PN-ABY-041

Report 3114-95-26-33

The Hashemite Kingdom of Jordan

Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Industrial Audit Background Paper:

Yeast Industry

Harza Environmental Services, Inc.

Development Alternatives, Inc.

USAID

The Technical Assistance Team Includes:

Development Alternatives, Inc.
Science Applications International Corp.
Harza Environmental Services, Inc.
Development Associates, Inc.

United States Agency for International Development
Contract No. 278-0288-00-C-4026-00

March 1995

PREFACE/ACKNOWLEDGMENTS

This report presents the background materials for Yeast 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.

YEAST PRODUCTION INDUSTRY
BACKGROUND MATERIALS

INDUSTRIAL WASTEWATER DISCHARGE POLLUTION PROGRAM
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan

TABLE OF CONTENTS

1.0 INTRODUCTION 1
- 1.1 Background 1
- 1.2 Objectives 1

2.0 INDUSTRIAL OVERVIEW 3
- 2.1 Typical Yeast Production Processes 4
  - 2.1.1 Raw Material Preparation 4
  - 2.1.2 Fermentation 5
    - 2.1.2.1 Flask Stage 5
    - 2.1.2.2 Pure Culture Stage 5
    - 2.1.2.3 Main Fermentation Stage 6
  - 2.1.3 Product Recovery 7
  - 2.1.4 Product Finishing and Packaging 8
    - 2.1.4.1 Compressed Yeast Finishing and Packaging 8
    - 2.1.4.2 Dry Yeast Finishing and Packaging 8
  - 2.1.5 Ancillary Operations 9
    - 2.1.5.1 Equipment Cleaning and Sterilization 9
    - 2.1.5.2 Steam Production 9
    - 2.1.5.3 Cooling System 9
    - 2.1.5.4 Facility Housekeeping 10
    - 2.1.5.5 Wastewater Treatment 10
- 2.2 Water Usage 11
  - 2.2.1 Process Water 11
  - 2.2.2 Cooling Water 11
  - 2.2.3 Boiler Feed Water 12
  - 2.2.4 Housekeeping and Domestic Water 12
- 2.3 Wastes and Emissions 12
  - 2.3.1 Wastewater 12
  - 2.3.2 Air Emissions 13
    - 2.3.2.1 The Fermentors 13
    - 2.3.2.2 The Steam Plant Boiler 14
    - 2.3.2.3 The Fluidized Bed Dryer 14
  - 2.3.3 Solid Waste 14

3.0 THE YEAST INDUSTRIES COMPANY, LTD. 15
3.1 Process Description 15
3.2 Raw Materials and Water Supply 16
3.3 Wastewater Discharges 17

4.0 AREAS FOR POTENTIAL IMPROVEMENT 18
4.1 Water Conservation 18
4.1.1 Wastewater Treatment Plant Recycle 18
4.1.2 Process Water Recycle 19
4.1.3 Steam Recycle 19
4.1.4 General Process and Management Improvements 20
4.2 Pollution Prevention/Waste Minimization 20
4.2.1 Wastewater PP/WM 20
4.2.2 Air Emission PP/WM 22
4.2.2.1 Fermentor VOC Emissions 23
4.2.2.2 Boiler Emissions 24
4.2.3 Solid Waste PP/WM 25

5.0 REFERENCES 26

FIGURES

Figure 1: Block Flow Diagram of a Typical Baker's Yeast Production Process.

Figure 2: Process Flow Diagram of Production Processes; Yeast Industries Co., Ltd.

Figure 3: Process Water Recycle Diagram.

1.0 INTRODUCTION

This document presents the material collected as background information for a pollution prevention, waste minimization, and water conservation audit of Jordan's Yeast Industries Company, Limited.

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 the 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 "yeast production 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 PP/WM and suggest 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 technologies being practiced for PP/WM and water conservation for the yeast production industry. To best address the industry practices in Jordan, the specific focus of the review was on the baker's yeast segment of the industry.

The literature review included published literature and conversations with personnel within the United States (US) yeast industry. The literature consisted of PP/WM related books and articles, yeast industry journals and conference proceedings, and US Environmental Protection Agency (USEPA) documents and communications.

Section 2.0 of this report provides an overview of the baker's yeast production industry, while Section 3.0 details the processes used at Jordan's Yeast Industries Company, Limited. 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 review: copies of the appropriate sections of these references are provided under a separate cover.

2.0 INDUSTRIAL OVERVIEW

Yeast, like mold, is a fungus. As a branch of non-green plants, fungi feed upon organic materials. If they are supplied with the necessary organics together with other needed nutrients, then they will not only grow and multiply, but also will change the food into other chemical substances. Of the many species of yeast, the most commercially significant are the related strains of *Saccharomyces cerevisiae*. As brewer's yeast these organisms have been utilized to ferment the sugars of various grains to produce alcoholic beverages, and as baker's yeast they have been used to expand, or raise, dough. The focus of this report is on the production of baker's yeast.

There are two types of baker's yeast: compressed yeast and dry yeast. The primary difference between these two yeasts is the level of drying or dewatering which takes place before the product is packaged for distribution. Eighty-five percent of the 223,500 megagrams of baker's yeast produced in the US in 1989 was compressed yeast; the remainder was dry yeast.

> **Compressed Yeast.** Compressed yeast is marketed in the form of moist cakes with a moisture content of about 70%. Compressed yeast is a perishable commodity and, if properly refrigerated or frozen, has a useful life of several weeks.
>
> **Dry Yeast.** Dry yeast is marketed in the form of packaged granules with a moisture content of about 7.5%. Although the useful life of dry yeast is much greater than that of compressed yeast (up to two years without refrigeration) its activity, on a dry weight basis, is only approximately 65% of compressed yeast: as such, much more must be used to achieve the same effect.
>
> There are two types of dry yeast, active and instant; the main difference between the two is that active dry yeast must be rehydrated in warm water prior to usage.

The manufacture of baker's yeast has been practiced for centuries. Its earliest roots lie in the use of leaven to make bread rise: the leaven (or "starter") was typically a portion of the previously fermented batch of dough which, when mixed with fresh dough, transferred its biological activity. The same concept is still used today to make sourdough bread. Yeast has also historically but inefficiently been produced as a by-product of the brewing industry, called barm.

In the past century scientists have gained a detailed understanding of yeast and the fermentation process used to make it grow and multiply. Several innovative steps have moved baker's yeast production to a more commercially efficient scale. For example, brewing industry by-products have been replaced with molasses as the yeast's principal substrate. Also, fermentation process tanks have been equipped with air supply and incremental feed systems to reduce the formation of undesirable alcohols and to increase the yeast growth rate.

The balance of this section describes the typical production processes, water usages, and wastes and emissions associated with the production of baker's yeast. A generalized block flow diagram of the production processes is given as Figure 1.

2.1 Typical Yeast Production Processes

The commercial production of yeast relies on the fermentation of an initial yeast culture (or "seed") in a carbohydrate and nutrient rich substrate. When the desired degree of culture seed multiplication is achieved, the yeast is "ripened" with additional carbohydrates in a series of fermentation vessels. The fermentation process takes place under carefully controlled conditions, especially in regards to pH, temperature, and aeration. Finally, the yeast is harvested, dewatered as appropriate, cut, and packaged.

The yeast production process is described below in accordance with its five major steps: raw material preparation, fermentation, product recovery, product finishing and packaging, and ancillary operations. As noted previously, the production of compressed yeast and dry yeast are essentially the same with the exception of final product dewatering and packaging.

2.1.1 Raw Material Preparation

The primary substrate upon which the yeast culture feeds during the production of yeast is molasses: this carbohydrate provides the energy necessary to sustain the fermentation process, as well as several essential nutrients and vitamins. Depending on a variety of factors, such as cost and availability, beet molasses, refiner's cane molasses, blackstrap molasses, or a blend of these, is used. Because each of the types of molasses has a slightly different composition, the selection of molasses determines which nutrients will need to be supplemented in the substrate to maximize yeast production.

The nutrients required to support yeast production are nitrogen, phosphate, magnesium, potassium, and calcium. These nutrients are usually prepared in batch solutions and introduced into the fermentation reactors as necessary. Nitrogen is normally supplied through the addition of ammonium salts, aqueous ammonia, or anhydrous ammonia. Phosphates and magnesium are added in the form of phosphoric acid or phosphate and magnesium salts. Potassium and calcium are typically present in sufficient amounts in the molasses substrate.

Trace amounts of vitamins, such as biotin (vitamin H), and other minerals, such as iron, zinc, and copper, may also be added as necessary to maximize the fermentation process.

Prior to use, the raw molasses is clarified to remove any sludge and decolorized. The pH of the molasses is adjusted during these processes; too high a pH promotes bacterial growth. (The pH is also carefully maintained throughout the fermentation process, which is described in the following section).

After this initial molasses preparation, the molasses is sterilized by heating it to 38 to 43 degrees centigrade (°C) for about an hour. The heating is typically achieved with high-pressure steam. During sterilization the molasses's pH is again adjusted; it is held between 6.0 and 8.0 to prevent caramelization, or burning, of the sugars. After sterilization, the prepared molasses is diluted with water and stored in tanks to await its mixing with the yeast culture in the fermentation vessels.

2.1.2 Fermentation

Yeast is grown in a series of fermentation vessels, or fermentors. The process begins by placing a small, "starter," portion of yeast culture into the molasses substrate and allowing it to grow. Yeast is propagated when the yeast mixture is placed into the next fermentation vessel, which is equipped for batch or incremental feeding of the molasses substrate. The process continues in stages until the yeast mixture reaches the final fermentor. Each of the fermentation stages, the flask stage, the pure culture stage, and the main fermentation stage, is described in greater detail below.

2.1.2.1 Flask Stage

The first fermentation stage typically takes place in the laboratory when a portion of yeast seed is mixed with the molasses substrate in an Erlenmeyer flask. The total contents of the flask are typically less than five liters (L) and the yeast is allowed to grow in the flask for two to four days.

The seed is pure culture. The pure culture is an active strain of the yeast microorganism which has typically been cultivated in a laboratory. This active strain, after cultivation, may be preserved indefinitely by freeze drying until its use is required.

2.1.2.2 Pure Culture Stage

The pure culture fermentation stage usually consists of two fermentations. The capacities of the vessels used in this stage typically range from 1,100 to 26,500 L. The yeast yields in the two fermentors are typically approximately 30 and 600 kilograms (kg), respectively.

These fermentations are batch fermentations, where the yeast is allowed to grow in the molasses substrate for 13 to 24 hours. In batch fermentations all of the required substrate is present in the fermentor when the yeast is added. This method is not as efficient as the incrementally-fed method, which is used during main fermentation and is described in the following section.

Briefly, batch fermentors are not as efficient as incrementally-fed fermentors because they do not control the ratio of fermentable sugars to yeast throughout the

fermentation process. However, since the overall economy of yeast production depends on the yield from the final, main, fermentation stage, it is not important to have incrementally-fed pure culture fermentors.

The pure culture stage is basically a continuation of the flask stage, except that the pure culture fermentations have provisions for sterile aeration and aseptic transfer to the next stage. Sterility is critical; if a sterile environment is not provided, contaminating microorganisms can easily outgrow the yeast.

2.1.2.3 Main Fermentation Stage

The majority of the yeast yield grows in the final fermentation stages. These fermentations typically take place in two to four vessels, resulting in five to seven fermentors in the total fermentation process, including the flask stage. The processes unique to the two- and four-vessel main fermentations are described below, after the following discussion of the parameters common to both.

The fermentors used in the main fermentation stage vary greatly in size: their volumes range from 37,900 L to over 283,900 L, with the larger vessels corresponding to the later stages. The vessels have diameters greater than 7 meters (m) and heights up to 14 m.

The vessels are usually made of stainless steel and, unlike the batch reactors used in the previous stage, some vessels are equipped with an incremental feed system to deliver the molasses substrate to the yeast at an optimal rate. The incremental feed system is a series of pipes that distributes the molasses over the entire surface of the fermentor liquid. The system is regulated to deliver the molasses at time intervals corresponding to the yeast's growth curve, thus controlling the ratio of fermentable sugars to yeast. By maintaining a low excess-sugar concentration the yeast's respiratory activity is maximized, resulting in a greatly increased final yield. Nutrient solutions of minerals and vitamins are pumped into the fermentors from small tanks, but the rate of feed is not as critical as that of the molasses.

The fermentors are typically operated at a temperature of 30°C. Higher temperatures negatively influence the keeping and baking qualities of the yeast. As such, the fermentors must be equipped with heat exchangers to remove the heat generated from the production process and to cool them. The type of heat exchanger system used is dependent on the size of the vessel.

The size of the fermentor also determines the type of aeration system used: large volumes of air must be supplied to the vessels during this stage of fermentation to maintain the dissolved oxygen content in the substrate at an optimally high level. Yeast yields are much greater under aerobic conditions than anaerobic conditions; under anaerobic conditions the fermentable sugars in the molasses are

consumed by the production of ethanol and carbon dioxide rather than by yeast. Horizontal perforated pipes, compressed air and mechanical agitation, and a self-priming aerator are among the types of aeration systems used.

Four-Vessel Main Fermentation. When using four main fermentors, the pure yeast culture stage is followed by an intermediate stage of yeast growth without incremental feeding. The entire contents of that batch fermentor are then transferred to an incremental feeding tank having good aeration. This second main fermentor is often called the stock fermentor since, after fermentation is completed, the yeast mixture is centrifuged, producing a stock of yeast for the next fermentor.

The third and fourth main fermentors are equally large. In the third main fermentor aeration is vigorous and molasses and other nutrients are fed incrementally. The fermentor liquor from this vessel is typically divided into several parts for starting the fourth and final, or trade, fermentation. In some cases, the yeast is instead centrifuged and stored for several days before being used in the trade fermentation. The trade fermentor has the highest degree of aeration, and molasses and other nutrients are again fed incrementally.

Each of the four main fermentation stages lasts approximately 13 hours. The amount of yeast growth increases from approximately 120 kg in the first fermentor to approximately 15,000 to 100,000 kg in the fourth fermentor.

Two-Vessel Main Fermentation. When using two main fermentors, the only fermentations are the stock and trade fermentations; these fermentations correspond to the second and fourth main fermentations in the four-vessel process.

2.1.3 Product Recovery

When the optimal quantity of yeast has been grown, the fermentation stage of the production process ends and the product recovery steps begin. The first step is to recover the yeast cells from the spent substrate. This is accomplished by passing the final fermentor liquor, at about 3.5 to 4.5% solids, through a series of centrifugal separators. The desired solids content in the recovered material is between 18 and 21%, which can usually be achieved with two or three passes through the separators. The yeast is washed with water between each pass through the separators.

At this point, the yeast is referred to as "yeast cream." Yeast cream can be stored for several weeks at a temperature slightly above freezing. After storage, the yeast cream can be used to seed a fermentor or can be finished into a final product. Often, if used to seed a fermentor, the yeast cream is referred to as "mother liquor."

2.1.4 Product Finishing and Packaging

The final finishing and packaging steps are different depending on which product, compressed yeast or dry yeast, is desired. The finishing and packaging steps for each product are described below.

2.1.4.1 Compressed Yeast Finishing and Packaging

As stated previously, compressed yeast product has a moisture content of approximately 70%, which is equivalent to a solids content of approximately 30%. However, when the yeast is recovered from the fermentation stage as yeast cream, it has a solids content of only approximately 20%. The necessary increase in the yeast's solids content is achieved through filtration.

Filter presses or rotary vacuum filters are used to dewater the yeast cream. Filter presses usually consist of cotton duck filter cloth in 58 to 115 centimeter frames. Pressures between 860 to 1,030 kiloPascals are applied to the presses to achieve yeast yields between 27 and 32% solids.

Rotary vacuum filters dewater the product by applying a vacuum to the inside of a filter drum coated in yeast cream; water is drawn out of the yeast and into the drum. The yeast is applied to the filters' rotary drums by rolling the drums in a trough of yeast or by spraying the yeast directly onto the drums. The filters are usually coated with potato starch and salt to aid in drying the yeast. The filter drums rotate at a rate of 15 to 22 revolutions per minute; as the drums rotate, blades at the bottom of the drums remove the yeast. The yeast yields from rotary vacuum filters are approximately 33% solids.

The resultant filter cakes are blended in mixers with small volumes of water, emulsifier, and cutting oil. The emulsifier is added to improve the appearance of the yeast and the oil, typically soybean oil or cottonseed oil, is added to help extrude the yeast product. The mixed cake is extruded through nozzles to form continuous ribbons of yeast, which are then cut into segments of yeast cake. The cakes are wrapped in wax paper and stored for shipment at approximately 8°C.

2.1.4.2 Dry Yeast Finishing and Packaging

Dry yeast is filtered and extruded in the same manner as compressed yeast. However, the emulsifiers and oils mixed in with the yeast prior to extrusion are different than those used for compressed yeast; they are added to texturize the yeast as well as improve appearance and extrusion.

After the yeast is extruded into ribbons and cut, it is dried in either a batch or continuous drying system to approximately 93% solids content; the system is

typically a fluidized drying bed. The drying time ranges between one-half hour and four hours. Following drying, the yeast is vacuum-packed or packed under nitrogen gas before heated sealing.

2.1.5 Ancillary Operations

To fully support the commercial production of yeast via fermentation, a number of ancillary operations are necessary. These operations include equipment cleaning and sterilization, steam production, equipment cooling, facility housekeeping, and wastewater treatment. Some of these operations were noted previously in this report, and each is described more fully below.

2.1.5.1 Equipment Cleaning and Sterilization

Throughout the production of yeast, sterility is an absolute necessity: if a foreign culture is present inside a reaction vessel, it is likely that its propagation will rapidly overtake the yeast and spoil the batch. Sterility is also critical given that yeast is a food product and any foreign cultures present in the final product may be consumed by human beings.

To assist in assuring sterility, all transfer lines and reaction vessels are thoroughly cleaned and steam-sterilized as necessary. Additionally, the raw materials which make up the fermentation substrate, such as the molasses, are sterilized prior to their introduction into the process.

2.1.5.2 Steam Production

Steam is primarily required in a yeast production facility for equipment and raw material sterilization. The steam is typically produced using a boiler which may be fired by a number of sources, including oil, coal, or natural gas.

2.1.5.3 Cooling System

The fermentation process generates heat which must be controlled to maximize the yeast yield. The typical method of controlling the fermentors' heat is to transfer it to water via heat exchangers.

The water used as the cooling medium can pass through the cooling system in one of two ways: 1) it can be passed through the heat exchangers once and then be discharged as hot water; or, 2) it can be passed through the heat exchangers, then through cooling towers in which the heat is lost to the atmosphere, and then be either discharged as relatively cool water or recycled back to the exchangers.

2.1.5.4 Facility Housekeeping

Facility housekeeping procedures are routine janitorial services, and include floor and equipment washings. The wastewater generated from these wash-downs will contain a high organic content due to the residual yeast materials.

In addition to the chemicals used at a yeast facility during the various stages of the production process, chemicals are also used at the facility for cleaning purposes. These chemicals include sulfuric acid, caustic soda, and ammonia. Like the residual yeast product chemicals, many cleaning chemicals will ultimately be discharged as wastewater.

2.1.5.5 Wastewater Treatment

The highest strength facility wastewaters are typically those discharged from the molasses and yeast centrifuge and filter systems. Medium and low strength wastewaters include floor and equipment cleaning waters, fermentor cooling system waters, domestic wastewaters, and storm water.

The wastewaters are typically treated prior to discharge. The primary objective of wastewater treatment is to remove or modify those contaminants detrimental to human health or the environment. Land disposal, evaporative ponds, and/or deep-well injection are occasional discharge options, but usually the only practical outlets for the disposal of treated (or untreated) wastewater are lakes, oceans, or other water bodies. To protect water resources, the discharge of pollutants into them must be controlled. The facility's options for removing pollutants are to send the wastewater off-site to a public wastewater treatment plant or to treat it on-site.

A typical wastewater treatment plant utilizes physical, chemical, and biological treatment methods to remove the suspended, colloidal, and dissolved contaminants present in the water. In general, the contaminants are removed in order of increasing difficulty.

The operations of a typical wastewater treatment plant proceed as follows, with exceptions specific to a yeast facility's treatment plant noted: First, rags, sticks, and miscellaneous large objects are removed from the wastewater by retention on coarse screens. Then grit is removed in grit tanks. At this point, most of the small solids remain in suspension. These first two steps would not be required at a yeast facility's treatment plant, however, since the largest particles in the facility's effluent would be suspended solids.

The settleable fraction of the suspended solids can be removed and concentrated in gravity settling tanks. The settling tank's concentrated solids, called raw

sludge, are pumped to an anaerobic sludge digester to be reduced in volume through consumption by microorganisms; the tank's wastewater effluent flows from this "primary treatment" to "secondary treatment."

Secondary wastewater treatment typically consists of an aerobic biological treatment unit. In this unit, microorganisms aerobically digest the dissolved and colloidal matter in the wastewater; the organic matter is converted to carbon dioxide and water in the process. Less frequently, anaerobic biological treatment units, rather than aerobic units, are used. (As stated above, anaerobic digestion units are commonly used to reduce primary treatment sludge volume; they are not, however, as commonly used to treat the wastewater.) Carbon dioxide and methane are the principal products of anaerobic digestion.

Following bioreaction, the microorganisms are settled out of the bioreactor effluent in a settling tank. Part of the concentrated biological sludge is returned to reseed the bioreactor unit, but most is thickened and sent to an anaerobic sludge digester. The last stage in wastewater treatment prior to discharge is typically chemical disinfection.

2.2 Water Usage

A typical yeast production facility has the following water needs: process water, cooling water, boiler feed water, and water for housekeeping and other domestic uses. Most of these water requirements have already been mentioned in previous sections of this report, but each is briefly described below.

2.2.1 Process Water

Process water requirements include dilution water to prepare the molasses substrate, rinse water for product recovery rinses, and mixing water for product extrusion.

2.2.2 Cooling Water

Water is typically used as the cooling medium in the heat exchangers used to cool the fermentors. In a cooling system with no recycle, or a "once-through" system, a full supply of fresh water is constantly required to pass through the heat exchangers. In a "closed-loop" system with recycle, however, only a smaller volume of fresh "make-up" water is required periodically to replace the water lost from the system.

Water is lost from the closed-loop system by two means: evaporation and "blowdown." Evaporation occurs in the cooling towers. Blowdown is a small volume water that is periodically purged from the system and replaced with fresh water to help maintain the desired water quality. In addition, the cooling water often must have chemical additives to prevent scaling and corrosion of the system's metal components.

2.2.3 Boiler Feed Water

Boiler feed water is the water heated in the boiler to produce steam for equipment and raw material sterilization. Steam is produced by feeding the water through tubes arranged along the walls of the boiler; the water is vaporized into steam by the heat generated in the boiler.

If, after use, the condensed steam can be captured, then it can be recycled. However, this water must be of high purity and/or have chemical additives to prevent scaling and corrosion of metal components. A small volume of boiler blowdown is periodically purged from the recycle system and replaced with fresh water to further minimize scaling and chemical concentration.

2.2.4 Housekeeping and Domestic Water

Housekeeping and domestic water is required for routine wash-down of facility equipment and floors, general janitorial cleaning, and sanitary and personal use.

2.3 Wastes and Emissions

The most significant waste generated at a typical yeast production facility is wastewater: a major facility operation is dewatering the product. A great amount of washwater is also generated as a result of sterility concerns. Air emissions and solid wastes, though not as significant in volume as wastewaters, are also discharged from the facility. Each facility waste is briefly described below; those wastes that are generated during the production process are also listed on Figure 1.

2.3.1 Wastewater

A great and regular volume of wastewater is generated from production process operations. The process wastewaters are given on Figure 1:

- Effluent from molasses clarification;
- Spent substrate and rinse water from product recovery; and
- Discharge from the filters during product dewatering.

These wastewaters are highly-organic since they are derived from processing molasses substrate and yeast, thus they will carry substrate and yeast residue. The wastewater has been reported as having a chemical oxygen demand (COD) of 10,000 to 30,000 milligrams per liter (mg/L) and pH values in the range of 5.0 to 7.4. Typical BOD values have not been identified.

Other sources of facility wastewater include:

- Steam plant boiler blowdown;
- Effluent from air emission control devices employing water, if any (these are noted in the following section);
- Floor and equipment wash-down water;
- Janitorial and domestic wastewaters; and
- Storm water runoff from the facility grounds.

Of these lower strength effluents, only the floor and equipment wash-down water would be expected to carry significant substrate or yeast residue. These wastewaters typically have an average COD of approximately 1,700 mg/L.

Because the higher strength process wastewaters are discharged more frequently and in greater volume than the lower strength wastewaters, the combined effluent is usually more characteristic of a high-strength wastewater.

Wastewaters are typically sent to a treatment plant on- or off-site.

2.3.2 Air Emissions

There are three notable sources of air emissions at a yeast facility: the fermentors, the steam plant boiler, and the fluidized bed dryers. A wastewater treatment plant may also contribute to facility air emissions. Emissions from the fermentors and the fluidized bed dryers are yeast production process wastes, and are listed on Figure 1. All emission sources are described below.

2.3.2.1 The Fermentors

The most significant source of air emissions is the fermentors: volatile organic compounds (VOCs) are generated by metabolic activity in these vessels. Ethanol, which is formed from acetaldehyde, and carbon dioxide are of particular concern.

The referenced USEPA report estimates the VOC mass emission rate from a typical facility at 82 megagrams per year, primarily from the trade fermentors. This rate corresponds to 0.0005 kg of VOCs per liter per batch of fermentor operating capacity.

Yeast facilities typically employ process controls to reduce the amount of VOCs generated, and some facilities also apply air pollution control systems, such as wet scrubbers and incinerators. Depending on the control system, the pollution will be removed from the air through chemical alteration into less toxic substances, or through physical transfer into wastewater or solid waste. The pollutant would then have to be handled in the wastewater or solid waste, accordingly.

An on-site wastewater treatment plant is also a potential VOC emission source at the facility; significant quantities of VOCs could be emitted during microorganic digestion.

2.3.2.2 The Steam Plant Boiler

A variety of air pollutants could be emitted from combustion in the steam plant boiler. For example, fossil fuel combustion results in gaseous products, called flue-gas, and a solid ash residue, some of which is carried along with the flue-gas as fly ash. The amount and characteristics of the emissions produced depends upon the type of fuel and boiler, but usually include vanadium and sulfur and nitrogen oxides.

Like VOC emissions, boiler emissions are typically reduced with process controls and air pollution control systems, such as scrubbers; depending on the pollution control system, it may generate wastewater or solid waste.

2.3.2.3 The Fluidized Bed Dryer

Fluidized bed dryers are another potential source of air emissions. The dryer suspends moist yeast on a bed of air to further dry it; vapors and fine particulate may be given off during the process.

VOC and particulate emissions from fluidized beds can be reduced with air pollution control systems similar to those for the fermentors and boiler; again, the control system may generate wastewater or solid waste.

2.3.3 Solid Waste

Solid waste is typically the least significant source of waste from a yeast production facility. Molasses clarifier sludge is the primary solid waste generated from the yeast-making process, as is shown on Figure 1.

In addition to molasses clarifier sludge, other facility solid wastes are:

- Steam plant boiler combustion residue, (bottom ash);
- Wastewater treatment plant sludge;
- Residue from air emission control devices, if any (these are noted in the previous section);and
- General housekeeping, or janitorial, and domestic wastes.

The solid wastes are typically hauled off-site to be disposed.

3.0 THE YEAST INDUSTRIES COMPANY, LTD.

The Yeast Industries Company, Ltd. (YIC) operates a facility producing compressed and dry active baker's yeast. It is a privately owned company which was established in 1976 and started production in 1978. In 1992 the facility's production was 2,582 tons of compressed yeast and 865 tons of dry yeast. This output was only slightly greater than half of the facility's total production capacity, which is 6,000 tons per year. The facility operates 24 hours a day, six to seven days a week.

The facility is located on the north bank of the Zarqa River in Jordan. The location is an agricultural area near the western perimeter of the Russeifa Municipality, 20 kilometers east of Amman. The facility covers 10,000 square meters of land.

Processes at the YIC are very similar to the typical processes described in the previous section of this report. The following three sections are intended to better describe operations specific to YIC.

3.1 Process Description

The facility's production processes are schematicized in Figure 2. As shown on the figure, YIC's operations appear to be typical for a facility having a two-vessel main fermentation stage. The figure, adapted from a schematic provided to Harza in the referenced COWIconsult/Royal Scientific Society report, indicates that both main fermentors are batch fermentors, rather than incrementally fed vessels. The cooling system used for the fermentors is a closed system with cooling towers.

As is typical, following fermentation, cultivated yeast is separated from the substrate by filtration, dewatered and/or dried, and packaged for sale. The compressed yeast product is dewatered on a rotary vacuum filter until it reaches 28% solids content. This product is packaged in 0.5 kg packs. The dry yeast product is dewatered on a filter press, then, after extrusion, is further dried on a fluidized bed dryer; the resultant product has a 95 to 98% solids content. This product is packaged in 100 g, 500 g, and 1kg packs and 25 kg bags.

3.2 Raw Materials and Water Supply

The facility's consumption of raw materials in 1992 was as follows:

Raw Material	Consumption (Ton)
Substrate	
Beet Molasses	8,000
Ammonium Phosphate	56
Potassium Chloride	21
Magnesium Sulfate	21
Urea	195
Vitamins	1
pH Control and Cleaning Agents	
Sodium Hydroxide	20
Sulfuric Acid	112
Product Drying Aid	
Sodium Chloride	18

All process water is supplied by a private well. The consumption is estimated by YIC to be 500 to 600 cubic meters per day (m^3/d), or 150,000 to 180,000 m^3/year. This represents approximately 50 m^3 of water per ton of yeast product, or 100 m^3 per ton of dry solid yeast. The COWIconsult/Royal Scientific Society report states that this is rather high compared to typical European rates of 30 m^3 of water per ton of dry solid yeast.

