INTRODUCTION

ROLE OF DEODORIZATION

In the conventional edible oil refinery, deodorization is the last in a series of process steps used to improve the taste, odor, color, and stability of the oils by the removal of undesirable substances. In subsequent process steps, such as in the production and packaging of shortening, margarine, salad oil, and other specific products, the processor strives to maintain the quality attained in the deodorized oil.

Refined soybean oil retains a good deal of the natural odor and flavor of soybeans, the solvent-extracted oil having a "beany" odor and flavor and a greenish cast. After bleaching, the oil has a musty or earthy odor. Hydrogenation of soybean oil introduces an atypical odor and flavor which can be removed by deodorization. Deodorization primarily removes volatile substances and converts the oil into a bland-tasting, clear, brilliant liquid.

MATERIALS REMOVED

The materials removed by deodorization include free fatty acids (FFA); various flavor and odor compounds classified largely as aldehydes, ketones, alcohols, and hydrocarbons; and other compounds formed by the heat decomposition of peroxides and pigments (see Chapter 14). Concentration of individual constituents in the undeodorized oil is generally no greater than about 0.1% unless the oil has been abused. The type and
concentration of the FFA are readily determined, but the identity and concentration of the other contaminants are much more difficult to determine. Some of these materials are present in very low concentrations but still can be detected organoleptically. For example, decadienal, one of the materials found in the deodorizer distillate of soybean oil and several other fatty oils, has a flavor threshold in water of about 0.5 part per billion (ppb) (Patton et al., 1959). Upon addition to freshly deodorized cottonseed oil of a number of compounds (other than aldehydes) formed by the autoxidation of fat, Evans et al. (1971) found the odor and flavor thresholds of many to be in the range of 1 to 30 ppm.

Normally, for an oil with an initial FFA content of 0.10%, the noticeable flavors and odors will have essentially disappeared when the FFA content has been lowered to 0.01-0.03%, assuming a zero peroxide value (Gavin, 1978a). In instances where the oil was of poor quality, in spite of its FFA content having been reduced to the stipulated level, the trouble has been attributed to faulty operation such as inadequate deaeration of the oil, oxidation of the oil because of air leakage, excessive condensation and refluxing of volatilized materials within the deodorizer, short-circuiting of insufficiently deodorized oil within the deodorizer (Mattil, 1964), or to abuse of the oil prior to deodorization (Evans et al., 1960).

Tattrie and Yaguchi (1973) found a minuscule amount (0.0001%) of protein in an alkali-refined, bleached soybean oil, but none in an amount that could conceivably cause an allergic reaction was detected in the steam-deodorized oils from soybeans, peanuts, coconuts or herring.

NATURE OF THE DEODORIZATION PROCESS

Deodorization is primarily a high-temperature, high-vacuum, steam-distillation process. To produce a high-quality finished product, each deodorizer installation must perform the following operations in an efficient manner: deaerate the oil, heat the oil to deodorization temperature, steam strip the oil, and cool the oil before it is exposed to the atmosphere. Also, some authorities believe that thermal decomposition of certain minute, largely unidentified constituents and possibly removal of their decomposition products is necessary for soybean oil.

Deodorization increases the oil's flavor and oxidative stability by nearly complete removal of FFA and other volatile odor and flavor materials, by partial removal of tocopherols, and by thermal destruction of peroxides. The thermal treatment that is a necessary part of the deodorization process also heat bleaches the oil by destruction of the carotenoids that are unstable at deodorization temperature. At the concentrations at which they are present, the volatile substances have partial pressures that presumably approximate or exceed those of palmitic and oleic acids, because, as Bailey (1941) states, flavor and odor removal usually parallel FFA removal. Because these reactions and the bleaching effect are time and temperature dependent, commercial systems provide the necessary retention period at deodorization temperature, by intentional design or otherwise, to allow these reactions and the heat bleaching to occur (Gavin, 1977). Stage (1979) disagrees with this view and believes the additional time merely promotes completion of the steam-stripping operation.

Some operations, such as heating the oil, may be done in two steps. For example, with the semicontinuous and continuous deodorizers, but not the batch deodorizers, it is possible to preheat the feedstock with the hot, deodorized oil and thus effect a fuel savings of 40% or more.

Frequently, a blend of two or more oils and/or fats, i.e., stocks, is used in preparation of a finished product, such as margarine (see Chapter 10). The usual practice is to blend these stocks before rather than after deodorization to minimize handling and storage of the deodorized oil.

TYPES OF DEODORIZERS

The first deodorizers were of the batch type, followed in the 1930's by continuous deodorizers. The semi-continuous deodorizer was introduced in 1948. The latter has been widely
accepted because the design incorporates many of the advantages of a continuous deodorizer, practically eliminates oxidation of hot oil within the deodorizer shell, and readily handles the change from one feedstock to another. The continuous deodorizer can offer operating economy over the other types, although the semicontinuous deodorizer is reasonably efficient.

**PHYSICAL OR STEAM REFINING**

A process very similar to deodorization is one called physical or steam refining. The steam refining unit is similar to the semicontinuous and continuous deodorizers but is designed for a longer holding time at deodorization temperature or with additional steam stripping trays. The unit is usually constructed of type 316 stainless steel to withstand corrosive action of the fatty acids. Steam refining has been used in Europe for a number of years to lower the FFA content of certain high-acid oils to 0.5-0.8%. The oils are then caustic soda refined, bleached, and steam deodorized. Gavin et al. (1977), Stage (1979), and Sullivan (1976) describe the principles and equipment used. Recent installations of steam-refining systems produce from crude palm oil containing up to 5.0% FFA a fully deodorized oil with a FFA content of 0.02-0.03%.

With a water-degummed, activated earth-bleached soybean oil, steam refining/deodorization on a commercial scale did not produce a finished oil of satisfactory keeping quality (James, 1958). Adequate removal of phosphatides and trace metals from the steam refiner feedstock is necessary for the production of a high-quality oil. By use of phosphoric-acid degumming, bleaching, and steam refining in laboratory tests, List et al. (1978a, 1978b) produced a finished soybean oil of keeping quality comparable to a caustic-refined, bleached, and deodorized oil.

Two commercial steam refining installations under construction in Singapore in 1979 will be operating on batches of crude degummed soybean oil that are amenable to this process (Sullivan, 1979).

With steam refining, good-quality fatty acids can be recovered without the additional step of acidulating the soapstock. Generally, a higher yield of acids is obtained, and also one source of waste-water pollution is eliminated.

**THEORETICAL BASIS**

Steam deodorization is feasible because the flavor and odor compounds that are to be removed have appreciably greater volatility than do triglycerides. Operation at high temperature increases the volatility of these odoriferous compounds; furthermore, introduction of an inert gas, such as stripping steam, into the deodorizer greatly increases the rate at which the odoriferous compounds are volatilized. Any inert gas can be used, but steam has the advantage of being readily available and is readily condensed; thus cost of the vacuum-producing equipment is minimized. Reduced pressure operation further aids in removal of the odoriferous compounds, greatly reduces the quantity of stripping steam needed, reduces the formation of FFA resulting from the hydrolysis of oil by steam, although the amount is slight, and protects the oil from atmospheric oxidation.

**IMPORTANT VARIABLES**

The deodorization process is dependent upon the following variables: (a) vapor pressure of the FFA and the other materials to be removed, (b) deodorization temperature and concentration (i.e., molal fraction) of the materials to be removed—two factors that determine their partial vapor pressure, (c) absolute pressure under which the deodorization is to be carried out, (d) quantity of stripping steam per unit quantity of oil, (e) intimacy of mixing of the stripping steam and oil (therefore, volume of the stripping steam rather than its weight is an important factor), (f) composition of the feedstocks and finished oil, and (g) deodorization time. The time is dependent upon the relationship between absolute pressure, temperature, stripping steam-to-oil ratio, and equipment design. Also, proper design and operation of the deodorizer reduces to a minimum the amount of volatilized materials that condense and flow back into the oil being deodorized.

