Deodorization and Finished Oil Handling

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ABSTRACT

Deodorization is the final processing step in the production of edible oil products. Chemical/physical aspects of deodorization and mechanical design of deodorizers are explained, including chemical analysis of feedstock, finished product and by-products. This includes normal operating standards and means of correcting off specification operation. Operating procedures, labor requirements and maintenance are reviewed. Finished oil handling includes use of antioxidants, inert gas addition, pipelines and storage facilities. Emphasis is on the practical operations of deodorization and finished soybean oil handling.

INTRODUCTION

Deodorization is the last major processing step in refining of edible oils. It is responsible for removing both the undesirable ingredients occurring in natural fats and oils and those which may be imparted by prior unit processes such as caustic refining, bleaching, hydrogenation, or even storage. This unit process finally establishes the oil characteristics of "flavor and odor," which are those most readily recognized by the consumer when the shortening, lard, salad oil, cooking oils and margarine are used (1,2).

PROCESS REQUIREMENTS

Because of the many types of vegetable oils, it is difficult to list all of the components of these oils which produce flavor and odor. These components have been identified as ketones, aldehydes and free fatty acids. Their concentration is usually quite low, ranging from 0.1 to 1.0%. The odor imparted to a hydrogenated oil seems to be characteristic of the hydrogenation reaction.

Experience has shown that flavor and odor removal correlates well with the reduction in free fatty acid (FFA) content of the oil. If an oil has an FFA of 0.1%, it will have an odor that will be eliminated when the FFA is reduced to 0.01-0.03% assuming a zero peroxide value. In some commercial deodorizers, on occasion, reduction of the FFA will not correspond with deodorization of the oil, but in these cases there are usually other complicating factors.

All commercial deodorization, whether in continuous, semicontinuous, or batch units, consists of steam-stripping the oil for FFA removal. The four operating variables which influence deodorizer design are product throughput, stripping steam rate, pressure and temperature.

The amount of FFA removed from the oil is inversely proportional to the system pressure and directly proportional to the vapor pressure of the FFA and the sparge steam rate. Thus, the lower the system pressure at a fixed vapor pressure (or temperature) and sparge steam rate, the greater the FFA reduction. Because the vapor pressure of the FFA is directly proportional to the temperature, both an increase in temperature and increased sparge steam rate increase FFA reduction. The maximal temperature that can be used, however, is limited because of the detrimental effects on oil stability. The operating pressure and sparge steam rate are limited by economic considerations.

A useful relationship in the design of a commercial deodorizer, for a given FFA reduction and temperature, is: the ratio of the system pressure to the sparge steam rate is a constant, and a lower system pressure allows a lower sparge steam rate.

Three other principal factors must be taken into consideration in the design of a deodorizer. The first is the type of materials used for its construction. Due to the deleterious catalytic activity of copper and iron on oils, modern deodorizers are fabricated from type 304 stainless steel at points contacted by hot oil (Table I). The stability of the oil also will be adversely affected if the oil is in contact with oxygen at deodorizing temperatures. Proper deodorizer design provides deaeration of the oil before heating and precludes the possibility of air contacting hot oil in the process.

The final factor to be considered in the process design of a commercial deodorizer is heat treatment. Experience has shown that certain reactions within the oil itself, unrelated to FFA removal, are necessary to provide a stable oil after deodorization. This thermal treatment also will "bleach" certain oils to a much lighter color; this is particularly noticeable in soybean oil. These reactions and the heat bleaching are time- and temperature-dependent; therefore, commercial deodorizing systems should provide a retention period at deodorizing temperatures to allow these reactions and the heat bleaching to occur (2).

MECHANICAL DESIGN

Batch Deodorizer

Although many odd designs for batch deodorizers are described in patent literature, few of them have found practical use, and substantially all present batch deodorization is done in vessels of simple and quite uniform design.

The conventional batch deodorizer is a vessel in the form of a vertical cylinder with dished or cone heads; in modern installations, the vessel is invariably welded and well insulated. The usual range of capacity is 10,000-40,000 pounds, with a capacity of ca. 25,000 pounds being the most common. Batch deodorizers usually are designed to hold 8-10 ft of oil and to have a similar amount of headspace above the surface of the oil; hence, a 25,000-pound vessel may be ca. 8.5 ft. in diameter and 17-18 ft high. The stripping steam is injected into the bottom of the vessel through a distributor, which usually consists of a flat "spider" of perforated pipes radiating from a central steam

TABLE I

Activity of Metals toward Soybean Oil Oxidation (3) (Temp 100 C)

Metal	Relative catalytic activity toward oxidation
Copper	389
Mild steel	140
Stainless steel (T.304)	100
Stainless steel (T.316)	85
Nickel	75
Hastelloy B	66
Inconel	60
Aluminum	45

delivery line. A convenient method of controlling the flow of stripping steam is to maintain a fixed pressure behind an orifice of known size. As the steam pressure always falls to a low value beyond the orifice, the flow of steam will be proportional to the absolute pressure on the high side. In addition to the steam ejector system and means for heating, cooling and pumping the oil, necessary accessories include a thermometer or other device for indicating temperature of the oil and a pressure gauge designed to indicate accurately low pressures within the deodorizer, independently of the barometric pressure.

To avoid excessive refluxing, it is desirable to make the vapor line leading from the top of the vessel to the booster or to an entrainment separator as short as possible. In some installations, the top of the deodorizer and the vapor outlet are jacketed and heated. Entrainment separators are sometimes placed in the vapor line; in other installations, separators of the centrifugal or "Venetian blind" type are placed in the upper part of the deodorizer proper.

With equipment operating at a high temperature and a 6-12 mm pressure, about 8 hr is usually allowed for the complete cycle of charging, heating, deodorizing, cooling and discharging. Older installations operating at a higher pressure and/or a lower temperature may require a time cycle as long as 10-12 hr. Ordinarily, stripping steam is injected at a rate of ca. 3 lb/100 lb of oil/hr at 6 mm pressure, with the steaming rate proportionately greater at higher pressures. The total amount of stripping steam used may vary from ca. 10-50 lb/100 lb of oil; the average is probably ca. 25 lb.

After deodorization is completed, the oil must be cooled before it is discharged to the atmosphere. Hydrogenated products which are relatively resistant to oxidation may be brought out of the deodorizer at a temperature as high as ca. 150 F (66 C) without appreciable injury to the flavor, but a temperature of 100-120 F (38-49 C) is generally preferred for oils. Some processors do not expose deodorized fats or oils to the atmosphere at all, but discharge them to nitrogen-blanketed tanks to fill all packages of the finished product under nitrogen. If the oil is not afforded the protection of an inert gas, it should be packaged as soon as possible, preferably within a few hours after deodorization, as even the more stable products will deteriorate slightly in flavor upon prolonged holding in storage tanks or upon being repeatedly melted and resolidified.