Process water is primarily used in the production process and for cleaning of equipment, including machinery and tanks. There is a considerable demand for cooling water by the fermentation process.

3.3 Wastewater Discharges

Wastewater sources include spent substrate solution and rinse water from product recovery, filter discharge from product filtration, equipment and floor wash-down water, boiler blowdown, and domestic water. All discharged wastewater is applied to the land in a nearby forest.

Average 1993 values for measured wastewater parameters are given in the following table:

4.0 AREAS FOR POTENTIAL IMPROVEMENT

Beyond assembling background information regarding baker's yeast production facilities, the primary purpose of this document is to present information gathered from the literature search regarding the latest advances in water conservation, pollution prevention, and waste minimization.

The subjects can be generally defined as follows:

> **Water Conservation:** Reducing the process, clean-up, and domestic water use requirements of a facility.
>
> **Pollution Prevention and Waste Minimization (PP/WM):** Reducing the 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 sections present techniques identified as areas for potential improvement at YIC. 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. The areas for improvement listed are only suggestions for a typical yeast production facility; their applicability and net benefit to YIC depends on facility-specific factors.

4.1 Water Conservation

Water conservation improvements identified in the literature apply to recycling treated wastewater, steam, and process water, and replacing the cooling water system. General process improvements and good housekeeping practices have also been identified as water conservation techniques. All identified techniques are described in the following sections.

4.1.1 Wastewater Treatment Plant Recycle

Secondarily treated wastewater is used as a cooling medium at industrial facilities in a program sponsored by the King County, Washington, Department of Metropolitan Services. This program supplies and reaccepts treated municipal wastewater to local industries through an extensive looped pipeline system. A similar, smaller-scale system could also be developed for an individual facility that has its own wastewater treatment plant.

The cooling system works by pumping effluent from the wastewater treatment plant to heat exchangers at the industrial facility; the heat exchangers transfer process heat to the piped effluent. After it has been used to cool, the effluent is returned to the treatment plant to be discharged as usual.

Using wastewater treatment plant effluent conserves more water than conventional cooling systems, even those that recycle water through cooling towers. The system in Washington is expected to save one user facility 40 million gallons of water each year.

4.1.2 Process Water Recycle

Water that would otherwise become wastewater can potentially be conserved through recycle as process water in two facility processes: molasses preparation and product recovery. These applications are suggested provided they do not adversely affect the quality of the yeast product.

Molasses Preparation Water. Fresh water is used to dilute the molasses in the molasses preparation process. The fresh water could potentially be replaced with recycled molasses tank (and other molasses equipment) rinse water.

Product Recovery Water. Fresh water is used to rinse centrifuged yeast in the product recovery process. The fresh water could potentially be replaced with recycled centrifuge effluent, filter press effluent, or fermentor wash-down water. If the solids loading in these process waters is too great to be used effectively as rinse water, then they could be prepared for use by being clarified, filtered, and mixed with fresh make-up water.

In addition, the product recovery rinse water itself can be recycled. In a process reported in a French publication (ref.: Overcash) to be widely practiced, the spent rinse water and the centrifuge effluent are evaporated and then condensed. The condensate is recycled to other facility processes, and the solids are processed as products: potassium sulfate and concentrated protein. In addition to conserving fresh water, the process has been claimed to reduce the BOD and COD levels of the wastewater from the product recovery process by approximately twenty times. A flow diagram of the process is given as Figure 3.

The applicability of these improvements may be subject to cleanliness requirements. However, since surge tanks and/or gravity separators would be required to store the recycled water, sterilization could be performed here as necessary.

4.1.3 Steam Recycle

A state-of-the-art fermentation facility operated by the Pfizer Corporation in Connecticut captures spent sterilization steam. Instead of being wasted to the air, the spent steam

goes to a catch compartment for condensation and disinfection before any effluent leaves the plant. This condensate could potentially be recycled back into steam or into another process at the facility.

4.1.4 General Process and Management Improvements

Several general process improvements having the potential to conserve water have been identified and are listed here:

- Most importantly, explore installing a wastewater treatment system, with recycle, to treat and then reuse wastewaters generated at the facility.

- Minimize floor and equipment washes, as well as the volume of water used in each. As an example, higher pressure/temperature water streams may reduce the volume of water required to clean a surface. The applicability of this improvement may be subject to regulatory or process requirements.

- Where appropriate, use the last rinse from a piece of equipment as the first rinse (on the same piece of equipment) the next time around.

- Generate an accurate measurement and balance of facility water use. The balance should track process water use per batch of yeast. Compare the measurements to those of typical European facilities and make process adjustments accordingly. (The COWIconsult/Royal Scientific Society report states that the facility's water use is estimated to be much greater than that required by a typical European facility.)

- Install flow-control valves and timers on pipes and other equipment to better control process water usage.

- Implement a water management system that involves facility personnel, such as employee training in water use reduction programs and good housekeeping.

4.2 Pollution Prevention/Waste Minimization

The state-of-the-art PP/WM opportunities documented in the literature apply primarily to air emissions. However, techniques that apply to water and solid wastes have also been identified. All opportunities are summarized in the following sections.

4.2.1 Wastewater PP/WM

Nearly all of the water conservation techniques stated in the previous section also apply to wastewater PP/WM. The techniques that can most significantly be used for wastewater PP/WM are:

- Product recovery and recycle, such as the Overcash process water recycle system described above and illustrated in Figure 3. This system not only reduces the need for fresh water, but also reduces the amount of process effluents discharged as waste by recycling them.

- Process optimization. Two examples are:

    i) Installing flow-control valves and timers on pipes and other equipment to better control process water usage; the less water that is used, the less water that is discharged as waste.

    ii) Using incrementally-fed fermentor systems. Because these systems maximize the yeast yield from a given amount of substrate, less material has to be input to the system for the same product output. As a result, the wastes generated during production are minimized.

- Good housekeeping practices. For example, using the last rinse from a piece of equipment as the first rinse the next time around not only reduces fresh water consumption, it also reduces wastewater discharge.

- A wastewater treatment system. Two very effective systems, the Biothane system and a sequencing batch reactor system, are described below.

Biothane. An anaerobic biological wastewater treatment technology has been developed by Biothane Corporation of New Jersey. Biothane's system is used to treat baker's yeast wastewater at more than a dozen facilities throughout the world, including one in the Middle East. The two most significant benefits of the process are:

i) Greatly lower sludge generation than conventional aerobic biological treatment processes (only one-tenth as much).

ii) A useable energy by-product in the form of methane gas. The methane gas could be used to generate electricity at the yeast facility or to fire the steam plant boiler.

The operating principle of the process is similar to Upflow Anaerobic Sludge Blanket (UASB) concepts. UASBs are conventional biological treatment units, though relatively uncommon compared to aerobic biological treatment units. The Biothane process incorporates a patented three-phase separator into the treatment unit, and eliminates the need for moving parts, thus easing unit maintenance and operation.

More specifically, the Biothane process is as follows: first, wastewater enters the bottom of a digester tank and passes upwards through a dense bed of anaerobic sludge. Soluble COD is converted to biogas rich in methane and an upward circulation of water and gas-borne sludge is established.

Separators at the top of the tank allow degasification of the water/sludge slurry. The directly combustible biogas is recovered from collection pockets. The granular sludge particles, now devoid of attached gas bubbles, sink back to the bottom of the tank, establishing a return circulation. The treated effluent flows over a weir at the top of the tank and is discharged. The established upward and downward circulation pattern insures effective sludge-to-wastewater contact without the need for supplementary agitation.

The BOD purification efficiency achieved through the Biothane process has been determined to be up to 90%; the COD purification efficiency is typically 65%.

Sequencing Batch Reactors (SBRs). An SBR is an aerobic biological treatment unit. Specifically, it is a fill-and-draw activated sludge system comprised of treatment tanks 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 reason that this treatment technology is significant to a yeast facility is that SBR tanks can easily tolerate shock loads of BOD without degradation in effluent quality. In fact, the performance of several conventional activated sludge systems have been shown to significantly improve after conversion to SBR operation.

4.2.2 Air Emission PP/WM

The air emission PP/WM techniques identified in the literature apply to controlling fermentor VOC emissions and controlling boiler emissions. The topics are discussed in that order below.

4.2.2.1 Fermentor VOC Emissions

The primary air pollutant from yeast facilities is VOC emissions from the fermentors. As stated in Section 2.3.2.1, yeast facilities typically employ process controls to reduce the amount of VOCs generated, and some facilities also apply air pollution control systems, such as wet scrubbers and incinerators. Although these technologies are not state-of-the-art, a discussion of VOC emissions will be presented here based on the results of a recent study to identify the best VOC control devices.

The USEPA, through the Control Technology Center, performed a comprehensive evaluation of VOC emission control alternatives. The following alternatives were evaluated:

- Process control measures to reduce the formation of VOC emissions;
- Wet scrubbers;
- Carbon adsorbers;
- Incinerators;
- Condensers; and
- Biological filters.

The study results indicate that process control measures and trains of treatment technologies are the most feasible ways to control emissions.

Process Control Measures. Process control measures are expected to reduce VOC emissions from 75 to 95%; an example is incremental feed systems. Incrementally-fed fermentors, as opposed to batch fermentors, can limit the amount of ethanol formed during fermentation.

As has been stated previously, they accomplish this by matching the addition of substrate to the yeast's growth curve. By maintaining a low excess-sugar concentration and sufficiently aerating the fermentor, the yeast's respiratory activity is maximized. The result is a greatly increased final yield and decreased VOC emission rate. Since the majority of yeast growth occurs in the final fermentation stages, it is most beneficial to equip the final fermentors with incremental feed systems.

Treatment Trains. The efficiency associated with train of technologies is estimated to be greater than 90%; an example is a wet scrubber followed by a catalytic incinerator or biological filter.

It is significant to note that since some of these technologies, wet scrubbers for example, consume water, a trade-off between emission reduction and water conservation exists.

4.2.2.2 Boiler Emissions

Emissions of concern from a boiler burning fossil fuels are sulfur oxide, NOx (oxides of nitrogen), and fly ash. State-of-the-art PP/WM techniques for each are described below.

Sulfur Oxide. The simplest way to reduce sulfur oxide emissions is to burn fuel containing relatively less sulfur. Beyond that, sulfur oxide emissions are typically reduced in a flue-gas desulfurization system. Lime scrubbing is the most common system, but because it can generate a significant amount of wastes, magnesium-enhanced-lime scrubbing and dry scrubbing are emerging as alternatives to lime scrubbing. Each are described briefly here.

Lime Scrubber

In a typical lime scrubber the sulfur oxide reacts with a lime slurry and forms sulfite or sulfate solids that remain in solution or suspension with the slurry. The solids are separated from the slurry in settling tanks, the liquid is enriched by adding more lime, and then is recirculated. The sulfite may be stored in basins or ponds, or converted to gypsum through oxidation.

Magnesium-Enhanced-Lime Scrubber

The addition of magnesium in a magnesium-enhanced-lime scrubber increases the absorption capacity of the slurry by 10 to 15 times. Thus, sulfur oxide removal efficiencies can be greatly improved with significantly less liquid waste.

Dry Scrubber

In a dry scrubber, liquid slurry drops containing very little water are sprayed into a hot gas stream. The liquid evaporates as chemical reactions and absorption of sulfur dioxide occurs in reactions similar to those in wet scrubbers. The solid particles can be collected along with the fly ash. The advantage of dry scrubbers is that a dry powder is produced, avoiding disposal of a liquid slurry or wet sludge, and water is conserved as well.

NOx. The basic tools for reducing NOx emissions have not changed much in the past twenty years, but the manner in which they are being applied has. Categories of NOx PP/WM options receiving the most attention in the literature include combustion modifications and post-combustion control devices, such as selective catalytic reduction and

selective noncatalytic reduction systems. Both methods are briefly described here.

Combustion Modifications

Combustion modifications control nitrogen oxide emissions by reducing the amount of pollutant produced. Reducing the formation of NOx depends on carefully controlling the combustion temperature and fuel-air mixture in various parts of the flame. Low-NOx burners can reduce emissions to about 15% of uncontrolled levels.

Selective Catalytic and Noncatalytic Systems

Selective catalytic and noncatalytic systems use ammonia to reduce NOx to water and elemental nitrogen. The pertinent reactions normally proceed at very high temperatures, so in selective catalytic systems a catalyst is used to promote the reactions at lower temperatures. In selective non-catalytic systems, an ammonia compound is injected into the boiler at the appropriate temperature window. These systems can remove between 30 and 80% of NOx emissions. Some systems can also be adapted to remove sulfur oxides at up to 95% efficiency.

Fly Ash. Fly ash is typically collected on a standard control device, such as an electrostatic precipitator, and then ponded or landfilled. However, partial utilization of the collected ash to manufacture pozzolanic material has become more commonly practiced. The pozzolanic material can be used as fill for roads, runways, and construction sites, and as cement and brick admixtures. Recovery of the metal components of the ash, such as aluminum, vanadium, titanium, and iron, for commercial use is also now possible.

4.2.3 Solid Waste PP/WM

The only potential PP/WM technique identified for solid wastes is to reslurry the molasses sludge and reuse it to produce the molasses substrate, if technically feasible.

5.0 REFERENCES

The following documents were reviewed to prepare this report. The essential components of each are included as an attachment to this report under a separate cover.

1. Arora, M.L., and E. Barth, M.B. Umphres. "Technology Evaluation of Sequencing Batch Reactors." Journal WPCF. Volume 57, No. 8, August 1985. p. 867-875.

2. "Background Report: Thermal Electric Power Plant Industry, Al Husein Thermal Power Station, Jordan." USAID, Report No. 3114-94-2b-07. October, 1994.

3. Barker, Robin and Maresa Williamson. Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities. USEPA Control Technology Center. January, 1992.

4. "Biothane Anaerobic Wastewater Treatment Process." Pamphlet published by the Biothane Corp., New Jersey, USA. 1992.

5. Ciftci, T. and I. Ozturk. "Anaerobic Treatment from the Yeast Industry." Water Science and Technology. Volume 28, No. 2, 1993. p. 200-209.

6. "Enterprise No. 24: Yeast Industries Co., Ltd." Industrial Pollution Control Project, Jordan. Project Component No. 2: Industrial Wastewater Pretreatment Requirements Report, Chapter 32. COWIconsult/Royal Scientific Society.

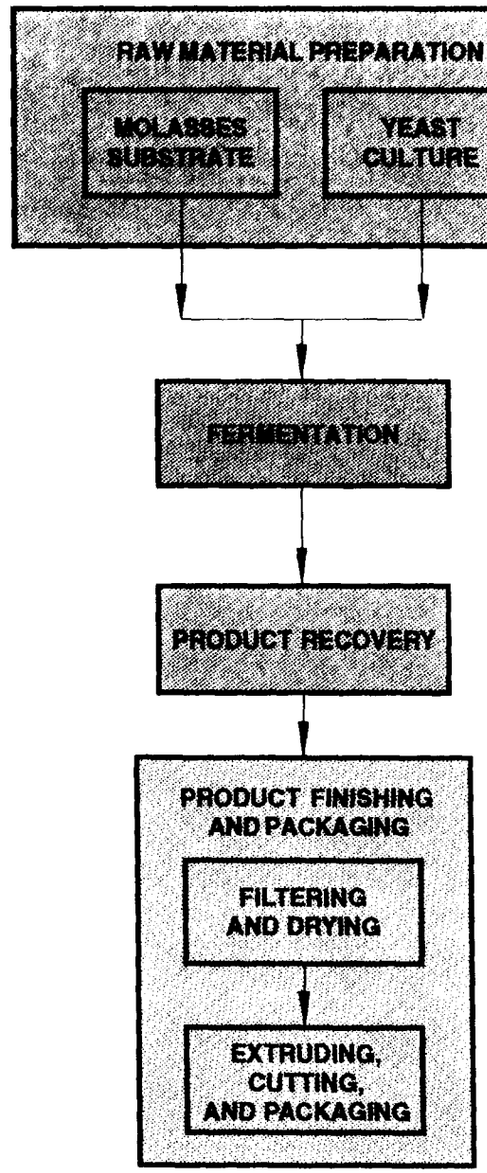
7. Overcash, M.R. Techniques for Industrial Pollution Prevention. Lewis Publishers, Michigan, USA. 1986. p. 42-43.

8. "Pfizer Starts Up Advanced Fermentation Plant." Chemical & Engineering News. October 14, 1991. p. 25.

9. Shreve, R. Norris and Joseph A. Brink, Jr. Chemical Process Industries, 4th Edition. Fermentation Industries, Chapter 31. McGraw-Hill, Inc., New York, USA. 1977.

10. "Wastewater is No Waste if It's Reused." Civil Engineering. December, 1994. p. 14.

FIGURES



KEY: Associated Process(es) indicated by color

INPUTS	WASTES
INPUTS	**WATER**
Emulsifier	Filtration Effluent
Molasses	Molasses Clarification Effluent
Nutrients	Product Rinse Water
Oil	Spent Substrate Solution
pH Adjusters	Wash-down Water
Salt	
Starch	**AIR**
Vitamins	Dryer Emissions
Water	Volatile Organic Compounds
	SOLID
	Molasses Sludge

HARZA *Consulting Engineers and Scientists*

Figure 1

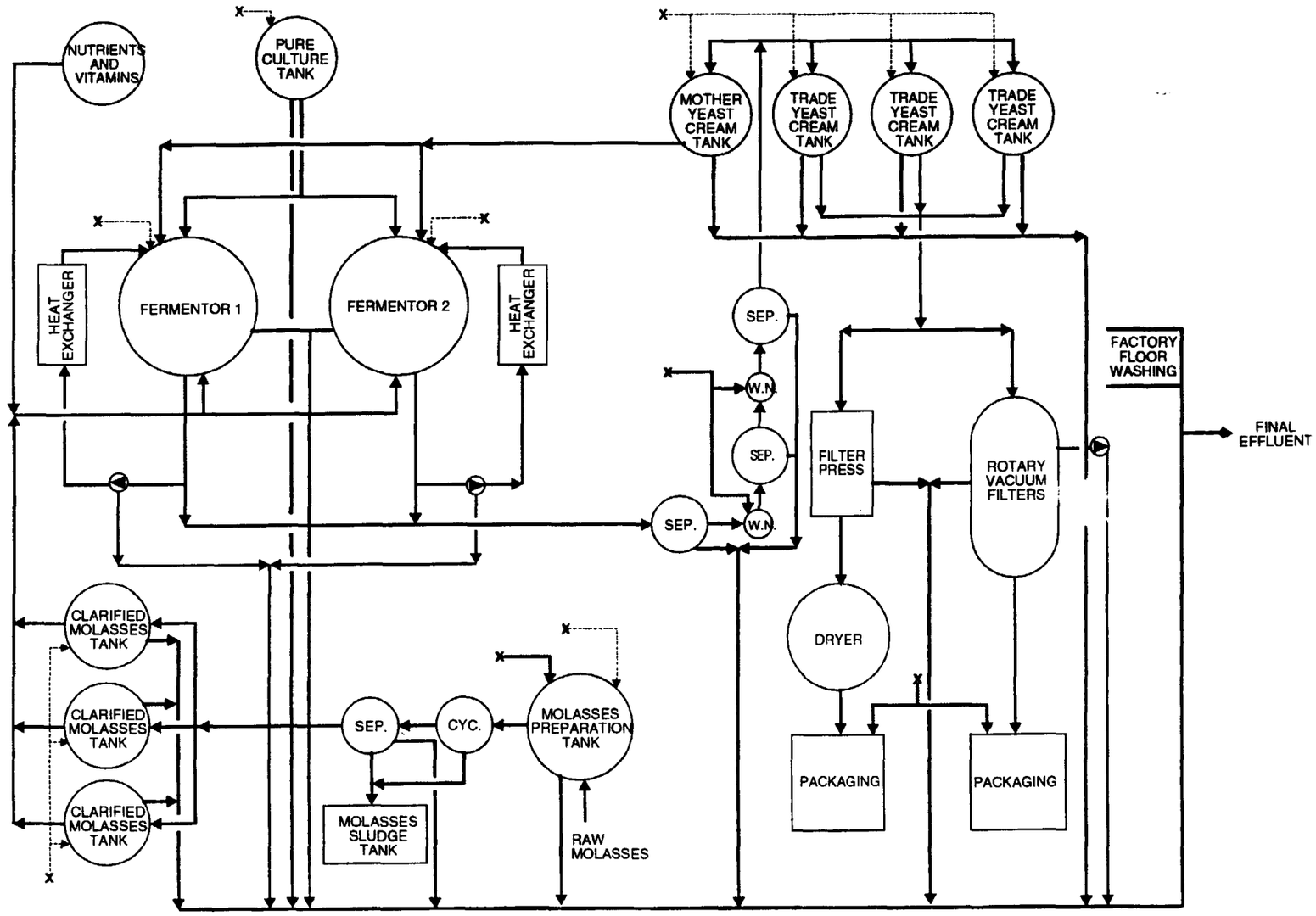
BLOCK FLOW DIAGRAM

TYPICAL BAKER'S YEAST PRODUCTION PROCESS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION

WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan



LEGEND:

- Process Line
- Equipment Rinses
- Process Overflow
- Emergency Relief
- Process Water
- Sterilization Steam
- Cyc. Cyclone
- Sep. Separator
- W.N. Washing Nozzle

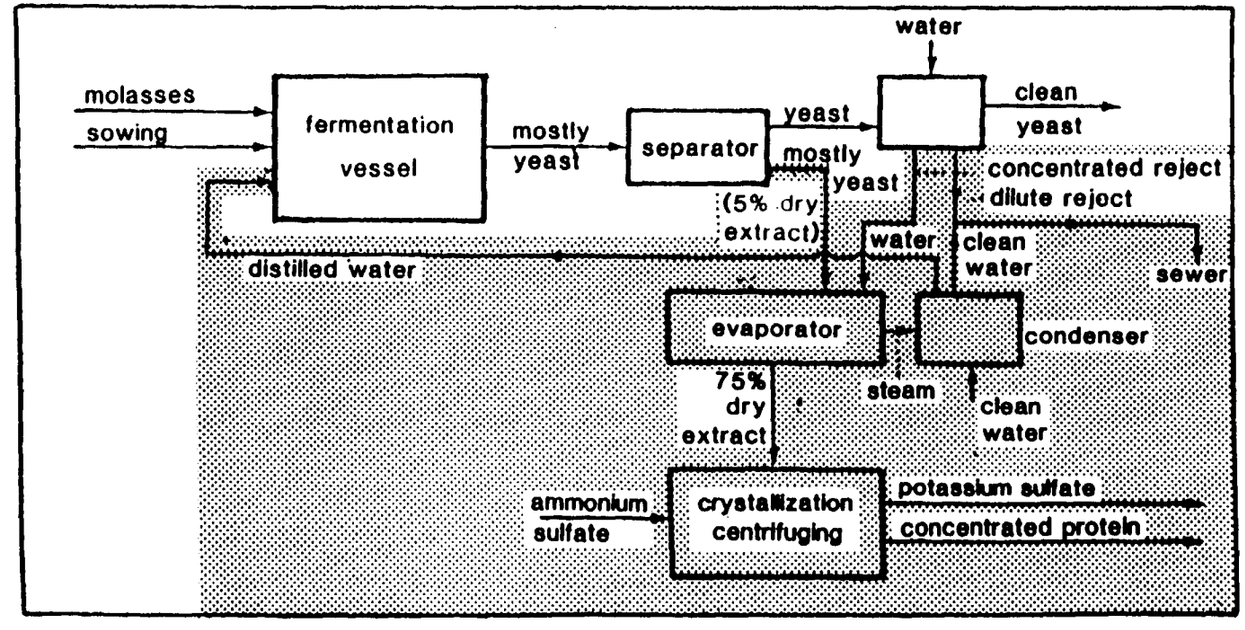
Figure 2

PROCESS FLOW DIAGRAM

YEAST INDUSTRIES CO., LTD

Ruseifa, Jordan

HARZA Consulting Engineers and Scientists



SOURCE: Overcash, M.R.
Techniques for Industrial Pollution Prevention

Figure 3
PROCESS WATER RECYCLE DIAGRAM
INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
Amman, Jordan

HARZA *Consulting Engineers and Scientists*

e:\Jordan\fig2.pm5

REFERENCES

YEAST PRODUCTION INDUSTRY
BACKGROUND MATERIALS

INDUSTRIAL WASTEWATER DISCHARGE POLLUTION PROGRAM
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan

REFERENCES

1. Arora, M.L., and E. Barth, M.B. Umphres. "Technology Evaluation of Sequencing Batch Reactors." Journal WPCF. Volume 57, No. 8, August 1985. p. 867-875.

2. "Background Report: Thermal Electric Power Plant Industry, Al Husein Thermal Power Station, Jordan." USAID, Report No. 3114-94-2b-07. October, 1994.

3. Barker, Robin and Maresa Williamson. Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities. USEPA Control Technology Center. January, 1992.

4. "Biothane Anaerobic Wastewater Treatment Process." Pamphlet published by the Biothane Corp., New Jersey, USA. 1992.

5. Ciftci, T. and I. Ozturk. "Anaerobic Treatment from the Yeast Industry." Water Science and Technology. Volume 28, No. 2, 1993. p. 200-209.

6. "Enterprise No. 24: Yeast Industries Co., Ltd." Industrial Pollution Control Project, Jordan. Project Component No. 2: Industrial Wastewater Pretreatment Requirements Report, Chapter 32. COWIconsult/Royal Scientific Society.

7. Overcash, M.R. Techniques for Industrial Pollution Prevention. Lewis Publishers, Michigan, USA. 1986. p. 42-43.

8. "Pfizer Starts Up Advanced Fermentation Plant." Chemical & Engineering News. October 14, 1991. p. 25.

9. Shreve, R. Norris and Joseph A. Brink, Jr. Chemical Process Industries, 4th Edition. Fermentation Industries, Chapter 31. McGraw-Hill, Inc., New York, USA. 1977.

10. "Wastewater is No Waste if It's Reused." Civil Engineering. December, 1994. p. 14.

BEST AVAILABLE COPY

JAN-10-1995 15:49 FROM JOHN CRERAR LIB/U OF C TO 98313999 P.08

R7032

Technology evaluation of sequencing batch reactors

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

NOTICE: This Material may be protected by copyright law (Title 17 US. Code)

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. Further, it is important that limitations and constraints, if 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 in 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, and withdrawal the wastewater flow is either directed to another SBR tank in the system, as in a multiple tank configuration, or to a storage tank in a single SBR tank configuration where it is drawn for treatment after the supernatant withdrawal has been completed.

One modification of the SBR process, the intermittent cycle extended aeration system (ICEAS), operates on the principle of continuous 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.

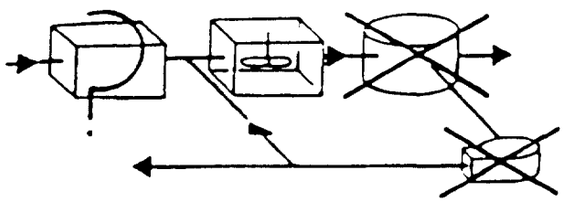


Figure 1—Comparison between SBR and a conventional activated sludge plant.

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-flow systems resulted primarily from operational considerations and not from any process-related weaknesses of the batch systems.

Times have changed. New hardware devices, such as motorized valves, pneumatically actuated valves, solenoid valves, level sensors, flowmeters, automatic timers, and microprocessors or process controllers have been developed and are routinely available. It is important, therefore, that the application of SBR technology, abandoned because of the unavailability of these devices, be reevaluated. A series of articles[5-11] published recently provided a broad overview of SBR systems and their use. In the early 1980s EPA attempted to revive interest in this technology and spent considerable sums of money evaluating the process on a full-scale basis.[12] This research examined a full-scale demonstration of a two-tank SBR activated sludge treatment plant over a 20-month period in Culver, Ind. Results of this project led to the use of SBR technology at several other municipal facilities.

ADVANTAGES OF SBR

Proponents of the continuous-flow activated sludge systems cite flexibility as one of the main reasons this process is preferred over the trickling filter process. This flexibility comes from several sources: ability to vary the return activated sludge (RAS) rate and resultantly the food-to-microorganism ratio (F/M), dissolved oxygen (DO) concentration in the reactor by changing the aeration 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

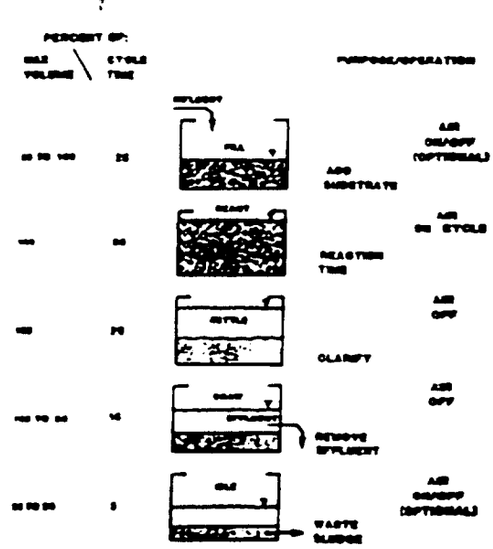


Figure 2—Typical SBR operation for one cycle.

BEST AVAILABLE COPY

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 do ments and field trips was carefully analyzed. Table 2 lists portant information for each of the eight plants visited. Seve comparisons and conclusions were drawn from the informat in Tables 1 and 2:

• Operating staff at each of these plants indicated that SBR process was more simple to operate compared to the c ventional continuous-flow processes, activated sludge, a trickling filters that they had previously operated.

• All plants were meeting effluent requirements with the ception of Grundy Center Wastewater Treatment Facility. T problem at Grundy Center was alleged to be the result of unsatisfactory decanter design, which permitted the MLSS enter the decanter piping system during fill, react, and set periods; these solids are subsequently discharged with the canted effluent. The city is in the process of replacing the canter.

