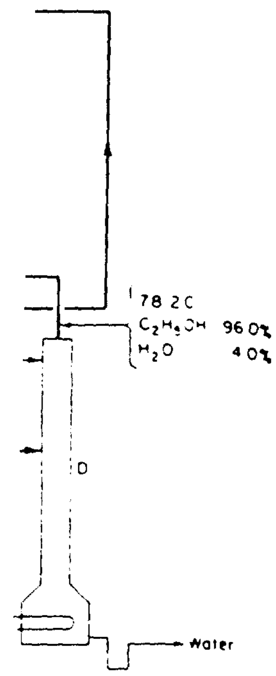
[31] Continuous Brewery Opens in Spain, *Chem. Eng.* (N.Y.), 74(19), 156 (1967); cf. ECT, 2d ed., vol. 2, pp. 384-413; Chopey, What's Doing in Beer Brewing', *Chem. Eng.* (N.Y.), 69(13), 94 (1962) (process flowchart with pictures).

[32] The wort is the liquid resulting from the mash.
Wort composition varies from 17 to 24% solids by
by the sparge water.

[33] Cf. Chopey, *op. cit.*



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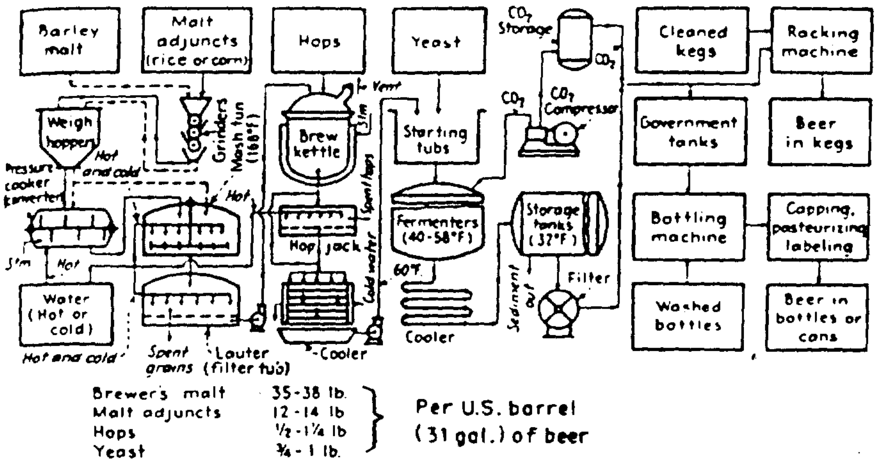

Fig. 31.5 Flowchart for the manufacture of beer

make a dark beer. In the pressure cooker the insoluble starch is converted into liquefied starch, and the soluble malt starch into dextrin and malt sugars. The resulting boiling cooker mash, mixed with the rest of the malt in the mash tun, raising the temperature to 168°F, is used to prepare the brewers' *wort*.[32] This is carried out in the mash tun. After all the required ingredients have been dissolved from the brewing materials, the entire mash is run from the mash tun to filter presses or the lauter or straining tub, where the wort is separated from the insoluble spent grains through a slotted false bottom and run into the copper wort cooker. For complete recovery of all substances in solution, a spray of decarbonated water at 165°F is rained through the grains. This is called *sparging*.

The wort is cooked for approximately 3 h, during two of which it is in contact with hops. The purpose of boiling is to concentrate the wort to the desired strength, to sterilize it (15 min) and destroy all the enzymes, to coagulate certain proteins by heat (180°F), to modify its malty odor and to extract the hop resins' tannin and aroma from the hops, which are added during the cooking process. At the end of the 3 h the spent hops are separated from the boiling wort very quickly through a false bottom in the hop jack or strainer underneath the copper cooker. Since the spent hops retain 3 bbl of wort per 100 lb of hops, they should also be sparged. The wort is then ready to be cooled.

The cooling step is not only to reduce the temperature, but also to allow the wort to absorb enough air to facilitate the start of fermentation. In addition, the protein and hop resins are precipitated. The hot wort first may be cooled to about 150 to 160°F in a large, shallow cooler, where certain of the resins precipitate. The wort is then run over the horizontal, brine-cooled copper tubes of the open Baudelot cooler or through a shell and tube heat exchanger,[33] where aeration also takes place. Slight concentration, due to evaporation, occurs. This operation is performed under controlled conditions to prevent contamination by *wild* yeasts. Frequently, sterilized air is used.

The cooled wort is mixed with selected yeasts in the line leading to the starting tubs, between ¾ and 1 lb of yeast being used per barrel of beer. The initial *fermentation* temperature is 40 to 43°F but, as the fermentation proceeds, the temperature rises to 58°F. This is easily explained by the fact that the conversion of the sugar to carbon dioxide and ethyl alcohol by the enzymes of the yeast generates 280 Btu/lb of maltose converted. The temperature is partly controlled by attemperators

[32] The wort is the liquid resulting from the mashing process, i.e., the extracting and solubilizing of the malt and malt adjuncts. Wort composition varies from 17 to 24% solids by weight for the first wort to approximately 1% solids for the last wort removed by the sparge water.

[33] Cf. Chopey, *op. cit.*

inserted in the fermentors. The mixture is skimmed to remove the foreign substances the evolved carbon dioxide brings to the top. Thus it is quite evident that a steady evolution of gas is necessary to cleanse the beer properly. The carbon dioxide evolved is collected by using closed fermentors and stored under 250 lb of pressure for subsequent use in carbonating beer.