**MATHEMATICAL CONSIDERATIONS**

A mathematical equation relating several of the main operating variables in batch deodorization has been developed by Bailey (1941) and reviewed by Bates (1949), Gavin (1978a), White (1953), and Zehnder and McMichael (1967). Because vegetable oil-fatty acid solutions deviate considerably from ideal solutions, Szabo Sarkadi (1958a) modified Bailey's equation by the addition of an activity coefficient, A. The final equation is:

\[ S = \left( \frac{PO}{EP} \right) \cdot \left( \frac{\ln V_1}{V_2} \right) \]  

or
\[ \ln \frac{V_1}{V_2} = \frac{(SEP_A)}{PO} = K \cdot \left( \frac{P_f}{P} \right) \cdot \left( \frac{S}{O} \right) \quad (eq. 2) \]

where

- \( S \) = moles of stripping steam
- \( O \) = moles of oil
- \( P_f \) = vapor pressure of the FFA
- \( P \) = total system pressure
- \( V_1 \) = initial number of moles of FFA in the oil
- \( V_2 \) = final number of moles of FFA in the oil
- \( E \) = the vaporization efficiency, a measure of the steam's ability to become saturated with the FFA and other volatile substances during its passage through the oil
- \( A \) = activity coefficient
- \( K \) = experimental constant = \( E \cdot A \)

Based on this equation, the amount of stripping steam required to deodorize a batch of oil varies directly with (a) size of the oil batch, (b) absolute pressure in the deodorizer, and (c) logarithmic ratio of initial to final concentration of the FFA (and other volatile constituents) in the oil, and inversely with (a) vapor pressure of the volatile compounds at the deodorization temperature, (b) vaporization efficiency, and (c) activity coefficient.

The activity coefficient is usually determined experimentally. At 180°C (356°F), the coefficient for solutions containing 0.1% stearic acid in peanut oil was 1.4-1.5 and at acid concentrations above 30%, the coefficient was essentially unity (Szabo Sarkadi, 1958a and b). Based upon a study made by Wilson (1964) of the excess free energy of mixing, Stage (1979) calculated the activity coefficient to be 0.63-0.64 for a fatty acid concentration of 0.1%.

For continuous deodorization, the equation is rewritten using time-dependent variables (Gavin, 1978a):

\[ \frac{V_1}{V_2} = 1 + \left( \frac{K}{P} \right) \cdot \left( \frac{P_f}{P} \right) \cdot \left( \frac{S}{O} \right) \quad (eq. 3) \]

where

- \( V_1, V_2 \) = moles/hr of FFA in the oil entering and leaving the deodorizer.
- \( K, P, P_f \) = same as for batch deodorization
- \( S \) = moles/hr of stripping steam
- \( O \) = moles/hr of oil.

For a given hourly flow of oil through the deodorizer and a given initial FFA concentration (\( V_1 \)), we see that FFA content of the deodorized oil (\( V_2 \)) must decrease as the deodorizer temperature (which controls \( P_f \)) and the steam flow rate (\( S \)) increase as the deodorizer pressure (\( P \)) decreases.

**LIMITATION ON FREE FATTY ACID REDUCTION**

While deodorization removes FFA from the oil, the FFA content cannot be reduced below about 0.005% because hydrolysis of the oil by the stripping steam is continually producing more FFA. The rate of hydrolysis decreases as the oil's FFA content decreases. Eventually the rate of FFA formation by hydrolysis equals the rate of removal by the stripping steam, and the oil's FFA cannot be reduced any further (Mattil, 1964). A reduction in absolute pressure in the deodorizer also reduces the hydrolysis rate by a small but definite amount (Szabo Sardaki, 1959).

**SOME DEODORIZER DESIGN CONSIDERATIONS**

This discussion will be limited to only a few of the aspects related to deodorizer design.

**MATERIALS OF CONSTRUCTION**

Batch deodorizers generally have been made of carbon steel; but nowadays, surfaces in contact with the hot oil in semicontinuous and continuous deodorizers are usually of stainless steel (18-8) or nickel, because ordinary carbon steel acts as a prooxidant for the oil at the deodorization temperatures now employed (Beal and Lancaster, 1951; Ziels and Schmidt, 1945). Nickel and aluminum have the least effect on oil stability. However, because aluminum is structurally weak at deodorization temperatures and is difficult to clean of films of polymerized oil, it is not used. Beal and Lancaster (1951) found that type 316 stainless steel is a good metal to use. Also, an oxidized oil film is an effective protective coating for the metal surfaces. However, cleaning the metal surfaces with hot 5% aqueous caustic solution lowers the oxidative stability of the next batch of oil.

**DEODORIZER EFFICIENCY**

Theoretically, deodorizer efficiency increases with total surface area of the steam bubbles and their time of contact with the oil. In practice, these two variables have little effect because the steam apparently is rapidly saturated at deodorization temperatures. The efficiency also varies with the concentration of the volatile substances in the oil. For commercial batch deodorizers operating at 6 to 25 mm absolute
pressure, the vaporization efficiency generally is 0.7 to 0.9 (Bailey, 1941; and Gavin, 1978a).

Even though well insulated, the upper shell and vapor outlet of a batch deodorizer generally are cooler than the body of oil and serve as a condensing surface for easily condensable materials carried by the stripping steam. Re-refluxing, i.e., a return to the oil charge of some of this condensate, contributes to the reduction in vaporization efficiency. Jacketing and heating the upper shell to avoid the cooling effect have been proposed by Phelps and Black (1946), but these steps have not been generally adopted. Although the vaporization efficiency can be very low (e.g., 0.3-0.5) in poorly designed laboratory apparatus, Szabo Sarkadi (1958a) increased the efficiency to 1.0 in an "isothermal" laboratory deodorizer that was designed to prevent minutest cooling of any deodorizer surface. Furthermore, he concluded that "cooling of the oil surface by 1°C has the same effect on vaporization efficiency as does the lowering of the temperature of the whole oil by 1°C." He also went on to state that "reduction in the vaporization efficiency may occur even when no condensate of volatile substances takes place." (Underlining added.)

In continuous or semicontinuous deodorizers, the vaporization efficiency increases up to a point with the steaming rate because of the larger oil-steam interface created by violent splashing of the oil against suitable baffles (Mattil, 1964). Naturally, the steaming rate must not cause appreciable loss of oil due to mechanical entrainment. In the stripping of oil in layers only 6-12 in. (15-30 cm) deep in experimental tests made at 6 mm Hg pressure, Bailey (1949) increased the vaporization efficiency from 0.40-0.45 to 0.80-0.90 by the use of proper baffling. The first commercial semicontinuous deodorizer operated with a 24-in. (61 cm) oil layer and had an efficiency of 0.80-0.90 (Bailey, 1949). Proper baffling, violent agitation, and diversion of any condensables from the oil charge all contributed to the good efficiency.

PRODUCTION OF STRIPPING STEAM

Because semicontinuous and continuous deodorizers use considerably less stripping steam than do batch deodorizers and also require a relatively short deodorization time, the steam is no longer superheated, a practice sometimes carried out in batch deodorization to avoid excessive cooling of the oil. Lineberry and Dudrow (1972) reported a drop in oil temperature of 9-17°F (5-10°C) as the percentage of stripping steam increased from 0.5-3.1 in tests made in a semicontinuous deodorizer having an improved stripping tray. The stripping steam should, of course, be dry and free of both oxygen and traces of mineral salts. For this reason, it is made from deaerated water, and good boiler operating practices must be enforced to prevent carryover of boiler-water solids into the steam.

