

Deodorization

F. B. WHITE, Process Plants Division, Foster Wheeler Corporation, New York, New York

DEODORIZATION IMPLIES the holding and steam-stripping of preredefined glyceride oil at elevated temperature under low absolute pressure to produce a bland or palatable edible oil. This is a simplified definition. For a more inclusive and general meaning, as well as for historical background and additional details, references may be used (1, 2, 3). Within the limits set by this definition this paper will cover three main categories: Theoretical Approach to Deodorization, Deodorization Systems in Current Use, and Engineering Aspects of Deodorization Equipment.



F. B. White

edible oil. During this operation it is possible that the chemical nature of some constituents in the oil may be changed as a result of the treatment at high temperature. However the principal measurable difference is the reduction in free fatty acid content of the oil. This measurement of reduction in free fatty acid content has generally been used as a yardstick by which progress of deodorization may be estimated. Yet it is not a perfect yardstick since oil stability does not improve indefinitely with reduction in free fatty acid content. The stability may actually increase at the start of deodorization and decrease toward the finish (4).

Thus deodorization is an operation which principally removes volatile materials from the oil which are undesirable in the finished product. It may also change the chemical nature of trace constituents. With this background the various factors which influence the quality of finished deodorized oil can be set down.

I

The preparation of oil for the deodorizer has a significant effect upon the finished deodorized product. Needless to say, if the refining and bleaching operations leave appreciable amounts of non-volatile metallic soaps in the oil, the deodorized oil will contain most of these and will be subject to whatever effects these contaminants have on the oil. Thus the first requirement of good deodorization is to make sure that the refining and bleaching steps preceding deodorization are properly carried out. The complete chemistry of edible oils has not been fully worked out although the procedure needed to change a crude oil into finished deodorized products has been well defined. For example, a crude cottonseed oil contains many compounds in addition to free fatty acids and mucilaginous substances. These include chloro-

phyll, pentosans, peptones, phosphates, phosphatides, phospholipins, phytoseroline, phytosterols, proteoses, raffinose, resins, and xanthophyll (5).

II

It is important to eliminate air or oxygen from deodorization equipment. Oxidation of oil at elevated deodorization temperatures will result in a degraded product. Even small amounts of oxygen will have a harmful effect upon the oil. Not only must the deodorization equipment be designed to prevent inward leakage of air, but the stripping steam supply must be checked to insure absence of air from this source. A regular guarantee from deaerator manufacturers promises less than 0.005 cc. of oxygen per liter of boiler feed water.

The use of a high vacuum is not in itself sufficient insurance against oxidation. This is because of the fact that vacuum equipment should be over-designed to permit reasonably rapid plant start-up and larger than needed for the amount of air that could leak into a well-constructed deodorization system.

Once oxygen has been effectively removed from the oil in process, contact with additional oxygen from the air positively may be avoided by keeping the oil under a pressure greater than atmospheric. This is done where external heat exchangers and heaters are used.

To prevent oxidation of the oil by trace amounts of dissolved or occluded air, a number of approved antioxidants are available, such as lecithin. Considerable background and information are available as a result of a former A.O.C.S. short course (6).

III

According to the definition of "deodorization," in this paper its principal function may be considered to be a distillation process. Thus, to promote distillation of fatty acids and other undesirables, the following interrelated conditions are essential:

- a) The temperature of deodorization must be sufficiently high to make the vapor pressure of volatile impurities in the oil conveniently high.
- b) The absolute pressure in the deodorizer must be low enough to permit boiling of traces of impurities from the exposed oil surface.
- c) Adequate stripping steam, consistent with temperature and pressure in the deodorizer, is needed.
- d) Agitation of the oil is necessary constantly to expose new oil surface to the low absolute pressure.

Agitation is generally accomplished by the use of carefully distributed stripping steam, which has the added beneficial effect of reducing the partial pressure of the volatile impurities needed to permit boiling of these impurities because every unit volume of stripping steam can replace the same volume of fatty acid vapor with which it is brought into intimate contact.

