Emission Factor Documentation for AP-42
Section 9.13.4

Yeast Production

Final Report

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch

EPA Contract No. 68-D2-0159
Work Assignment No. I-08

MRI Project No. 4601-08

March 4, 1994

Emission Factor Documentation for AP-42
Section 9.13.4

Yeast Production

Final Report

EPA Contract No. 68-D2-0159
Work Assignment No. I-08

MRI Project No. 4601-08

Prepared For
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Technical Support Division
Emission Inventory Branch
Research Triangle Park, NC 27711

Mr. Dallas Safriet (MD-14)
Emission Factor and Methodologies Section

March 4, 1994

NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68-D2-0159 to Midwest Research Institute. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Emission Inventory Branch, Technical Support Division, Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under EPA Contract No. 68-D2-0159. The EPA work assignment manager for this project is Mr. Dallas Safriet.

CONTENTS

	Page
PREFACE	iii
FIGURES	v
TABLES	v
1. INTRODUCTION	1
2. INDUSTRY DESCRIPTION	2
2.1 INDUSTRY CHARACTERIZATION	2
2.2 PROCESS DESCRIPTION	2
2.2.1 Raw Materials	3
2.2.2 Fermentation	5
2.2.3 Concentration of Yeast Solids and Filtration	8
2.2.4 Extrusion, Cutting, and Packaging	8
2.2.5 Production of Dry Yeast	8
2.3 EMISSIONS	9
2.4 CONTROL TECHNOLOGY	9
REFERENCES FOR SECTION 2	10
3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES	12
3.1 LITERATURE SEARCH AND SCREENING	12
3.2 DATA QUALITY RATING SYSTEM	12
3.3 EMISSION FACTOR QUALITY RATING SYSTEM	13
REFERENCES FOR SECTION 3	14
4. AP-42 SECTION DEVELOPMENT	15
4.1 REVIEW OF SPECIFIC DATA SETS	15
4.2 DEVELOPMENT OF CANDIDATE EMISSION FACTORS	17
REFERENCES FOR SECTION 4	20
5. PROPOSED AP-42 SECTION 9.13.4	21

FIGURES

NUMBER		PAGE
2-1	Typical process flow diagram for the seven-stage production of baker's yeast, with Source Classification Codes	4
2-2	Typical fermentation process	5

TABLES

2-1	YEAST MANUFACTURING PLANTS	2
4-1	VOC EMISSIONS FROM YEAST FERMENTATION	18
4-2	VOC EMISSIONS FOR A TYPICAL YEAST MANUFACTURING FACILITY	19

SECTION 1

INTRODUCTION

The document Compilation of Air Pollutant Emissions Factors (AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. The EPA also routinely updates AP-42 sections in response to the needs of Federal, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. Emission factors reported in AP-42 are used to:

1. Estimate areawide emissions;
2. Estimate emissions for a specific facility; and
3. Evaluate emissions relative to ambient air quality.

The purpose of this background report is to provide information to support preparation of a new AP-42 Section 9.13.4, Yeast Production.

The remainder of this report consists of four sections. Section 2 provides a description of the yeast production industry. Section 3 describes the process of data review, guidelines for rating emission source reports, and guidelines for rating emission factors. Section 4 presents the development of the emission factor for the draft AP-42 Section. Section 5 presents the proposed AP-42 Section 9.13.4, Yeast Production.

SECTION 2

INDUSTRY DESCRIPTION

2.1 INDUSTRY CHARACTERIZATION[1]

Baker's yeast (SIC Code 2099) is currently manufactured by six major companies in the United States. These companies are Universal Foods (Red Star Yeast), Fleischmanns, Gist-brocades, Lallemand (American Yeast), Minn-dak, and Columbia. There are 13 manufacturing plants owned by these companies. Table 2-1 lists the locations of these plants by manufacturer.

TABLE 2-1. 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

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

2.2 PROCESS DESCRIPTION[1-3]

Two main types of baker's yeast are produced: compressed yeast and active dry yeast (ADY). Compressed yeast is perishable and must be refrigerated or frozen at all times. Active dry yeast has a lower bake activity than compressed yeast but can be stored for 1 to 2 years without refrigeration before the bake activity is lost.

Compressed yeast is sold mainly to wholesale bakeries, and ADY is sold mainly to consumers for home baking needs. Compressed yeast and ADY are produced in a similar manner, but dry yeasts are developed from a different yeast strain and dried after processing. One type of dry yeast, instant dry yeast (IDY), is produced from a faster-reacting yeast strain than that used for ADY. The main difference between ADY and IDY is that ADY has to be dissolved in warm water before usage, but IDY does not.

Figure 2-1 is a process flow diagram for the production of baker's yeast. 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.

The first stage of production consists of growing the yeast from the pure yeast culture in a series of fermentation vessels. The yeast is recovered from the final fermentor using centrifugal action to concentrate the yeast solids. Next, the yeast product is subjected to one or more washings in another centrifugal separator. The yeast solids are then filtered by a filter press or a rotary vacuum filter to concentrate the yeast further. Then, the yeast filter cake is blended in mixers with small amounts of water, emulsifiers, and cutting oils. After mixing, the mixed pressed yeast cake is extruded, cut, and either packaged or dried to form dry yeast and then packaged. The stages of the production of baker's yeast are discussed in more detail below.