In batch deodorizers, the oil may be cooled either within the deodorizer, by the circulation of water through cooling coils, or externally, as it is pumped through a shell and tube cooler.

When cooling is conducted wholly within the deodorizer at 6 mm pressure, the temperature may be reduced to 130-150 F, depending on the oil depth, before condensation of the stripping steam begins to occur. Transferring the hot, deodorized oil to a separate cooling tank is not recommended unless the tank is, like the deodorizer, maintained under high vacuum and provided with stripping steam.

Theoretically, less hydrolysis of the oil should occur, and it should be possible to reduce the FFA of oil to a lower value when stripping is done in shallow layers than when the oil is in a deep layer and the average hydraulic pressure of the oil upon the injected steam bubbles is relatively high. Comparative results in which stripping is done in layers of oil varying from a few inches to several feet in depth do, in fact, reveal a slight trend toward lower acidities at the lesser oil depth. However, the factor of oil depth is less important in this respect than is the absolute pressure above the oil. As mentioned previously, deodorization in efficient batch equipment at about 6 mm pressure can reduce the FFA of most oils to 0.015-0.030%.

If the deodorizer is designed such that extensive cool surfaces are above the surface of the oil, upon which volatile materials may condense and return to the oil, the efficiency of stripping with respect to all volatile constituents may be seriously impaired (4). The principal advantage of a batch deodorization system is its simplicity. It can be operated for as long or as short a period as desired. However, the cost of utilities for the operation of a batch deodorizer is much higher than the cost of utilities for a semicontinuous or continuous deodorizer.

Semicontinuous Deodorizer

The semicontinuous deodorizer consists principally of a tall cylindrical shell of carbon steel construction in which are placed 5 trays of type 304 stainless steel construction. Semicontinuous deodorizers operate on the basis of handling finite batches of oil in a timed sequence of deaerating/heating, holding/steam-stripping and cooling, such that each quantum of oil is completely subjected to each condition before proceeding to the next step. These plants are normally automated and controlled from a central panel with time cycle controller and interlocks such that the sequence steps are interrupted in the event of insufficient batch size, improper drop valve opening or closing, or the oil not reaching the present heating or cooling temperatures in the allotted time.

The advantages and disadvantages of continuous and semicontinuous deodorizers, the two most widely used types, are important to our discussion. Continuous deodorizers provide uniform utility consumptions by not being subject to the peak loads attendant with batch-type heating and cooling of semicontinuous operation. This permits smaller heating and cooling auxiliaries and the optimum in heat recovery through interchange between incoming and outgoing oil. Semicontinuous deodorizers ensure identical treatment for all of the oil and permit frequent stock changes with the minimal amount of lost production and practically no intermixing (1).

Continuous Deodorizer

In a double-shell continuous deodorizer, the deodorization is conducted in a series of seven vessels all mounted within, but separate from, a single outer shell which is maintained under vacuum. The internal vessels are fabricated from type 304 stainless steel at points of contact with the oil in process; the outer shell is carbon steel.

Figure 1 is a schematic diagram of a double-shell deodorizer. Feedstock at 120 F is pumped into the external deaerating vessel, which is maintained under the same vacuum as the deodorizer to accomplish deaeration before heating. The deaerated feedstock flow is regulated by a liquid level controller and pumped into an internal heat recovery tank where it flows through pipe coils and is preheated by the hot oil surrounding the coils and moving countercurrent to the feedstock. This preheated, deaerated oil absorbs 50% of the heat normally required for deodorization by heat exchange with the hot, deodorized oil prior to being pumped to the top of the tank in the deodorizer. This tank contains a series of baffles and pipe coils for steam-heating. Steam-heating is only required when a change is made in the feedstock. The oil then flows by gravity to the next tank.

The second vessel is the heating tank; it also is constructed with baffles to direct the flow of oil and provided with pipe coils for use with Dowtherm or other heating medium to raise the oil to the deodorizing temperature, usually between 400 and 525 F. This tank is sparged with steam to aid in heat transfer and to prevent pockets of oil from remaining in contact with the hot pipe surface. After reaching the desired deodorizing temperature, the oil flows, again by gravity, to the third vessel.

In this vessel, the prestripping tower, oil is deodorized by passing it in a thin film over a series of stripping trays countercurrent to the flow of stripping steam, which is injected into the bottom of the section. This vessel is maintained under the same high vacuum applied to all sections because it is connected directly to the high vacuum system by means of passages which bypass the other sections. Thus, the highest temperature and highest vacuum are applied at the most advantageous stage of the process; the low-pressure drop/high efficiency stripping tray design ensures maximal use of these optimal conditions. After prestripping, the oil continuously flows down to the holding tank, which contains a series of baffled passages with perforated pipe for steam-sparging. This labyrinth effectively provides the required retention period for the thermal treatment of all the oil.

In final stripping, the oil from the holding tank is again deodorized in another series of stripping trays to remove any additional odoriferous materials released during the holding period. Full vacuum is maintained on the final stripping tower by direct connection to the vacuum system through passages which bypass the other sections. The oil flows from the final stripping tower by gravity into the heat recovery tank where it preheats the incoming feedstock for maximal heat recovery.

The oil flows from the heat recovery tank by gravity to the cooling tank. This tank is similar in construction to the heating tank except water is used in the coils to cool the oil to 150 F. Steam-sparging is provided to aid in heat transfer. The cooled, deodorized oil is then pumped from the vessel.

The steam used in sparging and stripping, along with the volatile impurities, passes from each vessel into the outer annular shell space and is removed through a single connection to the vacuum system. Wire-mesh entrainment separators are provided in the covers of the tanks and towers to remove entrained oil from the vapors leaving them. Any entrained oil not removed, together with any volatile materials that condense on the outer shell surfaces, drains to the bottom of the outer shell and is removed periodically.

