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

control technology center

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

Control Technology Center

Sponsored by:

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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.

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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.

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1.0 INTRODUCTION

The objectives of this study were to obtain information on baker'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 sources 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 found in 10 different States. Ten of the facilities are located in ozone nonattainment areas. The majority of yeast manufacturing facilities employ a moderate degree of process control to reduce the amount of volatile organic compounds (VOC's) generated. However, only one facility has applied an air pollution control system to control emissions from the process. Because of the location of some facilities in nonattainment areas, controlling yeast production VOC emissions may help bring these areas into 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

Plant 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

[a]Gastonia 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,

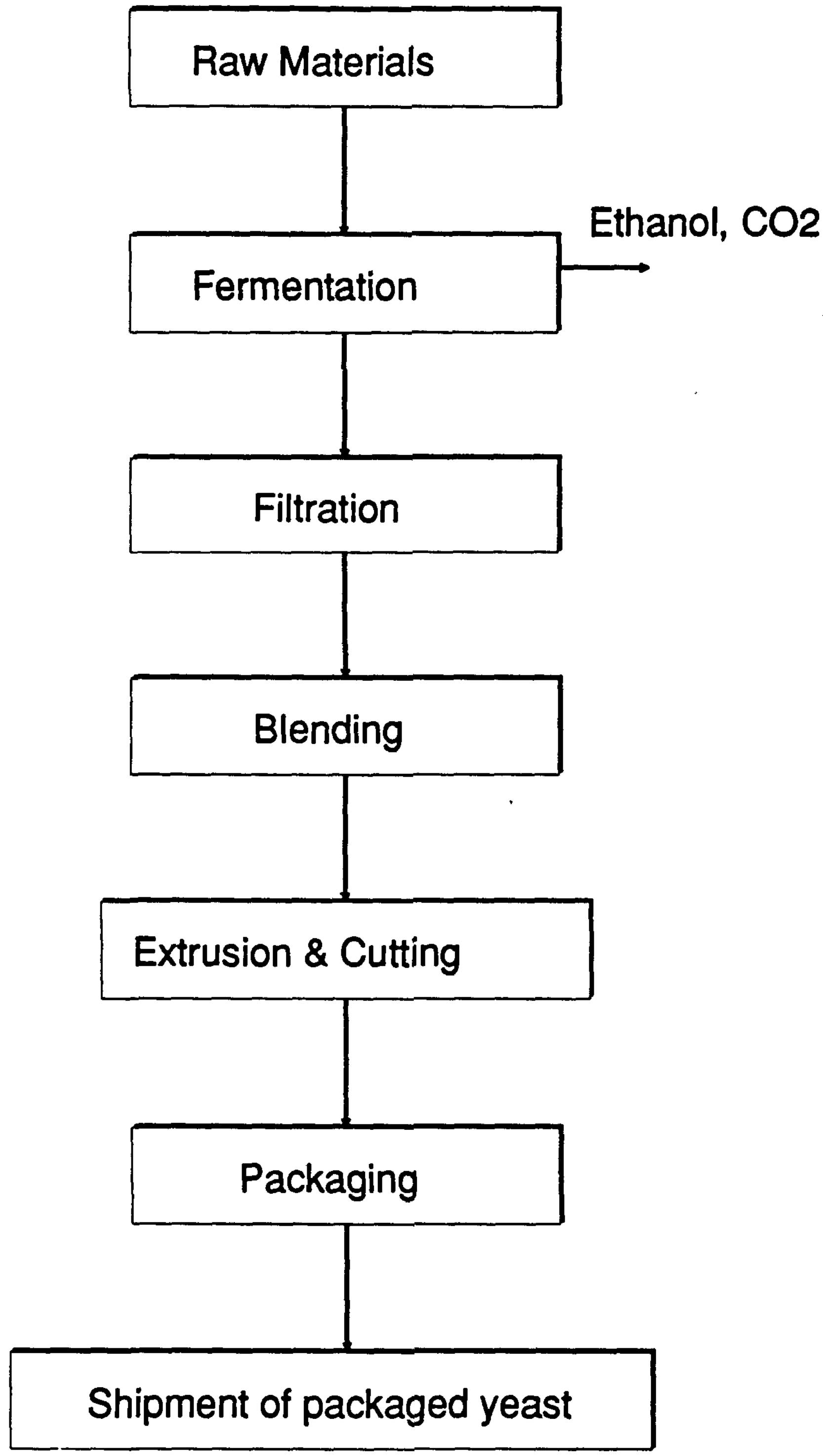

Figure 1. Process flow diagram for producing baker's yeast.