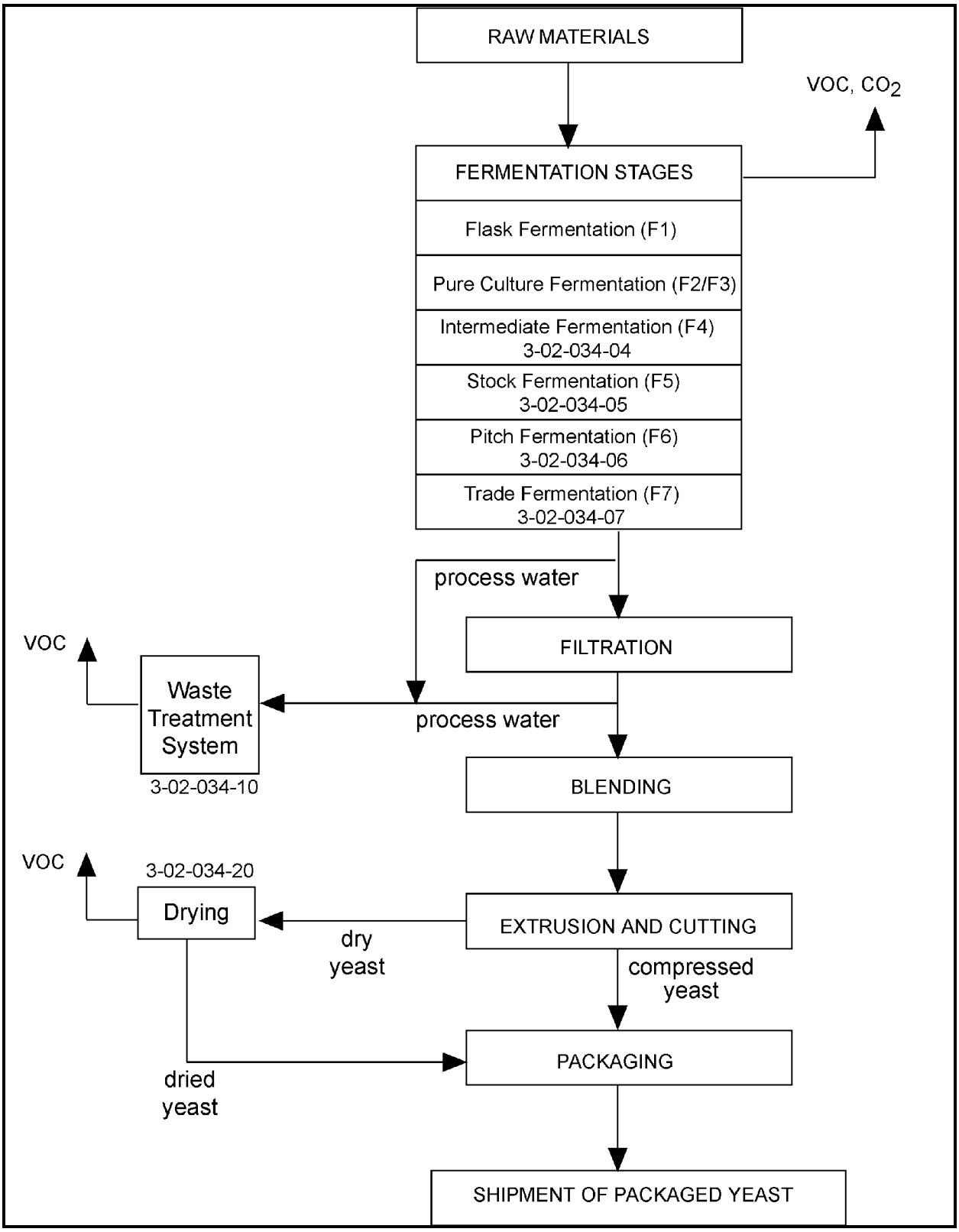

Figure 2-1. Typical process flow diagram for the seven-stage production of baker's yeast, with Source Classification Codes.

2.2.1 Raw Materials[1-3]

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*. Cane and beet molasses are used as the principal carbon sources to promote yeast growth. Molasses contains 45 to 55 weight percent fermentable sugars in the forms of sucrose, glucose, and fructose. Other sources of sugar, such as corn grits or raisins, are available, but molasses is the least expensive source of sugar known. Usually, a blend consisting of both cane and beet molasses is used in the fermentations.

Other raw materials required for producing baker's yeast include nitrogen, potassium, phosphate, magnesium, and calcium. Nitrogen is usually supplied through the addition of ammonium salts, aqueous ammonia, or anhydrous ammonia to the feedstock. Sufficient quantities of potassium and calcium normally come from the molasses. Phosphates and magnesium are added in the form of phosphoric acid or phosphate salts and magnesium salts. 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. Thiamine is normally added to the feedstock 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.

Once the feed materials are blended, the pH of the molasses mixture is adjusted because an alkaline solution is conducive to bacteria growth. Bacteria growth occurs under the same conditions as yeast growth, making pH monitoring very important. Optimum yeast yields are obtained at pH values between 4.5 and 5.0. The pH of the fermentation mixture is partly controlled by the feed rate of ammonia to the fermentation.

Following pH adjustment, the molasses mixture is clarified to remove any sludge. The clarified molasses mixture is subsequently sterilized with high-pressure steam, diluted with water, and held in holding tanks until it is needed for the fermentation process.

2.2.2 Fermentation[1-3]

Yeast cells are grown in a series of fermentation vessels. A typical fermentation process is shown in Figure 2-2. In general, the process consists of placing a laboratory-grown pure yeast culture, along with the other feed materials, into the first fermentor and allowing the yeast to grow. Yeast is propagated when the mixture (or a portion of the mixture) is placed in consecutive fermentors that are equipped for batch or incremental feeding of the molasses malt.

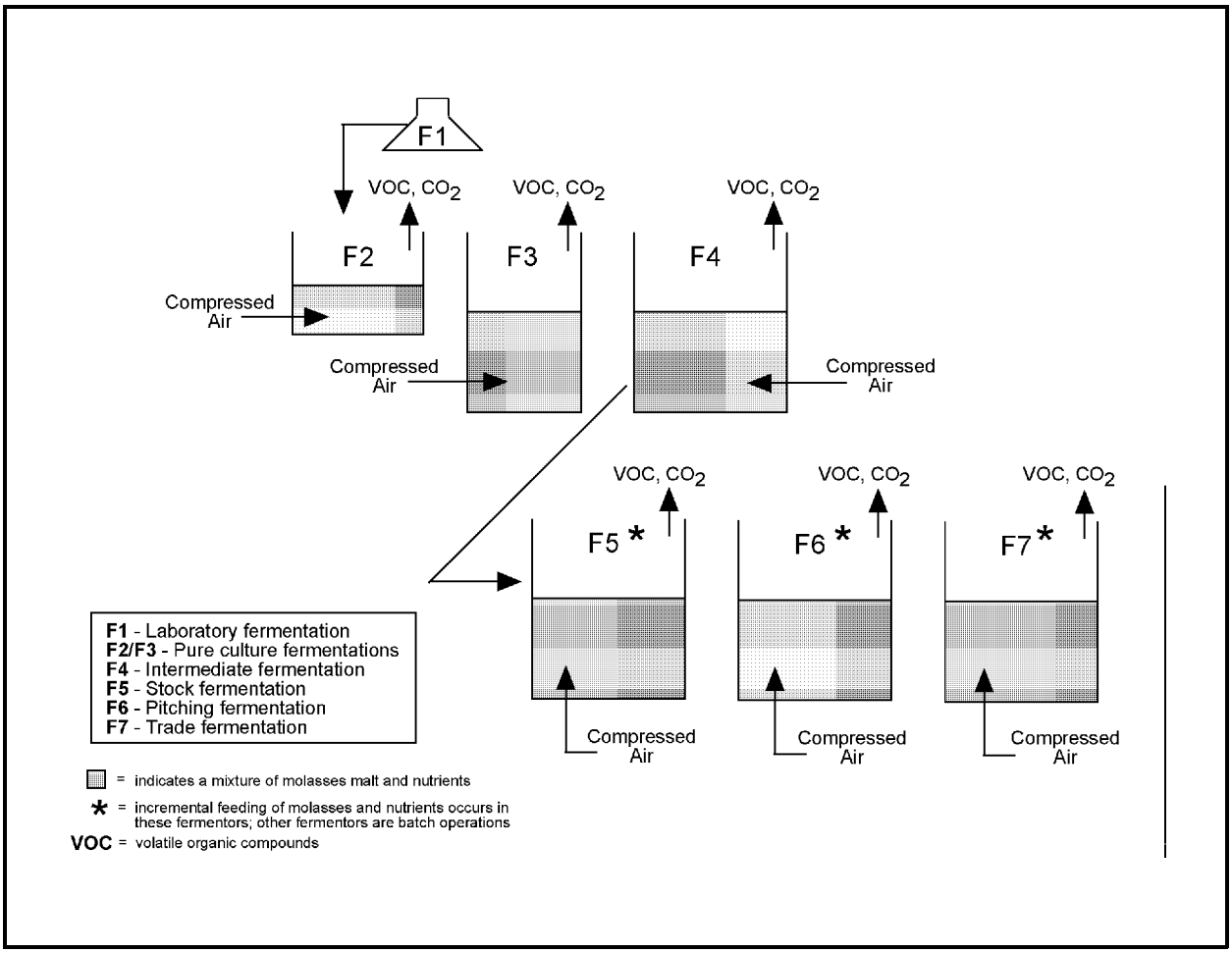

Figure 2-2. Typical fermentation process.