DEODORIZER VARIABLES AND OPERATION

EFFECT OF VACUUM

Mattil (1964) summarized the effect of vacuum as follows: "A high vacuum in deodorizing is advantageous in every respect. It leads to economy of operation, more rapid deodorization, and a lower FFA content in the finished oil." The reason for his statement will become apparent in the next several paragraphs.

As discussed under Theoretical Basis, the quantity of stripping steam required is directly proportional to the absolute pressure in the deodorizer. Operation at 24 mm pressure requires twice as much steam as at 12 mm and four times as much as at 6 mm. With the improvements made in design and fabrication of deodorizers, vacuum-producing equipment, and auxiliary equipment, high vacuums are readily attainable. Three-stage, steam-jet ejectors routinely maintain an absolute pressure of 6 mm in deodorizers under a high stripping steam load. With the usual utilities, i.e., water at 77-86°F (25-30°C) and steam at 110-210 psig (8-15 kg/sq cm), a 4-stage ejector system designed for 6 mm Hg operation can be more economical in steam consumption than a 3-stage system (Zehnder, 1976). With three- or four-stage ejectors, deodorizers can be operated at 1-3 mm, but Zehnder and McMichael (1967) advise an evaluation be made based on qualitative advantages of the product against the increased operating costs.

The absolute pressure also influences the time required to deodorize a given batch of oil. The quantity of stripping steam required decreases in direct proportion to the decrease in absolute pressure, whereas allowable linear velocity of the vapors (principally steam) can be increased only in inverse proportion to the 0.5 power of their density. Thus, a decrease in pressure from 24 to 6 mm reduces the required quantity of stripping steam to one-fourth, whereas the allowable steam flow rate must be decreased about twofold. The net result is that the deodorization time can be reduced by one-half (Mattil, 1964).

The lower pressure and shorter time reduce the loss of oil due to hydrolysis and also aid in the production of a deodorized oil of low FFA content, as is evident from Figure 1.
EFFECT OF TEMPERATURE, STEAMING RATE, AND TIME

The vapor pressure-temperature relationship for various compounds (Stage, 1956) representative of the several types removed by deodorization are given in Figure 2. In their pure state, many of these compounds have vapor pressures exceeding those of the free fatty acids found in soybean oil. However, because the more volatile compounds normally are present in the oil in lesser amounts than the free fatty acids, the partial pressures developed by these compounds, as expressed quantitatively by Raoult's law, probably approximate those developed by the free fatty acids.

As shown in Figure 2, vapor pressures of the volatile constituents in the oil increase rapidly with successive increases in the temperature. For this reason, operation at the highest practical temperature aids in removal of the odoriferous compounds. Over the temperature range normally used for deodorization, the vapor pressure of palmitic acid, for example, increases from 8 mm Hg at 400°F (204°C) to 107 mm

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Fig. 1. Removal of free fatty acids from palm oil by steam deodorization in batch deodorizer. Run No. 1: 19,000 lb oil charge, 400 lb/hr of stripping steam, 460°F, 10 mm pressure (8636 kg, 182 kg/hr, 238°C). Run No. 2: 18,400 lb oil, 800 lb/hr stripping steam, 460°F, 25 mm pressure (8363 kg, 364 kg/hr, 238°C). (From Bailey, 1941.) (Reprinted from Industrial and Engineering Chemistry with permission.)

Fig. 2: Vapor pressure curves for some of the compounds removed by deodorization of vegetable oils. (From Stage, 1956.) (Reprinted from Fette Seifen Anstrichmittel with permission.)

1. Methyl heptyl ketone (C₉H₁₈O)
2. Methyl nonyl ketone (C₁₇H₁₈O)
3. Methyl undecyl ketone (C₁₉H₂₄O)
4. Methyl nonyl ketone (C₁₉H₂₄O)
5. Tridecadiene (C₁₃H₂₄)
6. Hexadecadiene (C₁₆H₃₀)
7. Nonadecadiene (C₁₉H₃₀)
8. Tricosadiene (C₂₃H₄₂)
9. Pentadecene-1 (C₁₅H₂₄)
10. Nonadecene-1 (C₁₉H₃₈)
11. Tetracosane (C₂₄H₅₀)
12. Hexacosane (C₂₆H₅₄)
13. Lauric acid (C₁₂H₂₄O₂)
14. Myristic acid (C₁₄H₂₈O₂)
15. Palmitic acid (C₁₆H₃₂O₂)
16. Stearic acid (C₁₈H₃₆O₂)
17. Pentadecadiene-1,8 (C₁₅H₂₈)
18. Nonadecene-1 (C₁₉H₃₈)
at 525°F (274°C) (Fig. 2; and Ralston, 1948). This is an increase in its volatility and in its expected rate of removal during deodorization by about thirteenfold. Szabo Sarkadi (1958b) noted that for up to 20% of stearic acid dissolved in peanut oil, vapor pressure of the acid at 356°F (180°C) exceeded that predicted by theory, i.e., by Raoult's law. Such an increase would, of course, have a beneficial effect during deodorization. Szabo Sarkadi concluded that the increased vapor pressure arose from dissociation of the diluted acid, the pure acid being a mixture of monomer and dimer molecules.

Based on the theory discussed above, the deodorization time is halved for each increase in temperature of about 30°F or 17°C. The results from operation of commercial deodorizers agree quite well with the predicted values when the comparison is made with a given deodorizer (Mattil, 1964).

Because the required amount of stripping steam varies inversely with vapor pressure of the volatile constituents being removed (see eq. 1), operation at the higher temperatures, such as up to 525°F (274°C), proportionally reduces the amount of stripping steam required. At a fixed pressure, the maximum flow of stripping steam possible without excessive entrainment is essentially constant over the temperature range employed for deodorization and, consequently, the deodorization time is shortened as the deodorizer temperature is increased.

Operation at the elevated temperatures can also promote thermal decomposition of some constituents naturally present in soybean oil, such as peroxides, pigments, and some trace metal-prooxidant complexes (see Chapter 14). The carotenoid pigments can be decomposed and removed by deodorization at about 500°F (260°C) (Young, 1978).

Although operation at high temperatures has several beneficial effects as related above, deodorization of soybean oil for 15-30 min at 525°F (274°C) appears to be at or near the top limit for production of the best quality oil, based upon results obtained with glass apparatus (Moser et al., 1966).

OIL LOSSES IN DEODORIZATION

The oil losses encountered in deodorization are attributed to three factors: odoriferous compounds removed from the oil, which rarely exceed 0.1%, oil droplets entrained in the exit vapors, and losses due to unavoidable hydrolysis of the oil by the stripping steam.

Mattil (1964) reports a material loss of 0.2 to 0.8% when completely bland products containing 0.1% FFA or less are produced by deodorization at 400-475°F (204-246°C) of vegetable oils in modern plants where mechanical entrainment is minimized. Based on information obtained from industrial processors, White (1956) reports total average losses of 0.60, 0.56, and 0.50% for batch, semicontinuous and continuous deodorizers, respectively. The deodorizers operated on feedstocks with initial FFA contents of 0.10, 0.11, and 0.13%, respectively, and each lowered the final FFA content to 0.03%. Myers (1957) reported an average loss of 0.47% for caustic-refined, bleached soybean oil deodorized in the Bailey semicontinuous deodorizer then in use in one refinery.

Loss by distillation. Distillation losses include FFA, the fatty acids formed by hydrolysis of the oil, small amounts of the triglyceride itself, plus sterols, tocopherols, and other unsaponifiable matter. Under commercial deodorization conditions, the FFA form roughly 25 to 45% of the deodorizer distillate (Wilson, 1970). In deodorization of cottonseed oil at 6 mm and 460°F (238°C), each pound of stripping steam is calculated to split out 0.024 to 0.049 pound of fatty acid (Mattil, 1964). The neutral oil loss probably consists mainly of mono- and di-glycerides produced by hydrolysis during deodorization. The loss increases in the order: soybean, cottonseed, and coconut oils (Mattil, 1964).