These statements can be more clearly understood by reference to two equations which are known as Raoult's Law and Dalton's Law. They are:

$$\begin{aligned} \text{Raoult's Law: } p_a &= x_a P_a, \text{ and} \\ \text{Dalton's Law: } p_a &= y_a \pi \end{aligned}$$

where: p_a = partial pressure of constituent "a" over the solution (practically speaking, the fatty acid vapor pressure over the oil)
 x_a = mol fraction of constituent "a" in the oil
 P_a = vapor pressure of constituent "a" in the pure state
 y_a = mol fraction of constituent "a" in the vapor
 π = total pressure on the system.

From Raoult's Law may be noted the partial pressure of the fatty acid (p_a) over the oil is directly proportional to the vapor pressure of the fatty acid in the pure state (P_a). Thus the temperature must be raised sufficiently so that the vapor pressure of pure fatty acid, multiplied by its mole fraction in the liquid phase, equals the partial pressure needed for boiling, which is determined by Dalton's Law.

This partial pressure requirement can be kept reasonably low, and consequently the deodorizing temperature can also be kept low, by maintaining a low absolute pressure (π) in the deodorizing vessel and by employing stripping steam. A low absolute pressure (π) directly affects the numerical value of the fatty acid partial pressure (p_a), as can be seen from the Dalton's Law equation. The proportion of stripping steam in relation to the fatty acid vapor also changes p_a since the mole fraction of fatty acids in the vapor

$$y_a = \frac{\text{moles fatty acid vapor}}{\text{moles steam} + \text{moles fatty acid vapor}}$$

With an increasing flow of stripping steam this fraction becomes smaller and p_a also becomes smaller. In this way the deodorizing temperature may be lowered. It is also evident that improved vacuum will permit lower deodorizing temperature, and, conversely, higher temperatures will compensate for the poorer vacuum.

Using Raoult's and Dalton's Law, on the basis of an oil such as soybean oil containing fatty acids with 18 carbon atoms, the theoretical quantities of stripping steam required to remove fatty acids at various concentrations in the oil have been calculated (Figure 1). This chart, which is based upon an operating temperature of 445°F., shows theoretical stripping steam requirements plotted against free fatty acid concentration for a series of absolute pressures. Similar charts could be drawn for other operating temperatures, but this has not been done. However the quantity of fatty acids distilled with each pound of steam is directly proportional to the vapor pressure of the fatty acids in the pure state; the relationship of fatty acid vapor pressure with temperature is shown in Figure 2.

To illustrate the use of Figure 1, Figure 3 has been plotted, based upon the information given in Figure 1. Thus, in the case of batch deodorization, it can be seen that steam used in the beginning of the cycle can induce distillation of far more fatty acid than steam at the end of the deodorization. Putting this into figures, if we wish to batch-deodorize an oil having a free fatty acid content of 0.2% only 5.85 lbs. of steam, per pound of fatty acid stripped off in the vapor, are theoretically needed at the very beginning. If the end-point is 0.02% free fatty acid in the oil, 59 lbs. of steam are finally needed per pound of fatty acid. If a final free fatty