Yeast fermentation vessels are operated under aerobic conditions (free oxygen or excess air present) because under anaerobic conditions (limited or no oxygen), the fermentable sugars are consumed in the formation of ethanol and carbon dioxide, which results in low yeast yields. To maximize yeast yields, it is important to supply enough oxygen to keep the dissolved oxygen content in the liquid surrounding the yeast cells at an optimal level. In practice, however, oxygen transfer rates are often inadequate. Under such conditions, some ethanol is formed. In addition, it is also important to control the amount of fermentable sugars present, 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, which is further described in Section 2.2.2.3.

In the first stages of yeast propagation, the medium is richer in nutrients and there is less aeration than in subsequent fermentation stages. Consequently, the fermentor liquor in the initial stages contain more alcohol, and yields of yeast are lower than in later stages. Lower yeast yields in the initial stages are not necessarily a drawback because the overall economy of the operation depends on the yield from the final trade fermentation stage. The following subsections describe each stage in the fermentation sequence. The stage notations in parentheses (F1, F2, etc.) refer to the stages identified in Figure 2-2.

2.2.2.1 Laboratory Stage (F1). The initial fermentation stage (F1) takes place in the laboratory. A portion of the pure yeast culture is mixed with the molasses malt in a sterilized flask. The total contents of the flask are typically less than 5 liters (L) (1.3 gallon [gal]), and the yeast is allowed to grow in the flask for 2 to 4 days. The entire flask contents are then used to inoculate the second fermentation stage.

2.2.2.2 Pure Culture Stages (F2 and F3). Typically, the next stage consists of two pure culture fermentations (F2 and F3). 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 in which the yeast is allowed to grow for 13 to 24 hours (hr). The contents of the fermentor from the first pure culture stage (F2) are added to the next fermentation vessel, which already contains the nutrient-rich molasses malt. These fermentations are a continuation of the flask fermentation, except that they 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 this stage 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. Microbiological testing of the medium before, during, and after each fermentation is essential.

2.2.2.3 Main Fermentation Stages (F4-F7). The majority of the yeast yield grows in the final fermentation stages (F4 to F7). The main fermentation steps may take place in a two-stage or four-stage sequence, depending on company operations. The fermentors used in the final stages are usually constructed of stainless steel and vary considerably in size, ranging from 37,900 L (10,000 gal) to over 283,900 L (75,000 gal). These 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 30°C (86°F).

Fermentors are usually equipped with an incremental feed system. This incremental feed system may be a pipe or a series of pipes that distributes 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 added through rotameters into the fermentor. The rate of this feed is not as critical as the molasses feed rate. However, if ammonia is used as a nitrogen source, additions must be made in a manner that avoids sudden pH changes. Nitrogen salts and phosphates may be charged in a shorter period of time than the molasses.

Fermentors used in the final stages 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 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 and the type of aeration system selected are interdependent. 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 cubic meters (m^3) (880 to 1,060 cubic feet [ft^3]) of air to produce 0.45 kilograms (kg) (1 pound [lb]) of yeast.

The efficiency of aeration with a given volume of air is 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 disk 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 disk. 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.

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 the four-stage fermentation series is used, the pure culture stage (F3) is followed by the first of the four stages, an intermediate stage (F4) of yeast growth without incremental feeding. The entire fermentor contents from the intermediate stage then enter the second stage, where they are 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, or 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 liquid from this fermentor (F6) is usually divided into several parts, creating a pitch of yeast for the final trade fermentation. Alternately, the yeast may be separated by centrifuging and stored for several days prior to being used in the final trade fermentations.

The final trade fermentation (F7), stage four, has the highest degree of aeration, and molasses and other nutrients are fed incrementally. Large air supplies are required during the final trade fermentations, so these vessels are often started in a staggered fashion to reduce the size of the air compressors required. The duration of each of the final fermentation stages ranges from 11 to 15 hr.

In each of the above stages, the liquid is aerated for an additional 0.5 to 1.5 hr after all of the required molasses has been fed into the fermentor. This extended aeration period permits further maturing of the yeast and more stability in refrigerated storage.

The amount of yeast growth increases in each of the main fermentation stages (F4 through F7) and is typically 120 kg (270 lb) in the first stage, 420 kg (930 lb) in the second stage, 2,500 kg (5,500 lb) in the third stage, and 15,000 to 100,000 kg (33,000 to 220,000 lb) in the fourth stage. When the two-stage final fermentation series is used, 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.

2.2.3 Concentration of Yeast Solids and Filtration[1,2]

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. A yeast solids concentration between 18 and 21 percent is desired. Two or three passes through the separators are normally required to achieve this solids content. 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 filter 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 and 1,030 kilopascal (kPa) (125 to 150 pounds per square inch [psi]) are applied. Yeast yields between 27 and 32 percent solids may be obtained by pressing.

Rotary vacuum filters are also 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. 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.

2.2.4 Extrusion, Cutting, and Packaging[1]

After filtration, the filter cake is blended in mixers with small amounts of water, emulsifiers, and cutting oils to form the end product. 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. For producing compressed yeast, the ribbons are cut, and the yeast cakes are wrapped with wax paper and cooled to below 8°C (46°F), at which time they are ready for shipment in refrigerated trucks.

2.2.5 Production of Dry Yeast[1,2]

Although ADY and IDY are each produced from different yeast strains than that used in producing compressed yeast, they 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 it. After the yeast is extruded in thin ribbons, it is cut and 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 hr. 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 heat-sealing. The shelf life of ADY and IDY at ambient temperature is 1 to 2 years.

2.3 EMISSIONS[1]

Volatile organic compound (VOC) emissions are generated as byproducts of the yeast fermentation process. The two major byproducts emitted are ethanol, which is formed from acetaldehyde, and carbon dioxide. Other byproducts consist of other alcohols, such as butanol, isopropyl alcohol, 2,3-butanediol, organic acids, and acetates; these byproducts form as a result of either excess sugar present in the fermentor or an insufficient oxygen supply to it. Under these conditions, anaerobic fermentation occurs, breaking down the excess sugar in to 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, ethanol formation increases as yeast yields decrease. Therefore, manufacturers strive to suppress ethanol formation in the final fermentation stages by process control, i.e., 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 than in the final stages of the fermentation process. The earlier fermentation stages are batch fermentors, in which 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. Therefore, there is no economic reason for equipping the earlier fermentation stages with process control equipment.

Another potential emission source at yeast manufacturing facilities is the wastewater treatment system used to treat process wastewaters. If the facility does not use 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 Control Technology Center (CTC) document on industrial wastewater treatment systems entitled "Industrial Wastewater Volatile Organic Emissions--Background Information for BACT/LAER Determinations," or to Section 4.13 of AP-42. At facilities manufacturing dry yeast, VOC's may also be emitted from the dryers used to dry the yeast. However, no information on the relative quantity of VOC emissions from this source is known.