The yeast gradually settles to the bottom of the tub, so that at the end of 7 to 10 days the fermented beer is ready to be vatted. The liquid is very opalescent in appearance, under a cover of foam. As the beer leaves the fermenting cellar, it contains in suspension hop resins, insoluble nitrogenous substances, and a fair amount of yeast. The beer is cooled to 32°F and stored in the cellar for 3 to 6 weeks at this temperature. During this period, clarification, separation, and precipitation of hard resins and improvement in palatability (mellowing) occur. Haze on cooling may be reduced (chillproofing) by the addition of polyvinylpyrrolidone.[34] At the end of the period the beer is carbonated[35] and pumped through a pulp filter with or without such a non-taste-imparting filter aid as asbestos fiber. In the United States, public demand favors a brilliant beverage. As a result, the beer is sometimes refiltered through cotton pulp, keeping carbon dioxide on the entire system. About 97 bbl of beer is produced per 100 bbl of wort in the starting tubs. After bottling, the beer is pasteurized at 140°F.

Some beer is not pasteurized but biologically purified by membrane filtration, which removes residual yeast cells and harmful bacteria. This ultrafiltration, and several other new procedures including the addition of antimicrobials, produce so-called bottled draft beer. Beer with the carbohydrate content reduced from the usual 4% to near zero, which reduces the food content from 160 calories to 100 calories per 12-oz bottle is also available.

MAKING OF WINE Wine has been made for several thousand years by fermentation of the juice of the grape. Like other fermentations, many primitive procedures have been supplanted by improved science and engineering to reduce costs and to make more uniform products. But now, as always, the quality of the product is largely related to grape, soil, and sun, resulting in a variation in flavor, bouquet, and aroma. The color depends largely upon the nature of the grapes and whether the skins are pressed out before fermentation. Wines are classified as natural (alcohol 7 to 14%), fortified (alcohol 14 to 30%), sweet or dry, still or sparkling. Fortified wines have alcohol or brandy added. In the sweet wines some of the sugar remains.

For the manufacture of dry red wine, red or black grapes are necessary. The grapes are run through a crusher, which macerates them but does not crush the seeds, and also removes part of the stems. The resulting pulp, or *must*, is pumped into 3,000- to 10,000-gal tanks,[36] where sulfurous acid[37] is added to check the growth of wild yeast. An active culture of selected and cultivated yeast equal to 3 to 5% of the volume of juice is added. During fermentation, the temperature rises, so that cooling coils are necessary to maintain a temperature below 85°F. The carbon dioxide evolved carries the stems and seeds to the top, which is partly prevented by a grating floated in the vat. This allows extraction of the color and the tannin from the skins and seeds. When the fermentation slows up, the juice is pumped out of the bottom of the vat and back over the top. The wine is finally run into closed tanks in the storage cellar, where, during a period of 2 or 3 weeks, the yeast ferments the remainder of the sugar. The wine is given a cellar treatment to clear it, improve the taste, and decrease the time of aging. During this treatment the wine is first allowed to remain quiet for 6 weeks to remove part of the matter in suspension, and then racked for clarification.[38] Bentonite, or other

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[34] *Brew. Dig.* 47(5), 75 (1972).

[35] The carbon dioxide should be kept free from air, which would interfere with the stability and quality of the beer. The gas is pumped in cooled to 32°F and amounts to between 0.36 and 0.45% of the weight of the beer.

[36] In many western American wineries these tanks are even larger and are constructed of concrete.

[37] Potassium or sodium metabisulfite and/or sodium bisulfite may also be used.

[38] During this and the following period the new wine undergoes a complicated series of reactions, resulting in the removal of undesired constituents and development of the aroma, bouquet, and taste. Oxidation takes place, as well as precipitation of proteins and argols and esterification of the acids by alcohols. Certain modifications of this process are presented in Chemical Technology Key to Better Wines, *Chem. Eng. News*, July 2, 1973, p. 14; Chemistry Concentrates on the Grape, *Chem. Eng. News*, June 25, 1973, p. 16.

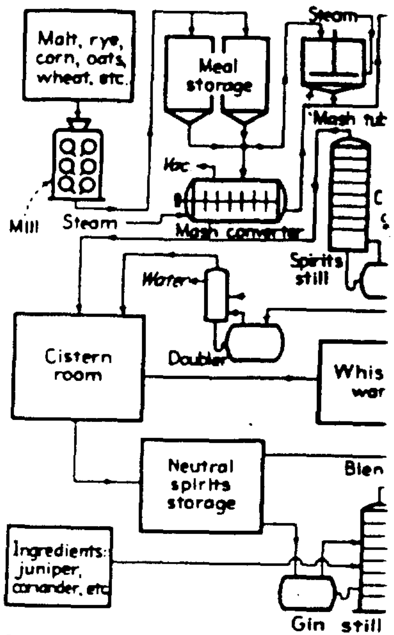

Fig. 31.6 Flowchart for the production of distille

diatomaceous earth, may be used for clea
An insoluble precipitate with the tannin
wine racked and filtered through diatoma
to commercial standards by blending it
tannins. It is standard procedure to chill
acid tartrate, which constitute the commer
ment also gives a more stable finished win
sweet wine in 4 months. These methods
light, ozone, agitation, and aeration. The w
and a small amount of oxygen gas bubbled
in the usual manner. The wine trade is l

DISTILLED SPIRITS Various ferme
liquors. Figure 31.6 shows the flowchart
Brandy is distilled from wine or from the m
a beer[39] from a grain mixture containing at
whisky. Similarly, rye whisky must start w
inspecting the flowchart in Fig. 31.6 in the
panying them, the procedures in Fig. 31.6
the equipment,[40] up to the stills, is of steel.
or rye whisky of claimed age must take pla
gal. These are kept in bonded warehouses

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[39] The yeast in this fermentation is grown in the
quality of the product (whisky).