raisins, or sugar-containing wastes of the confectionary industry are also effective, but for various reasons (mostly economic), these 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, potassium, 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,

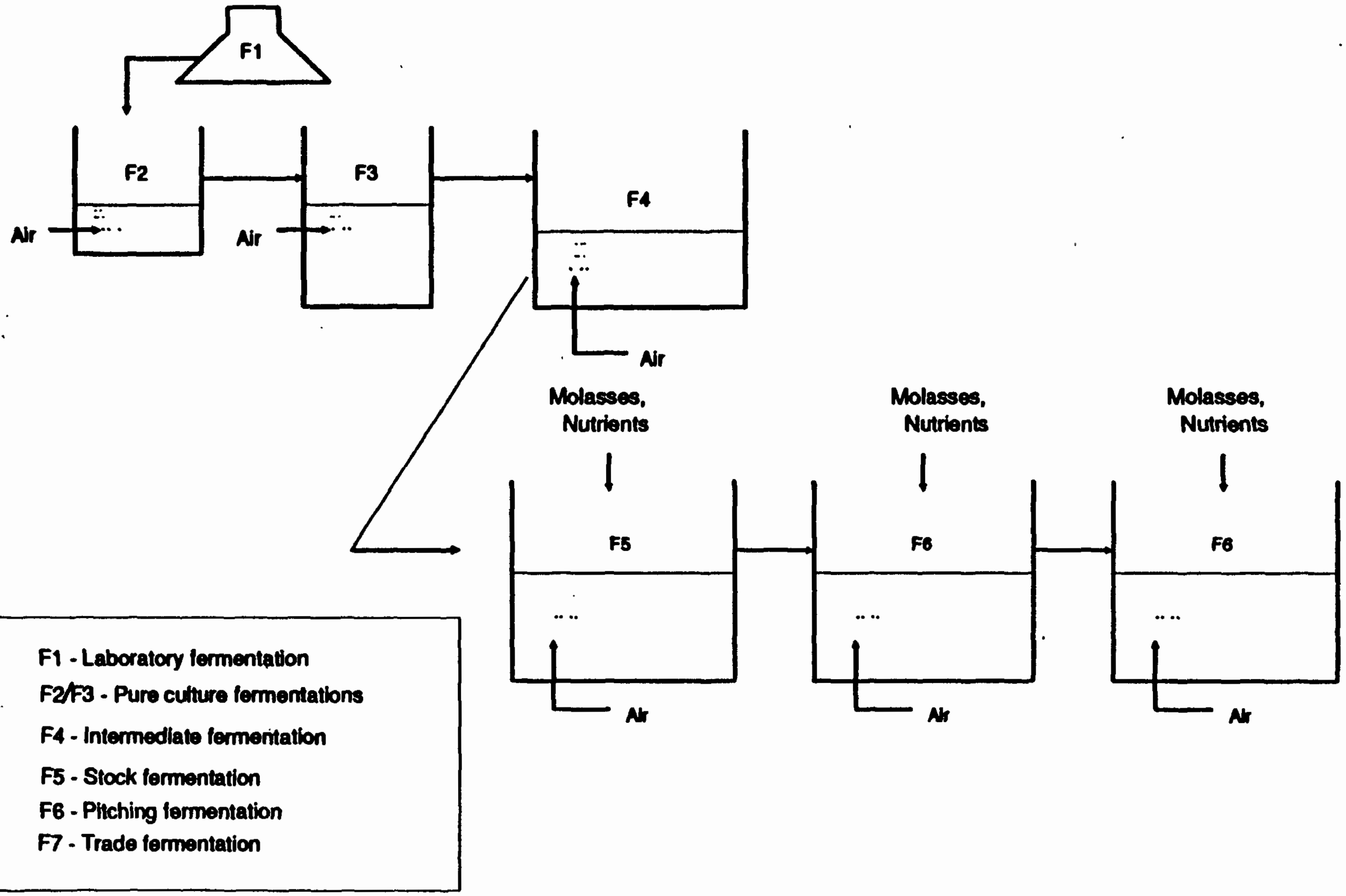

Figure 2. Fermentation sequence used in producing baker's yeast.