Loss by entrainment. Mechanical entrainment of oil droplets by the stripping steam has led to an appreciable loss of oil in many batch deodorizers. The amount of entrainment is proportional to both the density and the velocity of the stripping steam. Entrainment increases very rapidly with the increase in steam flow. It can be shown mathematically that the weight of the largest oil droplets that will be entrained varies with the sixth power of the steam velocity (Mattil, 1964). By use of baffles and demisters in continuous and semicontinuous deodorizers of modern design, entrainment losses are held to acceptable levels.

For deodorization of hydrogenated soybean oil in a semicontinuous unit, Bodman et al. (1951) gave the entrainment loss as 0.25-0.40% above the FFA loss. Because of the longer deodorization time and the larger quantity of stripping steam, they reported the entrainment loss in batch deodorizers to be between 0.8 and 1.5%.

HEATING THE OIL

General industrial practice is to operate steam boilers at about 150 psig (i.e., 10.5 kg/cm² and 366°F or 185°C). The resultant steam cannot heat the oil to 475-525°F (246-274°C), the temperature at which most commercial deodorizers operate. When steam is to be used as the heat-transfer medium, a boiler operating at about 900 psig (65 kg/cm² and 534°F or 279°C) is...
Because of the capital investment and operating expense for such a boiler, U.S. edible oil processors for a number of years have employed a vapor-phase heat-transfer medium consisting of an eutectic mixture of diphenyl and diphenyl oxide, sold under the tradenames of Dowtherm A and Therminol VP-1. This mixture, which is flammable, develops a pressure of only about 16 psig (1.1 kg/sq. cm²) for heating the oil to a deodorization temperature of 500°F (260°C). The heating system consists of a vaporizer (i.e., a boiler), burner, piping for carrying vapors to the deodorizer, piping for gravity return of condensate from the deodorizer, and safety controls for the system as required by insurance regulations.

Because rapeseed oil allegedly contaminated by Dowtherm A caused illnesses and death in Japan in 1973, the Japanese government now prohibits the installation of new deodorizers using a Dowtherm heating system; also, existing users were given two years to convert to another system. Imai et al. (1974) reported that tests made by them and by other laboratories failed to detect any Dowtherm A in the contaminated rapeseed oil. Although the deodorizer tray was found to have a leaky heat-transfer coil, Imai et al. demonstrated that the deodorizer conditions employed should remove from rapeseed oil both Dowtherm A and ESK-60 oil, the two components of the suspect heat-transfer medium. However, the components causing the illnesses and death were not identified.

The use of chlorinated biphenyl compounds such as Aroclor and FR series Therminols as liquid-phase heat-transfer media for the processing of edible products is prohibited in the U.S.; usage of Dowtherm A and Therminol VP-1 is permissible. Gavin (1978a) reports an apparent world-wide shift to high-pressure steam as the heat-transfer medium in spite of the fact that a packaged-type, high-pressure boiler for deodorizer service costs about twice that of a Dowtherm vaporizing system (Zehnder, 1976).

Other heating means that have been tried but found wanting for any of several reasons include: direct firing of the batch deodorizer, circulation of the deodorizer oil charge through an external furnace, and use of superheated steam in the deodorizer heating coils (Mattil, 1964).

Because of its cyclical nature, operation of a batch deodorizer causes wide variations in the load of utilities used for heating, cooling, and pumping the oil. With the continuous deodorizer, the demand is essentially constant; thus the continuous deodorizer heat exchangers and other equipment and the service lines for providing the various utilities need not be oversized. As a result, there is considerable savings in capital investment. The continuous deodorizer also uses considerably less stripping steam, with further savings in reduced usage of ejector motive steam and barometric condenser water. With the semicontinuous and continuous deodorizers, the hot oil can preheat the feedstock to an intermediate temperature and thus reduce the fuel requirements. On the basis of actual performance of a commercial continuous deodorizer, Bodman et al. (1951) estimated the operating costs at that time were about one-third those of a similar batch operation.

With the semicontinuous deodorizer, the load is not as uniform as the continuous unit but does approach it.

**PROTECTION OF THE OIL AGAINST OXIDATION**

The edible oil processor protects the oil from oxidation by most or all of the following measures: (a) exclusion of air during processing, (b) cooling the deodorized oil to proper temperature before exposure to the atmosphere, (c) protection of deodorized oil from the atmosphere by nitrogen blanketing, and (d) addition of chemicals that serve as metal scavengers and antioxidants. He also maintains a full vacuum on the deodorizer even when not in use to avoid oxidation of the adhering film of residual oil, which could then contaminate the next lot.

Avoiding contact with air. Soybean oil must be scrupulously protected from air throughout the entire deodorizing operation. Deaeration of the feedstock as a first step is very essential, because the oil may contain an appreciable amount of dissolved oxygen due to previous exposure to the atmosphere. A continuous method for deaerating the oil to less than 0.10 vol. % dissolved oxygen has been described by Baker and Edwards (1970).

At deodorization temperatures, the oil reacts very rapidly with oxygen with a decidedly bad effect on the oil's flavor and oxidative stability. Periodic preventative maintenance is needed to prevent air leaks from occurring in deodorizer fittings below the oil level and in external pumps, heaters, and coolers that contact the oil. Welded construction of the deodorizer shell greatly reduces the possibility of leakage. In addition, the double shell feature of the semicontinuous deodorizer and at least one type continuous deodorizer eliminates the possibility of the hot oil being exposed to air entering through leaks in the outer shell. This feature has contributed considerably to acceptance of this design.

The stripping steam also must be oxygen-free and therefore generated from deaerated water.

**Oil cooling.** Unhydrogenated oil should be cooled to 100-
120°F (38-49°C) before exposure to the atmosphere. Partially hydrogenated oils and fats melting above room temperature are somewhat more resistant to oxidation and should be cooled to within 25-30°F (ca. 15°C) of their melting points (Young, 1978).

During cooling within the deodorizer, the sparge steam flowrate should be sufficient to provide the agitation needed for good heat transfer. At a deodorizer pressure of 6 mm, and depending also upon the oil depth, the oil can be cooled only to 130-150°F (54-66°C) before steam condensation occurs, thus resulting in a wet oil. After removal of dry oil from the deodorizer, the oil should be further cooled to the appropriate temperature in a heat exchanger following the polishing filter.

Nitrogen blanketing. Nitrogen blanketing is often used during storage, packaging, and shipment to protect the deodorized oil. The storage tank is filled with nitrogen, then oil is pumped in through a pipe leading to the tank bottom to avoid splashing. Containers on the packaging line are flushed with nitrogen, passed into a compartment filled with nitrogen, filled with oil saturated with nitrogen, and sealed before they are returned to normal atmospheric conditions.

Some processors prefer to cool the oil to 100°F (38°C) and omit the nitrogen blanketing. They believe that this method gives better protection because, in their opinion, unless the nitrogen is exceptionally pure, the presence of a very small amount of oxygen or NO, can have a detrimental effect (Also see Chapter 16).

Effect of light. Soybean oil will develop off flavors upon exposure to light (Moser et al., 1965) as will other fats and oils. Addition of citric acid (10-50 ppm) does not inhibit deterioration of soybean oil by light (Miyakoshi et al., 1978). For this reason, some companies package the oil in cans or brown glass bottles, although retail market experience indicates that the housewife preferentially selects oils packaged in clear bottles. Daubert (1950) concluded that certain natural pigments, such as carotenoids and chlorophyll, act as prooxidants in an oil exposed to light but they are inactive or act as antioxidants in the dark. (Also see Chapter 14).