2.4 CONTROL TECHNOLOGY[1,4-6]

Only one yeast manufacturing facility uses an add-on pollution control system to reduce VOC emissions from the fermentation process. However, all yeast manufacturers suppress ethanol formation through varying degrees of process control. Traditionally, yeast manufacturing facilities have implemented incremental feed systems on the final fermentation vessels in an effort to optimize yeast yields and suppress ethanol formation. Incrementally feeding the molasses mixture to the fermentors so that excess sugars are not present helps to suppress ethanol formation. However, these feed systems were established to add a given amount of molasses and nutrients over specified time intervals. A greater degree of control can be achieved by implementing a continuous monitoring system.

Both yeast and ethanol formation are directly related to the sugar concentration. Therefore, by optimizing the sugar feed rate, the rate of ethanol formation is controlled. Because a sensor is not available

that can directly measure sugar concentration, other related parameters are measured. For example, a process control system could be developed that monitors airflow, carbon dioxide and ethanol production, and oxygen consumption. A computer can take this information and, through material balance techniques, calculate sugar consumption rate and other related parameters. Based on the monitored information, the computer continuously controls the addition of molasses. This type of system is feasible, but it is difficult to design and implement. Some yeast manufacturing facilities have implemented varying degrees of computerized process control in conjunction with stack gas monitoring on the final trade fermentations. However, the exact process control techniques used by these facilities are not presented in this document because the information is considered to be confidential business information.

Another method of process control used at the facilities to suppress ethanol formation relates to the design of the air sparger system on the fermentor. (see Section 2.2.2.3 for a description of different types of aeration systems). The distribution of oxygen by the air sparger system to the malt mixture is critical. If oxygen is not being transferred uniformly throughout the malt, then ethanol will be produced in the oxygen-deficient areas of the fermentor. The type and position of baffles and/or a highly effective mechanical agitation system can ensure proper distribution of oxygen.

Based on available emission test data, it is anticipated that an overall emission reduction of 75 to 95 percent can be achieved through the combination of continuous monitors or feedback controls and optimizing fermentor design.

Only one yeast manufacturing facility uses an add-on control device for VOC emission control. The pollution control system at this facility consists of a wet scrubber followed by a biological filter. Performance data from this unit suggest an overall VOC emission control efficiency of better than 90 percent.

REFERENCES FOR SECTION 2

1. *Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities*, EPA-450/3-91-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1992.

2. S. L. Chen and M. Chigar, "Production of Baker's Yeast," *Comprehensive Biotechnology, 20*:74-76, 430-442 (1985), Pergamon Press, New York, NY.

3. G. Reed and H. Peppler, *Yeast Technology*, Avi Publishing Company, Westport, CT, 1973.

4. H. Y. Wang *et al*. "Computer Control Of Baker's Yeast Production," *Biotechnology and Bioengineering*, Cambridge, MA, *21*:975-995 (1979).

5. Written correspondence from R. Barker and M. Williamson, MRI, Cary, NC, to M. Smith, ESD/CPB, Research Triangle Park, NC, August 1991, trip report for Gist-brocades, East Brunswick, NJ.

6. Written correspondence from R. Barker, MRI, Cary, NC, to M. Smith, ESD/CPB, Research Triangle Park, NC. January 1992, Process Control Measures in Use at Yeast Manufacturing Facilities.

SECTION 3

GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

This section describes the literature search to collect emission data and the EPA quality rating systems applied to data and to any emission factors developed from those data.

3.1 LITERATURE SEARCH AND SCREENING

Midwest Research Institute conducted a search of the available literature related to emissions from yeast production. This search included data contained in the open literature (e.g., National Technical Information Service); source test reports and background documents from EPA's Office of Air Quality Planning and Standards (OAQPS); and MRI's internal files (Kansas City and North Carolina offices).

During the review of each document, the following criteria were used to determine the acceptability of reference documents for emission factor development:

1. The report must be a primary reference:

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data.

2. The referenced study must contain test results based on more than one test run.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

3.2 DATA QUALITY RATING SYSTEM[1]

Based on OAQPS guidelines, the following data are always excluded from consideration in developing AP-42 emission factors:

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods; and

3. Test series in which the production and control processes are not clearly identified and described.

If there is no reason to exclude a particular data set, data are assigned a quality rating based on an A to D scale specified by OAQPS as follows:

A--This rating requires that multiple tests be performed on the same source using sound methodology and reported in enough detail for adequate validation. Tests do not necessarily have to

conform to the methodology specified by EPA reference test methods, although such methods are used as guides.

B--This rating is given to tests performed by a generally sound methodology but lacking enough detail for adequate validation.

C--This rating is given to tests that are based on an untested or new methodology or that lack a significant amount of background data.

D--This rating is given to tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following are the OAQPS criteria used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated should be well documented in the report, and the source should be operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures should conform to a generally accepted methodology. If actual procedures deviate from accepted methods, the deviations must be well documented. When such deviations occur, an evaluation should be made of how such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data should be documented in the report. Many variations can occur without warning during testing and sometimes without being noticed. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports should contain original raw data sheets. The nomenclature and equations used are compared to those specified by EPA (if any) to establish equivalency. The depth of review of the calculations is dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn is based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM[1]

The EPA guidelines specify that the quality of the emission factors developed from analysis of the test data be rated utilizing the following general criteria:

A--Excellent: The emission factor was developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* was specific enough to minimize variability within the source category population.

---

* Source category: A category in the emission factor table for which an emission factor has been calculated.

B--Above average: The emission factor was developed only from A-rated test data from a reasonable number of facilities. Although no specific bias was evident, it was not clear if the facilities tested represented a random sample of the industries. As in the A-rating, the source category was specific enough to minimize variability within the source category population.

C--Average: The emission factor was developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias was evident, it was not clear if the facilities tested represented a random sample of the industry. As in the A-rating, the source category was specific enough to minimize variability within the source category population.

D--Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there was reason to suspect that these facilities did not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E--Poor: The emission factor was developed from C- and D-rated test data, and there was reason to suspect that the facilities tested did not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of the above criteria is somewhat subjective depending to a large extent on the individual reviewer. Details of how each candidate emission factor was rated are provided in Section 4.

REFERENCES FOR SECTION 3

1. *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

SECTION 4

AP-42 SECTION DEVELOPMENT

This section describes the test data and methodology used to develop pollutant emission factors for yeast production. Section 9.13.4, Yeast Production, will be entirely new to Chapter 9 of AP-42.

4.1 REVIEW OF SPECIFIC DATA SETS[1-7]

Five references were documented and reviewed during the literature search. These references are listed at the end of this chapter. The first reference presented the results of an EPA-funded study that provided an overview of the baker's yeast production process, summarized available data on VOC emissions from baker's yeast manufacturing facilities, and evaluated potential emission control options. The remaining references consisted of emission test data from three yeast manufacturing facilities.