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 have baffles to keep the fermentor liquid from rotating in the direction of the motion of the disc. This uniform distribution of air bubbles reduces the volume of air needed to grow the yeast. In an agitated system, only 10 to 15 m^3 (350 to 530 ft^3) of air are required to produce 0.45 kg (1 lb) of yeast.[10]

The self-priming aerator operates with a turbine that draws air through a hollow, vertical shaft into the fermentor liquid. Because air is drawn through the shaft of the turbine without a compressor, the pressure of the air at the outlets is not very high and the depth to which the turbine can be submerged is limited.

When using the four-stage fermentation series, the pure culture stage is followed by an intermediate stage (F4) of yeast growth without incremental feeding. The entire fermentor contents from the intermediate stage are then pumped into a tank that is equipped for incremental feeding and that has good aeration. This stage (F5) is often called stock fermentation because, after fermentation is completed, the yeast is separated from the bulk of the fermentor liquid by centrifuging, producing 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 11 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 fermentation process. The two major by-products are ethanol, which 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 stages (pure culture stages) than in the final stages of the fermentation 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 systems 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

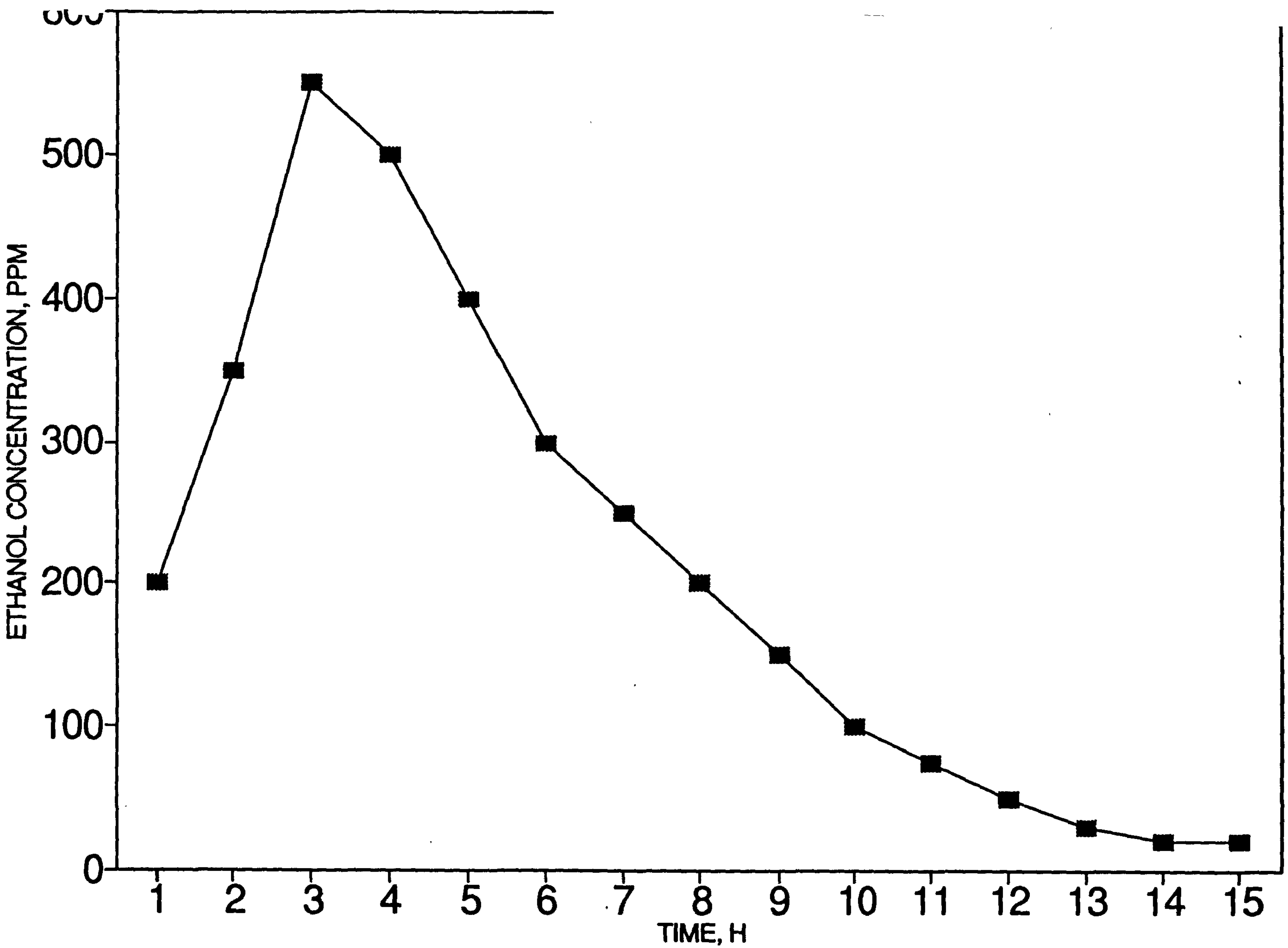

Figure 3. Emissions profile of a typical trade fermentation.

the precise demand for sugar. By continuously adding only the exact amount of molasses required by the fermentation, conditions of 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.

5.2 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

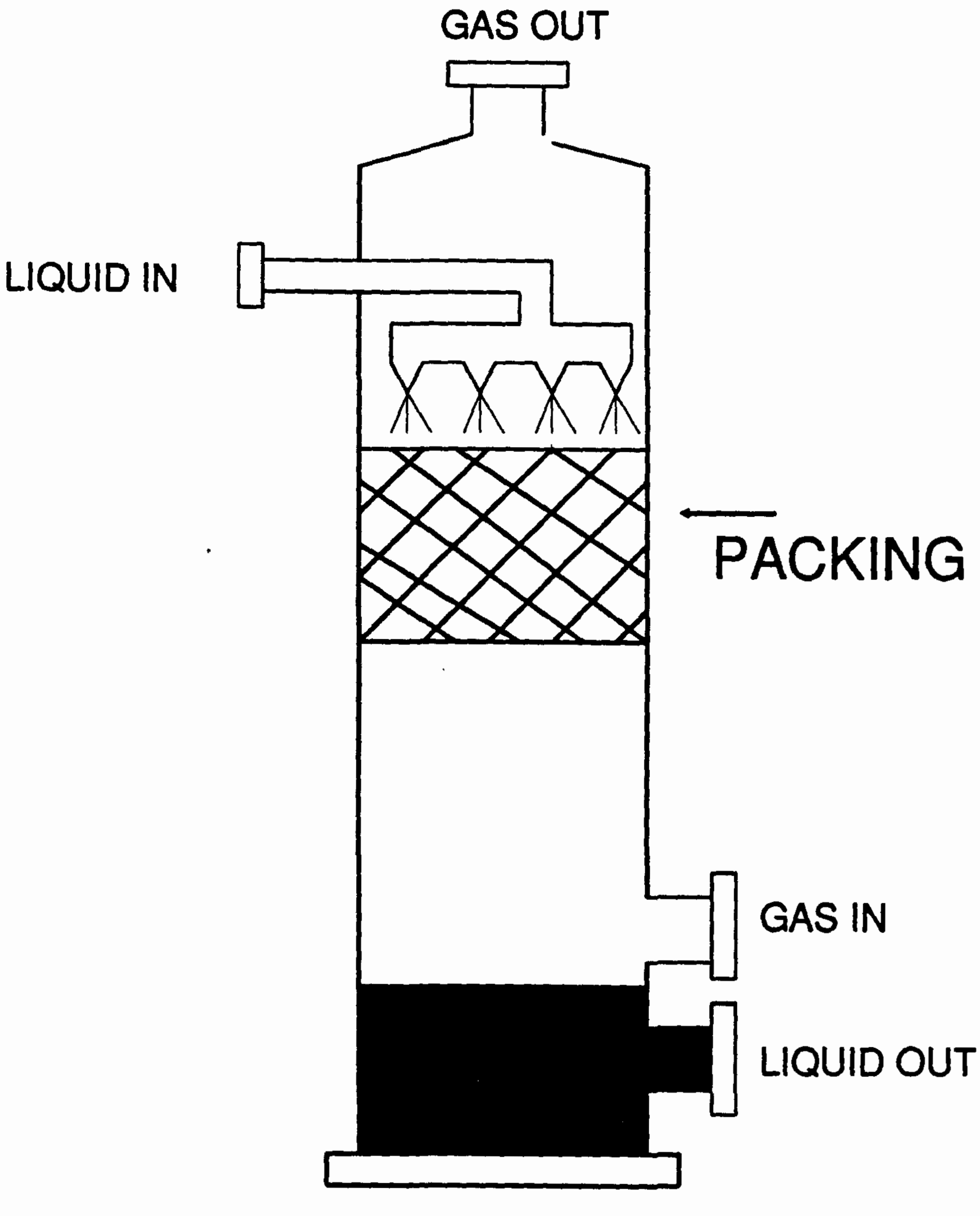

Figure 4. Schematic of packed tower absorber.