Additives. A common practice is to add citric acid (0.005 to .01% based on weight of the oil), preferably at the cooling stage in the deodorizer, to protect the oil against oxidation. The acid inactivates traces of metal (Dutton et al., 1948, 1949), particularly iron and copper, which appear both in the native oil and as a result of processing (Evans et al., 1952, 1974). Although some U.S. refiners believe the acid is effective when added before deodorization, it decomposes rapidly at temperatures above 302°F (150°C), and Miyakoshi and Komoda (1978) deemed it to be ineffective as a metal scavenger when added at this point. Because of the unresolved questions on the composition and possible toxicity of the decomposition products that may remain in the oil, the usual practice now is to add the acid at the cooling stage in the deodorizer. Also, complexes formed by these and other trace metals with oxygen and hydroperoxides presumably are decomposed at deodorization temperatures, and the metal inactivators then become more effective (Uri, 1961). (Also see Chapter 14).

Miyakoshi and Komoda (1978) reported it desirable to add the acid as an aqueous solution to avoid the loss encountered upon addition as an ethanol solution. Miyakoshi et al. (1978) found that up to but not in excess of 50 ppm of the acid can be dissolved in the oil at a temperature of 266°F (130°C) or less during the cooling stage, and that this amount will remain dissolved or dispersed during storage of the oil, although as little as 10 ppm will protect the oxidative and flavor stability of the oil.

When soybean oil containing 50 ppm of citric acid was heated under various deodorizing conditions (257 to 392°F or 125 to 200°C and 10 to 40 min) and then examined for the presence of citric acid and its decomposed acids, i.e., aconitic, itaconic, and citraconic, no acid other than citric was found after the oil had been heated to 150°C or more for 10 min or longer. A trace of aconitic was detected in the oil heated 40 min at 125°C. When oil containing 1000 ppm of citric acid was deodorized, a trace of itaconic and from a trace up to 16 ppm of aconitic acid were found. The quantity of both these acids and of citric acid decreased as the deodorization temperature or time were increased (Miyakoshi and Komoda, 1978).

Phosphoric acid can also serve as a metal inactivator, but the level of usage is a critical factor (Evans et al., 1954a). Excessive amounts of the acid lead to the development of melony and cucumbery off-flavors and to lower flavor scores for the aged oils in spite of their improved oxidative stability. A similar effect was noted for phosphatide levels above 0.02-0.05% (Evans et al., 1954b).

Stabilizers other than metal-inactivating agents are also often added to the oil while it is being cooled in the deodorizer (Stuckey, 1968). Propyl gallate, tertiary-butylhydroquinone (TBHQ), t-butylhydroxytoluene (BHT), and t-butylhydroxyanisole (BHA) are used as antioxidants. The latter two are used to improve the oil's shelf life and to provide carryover protection into baked and cooked foods. The gallate and TBHQ increase the oil's oxidative stability. These oxidants may be
used singly up to 0.01% level or in combination of two or more at a maximum concentration of 0.02% (Code of Federal Regulations, 1976). Mixtures of several combinations are available commercially.

As part of its review of all substances Generally Recognized As Safe (GRAS) for use in foods, the Food and Drug Administration (FDA) has asked for new tests to determine whether BHT meets safety standards as determined by modern testing methods. Meanwhile, the use of BHT is temporarily restricted to current levels in foods for which it is now approved (Anonymous, 1977).

Recently, Mounts et al. (1978) reported that addition of two antioxidants (BHA and BHT) did not improve the flavor stability either of one unhydrogenated or of two hydrogenated soybean oils in accelerated storage tests but did improve the flavor stability of the hydrogenated oils exposed to light. Both hydrogenation and the antioxidants improved the oxidative stability of the oil. At least one firm is now marketing a 100% soybean salad/cooking oil that contains no added antioxidants or anti-foam agent.

Methyl silicone at a level of 1 to 5 parts per million is sometimes added as an antifoam agent (Freeman et al., 1973; Martin, 1953).

Because most additives break down under heat, they are added at oil temperatures under 180°F (82°C). Sufficient agitation and mixing time are required to obtain uniform dispersion and true solution.

Sherwin (1976, 1978) provides further information on the performance of various antioxidants and precautions to be observed in their application. (Also see Chapter 16.)

Filtration of Deodorized Oil

The deodorized oil is filtered to remove solids that unavoidably appear in the oil for several reasons. Small carbonaceous particles may be present because of the oil having been subjected to high temperatures and localized overheating in the deodorization process. The feedstock storage tanks inevitably become contaminated with traces of bleaching earth, and the latter can be carried into the deodorizer. Not all of the citric acid added during cooling of the oil may have dissolved.

After cooling to 150°F (66°C) or less, the deodorized oil is filtered in a so-called "polishing" filter, usually through paper. The filter medium should be capable of removing 30-micron (0.0012 in.) particles for normal use oils and 10-micron particles for bottled oils. The filter should be easy to clean, be simple to assemble correctly, and have a low-volume holdup to reduce the risk of contamination, and the filter medium should be inexpensive (Young, 1978).

Deodorization of Soybean Oil

A high-quality deodorized product can be produced from soybean oil if one starts with good soybeans and if the proper precautions are taken to protect product quality in each processing step. As Gavin (1978a) states, the proper strength and amount of caustic must be used to insure adequate removal of the phosphatides during caustic refining (Beal et al., 1956), and the oil must be washed and bleached properly for good removal of soaps, followed by deodorization at the proper temperature and pressure and with sufficient stripping steam. He also advocates addition of citric acid or antioxidants and nitrogen to the oil immediately after deodorization. The deodorized oil then should have less than 0.03% FFA, a peroxide value of zero, Lovibond colors of 10 yellow and 0.7 red, and a bland taste. Gavin emphasizes that a good-quality deodorized oil will not be produced unless the deodorizer feedstock is of good quality—a statement that is true for all vegetable oils and especially so for soybean oil.

Typical conditions used commercially for deodorization of unhydrogenated soybean oil in a semicontinuous deodorizer are: top temperature 475 to 500°F (246-260°C), 15 to 40 min at the deodorization temperature with the shorter time used at the higher temperature and higher stripping steam rate, 3-6 mm Hg absolute pressure, 3-8% stripping and sparge steam based on oil throughput, and oil cooled to 150°F (66°C) in the deodorizer. Then 0.01% citric acid and antioxidants as desired are added to the cooled oil either in the deodorizer or after removal.

For EMI continuous deodorizers having a heat recovery unit (described later under equipment), preferred conditions are: top temperature 510°F (266°C), 90 min total time with 30 min at the top temperature, 3 mm absolute pressure, and 2.6% stripping steam. Additives such as citric acid are added as described for the semicontinuous deodorizer (Gavin, 1978b).

Deodorization Equipment and Practice

The conditions used commercially for deodorization of fatty oils vary appreciably with the type of equipment used (Table 1), the type of oil being deodorized, and the degree to which the oil needs to be deodorized.

The equipment descriptions that follow are not all inclusive but rather aim to give the reader a better understanding of the deodorization process, of the basic types of deodor-
The conventional batch deodorizer is a vertical cylindrical vessel of welded construction with dished or conical ends and a height two to three times the diameter. Capacities range from 5,000 to 60,000 lb (2,270 to 27,270 kg), and a typical capacity is 20,000 to 30,000 lb (9,090 to 13,640 kg). The deodorizer is filled to a depth of 8-10 ft (2.4-3.0 m) (hot oil measurement) with a headspace volume approximately equal to the depth of the oil. The large headspace volume minimizes carryover into the vapor outlet of oil droplets projected into the headspace by violent splashing during deodorization. An entrainment separator in the vapor line further reduces the carryover. Sometimes a centrifugal separator or a slotted, baffle-type separator is installed in the upper part of the deodorizer for the same purpose. The outlet vapor line to the entrainment separator or vacuum source should be as short as possible to minimize condensation of distilled volatiles in the outlet.