Reference 1

This report provided a general overview of the yeast production industry and summarized available data on VOC emissions from baker's yeast manufacturing facilities. Typical emission factors were based either on fermentor operating capacity or on yeast production. These emission factors were used to estimate the total nationwide VOC emissions from yeast manufacturing.

The input data from which the emission factors were generated were generally the result of sound sampling techniques that were well documented. The data used in this study are the same data described in References 2 through 5, which were rated as described below. Because Reference 1 only summarizes these data, it was not rated.

Reference 2

This reference reports the results of tests to determine compliance of the VOC emission rates from fermentor No. 3, a trade fermentor (F7), at the Universal Foods plant in Baltimore, Maryland with Maryland VOC regulations. Emissions from the fermentor were continuously monitored throughout a 15-hr batch process.

The VOC emissions were measured as propane with a flame ionization analyzer using EPA Reference Method 25A. The average VOC emissions measured as propane were calculated for each 1-hr interval throughout the test. Data were converted to total VOC's as ethanol, based on the assumption that the primary VOC emitted is ethanol. (Approximately 80 to 90 percent of the emissions generated are ethanol, and the remaining 10 to 20 percent consists of other alcohols and acetaldehyde.) The following equation was used to convert emissions from parts per million by volume (ppmv) propane to ppmv ethanol:

$$\text{ppmv ethanol} = \text{ppmv propane}/0.47$$

The factor of 0.47 is the ratio of the effective carbon number of ethanol to the effective carbon number for propane (1.4/3.0). The effective carbon number is a function of the number and type of molecular bonds in a compound. Each type of bond is assigned a value; an aliphatic bond, for example, has a value of one. The effective carbon number is calculated by assigning each carbon atom in the compound a value based

on the type of bond with which it is associated, then modifying this value for each noncarbon bond. Because propane consists of three carbon molecules, each with an aliphatic bond, an effective carbon number of three is assigned. Ethanol has two carbon atoms involved in an aliphatic bond which would yield an effective carbon number of two. However, the alcohol bond is assigned a value of -0.6; thus, the overall effective carbon number for ethanol is 1.4.

Flow was measured by Maryland Air Management Administration Stack Methods 1001 and 1002. These methods are analogous to EPA Methods 1 and 2, respectively, for flow measurement and identify the number and location of air flow sampling points. Raw data and calculation examples are included in the report. The data reported represent the results of a single test from a source that is believed to have a significant degree of variability in the emissions, so these data were assigned a rating of D.

Reference 3

This reference is a VOC compliance test report for fermentor No. 5, a trade fermentor (F7), at the American Yeast facility in Baltimore, Maryland. Emissions from the fermentor were continuously monitored throughout a 15-hr batch process.

The VOC emissions were measured as propane with a flame ionization analyzer using EPA Reference Method 25A. The average VOC emissions measured as propane were calculated for each 1-hr interval throughout the test. Data were converted to total VOC's as ethanol as explained above, based on the assumption that the primary VOC emitted is ethanol. Flow was measured by Maryland Air Management Administration Stack Methods 1001 and 1002. Raw data and calculation examples were included in the report. The data reported represent the results of a single test from a source that is believed to have a significant degree of variability in the emissions, so these data were assigned a rating of D.

Reference 4

This reference is a test report to determine the emission rates from three fermentors at the Gist-brocades plant in East Brunswick, New Jersey. One of the fermentors was a stock fermentor (F5), and the others were trade fermentors (F7). Two tests were performed on each of three fermentors. The samples were analyzed by gas chromatography (GC) for isoamyl alcohol, isobutyl alcohol, isopropyl alcohol, ethanol, and acetone. Unidentified peaks were quantitated with the same response factor as ethanol. Results were reported as micrograms per liter of gas sampled and were converted to ppmv.

The only documentation of test procedures was a list of the GC parameters. There was no indication of the methodology used to measure airflow. Also, sampling procedures were not described, and no raw data or calculation examples were included. Therefore, these data were assigned a rating of D.

Reference 5

This reference reported the results of tests that were performed in 1990 at a Universal Foods plant to determine the VOC emissions from each of the fermentation stages other than the pure culture stage. Throughout a batch process, samples were drawn from the exhaust gas stream of each of the fermentors. Analyses were performed at 20-min intervals, and each sample represented an average concentration over the 20-min period prior to extraction. The samples were analyzed by gas chromatography for ethanol.

Ethanol concentrations were calculated as part per million by weight (ppmw), and based on the measured airflow, total ethanol emissions during the batch process were reported for each of the five fermentors. Results were reported as total mass of emissions and represented the results of a single test for each process. Although there was no reference to any standard protocol, the procedures were described and are deemed valid. Raw data and calculation examples were given for calibrations as well as samples. Multiple tests were not conducted for each fermentor, and the sources are believed to have a significant degree of variability in the emissions. For these reasons, the results reported were assigned a rating of D.

Emission test data from the above references include data from a total of three yeast manufacturing facilities. From a combination of these three facilities, emission test data were available for the last four fermentation stages (F4 to F7).

4.2 DEVELOPMENT OF CANDIDATE EMISSION FACTORS[1-5,8]

During the fermentation process, ethanol and acetaldehyde are not formed at constant rates. Therefore, over the course of fermentation, the concentrations of these compounds vary significantly, depending on 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 varied from fermentor to fermentor because of the differences in the design of the aeration system and the placement of baffles and mechanical agitators within the fermentors.

Table 4-1 summarizes the industry test data, presenting the VOC emission levels measured during batch cycles for each type of fermentation. All emission test data expressed in terms of total VOC were converted to total VOC as ethanol because ethanol is the primary VOC compound emitted. The raw emission and process data provided by industry and all emission calculations that form the basis for Table 4-1 are contained in a confidential memorandum to the project files.

TABLE 4-1. VOC EMISSIONS FROM YEAST FERMENTATION[a]

DATA QUALITY RATING: E

	Fermentation stages		
	F4 (intermediate)	F5/F6 (stock/pitch)	F7 (trade)
Emission data[2-5]			
Concentration range, ppmv	900 to 4,600	2 to 1,350	5 to 600
Average concentration, ppmv	1,900 to 2,400	50 to 700	20 to 325
Maximum concentration, ppmv	2,800 to 4,600	165 to 1,350	140 to 600
Batch emissions, kg (lb)	15 to 71 (32 to 156)	6 to 480 (13 to 1,065)	4.5 to 275 (10 to 605)
Emission factors			
VOC's emitted per volume of fermentor operating capacity (tank size), kg/L (lb/gal)	0.0006 to 0.0014 (0.005 to 0.012)	0.0001 to 0.002 (0.0008 to 0.015)	0.000036 to 0.001 (0.0003 to 0.008)

The emission data provided by industry indicated significant variation in VOC emission levels. To obtain more meaningful data, the process emission factors presented in Table 4-1 were developed in an effort to normalize the fluctuations in emission data between facilities and fermentors. The process emission factors developed from the process and emissions data are shown in Table 4-1 without reference to process data because the process data were considered by the facilities to be confidential business information.

A review of the process emission factors shows there is still significant variation in the process emissions. Upon reviewing process information obtained from these 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. Due to the variability of the emission factors from one facility to the next, the emission factors presented in Table 4-1 are given an E rating.