As previously discussed, the six principal factors considered in the design of a deodorizer are: (a) *pressure*. Because the entire outer shell space is evacuated, all the deodorizing operations are conducted at the same low absolute pressure; (b) *temperature*. The temperature of the heat transfer fluid flowing to the coils in the heating tank is controlled to maintain the desired deodorizing temperature. Agitation of the oil to provide a high rate of heat transfer is accomplished by sparging with steam; (c) *steam rate*. The steam rate to each tower is metered and controlled individually, with fresh steam used in each tower; (d) *materials of construction*. The seven tanks and all the interconnecting piping are made of type 304 SS. The outer shell is made of carbon steel as it does not come in contact

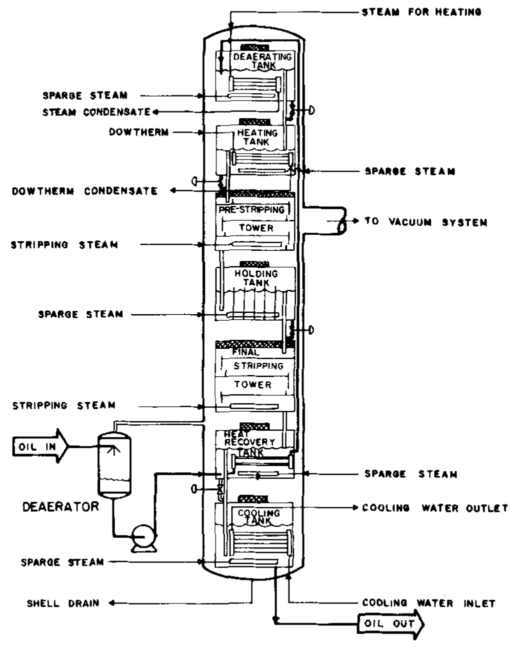

FIG. 1. Schematic diagram of a double shell deodorizer.

with the oil; (e) *thermal treatment*. The holding tank provides the necessary retention time; (f) *protection from oxygen*. The external deaerator removes dissolved and entrained oxygen from the oil before it is heated to the deodorizing temperature. In addition, if any air leaks through connections or seams in the outer shell, it will pass directly to the vacuum system without coming in contact with the hot oil.

The double-shell deodorizing system is available in capacities of 15,000-60,000 lb/hr; however, the single-shell deodorizer is more economical to fabricate for lower capacities. Figure 2 is a schematic diagram of the single-shell deodorizer. With this design, we found it was less expensive to use Dowtherm for all 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.

Feedstock at 120 F is pumped into the external deaerating vessel, which is maintained under the same vacuum as the deodorizer to accomplish deaeration before heating. The deaerated feedstock flow is regulated by the liquid level controller and is pumped through a U-tube heat recovery exchanger mounted inside the deodorizer where the oil is preheated by the hot oil surrounding the tubes. The oil then enters the top section of the deodorizer, which contains an integral U-tube heating coil for use with Dowtherm, a series of passages and baffles for directing oil flow and a perforated pipe for steam-sparging to aid in heat transfer. It flows by gravity into the second section of the deodorizer, the prestripping section, then flows by gravity into a holding section sparged by steam, then into a final stripping section. The two stripping sections have the same process design features as the double-shell deodorizer. The oil then flows by gravity into the heat recovery section, where it gives up heat to preheat the incoming feedstock, and next, by gravity, flows into the cooling section which contains and integral, water-cooled, U-tube coil to cool the oil to 150 F. The cooled oil is then pumped from the

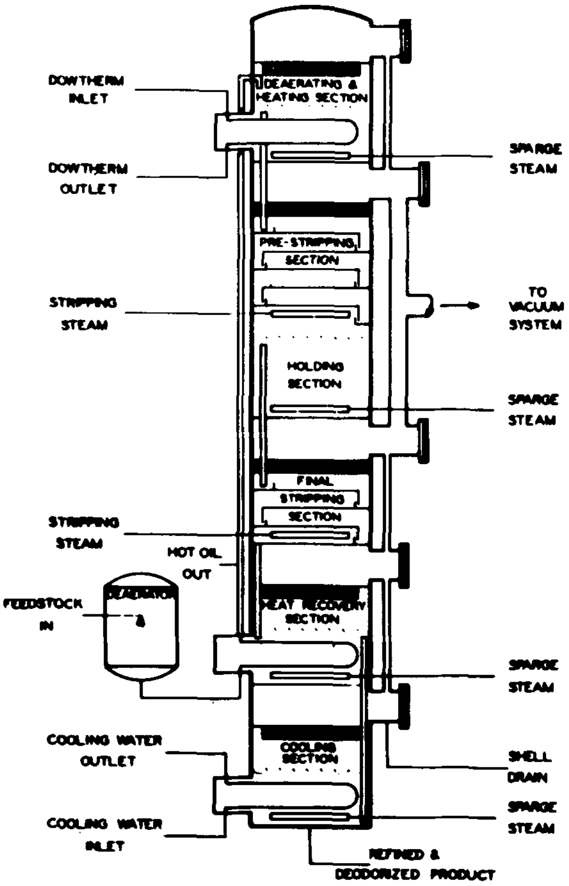

FIG. 2. Schematic diagram of a single-shell deodorizer.

deodorizer.

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, passes from each section directly into the vapor take-off pipe and is removed through a single connection to the vacuum system. Wire-mesh 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, are supplied with the same process guarantee; they will produce a deodorized oil with a bland flavor, a maximal free fatty acid content of 0.03% and a zero peroxide value (2).

Steam or Physical Refining Deodorizer

In Figure 3 the term steam refining refers to the removal of the free fatty acids from the oil by a distillation process instead of by reaction with an alkali. It has application to oils such as palm, palm kernel, coconut, soy, sunflower, corn oil and animal fats, from which all of the nonvolatile impurities can be removed by degumming, clay treating, or other means, so that only the FFA and other volatile impurities remain to be removed by steam refining. If such oils have a high FFA, steam refining has potentially lower losses and operating costs than alkali refining, particularly if it is combined with deodorizing. It also affords the possibility of recovering the FFA in good quality and without the additional process of acidulation which is required for the soapstock resulting from alkali refining.

In this process, the phosphatide-free oil from a pretreatment process is deodorized by three operations conducted under high vacuum at high temperature. First, the free fatty acids are removed by multistage countercurrent contact with steam. Then the pigments are converted to a colorless form by retention of the hot oil for the required reaction time. Finally, the oil is deodorized by additional multistage countercurrent contact with steam.

In order to achieve the full potential of the steam refining deodorizer, the process is designed with the following objectives: (a) reduction of the free fatty acids from 5.0 to 0.03% or less; (b) production of a fully deodorized product; (c) operation without substantially greater utilities consumption than a standard deodorizer; (d) recovery of the fatty acids from the sparge steam. In addition, the steam refining deodorizer also must be suitable for normal deodorization of the usual salad oils, shortening stocks and margarine oils without sacrifice of product quality or operation efficiency. The steam refining deodorizer is designed and operated in a manner similar to the single-shell deodorizer.

In Figure 3, the pretreated oil feedstock is continuously pumped through a filter, and sprayed into the deaerator, **1**, under vacuum to remove entrained and dissolved air. The deaerated oil is pumped to the refining deodorizer, **3**, in which it passes through coils in the heat recovery section and up into the heating section in the top of the deodorizer. In this section, the oil is heated to the required processing temperature by vapor-heated coils from the Dowtherm vaporizer, **10**, or by other suitable heating media. The oil then flows down to the refining section, in which it passes over a series of trays countercurrent to the flow of stripping steam, which is injected below the bottom tray.