[40] Owen, Modern Distillery Design, *Sugar*, 37(3
flowchart of a distillery); Stallings *et al.*, Chemical Engin

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BREWERY OPERATIONS

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105

Chapter 6.

SECONDARY RESOURCES UTILIZATION

George O. Wornson,
Miller Brewing Company

"WE HAVE A challenge."

How many times a week do we hear that statement? Yet the very real challenge we're addressing today is how to expand our recycling efforts.

Recycling is challenging. It's shaping up to be one of the critical issue of the Nineties. It's certainly one of the most visible of all the environmental issues. Recycling is becoming the centerpiece of society's interest in the environment.

Why is recycling a challenge? We have this one little planet in our vast solar system that is our one and only home—at least at this point in time. We need to protect it. In fact, we need to do more to protect it. For example, Brazil has discontinued its support for ethanol fuel as being too costly. The result is more air pollution. Also in Brazil, rain forests are being harvested at an alarming rate over in the Amazon region. The result is fewer trees to replenish our oxygen supply. Further, we're learning that a throw-away society increasingly taxes the world's resources. Our efforts to deal with mushrooming volumes of wastes is revealing new recycling options. Yet one key problem is that

present landfill sites are closing, and it is tough to get a permit for new sites. Protestors shout, "NIMBY." Not in my backyard!

The business world can help meet this challenge. We as businessmen and women can find business opportunities for waste products. In so doing, we must not look at them merely as wastes, but as secondary resources. Recycling and reuse is a practical solution to our environmental challenges, and breweries can easily become models for the reuse and recycling of secondary resources.

In the beer industry we have a wealth of secondary resources. We at Miller Brewing Company (MBC) are developing these and that's part of what I'm going to describe here. These secondary resources represent a great business opportunity for Miller.

One key problem we continually face is the question of perception. First, let's not call recyclable items waste products! They are, in fact, secondary resources, and as such they provide a great opportunity. Communicating to society and potential customers that distinction is a major challenge we face everyday. Yet, we must continue the effort, for there is an old truism, "Perception is reality."

My position at Miller involves working with eight breweries and various support manufacturing facilities in the US. Any one of these breweries puts out lots of quality packaged beer—and also tons of byproducts. The list of opportunities for recycling at MBC is long:

- wet and dry brewers grains,
- liquid brewers yeast,
- food grade carbon dioxide,
- recycled aluminum cans and cullet (recycled glass),
- corrugated materials,
- residuals (which we call biomass) from washing out tanks

and brewkettles treated in our wastewater treatment plants,

- plastic strapping.

Each of these items represents a real opportunity.

How great is the opportunity? Miller's profit from byproducts over the past five to six years has increased more than 50 percent. What we're trying to do is earn a fair and equitable profit in all of our operations. This certainly includes our beer and also our byproducts.

Specific Byproducts

Let's take a look at specific byproducts we produce at MBC and see what we're doing to capitalize on the opportunities they present.

- *Brewer's grains*. These are the substances that remain from the malt after the simple carbohydrates have been removed in the mashing process. These brewer's grains have certain excellent nutrient qualities that provide a wide variety of secondary uses. They are actually a concentrated form of high-quality barley malt with only the simple carbohydrates extracted. They therefore have concentrated protein, dietary fiber (a big subject for consumers these days), complex carbohydrates, valuable trace minerals, plus a concentration of barley oil.

Historically, brewer's grains have been marketed as a high-quality ingredient in dairy feed. This application is now common to the brewing industry. Miller, for example, has been selling its grains for feed purposes for years.

In recent years, we've been working to find new uses for brewer's grains and maximize the beneficial use of this resource. For example, working through our breweries, we've been able to contract directly with local customers who can provide better service and improved marketing expertise. We've also increased the number of contract customers for our grains six-fold—from just one customer in 1982 to six at the present time.

What has this meant to Miller? That because the breweries are directly involved, both service and profits have improved.

A further step into the food area is being explored as we market brewer's grains as our Barley's Best product. MBC has worked very hard and long to bring this product to reality. This idea is not new, but timing in the marketplace now seems very right. American consumers have recently become preoccupied with cholesterol reduction and a study completed at Texas A&M shows Barley's Best barley bran is about twice as successful in lowering cholesterol as oat bran. Sales are expected to continue to increase.

- *Brewer's yeast*. Yeast is another prevalent brewery byproduct we've been addressing from day one. Great strides have been made in turning this byproduct into a very profitable side business, one with many food applications. We have done this without necessitating a capital expenditure for major processing equipment. We had two paying customers in 1982, and now we have more than ten customers contracted to buy our yeast byproduct.

We have also found that injecting yeast into wet brewer's grains makes a very enhanced food product.

We continually strive to maintain a high level of service to our direct brewers yeast customers. This open line of communication is appreciated by our soup and food processors customers. We have also cultivated pharmaceutical and other speciality customers in order to foster steady sales of brewer's yeast slurry.

- *Food grade carbon dioxide*. One of our biggest success stories has been the recovery and reuse of our excess carbon dioxide gas (CO_2), which is produced during the fermentation process. Today six of our breweries have succeeded in using their CO_2 more efficiently and have even generated surplus for outside sales.