• None of the plants, with the exception of Culver and Yam has primary treatment in its flow scheme. Culver and Yam had existing primary clarifiers which they continued to use the SBR process scheme.

• Even though the water quality objectives at the eight pla visited were essentially the same, the design criteria and the actor sizes and power usages were not. For example, the the retical detention time (V/Q) varied from 7.6 hours at Rivercre to 49 hours at Glenlea. The differences in the values of F/ ratio were also of the same order of magnitude as the detenti time, 0.18 day^{-1} at Rivercrest and 0.032 day^{-1} at Glenlea.

• The approach used by the design engineers in designi these plants varied from an entirely empirical approach involvi sizing of the SBR reactor(s) based on somewhat arbitrarily lected detention times to an approach where sizing of the actor(s) and aeration equipment was based on the values of ganic loading, F/M ratio, sludge concentration at the end of t decant period, and durations of different periods comprising t overall cycle. Both approaches produced relatively conservati designs.

• Partial to nearly full nitrification was achieved in almo all facilities visited, although it was mandated at only tw (Grundy Center and Eldora). Operators did not believe the ir plementation of a nitrification control strategy was difficult. O of the facilities, Culver, Ind., is currently removing phosphor biologically to levels less than 1 mg/L without any chemic addition. This is being accomplished by adjusting the operati strategy so that an anaerobic (no oxygen and no nitrates) f period is followed by an aerobic react period.

• The operating cycles (fill, react, settle) used at the facilit were also significantly different. For example, the react perio varied from 22 hours in Glenlea to about 1.5 hours in Rivercres

• The operating strategy used by some operators (Rivercres Glenlea, and Choctaw) involved aeration during the entire f period which, although contrary to the recommendations Chiesa and Irvine,[17] did not necessarily encourage the growt of filaments to any significant degree.

• Because of the differences in the operating strategies, powe usage at these plants was significantly different: from as low a 0.8 kWh/kg BOD applied to 22.9 kWh/kg BOD applied.

• Several types of decanter mechanisms are used at these f cilities. They range from an extremely simple system that consis

BEST AVAILABLE COPY

BEST AVAILABLE COPY

18-1995 15:54 FROM JOHN CRERAR LIBRARY OF C TO 98313999 P.11

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	Glentee 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 with drawal	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 with drawal	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 with drawal	Gravity	June 1983
8	Yambo 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 technolog from the research realm to the practical arena, where it woul be considered a viable option by a practicing engineer designin facilities. Unless this is done most practicing engineers may con tinue to believe that the technology is in the developmental stage with associated uncertainties of success and that their client may be risking their investments in using SBR for propose projects. This would be far from the truth, because the technolog is not only proven, but can also be cost-effective in several ap plications. Communities such as Rivercrest, Glenlea, Eldora Tamworth, and Yamba built SBR facilities entirely out of the own funds because they believed no undue risks were associate with this technology.

SUGGESTED DESIGN APPROACH

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

1. Calculate daily BOD loading (F).
2. Assume a suitable F/M ratio consistent with the wate quality objectives and calculate M.
3. Assume a suitable value of MLSS concentration expecte at the end of the decant period and calculate volume occupie by the settled mixed liquor solids (M) based on the assume concentration.
4. Select the number of SBR tanks to be used and determin the volume occupied per tank by the mixed liquor solids ca culated in Step 3.
5. Decide the number of operating cycles per day and calculat the volume of liquid to be handled per decant per SBR tank.
6. Volume of each SBR tank equals the volume calculate in Step 4 plus the volume calculated in Step 5.
7. Assume a suitable SBR tank depth and calculate area re quired per tank; decide length and width.
8. Based on the calculated tank area, check the depth of th decanted liquid necessary to accommodate the liquid volum calculated in Step 5. Make sure that it is reasonable (1 to 1. m). If not, repeat the previous steps (for example, increase th 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 th depth of the sludge blanket necessary to accommodate the vo ume of sludge calculated in Step 3. Make sure it is reasonabl (about half the depth of the tank).
10. Determine the daily oxygen requirement based on wate quality objectives.
11. Size aeration equipment based on the calculated oxyge requirement to be satisfied during aerated fill plus react tim provided in the total number of operating cycles per day decide in Step 5. This can also be done based on satisfying the expecte oxygen uptake rate of the mixed liquor.
12. Size decant mechanism and piping to handle decant vo ume (Step 5) during the selected decant period.

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

BEST AVAILABLE COPY

	Australia	
Culver, Indiana[b]	Tamworth, New South Wales	Yamba New South Wales
4/84	7/10/84	7/11/84
3 × 10[a]	2.02 × 10[a]	956 340
[illegible][a]	260	260[a]
[illegible][a]	—	—
[illegible]	35 to 40	--
7 × 10[a]	2.02 × 10[a]	--
[illegible]	30	30
[illegible]	30	30
[illegible]	6 to 10	6 to 10
	5 to 10	10 to 15
0	2.2	1.0
80 minutes	continuous	continuous
2 minutes	120 to 150 minutes	150 minutes
2 minutes		180 minutes
2 minutes	45 minutes	45 minutes
0 minutes	45 minutes	
30% mixed 70% aerated		

Important design parameters								
Detention time hours	7 6	49	48	20 4	43	18 5[e]	46	36
F/M, kg BOD/kg MLSS	0 18[e]	0 032[e]	0 037	0 078	0 06	0 08 to 0 18	0 04	0 05
SRT, days	43[e]	18 to 80[e]	0 028[e] Sludge wasted twice in 10 months	0 067[e] 25 to 30[e]	Sludge not wasted in last 2 months	15 to 45[e]	—	—
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 the 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

[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

BEST AVAILABLE COPY

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[13] 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

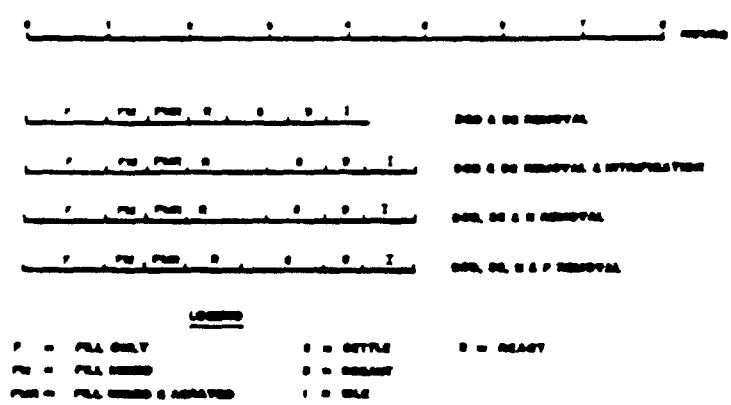


Figure 3—Suggested operating strategies for different water quality objectives.

BEST AVAILABLE COPY

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

Credits. Robert Irvine of the University of Notre Dame reviewed the study report and made many valuable suggestions. This paper was prepared in fulfillment of the requirements of Contract No. 68-02-1821 with the U. S. Environmental Protection Agency Environmental Research Center, Cincinnati, Ohio.

Authors. Madan L. Arora is manager of the Wastewater Reclamation Division, James M. Montgomery Consulting Engineers, Inc., Pasadena, Calif. At the time of this study Edwin F. Barth was with the U. S. Environmental Protection Agency, Environmental Research Center, Cincinnati, Ohio. Margaret B. Umphres is senior engineer with James M. Montgomery Consulting Engineers, Inc., Pasadena, Calif. Correspondence should be addressed to Madan L. Arora, James M. Montgomery Consulting Engineers, Inc., 250 North Madison Ave., Pasadena, CA 91109-7009.

REFERENCES

1. Irvine, R. L., "Technology Assessment of Sequencing Batch Reactors." U. S. Environ. Prot. Agency (in press).
2. Sidwick, J. M., and Murray, J. E., "A Brief History of Sewage Treatment (Part 1)." *Effluent and Water Treatment J.*, 65, 205 (1976).
3. Barth, E. F., "Sequencing Batch Reactors for Municipal Wastewater Treatment." Presented at the Eighth U. S./Jpn Conf. on Sew. Treat. Technol. (1981).
4. Ardern, E., and Lockett, W. T., "Experiments on the Oxidation of Sewage Without the Aid of Filters." *J. Soc. Chem. Ind.*, 33, 523 (1914).
5. Irvine, R. L., and Bush, A. W., "Sequencing batch biological reactors—an overview." *J. Water Pollut. Control Fed.*, 51, 235 (1979).
6. Irvine, R. L., *et al.*, "Sequencing batch treatment of wastewaters in rural areas." *J. Water Pollut. Control Fed.*, 51, 244 (1979).
7. Dennis, R. W., and Irvine, R. L., "Effect of fill: react ratio on sequencing batch biological reactors." *J. Water Pollut. Control Fed.*, 51, 255 (1979).
8. Hoepker, E. G., and Shroeder, E. D., "The effect of loading rate on batch-activated sludge effluent quality." *J. Water Pollut. Control Fed.*, 51, 264 (1979).
9. Goronszy, M. C., "Intermittent operation of the extended aeration process for small systems." *J. Water Pollut. Control Fed.*, 51, 274 (1979).
10. Ketchum, L. H., Jr., *et al.*, "First cost analysis of sequencing batch biological reactors." *J. Water Pollut. Control Fed.*, 51, 288 (1979).
11. Ketchum, L. H., Jr., and Liao, P.-C., "Tertiary chemical treatment for phosphorus reduction using sequencing batch reactors." *J. Water Pollut. Control Fed.*, 51, 298 (1979).
12. Irvine, R. L., and Ketchum, L. H., "Full-Scale Study of Sequencing Batch Reactors." U. S. Environ. Prot. Agency (in press).
13. Barth, E. F., "Implementation of Sequencing Batch Reactors for Municipal Wastewater Treatment." Presented at the 6th Symposium on Wastewater Treat., Ottawa, Canada (1983).
14. Schmidtke, N. W., and Topnik, B. H., "Application of Biological Reactor Technology in Wastewater Treatment." Presented at the Annu. Meeting of the Can. Soc. of Civ. Eng., Ottawa, Ontario (1983).
15. Herzbrun, P. A., *et al.*, "Treatment of Hazardous Wastes in a Sequencing Batch Reactor." Presented at the 39th Annu. Ind. Waste Conf., Purdue University, Lafayette, Ind. (1984).
16. Schmidtke, N. W., and Topnik, B. H., "Design and Performance Assessment of Three Sequencing Batch Reactor Sewage Treatment Plants in Canada." Draft Report Prepared for the Wastewater Tech. Center, Environ. Protection Serv., Canada (1984).
17. Chiesa, S. C., and Irvine, R. L., "Growth and Control of Filamentous Microbes in Activated Sludge—An Integrated Hypothesis." Presented at the 55th Annu. Water Pollut. Control Fed. Conf., St. Louis, Mo. (1982).
18. Irvine, R. L., "Structured Models for Biological Waste Treatment Systems." Research Grant, National Science Foundation (1985).
19. "Technology Evaluation of Sequencing Batch Reactors." Final Rept., U. S. Environmental Prot. Agency, Environ. Res. Center, Cincinnati, Ohio (1984).
20. Manning, J. F., Jr., and Irvine, R. L., "The biological removal of phosphorus in a sequencing batch reactor." *J. Water Pollut. Control Fed.*, 57, 87 (1985).

BEST AVAILABLE COPY

The document: "Background Report: Thermal Electric Power Plant Industry, Al Husein Thermal Power Station, Jordan" has already been provided under separate cover.

PB92-145408

Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities

Midwest Research Inst., Cary, NC

Prepared for:

Environmental Protection Agency, Research Triangle Park, NC

Jan 92

partment of Commerce
l Technical Information Service
NTIS

BEST AVAILABLE COPY

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before complete)

1. REPORT NO. EPA 450/3-91-027	2.	3. PB92-145408
4. TITLE AND SUBTITLE ·essment of VOC Emissions and Their Control m Baker's Yeast Manufacturing Facilities		5. REPORT DATE January 1992
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robin Barker and Maresa Williamson		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 401 Harrison Oaks Boulevard Suite 350 Cary, NC 27513		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-0115
12. SPONSORING AGENCY NAME AND ADDRESS Control Technology Center U. S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Environmental Protection Agency's (EPA's) Control Technology Center (CTC) conducted a study to obtain information on the baker's yeast manufacturing industry. Baker's yeast is produced by a fermentation process that generates arge quantities of ethanol and acetaldehyde. Currently, 13 facilities produce aker's yeast in the United States. The volatile organic compound (VOC) emission rate from a typical facility is estimated at 82 megagrams per year (90 tons per year). The majority of these emissions occurs in the final trade fermentations. The VOC emission alternatives that were evaluated during this study were process control measures to reduce the formation of VOC emissions as well as wet scrubbers, carbon adsorbers, incinerators, condensers, and biological filters to control VOC emissions. Of these approaches, it appears that process control measures, catalytic incinerators, or a combination of add-on control techniques (e.g., wet scrubbers followed by an incinerator or a biological filter) are the most feasible approaches for controlling yeast process emissions. Based on the results of this study, the control efficiency associated with the add-on control systems is estimated to be 95 to 98 percent. This report contains information on the baker's yeast fermentation process, the number and locations of yeast plants, the potential emissions from the process, and an evaluation of potential emission control options.

KEY WORDS AND DOCUMENT ANALYSIS

DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Baker's yeast	yeast manufacturing		
yeast	ethanol		
fermentation	acetaldehyde		
active dry yeast	VOC emissions		
compressed yeast	VOC controls		
cream yeast	process control		
instant dry yeast	biological filtration		

17. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 53
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-91-027
January 1992

Air

EPA

Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities

control technology center

REPRODUCED BY

ASSESSMENT OF VOC EMISSIONS AND THEIR CONTROL FROM BAKER'S YEAST MANUFACTURING FACILITIES

Control Technology Center

Sponsored by:

Emission Standards Division
Office of Air Quality Planning and Standards
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Air and Energy Engineering Research Laboratory
Office of Research and Development
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

January 1992

EPA No. 450/3-91-027
January 1992

ASSESSMENT OF VOC EMISSIONS AND THEIR CONTROL FROM BAKER'S YEAST MANUFACTURING FACILITIES

By

Midwest Research Institute
401 Harrison Oaks Boulevard
Suite 350
Cary, North Carolina 27513

EPA Contract Nos. 68-D1-0115,
68-D0-0137, and 68-02-4379

Project Lead
Martha Smith
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Prepared for:

Control Technology Center
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

NOTICE

This report was prepared by Midwest Research Institute, Cary, North Carolina. It has been reviewed for technical accuracy by the Emission Standards Division of the Office of Air Quality Planning and Standards and the Air and Energy Engineering Research Laboratory of the Office of Research and Development, U. S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation of use.

ACKNOWLEDGEMENT

This report was prepared for EPA's Control Technology Center (CTC) by Robin Barker and Maresa Williamson of Midwest Research Institute. The Work Assignment Manager was Martha Smith of EPA's Chemicals and Petroleum Branch (CPB). Also participating on the project team were Bob Blasczcak, CTC; Chuck Darvin, EPA Air and Energy Engineering Research Laboratory; and K.C. Hustvedt, CPB.

PREFACE

The Control Technology Center (CTC) was established by the U. S. Environmental Protection Agency's (EPA's) Office of Research and Development and Office of Air Quality Planning and Standards to help State and local air pollution control agencies implement their air toxics and other pollution programs. Three levels of assistance can be accessed through the CTC. First, a CTC Hotline has been established to provide telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The major objectives of this document are to provide a general overview of the baker's yeast production process, to summarize available data on VOC emissions from baker's yeast manufacturing facilities, and to evaluate potential emission control options. This work was initiated by a State of Maryland request for technical support from the CTC. The State is concerned that while VOC concentrations in the flue gas from the yeast fermentors at a facility in Baltimore, Maryland, are low, the large volume of flue gas indicates a high mass emission rate. Thus, the State of Maryland is looking for guidance on controlling these dilute, high-volume gas streams.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

1.1 OVERVIEW 1

2.0 INDUSTRY PROFILE 3

2.1 EVOLUTION OF THE INDUSTRY 3
2.2 NUMBER AND LOCATION OF FACILITIES 3
2.3 OZONE NONATTAINMENT STATUS 5
2.4 PRODUCTION STATISTICS AND GROWTH PROJECTION . . . 5

3.0 PROCESS DESCRIPTION 5

3.1 RAW MATERIALS 7
3.2 FERMENTATION 10

3.2.1 General 10
3.2.2 Fermentation Sequence 10
3.2.3 Laboratory Stage, or Flask Stage (F1) . . 12
3.2.4 Pure Culture Stages (F2 and F3) 12
3.2.5 Main Fermentation Stages (F4-F7) 13
3.2.6 Harvesting and Packaging 15
3.2.7 Production of Dry Yeast 17

4.0 EMISSION ESTIMATIONS 17

4.1 SOURCES OF EMISSIONS 18
4.2 EMISSION DATA AND PROCESS EMISSION FACTORS . . . 19
4.3 NATIONWIDE EMISSION LEVELS 23
4.4 MODEL EMISSION STREAM 23

5.0 EMISSION CONTROL TECHNIQUES 24

5.1 COMPUTERIZED PROCESS CONTROL MEASURES 24
5.2 ENGINEERING CONTROLS 27

5.2.1 Wet Scrubbers (Gas Absorption) 27
5.2.2 Carbon Adsorption 30
5.2.3 Incineration 30
5.2.4 Condensation 33
5.2.5 Biological Filtration 35
5.3 IMPACT ASSESSMENT OF CONTROL OPTIONS 37

6.0 CONCLUSIONS 41

7.0 REFERENCES 44

LIST OF FIGURES

		Page
Figure 1.	Process flow diagram for producing baker's yeast	8
Figure 2.	Fermentation sequence used in producing baker's yeast	11
Figure 3.	Emissions profile of a typical trade fermentation	25
Figure 4.	Schematic of a packed tower absorber	28
Figure 5.	Schematic of a biofiltration system	36

LIST OF TABLES

TABLE 1.	YEAST MANUFACTURING PLANTS	4
TABLE 2.	OZONE NONATTAINMENT STATUS	6
TABLE 3.	VOC EMISSIONS FROM YEAST FERMENTATION	20
TABLE 4.	VOC EMISSIONS FROM A TYPICAL YEAST FERMENTATION FACILITY	22
TABLE 5.	SUMMARY OF THE COST AND ENVIRONMENTAL IMPACTS OF THE CONTROL OPTIONS	38
TABLE 6.	CAPITAL COSTS OF ADD-ON CONTROL OPTIONS . . .	39
TABLE 7.	ANNUAL COSTS OF ADD-ON CONTROL OPTIONS	40
TABLE 8.	COSTS FOR CONDENSER CONTROL OPTION	42

1.0 INTRODUCTION

The objectives of this study were to obtain information on .er's yeast fermentation processes, to determine the number and locations of yeast plants, to estimate the potential emissions from the process, and to evaluate potential emission control options. The information contained in this report includes an industry profile, descriptions of the production process, available emission data, descriptions and technical evaluations of the control options, the impacts (cost and environmental) of each option, and the results of an evaluation to determine the most effective and least costly technology options.

This document is organized into the following sections: Section 2.0 provides a brief characterization of the baker's yeast manufacturing industry, including the number, locations, and production capacities of facilities; Section 3.0 describes the baker's yeast fermentation process, including the equipment used, feed materials and process requirements, and typical process yields and limitations; Section 4.0 presents the emission urces and pollutant types, available emission test data, process emission factors, nationwide emission levels, and model emission stream data; Section 5.0 presents the available information on potential emission controls for the pollutants and emission points identified in Section 4.0; Section 6.0 summarizes the conclusions derived from this investigation; and Section 7.0 provides references for this report.

1.1 OVERVIEW

Currently 13 facilities produce baker's yeast in the United States. The facilities are widely dispersed and can be fou

compliance with the national ambient air quality standard (NAAQS) for ozone.

Baker's yeast is produced by a fermentation process in which large quantities of ethanol and acetaldehyde are generated and emitted to the atmosphere. Based on test data from three facilities, the VOC mass emission rate from a typical facility is estimated at 82 megagrams per year (Mg/yr) (90 tons per year [tons/yr]). Ethanol is approximately 80 to 90 percent of the emissions generated, and the remaining 10 to 20 percent consists of other alcohols and acetaldehyde. The VOC concentration from a typical trade fermentor varies over a range from 5 to 600 parts per million by volume (ppmv). The fluctuation in the VOC concentration is attributable primarily to the variation in feed rates to the fermentor, variation in the airflow rate, and the design of the fermentor's air sparger and agitation systems. Based on the number of yeast facilities and the typical VOC emission levels, the total annual VOC emissions from this source category are estimated to range from 780 to 1,060 Mg/yr (860 to 1,170 tons/yr).

The VOC emission alternatives that were evaluated during this study were process control measures to reduce the formation of VOC emissions as well as wet scrubbers, carbon adsorbers, incinerators, condensers, and biological filters to control VOC emissions. Of these approaches, it appears that process control measures, catalytic incinerators, or a combination of add-on control techniques (e.g., wet scrubbers followed by an incinerator or a biological filter) are the most feasible approaches for controlling yeast process emissions. Based on the results of this study, the control efficiency associated with the add-on control systems is estimated to be 95 to 98 percent.

Process control measures would limit the amount of ethanol formed by the process. This can be accomplished by incrementally feeding the molasses mixture (the principal source of carbon for yeast growth) and by supplying sufficient oxygen to the fermentors. Although these process control strategies are routinely employed at yeast production facilities for economic

reasons (i.e., to optimize the use of raw materials), these steps are not optimized to limit VOC emissions. Implementing and optimizing more stringent process control, especially during the early stages of fermentation where close process control is usually not required, would reduce the formation of VOC emissions by 75 to 95 percent.

2.0 INDUSTRY PROFILE

Information on the evolution of the baker's yeast industry, the number and location of facilities, the ozone nonattainment status of facility locations, yeast production statistics, and growth projections for the industry is presented below.

2.1 EVOLUTION OF THE INDUSTRY

The production of baker's yeast is a process that has been developed over centuries. The earliest means of producing baker's yeast was to inoculate fresh dough with a portion of the preceding fermented dough. Yeast will grow indefinitely by this means, and this method is still used today in producing sour dough breads. Before the 1800's, the top-fermenting yeast from breweries was used for baking bread. However, the yeast yields were very low and the ethanol yield was very high. Over the last 100 years, grain mashes were replaced with molasses as the principal carbon source for producing yeasts, fermentation process tanks were equipped with air supply and incremental feed systems to reduce the formation of ethanol and increase the quantities of yeast produced. At this point, the yeast production process became independent of the brewery process and has remained virtually unchanged since the 1920's.

2.2 NUMBER AND LOCATION OF FACILITIES

Six major companies manufacture baker's yeast in the United States. These companies are Universal Foods (Red Star Yeast), Fleischmanns, Gist-brocades, Lallemand (American Yeast), Minn-dak, and Columbia. There are a total of 13 manufacturing plants owned by these companies in the United States. Table 1 lists the locations of the plants by manufacturer.

TABLE 1. YEAST MANUFACTURING PLANTS

Lallemand (American Yeast)	Baltimore, Maryland
Columbia	Headland, Alabama
Fleischmanns	Gastonia, North Carolina Memphis, Tennessee Oakland, California Sumner, Washington
Gist-brocades	Bakersfield, California East Brunswick, New Jersey
Minn-dak	Wahpeton, North Dakota
Universal Foods Corp. (Red Star Yeast)	Baltimore, Maryland Dallas, Texas Milwaukee, Wisconsin Oakland, California

2.3 OZONE NONATTAINMENT STATUS

The baker's yeast manufacturing plants in the United States are located in both attainment and nonattainment areas for ozone. This ranking is according to the latest update of the cities exceeding the ozone limit, made in 1988.[1] The ozone air quality standard calls for no more than 1 hour in a year during which any monitor in an area records an O_3 level in excess of 0.12 ppm.[1] Table 2 presents the locations of all the yeast manufacturing plants located in the United States and whether or not they are located in ozone nonattainment areas.

2.4 PRODUCTION STATISTICS AND GROWTH PROJECTION

In 1989, only 12 yeast plants were in operation. The total U.S. production of baker's yeast in 1989 was 223,500 Mg (245,000 tons). Of this total, approximately 85 percent of the yeast was compressed or cream yeast, and the remaining 15 percent was dry yeast.

Between 1990 and 1991, two additional facilities were opened and are currently in production, and one facility was closed down. A foreign manufacturer of baker's yeast, Minn-dak, has recently opened a new yeast plant in Wahpeton, North Dakota. Fleischmanns also has opened a plant in Memphis, Tennessee, but closed its plant in St. Louis, Missouri. The opening of these two facilities in 1990 is expected to increase production of baker's yeast by approximately 5 to 10 percent.

3.0 PROCESS DESCRIPTION

Two main types of baker's yeast are produced: compressed yeast and active dry yeast (ADY). Compressed yeast is a perishable commodity and must be refrigerated or frozen at all times. Refrigerated compressed yeast remains useful for several weeks before molds begin to develop. Frozen compressed yeast can be stored and used for up to a month, but some softening of the yeast cake occurs. Active dry yeast has a lower bake activity than compressed yeast, but it can be stored for 1 to 2 years without refrigeration before the bake activity is lost. Compressed yeast is sold mainly to wholesale bakeries, whereas ADY is sold mainly for home baking needs and, to a limited

TABLE 2. OZONE NONATTAINMENT STATUS

ant location	Company	Nonattainment for ozone
Milwaukee, WI	Universal Foods Corporation (UFC)	Yes
Oakland, CA	UFC	Yes
	Fleischmanns	Yes
Baltimore, MD	Lallemand (American Yeast)	Yes
	UFC	Yes
Dallas, TX	UFC	Yes
Bakersfield, CA	Gist-brocades	Yes
East Brunswick, NJ	Gist-brocades	Yes
Sumner, WA	Fleischmanns	No
Memphis, TN	Fleischmanns	Yes
Gastonia, NC	Fleischmanns	Yes[a]
Headland, AL	Columbia	No
Wahpeton, ND	Minn-dak	No

stonia is not formally recognized by EPA as an ozone nonattainment area, but exceedances for ozone occur, and the area will most likely be nonattainment for ozone when the 1990 Clean Air Act Amendments are fully implemented.

extent, to bakeries. Compressed yeast and ADY are produced in a similar manner, but ADY is dried after processing and is developed from a different yeast strain. Another dry yeast product, instant dry yeast (IDY), is dried after processing and is produced from a faster-reacting yeast strain than that used for ADY. The main difference between ADY and IDY is that IDY does not have to be dissolved in warm water prior to usage, whereas ADY does. The following discussion is directed towards compressed yeast manufacturing, although a brief discussion of the production of dry yeast is also presented (Section 3.2.7).

A variety of processes are used in producing baker's yeast. Most processes, however, are a variation on the Zulauf process, which was introduced in the early 1900's. This report provides a general description of the Zulauf production process.

Figure 1 presents a process flow diagram for the production of baker's yeast. The first stages of production consist of growing the yeast from the pure yeast culture in a series of fermentation vessels. The yeast is then recovered from the final fermentor using centrifugal action to concentrate the yeast solids. The yeast product is subjected to one or more washings in the centrifugal separator. The yeast solids are then filtered by a filter press or a rotary vacuum filter to further concentrate the yeast. Next, the yeast filter cake is blended in mixers with small amounts of water, emulsifiers, and cutting oils. After mixing, the mixed press cake is extruded and cut. The yeast cakes are then either wrapped for shipment or dried to form dry yeast.