Due to the high variability of the emission factors in Table 4-1, supplementary emission levels and process emission factors were developed to represent a typical facility with a moderate degree of process

control. These are presented in Table 4-2. The emission factors in Table 4-2 were generated from the same data base as those in Table 4-1, but data points that were considered atypical of the industry were not included in the calculations. Based on process control information obtained from yeast facilities, emissions from the majority of yeast manufacturing facilities are expected to fall within the concentration ranges presented in Table 4-2. However, the emission factors are rated E due to the variability of the original data.

TABLE 4-2. VOC EMISSIONS FOR A TYPICAL YEAST MANUFACTURING FACILITY[a]

DATA QUALITY RATING: E

	Fermentation stages		
	F4 (intermediate)	F5/F6 (stock/pitch)	F7 (trade)
Emission data[1-5]			
Concentration range, ppmv	900 to 4,600	2 to 400	6 to 600
Average concentration, ppmv	2,000	165	200
Maximum concentration, ppmv	2,800 to 4,600	165 to 400	300 to 600
Batch emissions, kg (lb)	52 (115)	55 (120)	60 (135)
Typical process emission factors			
VOC's emitted per volume of fermentor operating capacity (tank size), kg/L (lb/gal)	0.0012 (0.010)	0.0003 (0.0025)	0.0004 (0.0035)
VOC's emitted per stage per amount of yeast produced in a stage, kg/Mg (lb/ton)	18 (36)	2.5 (5)	2.5 (5)
Operating time			
No. of batches per week	3	4	20
No. of batches per year	156	208	1,040

The typical emission levels for each fermentation stage reveal the process control changes between fermentation stages. The intermediate stage that follows pure culture fermentations is either batch or fed-batch. The degree of process control for the intermediate stage (F4) that follows pure culture fermentation is not as stringent as it is for trade (F7) fermentation. Less control is implemented in the early stages 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 to 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 4-2 were developed based on the average batch emissions from each fermentor and the typical number of batches produced per year. The majority of emissions are associated with trade fermentation, which accounts for 80 to 90 percent of the emissions generated from a given facility. Therefore, to estimate VOC emissions from yeast production at a facility, an estimate of emissions from the final trade fermentor stage (F7) would be a reasonable approximation. To estimate emissions from each stage, the amount of yeast produced in that stage would need to be known.

REFERENCES FOR SECTION 4

1. *Assessment of VOC Emissions and Their Control from Baker's Yeast Manufacturing Facilities*, EPA-450/3-91-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1992.

2. *Fermentor Emissions Test Report*, Prepared for Universal Foods, Inc., Baltimore, MD, Prepared by Gannett Fleming, Inc., Baltimore, MD, October 1990.

3. *Final Test Report For Fermentor No. 5*, Prepared for American Yeast, Baltimore, MD, Prepared by Gannet Fleming, Inc., Baltimore, MD, August 1990.

4. Written correspondence from J. Leatherdale, Trace Technologies, Bridgewater, NJ, to J. Hogan, Gist-brocades Food Ingredients Inc., New Brunswick, NJ, April 7, 1989.

5. *Fermentor Emissions Test Report*, Universal Foods, Inc., Baltimore, MD, Universal Foods, Inc., Milwaukee, WI, 1990.

6. *The Measurement Solution: Using a Temporary Total Enclosure for Capture Efficiency Testing*, EPA-450/4-91-020, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1991, pp. C-14-C-18.

7. Method 25A: Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer, 40 CFR 60, Appendix A, July 1, 1992.

8. Written correspondence from R. Jones, MRI, Cary, NC, to the project file, April 28, 1993, development of AP-42 emission factors for baker's yeast production.

SECTION 5

PROPOSED AP-42 SECTION 9.13.4

A proposed new AP-42 section for yeast production is presented on the following pages as it would appear in the document.

9.13.4 YEAST PRODUCTION

9.13.4.1 General[1]

Baker's yeast is currently manufactured in the United States at 13 plants owned by six major companies. Two main types of baker's yeast are produced, compressed (cream) yeast and dry yeast. The total U. S. production of baker's yeast in 1989 was 223,500 megagrams (Mg) (245,000 tons). Of the total production, approximately 85 percent of the yeast is compressed (cream) yeast, and the remaining 15 percent is dry yeast. Compressed yeast is sold mainly to wholesale bakeries, and dry yeast is sold mainly to consumers for home baking needs. Compressed and dry yeasts are produced in a similar manner, but dry yeasts are developed from a different yeast strain and are dried after processing. Two types of dry yeast are produced, active dry yeast (ADY) and instant dry yeast (IDY). Instant dry yeast is produced from a faster-reacting yeast strain than that used for ADY. The main difference between ADY and IDY is that ADY has to be dissolved in warm water before usage, but IDY does not.

9.13.4.2 Process Description[1]

Figure 9.13.4-1 is a process flow diagram for the production of baker's yeast. The first stage of yeast production consists of growing the yeast from the pure yeast culture in a series of fermentation vessels. The yeast is recovered from the final fermentor by using centrifugal action to concentrate the yeast solids. The yeast solids are subsequently filtered by a filter press or a rotary vacuum filter to concentrate the yeast further. Next, the yeast filter cake is blended in mixers with small amounts of water, emulsifiers, and cutting oils. After this, the mixed press cake is extruded and cut. The yeast cakes are then either wrapped for shipment or dried to form dry yeast.