The refined oil flows down to the holding section which provides the retention time required for heat-bleaching of the oil, after which it flows down to the deodorizing section. In this section, the oil again passes over a series of trays countercurrent to the ascending stripping steam. The completely deodorized oil flows down through the heat recovery section to transfer its heat to the feedstock and then flows down to the cooling section. In this section, the oil is cooled to the required discharge temperature and is pumped out through a polishing filter, **7**. Metered quantities of solution from the antioxidant tank, **8**, and nitrogen are injected as the oil is discharged to product storage.

Because of the corrosive properties of the large quantities of fatty acids at high temperature, type 316 stainless steel must be used for deodorizer fabrication. Either the double-shell or single-shell design can be furnished as a steam refining deodorizer in capacities of 5,000-60,000 lb/hr. However, it is much more economical to fabricate the single-shell deodorizer from type 316 stainless steel than it is the double-shell deodorizer.

The steam refining deodorizer design achieves the objectives originally stated. (a) It removes the large quantities of FFA from high-acid oils by means of additional stripping trays with no need for increased sparge steam in accordance with proven design principles; (b) it produces a fully deodorized product, and it is also suitable for the deodorization of normal feedstocks, because it is based on a deodorizer of proven performance; (c) it operates with only a moderate increase in utilities consumption; (d) it permits recovery of the distillate without further processing.

OPTIONAL ITEMS

Heat Recovery

The high cost of fuel has made the deodorizer internal heat

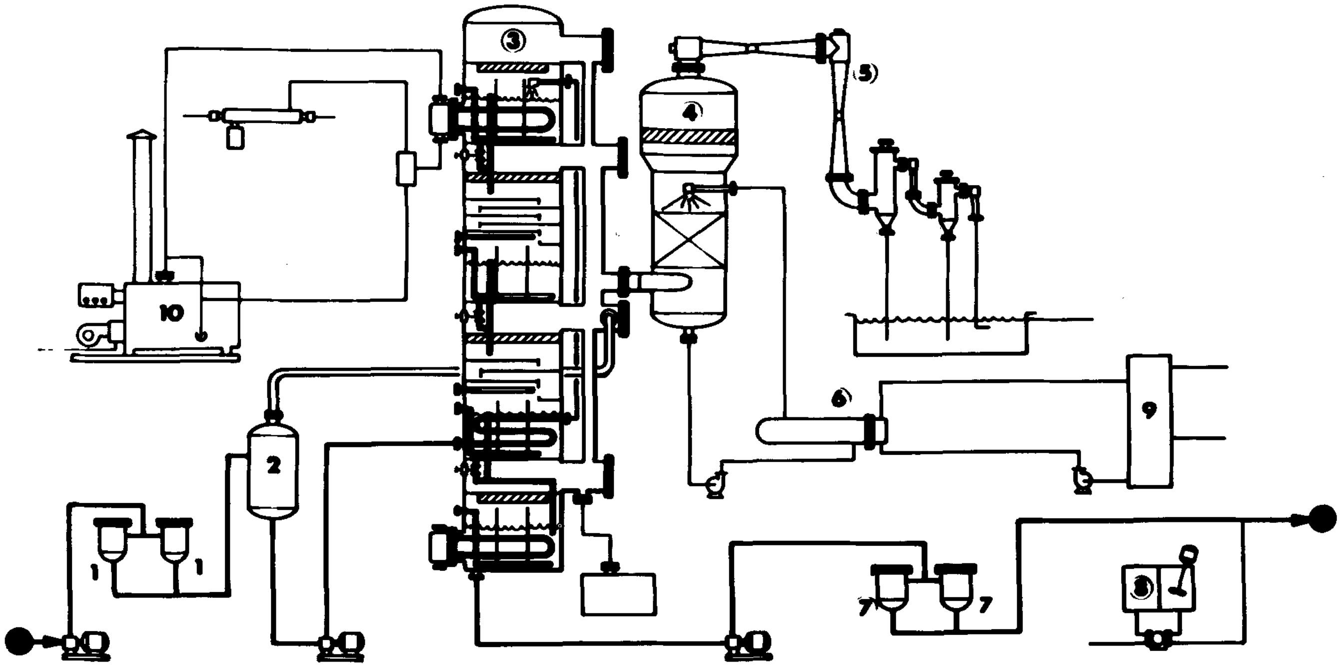

FIG. 3. Flowsheet of a steam refining deodorizer.

recovery system a standard part of deodorizing and steam refining deodorizing systems. Supplemental piping is provided to permit change of feedstock through the heat recovery system without intermixing. When it is necessary to change feedstock, the feed pump is stopped and oil in the deaerator is pumped through the heat recovery tank into the top section of the deodorizer. The flow is then reversed, and oil remaining in the pipe line and pipe coil is blown with steam into the top section of the deodorizer, thus completely emptying the system. This heat recovery system will save 125 lb steam/1,000 lb oil deodorized and is consistent with the principles of the original design, as hot oil is not piped or pumped outside the deodorizer vessel (5).

Change of Feedstock

The single-shell, double-shell, and steam refining deodorizer systems include as standard equipment a manual stock-changing system remotely operated from the panel 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. A system is available for accurate addition of a metal inactivator to the feedstock, and of antioxidant to the product (5).

Deodorizer Distillate Recovery

Because deodorization involves the steam-stripping of organic material from oil under vacuum, this organic material, commonly called distillate, passes into the vacuum system steam. Early deodorizer installations used once through water to condense this steam, with the discharge water returned to its source, such as a river or lake, or to a local water treatment plant. When governmental agencies began to restrict the discharge of organic material or charge high treatment fees, closed circuit water systems were introduced. In these systems the water from the vacuum system is cooled in a cooling tower and returned. However, it was quickly found that this organic material caused problems in the tower. It would collect on the tower fill, causing periodic shutdowns for cleaning. Between shutdowns it would decay, creating odors in the area around the tower. Wind currents would carry the odor beyond the plant boundaries, causing complaints from neighbors. A partial, though more costly, solution was attempted by the introduction of unfilled spray-type cooling towers, but even these had maintenance problems, especially plugged spray nozzles, and did not completely eliminate the odor. Thus, it was necessary to develop a method of treatment of the deodorizer discharge vapor to reduce, as much as possible, its organic content.