A 3-stage steam-ejector system is normally used to maintain the deodorizer vacuum. Internal pipe coils are generally used to heat and cool the oil. The deodorizer is well insulated.

The deodorizer is independent of barometric pressure, and means for moving oil into and out of the deodorizer. Batch deodorizers are being replaced by semicontinuous and continuous units. Young (1978) states that in England and on the European continent, batch deodorizers are useful for quantities of 12 tons or less and particularly for erucic acid oils that are deodorized satisfactorily at 356-392°F (180-200°C), the normal temperature range for batch deodorizers.

BATCH DEODORIZATION

The conventional batch deodorizer is a vertical cylindrical vessel of welded construction with dished or conical ends and a height two to three times the diameter. Capacities range from 5,000 to 60,000 lb (2,270 to 27,270 kg), and a typical capacity is 20,000 to 30,000 lb (9,090 to 13,640 kg). The deodorizer is filled to a depth of 8-10 ft (2.4-3.0 m) (hot oil measurement) with a headspace volume approximately equal to the depth of the oil. The large headspace volume minimizes carryover into the vapor outlet of oil droplets projected into the headspace by violent splashing during deodorization. An entrainment separator in the vapor line further reduces the carryover. Sometimes a centrifugal separator or a slotted, baffle-type separator is installed in the upper part of the deodorizer for the same purpose. The outlet vapor line to the entrainment separator or vacuum source should be as short as possible to minimize condensation of distilled volatiles in the outlet.

Internal pipe coils are generally used to heat and cool the oil. The deodorizer is well insulated. Sometimes the upper half is heated to prevent condensation of distilled volatiles within the deodorizer and their return to the oil (Phelps and Black, 1946). Stripping steam is admitted at the bottom of the vessel through a perforated pipe fashioned either as a coil or a flat spider.

Other accessories include a thermometer or appropriate device for measuring the oil temperature, a pressure gage that accurately measures the absolute pressure within the deodorizer independent of barometric pressure, and means for moving oil into and out of the deodorizer.

Batch deodorizers generally are constructed of common iron, but iron has a detrimental effect on oil quality at deodorizer temperatures (Beal and Lancaster, 1951). Surfaces contacting the hot oil would more appropriately be constructed of metal such as type 304 or 316 stainless steel or nickel, but then the vessels would be more costly. Batch deodorizers are being replaced by semicontinuous and continuous units.

Table 1: Commercial Deodorization Conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute pressure</td>
<td>1-6 mm Hg</td>
</tr>
<tr>
<td>Deodorization temperature</td>
<td>410-525°F</td>
</tr>
<tr>
<td>Holding time at deodorization</td>
<td></td>
</tr>
<tr>
<td>Batch deodorizers</td>
<td>3-8 hr</td>
</tr>
<tr>
<td>Continuous and semicontinuous deodorizers</td>
<td>15-120 min</td>
</tr>
<tr>
<td>Stripping steam as wt % of oil</td>
<td></td>
</tr>
<tr>
<td>Batch deodorizers</td>
<td>5-15%</td>
</tr>
<tr>
<td>Continuous and semicontinuous deodorizers</td>
<td>1-5%</td>
</tr>
<tr>
<td>Free fatty acid contents</td>
<td></td>
</tr>
<tr>
<td>Feed, including steam refining</td>
<td>0.05-0.6%</td>
</tr>
<tr>
<td>Deodorized oil</td>
<td>0.02-0.05%</td>
</tr>
</tbody>
</table>

flows by gravity through succeeding tanks and vessels within the deodorizer.

The second uppermost tank is equipped with heating coils for heating the oil by Dowtherm vapor or other heat transfer media to the deodorization temperature, usually in the range of 400-525°F (204-275°C). In this tank and all others within the deodorizer, the oil is constantly agitated by a stream of sparge steam. This agitation increases the heat-transfer rate, prevents the formation of pockets of stagnant oil, and prevents prolonged contact of any portion of the oil with the hot coil surfaces.

Next, in the prestripping vessel, deodorization occurs as the oil flows in a thin film over a series of stripping trays counter-current to the flow of stripping steam injected in the bottom of the vessel.

Oil then enters the holding tank wherein further thermal treatment occurs for breakdown of heat-sensitive pigments, peroxides, etc.

For removal of any odoriferous, volatile materials released during the holding period, the oil is given a final stripping/deodorization in a vessel similar in design and operation to the prestripping vessel.

Hot oil flows from the final stripping vessel to the heat-recovery tank for preheating the incoming feedstock and then to the cooling tank for cooling to 150°F (66°C) or less. The latter tank is similar in construction to the heat-recovery tank except that cooling water is used in the coils.

With the double shell concept employed in this deodorizer, each internal tank or vessel is maintained at the same high vacuum. Thus the highest vacuum and highest temperature attained in the system are used for deodorization of the oil in the two stripping vessels. The oil is deaerated under this high vacuum both before and after heating. Also, any air leakage through the outer shell does not come in contact with the hot oil, but instead passes directly to the vacuum system. Surfaces of the internal trays, vessels, and piping that come in contact with the oil normally are of type 304 stainless steel, whereas the outer shell can be constructed of less costly carbon steel.

Sparge and stripping steam leaving each of the internal vessels, plus volatile material removed from the oil, flow through the annular space surrounding these vessels and into the vacuum system. A wire-mesh type entrainment separator in the cover of each vessel removes entrained oil droplets from the vapors. Any volatile material condensing on the internal wall of the outer shell collects at the bottom for periodic removal as shell drain condensate.

EMI single shell deodorizer. Figure 4 is a schematic
diagram of a single shell deodorizer also designed for heat recovery. Gavin (1978a) comments as follows:

"With this design, we found it was less expensive to use Dowtherm for all of the heating instead of the steam-Dowtherm heating combination used in the double shell design. The single shell deodorizer consists of a type 304 stainless steel tower containing the same process elements as the double shell deodorizer. The carbon steel shell is replaced with a carbon steel vapor pipe manifold mounted alongside, with individual connections to each of the sections in the stainless steel deodorizer tower.

"The carbon steel vapor pipe connections to the stainless steel tower are located so that steam used in sparging and stripping, along with the volatile impurities, pass from each section directly into the vapor take-off pipe and are removed through a single connection to the vacuum system.

"Wire mesh type entrainment separators are provided in the top of each section. Manways, which are required for removal of the mist eliminators for cleaning, are mounted on the vapor take-off pipe in such a manner that any air leakage will flow directly to the vacuum system making it impossible for air to contact the hot oil in process.

"Both the single and double shell deodorizers, which have been proven in commercial operation for more than 10 years, will produce a deodorized oil with a bland flavor, a maximum free fatty acid content of 0.03%, and a zero peroxide value.

"The single shell, double shell, and steam refining deodorizer systems include as standard equipment a manual stock changing system which is effective and convenient for occasional stock change. If feedstock is to be changed more than once a day, the deodorizer can be furnished with an automatic feedstock change system. With this system, a change of feedstock is accomplished from the control panel by simply pressing the start button for the automatic feedstock change system.

"By timed automatic integrated operation of the internal tank drain valves and the feed, discharge, and steam purge valves, the controller will automatically empty and fully drain the tanks and towers in sequence and then refill the deodorizer with the next oil to be deodorized with one empty section between the new and old stock to eliminate intermixing. No operator attention is required for this operation, so the operator can direct his attention to operating the feed and product lines to and from storage for the feed and product polishing filters."