3.1 RAW MATERIALS

The principal raw materials used in producing baker's yeast are the pure yeast culture and molasses. The yeast strain used in producing compressed yeast is Saccharomyces cerevisiae.[2] Cane and beet molasses are used as the principal carbon source to promote yeast growth. Molasses contains 45 to 55 percent fermentable sugars by weight in the forms of sucrose, glucose, and fructose. This sugar by-product is the least expensive source of sugar known. Other sources, such as corn grits,

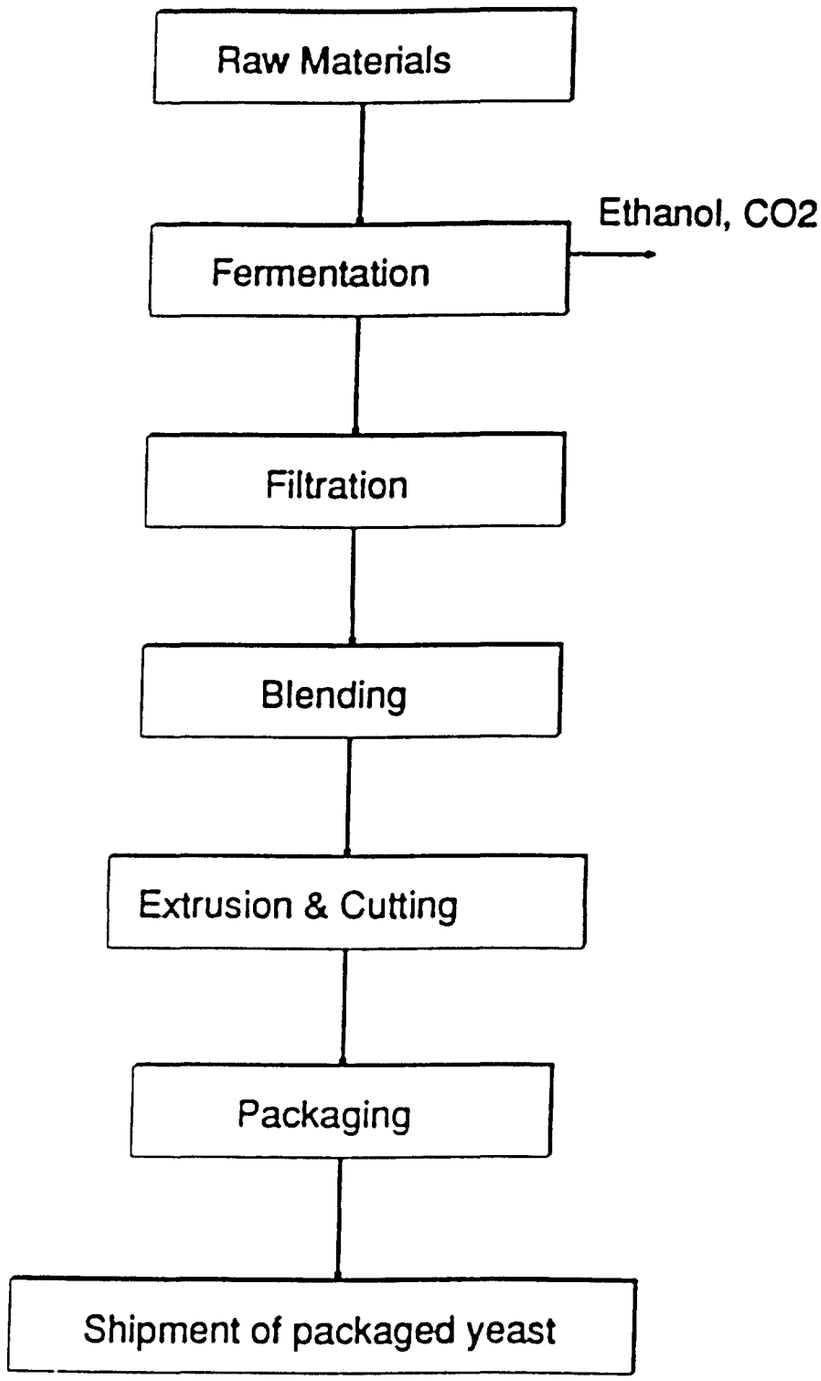


Figure 1. Process flow diagram for producing baker's yeast.

raisins, or sugar-containing wastes of the confectionary industry, are also effective, but for various reasons (mostly economic), se alternatives were found to be unsuitable as carbon and energy substrates for baker's yeast production.[3]

The amount and type of cane and beet molasses used depends on the availability of the molasses types, cost, and the presence of inhibitors and toxins. Usually, a blend consisting of both cane and beet molasses is used in the fermentations. Once blended, the molasses mixture is clarified to remove any sludge. Prior to clarification, the pH of the molasses mixture is adjusted because too high a pH will promote bacterial growth. Bacterial growth occurs under the same conditions as yeast growth, making pH monitoring a very important factor. The clarified molasses mixture is then sterilized with high-pressure steam. After sterilization, it is diluted with water and held in holding tanks until it is needed by the fermentation process.

Other required raw materials are a variety of essential nutrients and vitamins. Mineral requirements include nitrogen, :assium, phosphate, magnesium, and calcium. Nitrogen is normally supplied through the addition of ammonium salts, aqueous ammonia, or anhydrous ammonia to the feed stock.[4] The molasses normally provides sufficient quantities of potassium and calcium. Phosphates and magnesium are added in the form of phosphoric acid or phosphate salts and magnesium salts.[5] Iron, zinc, copper, manganese, and molybdenum are also required in trace amounts.

Several vitamins are required for yeast growth (biotin, inositol, pantothenic acid, and thiamine). Yeast will not grow in the absence of biotin.[6] Thiamine is not required for yeast growth but is normally added to the feed stock because it is a potent stimulant for fermenting doughs. Both cane and beet molasses usually provide enough inositol and pantothenic acid for yeast growth. However, if beet molasses, which is deficient in biotin, is used, biotin must be added or a mixture of cane and beet molasses is required.

3.2 FERMENTATION

Yeast cells are grown in a series of fermentation vessels. A typical fermentation process is shown in Figure 2. The process begins when a pure yeast culture is grown in the laboratory. Portions of this pure culture are placed in the first fermentor along with the other feed materials and are allowed to grow. Yeast is propagated when the entire yeast mixture (or a portion of the mixture from the preceding fermentor) is placed into the next fermentor, which is equipped for batch or incremental feeding of the molasses malt. The process continues until the yeast mixture reaches the final fermentation vessel.

3.2.1 General

Yeast fermentation vessels are operated under aerobic conditions (free oxygen present, or excess air) because under anaerobic conditions (limited or no oxygen available) the fermentable sugars are consumed in the formation of ethanol and carbon dioxide, which results in low yeast yields.[7] Yeast yields under anaerobic conditions are often less than 10 percent-by-weight of fermentable sugars, whereas yeast yields of up to 50 percent-by-weight of fermentable sugars are obtained under aerobic conditions.[7] Therefore, to maximize yeast yields, it is important to supply enough oxygen for the dissolved oxygen content in the liquid surrounding the yeast cells to be at an optimal level. In practice, oxygen transfer rates are often inadequate, and under such conditions, some ethanol is formed. In addition, it is also important to control the amount of fermentable sugars present in the fermentor, so that the sugar is assimilated by the yeast as fast as it is added. This balance is accomplished by using an incremental feed system in the final fermentation stages.

3.2.2 Fermentation Sequence

Compared with subsequent fermentation stages, in the first stages of yeast propagation, the medium is richer in nutrients, and there is less aeration. Consequently, the fermentor liquor contains more alcohol and yields of yeast are lower. The lower yields in the first stages are not necessarily a drawback,

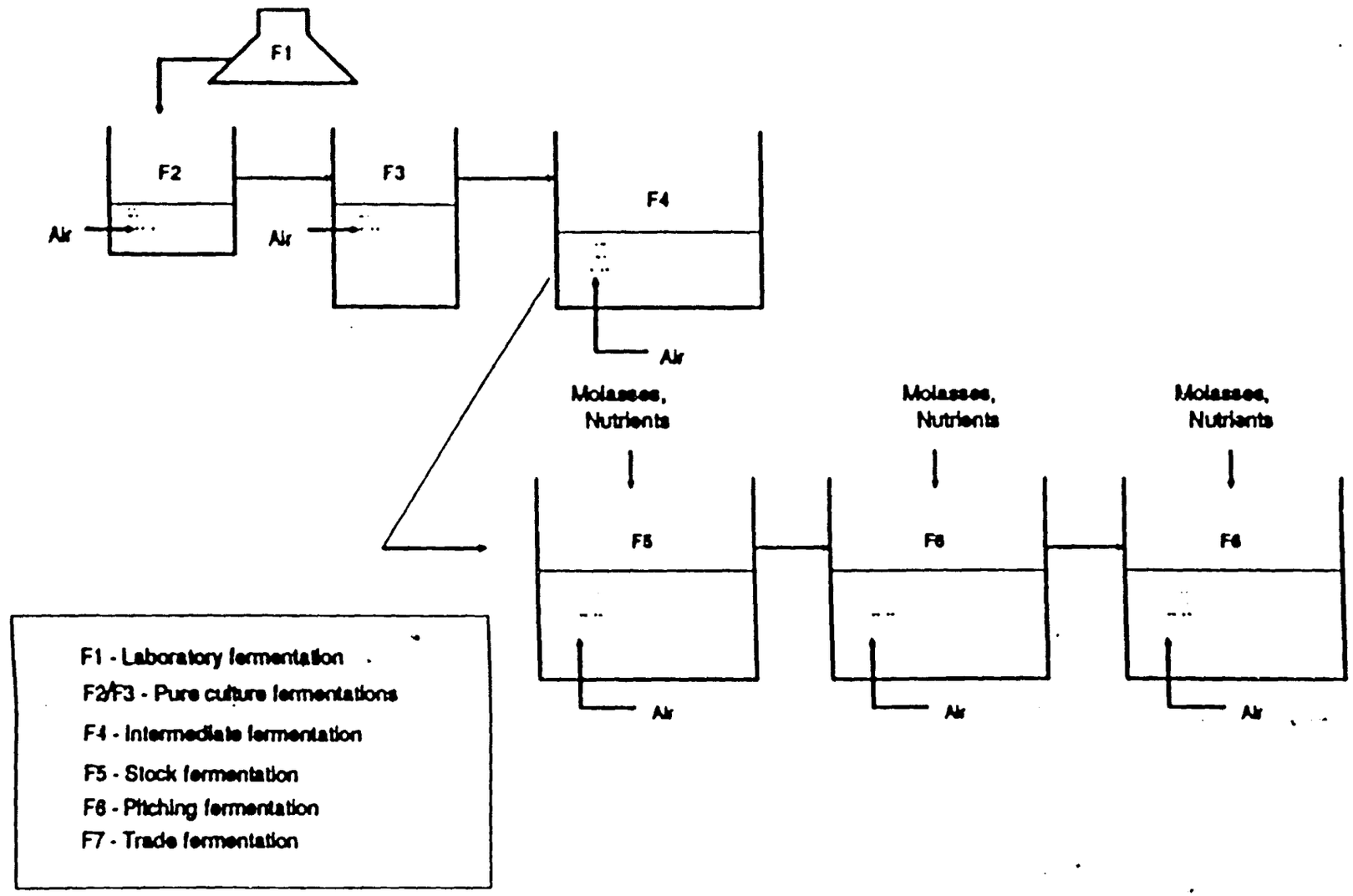


Figure 2. Fermentation sequence used in producing baker's yeast.

because the overall economy of the operation depends on the yield from the final trade fermentation stage. The following sections describe each stage in the fermentation sequence.

3.2.3 Laboratory Stage, or Flask Stage (F1)

The first fermentation stage takes place in the laboratory when a portion of the pure yeast culture is mixed with the molasses malt in a sterilized Erlenmeyer or Pasteur flask. The total contents of the flask are typically less than 5 liters (L) (1.3 gallons [gal]), and the yeast is allowed to grow in the flask for 2 to 4 days.[8] The entire flask contents are then used to inoculate the second fermentation stage.

3.2.4 Pure Culture Stages (F2 and F3)

Generally, this stage consists of two pure culture fermentations. The capacities of the fermentation vessels used in this stage range from 1,140 L (300 gal) to 26,500 L (7,000 gal). The pure culture fermentations are batch fermentations where the yeast is allowed to grow for 13 to 24 hours. The contents of the fermentor from the first pure culture stage (F2) is added to the next fermentation vessel, which already contains the nutrient-rich molasses malt. The pure culture fermentations are basically a continuation of the flask fermentation, except that the pure culture fermentations have provisions for sterile aeration and aseptic transfer to the next stage. The yeast yield in the pure culture fermentations is approximately 27 kilograms (kg) (60 pounds [lb]) in the first fermentor and 600 kg (1,300 lb) in the second fermentor.

The critical factor in the pure culture operation is sterility. Rigorous sterilization of the fermentation medium prior to inoculation is conducted by heating the medium under pressure or by boiling it at atmospheric pressure for extended periods. If a sterile environment is not provided, contaminating microorganisms can easily outgrow the yeast.

The need for process control in the pure culture medium is limited. However, microbiological testing of the medium before, during, and after each fermentation is essential. The malt concentration of the initial fermentor is often standardized to

between 5 and 7.5 percent sugar.[9] Once the pure culture fermentation is started, the only controllable parameters are the temperature and the degree of aeration. However, control of aeration is not critical because of the excess sugar present, and control of temperature is not critical because the fermentation operates over a broad temperature range.

3.2.5 Main Fermentation Stages (F4-F7)

The majority of the yeast yield grows in the final fermentation stages. The main fermentation stage takes place in two to four fermentation vessels. These yeast fermentors vary considerably in size. The volumes of fermentation vessels in the F4 through F7 stages range from 37,900 L (10,000 gal) to over 283,900 L (75,000 gal). The vessels have diameters in excess of 7.0 meters (m) (24.5 feet [ft]) and heights up to 14 m (45 ft). The larger vessels are associated with the final fermentation stages (F6 and F7). The fermentation vessels are typically operated at a temperature of 30°C (86°F).

The fermentors are usually constructed of stainless steel and are equipped with an incremental feed system. This incremental feed system may be a pipe or a series of pipes that distribute the molasses over the entire surface of the fermentor liquid. The rate at which the molasses is fed is critical and may be controlled by a speed controller connected to a pump or by a valve on a rotameter, which delivers a certain volume of molasses at regulated time intervals. Nutrient solutions of vitamins are kept in small, separate tanks and are charged through rotameters into the fermentor, but the rate of feed is not as critical as with molasses. However, if ammonia is used as a nitrogen source, additions must be made in a manner that avoids sudden pH changes. The nitrogen salts and phosphates may be charged in a shorter period of time than the molasses feed. Fermentors must also be equipped with heat exchangers to remove the heat produced from the production process and to cool the fermentor. The type of heat exchanger system used depends on the size of the fermentation vessel. Because large volumes of air are supplied to the fermentation vessels during this stage of

production, the fermentor size influences the type of aeration system selected. The different types of aeration systems include horizontal, perforated pipes; compressed air and mechanical agitation; and a self-priming aerator.

In the horizontal, perforated pipe system, air is blown through a large number of horizontal pipes that are placed near the bottom of the fermentor. With this aeration system, the only agitation of the fermentor liquid is carried out by the action of the air bubbles as they rise to the surface. Typically, this type of aeration system requires from 25 to 30 m^3 (880 to 1,060 ft^3) of air to produce 0.45 kg (1 lb) of yeast.[10]

The efficiency of aeration with a given volume of air can be greatly increased by mechanical agitation. In a compressed air/mechanical agitation aeration system, air under pressure is supplied to a circular diffuser pipe. Directly above the air outlets, a horizontal turbine disc provides mechanical agitation, which distributes the air bubbles uniformly. Agitation systems

a stock (pitch) of yeast for the next stage. The third stage (F6) is usually carried out in fermentors as large as those used for the trade fermentation or final fermentation. Aeration is vigorous, and molasses and other nutrients are fed incrementally. The fermentor liquor from this fermentor (F6) is usually divided into several parts for pitching the final trade fermentation (adding the yeast to start fermentation). Alternately, the yeast may again be separated by centrifuging and stored for several days prior to its use in the final trade fermentations. The final trade fermentation (F7) has the highest degree of aeration, and molasses and other nutrients are fed incrementally. Due to the large air supplies required during the final trade fermentations, these vessels are often started in a staggered fashion to reduce the load or size of the air compressors required. The duration of each of the final fermentation stages ranges from 12 to 15 hours. The amount of yeast growth increases in each stage and is typically 120 kg (265 lb) in the first stage, 420 kg (930 lb) in the second stage, 2,500 kg (5,510 lb) in the third stage, and 15,000 to 100,000 kg (33,070 to 220,460 lb) in the fourth stage.[11]

When using the two-stage final fermentation series, the only fermentations are the stock fermentation and the trade fermentation (F5 and F7, respectively). About half of the 13 yeast manufacturing facilities use the four-stage final fermentation series and the other half use the two-stage process.

After all of the required molasses has been fed into the fermentor, the liquid is aerated for an additional 0.5 to 1.5 hours. This permits further maturing of the yeast and results in a yeast that is more stable in refrigerated storage.

3.2.6 Harvesting and Packaging

Once an optimum quantity of yeast has been grown, the yeast cells are recovered from the final trade fermentor by centrifugal yeast separators. The separators used in this process are continuous dewatering centrifuges.[12] After the first pass through the separators, a yeast solids content of 8 to 10 percent can be acquired from a fermentor liquor containing 3.5 to

4.5 percent solids.[12] Next, the yeast is washed with water and passed through the separators a second time. The second pass usually produces concentrations of 18 to 21 percent solids.[12] If the concentration of yeast solids recovered from the second pass is below 18 percent, then another washing and a third pass through the separators is normally required. The yeast cream resulting from this process can be stored for several weeks at a temperature slightly above 0°C (32°F). After storage, the yeast cream can be used to propagate yeast in other trade fermentations or can be further dewatered by filtration.

The centrifuged yeast solids are further concentrated by pressing or filtration. Two types of filtering systems are used: filter presses and rotary vacuum filters. In the filter press, the filter cloth consists of cotton duck or a combination of cotton duck and synthetic fibers so tightly woven that no filter aid is necessary. Filter presses having frames of 58 to 115 centimeters (cm) (24 to 48 inches [in.]) are commonly used, and pressures between 860 to 1,030 kiloPascals (125 to 150 pounds per square inch) are applied.[12] Yeast yields between 27 and 32 percent solids may be obtained by pressing.[12] Rotary vacuum filters are used for continuous feed of yeast cream. Generally, the filter drum is coated with yeast by rotating the drum in a trough of yeast cream or by spraying the yeast cream directly onto the drum. The filter surface is coated with potato starch containing some added salt to aid in drying the yeast product. The filter drum rotates at a rate of 15 to 22 revolutions per minute (rpm).[12] As the drum rotates, blades at the bottom of the drum remove the yeast. After a filter cake of yeast is formed and while the drum continues to rotate, excess salt is removed by spraying a small amount of water onto the filter cake. From this process, filter cakes containing approximately 33 percent solids are formed.

The filter cake is blended in ribbon mixers with small amounts of water, emulsifiers, and cutting oils. Emulsifiers are added to give the yeast a white, creamy appearance and to inhibit water-spotting of the yeast cakes. A small amount of oil,

usually soybean or cottonseed oil, is added to help extrude the yeast. The mixed press cake is then extruded through open-throated nozzles to form continuous ribbons of yeast cake. The ribbons are cut and the yeast cakes are wrapped with wax paper. The wrapped cakes are cooled to below 8°C (46°F), at which time they are ready for shipment in refrigerated trucks.

3.2.7 Production of Dry Yeast

In yeast manufacturing, two types of dry yeast are produced: (1) ADY and (2) IDY. Active dry yeast is produced from a yeast strain identified as No. 7752 in the American Type Culture Collection.[13] This strain gives better yields than that used in producing compressed yeast and is commonly referred to as the "dry yeast strain." Instant dry yeast is produced from a yeast strain different from that used for ADY. The ADY and IDY are produced through the same process as that described for compressed yeast. After filtration, the dry yeast product is sent to an extruder, where emulsifiers and oils different from those used for compressed yeast are added to texturize the yeast and aid in extruding the yeast. After the yeast is extruded in thin ribbons and cut, the yeast is dried in either a batch or a continuous drying system. Fluidized bed dryers can be used to dry the extruded yeast. The extruded yeast strands are fed into the drying chamber of a fluidized bed dryer. Heated air blown into the bottom of the dryer suspends the yeast particles into a fluid bed and dries them. The drying time varies from 0.5 to 4 hours (hr).[14] The humidity in the dryers is continuously monitored to determine when the drying cycle is complete. Following drying, the yeast is vacuum-packed or packed under nitrogen gas before heated sealing. The shelf life of ADY and IDY is 1 to 2 years at ambient temperature.[15]

4.0 EMISSION ESTIMATIONS

The following sections present a composite of the available emissions data, process emission factors, nationwide emissions estimates, and the documentation on the development of a model process emission stream.

4.1 SOURCES OF EMISSIONS

The VOC emissions are generated as by-products of the f mentation process. The two major by-products are ethanol, h is formed from acetaldehyde, and carbon dioxide. Other by-products consist of other alcohols and organic acids such as butanol, isopropyl alcohol, 2,3 butanediol, and acetate. These by-products form as a result of excess sugar present in the fermentor or an insufficient oxygen supply to the fermentor. Under these conditions, anaerobic fermentation occurs and results in the excess sugar being broken down to form alcohols and carbon dioxide. When anaerobic fermentation occurs, 2 moles of ethanol and 2 moles of carbon dioxide are formed from 1 mole of glucose.

Under anaerobic conditions, the ethanol yield is increased and yeast yields are decreased. In producing baker's yeast it is essential to suppress ethanol formation in the final fermentation stages by incremental feeding of the molasses mixture and by supplying sufficient oxygen to the fermentor.

The rate of ethanol formation is higher in the earlier ges (pure culture stages) than in the final stages of the mentation process. The earlier fermentation stages are batch fermentors, where excess sugars are present and less aeration is used during the fermentation process. These fermentations are not controlled to the degree that the final fermentations are controlled, because the majority of yeast growth occurs in the final fermentation stages and, therefore, there is no economical reason for equipping the earlier fermentation stages with the necessary process control equipment.

Another potential emission source is the wastewater treatment system used to treat process wastewaters. If the facility does not employ an anaerobic biological treatment system, significant quantities of VOC could be emitted from this stage of the process. For more information on wastewater treatment systems as an emission source of VOC's, please refer to an earlier CTC document on industrial wastewater treatment stems entitled "Industrial Wastewater Volatile Organic

Emissions--Background Information for BACT/LAER Determinations."[16]

4.2 EMISSION DATA AND PROCESS EMISSION FACTORS

Emission test data were received from three yeast manufacturing facilities.[17-21] From a combination of these three facilities, emission test data were available for the last four fermentation stages (F4-F7).

During the fermentation process, ethanol and acetaldehyde are not formed at constant rates; therefore, over the course of the fermentation, the concentrations of these compounds vary significantly depending upon the amount of excess sugars present and the combined effectiveness of the aeration and agitation systems to supply sufficient oxygen throughout the fermentor volume. A review of the emission test data showed that the VOC concentrations did vary significantly for each fermentation stage and between different fermentors at a given stage. This variation in emissions was expected between facilities because of the differences in the feed systems and the size of the fermentors. However, even within a given facility, the emission data vary from fermentor to fermentor because of the differences in the design of the air sparger system and the placement of baffles and mechanical agitators within the fermentors.

Table 3 presents the VOC emission levels measured during batch cycles for each type of fermentation. The emission test data were converted from total VOC concentrations to ethanol concentrations since ethanol is the primary VOC compound emitted. Ethanol is approximately 80 to 90 percent of the emissions generated, and the remaining 10 to 20 percent consists of other alcohols and acetaldehyde.

A review of the emission data in Table 3 reveals the significant variation in VOC emission levels. To obtain more meaningful data, the process emission factors presented in Table 3 were developed in an effort to normalize the fluctuations in emission data between facilities and fermentors. However, there was still a significant variation in the process emission factors. Upon reviewing process information obtained from these

TABLE 3. VOC EMISSIONS FROM YEAST FERMENTATION[17-21a]

	Fermentation stages		
	F4 (Intermediate)	F5/F6 (Stock/pitch)	F7 (Trade)
Emission profile			
Concentration range, ppmv	900-4,600	2-1,350	5-600
Average concentration, ppmv	1,900-2,400	50-700	200
Maximum concentration, ppmv	3,000-4,600	200-1,350	600
Batch emissions, kg (lb)	24-71 (53-156)	6-821 (13-1,810)	4.5-154 (10-340)
Process emission factors			
VOC's emitted per volume of fermentor operating capacity, kg/L (lb/gal)	0.0011-0.0014 (0.009-0.012)	0.0001-0.003 (0.0008-0.025)	0.000036-0.0006 (0.0003-0.005)
VOC's emitted per amount of yeast produced, kg/1,000 kg (lb/1,000 lb)	12-49 (12-49)	0.5-40 (0.5-40)	0.19-4.7 (0.19-4.7)

[a]Total VOC emissions as ethanol.

facilities, it was concluded that the low end of the data range is attributable to facilities that have implemented a greater degree of process control or have improved fermentor designs over those facilities that represent the high end of the data range. Therefore, the typical emission levels and process emission factors presented in Table 4 were developed to represent a typical facility with a moderate degree of process control. Based on process control information obtained from yeast facilities, it is believed that the majority of yeast manufacturing facilities fall within the emission ranges presented in Table 4.

The typical emission levels for each fermentation stage reveal the process control changes between fermentation stages. The intermediate stage (F4) that follows pure culture fermentations is either batch or fed-batch. The degree of process control is not as stringent for this type of fermentation as it is for trade fermentation because the yeast production output from this fermentor is not as critical as that from the final trade fermentation. As a result, the emission levels for the intermediate fermentation are much higher than those for the trade fermentation. However, total batch emissions from the intermediate fermentation stage are lower than those from the trade fermentation stage due to the smaller fermentors used and the lower production rate. The final three fermentations (F5-F7) are typically carried out in the same fermentors. The tighter process control measures used during these fermentations result in the lower emission levels.

The annual VOC emission rates presented in Table 4 were developed based on the batch emissions from each fermentor and the typical number of batches produced per year. As shown in Table 4, the majority of emissions are associated with trade fermentation as a result of the number of batches produced per year. Trade fermentations account for 80 to 90 percent of the emissions generated from a given facility.

TABLE 4. VOC EMISSIONS FOR A TYPICAL YEAST MANUFACTURING FACILITY[a]

	Fermentation stages		
	F4 (Intermediate)	F5/F6 (Stock/pitch)	F7 (Trade)
Typical ethanol emission levels			
Concentration range, ppmv	900-4,600	2-400	6-600
Average concentration, ppmv	1,900	200	250
Maximum concentration, ppmv	3,000-4,600	200-400	500-600
Batch emissions, kg (lb)	36.3 (80)	49.9 (110)	63.5 (140)
Typical process emission factors			
VOC's emitted per volume of fermentor operating capacity, kg/L (lb/gal)	0.0012 (0.010)	0.0004 (0.0035)	0.0005 (0.0045)
VOC's emitted per amount of yeast produced, kg/1,000 kg (lb/1,000 lb)	15 (15)	5.0 (5.0)	3.5 (3.5)
Operating time			
No. of batches per week	3	4	20
No. of weeks per year	52	52	52
Annual VOC emissions rate, Mg/yr (tons/yr)	5.6 (6.2)	8.5 (9.4)	66 (73)

[a]Total VOC's as ethanol.

4.3 NATIONWIDE EMISSION LEVELS

Based on the process emission factor of 0.0005 kilogram of VOC's emitted per liter per batch (0.0045 pound per gallon per batch) of fermentor operating capacity, the typical size (117,260 L [31,000 gal]) of trade fermentors, the number of batches processed per year (1,040) at each facility, and the number of yeast manufacturing facilities (13), the nationwide VOC emissions from manufacturing baker's yeast is estimated at 860 Mg/yr (950 tons/yr).

Based on the process emission factor of 0.0035 kilogram of VOC's emitted per kilogram (0.0035 pound per pound) of yeast produced and the current nationwide annual production of baker's yeast (220 million kilograms [490 million pounds]), the nationwide VOC emissions from yeast manufacturing is estimated at 780 Mg/yr (860 tons/yr).

4.4 MODEL EMISSION STREAM

A model emission stream was developed in order to evaluate control device performance at yeast manufacturing facilities. The model emission stream was developed based on the combined emission levels from five 117,260-L (31,000-gal) trade fermentors. Trade fermentation was selected because the majority of emissions are generated from this stage of the process. In addition, the majority of the final fermentations (F5-F7) are carried out in the same fermentors. Therefore, any control technique applied to the trade fermentors would also control emissions from the stock and pitching fermentation stages. Five 117,260-L (31,000-gal) trade fermentors were selected because this was the average number and capacity of trade fermentors at all yeast manufacturing facilities. Each trade fermentor was assumed to have an air flow rate of 159 m^3/min (5,600 ft^3/min), which was based on air flow rate data for actual trade fermentors. Therefore, the model emission stream has an air flow rate of 790 m^3/min (28,000 ft^3/min) and an average VOC concentration of 200 to 300 ppmv. The average VOC concentrations were determined based on the emission levels from actual trade

fermentors. An emission profile for this fermentation stage is presented in Figure 3.

5.0 EMISSION CONTROL TECHNIQUES

Only one yeast manufacturing facility employs an add-on pollution control system to reduce VOC emissions from the fermentation process. The pollution control system at this facility consists of a wet scrubber followed by a biological filter. However, all of the yeast manufacturers suppress ethanol formation through varying degrees of process control.

The process control measures consist of incrementally feeding the molasses mixture to the fermentors so that excess sugars are not present and of supplying sufficient oxygen to the fermentors to optimize the dissolved oxygen content of the liquid in the fermentation vessel. The following sections provide a more detailed discussion of the process control measures to reduce ethanol formation and provide information on the feasibility of implementing add-on control devices to reduce or eliminate ethanol emissions from yeast fermentation vessels.

5.1 COMPUTERIZED PROCESS CONTROL MEASURES

Traditionally, yeast manufacturing plants have implemented incremental feed systems on the final fermentation vessels in an effort to optimize yeast yields and suppress ethanol formation. However, these systems were established to add a given amount of molasses and nutrients over specified time intervals. This practice does reduce ethanol formation beyond that achieved under a total batch condition; however, it does not minimize ethanol formation to the highest degree possible. A greater degree of control can be achieved by implementing a continuous monitoring system.