In the late 1950s a direct contact cooling process was developed, and today almost every deodorizing system contains some version of this process. A typical flowsheet is shown in Figure 4. The deodorizer discharge vapor and vacuum booster steam flows into a tower where it is cooled by direct contact with a stream of circulating distillate. To provide for intimate contact between the vapor and liquid, some towers are partially filled with packing material whereas others spray the liquid into fine droplets, and still others contain a jet venturi. In all cases, however, the tower's purpose is to cool the deodorizer discharge sufficiently to condense most of the distillate. The tower bottoms are then pumped through a heat exchanger to remove the heat of condensation before being recycled to the tower. Automatic level control is supplied in the tower with excess distillate being pumped to storage. The location of the tower within the vacuum system and the operating conditions within the tower are selected to maximize

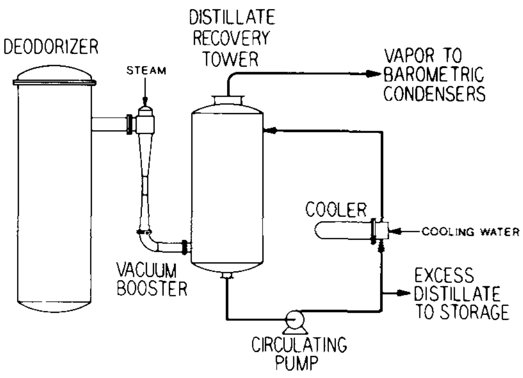

FIG. 4. Flowsheet of a deodorizer distillate recovery system.

distillate recovery, maintain a pumpable liquid in the tower and to prevent condensing of any of the vacuum system steam. In the early installations, the recovered distillate was returned to the crude oil or other location in the refinery for reprocessing.

With the introduction of distillate recovery systems on large-scale soybean oil deodorizers, it was found that this pollution control device actually produced a valuable by-product. The distillate contained high-quality sterol and tocopherol compounds which were in great demand for the production of natural vitamin E and other pharmaceuticals. During the 1960s and early 1970s, users of these raw materials actively campaigned to have all old and new deodorizer installations equipped with these systems to satisfy their raw material needs, and the value of good quality distillate skyrocketed. In 1974-75, however, a reduced vitamin E market, coupled with increasing quantities of synthetic substitutes, caused a substantial drop in the value of the distillate. Only time will determine whether the distillate recovery system will return to a "profit-maker" status or remain strictly a pollution control device.

Condenser Water Recycling

The distillate recovery systems were very successful in substantially reducing the maintenance and odor problems in closed-circuit water sytems. However, because the operating conditions of the tower must be carefully controlled to allow the distillate to be pumped and to prevent steam condensation, some organic material still escapes and ends up in the hotwell. Over a long period of time, problems still develop with the cooling tower. With increasing emphasis on odor elimination by government agencies, the need of operating the cooling tower on only clean water was apparent. Thus, condenser water recycling systems were developed (6).

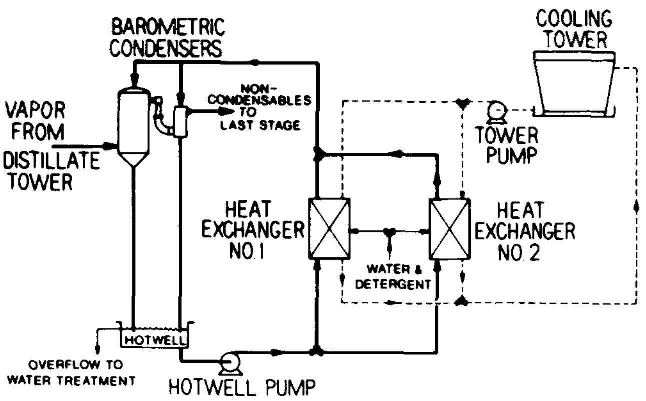

FIG. 5. Flowsheet of a condenser water recycling system.

The basic concept of such a system is shown on Figure 5. The dirty hotwell water is cooled in a heat exchanger with cooling tower water before being recycled to the vacuum system barometric condensers. There is no direct contact between the two water streams and, therefore, the cooling tower remains clean. This also allows the operator to start using more efficient, lower cost, packed cooling towers once again. The heat exchanger is specially designed, usually the plate type, to maintain high velocity through the passages to prevent the organic material from plugging the exchanger or fouling heat transfer surfaces. This system then keeps the organic material in the hotwell water where a continuous bleed from the hotwell to the water treatment system prevents build-up of the material.

Despite special design, the heat exchanger eventually fouls sufficiently so that the temperature of water to the barometric rises. To prevent shutdown of the deodorizer due to erratic operation or loss of vacuum, a second heat exchanger is supplied. At a fixed timed interval or when barometric water temperature starts to rise, the flow of hotwell and cooling tower water is switched to the second exchanger. The dirty exchanger is then cleaned by backwashing with detergent in heated water and is ready for reintroduction into the system when it is needed. These types of systems are usually put under complete automatic control. Thus, at the appropriate time, the line valves switch, the hot water pump starts and runs for a special length of time, determined by actual operating experience to insure complete cleaning.

Vapor Scrubbing

Some of the low-boiling compounds in the FFA continue in the vapor phase through the barometric condenser and exit with the final vacuum stage discharge. Because a typical deodorizer vacuum system will have a noncondensing final stage, most installations pipe the discharge a few inches below the hotwell water level. The volatile compounds dissolve in the hotwell water, and, where barometric condenser water recycling is not used, are reintroduced into the air in the cooling tower. Where recycling is used, they build up in the hotwell and can cause odor emissions around the deodorizer installation. Thus, in installations where this type of odor becomes a problem, a vapor-scrubbing system such as shown in Figure 6 is used to eliminate the volatile material. The vapor scrubber is a packed tower to provide sufficient contact time and area between the volatile materials and the scrubbing liquid. The bottom of the packed tower acts as a small hotwell to condense the vacuum jet steam and provide for some absorption of the volatiles. The remainder of the vapor then passes through the actual packed bed section. All the liquid collects in a small storage tank, is pumped through a heat exchanger for cooling and then is recirculated to the tower.

To aid the removal of odor-causing materials, chemical reagents are added to the circulating water stream to oxidize organic compounds. Reagents such as sodium hypochlorite, calcium hypochlorite, or potassium permangante can be used with the secretion and concentration required, usually chosen based on actual operating experience with each installation (6).

Auxiliary equipment normally supplied with deodorizing systems includes vessels, pumps, vacuum system, Dowtherm vaporizer with vent condenser, polish filters, control panel, instruments and controls. Engineering services include process flowsheet, equipment layout, structural steel design, detail piping layout, piping bill of materials, piping and insulation specifications, start-up services and operator training.