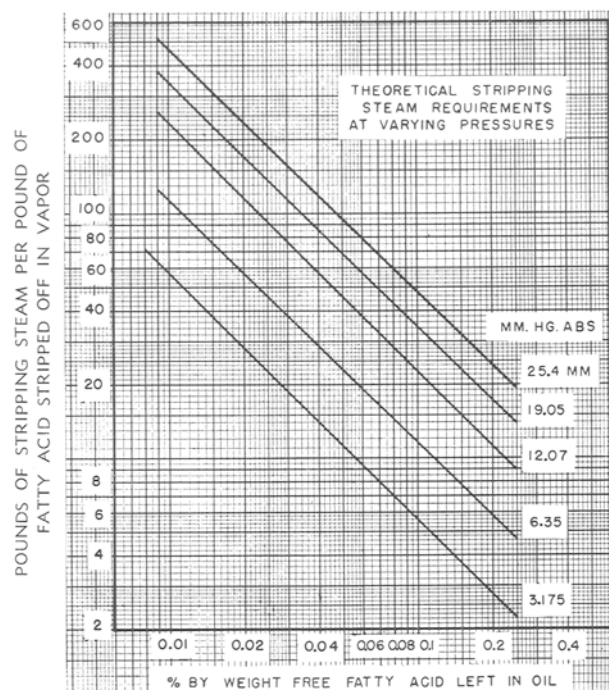


FIG. 1

acid content of 0.01% is desired, 119 lbs. of steam are needed per pound of fatty acid. As shown in Figure 3, the deodorization is carried out at 445°F. at an absolute pressure of 6.35 mm. of mercury. The data show that most existing batch deodorizers operate very inefficiently.