Experimental studies have shown that the ethanol production rate is a function of the yeast growth rate, and both of these parameters are related to the residual sugar concentration.[22] It is therefore important that the actual sugar concentration in the fermentor be maintained at a low but optimal value at all times. In order to achieve this, the fermentation process must be continuously monitored with the aid of a computer to anticipate

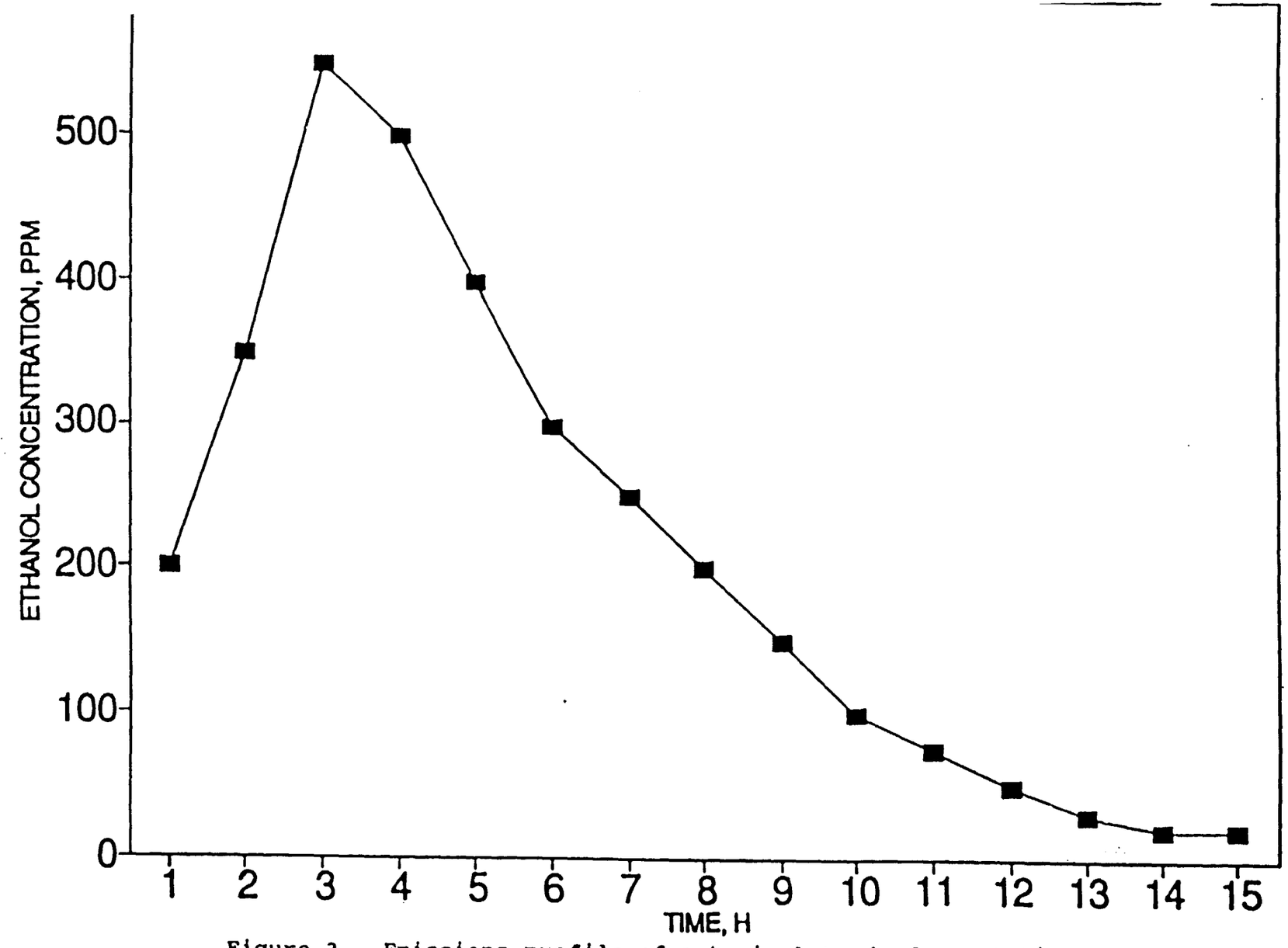


Figure 3. Emissions profile of a typical trade fermentation.

the precise demand for sugar. By continuously adding only the exact amount of molasses required by the fermentation, conditions excess sugar are eliminated, thus minimizing ethanol formation.

The demand for molasses depends on the cell concentration, specific growth rate, and cell yield. Since no sensors are available that can quickly and reliably give a direct measurement of cell mass, computer-aided material balance techniques can be used to calculate continuously the cell concentration, specific growth rate, sugar consumption rate, and other growth-related parameters.[22] A computer can process information taken from direct measurement of airflow, carbon dioxide production, oxygen consumption, and ethanol production to anticipate the demand for sugar by the system. The result is an indirect method for monitoring yeast production that is regulated by a computer. The computer continuously controls the addition of molasses, thereby achieving optimum productivity with minimal ethanol production. However, this type of process control system is extremely difficult to refine and implement because of the time delays between ethanol formation in the fermentor, its detection in the stack, and the computer adjustments to the feed rates.

Another process measure that can reduce ethanol formation is in the equipment design of the aeration and mechanical agitation systems installed in each fermentor. The distribution of oxygen by the air sparger system to the malt mixture is critical in minimizing ethanol formation. If oxygen is not being transferred uniformly throughout the malt, then ethanol will be produced in the oxygen-deficient areas of the fermentors. The type and position of baffles and/or a highly effective mechanical agitator in the fermentors also ensures proper distribution of oxygen throughout the malt mixture.

Facilities that are able to implement feed rate controls through stack gas monitoring and that have efficient aeration and mixing systems can optimize yeast production and suppress ethanol formation to the highest degree. Based on available emission test data, it is anticipated that a reduction of 75 to 95 percent

can be achieved through the combination of feedback controls and optimizing fermentor design.

ENGINEERING CONTROLS

The most common add-on control devices for controlling VOC emissions are wet scrubbers (gas absorbers), carbon adsorbers, incinerators, and condensers. These types of controls are widely used in a variety of industries to control VOC emissions. The following sections present a description of these control techniques, operating parameters that affect their performance, and the feasibility of implementing these controls to reduce ethanol emissions from yeast manufacturing processes. In addition to these traditional VOC controls, a section on biological filtration is also presented below. Biological filtration is a relatively new control technique for reducing VOC emissions, although the engineering concept has been used for over 50 years in treating process wastewaters.

5.2.1 Wet Scrubbers (Gas Absorption)

Wet scrubbers can control ethanol emissions from yeast fermentation vessels. In this type of system, the contaminant is absorbed in an absorbing liquid. Absorption techniques require large liquid surface areas for the incoming gas stream to make good contact with the absorber liquid. Good gas/liquid contact is increased by using hydraulic sprays, impingement trays, bubble cap trays, sieve trays, packing (modular and dump-type), grids, or a combination of devices to create a high liquid surface area while minimizing volume. These scrubbers can be divided into two types: (1) packed/tray towers or (2) spray towers.

Figure 4 presents a schematic of a packed tower. In packed/tray towers, the incoming gas stream enters the base of the scrubber and passes up through the trays or packing countercurrent to the absorbing liquid, which flows down through the packing or tray media. In the packing section of the scrubber, the contaminant in the gas stream is absorbed by the absorbing liquid, and the cleaned gas stream flows up and out the

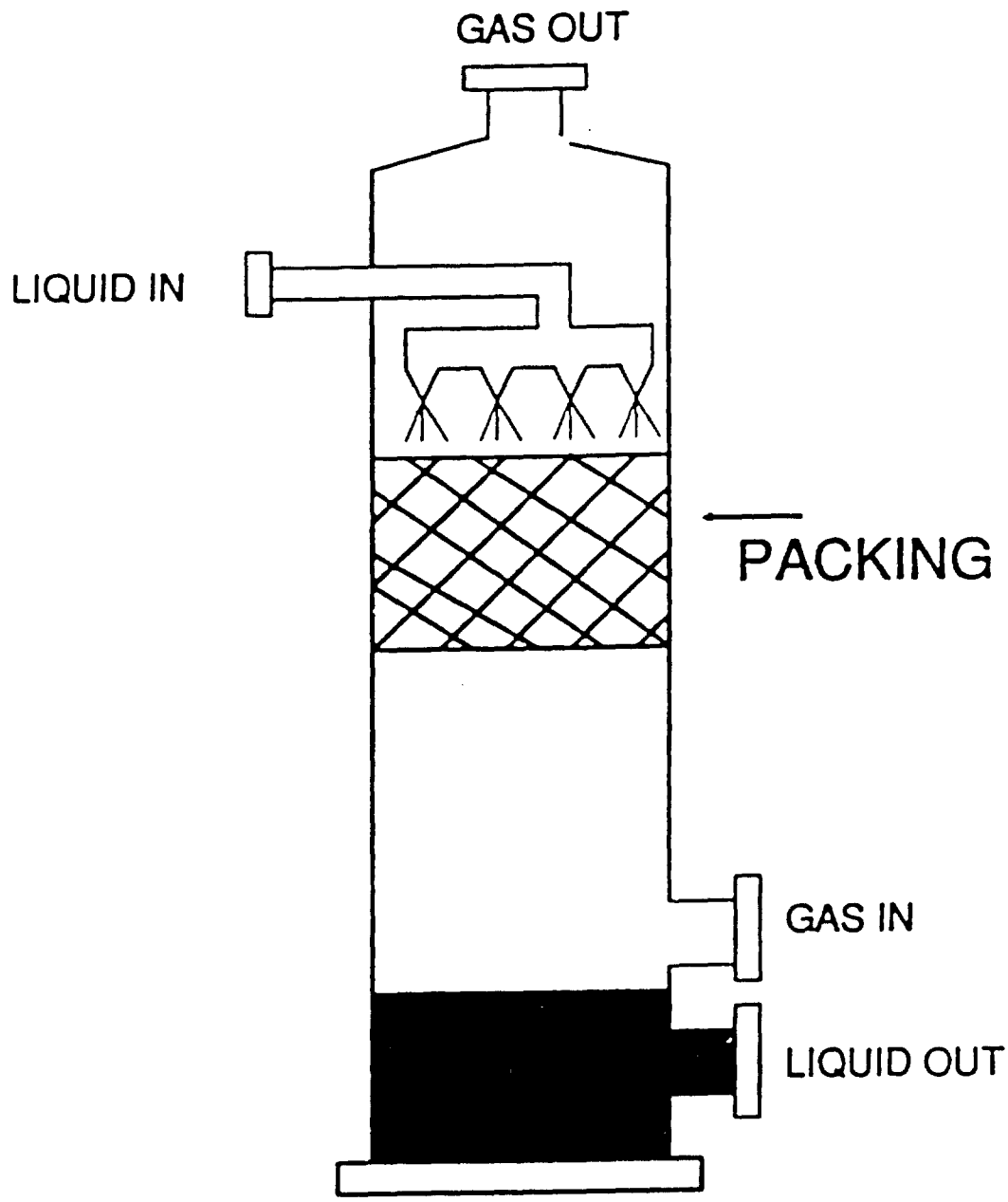


Figure 4. Schematic of packed tower absorber.

top of the unit. The absorbing liquid flows down and out the bottom of the unit.

In spray towers, the absorbing liquid used in the tower is sprayed countercurrent to the gas flow using high-pressure sprays to create a uniform distribution of very small droplets of the absorbent within the absorber. As in packed towers, the contaminated gas stream enters the base of the unit and flows up the tower, where it mixes with the liquid droplets in the unit. This mixing of the gas and liquid streams results in the contaminant's being absorbed by the liquid. The cleaned gas stream then flows up and out the top of the unit, and the liquid stream flows out the bottom of the unit.

Factors affecting the design and the performance of packed towers include the VOC concentration and temperature of the inlet gas stream, the type of absorbent used, the size and type of packing material or trays used, the liquid-to-gas ratio, the particulate loading, and the distribution of the liquid across the packing media. The first parameters given depend on the ocess being controlled. The next three parameters are design parameters for the unit and depend on the type and concentration of the contaminant to be removed. The contaminant must be highly soluble in the absorbent selected. The particulate loading also affects the performance of the scrubber: if the gas stream has a moderate-to-high particulate content, the packing media and spray nozzles will become clogged. Therefore, a filter needs to be placed before the absorber to remove any particulates in the gas stream prior to entry into the absorber. The distribution of liquid across the packing media is critical for adequate contact between the contaminated gas stream and the absorbing liquid.

For spray towers, the factors affecting performance are the concentration and temperature of the inlet gas stream, the type of absorbent selected, the liquid-to-gas ratio, the particulate loading, and the uniform distribution and droplet size of the absorber liquid. The first four factors are the same as those r packed towers and affect the design of the unit in a similar manner. The last two parameters are very important because if

the absorbing liquid is not distributed uniformly across the absorber volume and the droplet sizes are too large, the performance level of the absorber will be adversely affected.

Applying wet scrubbers to control VOC emissions from yeast manufacturing is feasible because both ethanol and acetaldehyde are extremely soluble in water. Using water as the absorbing liquid, a control device efficiency of better than 90 percent can be achieved. The only adverse factor associated with using a scrubber system is the amount of wastewater generated from the scrubber system and its associated treatment. The wastewater treatment procedure used to treat scrubber effluent should be an anaerobic treatment system that prevents or minimizes VOC emissions from the treatment process. If this type of treatment system is not used, then the VOC emissions may not be reduced but transferred to a different source at the plant site.

5.2.2 Carbon Adsorption

Carbon adsorption has been used for the last 50 years by many industries to recover a wide variety of solvents from solvent-laden air streams.[23] Carbon adsorbers reduce VOC emissions by adsorbing organic compounds onto the surface of activated carbon. The high surface-to-volume ratio of activated carbon and its preferential affinity for organics make it an effective adsorbent of VOC's.[23] The organic compounds are subsequently desorbed from the activated carbon and recovered.

Carbon adsorbers do not apply to the low-VOC-concentration gas streams from the final fermentation because of the low adsorbtivity of ethanol at levels less than 500 ppmv. In addition, one carbon adsorber vendor stated that the acetaldehyde present in the gas stream is very reactive with the carbon and would break down the carbon, resulting in low VOC removal efficiencies.[24] Therefore, carbon adsorption was not considered to be a viable control option for yeast manufacturing facilities.

5.2.3 Incineration

Incineration is the oxidation of organic compounds by exposing the gas stream to high temperatures in the presence of oxygen and sometimes a catalyst. Carbon dioxide and water are

the oxidation products. Incineration is often used in industries when solvent recovery is not economically feasible or practical such as at small plants or at plants using a variety of solvent mixtures.[25] The two types of incinerators used to control VOC emission are thermal and catalytic. Both designs may use primary or secondary heat recovery to reduce energy consumption.

5.2.3.1 Thermal incinerators. Thermal incinerators are usually refractory-lined oxidation chambers with a burner located at one end. In these units, part of the solvent-laden air is passed through the burner along with an auxiliary fuel. The gases exiting the burner that are blended with the by-passed solvent-laden air raise the temperature of the mixture to the point where the organics are oxidized. With most solvents, oxidization occurs in less than 0.75 second at a temperature of 870°C (1600°F).[26]

The interrelated factors important in incinerator design and operation include:

1. Type and concentration of VOC's;
2. Solvent-laden airflow rate;
3. Solvent-laden air temperature at incinerator inlet;
4. Burner type;
5. Efficiency of flame contact (mixing);
6. Residence time;
7. Auxiliary fuel firing rate;
8. Amount of excess air;
9. Firebox temperature; and
10. Preheat temperature.

The first three parameters are characteristics of the fermentation process. The next three parameters are characteristics of the design of the incinerator. The auxiliary fuel firing rate is determined by the type and concentration of VOC's, the solvent-laden airflow rate, the firebox temperature, and the preheat temperature. The auxiliary fuel firing rate, the amount of excess air, the firebox temperature and the preheat temperature are operating variables that may affect the performance of the incinerator. Well-designed and -operated

incinerators in industry have achieved VOC destruction efficiencies of 98 percent or better.[25]

Applying thermal incinerators to reduce VOC emissions from the fermentation process should result in destruction efficiencies of better than 98 percent. The costs associated with operating a thermal incinerator are presented in Section 5.3.

5.2.3.2 Catalytic incinerators. Catalytic incinerators use a catalyst to promote the combustion of VOC's. The solvent-laden air is preheated by a burner or heat exchanger and then brought into contact with the catalyst bed, where oxidation occurs. Common catalysts used are platinum or other noble metals on supporting alumina pellets or ceramic honeycomb. Catalytic incinerators can achieve destruction efficiencies similar to those of thermal incinerators while operating at lower temperatures, i.e., 315° to 430°C (600° to 800°F). Thus, catalytic incinerators can operate with significantly lower energy costs than can thermal incinerators that do not practice significant heat recovery.[26] The materials of construction may also be less expensive because of the lower operating temperatures.

Factors important in designing and operating catalytic incinerators include the factors affecting thermal incinerators as well as the operating temperature range of the catalyst and the presence of constituents in the gas stream that could foul the catalyst. The operating temperature range for the catalyst sets the upper VOC concentration that can be incinerated. For most catalysts on alumina, catalyst activity is severely reduced by exposure to temperatures greater than 700°C (1300°F).[26] Consequently, the heating value of the inlet stream must be limited. Typically, inlet VOC concentrations must be less than 25 percent of the lower explosive limit (LEL). The typical VOC concentrations emitted from yeast manufacturing facilities are less than 25 percent of the LEL.

As with thermal incinerators, catalytic incinerators are a viable control option for reducing VOC emissions from the

fermentation process, having typical destruction efficiencies greater than 98 percent. The costs associated with operating catalytic incinerators are presented in Section 5.3.

5.2.4 Condensation

Condensation is a process in which all or some portion of the volatile components in the vapor phase are transformed into the liquid phase. This process can be accomplished through several different methods. Increasing the system pressure at a constant temperature, reducing the temperature, or a combination of increasing pressure and reducing temperature are possible methods. However, the most widely used condensation method is decreasing the temperature at a constant pressure.

In a two-component vapor stream, where one of the components is noncondensable, condensation occurs when the partial pressure of the condensable component becomes equal to the component's vapor pressure. At these conditions, the liquid begins to form. As the temperature of the stream is further reduced, condensation continues until the partial pressure of the vapor is equal to the vapor pressure of the liquid phase at the lower temperature. The amount of the compound that can remain as a vapor at a given temperature is directly related to the volatility of the compound. The more volatile the compound, the greater the amount that will remain as a vapor. The type of coolant needed for the condensation process depends on the temperature required for condensation to occur.

Condensers are most effective on streams that are saturated or nearly saturated with condensable VOC. When a gas stream is dilute, as is the case with baker's yeast manufacturing, extensive cooling is required just to bring the stream to the saturation point. Furthermore, additional cooling is then needed to actually condense the VOC. Condensers are not effective on gas streams that contain low-boiling-point VOC's (i.e., highly volatile compounds) or for gas streams that have a high flow rate of noncondensables, such as carbon dioxide, nitrogen, or air. The VOC's with low boiling points exert a high vapor pressure and hence are more difficult to condense totally under normal

condenser operating conditions. High flow rates of noncondensable gases in the stream dilute the stream and reduce condenser efficiency by increasing the heat load that must be removed from the gas stream.

There are two major types of condensers: surface condensers and contact condensers. Surface condensers are usually shell and tube heat exchangers. The coolant flows through the tube, and the vapor condenses on the outside, or shell-side, of the tube. The condensate forms a film or masses of droplets on the tube and drains into a collection tank for storage or disposal. Surface condensers usually require more auxiliary equipment than contact condensers, but solvent recovery is possible since the coolant and the condensate are kept separate. Also, the coolant cannot become contaminated in a surface condenser. Equipment typically needed for surface condensers includes dehumidification equipment, a shell-and-tube heat exchanger, a refrigeration unit, a recovery tank for the condensate, and a pump to discharge recovered VOC to storage or disposal.

Contact condensers cool the vapor by spraying a liquid, usually at ambient temperature or slightly chilled, into the gas stream. The result is intimate mixing of the gas stream and the cooling medium. In some instances, contact condensers act as scrubbers in that they collect noncondensables that are miscible with the cooling medium. Contact condensers are simple in design and relatively inexpensive to install. Although contact condensers have advantages, their application is limited because, like wet scrubbers, the VOC-contaminated coolant cannot normally be reused directly.

The most obvious area to use condensers in the baker's yeast manufacturing process is during the early stages of yeast growth (pure culture stages). In these early stages, the concentration of ethanol is expected to be at its highest and the airflow rates are lowest. Although no emissions test data were available, information supplied from yeast manufacturing facilities indicates that the airflow rate from pure culture fermentation is typically 10 m^3/min (400 ft^3/min) with an average VOC

concentration of 5,000 to 10,000 ppmv. At these levels, condensers should achieve better than 90 percent emission reduction at condensation temperatures below -40°C (-40°F).

5.2.5 Biological Filtration

Figure 5 presents a simplified schematic of a biofiltration system. A biological filter is basically a compost bed that has been inoculated with aerobic microorganisms. The filter eliminates VOC emissions by passing the VOC-laden gas stream through the compost bed. As the gas stream passes through the bed, the contaminants are removed through adsorption, absorption, and chemical degradation. Portions of the contaminants are adsorbed by the compost material while others are absorbed by the water in the bed. These contaminants are then metabolized by the microorganisms and are converted to carbon dioxide and water. Ethanol conversion, in the case of yeast fermentation, is accomplished in two stages. First, one type of microorganism consumes the alcohol and converts it to organic acids. In the second stage, another microorganism converts the organic acids into carbon dioxide and water. A delicate balance between the two microorganisms must be maintained to ensure proper operation of the biological filters. After the gas stream passes through the bed, the cleaned gas is vented out stacks located at the top of the filtration unit. Volatile organic compound efficiencies of better than 90 percent have been obtained when biofiltration units have been installed to control emissions from yeast fermentation vessels.[27]

The critical parameters for a biofiltration system are the VOC concentration in the inlet gas stream, the pH and moisture content of the bed, and the bed temperature. The bed temperature must be maintained above 10°C (50°F) or the microorganisms in the compost will become dormant. The pH and moisture content of the bed should be in the range of 6.5 to 7.0 and 65 to 70 percent, respectively. Water spray lines are located at the top of the biofiltration unit to help maintain the moisture content at the appropriate level. The inlet VOC concentration is also critical to the performance of the biofiltration system. The

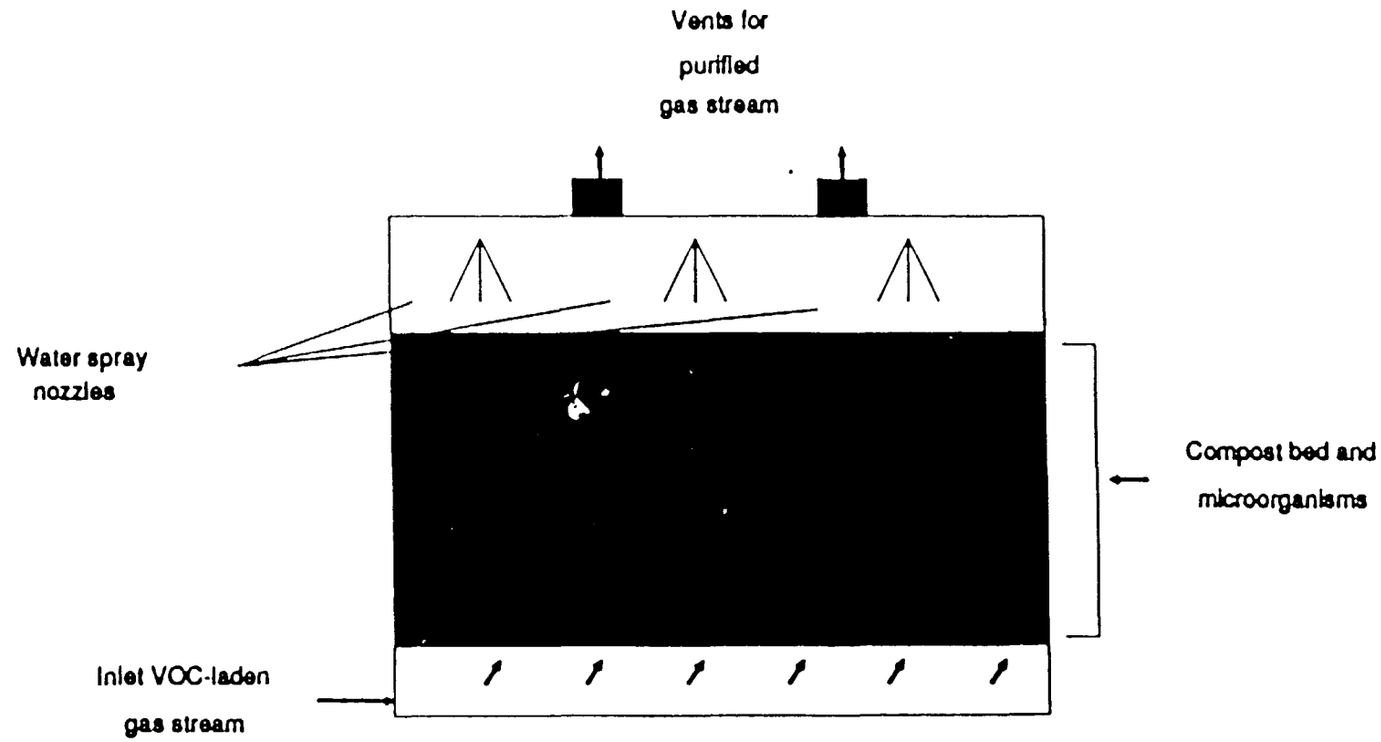


Figure 5. Schematic of a biofiltration system.

biofiltration system is designed to handle dilute VOC streams with fixed concentrations. Fluctuations in the concentration or high VOC concentrations result in an imbalance between the two controlling microorganisms. The microorganism that converts alcohols to organic acids assimilates the alcohols at a rate that decreases the pH of the bed, making the bed acidic. A low pH will kill the other type of microorganism, the bed will no longer operate efficiently, and incomplete conversion of the alcohols will occur. For this reason, biofiltration systems were not designed for batch processes but for continuous, dilute VOC streams. However, a control system (i.e., wet scrubber) located upstream of the biofiltration system that could control the peak concentration levels would result in a fairly constant dilute VOC stream to the biofiltration system. This combination of a scrubber plus a biofiltration system would be a practical approach to controlling emissions from a batch process.

5.3 IMPACT ASSESSMENT OF CONTROL OPTIONS

Based on the technical evaluation of traditional add-on VOC control techniques, the most promising options for controlling VOC emissions from the final fermentations appear to be wet scrubbers, thermal incinerators, and catalytic incinerators. Therefore, these control systems were evaluated further to determine their associated cost and environmental impacts. The impacts of the control options were determined based on the effectiveness of the control systems to handle the model emission stream presented in Section 4.4.

Table 5 summarizes the cost and environmental impacts of each control system. To determine the cost impacts of the control options, cost algorithms were developed based on standard EPA methods.[28,29] Tables 6 and 7 give details of the annual and capital costs associated with each control device. The environmental impacts were derived as a function of the design and size of the control system. As shown in Table 5, catalytic incinerators appear to be the most cost-effective control system for this application.

TABLE 5. SUMMARY OF THE COST AND ENVIRONMENTAL IMPACTS OF THE CONTROL OPTIONS

Control technique	Capital cost, $	Annual cost, $/yr	VOC emissions reduction, Mg/yr (tons/yr)[a]	Cost-effectiveness, $/Mg ($/ton)	Energy use MWh/yr[b]	Wastewater generated, L/yr (gal/yr)	Fuel requirements, kcal/yr (Btu/yr)[c]
Wet scrubbers[d]	312,000	346,000	80 (88)	4,300 (3,900)	257	4.12×10^8 (1.09×10^8)[e]	--
Thermal incinerators[f]	610,000	519,000	89 (98)	5,800 (5,300)	450	--	2.42×10^{10} (9.59×10^{10})
Catalytic incinerators[f]	883,000	294,000	89 (98)	3,300 (3,000)	494	--	2.50×10^9 (9.92×10^9)

[a]Based on the emissions reduction at the average VOC concentration in the emission stream.
[b]Based on total electrical requirements for the control systems.
[c]Based on using natural gas as the auxiliary fuel.
[d]Based on a control efficiency of 95 percent.
[e]Based on the use of once-through scrubber water.
[f]Based on a destruction efficiency of 98 percent.

TABLE 6. CAPITAL COSTS OF ADD-ON CONTROL OPTIONS[a]

Cost item	Factor	Cost, $		
		Thermal regen. incinerator	Catalytic incinerator	Wet scrubber
Direct costs, DC				
Purchased equipment costs				
Control device		286,840	426,350	34,340
Auxiliary equipment[b]		34,000	38,190	130,020
Subtotal, A		320,840	464,540	164,360
Instrumentation	0.1A*	32,080	46,450	16,440
Sales taxes	0.03A*	9,630	13,940	4,930
Freight	0.05A*	16,040	23,230	8,220
Total purchased equipment cost, B		378,590	548,150	193,940
Direct installation cost, C [Foundation and supports, handling and erection, electrical, piping, insulation, and painting]	0.30B*	113,580	164,450	58,180
Indirect costs (installation), IC [Engineering, construction and field expenses, contractor fees, start-up, performance test, and contingencies]	0.31B*	117,360	169,930	60,120
TOTAL CAPITAL INVESTMENT, TCI[c]	Sum of B, C, IC	609,500	882,500	312,200

[a]Numbers may not add exactly due to independent rounding.
[b]For incineration, auxiliary equipment consists of ductwork, stack, and fan. For wet scrubbers, auxiliary equipment consists of ductwork, stack, fan, pump, platform and ladders, and packing.
[c]Rounded to nearest $100.

*Source: OAQPS Control Cost Manual. Fourth Edition. EPA 450/3-90-006. January 1990. Chapter 3.

TABLE 7. ANNUAL COSTS OF ADD-ON CONTROL OPTIONS[a]

Cost item	Factor	Unit cost	Thermal regen. incinerator	Catalytic incinerator	Wet scrubber
st annual costs, DAC					
Operator labor					
Operator	0.5 hr/shift*	12.96/hr*	3,590	3,590	3,290
Supervisor	15% of operator*		540	540	490
Maintenance					
Labor	0.5 hr/shift*	$14.26/hr*	3,950	3,950	3,620
Material	100% of maintenance labor*		3,950	3,950	3,620
Catalyst replacement	100% catalyst (2-yr life)*	$650/ft^3 for metal oxide*	–	42,220	–
Waste disposal		$2/1,000 gal**	–	–	217,650
Utilities					
Water		$0.3/1,000 gal**	–	–	32,650
Natural gas		$3.30/1,000 ft^3*	349,280	32,050	–
Electricity		$0.059/kWh*	26,570	29,190	15,190
TOTAL DAC			387,870	115,480	276,510
Indirect annual costs, IAC					
Overhead	60% of sum of operator, supervisor, labor, and materials*		7,210	7,210	6,610
Administration	2% TCI[b]*		12,190	17,650	6,250
Property taxes	1% TCI*		6,100	8,830	3,120
Insurance	1% TCI*		6,100	8,830	3,120
Capital recovery[c]	CRF (TCI)*		99,200	136,210	50,820
TOTAL IAC			130,790	178,720	69,920
TOTAL ANNUAL COST	Sum of DAC, IAC		518,700	294,200	346,400

[a]Numbers may not add exactly due to independent rounding.
[b]Total capital investment.
[c]The capital recovery cost factor, CRF, is equal to 0.163 for a 10-year equipment life and a 10 percent interest rate. For catalytic incineration, capital recovery is equal to 0.163(TCI-1.08 x catalyst replacement).