The double shell deodorizer is available in capacities of 15,000 to 60,000 lb/hr (6,804-27,216 kg/hr). For capacities under 15,000 lb/hr, the single shell deodorizer is more economical.
SEMICONTINUOUS DEODORIZER

The semicontinuous deodorizer is a development resulting from research undertaken by Bailey (1949). The first commercial unit based on his design went into operation in 1948 and consisted of a series of special trays or tanks mounted within a vertical, cylindrical tower. The oil moved batchwise from one tray to the next and was deaerated, heated, deodorized, and cooled in successive, distinct steps, each of which was conducted in a specific tray. As mentioned earlier, this type deodorizer has been widely accepted, because the design permits frequent changes of feedstock with very little intermingling of the successive changes, practically eliminates oxidation of the hot oil, and also reduces the wide variations in the utility loads encountered with the batch deodorizer.

Bailey's original design (1949) employed five trays, two of which were used specifically for deodorization. Oil was retained within the deodorizer for 2.5 hr, 1.0 hr being devoted to deodorization. By use of a deodorizer tray of improved design (Lineberry and Dudrow, 1972), which gives more intimate contact between the steam and oil and permits a high steam flow, only one tray is now needed. The deodorization time on this tray is reduced to 15 min, and deodorizer capacity can be increased.

Flow diagram. The schematic diagram and flowsheet for a semicontinuous deodorizing plant of recent design with a heat recovery unit is shown in Figure 5. Also shown are a vapor scrubber (labeled scrub-cooler) for deodorizer distillate recovery, a high-temperature heat source for heating the oil, a four-stage steam ejector system for the vacuum source, a polishing filter and instrument panel.

After a simple filtration (filter not shown) to remove
solid particles, feedstock at 120-130°F (49-54°C) is pumped into an atmospheric-pressure measuring tank that is fitted with a level controller and is used to establish the proper amount of oil to be charged to the deodorizer trays. In response to a signal from the sequence controller, an automatic valve opens and a batch of oil is drawn into the top tray (No. 1) of the deodorizer. In this tray the oil is deaerated and is preheated by steam generated in the heat recovery tray (No. 4). After 15 min, which is the normal oil retention time in each tray, internal drop valves open in sequence and the oil flows by gravity into the high-temperature heating tray and is heated to deodorization temperature by Dowtherm, Therminol, or another high-temperature heating media.

Oil next flows to the deodorizing tray and is deodorized by jets of stripping steam that are injected horizontally and at successive heights into a confined column of oil surrounding the steam distributor. The velocity of the steam jets and the width of the column are such that the steam substantially penetrates the oil column. The expanding steam decreases the density of the oil column and creates a violent pumping action. Oil is thrown against the bottomside of an overhead, umbrella-shaped baffle, moves radially outward, and is deflected downward by the outer lip of the baffle into the main body of oil in the tray. Oil returns for recirculation through an opening at the bottom of the vertical metal cylinder surrounding the steam jets. The violent agitation, splashing, and recirculation produce intimate contact between the oil and steam. Oil depth in the tray is about 24 in. (61 cm). The reversal in direction at the periphery of the umbrella baffle separates much of the steam and accompanying volatile matter from the oil stream. Oil droplets collecting on the underside of an overhead deflector (above the umbrella deflector) are returned to the oil in the tray. Vapors leave the tray through the annular gap between the sidewall of the tray and the overhead deflector. Any oil droplets that escape at this point either are carried out by the vapors or collect on the inner walls of the deodorizer shell and outer walls of the trays, drain to the bottom of the shell, and are removed periodically as part of the shell drain condensate. Condensed volatiles that accumulate on top of the overhead deflector cannot return to the oil being deodorized but instead accumulate as part of the shell drain condensate (Lineberry and Dudrow, 1972).

In tray no. 4, heat is abstracted from the freshly deodorized oil to preheat the incoming feedstock with about a 50% saving in the fuel required for deodorization. The hot oil generates steam in a closed loop thermosyphon that has been evacuated and partially filled with distilled water. Steam generated in the coils of this tray rises to the deaerating-preheating tray coils and condenses as it preheats the feedstock, and the condensate flows by gravity back to the heat-interchange tray.

In tray no. 5, the oil is further cooled with cooling water to about 150°F (66°C). Additives such as a metal scavenger, antioxidants, and/or an emulsifier are often added to the oil in this tray. Equipment for the addition is not shown.

From tray no. 5, the deodorized oil is discharged into a "built-in" drop tank created at the bottom of the deodorizer shell and is pumped as a continuous stream from there through a polishing filter and then either to the next point of usage or cooled further for storage. The oil usually is filtered through paper for the removal of any solids.

Stripping or sparge steam is introduced in each tray of the deodorizer. Total usage is about 4% based on weight of the feedstock. Of that, 3% is used in the deodorization tray, no. 3, and the remaining 1% is equally distributed among tray nos. 1, 2, 4, and 5.

The deodorizer is designed to operate at a maximum deodorizer temperature of 525°F (274°C) and normally operates at 6 mm Hg absolute pressure, but pressures as low as 1 mm can be used if the vacuum supply is designed for such operation.

Instrumentation is provided for automatically controlling process variables such as deodorization cycle, process temperatures, flows of oil, steam, and cooling water. Interlocks will halt the operation and signal the operator if trouble develops, such as faulty flow of oil or steam at any tray or improper temperatures at any point.

The deodorizer is built in capacities of 2,500 to 30,000 lb of oil per hr (1,135 to 13,640 kg/hr) (Chemetron Corp., 1977). Outside diameter of the shell varies from 90 to 126 in. (2.29 to 3.20 m) and the height typically from 37 ft 4 in. to 47 ft 1 in. (11.4 to 14.4 m). The trays and vapor scrubber are made of type 304 stainless steel, whereas the deodorizer shell, steam-jet ejector, and shell-drain tank are made of carbon steel.

RECOVERY OF DEODORIZER DISTILLATE

Until the late 1950's, the common practice was to discharge deodorizer distillates into the barometric condenser water with later partial recovery of the floc formed by distillate and water. The first distillate recovery systems were installed because of the restrictions placed on discharge of these fatty materials into waste waters entering public
In the present recovery process, vapors leaving the deodorizer are cooled sufficiently to condense high-boiling organic constituents removed from the oil but not the stripping steam. The cooling and condensation are effected as the deodorizer vapors pass through a recovery tower such as the Scrub Cooler shown in Figure 5, where they come in direct contact with the cooled distillate. Distillate collects in the bottom reservoir of the tower, is continually passed through a heat exchanger to remove the heat of condensation, and is then returned to the tower. Although a spray head is shown in Figure 4, other means can also be used to obtain the desired contact between vapors and liquid, such as a tower partially filled with packing material or a jet venturi system, as long as the deodorizer vacuum can be maintained. An automatic control maintains the desired liquid level in the reservoir and the excess liquid is withdrawn as product. Vapors leaving the condensing unit pass through a demister section for removal of entrained liquids.

In the recovery method developed by Fiala (1959), the deodorizer distillate vapors are condensed by direct contact with tepid (about 100°F or 38°C) water. Because the resultant emulsion can be troublesome, cooling the distillate and recycling a portion as described above is the preferred method of operation.

For maximum distillate recovery, the tower is installed between the first-stage ejector and the barometric condenser (Chemetron Corp., 1977). The tower then operates at 40-60 mm absolute pressure, and the distillate is cooled to about 140°F (60°C). However, if the cooler is installed ahead of the first-stage ejector (Fig. 5), the ejector steam consumption is less; this is a desirable feature when the utility savings exceed the loss from the lower degree of distillate recovery at the higher vacuum and the expense resulting from the greater load on the wastewater system. The degree of distillate recovery is difficult to determine precisely, but recoveries up to 95% have been obtained (Wilson, 1970).