This is a perfect example of how to use our resources successfully. We discovered that we were able to capture the CO_2 and create a market for it. At the same time, we found other environmentally conscious manufacturers who were able to use this gas in their refrigeration and freezing operations. Through this procedure, we have greatly reduced CO_2 escaping into the atmosphere.

Other manufacturers who use the gas to provide refrigeration, can strive to eliminate their use of freon, which can damage the ozone layer. By not only looking at our manufacturing needs but also the needs of others, we have successfully created the kind of chain reaction that environmentally conscientious individuals and companies are seeking.

- *Aluminum cans and cullet.* Miller was quick to develop an aluminum can recycling program. Aluminum is one of the most recyclable materials on the market today. In each of our facilities we recycle all of our scrap aluminum cans.

Cullet, or broken glass reclamation, is another growing area. We have found that we can get more for the material if we remove the impurities, and if the glass is color separated.

- *Corrugated cardboard.* Cardboard is another byproduct that is receiving more attention. Paper and paper products require a lot of space in landfills. We at Miller, like most manufacturing concerns, bale and recycle all of our corrugated.

Key to the successful recycling is the creation of markets and we've shown our commitment by buying as much recycled paperboard as is available. For example, on the West coast, all of our trays, bottle cartons, and basket carriers are made out of 100 percent recycled materials. We will continue to identify other suppliers who can provide to us the same quality so we can maximize the use of recycled board nationwide. It may cost a little more, but the long-term positive effect is well worth the cost.

Miller has also found that reusing materials saves landfill space. We have started a program to reuse boxes, whereby our cartons are shipped in from our suppliers. These boxes are set up to make four trips before being recycled. During 1990, more than 750,000 pounds of boxes were reused, and throughout 1991, more than 2.5 million pounds were reused. To make this system work, the boxes are inspected and reworked at handicapped centers, thereby providing employment opportunities within the community. Fees paid to organizations for the handicapped in 1991 exceeded $170,000.

We also have a successful paper, corrugated cardboard, and aluminum can recycling program at our corporate offices. Revenues from this program are generally slated for local charities.

- *Residuals from tank and brewkettle washing.* Next is a byproduct called FARM O.N. (farming with organic nitrogen), which is a soil conditioning and liming agent made from the organic residual collected after flushing out tanks and brewkettles processed through our WWT plants. Miller completed initial land application fertilizer trials through Cornell University. Results were very positive, demonstrating liming and fertilization value. It's becoming more and more popular with farmers.

I have been involved in legislative action in North Carolina to adopt a secondary nutrient law. New regulations for this are now passed, and it clearly identifies the distinct difference of food plant nutrients and regular industrial biomass products. This is a very positive step in the right direction.

Making Recycling Work

We now have individual byproduct groups at most of our breweries. Such groups are having a positive impact on recycling. Clearly the success of our secondary resource program can be directly attributed to the dedicated employees at Miller. Their voluntary participation and innovative ideas have made a positive impact on our environment.

In addition, it takes the participation and cooperation of many various departments. For example, we had the specs of our plastic strapping changed so that any that comes into the brewery is identical, thus paving the way for easy recycling. Another example is the box for our crowns. Two vendors used a glued box, while another used staples that made it unsuitable for reuse. Now our corporate specifications say that all of our crown boxes should be glued.

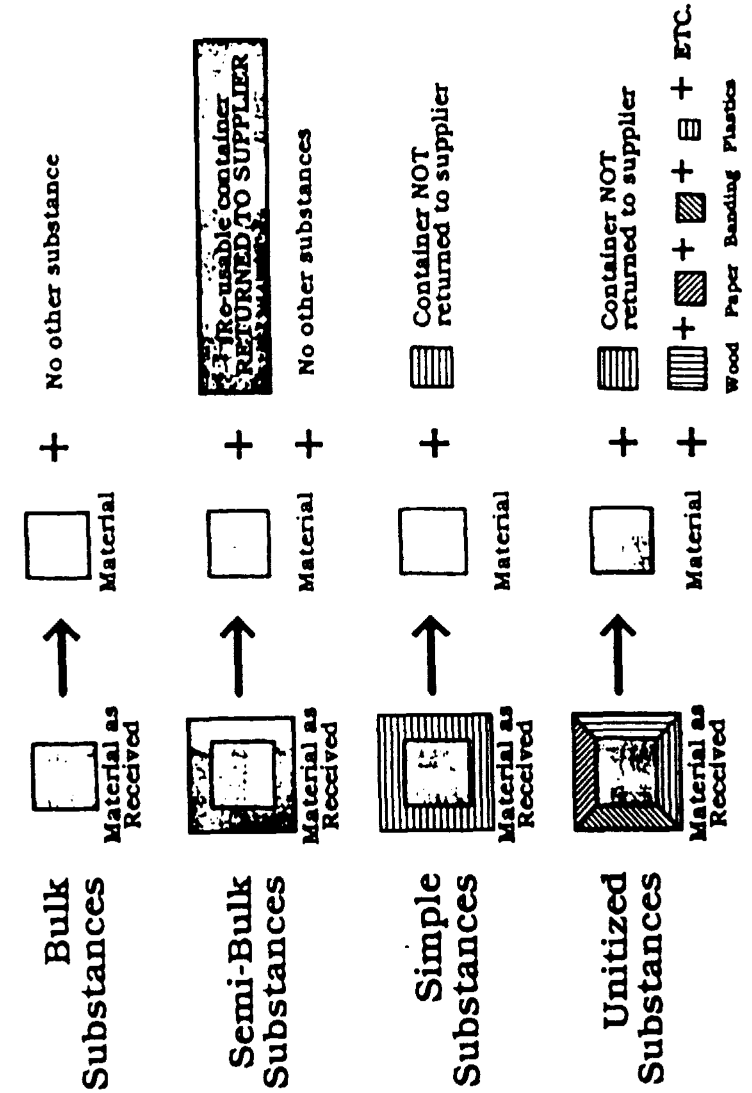
In August 1990, the Landfill Minimization Task Force was officially established. This group was formed per the recommendation of our senior Vice President of Operations. Our goal is to eliminate the use of landfills except where severe technological or economic restrictions are present. Our initial assigned measurement was to reduce landfill tonnage by 25 percent per year for the next three years.