High Temperature Operation

Most commercial deodorizers operate at a temperature of 475-525 F (245-275 C). If steam is used as a heating medium, the presure required would be ca. 900 psig. To reduce the cost and operating expenses associated with generation of steam at this pressure, most commercial deodorizer installations use other heat transfer mediums. Mineral oil was one of the first mediums to be used, but mineral oil is flammable, tends to break down at high temperatures, and there are considerable maintenance costs for the high temperature pump. The majority of the deodorizers use vapor-phase heating with Dowtherm A or Therminol VP-1. Both are trade names for the eutectic mixture of diphenyl and diphenyl oxide, which boils at ca. 496 F (255 C) at atmospheric pressure. Thus, to achieve a temperature required to deodorize at 500 F (257 C), only 16 psig is required. The typical system consists of a vaporizer (boiler), a burner complete with safety controls required by insurance regulations and a gravity return system for the condensate from the deodorizer. Thus, high temperature pumps are eliminated, but the heat transfer medium is flammable. Several years ago, the Therminol FR chlorinated biphenyls were popular as heat transfer media, as they are not flammable and are less expensive; however, they are liquid-phase transfer mediums and require high temperature pumping.

Heating of edible oils to deodorization temperatures has been the subject of considerable discussion, even to the extent of creating a bit of international intrigue. In 1973, contamination of rapeseed oil by a heat transfer medium resulting in illnesses and deaths was reported in Japan, and Dowtherm A was blamed. As a result, the Japanese government prohibited installation of new deodorization systems using Dowtherm, and existing users were given two years to stop using the Dowtherm heating systems. When the smoke cleared, we found that only one-fourth of the 116 Japanese deodorizers were using Dowtherm A as the organic heating medium. Further, the refinery involved in the reported accident was using a mixture of 40% Dowtherm A and 60% KSK-260 oil. C. Imai et al. (7) reported that tests made by them and other laboratories on this rapeseed oil failed to detect any heat transfer medium. Their report indicates that usual deodorizer operating conditions are sufficient to remove Dowtherm A from the oil. The chlorinated biphenyl compounds, such as Aroclor and FR series Therminols, have been prohibited from use as heat transfer media in the processing of edible products in the U.S., but Dowtherm is permitted.

Over the years, European processors have been the more frequent users of high pressure steam. Their deodorizing temperatures of 210-240 C permit the use of 40-60 kg/sq cm steam, whereas the higher temperatures of up to 275 C require steam pressures of 80-90 kg/sq cm. A packaged-type high pressure steam generator to handle the heating requirements of a deodorizer usually will cost about double that of a Dowtherm vaporizer unit (1).

Deodorizing Soybean Oil

In order to produce a quality product from soybean oil, careful attention must be paid to all steps in the refining process. As mentioned previously, deodorization is the last refining step before packaging and sale to the customer. Some refiners take the attitude that deodorization will produce a quality product regardless of the previous treatment of the oil. This simply is not true, particularly with soybean oil. The deodorizer will not make good quality deodorized oil unless the refiner sends good quality refined oil to the deodorizer. If the refiner is using the caustic process, he must treat the oil with the correct strength and amount of caustic to insure removal of phosphatides, he must water-wash and bleach properly to insure removal of soaps, he should add citric acid to the oil before deodorizing and insure the deodorizer is operating at the proper temperature, pressure and with the required amount of stripping steam.

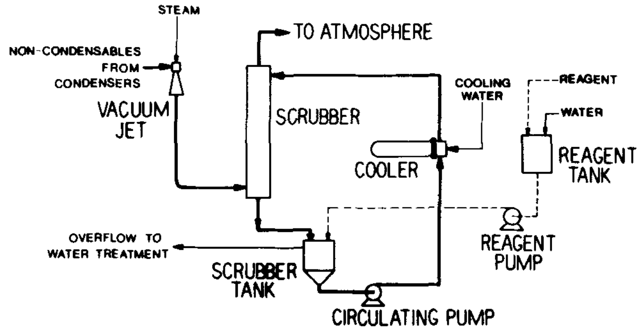

FIG. 6. Flow sheet of a vapor scrubbing system.

Citric acid or antioxidants and nitrogen should be added to the oil immediately after deodorization.

If the refiner is using the physical refining process, he must properly operate the degumming system to insure maximal removal of phosphatides, and monitor operating conditions of the pretreat-bleaching system to insure properly treated oil is fed to the steam refiner deodorizer, which should be operated under the same standards as outlined for the deodorizer in the previous paragraph.

Regardless of the refining method used, chemical or physical refining, the deodorized soybean oil should have less than 0.03% FFA, a zero peroxide, a color of 10 yellow, 1.0 red or lower and a bland taste.

Some deodorizing systems are incapable of producing deodorized oil with less than 0.05% FFA. If the FFA in the deodorized oil is higher than specified by deodorizer supplier the reasons are: (a) feedstock contains a higher FFA content than specified; (b) deodorizer not operating at design temperature; (c) deodorizer not operating at design pressure; (d) if sample taken after addition of antioxidant to the oil, FFA could analyze high due to an improper amount of antioxidant or citric acid addition, as 0.00227% citric acid analyzes as 0.01% FFA; (e) improper contact of sparge steam with oil, insufficient amount of sparge steam; (f) interior reflux of vaporized fatty acids into the oil.

If the peroxide value is higher than zero, reasons are: (a) air contacting oil at high temperature; (b) deodorizer has buildup of polymerized oil or oxidized oil which mixes with oil in process. Correction procedure: wash out deodorizer. Many refiners have a standard operating procedure of washing out the deodorizer every six months. This is especially necessary if the deodorizer is not operated continuously seven days a week, or refiner is subject to power failures. Deodorizers should not be operated more than 12 months without a thorough wash-out.

If the deodorized oil color is higher than 10 yellow 1.0 red, reasons are: (a) deodorizer not operating at design temperature; (b) feedstock has a phosphatide content above 20 ppm; (c) air contacting oil at high temperature; if this is happening, oil should show a peroxide value; (d) deodorized oil discharging at too high a temperature.

DEODORIZER OPERATING TECHNIQUES

Deodorizers generally operate under the supervision of one operator who monitors the instruments and controls, changes filter bags, prepares antioxidant solutions, controls pumping of feedstock to the deodorizer and pumping of deodorized oil into shift tanks.

Generally, four shift tanks are provided and each tank has a capacity for eight hr of deodorizer production. Thus, each operator has a shift tank. Samples are taken from the shift tank and analyzed before contents are pumped to larger storage tanks.

Maintenance requirements are generally minor. The two sources of possible problems are: (a) high temperature heater. Operational problems are caused by faulty fuel flow or instrument malfunction; (b) deodorizer vacuum. Operational problems are the inability to maintain design vacuum, which can be caused by gross air leakage, low steam pressure or "wet" steam to vacuum jets, insufficient condenser water, temperature of condenser water higher than specified for vacuum system.