*Source: OAQPS Control Cost Manual. Fourth Edition. EPA 450/3-90-006. January 1990. Chapter 3.
**Source: Organic Chemical Manufacturing Volume 5: Adsorption, Condensation, and Absorption Devices. EPA Report No. 450/3-80-027. December 1980. Appendix B.

The cost of control could be reduced further, however, by the use of a combination of control systems. A process using a wet scrubber followed by an incinerator or a biological filter could be conceptualized with the expectation that the annual cost would be reduced. The water from the scrubber would not be considered "wastewater" but would be recycled within the process and used to continually generate an emission stream with a constant concentration of ethanol at a reduced air volume. The generation of a low-volume constant ethanol concentration stream would allow the use of a smaller incinerator system or the use of a biological filtration system, which could conceivably result in lower control costs. Because of the complexity of such a system and the need to consider plant specific conditions, a cost analysis is not included in this report.

In addition, impacts for condensers were also evaluated based on the control of emissions from the pure culture fermentations. Table 8 gives details on the costing associated with using condensers for controlling emissions from the pure culture fermentors. These costs were developed based on a typical airflow rate from pure culture fermentation of 10 m^3/min (400 ft^3/min) at a VOC concentration of 7,500 ppmv. Based on a 95 percent control requirement, the condensation temperature of the condenser would be -47°C (-53°F). The capital cost per fermentor is estimated at $250,000. The annual operating cost is estimated at $111,000/yr. Based on an emission reduction of 27 Mg/yr (29 tons/yr), the average cost-effectiveness for condensers is $4,200/Mg ($3,800/ton).

6.0 CONCLUSIONS

The typical yeast manufacturing facility emits approximately 82 Mg/yr (90 tons/yr) of VOC emissions. The primary constituents in the emission stream are ethanol and acetaldehyde, with ethanol comprising approximately 80 to 90 percent of the emissions and acetaldehyde comprising the remaining 10 to 20 percent of emissions. The primary emission sources are the final trade fermentations, which account for 80 to 90 percent of the total facility emissions.

TABLE 8. COSTS FOR CONDENSER CONTROL OPTION[a]

Cost item	Factor	Unit cost	Cost, $
Refrigeration cost, Ref			91,840
Total systems cost, TSC	1.25 (Ref)*		114,800
TOTAL CAPITAL INVESTMENT, TCI	2.18 (TSC)		249,700
Direct annual costs, DAC			
Labor			
Operator	0.5 hr/shift*	$15.64/hr*	8,560
Supervisor	1.15 (operator)*		9,850
Maintenance			
Labor	0.5 hr/shift*	$17.21/hr*	9,420
Materials	100% of labor*		9,420
Electricity	$0.059/kwh*		8,560
TOTAL DAC			45,810
Indirect annual costs, IAC			
Overhead	60% of sum of operator and supervisor labor, and maintenance labor and materials*		22,350
Administration, taxes, insurance	0.04 (TCI)*		9,990
Capital recovery[b]	CRF (TCI)*		32,840
TOTAL IAC			65,180
TOTAL ANNUAL COSTS	Sum of DAC, IAC		111,000

[a]Numbers may not add exactly due to independent rounding.
[b]The capital recovery cost factor, CRF, is equal to 0.1315.

*Source: OAQPS Control Cost Manual. Fourth Edition. EPA 450/3-90-006. January 1990. Draft Chapter.

The two types of control measures that are currently employed at yeast manufacturing facilities are (1) process control and (2) add-on controls. The majority of yeast manufacturers use a moderate degree of process control in the final fermentation stages to reduce ethanol formation. However, these process control measures can be enhanced by implementing computer-based feed rate controls and improving fermentor designs. Implementing a computer-based feed rate control system and improved fermentor design can potentially suppress ethanol formation by 75 to 95 percent.

One yeast manufacturer has applied a combination wet scrubber and biofiltration system for controlling VOC emissions. Performance data from this unit suggests an emission control efficiency of better than 90 percent.[27] Other add-on control techniques that could potentially be applied to the yeast fermentation process are incinerators. The control technology evaluation suggests that a catalytic incinerator is the most cost-effective approach for reducing VOC emissions, if the use of a single control device is applied to the emission stream. However, a combination system such as that described above or a combination of a wet scrubber and incinerator could result in lower control costs and relatively equivalent emission reductions.

At present, no process control measures or add-on pollution control systems are currently being used to reduce VOC emissions from the pure culture fermentations. However, based on the information supplied by yeast manufacturing facilities, it appears that adding process control measures to the pure culture fermentations or applying condensers could potentially reduce VOC emissions from this stage of the process by better than 90 percent.

7.0 REFERENCES

1. Clean Air-Ozone. Press release, Associated Press. May 3, 1988.

2. Chen, S. L., and M. Chiger. Production of Baker's Yeast. Comprehensive Biotechnology. Vol. 20. NY, Pergamon Press. p. 430.

3. Reed, G., and H. Peppler. Yeast Technology. Wesport, CT, Avi Publishing Company. 1973. pp. 54-55.

4. Reference 2, p. 433.

5. Reference 3, p. 58.

6. Reference 3, pp. 57-58.

7. Reference 3, p. 60.

8. Reference 2, pp. 441-442.

9. Reference 2, p. 442.

10. Reference 2, pp. 74-75.

11. Reference 2, p. 80.

12. Reference 2, p. 84-85.

13. Reference 2, p. 90.

14. Reference 2, p. 91-92.

15. Reference 2, p. 96.

16. Industrial Wastewater Volatile Organic Emissions--Background Information for BACT/LAER Determinations. Control Technology Center. U. S. Environmental Protection Agency, Research Triangle Park, NC. EPA No. 450/3-90-004. January 1990.

17. Fermentor Emissions Test Report. Universal Foods Corporation, Baltimore, MD. Prepared by Gannett Fleming, Inc., Baltimore, MD. October 1990.

18. Fermentor Emissions Test Report. Gist-brocades Food Ingredients, Inc., East Brunswick, NJ. Prepared by Trace Technologies, Inc., Bridgewater, NJ. April 1989.

19. Fermentor Emissions Test Report. American Yeast, Baltimore, MD. Prepared by Gannett Fleming, Inc., Baltimore, MD. August 1990.

20. Fermentor Emissions Test Report. Universal Foods, Inc., Baltimore, MD. Prepared by Universal Foods, Inc., Milwaukee, WI. 1990.

21. Fermentor Emissions Test Report. Universal Foods, Inc., Baltimore, MD. Prepared by Environmental Technology and Engineering Corporation, Elm Grove, WI. May 1989.

22. Wang, H. Y., et al. Computer Control of Baker's Yeast Production. Biotechnology and Bioengineering, Volume 21. 1979. pp. 975-995.

23. U. S. Environmental Protection Agency. Polymeric Coating of Supporting Substrates - Background Information for Proposed Standards. EPA-450/3-85-022a. Research Triangle Park, NC. April 1987. p. 4-10.

24. Telecon. Hale, C., MRI, to Wersal, D., VIC Manufacturing, Minneapolis, MN. September 3, 1990. Information regarding the use of carbon adsorbers for controlling VOC emissions from yeast fermentation processes.

25. Reference 23, p. 4-30.

26. Reference 23, p. 4-31.

27. Memo from Barker, R., and M. Williamson, MRI, to Smith, M., ESD/CPB. Trip report for Gist-brocades, East Brunswick, NJ. August 1991.

28. Control Technologies for Hazardous Air Pollutants. U. S. Environmental Protection Agency, Research Triangle Park, NC. EPA/625/6-86/014. September 1986.

29. OAQPS Control Cost Manual. U. S. Environmental Protection Agency, Research Triangle Park, NC. EPA 450/3-90-006. January 1990.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 450/3-91-027	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE ssment of VOC Emissions and Their Control m Baker's Yeast Manufacturing Facilities		5. REPORT DATE January 1992
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robin Barker and Maresa Williamson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 401 Harrison Oaks Boulevard Suite 350 Cary, NC 27513		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-0115
12. SPONSORING AGENCY NAME AND ADDRESS Control Technology Center U. S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Environmental Protection Agency's (EPA's) Control Technology Center (CTC) conducted a study to obtain information on the baker's yeast manufacturing industry. Baker's yeast is produced by a fermentation process that generates ge quantities of ethanol and acetaldehyde. Currently, 13 facilities produce er's yeast in the United States. The volatile organic compound (VOC) emission rate from a typical facility is estimated at 82 megagrams per year (90 tons per year). The majority of these emissions occurs in the final trade fermentations. The VOC emission alternatives that were evaluated during this study were process control measures to reduce the formation of VOC emissions as well as wet scrubbers, carbon adsorbers, incinerators, condensers, and biological filters to control VOC emissions. Of these approaches, it appears that process control measures, catalytic incinerators, or a combination of add-on control techniques (e.g., wet scrubbers followed by an incinerator or a biological filter) are the most feasible approaches for controlling yeast process emissions. Based on the results of this study, the control efficiency associated with the add-on control systems is estimated to be 95 to 98 percent. This report contains information on the baker's yeast fermentation process, the number and locations of yeast plants, the potential emissions from the process, and an evaluation of potential emission control options.

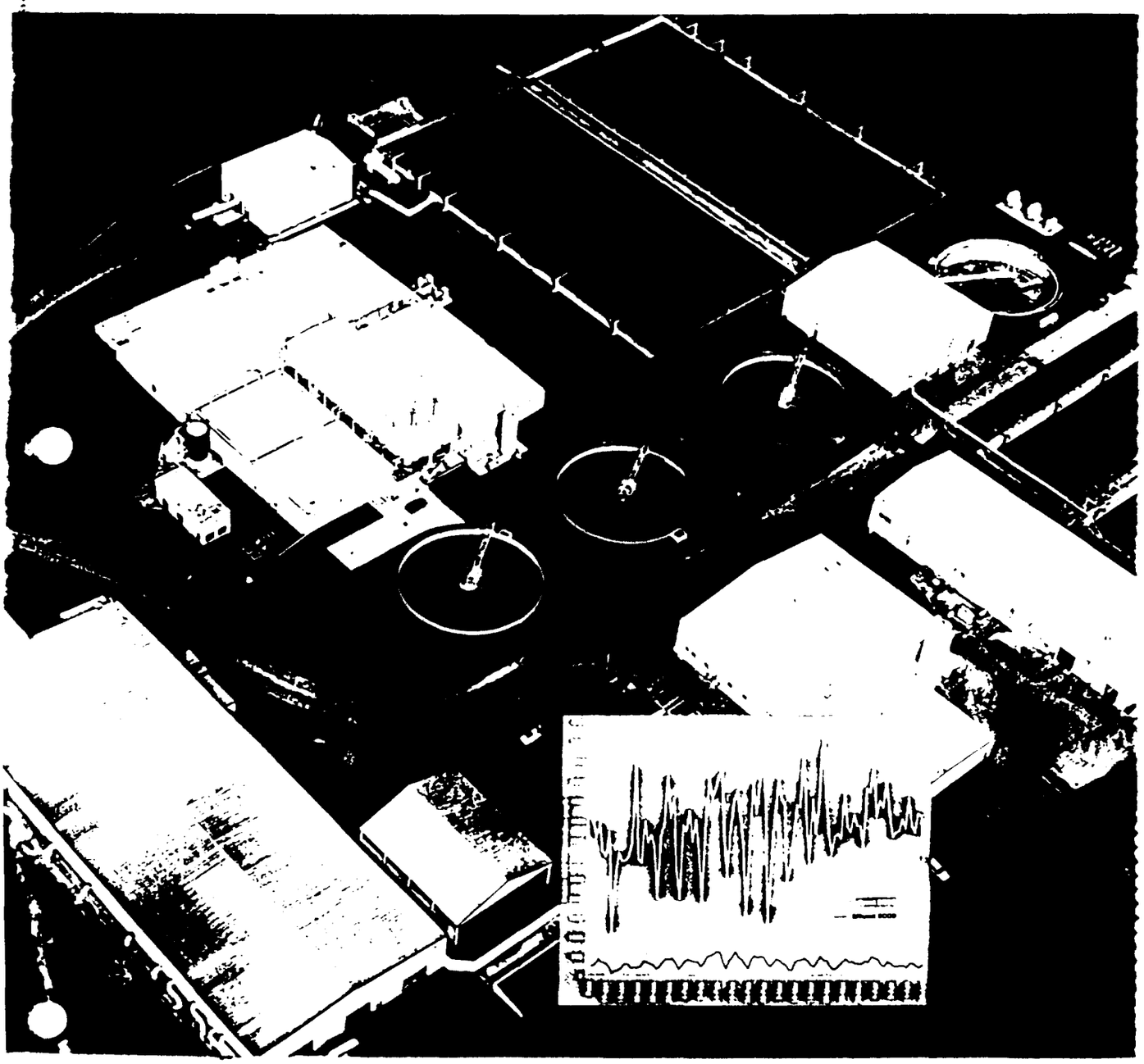
17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Baker's yeast	yeast manufacturing		
yeast	ethanol		
fermentation	acetaldehyde		
active dry yeast	VOC emissions		
compressed yeast	VOC controls		
cream yeast	process control		
ant dry yeast	biological filtration		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 53
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

Biothane®

ANAEROBIC WASTEWATER TREATMENT PROCESS



proven technology
for a cleaner environment

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/l 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.

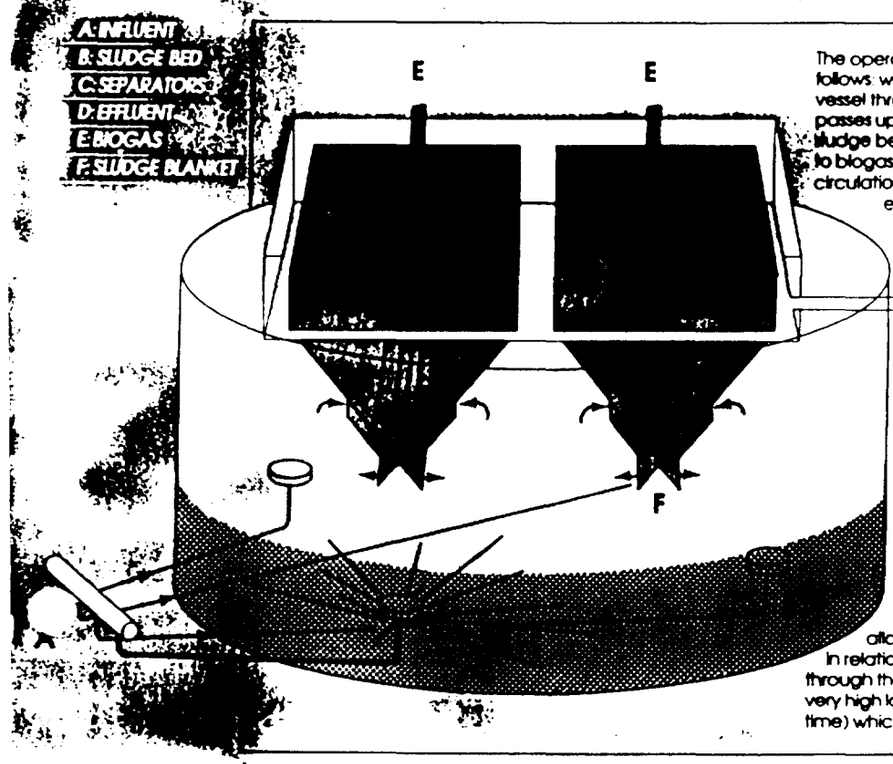
Biothane®

biothane... *still* the world leader in industrial anaerobic technology

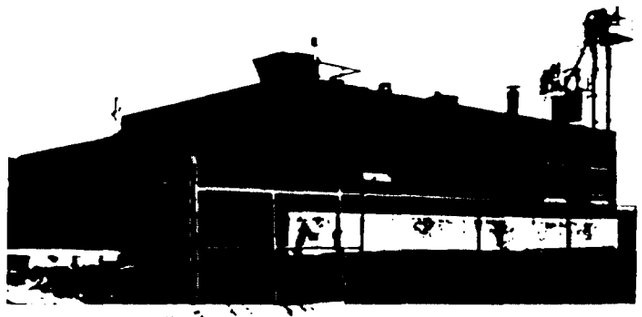
The Biothane anaerobic wastewater treatment process is available in the United States and Canada exclusively from Biothane Corporation of Camden, New Jersey, which owns the patent rights to the technology world wide. This unique biological process is an outgrowth of years of research and development work which originated in the Netherlands and continues 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 topworks has enabled it to evolve into the state-of-the-art technology for the treatment of wastewaters from a wide variety of food and related industries.

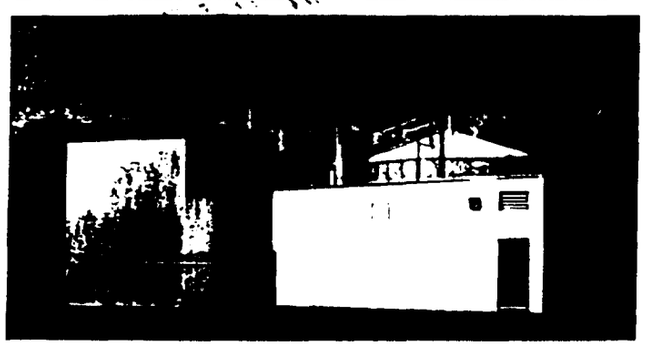
The special interior design for separation of the gas, liquid and solid phases is a critical feature which enables the sludge particles to settle and be retained within the digester while allowing for very rapid hydraulic throughput. The short hydraulic retention time creates conditions that encourage the development of the remarkable granular sludge which characterizes the Biothane process. Effective contact between biomass and wastewater is generated by gas formation in the sludge bed and occurs without the expenditure of costly mechanical or hydraulic energy input. Since there are no moving parts in the digester, the process is easy to maintain and operate.

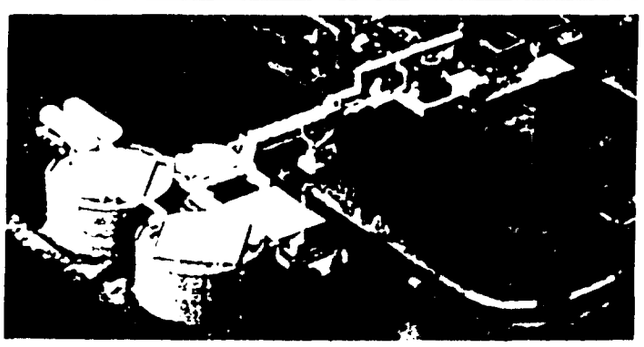
The performance of the Biothane process is unparalleled. More than 100 Biothane systems are in operation on six continents in a wide cross-section of industrial applications. Loadings of 10 to 18 Kg COD per cubic meter (600 to 11,000 lb COD per 1000 cubic feet) of digester volume are routinely achieved in most cases, often within only six to eight weeks following system start-up. BOD removal efficiencies of 90% or more are achieved in most applications. Recovery of biogas exceptionally rich in methane content (70-85%) contributes to the system economy. The process has shown itself to be resistant to upset within a wide range of imposed conditions, and the biomass has demonstrated extensive storage stability. The dependable Biothane process offers the timely combination of wastewater purification and supplemental energy production to meet the challenge of today's environmental problems.

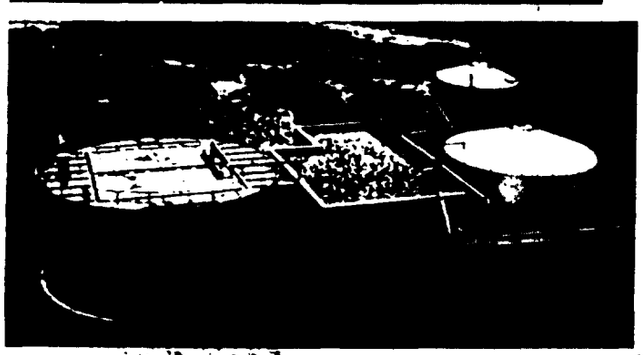


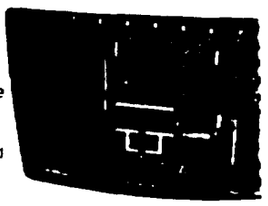
The operating principle of the Biothane process is as follows: wastewater enters the bottom of the digester vessel through the inlet distribution system **A** and passes upwards through the dense anaerobic sludge bed **B**. Soluble COD is rapidly converted to biogas rich in methane content and an upward circulation of water and gasborne sludge is established. The specially constructed settler sections **C** allow effective degasification to occur. The dense, granular sludge particles, now devoid of attached gas bubbles, sink back to the bottom establishing a return downwards circulation. The treated effluent flows over a weir at the top of the settlers into collection channels for discharge **D** while the directly combustible biogas is recovered from the collection pockets **E**. The upward flow of gasborne sludge through the blanket **F** in combination with the return downward flow of degassed sludge creates continuous convection and insures effective sludge to wastewater contact without the need for any energy-consuming mechanical or hydraulic agitation within the digester vessel. The unique design of the digester allows a highly active biomass concentration in relation to soluble organic solids passing through the sludge bed and is responsible for the very high loading rate (short hydraulic retention time) which can be achieved routinely.











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.

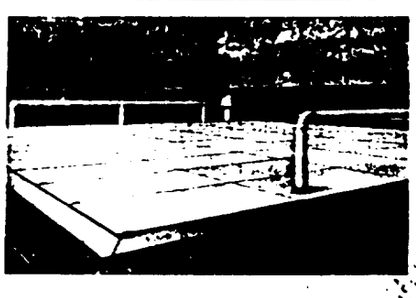
#3 The twin 2500 m³ digesters at Eagle Yeast each treat 26,000 kg/d of COD contained in a flow of 0.3 MGD. This New Jersey facility utilizes the generated biogas to supply a majority of the energy required in the manufacturing of its baker's yeast product. The system has been in operation since 1985 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.

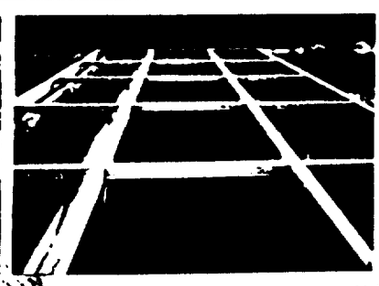
#4 The Biothane process offers significant energy savings compared to aerobic treatment systems. The generation of combustible biogas rich in methane can be utilized by the production facility, and the simple, space-efficient process hydraulics and controls require minimal horsepower to operate and can 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 efficient three-phase separation and promotes development of granular 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 covers to help retain heat and prevent escape of odors...the view from the top of the fiberglass tubular gridwork looking downwards into the settler section of a digester...The view shared by anaerobic bacteria looking upwards from inside the digester vessel.

Unparalleled technical, engineering and sales support for cost-efficient solutions to your waste treatment problems

experience and expertise... the key to resourceful problem-solving

Biothane Corporation's experience and expertise assures our customers of receiving the very best solution for their wastewater treatment problems. Industrial wastewater treatment is our only business ... and we've pioneered the concept with proven success.

PROJECT PLANNING
From lab-scale and pilot-scale wastewater characterization and treatability testing programs to conceptual design alternatives, Biothane Corporation works with you to develop the most innovative, cost-effective treatment solutions.

TURNKEY CAPABILITY
From modularized scope to total system design-build, our experienced staff can provide all necessary process engineering, construction, and project management services to assure completion of the facility on time and within budget.

GUARANTEED PERFORMANCE
Every Biothane system is warranted to perform to design specification and comes complete with biomass inoculation, operator-training and start-up assistance to bring the process on line within a few weeks.

PRODUCT DEVELOPMENT
Ongoing research and development at Biothane Laboratories in the U.S. and the Netherlands is creating new products to expand the range of treatment alternatives to solve environmental problems. The same reliability you have come to expect from Biothane products is now available to you with new processes such as Biobed, Biobulk and Biopuric, all designed to effectively treat specific pollution problems.

PEOPLE
Our dedicated staff of experienced people is our most important resource. Let our professional team of experts in biotechnology solve your wastewater treatment problem reliably, efficiently, and cost-effectively.

From our modern, fully equipped testing laboratories, to system engineering using the latest CAD techniques, Biothane Corporation is your full service wastewater treatment company.

biothane...since 1978, the preferred wastewater treatment process for the food, pulp and paper, chemical and pharmaceutical industries

biothane corporation
a subsidiary of Joseph Oat Corporation
2500 Broadway / Drawer 5, Camden, NJ 08104
609/541-3500 FAX: 609-541-3366

© Copyright 1992 biothane corporation PRINTED IN U.S.A. 7/92

12/29/94 09:26 NO. 394 P02

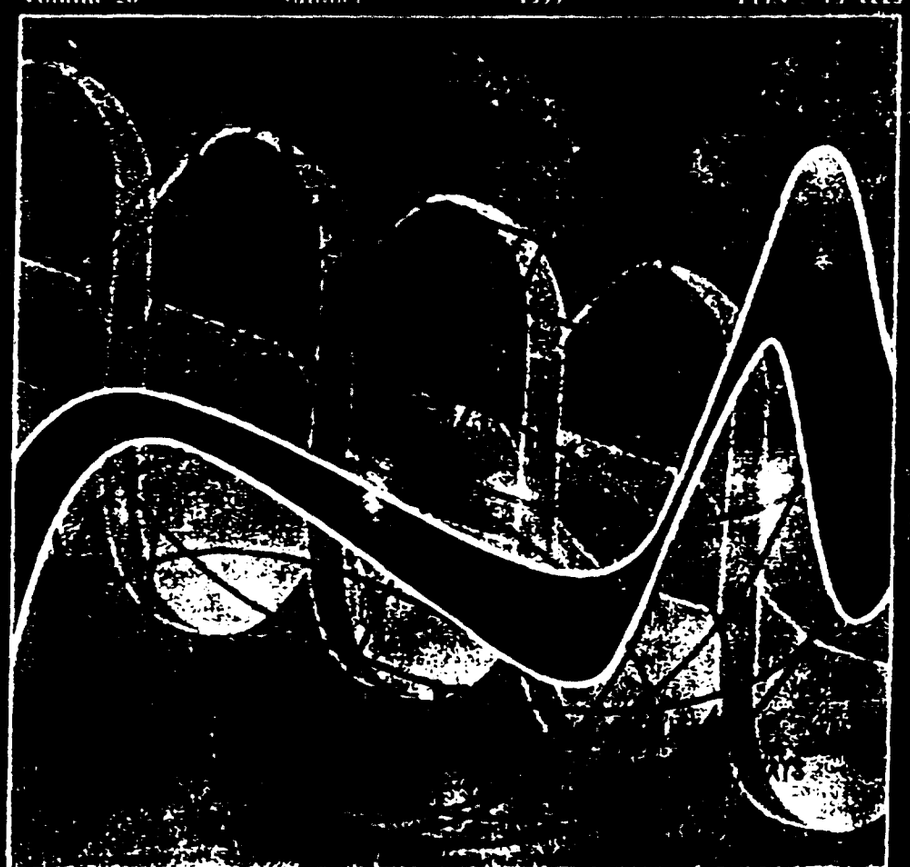
TD420
P76
v.28
no.2

JULY 93

IAWQ
INTERNATIONAL ASSOCIATION ON WATER QUALITY

WATER SCIENCE & TECHNOLOGY

Volume 28 Number 2 1993 ISSN 0273-1223



Waste Management Problems in Agro-industries 1992

Editors: D Orhon, M Henze, A C di Pinto, S Matsui,

The production of baker's yeast includes various processes including molasses preparation, fermentation, yeast separation and yeast drying. In the various stages of yeast production process and for cleaning purposes, some chemicals including sulphuric acid, phosphoric acid, mono ammonium phosphate, ammonium hydroxide, caustic soda, sodium hypochlorite and salt are used.

High strength process wastewaters are originated from yeast separators and rotary vacuum filters. In addition to these effluents, medium and low strength wastewaters including floor and equipment cleaning waters and domestic wastewaters are also present. Cooling waters from fermenters are directly discharged to the receiving water body together with storm waters. High strength process wastewaters have a chemical oxygen demand (COD) of 10 000-30 000 mg/l and their pH values vary in the range of 5 to 7.4. Low strength effluents with an average COD of 1700 mg/l are directed to the aerobic treatment system.

In this study, the full-scale treatment results from the two phase anaerobic wastewater treatment plant at Pakmaya Izmit Factory have been presented.

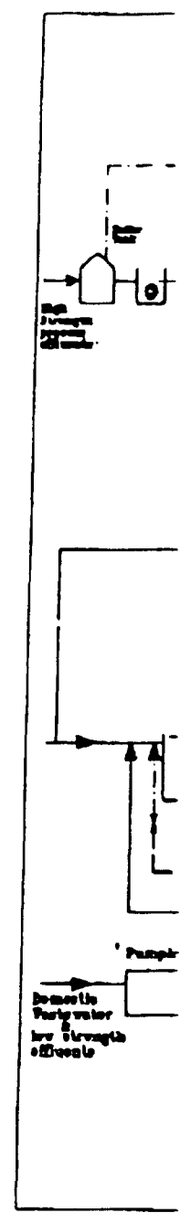
PLANT, MATERIALS AND METHODS

Measurements of polluting parameters on untreated influent and treated wastewaters of Pakmaya Izmit Industrial Wastewater Treatment Plant are the main material of the study. The plant consists of two treatment stages: anaerobic first stage and aerobic second stage (Figure 1). Anaerobic first stage is also a two-phase system: acid production phase and methane fermentation phases. Anaerobic treatment system has several units including a buffer tank, an influent pumping station, an acid reactor, two methane reactors, vacuum degasifiers, lamella separators, a gas storage tank, a boiler system and a flare for emergency. The nutrient requirements of the treatment system are supplemented by dosing H_3PO_4. Two methane reactors in the anaerobic first stage treatment system can be operated in parallel or in series. Anaerobic reactors were constructed as upflow anaerobic sludge blanket reactors (UASBR) and dedicated lamella separators with vacuum degasifiers were added to prevent the wash-out of the biomass from the system. Feeding and recirculation systems are automatically operated by timers.