The distillate consists of FFA, neutral oil, and unsaponifiable material including sterols and tocopherols (Fiala, 1959; Wilson, 1970). Evans et al. (1964) and Hoffmann et al. (1964) have characterized some of the unsaponifiable constituents of deodorizer condensates. During the 1960's and early 1970's, soybean oil deodorizer distillates were a valuable byproduct because they were then an economical source of high-quality sterol and tocopherol compounds. More recently, competition from synthetic products has caused a marked drop in market value of the distillate (Gavin, 1978a). Based on tests made with production-size deodorizers on soybean oil containing about 0.12% tocopherol, a distillate yield of 0.35-0.45% with a tocopherol content of 10-14% is typical for the following deodorization conditions: deodorization temperature, 525°F (274°C); 3-5% stripping steam; 5-7 mm absolute pressure; and a deodorization time of 15 min in a Votator semicontinuous deodorizer of improved design or 2 min (holding tank was bypassed) in an EMI continuous deodorizer. Both distillate yield and tocopherol content decrease as either the deodorization temperature or the percent of stripping steam decreases. The quantity and quality of recovered distillate depend upon both tocopherol content of the feedstock and the operating conditions used for the deodorizer and the distillate recovery unit. Market value of the distillate is determined by its tocopherol content (Wilson, 1978).

ADDITIONAL INFORMATION

Additional information on other makes of deodorizers in use in Europe and elsewhere is given by Andersen (1962), Bernardini (1973), Martinenghi (1971), Stage (1979), and Zehnder (1976).

White (1956) has discussed the engineering aspects of deodorization equipment. Stage (1979) has made an engineering analysis of a number of deodorizers of both European and American design based upon the deacidification-deodorization of palm oil. Earlier, Moeller (1964) reviewed the economics of deodorization, derived certain criteria for the construction and operation of deodorizers, and discussed briefly several of the continuous deodorizers then in use.

RECENT DEVELOPMENTS AND FUTURE TRENDS

With the recent, considerable increase in cost of utilities, a number of edible oil processors have added or plan to add heat-recovery units for their deodorizers. Gavin (1978a) has tabulated the utility requirements for both normal and physical refining deodorizers.

Zehnder (1976) states that the common trend for all deodorizers is toward larger capacity units. Whereas the average capacity was 10,000-15,000 lb/hr (3,940-5,900 kg/hr) in about 1965, the units being built in 1975, especially in the United States, often handle 30,000 lb/hr (11,800 kg/hr). One firm now will supply deodorizers handling 60,000 lb/hr (23,600 kg/hr) (Gavin, 1978b).

Gavin (1978a) foresees further emphasis on development of a satisfactory means for physically refining soybean oil. He also expects that all new installations of conventional and
physical refining deodorizers will include a system for recovery of the deodorizer distillate and that pollution regulations will require (a) the use of closed loop systems for the barometric condenser water and (b) the scrubbing of non-condensable gases for odor control. Gilbert and Tandy (1979) have described a system for distillate recovery and odor control. (See Chapter 24 for information on environmental aspects.)

The Cambrian Campro continuous deodorizer employs a thin film concept to strip volatiles from the oil at high transfer rates (Cambrian Processes, 1975; McGowan, 1978). The first production unit was installed in 1972 for use on rapeseed oil. A production unit installed in the U.S. in 1977 is operating on soybean oil. Three units installed in 1978 in Jamaica and Canada are used principally for palm oil physical refining. The operations of deaerating, heating, deodorizing, heat exchanging for heat recovery, and cooling the oil can be conducted within a single rectangular, stainless-steel processing tray that is housed in a split, horizontal, cylindrical shell connected to a vacuum exhaust system. All piping connections are made to the fixed end of the shell and the retractable end gives access to the processing tray. The process steps enumerated above are conducted in individual compartments of the tray, and oil flows sequentially from one compartment to the next. Each compartment can be emptied by a steam lift in advance of a change in feedstock. Stripping steam is used to propel the oil as a thin film through a series of vertical channels such as open-ended tubular conduits in the deodorizing compartment. The stripping steam requirement for deodorization is 1-1/2 to 2-1/2% of the oil weight. For steam refining, the steam stripping compartment is modified for removal of the larger amounts of FFA. The deodorizer is designed to operate at 460-520°F (238-271°C) and 3 mm absolute pressure with an oil retention period of 40 min.

Sullivan Systems, Inc. (1978), a subsidiary of the DeLaval Separator Co., recently announced a new continuous deodorization system that employs external heat exchangers for heating and cooling the oil. Compared with conventional deodorizers using internal heat exchangers, the Sullivan design reportedly achieves greater heat recovery (80 vs. 55%), lower installed costs because of a smaller deodorizer tower and fewer trays, and lower operating costs because of the greater heat recovery and lower consumption of stripping and motive steam.

Based upon laboratory experiments and analysis of commercial samples, Ackman et al. (1974) concluded that the conditions normally used in North America for the steam deodorization of edible vegetable oils convert up to 25% of the linolenic acid from the cis-form to the trans-form. The trans-9 and trans-15 forms exceeded the trans-12 form. The conversion (i.e., isomerization) occurs at the elevated temperatures (above about 400°F or 200°C) and residence times used in deodorization.

If the need should occur for limiting the formation of trans acids, interest may develop or intensify in other deodorization methods. Some of possible interest are described in the next section.

**NOVEL DEODORIZATION METHODS**

Palmson (1969) patented a continuous method for stripping volatile substances from fluids, including fatty oils, wherein the fluid (oil) is atomized and carried by the stripping steam through the tortuous path of a plate-type, low hold-up, short-residence time (fractional second) contactor designed for a high surface area to volumetric ratio. The steam-stripped oil and the mixture of steam and volatiles removed from the oil are separated in a highly efficient cyclone separator. The vapors pass through a scrubber for removal and recovery of the deodorizer distillate and then to the vacuum-producing-condensing apparatus. The apparatus, currently referred to as the Parkson Evaporator/Stripper, performs well on cocoa butter, and a research program is underway to make the apparatus effective on soybean oil (Moore, 1978).

Stage (1976) has studied on a laboratory scale the deodorization of fatty oils as a thin film flowing countercurrent to the stripping steam. Gravity flow of oil in combination with lateral heat flow through the cylindrical deodorizer wall and upward flow of the stripping steam presumably results in a wave-like motion of oil with continual renewal of the oil surface and efficient removal of the volatile impurities. With this design, Hammer and Stage (1979) expect to bring the consumption of stripping steam down to about 0.7% for the deacidification-deodorization of palm oil and thus also to reduce the amount of net energy required to heat and cool the oil.

Schumacher (1976) proposes the deodorization of fatty oils for only a fraction of a second at 428-482°F (220-250°C) and 20-30 mm pressure with reduced hydrolysis of the oil. Oil and water (1-4%) are mixed intimately at 464°F (250°C) and 60 atmospheres. Upon passing this mixture into a flash evaporator, the sudden drop in pressure (to 20-30 mm) results in extremely rapid and efficient removal of odor compounds but not necessarily adequate removal of FFA. At the high temperatures used, water has substantially greater solubility in the oil than at lower temperatures (4.4% at 464°F vs. 0.14% at...
90°F, i.e., 32°C).

Baker and Edwards (1970) patented a continuous process for the steam deodorization of edible oils, wherein the oil typically is held about 2 minutes at 480°F (249°C) in a packed chamber, the pressure is maintained at 0.1-50 mm Hg in the lower portion of the chamber, and the stripping steam usage is 0.1-1.0%.

Zosel (1979) patented a continuous process for deodorizing fats and oils with gaseous carbon dioxide (CO₂) at 302-482°F (150-250°C) and 100-250 atmospheres. Impurities taken up by the CO₂ are removed by a solid adsorbent such as activated charcoal before the CO₂ is recycled to the deodorizer column. In an example, the FFA content of a soybean oil was lowered from 0.4 to 0.02%. The process should reduce or eliminate the loss of neutral oil by hydrolysis.

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