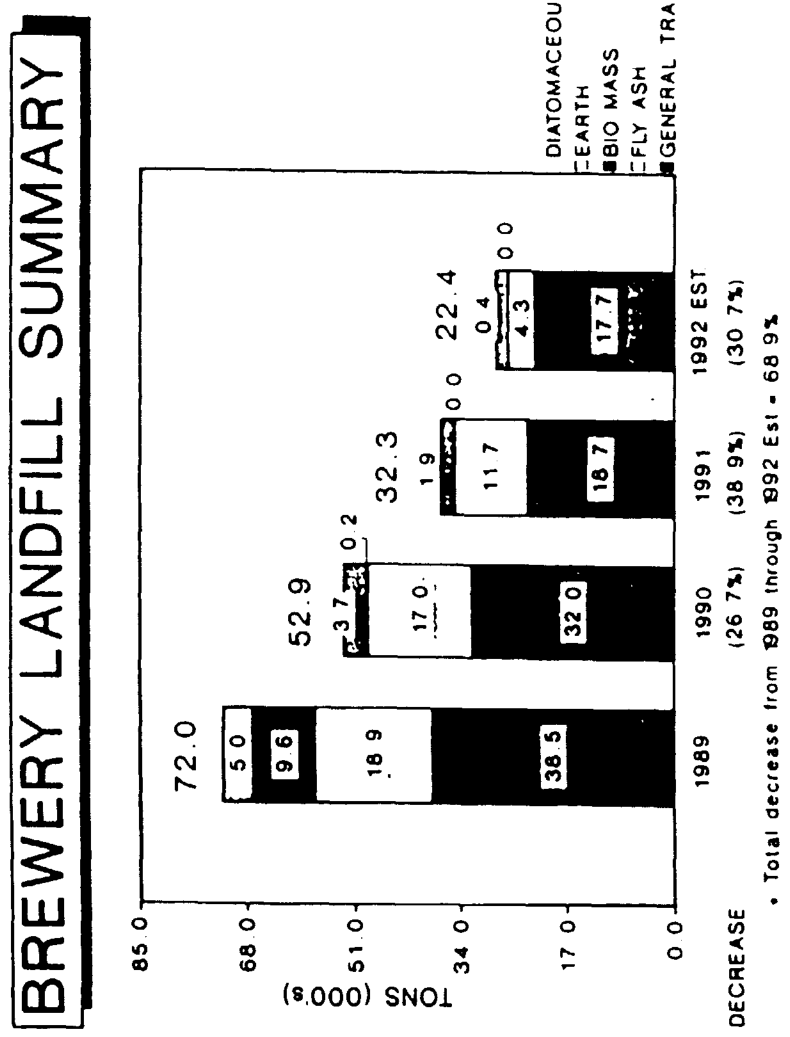
As shown in Figure 1, there are four basic ways items enter a plant:

- as bulk substances,
- as semi-bulk substances,
- as simple substances,
- as unitized substances.

The use of these individual items result, to a varying degree, in byproducts.

Let's look at figure 2 at some results of specific brewery landfill minimization. We see that from 1989 to 1992, the total volume of brewery landfill was reduced almost 69 percent. Figuring this volume was not necessarily a pretty job. I had a con-





tainer plant actually weigh and itemize all items discarded into a compactor for a two-week period. They then produced a Pareto analysis of the wasted materials, and projected the results into annual numbers. I would advise that if you are serious about a waste reduction program, implement a general audit.

Conclusion

In summary, turning waste into saleable byproducts and protecting the environment is a challenging endeavor. Whether it be brewer's yeast to food or pharmaceutical applications, brewer's grains to Barley's Best high-fiber flour, or FARM O.N. for crop application, it all relates to protecting the environment and maintaining a clean and profitable workplace. We all must continue looking for a beneficial use for everything. The Nineties will see an acceleration in environmental awareness in this country. We at Miller Brewing Company plan to continue to be part of that since we consider ourselves to be an "environmentally conscious brewery."

I would like to leave you with this one final thought. The challenge we face is being able to stretch our engineering and technical expertise so that we can communicate adequately about the issues. The success of so much of what we do depends upon the opinions and perceptions of others—the government, media, and the public. Remember, "perception is reality," and by communicating the facts about recycling, we have an opportunity to influence people's perceptions for the better. This will do a lot to smooth the way and help our secondary resources to be utilized to their true value, in harmony with our environment.

George O. Wornson joined Miller Brewing Company, Milwaukee, Wisconsin, in 1982. His assignment is Secondary Resources Corporate Manager. His position involves working with *the eight Miller breweries and some support facilities to maximize their best use of their secondary resources. From 1974 to 1982, he was manager of allied products with Coors Brewery in Golden, Colorado.*

Chapter 7.