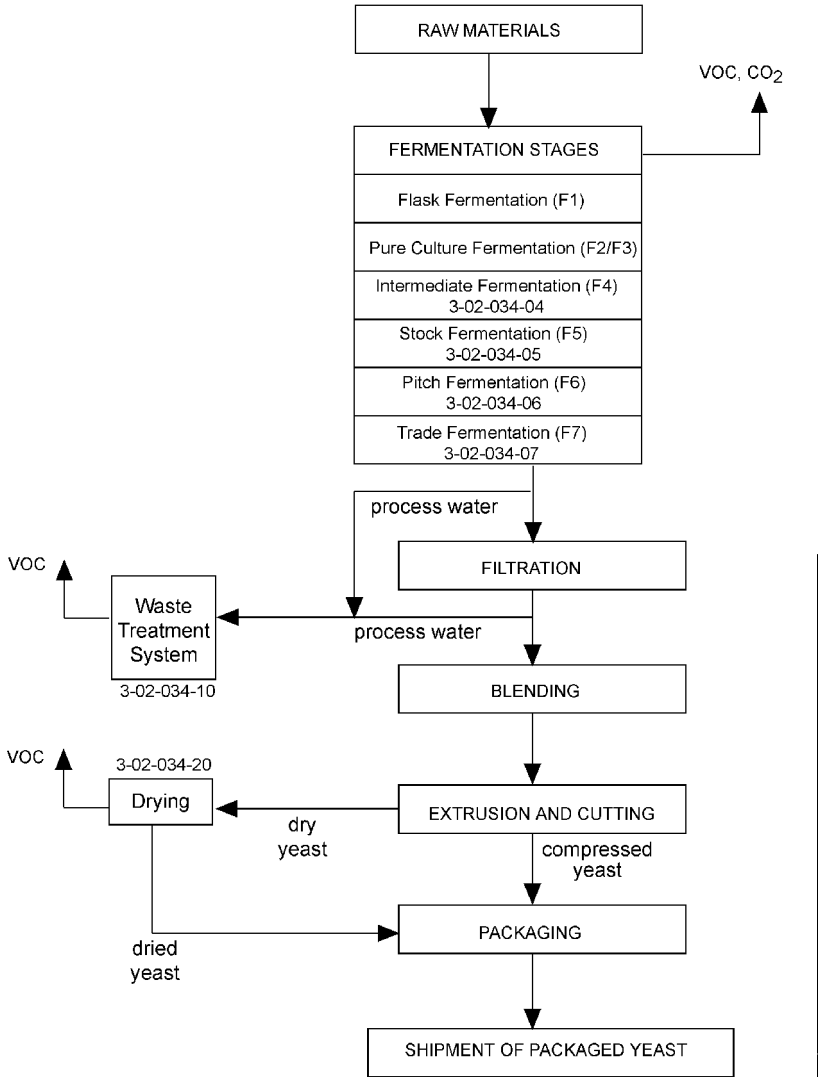

Figure 9.13.4-1. Typical process flow diagram for the seven-stage production of baker's yeast, with Source Classification Codes.

Raw Materials[1-3] - 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*. Other yeast strains are required to produce each of the two dry yeast products, ADY and IDY. Cane

molasses and beet molasses are the principal carbon sources to promote yeast growth. Molasses contains 45 to 55 weight percent fermentable sugars, in the forms of sucrose, glucose, and fructose.

The amount and type of cane and beet molasses used depend on the availability of the molasses types, costs, and the presence of inhibitors and toxins. Usually, a blend consisting of both cane and beet molasses is used in the fermentations. Once the molasses mixture is blended, the pH is adjusted to between 4.5 and 5.0 because an alkaline mixture promotes bacteria growth. Bacteria growth occurs under the same conditions as yeast growth, making pH monitoring very important. The molasses mixture is clarified to remove any sludge and is then sterilized with high-pressure steam. After sterilization, it is diluted with water and held in holding tanks until it is needed for the fermentation process.

A variety of essential nutrients and vitamins is also required in yeast production. The nutrient and mineral requirements include nitrogen, potassium, phosphate, magnesium, and calcium, with traces of iron, zinc, copper, manganese, and molybdenum. Normally, nitrogen is supplied by adding ammonium salts, aqueous ammonia, or anhydrous ammonia to the feedstock. Phosphates and magnesium are added, in the form of phosphoric acid or phosphate salts and magnesium salts. Vitamins are also required for yeast growth (biotin, inositol, pantothenic acid, and thiamine). Thiamine is added to the feedstock. Most other vitamins and nutrients are already present in sufficient amounts in the molasses malt.

Fermentation[1-3] - Yeast cells are grown in a series of fermentation vessels. Yeast fermentation vessels are operated under aerobic conditions (free oxygen or excess air present) because under anaerobic conditions (limited or no oxygen) the fermentable sugars are consumed in the formation of ethanol and carbon dioxide, which results in low yeast yields.

The initial stage of yeast growth takes place in the laboratory. A portion of the pure yeast culture is mixed with molasses malt in a sterilized flask, and the yeast is allowed to grow for two to four days. The entire contents of this flask are used to inoculate the first fermentor in the pure culture stage. Pure culture fermentations are batch fermentations, where the yeast is allowed to grow for 13 to 24 hours. Typically, one to two fermentors are used in this stage of the process. The pure culture fermentations are basically a continuation of the flask fermentation, except that they have provisions for sterile aeration and aseptic transfer to the next stage.

Following the pure culture fermentations, the yeast mixture is transferred to an intermediate fermentor that is either batch or fed-batch. The next fermentation stage is a stock fermentation. The contents from the intermediate fermentor are pumped into the stock fermentor, which is equipped for incremental feeding with good aeration. This stage is called stock fermentation, because after fermentation is complete, the yeast is separated from the bulk of the fermentor liquid by centrifuging, which produces a stock, or pitch, of yeast for the next stage. The next stage, pitch fermentation, also produces a stock, or pitch, of yeast. Aeration is vigorous, and molasses and other nutrients are fed incrementally. The liquor from this fermentor is usually divided into several parts for pitching the final trade fermentations (adding the yeast to start fermentation). Alternately, the yeast may be separated by centrifuging and stored for several days before its use in the final trade fermentations.

The final trade fermentation has the highest degree of aeration, and molasses and other nutrients are fed incrementally. Large air supplies are required during the final trade fermentations, so these vessels are often started in a staggered fashion to reduce the size of the air compressors. The duration of the final fermentation stages ranges from 11 to 15 hours. 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 to permit further maturing of the yeast, making it more stable for refrigerated storage.

The amount of yeast growth in the main fermentation stages described above increases with each stage. Yeast growth is typically 120 kilograms (270 pounds) in the intermediate fermentor, 420 kilograms (930 pounds) in the stock fermentor, 2,500 kilograms (5,500 pounds) in the pitch fermentor, and 15,000 to 100,000 kilograms (33,000 to 220,000 pounds) in the trade fermentor.

The sequence of the main fermentation stages varies among manufacturers. About half of existing yeast operations are two-stage processes, and the remaining are four-stage processes. When the two-stage final fermentation series is used, the only fermentations following the pure culture stage are the stock and trade fermentations. When the four-stage fermentation series is used, the pure culture stage is followed by intermediate, stock, pitch, and trade fermentations.

Harvesting And Packaging[1-2] - Once an optimum quantity of yeast has been grown, the yeast cells are recovered from the final trade fermentor by centrifugal yeast separators. The centrifuged yeast solids are further concentrated by a filter press or rotary vacuum filter. A filter press forms a filter cake containing 27 to 32 percent solids. A rotary vacuum filter formes cakes containing approximately 33 percent solids. This filter cake is then blended in mixers with small amounts of water, emulsifiers, and cutting oils to form the end product. The final packaging steps, as described below, vary depending on the type of yeast product.

In compressed yeast production, 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 through nozzles to form continuous ribbons of yeast cake. The ribbons are cut, and the yeast cakes are wrapped and cooled to below 8°C (46°F), at which time they are ready for shipment in refrigerated trucks.

In dry yeast production, the product is sent to an extruder after filtration, where emulsifiers and oils (different from those used for compressed yeast) are added to texturize the yeast and to aid in extruding it. After the yeast is extruded in thin ribbons, it is cut and dried in either a batch or a continuous drying system. Following drying, the yeast is vacuum packed or packed under nitrogen gas before heat sealing. The shelf life of ADY and IDY at ambient temperature is 1 to 2 years.

9.13.4.3 Emissions[1,4-5]

Volatile organic compound (VOC) emissions are generated as byproducts of the fermentation process. The two major VOCs emitted are ethanol and acetaldehyde. Other byproducts consist of other alcohols, such as butanol, isopropyl alcohol, 2,3-butanediol, organic acids, and acetates. Based on emission test data, approximately 80 to 90 percent of total VOC emissions is ethanol, and the remaining 10 to 20 percent consists of other alcohols and acetaldehyde. Acetaldehyde is a hazardous air pollutant as defined under Section 112 of the *Clean Air Act*.