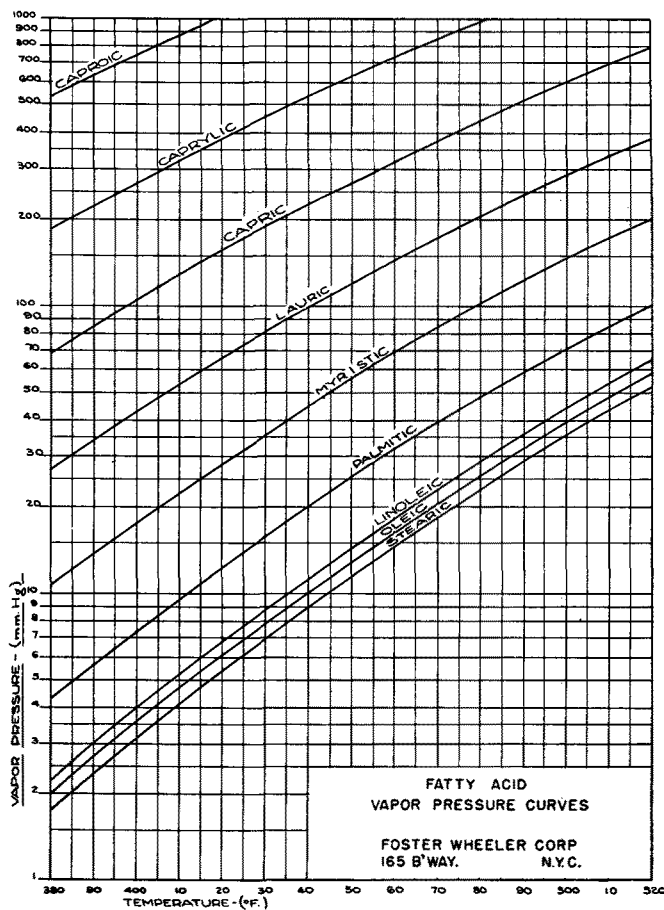


FIG. 2

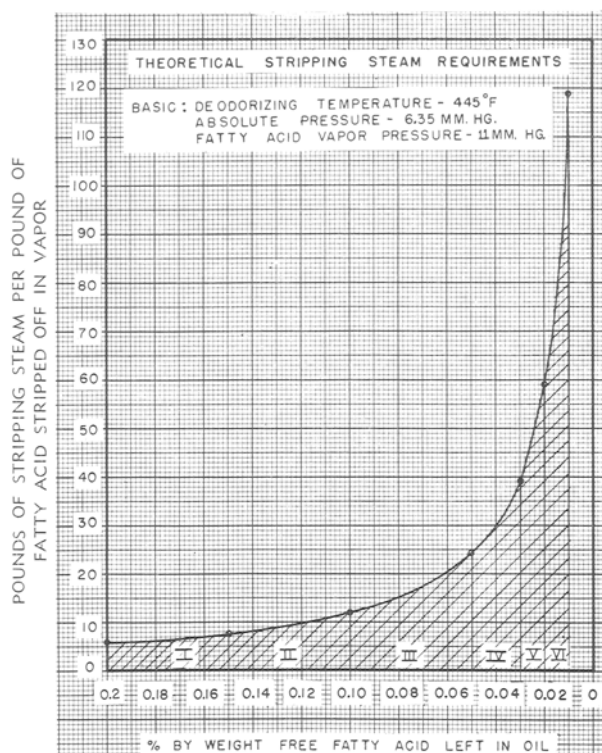


Fig. 3

IV

In consideration of any deodorization system it is necessary to make sure that undeodorized oil cannot by-pass all or part of the deodorization process and enter the finished product storage before receiving adequate treatment. This is necessary to assure both enough time at deodorization temperature and complete stripping of volatiles. In well-designed continuous, semicontinuous, and batch deodorizers this presents no problem whatsoever.

V

Although carbon steel batch deodorizers are extremely common, continuous and semicontinuous deodorizers, which present a relatively large metal surface to the oil, are ordinarily built of either 18-8 stainless steel or nickel. Carbon steel itself tends to promote oxidation of the oil, and the formation of iron soaps and deodorizers constructed of this metal must become coated with oil before fully satisfactory products are obtained. The use of stainless steel or nickel will reduce the possibility of metallic contamination. Copper or its alloys should never be used.

VI

Although not customary practice, it would be advantageous to eliminate condensation of once-distilled fatty acids upon vessel walls, thus preventing reflux into the oil. If condensation is avoided, it will be difficult for the acids to combine with the metal in the deodorizer wall to form metal soaps. These are higher-boiling than fatty acids and are likely to remain in the oil. Naturally this condition would be aggravated in the case of carbon steel deodorizers as contrasted with stainless steel and nickel deodorizers.

One simple way to avoid condensation of fatty acids on the relatively cool metal walls above the oil liquid level is described in a 1946 patent (7). This

patent calls for external heating or jacketing of a batch deodorizer above the oil level, to prevent condensation of fatty acids, thus avoiding the need to redistill them with the use of additional stripping steam.

VII

In any deodorizing system some metallic soaps may be present. Thus it is common practice to make use of a stabilizer or metal scavenger to complex and render harmless these residual metallic soaps. Citric acid is one such scavenger (8). Others are citric acid esters (9), tartaric acid, phosphoric acid, and lecithin. Other compounds, such as EDTA (ethylenediamine tetracetic acid), are being tested for their efficiency and safety as metal scavengers (10, 11).

To summarize, the seven factors affecting deodorization are correct preparation of oil before deodorization; elimination of oxygen; provision of proper conditions for distillation, high temperature, low absolute pressure, adequate stripping steam, and careful distribution of stripping steam; insurance of full deodorization treatment; materials of construction; elimination of fatty acid condensation and refluxing; and use of metal scavengers.

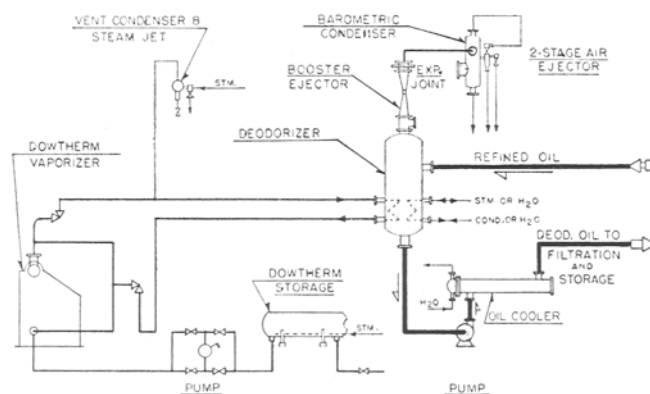
Just a word should be added about treatment of oil after deodorization. The oil should be cooled in the absence of air immediately upon completion of deodorization. This may be done under high vacuum in the deodorizer to minimize air contact, or it may be done under positive pressure—greater than atmospheric—to insure against inward leakage of air. The final temperature before storage should be no more than 150°F., but preferably less.

Contaminants should be avoided. This is assisted by filtration before storage. Light and air should be kept from the oil. This is accomplished by storing in opaque vessels under an inert atmosphere.