CLEANING AND SANITATION IN A BREWPUB

Wolfram Koehler,
Crescent City Brewhouse

HOW DO CLEANING and disinfecting the brewhouse impact the production of beer? After the wort has been boiled and sterilized, it becomes the target of a variety of microorganisms that change or highly alter—if not altogether spoil—our beer. This leads to only one possible conclusion about cleaning and sterilizing the brewhouse: cleanliness is one of the most crucial tasks performed in a brewery—large or small. In order to do this in an efficient and effective way, we must identify problem areas in our breweries and make plans to deal with them on a constant, defined level.

Small Brewery vs. Brewing Factory

I have heard the argument that the small brewer does not have the means to apply science and technology, as the big breweries do, for lack of funds or necessary machinery, but I don't believe this is the problem. Brewers in breweries of any size face basically the same problems. At this point, their cleaning and sanitizing efforts have come to a point where their hours spent with a brush and a broom have been reduced to a sensible appli-

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Operation Conditions for Anaerobic Treatment of Wastewater from a Beer Brewery

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An anaerobic fluidized-bed reactor (AFBR) was used to treat wastewater from a beer brewery (total organic carbon (TOC), about 1,200 mg/l; BOD, about 2,800 mg/l). The TOC concentration in effluent treated by a single-AFBR process was 70 mg/l (corresponding to a BOD of 107 mg/l) at a hydraulic retention time (HRT) of 25 h, while the TOC in effluent treated by a double-AFBR process connected in series was 38 mg/l at a HRT of 19.5 h. However these TOC values were not below the 24 mg/l (corresponding to a BOD of 20 mg/l) which is generally required for discharge into rivers. We therefore calculated the HRT necessary to give treated effluent with a TOC of less than 24 mg/l in both processes, using a kinetic formula for the TOC removal rate derived from the results of treatment in the single-AFBR process. The HRTs for the single- and double-AFBR processes were 40.3 and 21.1 h respectively, and it was found that the double-AFBR process was more advantageous in obtaining treated effluent which could be discharged into rivers.

Wastewater from beer breweries with a BOD concentration of 2,000–3,000 mg/l is treated by the activated sludge process which is designed to operate at a HRT of 24–30 h and has a power consumption of 1–2 kWh/kg BOD. Wastewater generally appears to be discharged at a minimum flow rate of 3,000 m^3/d, though this varies depending on the season and production capacity. Thus, the activated sludge process for treating wastewater from beer breweries needs a large ground area and consumes an enormous amount of power. In view of this situation, there is a need for the development of technology capable of treating efficiently the increasing volumes of wastewater from breweries. We have been studying ways to improve the efficiency of anaerobic treatment and how to make it a general process for the treatment of many kinds of wastewater (1–3; Kida, K. *et al.*, Abstr. Annu. Meet. Soc. Ferment. Technol., Japan, p. 129, 1989). Comparing the performances of four kinds of reactors used in the anaerobic treatment of low-strength synthetic wastewater, we found that the AFBR gave the best quality of effluent within a comparatively low temperature range below 20°C (3). In the present work, we investigated a mesophilic high-rate AFBR for the treatment of brewery wastewater, and studied the organic loading rates in a single-AFBR and double-AFBR connected in series. The HRT necessary to obtain treated effluent able to be discharged into rivers could be calculated through studies of organic loading rates. Comparing alkali consumption between the single- and double-AFBR processesin terms of running costs, we also report on some other factors which need to be considered in obtaining desirable operation conditions.

Brewery wastewater Brewery wastewater from a certain brewery was decanted and its supernatant was used in all experiments. A typical example of the composition is as follows (mg/l): BOD, 2,774; TOC, 1,156; ethanol, 1,353; acetic acid, 229; propionic acid, 513; protein, 110; sugar, not detected; pH, 5.5.

Seeding sludge Mesophilic sludge from a certain sewage works in Osaka was acclimated in synthetic wastewater by the draw-and-fill method (after settling and drawing culture broth, the same volume of new synthetic wastewater was put in a reactor) in our laboratory, and used as seeding sludge.

Support medium Cristobalite (0.1–0.3 mmϕ, product of Nittetsu Mining Co. Ltd., Tokyo) was used as the support medium for microbial adhesion in the AFBR (4).

Single anaerobic fluidized-bed reactor process Figure 1 shows a schematic diagram of the single-AFBR process. The AFBR (internal diameter, 50 mm; total height, 410 mm; working volume, 1 l) had a settling zone at the top. The temperature during all experiments was kept at 37°C by circulation of water through a water jacket, and the pH in the AFBR was kept at 7.0 by a pH controller. The influent wastewater was kept in a refrigerator at 4°C. After 100 ml of the seeding sludge and 200 g of the support medium were put into the reactor, anaerobically treated synthetic wastewater was added to the 1-l level. The liquid in the AFBR was circulated overnight at 37°C at a flow rate of 14 l/h by a roller pump P-2 to fluidize the support medium. A schematic diagram of the single-AFBR is shown in Ref. no. 4.

Double anaerobic fluidized-bed reactor process The double-AFBR system was comprised of two sets of reactors connected in series. Each reactor had a structure geometrically similar to the single-AFBR, except that the working volume and circulation rate of each were 0.45 l (internal diameter of fluidization part, 30 mm) and 7.6 l/h, respectively. After the experiment with the single-AFBR was completed, the support medium was divided into each reactor of the double-AFBR process. In this process, the effluent from the first reactor flowed into the bottom of the second reactor by gravity, and the treated effluent overflowed at the top of the second reactor.