If these conditions have been checked and are not the cause of the problem, the steam nozzles, steam chests and throat of the booster should be measured to determine if they are worn.

If air leakage is suspected, a drop test should be made by closing valves in the oil inlet and discharge pipelines, then quickly shutting off the steam and water supply to the vacuum system. The vacuum may drop rapidly while this is being done; it should stabilize at some value, and must be above 20 in. for a valid test. Vacuum should be noted and recorded every hour as it drops. The deodorizer manufacturer can advise a satisfactory drop in in./hr.

If the vacuum loss exceeds the design amount, tighten all pipe connections, valve packing glands and equipment flanges. If this does not reduce the vacuum loss to a satisfactory rate, the source of leakage may be detected by one of the following methods.

Freon test. Close all valves, blind vacuum system tailpipes, disconnect vacuum gauges, admit Freon into the system until 5 psig is reached and raise the pressure to 20 psig with compressed air. Examine all pipe connections, valve packing glands and equipment flanges with a Freon detector. An electronic type, such as General Electric Type H-6 is recommended for high sensitivity; but fairly small leaks may be detected with a propane torch. The flame is adjusted to a soft blue color and passed over all points of potential leakage (a change of flame color to green indicates the presence of a leak).

Ammonia/sulfur dioxide test. Prepare the system as in the freon test. Admit ammonia gas sufficient to raise the system pressure to 5 psig and further raise the pressure to 20 psig with compressed air. Examine the system by directing a small stream of sulfur dioxide gas around all possible points of leakage (the formation of white fumes indicates the presence of a leak). *Caution:* ammonia is very corrosive to brass and other copper alloys; therefore, if this test is of long duration, lines containing brass valves should be disconnected and openings plugged.

Soap solution test. If the supplies and equipment necessary for the two tests already described cannot be obtained, large leaks may be detected by painting all possible points of leakage with soap and water while the system is under 20 psig air pressure. This method is not sufficiently sensitive to detect small leaks which, if numerous, may overload the vacuum system.

Mark all leaks detected, release the pressure and purge the system with air, correct the leaks, restore the piping and gauge connections, and repeat the shut-off test to determine that the rate of vacuum loss does not exceed satisfactory rate.

HANDLING OF FINISHED OILS

Many of our modern storage, handling, and stabilization practices stem from industrial response to research findings on flavor stability. The demonstration that a significant correlation exists between the peroxide value and flavor scores suggested that flavor deterioration could be prevented by excluding air from the oil at key processing stages (8). Preventing oxidation is a key design feature in modern oil processing equipment, as is the use of inert gas blanketing when the oil is to be stored for extended periods or exposed to high temperatures.

Perhaps the most important milestone in flavor stability research was the demonstration that citric acid improves flavor stability and that it functions as a metal scavenger. Virtually all domestic processors inactivate traces of metallic impurities by treating the oil with citric acid or other metal chelator, usually during cooling after deodorization.

At one time, storage capacity at the soybean processing plant was considered desirable to give flexibility in markets. However, modern plants have very little product storage compared to their production because any reasonable storage compared to their production because any reasonable storage capacity would be filled so rapidly that there would be no relief from the necessity of shipping each day (9). In an integrated extraction plant-refinery, another factor in bulk storage trends to be considered is that the oil may be refined directly, without intermediary storage to permit truly continuous operation (10). So, the turnover of crude oil in modern extraction plants is rapid; storage works best for the whole beans.

A general scheme for storage and handling of finished oils is relatively shown simple but important. Oil coming from the deodorizer is passed through a heat exchanger and a polishing filter to remove any solid materials. After the polishing filtration, the oil is pumped through a cooler to a storage tank. Before packaging, the oil generally is filtered again to remove any solids picked up while in storage (11).

Autoxidation increases markedly with temperature. It has been estimated that, for salad oils in general, the rate of oxidation doubles for each 15 C increase in temperature within the range 20-60 C (68-140 F) (12). From this standpoint, it is desirable to handle the oil at temperatures as low as possible during discharge from deodorizer into the storage tank.

Storage Tanks

Finished oil storage tanks generally are constructed of iron, although more expensive, stainless steel is sometimes used. Finished oil storage tanks very considerably in size, and usually are closed and fitted with tank tops, internal heating or cooling coils, and an agitator to promote heat transfer and to prevent localized overheating.

Factors most likely to affect the quality of finished oils to such an extent that they would require reprocessing include contamination from atmospheric adulterants, internal contamination from water, overheating, and exposure to air and oxygen.

Atmospheric adulteration is avoided by storing the oil in completely closed tanks. Finished oils held in storage tanks can be contaminated by water leaking from steam or cooling coils, so properly maintained coils are necessary. Moisture in the oil can promote hydrolysis, particularly at elevated storage temperatures.

Finished oil storage tanks should be equipped with automatic temperature controllers to prevent overheating, which is undesirable because prooxidants are much more active at elevated temperatures.

Nitrogen Blanketing

Oxidation has the most detrimental effect on the quality of finished oils held in bulk storage. Thus, exclusion of oxygen during storage represents a highly desirable and practical method for preventing quality deteriorations.

The usual procedure involves replacing oxygen with nitrogen. Finished oil is delivered from the deodorizer to the storage tank under a complete nitrogen blanket. Nitrogen can be supplied from a tank of liquid nitrogen or from commercially available nitrogen generators. The nitrogen blanket is maintained by a pressure system controlled by a regulator. As the tank is filled with oil, the pressure builds and the gas is vented to the atmosphere. Conversely, as the oil is pumped from the tank, the pressure drops and replacement gas enters the tank. It is common practice to equip storage tanks with vacuum relief valve or rupture discs that prevent a vacuum and subsequent collapse of the tank. Nitrogen blanketing can be applied to multi-tank arrangements (Fig. 7). The design is similar to single-tank systems and has the advantage of being less wasteful of nitrogen because as one tank is emptied, the gas can be displaced to another. When oil is transferred from tank to tank, the inert gas is merely exchanged. During filling or emptying, the pressures vary, but relief valves are set to release at pressures above design pressure. Nitrogen-blanketed storage tanks will not support life and should be thoroughly purged before maintenance personnel attempt to enter the tanks. Signs warning of this hazard are normally displayed on nitrogen-blanketed tanks.

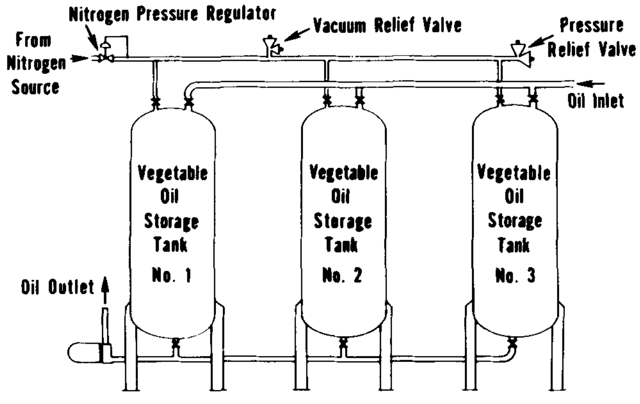

FIG. 7. Schematic diagram of nitrogen blanketing of storage tanks.