Deodorization Systems in Current Use

There are a number of deodorization systems in current use. These include standard and modified batch units, semicontinuous and continuous units. The nature of each system will be described and its advantages given.

Batch Deodorizers. A typical batch deodorization system is shown in Figure 4. This is a classical system in which cold oil is introduced into the deodorizer. It is heated, steam-stripped, and ultimately cooled before being discharged for storage.



BATCH DEODORIZING SYSTEM
Courtesy of Foster Wheeler Corporation

Fig. 4

The cycle of operations for a vegetable shortening might be the following:

	hours
Filling, heating, and steam-stripping.....	0.25
Heating, steam-stripping	1.25
Holding, steam-stripping	5.00
Internal cooling, steam agitation.....	0.50
Emptying, external cooling, and filtering.....	0.75
Total.....	8.00

Depending upon the nature of the feed stock and the market sought by the manufacturer, the time cycle may be cut to as low as four hours.

This is basically the simplest type of deodorization system that can be installed. The principal component parts consist of the deodorizer with heating coils, a vacuum system to provide low absolute pressure, a Dowtherm vaporizer to furnish high temperature heat, internal water cooling coils or an external oil cooler for final reduction of the oil temperature, and a steam superheater. Steam agitation during internal cooling actually speeds up the rate of cooling by improving the cooling coil heat transfer rate.

The steam superheater is frequently a simple coil arranged in the Dowtherm vaporizer itself. Sometimes the superheater is eliminated entirely. It is simply important that the steam at least be saturated, when entering the deodorizer, to avoid cooling the oil by a slug of water requiring vaporization.

An alternative arrangement is shown in Figure 5. In this unit coils are not used inside of the deodorizer for heating the oil. Instead an external shell-and-tube heater is used, with oil being circulated from the deodorizer, through the heater, and back again into the deodorizer. The final oil temperature from the heater must be slightly higher than the final deodorizer temperature. This arrangement is somewhat more complicated than the coil type unit, but it has the advantage of allowing installation of a Dowtherm-to-oil heater at any convenient location, which in some cases may make it possible to eliminate a Dowtherm condensate return pump. Generally speaking, external heaters are not common since they should not be constructed of carbon steel but of stainless steel or nickel and because they do require a pump circulating system.

Not indicated in any of the batch deodorization sketches of this paper is still another system which includes a drop tank beneath the deodorizer. This allows the draining of the hot oil from the deodorizer

into a separate vessel which can be used as a cooler. Thus the productivity of the deodorizer may be increased while the cooling may be accomplished under vacuum.

Typical utility requirements for a standard batch deodorization system are shown in Table I.

Depending upon the quantity of oil to be processed, some modifications of a standard batch deodorizer can be made. These include not only the cooling tank mentioned above but a heating tank as well. On the basis of such a system the utility requirements are also shown in Table I.

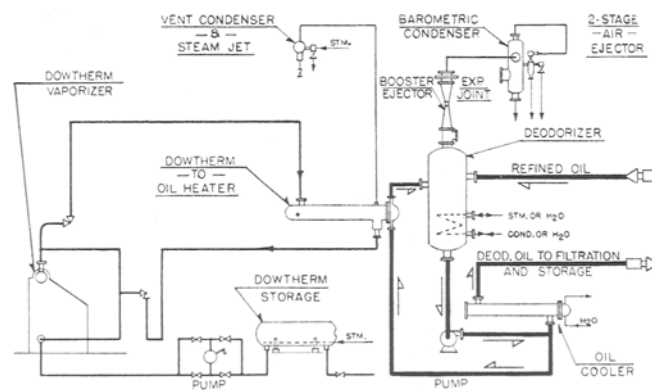
TABLE I
Typical Utility Requirements for Deodorization
100 lbs. of Oil

Type of deodorizer	Steam at 125 p.s.i.g.	Water at 85°F.	Power	Fuel oil
	lbs.		kwh	gal.
Standard batch.....	80.4	963	0.03	0.278
Modified batch.....	41.8	530	0.07	2.206
Semicontinuous.....	38.2	422	0.041	0.093
Continuous.....	38.6	468	0.114	0.11