Effect of the volumetric organic loading rate Maeda *et al.* (5) reported that the sludge concentration adhering

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t medium became constant after more than one aerobic treatment by the fixed bed process with aran nets. An experiment to examine the effect of ietric TOC loading rate on the performance was • TOC volumetric loading rate of 1.1 g/l·d after 't 2 to 3 g TOC/l·d for about three months to t concentration of sludge adhering to the sup-um. The sludge concentration in the reactor was ired during the acclimation. As shown in Fig. 1, :oncentration in the effluent increased with the in-volumetric TOC loading rate. The TOC concen-the effluent rose from 100 to 180 mg/l (the TOC :fficiency decreased from 91 to 84%) when the c TOC loading rate was increased from 1.1 .5 h) to 2.1 g/l·d (HRT, 12.8 h). Furthermore, removal efficiency decreased (about 33%) at the metric TOC loading rate of 6.5 g/l·d (HRT, owever, the TOC concentration was stably main-about 770 mg/l during 7-d operation at the same

wn in Fig. 1, the TOC removal efficiency in the FBR decreased with the increase in volumetric ling rate, in the same manner as in the single-he TOC removal efficiencies in both the single-le-AFBRs decreased to 35% at the high TOC ite of about 6 g/l·d. However, the TOC removal s in the double-AFBR were 95.7% and 93.4% at OC loading rates of 1.0 (HRT, 19.5 h) and 1.6 RT, 17.0 h) respectively, and resulted in higher nce than in the single-AFBR. This agreed with usion obtained in the anaerobic treatment of orted by Jeris (6), in which a double AFBR higher COD removal efficiency than the single

rison of performance between the single and dou-' processes The relationship between BOD ncentrations in the effluent is shown in the fol-ation, with a correlation coefficient of 0.94 om the analytical data during the anaerobic . Equation 1 can be applied for a BOD of 30 /l.

$$D = 1.9 \cdot TOC - 25.9 \qquad (1)$$

1, the TOC concentration to enable discharge was estimated as 24 mg/l, which corresponds to ncentration of 20 mg/l.

tionship between HRT and TOC concentration uent is shown in Fig. 2, based on the results in is evident from this figure, neither process can OC concentration of 24 mg/l required for dis-o rivers at any HRT examined.

'e tried to derive a kinetic formula for the TOC ate from the experimental results in the single-ocess in order to calculate the HRT necessary a dischargable level of TOC, assuming that the mpletely mixed the liquid, and the sludge con-adhering to the support medium became con-former assumption was based on the fact that little difference in the TOC concentrations of the aken from the top and bottom of the reactor; le, 770 and 775 mg/l for each sample at a volu-C loading rate of 6.5 g/l·d. The latter assump-ed on the fact that the sludge concentration adher-support medium was supposed to have reached level as a result of the preliminary loading ope-

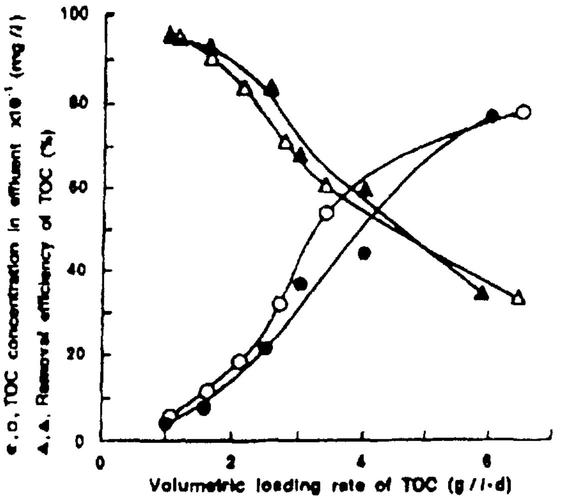

FIG. 1. Effect of volumetric TOC loading rate on the quality of treated effluent in anaerobic treatment in the single- and double-AFBR systems. Symbols: ○, △, single-AFBR; ●, ▲, double-AFBR.

of the volumetric TOC loading rate on performance. From the TOC concentrations of the influent S_0 (mg/l) and the effluent S (mg/l), the TOC removal rate υ (mg/l·h) can be calculated as follows:

$$\upsilon = F(S_0 - S)/V \qquad (2)$$

where, F = feeding rate of the brewery wastewater, l/h;
V = working volume of the reactor, l.

Substitution of experimental data F, S_0 and S into Eq. 2 led to the result that the TOC removal rate plotted against the TOC concentration in the effluent showed a saturation curve (data not shown), which was given by Lineweaver-Burk plot (Fig. 3), as follows:

$$\upsilon = 95.7 \cdot S/(54.8 + S) \qquad (3)$$

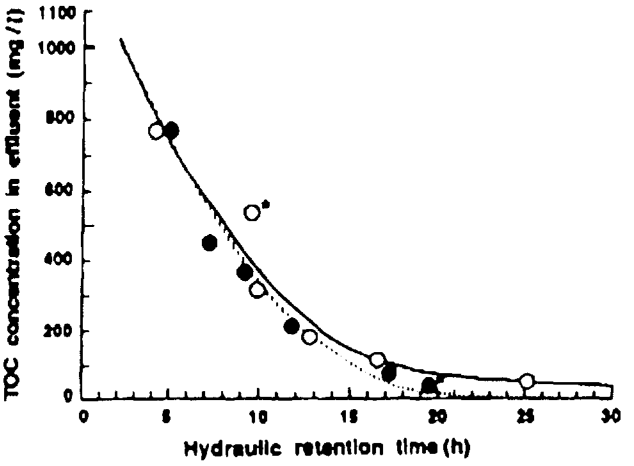

FIG. 2. Relationship between the quality of treated effluent and hydraulic retention times in the single- and double-AFBR processes. TOC concentration of wastewater (mg/l): ○, ●, 1,100–1,170; ○*, 1,350, ●*, 890.