Volatile byproducts form as a result of either excess sugar (molasses) present in the fermentor or an insufficient oxygen supply to it. Under these conditions, anaerobic fermentation occurs, breaking down the excess sugar into 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. Therefore, in producing baker's yeast, it is essential to suppress ethanol formation in the final fermentation stages by incremental feeding of the molasses mixture, with 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. Therefore, there is no economical reason for manufacturers to equip the earlier fermentation stages with process control equipment.

Another potential emission source at yeast manufacturing facilities is the system used to treat process waste waters. If the facility does not use an anaerobic biological treatment system, significant quantities of VOC could be emitted from this stage of the process. For more information on waste water treatment systems as an emission source of VOCs, please refer to EPA's Control Technology Center document on industrial waste water treatment systems, *Industrial Wastewater Volatile Organic Compound Emissions - Background Information For BACT/LAER*, or see Section 4.13 of AP-42. At facilities manufacturing dry yeast, VOCs may also be emitted from the yeast dryers, but no information is available on the relative quantity of VOC emissions from this source.

9.13.4.4 Controls[6]

Only one yeast manufacturing facility uses an add-on pollution control system to reduce VOC emissions from the fermentation process. However, all yeast manufacturers suppress ethanol formation through varying degrees of process control, such as incrementally feeding the molasses mixture to the fermentors so that excess sugars are not present, or supplying sufficient oxygen to the fermentors to optimize the dissolved oxygen content of the liquid in the fermentor. The adequacy of oxygen distribution depends upon the proper design and operation of the aeration and mechanical agitation systems of the fermentor. The distribution of oxygen by the air sparger system to the malt mixture is critical. If oxygen is not being transferred uniformly throughout the malt, then ethanol will be produced in the oxygen-deficient areas of the fermentor. The type and position of baffles and/or a highly effective mechanical agitation system can ensure proper distribution of oxygen.

A more sophisticated form of process control involves using a continuous monitoring system and feedback control. In such a system, process parameters are monitored, and the information is sent to a computer. The computer is then used to calculate sugar consumption rates through material balance techniques. Based on the calculated data, the computer continuously controls the addition of molasses. This type of system is feasible, but it is difficult to design and implement. Such enhanced process control measures can suppress ethanol formation from 75 to 95 percent.

The one facility with add-on control uses a wet scrubber followed by a biological filter. Performance data from this unit suggest an emission control efficiency of better than 90 percent.

9.13.4.5 Emission Factors[1,6-9]

Table 9.13.4-1 (Metric And English Units). VOLATILE ORGANIC COMPOUND (VOC) EMISSION FACTORS FOR YEAST MANUFACTURING[a]

EMISSION FACTOR RATING: E

Emission Point	VOC[b]	
	VOC emitted per stage per amount of yeast produced in a stage kg VOC/Mg yeast	VOC emitted per stage per amount of yeast produced in a stage lb VOC/ton yeast
Fermentation stages[c]		
Flask (F1)	ND	ND
Pure culture (F2/F3)	ND	ND
Intermediate (F4) (SCC 3-02-034-04)	18	36
Stock (F5) (SCC 3-02-034-05)	2.5	5.0
Pitch (F6) (SCC 3-02-034-06)	2.5	5.0
Trade (F7) (SCC 3-02-034-07)	2.5	5.0
Waste treatment (SCC 3-02-034-10)	See Section 4.13 of AP-42	
Drying (SCC 3-02-034-20)	ND	ND

[a]References 1, 6-10. Total VOC as ethanol. SCC = Source Classification Code. ND = no data. F numbers refer to fermentation stages (see Figure 9.13.4-1).

[b]Factors should be used only when plant-specific emission data are not available because of the high degree of emissions variability among facilities and among batches within a facility.

[c]Some yeast manufacturing facilities use a two-stage final fermentation process, and others use a four-stage final fermentation process. Factors for each stage cannot be summed to determine an overall emission factor for a facility, since they are based on yeast yields in each fermentor rather than total yeast production. Total yeast production for a facility equals only the yeast yield from the trade fermentations.

Table 9.13.4-1 provides emission factors for a typical yeast fermentation process with a moderate degree of process control. The process emission factors in Table 9.13.4-1 were developed from four test reports from three yeast manufacturing facilities. Separate emission factors are given for intermediate, stock/pitch, and trade fermentations. The emission factors in Table 9.13.4-1 are expressed in units of VOC emitted per fermentor per unit of yeast produced in that fermentor.

In order to use the emission factors for each fermentor, the amount of yeast produced in each fermentor must be known. The following is an example calculation for a typical facility:

Fermentation stage	Yeast yield per batch, lb (A)	No. of batches processed per year, #/yr (B)	Total yeast production per stage, tons/yr (C = A x B/2,000)	Emission factor, lb/ton (D)	Emissions, lb (E = C x D)	Percent of total emissions
Intermediate	265	156	21	36	756	0.84
Stock	930	208	97	5	485	0.54
Pitch	5,510	208	573	5	2,865	3.18
Trade	33,070	1,040	17,196	5	85,980	95.44
Total					90,086	100

In most cases, the annual yeast production per stage will not be available. However, a reasonable estimate can be determined based on the emission factor for the trade fermentor and the total yeast production for the facility. Trade fermentors produce the majority of all VOCs emitted from the facility, because of the number of batches processed per year and of the amount of yeast grown in these fermentors. Based on emission test data and process data regarding the number of batches processed per year, 80 to 90 percent of VOCs emitted from fermentation operations are a result of the trade fermentors.

Using either a two-stage or four-stage fermentation process has no significant effect on the overall emissions for the facility. Facilities that use the two-stage process may have larger fermentors or may produce more batches per year than facilities that use a four-stage process. The main factors affecting emissions are the total yeast production for a facility and the degree of process control used.

References for Section 9.13.4

1. *Assessment Of VOC Emissions And Their Control From Baker's Yeast Manufacturing Facilities*, EPA-450/3-91-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1992.

2. S. L. Chen and M. Chigar, "Production Of Baker's Yeast", *Comprehensive Biotechnology*, Volume 20, Pergamon Press, New York, NY, 1985.

3. G. Reed and H. Peppler, *Yeast Technology*, Avi Publishing Company, Westport, CT, 1973.

4. H. Y. Wang, *et al*., "Computer Control Of Baker's Yeast Production", *Biotechnology And Bioengineering*, Cambridge, MA, Volume 21, 1979.

5. *Industrial Wastewater VOC Emissions - Background for BACT/LAER*, EPA-450/3-90-004, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1990.

6. Written communication from R. Jones, Midwest Research Institute, Cary, NC, to the project file, April 28, 1993.

7. *Fermentor Emissions Test Report*, Gannet Fleming, Inc., Baltimore, MD, October 1990.

8. *Final Test Report For Fermentor No. 5*, Gannett Fleming, Inc., Baltimore, MD, August 1990.

9. Written communication from J. Leatherdale, Trace Technologies, Bridgewater, NJ, to J. Hogan, Gist-brocades Food Ingredients, Inc., East Brunswick, NJ, April 7, 1989.

10. *Fermentor Emissions Test Report, Universal Foods, Inc., Baltimore, MD*, Universal Foods, Inc., Milwaukee, WI, 1990.