The aerobic second stage was designed and operated as an extended aeration activated sludge system with a special selector unit at the beginning. The main treatment units of the aerobic stage are the selector compartment, the aeration basin with four equal aerated cells connected in series, and a final sedimentation tank with a sludge recirculation facility. Surface aerators have been used for aeration of activated sludge system.

At Pakmaya Wastewater Treatment System polluting parameters including flowrate, temperature, COD, pH concentration of suspended solids (SS), concentration of volatile acids (VFA), sludge volume index (SVI), concentration of ammonia nitrogen, ortho phosphate and sulphate have been regularly monitored at 9 different locations. Additionally, biogas flowrate and composition (CO_2 and H_2S) have also been monitored frequently. Table 1 shows the parameters measured regularly within the scope of the treatment plant monitoring program together with measuring methods and sampling frequencies.

Detailed information about aerobic treatment system performances are presented in a separate study (Ozturk *et al.*, 1992).



eparation, fermentation,
rocess ... for cleaning
amm phosphate,

cuum filters. In addition
ent cleaning waters and
ectly discharged to the
have a chemical oxygen
5 to 7.4. Low strength
tem.

water treatment plant at

ters of Pakmaya Izmit
plant consists of two
oic first stage is also a
c treatment system has
two methane reactors,
re for emergency. The
wo methane reactors in
naerobic reactors were
umella separators with
system. Feeding and

sludge system with a
tage are the selector
a fir mentation
n of ed sludge

mperature, COD, pH
volume index (SVI),
larly monitored at 9
also been monitored
the treatment plant

parate study (Ozturk

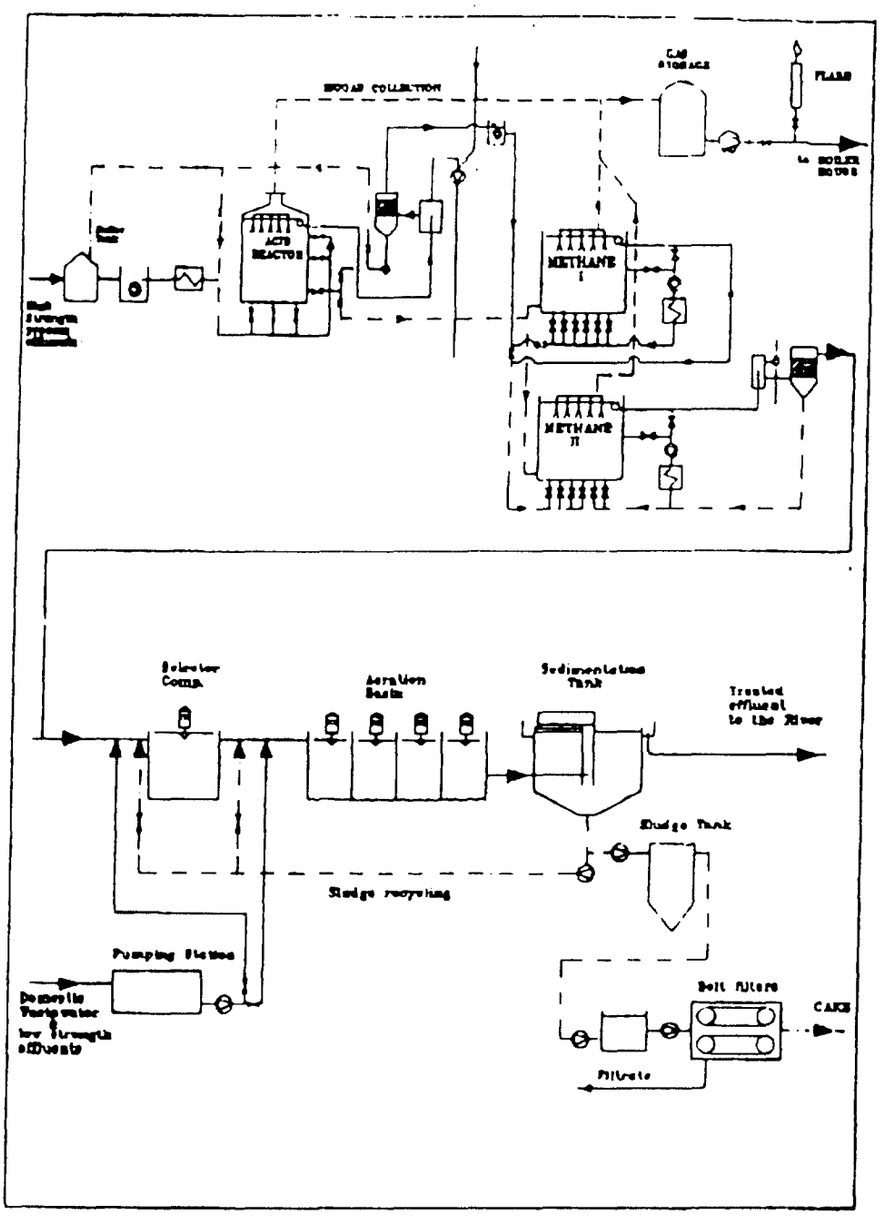


Figure 1. Flow diagram of wastewater treatment plant at Pakmaya Izmit.

TABLE 1 Monitoring Program and Sampling Frequencies for Pakmaya Izmit Wastewater Treatment Plant

Parameter	Sampling Frequency	Measurement or Analysis Method
Wastewater flowrate	Continuously	flowmeter
pH	Continuously	pH meter
COD	Daily	AWWA Standard methods (1985)
Volatile Fatty Acids (VFA)	Daily	AWWA Standard methods (1985)
SVI	Weekly	AWWA Standard Methods (1985) with SLC
NH_4-N	Weekly	NH_4 Probe
PO_4-P	Weekly	AWWA Standard Methods (1985)
Gas flowrate	Continuously	Gasmeter
CO_2 (%)	Daily	Orsat apparatus
H_2S (%)	Weekly	Dräger Tubes
Dissolved Oxygen	Continuously	DO Probes
SO_4	Weekly	AWWA Standard Methods(1985)
SS	Daily	AWWA Standard Methods(1985)
Biomass Ecology	Occasionally	Scanning Electron Microscopy(SEM)

RESULTS AND DISCUSSIONS

Wastewater Characterization

Process effluents from the baker's yeast industry are originated primarily from yeast separators and vacuum filters. In addition to these types of high strength organic effluents there are also some low strength effluents such as fermenter wash waters and domestic wastewaters. Considering the long term measurements, the polluting parameters for high strength fermentation effluents can be characterized by Table 2. Average flowrate of high strength process effluents is about 1200 m^3/d.

Low strength wastewaters were directly fed to the aerobic stage, to the effluent of the selector, via the domestic effluent pumping station. The flowrate of this diluted effluent is about 1200 m^3/d, and average COD of 1700 mg/l and BOD_5 of 1200 mg/l are typical for these effluents. Relatively high COD and BOD_5 concentrations compared to typical domestic effluents in this stream can be explained by contribution of fermenter washings. The average COD values after mixing the selector effluent with the low strength wastewaters are about 2500 mg/l.

Anaerobic Treatment Plant Operating Results

Anaerobic treatment results covering a period of more than one year were given in Table 3. These results of 13 months operation are representative for almost the whole operating period of the anaerobic treatment system. The anaerobic treatment system has successfully carried out its vital role within the complete treatment scheme.

Organic Loading Rates And COD Removal Efficiency

Average volumetric loading rates for the Acid, Methane-1 and Methane-2 Reactors are 9.8, 8.6 and 3.0 kg $COD/m^3.d$ respectively. At these organic loading rates (OLR) an average COD removal of 75 percent was achieved (Fig.2). COD removal efficiencies of anaerobic treatment stage can be as high as 80% in some

cases. The corresp
reason anaerobic f

TABLE 2

TABLE 3 Operatin

pH, Temperature and

pH, temperature and
monitoring for an eff
7.2 in acid reactors a
problem in the anaero
as 7.8 to 8.0 which ar
the characteristics of
reactors have been r
fermentation process.
Methane Reactors are
observed in the buffer

cases. The corresponding BOD_5 removals at these OLR's are in the range of 85 to 90 percent. For that reason anaerobic first stage treatment has provided an effective pretreatment at Pakmaya Izmit Factory.

TABLE 2 Characteristics of High Strength Process Effluents From Pakmaya Izmit Factory

Parameters	Range	ATV (1978) and Brown (1975)
Wastewater flowrate (m^3/day)	900-1500(1200)	
pH	6-6.5	4.5-6.5
Temperature (°C)	20-28	
COD (mg/l)	10000-30000 (18000)	14000-20000
BOD_5 (mg/l)	7000-21000(12500)	10000-16000
SS (mg/l)	50	50-2400
$SO_4^{=}$ (mg/l)	1000-2700	400-3000
TKN (mg/l)	250	100-200
PO_4 (mg/l)	27	20-50
Specific wastewater flowrate as m^3/t. molasses	10	9-12

TABLE 3 Operating Parameters and Treatment Results for Anaerobic Treatment System of Pakmaya (from 2.02.1991 to 28.02.1992)

Parameter	Acid reactor	First Methane reactor	Second Methane reactor	Total for Anaerobic
Flowrate (m^3/day)	1200	1200	1200	1200
OLR (kg COD/m^3.day)	9.8	8.6	3.0	
Temperature (°C)	37±1	37±1	37±1	
pH	6.6-7.2	7.5-7.8	7.5-7.8	
VFA (mg HA/l)	7000	800	300	
CH_4 (%)	55	82	85	70
Gas flowrate (m^3/day)				8000
Y gas/COD (m^3/kgCOD removed)				0.6
COD removal (%)				75-80

pH, Temperature and Volatile Fatty Acids (VFA)

pH, temperature and concentration of volatile fatty acids are operating parameters requiring continuous monitoring for an effective control of the anaerobic treatment process. pH values vary in the range of 6.6 to 7.2 in acid reactors and 7.5 to 7.8 in methane reactors as can be noticed in Table 3. There is no low pH problem in the anaerobic system, on the contrary pH values, especially in methane reactors, might be as high as 7.8 to 8.0 which are generally the upper limits for methane fermentation. This has mainly originated from the characteristics of the process effluents of yeast industry. The temperatures in both acid and methane reactors have been maintained in the range of 37 ± 1°C, which is optimum for mesophilic anaerobic fermentation process. Average volatile fatty acid (VFA) concentrations in the Acid, the First and Second Methane Reactors are 7000, 800 and 300 mg/l as acetic acid (Figure 3). A partial acidification has been observed in the buffer tank where the high strength process effluents are retained for about 10 hours at 20 to

25°C. Volatile acid concentrations of 3500 to 4000 mgHAc/l in the first methane reactor could easily be tolerated in the case of shock organic loadings.

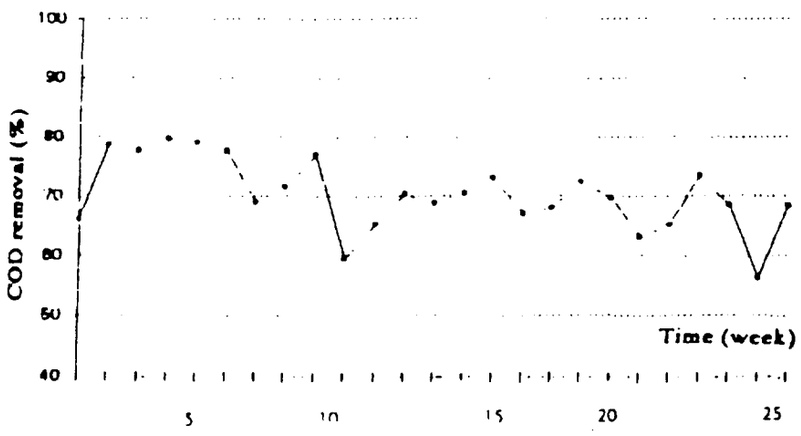


Figure 2. COD removal efficiencies vs time graph for anaerobic treatment stage of Pakmaya Izmit.

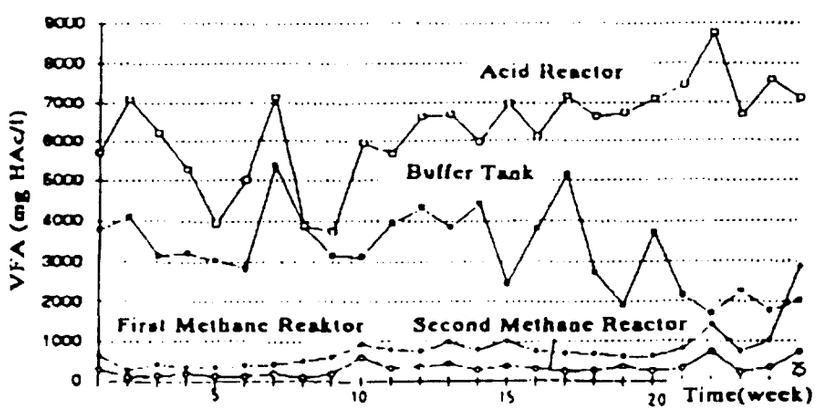


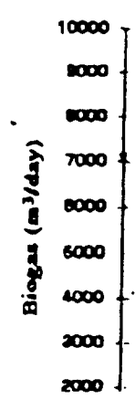
Figure 3. VFA vs time graph for anaerobic treatment stage of Pakmaya Izmit.

Anaerobic SO_4 Removal

In the anaerobic treatment of high strength industrial wastes containing high level sulphate, two major process of concern are sulphate reduction and methane production, the latter being inhibited by the former. In the process of anaerobic sulphate reduction, organic matter is diverted from methane production to sulphide (H_2S) generation. Sulphur reducing bacteria (SRB) such as *Desulfovibrio* and *Desulfomaculum* utilize sulphate as an electron acceptor with H_2S as the end product of the process. The kinetics of the anaerobic sulphate removal process can be found in the related literature: Abram and Nedwell (1978), Archer (1983) and Eroglu *et al* (1989).

As the free H_2S is
treatment system.
parallel operation.
negligible. About
of this H_2S is su
conversion of sulp
is low due to high
SO^{2-}_4 to H_2S is
anaerobic treatmen

Location	
Acid Reactor	infl.
	effl.
Methane Reactors	infl.
	effl.
Total	infl.
	effl.



Fig

Biogas Production an

In anaerobic treatmen
35°C. Average biogas
per kg COD removed
and this corresponds
is equal to the theor
removed are thought
production and metha

As the free H_2S is highly toxic to methane bacteria, a sulphur mass balance was set up for the anaerobic treatment system. Table 4 summarizes the results of the related mass balance set up for methane reactors in parallel operation. These results have shown that the contribution of SO^{2-}_3 to the sulphur balance is negligible. About 80% of incoming SO^{2-}_4 is converted to sulphide in the acid reactor, where more than 50% of this H_2S is stripped by the biogas produced. When the methane reactors are operated in parallel, conversion of sulphate to H_2S is almost completed. The stripping effect of the biogas in the methane reactors is low due to high pH (7.8). In the case of the methane reactors in serial operating mode, the conversion of SO^{2-}_4 to H_2S is generally completed in the first methane reactor and this increases the stability of the anaerobic treatment process.

TABLE 4 Sulphur Mass Balance For Anaerobic Treatment System

Location	Parameters (g/m³ of ww)				
	SO^{2-}_4-S	S^{2-}	Dissolved-S	S-in gas	Total S
Acid infl.	843	24	867	-	867
Reactor effl.	177	272	449	311	760
Methane infl.	177	272	449	-	449
Reactors effl.	31	342	373	65	438
Total infl.	843	24	867	-	867
effl.	31	342	373	376	749

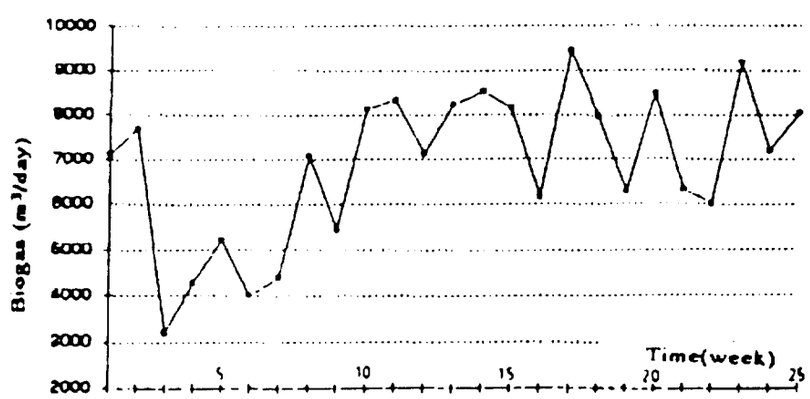


Figure 4. Biogas production vs time graph for anaerobic treatment of Pakmaya Izmir.

Biogas Production and Composition

In anaerobic treatment a methane production of 0.4 m³ per kg COD removed can generally be achieved at 35°C. Average biogas production yield of Pakmaya Izmit Wastewater Treatment Plant (Y_{gas}/COD) is 0.6 m³ per kg COD removed. In the mixed gas from the acid and methane reactors, average methane content is 70% and this corresponds to the methane production yield Y(CH_4/COD) of 0.40 m³ per kg COD removed which is equal to the theoretical maximum value. Biogas production yields of as high as 0.6 m³ per kg COD removed are thought to be originated from anaerobic digestion of excess biomass in the reactors. Biogas production and methane content of biogas from the acid and methane reactors vs. time graphs are shown in

Figures 4 and 5 respectively. Measurements of H_2S in the off gas have shown that volumetric concentrations of this corrosive gas are less than 3% in general. The biogas produced has an energy equivalent of 56.000 kw-h per day (4.7 tons fuel oil or 63 tons steam) in general. Currently, the biogas produced in the anaerobic reactors has been used as the fuel for steam production at the boiler house.

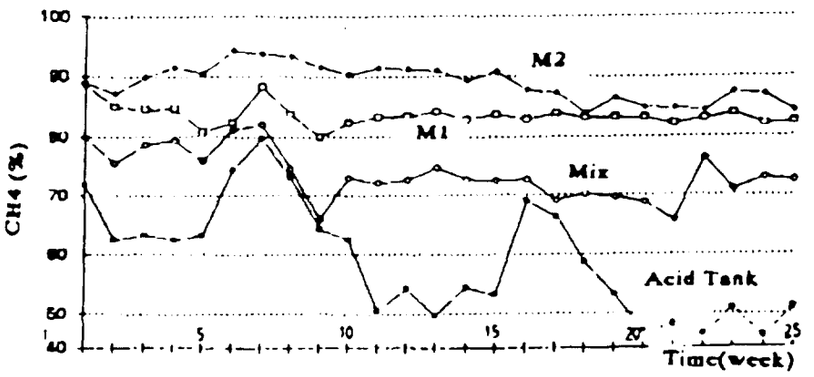


Figure 5. CH_4 contents of biogas from anaerobic digesters of Pakmaya Izmit.

Sludge Retention Time and Biomass Concentration

Long term measurements have shown that concentration of biomass, sludge retention times (sludge ages) (θ_c) and sludge volume indexes (SVI) in anaerobic reactors vary as in Table 5. Sludge age in biological treatment systems can be calculated by the following equation.

$$\theta_c = X.V/(Q_w.X_w+(Q-Q_w).X_e)$$

where,

V : Volume of reactors (m^3)
Q : Wastewater flow rate (m^3/day)
Q_w: Flowrate of intentionally wasted sludge from the system (m_3/day)
X : Concentration of suspended solids in the reactor (g/m^3)
X_e: Concentration of suspended solids in the reactor effluent (g/m^3)
X_w: Concentration of solids in the intentionally wasted excess sludge (g/m^3).

The sludges have excellent settling characteristics. Granular sludges have sludge volume indices (SVI) of less than 5 ml/g representing excellent settling properties. Anaerobic reactors can be kept without feeding for long periods even for seasons. Such an application had been practiced for ten months at Pakmaya Izmit wastewater treatment system. Following this period, the anaerobic treatment system was returned to its original operating conditions within 90 days without any serious problem. Long sludge ages in second methane reactors are mainly due to low excess sludge removal and efficient biomass separation in lamella separators.

T.

Parameter
Average and min. conc. (g SS/l)
SVI (ml/g)
Average and min. sludge age.(d)

Excess biological slu
horizontal belt filters t
some organic domestic

Biomass Ecology

The biological structu
scanning electron micr
McLeod *et al* (1990)
Acidogenic biomass
Methanogenic biomass
floccular structure at th
mixed population that i

TABLE 5 Sludge Characteristics in Anaerobic Reactors of Pakmaya

Parameter	Acid Reactor	First Methane Reactor	Sec. Methane Reac.
Average and min. conc. (g SS/l)	60-5	95-30	155-48
SVI (ml/g)	< 40	10 <	< 20
Average and min. sludge age.(d)	200-10	80-30	900-400

Excess biological sludge has been stored in the sludge holding tank and has been transferred to the horizontal belt filters for dewatering. Dewatered sludge cakes have been used for composing together with some organic domestic solid wastes.

Biomass Ecology

The biological structure of anaerobic biomass withdrawn from the anaerobic reactors was examined by scanning electron microscopy (SEM). Biomass samples were prepared according to the method applied by McLeod *et al* (1990) for SEM. Biomass from acid and methane reactors have different properties. Acidogenic biomass is mainly in floccular form rather than granular structure as shown in Fig.6. Methanogenic biomass in the methane reactors is mainly granular at the bottom (Fig. 7), while it has a dense floccular structure at the top (Fig. 8). Electron microscopy has shown that the granules are colonized by a mixed population that includes long and short rods, and chain forming cocci.

Figure 6. SEM photograph of biomass from acid reactor.

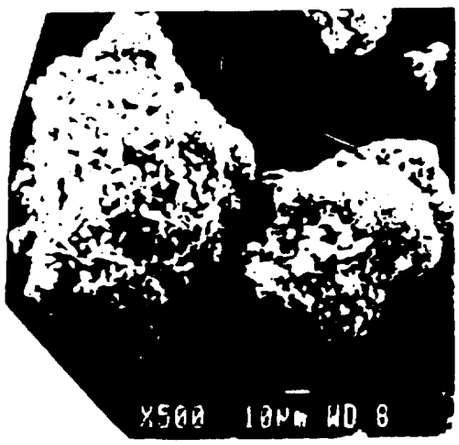
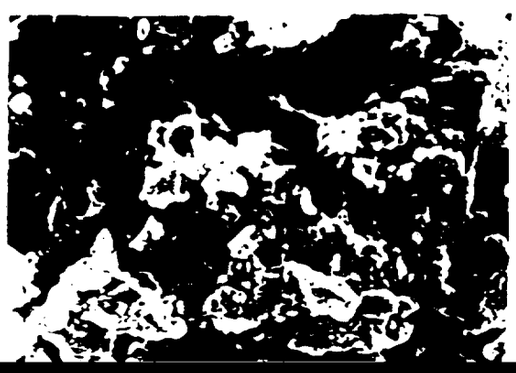


Figure 7. SEM photograph of granules from the bottom of methane reactor.



A(

The authors apprec
C. Aksit and all PAJ
We also thank M. U

RE

Abram, J. W and Nedw
hydrogen, *Arch*
Abwasserechnische Ve
Archer, D. B. (1983). T
Technol. 8: 162
Brown, W. K.(1975). Dis
Öztürk, I., Çiftçi, T., A
Proceedings of
Erogla, V., Öztürk, I., S
as Edible Oil R
McLeod, F. A., Guiot,
Anaerobic Stud
APHA, AWWA and WP

ACKNOWLEDGEMENTS

The authors appreciate the contributions of Assoc. Prof. Dr. L. Dagasan, Dr. R. Alkan, M. Tulay, E. Tuller, C. Aksit and all PAKBIOMER staff (PAK Biotechnology Research and Development Center, Izmit Turkey). We also thank M. Ulasir for his contributions (Dept. of Env. Eng. of Istanbul Technical University).

REFERENCES

Abram, J. W and Nedwell, D. B. (1978). Inhibition of methanogenesis by sulphate reducing bacteria competing for transferred hydrogen. *Arch. Microbiol.* 117: 89.

Abwassertechnische Vereinigung (ATV) (1978). *Korrespondenz Abwasser*. 25, H.9. S.322.

Archer, D. B. (1983). The microbial basis of process control in methanogenic fermentation of soluble wastes. *Enzyme Microb. Technol.* 5: 162-170

Brona, W. K.(1975). Die Abwasserbelastung bei Hefefabriken und Melassebrennereien. *Die Brennweinwirtschaft* 115. S.388.

Ozdirk, I., Çifçi, T., Alkan, R. and Aksit, C. (1992). Ekmek mayasi Üretim Atiksularinin Anaerobik-Aerobik Aritimi. In the Proceedings of the 3rd Industrial Pollution Conference of Istanbul Technical Univ. 7-9 Sept.Istanbul.

Eroglu, V., Özdirk, I., Sun, H. A. and Demir, I.(1990). Comparative Evaluation of Treatment Alternatives for Wastewaters From an Edible Oil Refining Industry. *Water Science and Technology* 22(9). 225-234.

McLeod, F. A., Guiot, S. R and Costron, J. W.(1990). Layered Structure of Bacterial Aggregates Produced in an Upflow Anaerobic Sludge Bed and Filter Reactor. *Appl. Environ. Microbiol.* 56(6): 1598-11607

APHA, AWWA and WPCF (1985). *Standard Methods for the Examination of Water and Wastewater*. APHA publication.

that anaerobic COD
eld of 0.6 m^3 per kg
treatment.

th organic industrial

119

32 Enterprise no. 24: Yeast Industries Co. Ltd.

32.1 Production

The enterprise is located in Ruseifa 20 km east of Amman. It covers an area of 10,000 m² land and has some 60 employees. It is a privately owned company which was established in 1976 and started production in 1978. The production is fresh yeast and dry active yeast (instant bakers yeast). The working time is 24 h/d, 6-7 days/week.

Fresh yeast is produced in 0.5 kg compressed cakes (28% dry solid) which are packed separately. Dry active yeast contains 95-98% dry solid. It is packed in different sizes: 100 g, 500 g and 1 kg packs and 25 kg bags.

In 1992 the production was 865 ton dry yeast and 2,582 ton fresh yeast. This was only appr half of the total capacity which is 6,000 ton per year. The total production of yeast in 1992 was 3,447 ton corresponding to appr 1,545 ton dry solid yeast.

32.1.1 Production of Yeast

The production processes are shown in the flow-sheet, Figure 32.1.

The main processes are:

1. Preparing a pure yeast culture
2. Full scale fermentation
3. Separating and washing the yeast

Liquid molasses is produced by dilution with water followed by sterilization. Finally the solution is clarified through a separator and stored. This liquid molasses is used in the fermentation tank.

From stage 3 the processes for production of the two types of yeast differ.

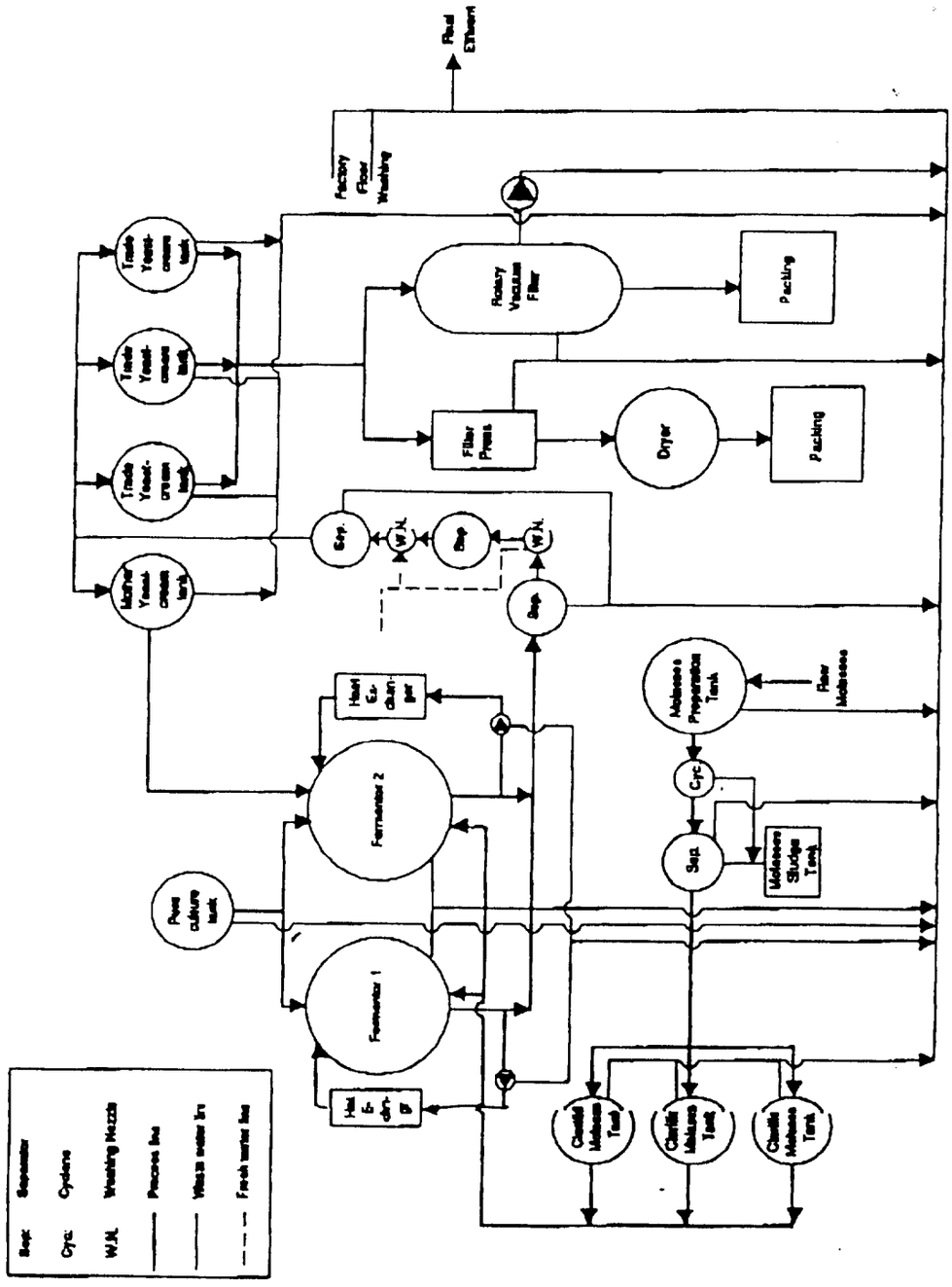


Figure 32.1 Yeast Industries Co. Ltd. Flow Sheet of Production Process.