	estimate	experiment
single-AFBR	——	○
double-AFBR	······	●

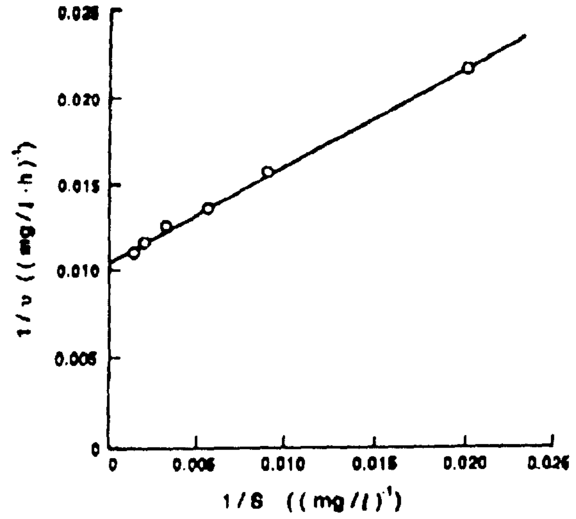

FIG. 3. Lineweaver-Burk plots for TOC removal.

From Eq. 2 and Eq. 3, the TOC concentration in the effluent, S, can be represented by HRT and S_0 as follows:

$$S = \frac{-(95.7\cdot \mathrm{HRT} + 54.8 - S_0) - \sqrt{(95.7\cdot \mathrm{HRT} - 54.8 - S_0)^2 + 4\times 54.8\cdot S_0}}{2} \quad (4)$$

The solid line (—) in Fig. 2 shows the relationship between the TOC concentration in the effluent and the HRT in the case of $S_0 = 1{,}200$ mg/l in Eq. 4. Except for the quality of the effluent (○*) obtained in the treatment of wastewater with a TOC concentration of 1,350 mg/l at a HRT of 9.4 h, the experimental data (○) agreed with the calculated results, so the value of 24 was substituted for S to estimate the HRT necessary to give a dischargable level of TOC. The calculation gave a HRT of 40.3 h, which is much longer than the HRT (24–30 h) in the activated sludge process.

Next, the HRT needed to give a dischargable level of TOC in the double-AFBR was estimated by applying Eq. 3 to the double-AFBR process. The mass balance for the substrate in the first and the second reactors at steady state can be described as follows:

$$v_1 = F(S_0 - S_1)/V_1 \quad (5)$$

$$v_2 = F(S_1 - S_2)/V_2 \quad (6)$$

where subscripts 1 and 2 denote the first and the second reactors, respectively. Substituting $V_1 = V_2$ into Eqs. 5 and 6, the relation between the HRT and TOC concentrations in the first and the second reactors can be derived from Eq. 3 as follows:

$$\mathrm{HRT} = \frac{2\cdot V_1}{F} = \frac{2\cdot(S_0 - S_2)}{\frac{95.7\cdot S_1}{58.4 + S_1} + \frac{95.7\cdot S_2}{58.4 + S_2}} \quad (7)$$

The dotted line (……) in Fig. 2 shows the relation between HRT and S_2 in the case of $S_0 = 1{,}200$ mg/l and $V_1 = 0.45$ l, and it seemed to be applicable to the experimental results. Substitution of 24 for S_2 in Eq. 7 gave a HRT of 21.1 h, which was about half that in the single-AFBR. These results showed that the double-AFBR process had advantages over the activated sludge process with respect to a reduction of both the HRT and the power consumption needed for aeration, and it can be regarded as an alternative process. Moreover, from the viewpoint of excess sludge production too, anaerobic treatment has an advantage over aerobic treatment. For example, the production yields of excess sludge were found to be 8.2 and 118%, respectively, for anaerobic (2) and aerobic (7) treatment of distillery wastewater from *shochu* making.

TABLE 1. Alkali consumption to control the pH in the reactors at 7

HRT (h)		Alkali consumption (mol/m^3 wastewater)		
Single	Double	Single	Double	
			1st	2nd
24.8	—	0	—	—
19.6	19.6	0	0	0
12.6	11.8	0	3.0	0
9.8	9.2	0	7.2	0
—	7.0	—	16.5	0
4.3	4.7	8.9	20.5	0

—, Not examined under these conditions.

In some prefectures in Japan it is permissible for treated effluent with a BOD of less than 600 mg/l to be discharged into the sewers at a charge. In such cases, it is necessary to select a suitable process. The BOD concentration of 600 mg/l corresponds to a TOC concentration of 330 mg/l, as calculated from Eq. 1. The HRTs necessary to attain a TOC concentration of 330 mg/l in the effluent for the single- and double-AFBRs are 10.6 and 10.2 h respectively, which means that the single-AFBR is more advantageous here due to the lower financial investment needed for construction. As shown in Table 1, alkali consumption to control the pH in the reactor at 7.0 increased with the decrease of HRT, both in the single- and double-AFBR processes. In particular, a large amount of alkali solution is consumed in the first reactor of the double-AFBR process because the HRT of 10.2 h in the double-AFBR means a HRT of 5.1 h in the first reactor. From these viewpoints, the single-AFBR has some economic advantages over the double one.

In conclusion, it was found that a HRT of about 21 h in a double-AFBR would produce effluent with a BOD concentration of 20 mg/l in the anaerobic treatment of wastewater from a beer brewery. However, as explained above, it is necessary to consider local regulations as well as kinetics before the process and design base are chosen for a particular brewery.

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116