BULK STORAGE AND HANDLING IN THE INDUSTRIAL USER SECTOR

Introduction

Industrial users of fats and oils, such as those involved in the manufacture of fried foods and baked goods, often purchase their supplies in bulk because of cost advantages. Among these are elimination of cost of shipping containers, reduced shipping rates, and reduced labor costs due to more efficient unloading and handling of products within the user's plant. Other advantages include a reduction in product waste and sanitary problems associated with small containers. Bulk handling also may reduce the amount of storage space needed and this factor can be of economic importance in some plants.

On the other hand, bulk handling offers some disadvantages, including sizable capital investment for the purchase and installation of pumps, tanks, and other essential equipment. Operation of a bulk handling system requires the attention of more skilled personnel than the simple unloading and handling of smaller containers. A further disadvantage is that the product may deteriorate before being used. This is particularly true of shortenings that must be held in a molten state. Melted products are generally more susceptible to deterioration than packaged products.

A prime requirement is that a minimal shipment, usually 30,000 lb, be used with the storage life of the product. The storage life of shortenings varies with formulations and the storage and handling conditions within the user's plant. Suppliers should be consulted to determine the storage life of shortening products.

Many types of fats and oils are amenable to bulk handling, including all salad and cooking oils, all types of frying fats, bread shortenings, and products normally fluid and pumpable at ordinary temperatures such as "fluid" bread and cake shortenings.

Precautionary Measures in Bulk Handling

In bulk storage systems where positive displacement pumps are used, special precautions are necessary on both sides of the pump. On the suction side, a double-check system should be used to avoid pumping the fat from a closed vessel, thereby preventing collapse of the tank. Similarly, on the discharge side, checking for closed valves is recommended to prevent danger to operating personnel, damage to equipment and loss of product from blown fittings.

When it is necessary to heat fats to keep them fluid, heat should be applied to line, pumps and tanks. Although insulation may be used to retain the necessary amount of heat, the ability to apply heat in emergency situations is most desirable.

Occasionally, even when shortenings are held above their apparent melting point, hard fractions will separate or "seed" out. In effect, the composition of the fat changes in different levels in the tank and possibly can block the pipe lines. Application of heat and agitation may be necessary to correct the problem. It is recommended that experimentation on the product be done at the projected temperatures and times to ensure that this problem will not occur under operating conditions in the plant.

Close control of temperature within handling systems is necessary because pumping rates are dependent on viscosity of the fat, which in turn is temperature-dependent. Similarly, where volumetric means are used to control weights, it is absolutely essential to control temperature because the specific gravity is related to temperature.

STORAGE AND HANDLING FACTORS THAT CONTRIBUTE TO OXIDATIVE DETERIORATION

Five factors contribute to the oxidative deterioration of fats and oils: oxygen or air, heat, light, prooxidant metals and time.

Elimination of air prevents oxidative deterioration. However, complete elimination of air is impractical. The solubility of oxygen in soybean oil is quite high (3.2 ml/ 100 ml) (13) and is sufficiently soluble to yield a peroxide value of 18 (14) assuming complete reaction. Flavor deterioration in soybean oil occurs at peroxide values considerably lower than 18. Published data show that soybean oil can have poor flavor at a peroxide value of 1.

Even when using nitrogen blanketing, sufficient oxygen already may be present in the oil to promote oxidative deterioration. A more practical approach is to minimize the incorporation of air into the oil by proper handling procedures.

Faulty handling procedures to be avoided are: (a) allowing a liquid fat to cascade or fall through air into storage or holding tanks; a more desirable procedure is to fill the tank from the bottom with subsurface entry; (b) sucking of air into the suction side of pumps or lines caused by faulty pump seal or fittings; (c) whipping air into a fat through improper agitation within storage tanks. Creation of whirlpools or vortexes should be avoided; (d) blowing of lines with air, which in turn may bubble air through the fat being held in the storage tank (11).

Heat accelerates the reaction of atmospheric oxygen with edible oils. For deodorized products, it is estimated that the speed of oxidation is doubled for each 15 C increase in temperature over the range 20-60 C (68-140 F) (12). A rule of thumb for handling is to keep the fat no warmer than necessary to facilitate handling with pumps. For hydrogenated fats, a holding temperature 10 F (5.6 C) above the melting point is considered sufficient. Design of bulk storage systems should take into account the use of low temperatures whenever possible. For example, short insulated lines, as opposed to long unheated ones, will permit lower storage temperatures and thus prolong the quality of bulk stored fats.

Localized overheating is detrimental to fat quality and should be avoided. Thus all storage tanks with heating devices should be equipped with a mechanical agitator. Power agitation will not only minimize fat damage from localized overheating but will save time and heating costs as well. If agitation is temporarily out of service, the temperature differential between the fat and the heating medium must be kept minimal.

The importance of avoiding metallic contamination cannot be overstressed. Copper and iron are strong prooxidants for soybean oil and are capable of lowering the flavor and oxidative stability of soybean oil at levels of 0.01 and 0.1 ppm, respectively. Copper or copper-containing alloys should never be used in equipment used for handling and storing soybean oil. The prevention of iron contamination is somewhat more difficult because most of the industry uses black iron for construction of tanks, pumps, and lines. However, through proper treatment and cleaning of black iron equipment, iron contamination can be kept to a minimum.

All edible fats and oils deteriorate under the effects of light. Normally, light-induced deterioration is not of concern in the oil processing operation or at the user level because processing, handling and storage are done within closed systems. However, light deterioration is an important factor in the storage stability of liquid oils packaged for retail trade.

Any fat or oil will deteriorate even if stored and handled under ideal conditions. Unhydrogenated or lightly hydrogenated oils, which do not require heat for keeping them liquid, have greater resistance to deterioration than shortenings. Shortenings, however, will keep for 2-3 weeks while in a melted condition. Shortenings should not be allowed to solidify and then be reheated during use. Bulk storage systems should be designed with a maximal turnover time of 2-3 weeks or within the storage life of the product. The mixing of fresh shipments with those already in storage should be avoided. Small quantities of old products in a tank may hasten the deterioration of new product mixed with it. Shipments should be scheduled so that mixing of old and new products does not occur. An auxiliary tank can be installed to hold the remainder of the old shipment and permit inspection and cleaning of the receiving tank.

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