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 process 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 for 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

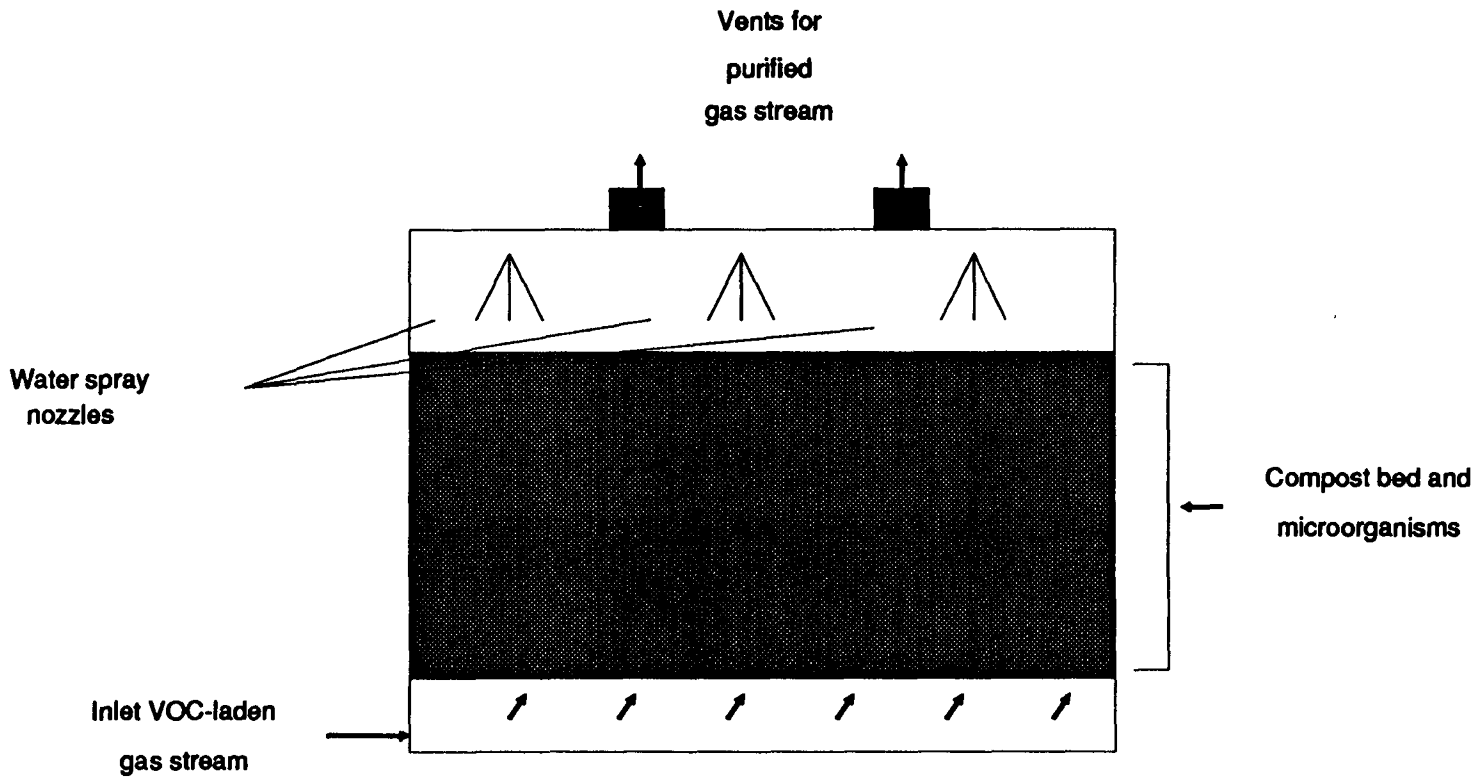

Figure 5. Schematic of a biofiltration system.

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
Direct 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.

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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 large quantities of ethanol and acetaldehyde. Currently, 13 facilities produce baker'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		
instant dry yeast	biological filtration		

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