Fresh yeast:

4. Dewatering on a rotary vacuum dryer
5. Extruding
6. Packing

Dry active yeast:

4. Dewatering on a filter press
5. Extruding
6. Drying (fluid bed dryer)
7. Packing

32.1.2 Raw Materials and Water

The consumption of raw materials (1992) is:

Beet molasses:	8,000 ton
Ammonium phosphate:	56 ton
Potassium chloride:	21 ton
Magnesium sulphate:	21 ton
Urea:	195 ton
Vitamins:	1 ton
Sodium hydroxide:	20 ton
Sulphuric acid:	112 ton
Sodium chloride:	18 ton

Water is supplied from the Company's own well. The consumption is estimated by the Company to 500-600 m^3/d. This is 150,000 - 180,000 m^3/year. The water consumption is appr 50 m^3 water per ton yeast or 100 m^3 per ton dry solid yeast. This is rather high compared to European practice where a water consumption of 30 m^3 per ton dry solid yeast is normal when closed cooling systems are used.

Process water is primarily used in the production process and for cleaning of machinery, equipment and tanks. There is a considerable demand of cooling water for the fermentation process but according to information from the Company, the cooling system is a closed system with cooling towers.

TECHNIQUES FOR INDUSTRIAL POLLUTION PREVENTION

A Compendium for Hazardous and Nonhazardous Waste Minimization

By Michael R. Overcash
Professor, Department of Chemical Engineering
North Carolina State University
Raleigh, North Carolina

Translation by
Michelle L. DeHertogh
Texas Instruments
Houston, Texas

rom
lew Processing Techniques of the Industry of France

a Mission Technologies Propres de la
irection de la Prévention des Pollutions
J Ministère de l'Environnement

LEWIS PUBLISHERS, INC.
121 S MAIN STREET, P O DRAWER 519, CHELSEA, MI 48118

YEAST MANUFACTURING
CONCENTRATION AND UTILIZATION OF EXTRACTION EFFLUENTS

ADVANTAGES OF THE NEW PROCESS

The new process lowers the pollution more effectively than an equivalent biological system. On the other hand, it allows the possibility of recovering polluting materials that can be commercialized. This process is also less expensive, both the investment and running costs, than an equivalent biological station.

POSSIBLE EXTENSIONS

This process is already widely used. It can help many different types of yeast factories for which the effluent volume is always a problem.

Basis: ton of molasses treated

Pollution balance:

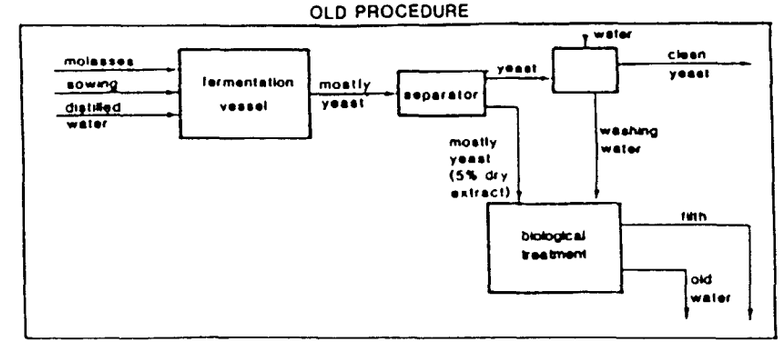
	Rejects		Old Procedure	New Procedure
	throughput	m^3/t	20	23
Water	MES	kg/t	3	0
	BOD	kg/t	130	5
	COD	kg/t	180	8.8

Economic balance: 1982 Dollars

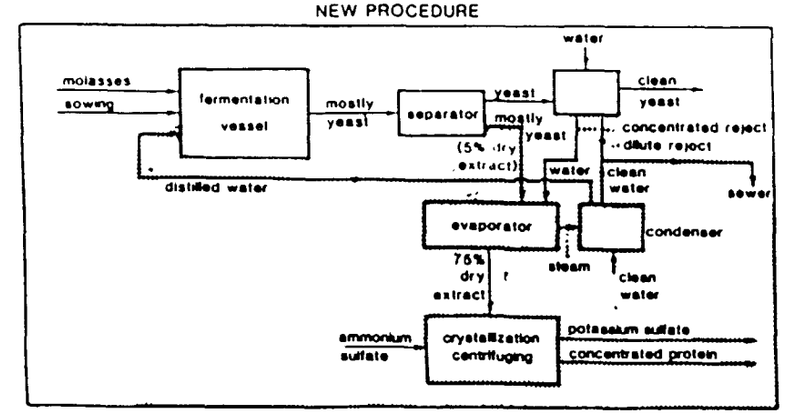
	Old*	New
Investment	4,567,300	2,199,600
Annual costs	456,840	363,780
Annual returns		431,500

*Cost of the biological treatment station to treat the effluents from the old procedure.

OLD PROCEDURE



NEW PROCEDURE



Pfizer Starts Up Advanced Fermentation Pilot Plant

A state-of-the-art fermentation pilot plant has been started up by Pfizer at its central research division in Groton, Conn. Spokesmen say the $23 million, 20,000-sq-ft plant is the most advanced of its kind in the world.

It's the most advanced, they say, because it combines fermentation and product isolation research labs in the same building as fermentation and isolation pilot plants and a supporting analytical lab. Also, Pfizer has the widest spectrum of fermentation products in industry, ranging from carboxylic acids and antibiotics to biopolymers, such xanthan gum, and enzymes, such as recombinant chymosin for cheese making.

The new plant will serve for research on fermentation processes and for support of Pfizer's biotechnological discovery teams. The purpose of the support function is to produce larger amounts of compounds made in the research labs.

The pilot plant section on two lower floors contains 12 fermentors ranging in size from 5 to 5000 gal, interconnected by 6 miles of stainless steel pipe.

Two things seem different from other fermentation plants. First, there are no white plumes rising into the air from steam used to sterilize fermentors between batches. Second, the floor is free of hoses to interconnect among fermentation and nutrient feed tanks.

Spent steam goes to a catch compartment for condensation and disinfection before any effluent leaves the plant, says biochemical engineer Arindam Bose, who is plant manager. As for interconnections, all the pipes from tank bottoms rise to the ceiling on one side of the building, while those from overheads are located on the other side. Operators make connections as needed by hooking into plumbing junction boxes called transfer panels.

As with all fermentation plants, the dominant concern at the new Groton plant is sterility. Microorganisms invading from outside could easily overwhelm the producing organism in a tank. Bose observes that many people think the main worry in biotechnology is escape of genetically engineered organisms, whereas he is most afraid that something else will get in.

But containment is also provided for. A dike surrounds the entire area under the tank bottoms, forming a sump capable of holding the entire 20,000-gal contents of all tanks should they all fail catastrophically at once.

Pilot production or process research begins nutrient concentration, and programed growth cycle for the organism. From this top floor, inocula are sent downstairs for pilot-scale runs.

To those who have wandered at laboratory equipment expositions past racks of shaking Erlenmeyer flasks filled with colored water, it is hard to believe that these could pose a problem in building design. But Bose says that in an older building in Groton the great number of racks used set up a resonance that shook the building. In the new facility, floors are insulated from the rest of the structure by vibration damping.

In supporting analytical labs, high-performance liquid chromatographs are instruments of choice for determining product and residual nutrient concentrations. For protein products in particular, HPLCs are isolated in cold boxes at 4 to 15 °C.

Among the first candidates for process engineering and pilot production in the new facility are animal health products semduramicin and doramectin. Semduramicin is Pfizer's new ionophore antibiotic for prevention of coccidiosis. Coccidiosis is a potentially fatal protozoan parasitic gastrointestinal infestation that, among other things, inhibits weight gain in turkeys and broiler chickens. Doramectin is a macrocyclic lactone glycoside effective against internal and external parasitic nematodes in a variety of animals.

Stephen Stinson

Cocaine analog for

fourth edition

CHEMICAL PROCESS INDUSTRIES

R. NORRIS SHREVE

Late Professor Emeritus of Chemical Engineering
Purdue University

JOSEPH A. BRINK, JR.

Consulting Chemical Engineer
Professor and Chairman of Chemical Engineering
Washington State University

McGRAW-HILL BOOK COMPANY

New York St. Louis San Francisco Auckland Bogotá
Düsseldorf Johannesburg London Madrid Mexico
Montreal New Delhi Panama Paris São Paulo
Singapore Sydney Tokyo Toronto

·h, and sent to a continuous horizontal-spiral-ribbon starch remover. . and skins, and the latter three is sieved, and the pulp from the is again passed through a centrifugal point on operations are similar

the major difficulty encountered hed by Martin's process, wherein ight of water, and stored for 1 h. circular sieve, where a traveling . The resulting liquor is treated recovered and sold.

has the brown outer cuticle attached is steeped for 24 h with caustic bottoms. At the end of the and steeping continued for an-

chapter 31

FERMENTATION INDUSTRIES

The employment of microorganisms to convert one substance into another is a science that is assiduously studied and energetically applied. Although the fermentation of fruits to alcohol was known to primitive humans, and although the making of various beverages out of fruits and grains has been well established for centuries, only during the past generation has wider application of this procedure been recognized. Now scientists are directing the life processes of yeasts, bacteria, and molds to the production of chemicals. Alcohol can be viewed as having been produced in this way for

TABLE 31.1 *Survey of Important Fermentations*

Food and feed	*Intermediates*	*Pharmaceuticals (Antibiotics)*
Beer (Y)	Acetic acid	Amphotericin B
Bread (Y)	Acetone	Bacitracin
Cheese (M or B)	Aspartic acid	Bleomycin
Cocoa (B and Y)	2,3 Butanediol	Candicidin
Coffee (M)	n-Butyl alcohol	Capreomycin
Koji (M and Y)	Carbon dioxide	Cephalosporin C
MSG (B)	Citric acid	Chloramphenicol
Olives (B)	Dextran	Chlortetracycline
Pickles (B and Y)	Dihydroxyacetone	Colistin
Sauerkraut (B)	Ethyl alcohol	Cycloheximide
Single-cell protein (Y, B, or M)	Fumaric acid	Cycloserine
Tea (B)	Fusel oil	Dactinomycin
Vinegar (B and Y)	Gallic Acid	Doxorubicin
Wine (Y)	Gluconic acid	Erythromycin
Whisky (Y)	Glycerol	Gentamicin
Vitamins	Isoleucine	Griseofulvin
Ergosterol (Y and M)	Itaconic acid	Kanamycin
Riboflavin (B and Y)	2-Ketogluconic acid	Lincomycin
Vitamin A (B)	5-Ketogluconic acid	Mithramycin
Vitamin B_2 (Y)	Kojic acid	Mitomycin C
Vitamin B_{12} (B and M)	Lactic acid	Neomycin
	Lysine	Novobiocin
	Succinic acid	Nystatin
	Sulfuric acid from sulfur	Oleandromycin
	Tartaric acid	Paromomycin
	Valine	Penicillins
	Yeast	Polymyxin
	Enzymes	Rifampin
	Amylase	Spectinomycin
	Cellulase	Streptomycin
	Diastase	Tetracycline
	Invertase	Vancomycin
	Maltase	Viomycin
	Zymase	

Y, Yeast; B, bacteria; M, molds.

the making of penicillin, which stimulated further important discoveries in the field of antibiotics. Many fermentation processes are frequently in direct competition with strictly chemical syntheses. Alcohol, acetone, butyl alcohol, and acetic acid produced by fermentation have largely been superseded by their synthetic counterparts. However, antibiotics have paced a recent fermentation revival and, with some exceptions, all the major antibiotics are obtained from fermentation processes. Dextran is another fermentation product. The microbiological production of vitamins has also become economically important. In Chap. 40 antibiotics, hormones, and vitamins are presented, together with several flowcharts. See Fig. 40.8 for penicillin, erythromycin, and streptomycin.

Actually, fermentation under controlled conditions involves *chemical conversions*.[2] Some of the more important processes are: *oxidation*, e.g., alcohol to acetic acid, sucrose to citric acid, and dextrose to gluconic acid; *reduction*, e.g., aldehydes to alcohols (acetaldehyde to ethyl alcohol), and sulfur to hydrogen sulfide; *hydrolysis*, e.g., starch to glucose, and sucrose to glucose and fructose and

[2]Wallen, Stodola, and Jackson, Type Reactions in Fermentation Chemistry, Dept. of Agriculture, Agricultural Research, 1959 (hundreds of reactions under 14 types).

BEST AVAILABLE COPY

on to alcohol; and *esterification*, e
certain chemical conversions can
ical synthesis.

Many chemical reactions ca
easily be classified; so the concept
According to Silcox and Lee,[3] th

1. A microorganism that for
gated and be capable of maintain
2. Economical raw materials
3. Acceptable yields.
4. Rapid fermentation.
5. A product that is readily

According to Lee, certain factors
conversion or unit-process concept.
Certain critical factors of the fer
fermentation, and uniformity of yie
comparatively simple and workabl
posium on engineering advances in

In understanding, hence in co
usually be made between the initia
quantity and the subsequent process
enzymes previously secreted, the de
yield, it is frequently advisable to su
Highly specialized microbiologists w
growing the particular strain of an
wanted with the *greatest yields*, the

No longer will just any yeast do
wild yeasts excluded, but a special s

The yeasts, bacteria, and molds
foods to ensure their activities. The
temperature most favorable varies (5
bacteriologist has developed acid-lovi
not flourish. Some microorganisms r
without air (anaerobic). Certain ana
directing these minute vegetative orga
cation of the organism first, and then
How important this is can be seen fro
1.5 to 2.0 g of monosaccharide per d
catalysts, or *enzymes*, are frequently fo
the growth period, in addition to the
various *nutrients* are needed, such as
well as favorable pH and temperature.
and their enzymes. Even the alcohol fo

[3]Silcox and Lee, Fermentation, *Ind. Eng. C*
[4]Humphrey *et al.*, Fermentation, I&EC Unit
Supplement, *Ind. Eng. Chem.*, 53, 66 (1962); Ph
(1961); Deindoerfer and Humphrey, Mass Transf
[5]Articles in *Ind. Eng. Chem.*, 32(1), 59 (19

125

on to alcohol; and *esterification*, e.g., hexose phosphate from hexose and phosphoric acid. Actually, certain chemical conversions can be carried out more efficiently by fermentation than by chemical synthesis.

Many chemical reactions caused by microorganisms are very complex, however, and cannot easily be classified; so the concept of fermentation itself as a chemical conversion has been developed. According to Silcox and Lee,[3] the five basic prerequisites of a good fermentation process are:

1. A microorganism that forms a desired end product. This organism must be readily propagated and be capable of maintaining biological uniformity, thereby giving predictable yields.
2. Economical raw materials for the substrate, e.g., starch or one of several sugars.
3. Acceptable yields.
4. Rapid fermentation.
5. A product that is readily recovered and purified.

According to Lee, certain factors should be stressed in relation to the fermentation chemical-conversion or unit-process concept, such as microorganism, equipment, and the fermentation itself. Certain critical factors of the fermentation are pH, temperature, aeration-agitation, pure-culture fermentation, and uniformity of yields.[4] The microorganisms should be those which flourish under comparatively simple and workable modifications of environmental conditions. See also the symposium on engineering advances in fermentation practice.[5]

In understanding, hence in correctly handling, microorganisms, a sharp differentiation should usually be made between the initial growth of a selected strain of these organisms to a sufficient quantity and the subsequent processes whereby, either through their continued *living* or as a result of *enzymes* previously secreted, the desired chemical is manufactured. To obtain a maximum chemical yield, it is frequently advisable to suppress additional increase in the quantity of the microorganism. Highly specialized microbiologists working in well-equipped laboratories are engaged in selecting and growing the particular strain of an organism that experiment has shown to produce the chemical wanted with the *greatest yields*, the *least by-product*, and at the *lowest cost*.

No longer will just any yeast do to make industrial alcohol or a fermented beverage; not only are wild yeasts excluded, but a special strain must be used.

The yeasts, bacteria, and molds employed in fermentation require specific environments and foods to ensure their activities. The concentration of the sugar or other food affects the product. The temperature most favorable varies (5 to 40°C), and the pH also has great influence. Indeed, the bacteriologist has developed acid-loving yeasts, so that *wild yeasts*, not liking acidic conditions, do not flourish. Some microorganisms require air (aerobic), and others go through their life processes without air (anaerobic). Certain anaerobes neither grow nor function in the presence of air. In directing these minute vegetative organisms, conditions can be controlled to encourage the *multiplication* of the organism first, and then its *functioning*, either directly or through the *enzymes* secreted. How important this is can be seen from the knowledge that to grow 1 g of yeast (dry basis) requires 1.5 to 2.0 g of monosaccharide per day, and 6 g to maintain it. By virtue of this growth, organic catalysts, or *enzymes*, are frequently formed that *directly cause the desired chemical change*. During the growth period, in addition to the primary, or energy food, such as monosaccharides for yeast, various *nutrients* are needed, such as small amounts of phosphates and nitrogenous compounds, as well as favorable pH and temperature. Finally, certain substances poison these useful little vegetables and their enzymes. Even the alcohol formed by the yeasts eventually reaches a concentration (varying

[3]Silcox and Lee, Fermentation, *Ind. Eng. Chem.*, 40, 1602 (1948).

[4]Humphrey *et al.*, Fermentation, I&EC Unit Processes Review, *Ind. Eng. Chem.*, 53, 934 (1961) (excellent); Annual Review Supplement, *Ind. Eng. Chem.*, 53, 66 (1962); Phillips *et al.*, Oxygen Transfer in Fermentations, *Ind. Eng. Chem.*, 53, 749–754 (1961); Deindoerfer and Humphrey, Mass Transfer from Individual Gas Bubbles, *Ind. Eng. Chem.*, 53, 1755–1759 (1961).

[5]Articles in *Ind. Eng. Chem.*, 52(1), 59 (1960); Gutcho, Chemicals by Fermentation, Noyes, 1973.

BEST AVAILABLE

with the yeast from about 2 to 15%) that will suppress the activity of the organism and of the enzymes. We are, furthermore, recognizing the importance of the life processes of microorganisms in making vitamins, some of which are being recovered and sold in a concentrated form. "As with all life, the activities of microorganisms can be reduced to a consideration of enzymes acting on a substrate."[6]

INDUSTRIAL ALCOHOL

Industrial alcohol was an outgrowth of alcoholic beverages, but now it has become important by virtue of its economically useful properties as a solvent and for synthesis of other chemicals. Alcohol is sold as tax-paid[7] alcohol or, much more widely, as nontaxed denatured alcohol. The *completely denatured* formulas comprise admixtures of substances which are difficult to separate from the alcohol and which smell and taste bad, all this being designed to render the alcohol nonpotable. Such completely denatured alcohol is sold widely without bond. Factories find it an essential raw material. A typical completely denatured alcohol formula follows:

Formula No. 18. To every 100 gal of ethyl alcohol of not less than 160 proof add:

0.125 gal of Pyronate or a compound similar thereto.

0.50 gal of acetaldol (β-hydroxybutyraldehyde), 2.50 gal of methyl isobutyl ketone, and 1.00 gal of kerosine.

The federal government has recognized the needs of industry for alcohol in such form that it can enter into specialized manufacturing processes where the denaturants used in completely denatured alcohols would interfere. So, since 1906, when the first U.S. denatured-alcohol law was passed, many formulas for *specially denatured* alcohol have been approved by the federal authorities. Such special formulas are limited to certain designated processes and are manufactured, stored, and used under bond, to prevent unlawful consumption. However, the 40 approved special formulas under their authorized uses enter into an exceedingly broad section of the entire industrial life of the nation.[8] Typical specially denatured formulas[9] are

To every 100 gal of ethyl alcohol, add for the designated number:

No. 1. Five gallons approved wood alcohol. Withdrawals for authorized uses: plastics, dehydrations, explosives, food products, chemicals, etc.

No. 28. One-half gallon benzene or one-half gallon rubber hydrocarbon solvent. Withdrawals for authorized uses: plastics, dehydrations, explosives, food products, chemicals, etc.

No. 29. One gal of 100% acetaldehyde or other approved denaturant. Withdrawals for authorized uses: manufacturing acetaldehyde, acetic acid, esters, ethers, etc.

In industrial nomenclature *alcohol* means ethyl alcohol, or ethanol (C_2H_5OH). It is sold by the gallon, which weighs 6.794 lb and contains 95% C_2H_5OH and 5% H_2O both by volume at 15.56 C.[10] No distinction is made as to the source of the alcohol, whether from fermentation or from synthesis.

[6]McGraw Hill Encyclopedia, vol. 7, p. 84, 1966.

[7]The federal tax is $10.50 per proof gallon, hence $19.95 on a gallon of 190-proof alcohol. The total sum collected by the Federal Alcohol Tax Unit was $5,110,001,000 in 1972, largely from beverages. A *proof gallon* (tax gallon) signifies a gallon containing 50% alcohol by volume; 100 volumes of 100-proof alcohol contain 50 volumes of absolute alcohol and 53.73 volumes of water owing to volume contraction. Ordinary alcohol of 95% strength is thus 190-proof alcohol, and pure anhydrous alcohol is 200 proof. It is interesting to observe that 100-proof alcohol is about the lower limit of burning for alcohol dilutions by direct ignition at ordinary temperatures. A *wine gallon* is a measure of volume (231 in.^{3}) of any proof.

[8]Withdrawals of specially denatured alcohol in 1965 amounted to 308.5 million wine gallons and only 2.2 million wine gallons of completely denatured alcohol.

[9]Formulas for Denatured Alcohol, U.S. Revenue Service, Part 12 of Title 26, Federal Regulations, 1961.

[10]This corresponds to 92.423% of ethyl alcohol by weight. However, when alcohol percentage strength is given, it refers to percentage by volume.

BEST AVAILABLE COPY

USES AND ECONOMICS T.
flavoring, and beverage purposes.
have arisen only since low-priced.
been toward the use of specially
only to water in solvent value and
material for making hundreds of ch
acetic acid, ethylene dibromide, gly
quantities of butadiene and styrene
as a supplemental raw material for
fact, in 1945, 75% of all speciall

In petroleum-poor countries it
in order to conserve petroleum prod
ing agent is needed. These procedu
tropical sugar-growing countries, wh
amount having been employed in Sv
United States, and even tried in lo

The cost of alcohol is largely th.
factors vary as to location. Raw mat
classifications: (1) hydrocarbon gase
cellulosic materials (wood, agricultu
terials (molasses from sugar beets a
55% fermentable sugar, consisting n
ture) sugar.

The economics of the situation
importance as a source of *industrial* a
less than 50% of the alcohol produc
laws specify the use of grain alcohol i
tax-paid solvent uses. Thus a demand
under these conditions lower-priced s

TABLE 31.2 *Ethyl Alcohol Production of Raw Material, Fiscal June 30 (In thousands of g of alcohol and spirits of 190*

Raw material	*1965*
Ethyl sulfate	447,596
Molasses	4,234
Ethylene gas	117,633
From redistillation	33,101
Grain and grain products	80,223
Sulfite liquors	7,050
Cellulose pulp, chemical and crude alcohol mixtures	2,076
Fruit	21,728
Whey	266
Potatoes	20
Marshmallows	5
Total alcohol produced	713,932

Source: Alcohol and Tobacco Summary Stati- 1971. n.a., Not available. *Estimated.

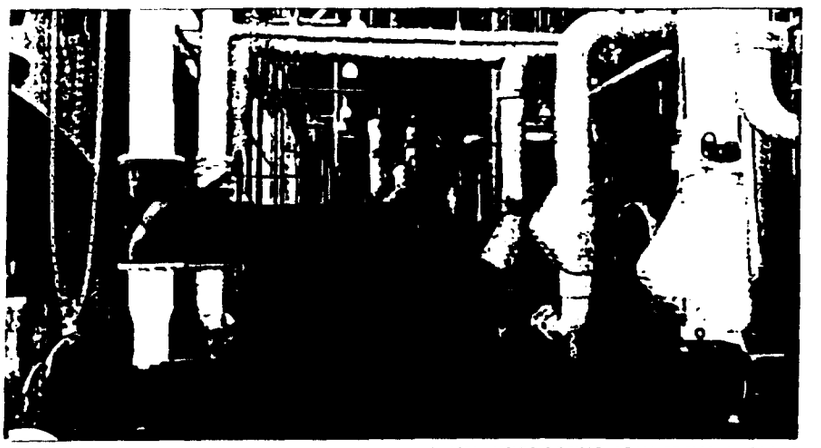
NEWS

The study determined that the nourishment project had oversteepened the slope of the beach, says coastal engineer David Skelly of San Diego, who is also a surfer and former environmental director for the Surf Rider Foundation. "It was assumed this beach would come back into equilibrium. It's not clear that it did," he adds.

A number of constraints mark the offshore construction of the engineered reef, which will result in an artificial surf spot. The area has a large tide range, a mobile bottom and waves coming from different directions. And as with any project of this type, artificial-reef plans will face an extensive permitting process, Skelly says. Chevron's $300,000 will cover reef design, permitting, construction and potential removal costs.

"It's my opinion that it's an extremely difficult problem and it has to be termed an experiment no matter what," says Skelly. Some options for an artificial reef include moored polyvinyl chloride structures and piled sandbags.

Surf along Southern California's coastline is already created as a by-product of many fabricated structures, but the Chevron reef would be the first project of its kind to intentionally create a surf spot, Skelly says. The project is expected to take three years to complete.



USING TREATED EFFLUENT IN ITS AIR-CONDITIONING SYSTEM HELPS BOEING COMMERCIAL AIRPLANE GROUP CONSERVE 40 MILLION GAL. OF WATER ANNUALLY.

WASTEWATER IS NO WASTE IF IT'S REUSED

Boeing Commercial Airplane Group's new closed-loop air-conditioning unit will conserve both energy and water by using something normally flushed away—treated effluent. The unit uses secondarily treated wastewater as an energy medium to cool Boeing's customer services training center at Longacres Park, Wash.

Wastewater use is being promoted under MetroTherm, a program sponsored by the King County (Wash.) Department of Metropolitan Services, Seattle, which provides effluent to private companies and government for heating and cooling. Boeing is its first commercial water-reuse customer. The project, reportedly the first of its kind in the nation, is funded with a $1.7 million energy conservation grant from Puget Sound Power & Light Co.

The cooling system works by pumping effluent through a looped pipeline to Boeing's central utility facility, where heat exchangers (chillers) transfer heat from the building's air conditioning to an effluent return line.

Using effluent makes the system run more efficiently because its temperature—about 65F—is 10–20F cooler than water returned from cooling towers, allowing heat to be absorbed more easily, says Kristiana Lang, spokeswoman for the Department of Metropolitan Services.

The effluent-based system is expected to shave 20% from the energy cost of previous systems and could save 40 million gal. of water each year—worth $120,000—when development of the system is complete. Annually, the water conserved could supply more than 500 homes, and the energy saved would be enough to fuel 300 homes.

The project contains other environmental benefits as well. Chillers use a new refrigerant, R-134A, that promoters call environmentally friendly. Also, the looped effluent system doesn't require water-treatment chemicals like a cooling tower would. The state departments of ecology and health will ensure that the recycled water is up to standard quality.

After it has been used, the effluent, now about 15F warmer, is returned to the treatment plant and discharged through the Duwamish River corridor pipeline into Elliott Bay. Pipeline discharge overall will increase by only 0.5–1F, says Lang, claiming that the environmental risk is "none whatsoever."

Boeing will receive the effluent free during a three-year demonstration period, but will pay for operations and maintenance costs for the pumps and pipeline. After the demo period expires, the Department of Metropolitan Services will receive one-third of Boeing's savings from operating the effluent system.

Plans to use effluent as a heating and cooling source were introduced in the mid-1980s by the state Energy Office. Since then, eight taps have been placed along the Duwamish discharge pipeline to make effluent commercially available to industries and others.

JACKETS ARREST CRACKING OF PRISON BRIDGE PILES

Instead of reconstructing an entire bridge that is showing moderate to potentially hazardous deterioration of its piles, engineers are rehabilitating the structure using fiberglass jackets filled with a layer of pumped concrete.

The cracking piles support Rikers Island Bridge, which provides the only vehicular access to the New York City correctional facility. Lichtenstein Engineering Associates, New York, was selected to design rehabilitation plans for the 30-year-old bridge after an inspection found cracks in 165 of the bridge's 260 piles. Those 165 piles, together with several others that had been banded previously to stop cracking, comprise a total of 217 piles that are being repaired using 1,190 m of fiberglass jacketing. Brand Marine Services, Inc., Birmingham, Ala., is performing the rehabilitation.

BEST AVAILABLE COPY