The principal advantage of a batch deodorization system is its complete simplicity. It can be operated for as long a period or as short a period as desired. Periodic cleaning is desirable, and deodorizer coils may need replacement in 5-10 years. However, from the point of view of mechanical equipment, there is very little that can go wrong with it. With the exception of the Dowtherm vaporizer there is no equipment in continuous operation which requires particular care. Even the Dowtherm vaporizer, if of a good design and not abused, may be operated at least 30 years with only annual checkups. With so little to get out-of-order this type of plant suits many operators with small maintenance staffs.

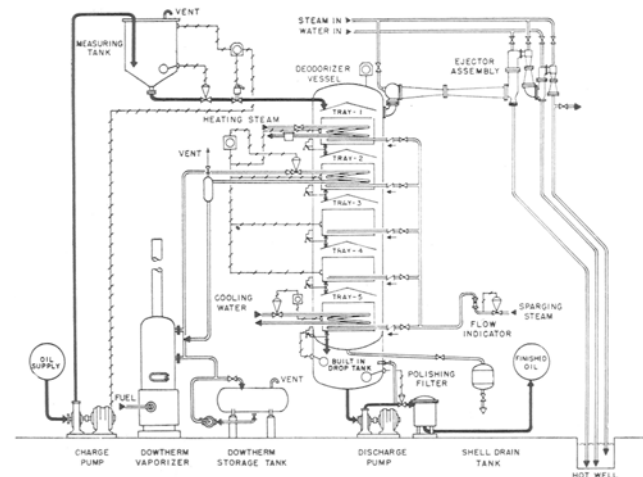
In the case of the standard carbon steel batch deodorizer, utility costs are relatively high. However these high costs must be balanced against the higher capitalization costs of more modern units.

Semicontinuous Deodorizer. The semicontinuous deodorizer is shown in Figure 6. It consists principally of a tall cylindrical shell of carbon steel construction in which are placed five pans of either nickel or stainless steel. In the top pan, oil is heated by means of steam which simultaneously helps deaerate the



BATCH DEODORIZER WITH EXTERNAL OIL HEATER
Courtesy of Foster Wheeler Corporation

FIG. 5



SEMI-CONTINUOUS DEODORIZER SCHEMATIC FLOW DIAGRAM
Courtesy of Girdler Company

FIG. 6

feed. In the second pan, heating of the oil is continued by means of condensing Dowtherm. The third and fourth pans are normally unheated deodorizing pans, and the fifth provides cooling under the same vacuum employed in deodorization. If required, heating coils may be provided in either or both of the deodorizing pans to compensate for heat loss due to radiation and other causes and thus to maintain the deodorization temperature. The holding time in each pan is approximately one-half hour, and stripping steam is injected into all of the pans. The larger proportion of the steam is introduced into the two deodorizing pans for stripping purposes.

The mechanical heart of this system is a motor-operated timing device, which opens and closes valves between pans automatically. Efficient baffles are used at each of the five pans to prevent excessive entrainment from entering the annular area between the tower shell and the pans, thus to be lost as product.

The principal advantage of this system derives from the fact that all pans of the deodorizing system are under the same relatively high vacuum. All oil receives substantially identical treatment, and the annular space between the pans and the shell provides some insurance against oxidation due to inward leakage of air. Quick change-over of feed stocks is practical.

The deodorizer also is arranged to avoid refluxing of once-distilled undesirable materials back into the oil. This reflux, plus any mechanical carry-over from any of the five pans, is permitted to drain from the bottom of the deodorizer shell. The accumulated drainage must be removed periodically. Typical utility requirements of the semicontinuous deodorizer are shown in Table I.

Continuous Deodorizer. In the continuous deodorization process, one type of which is shown in Figure 7, the oil is continuously charged to a deaerator which is maintained under high vacuum and is provided with a small amount of stripping steam. Rate of feed may be governed by a liquid level controller in the base of the deaerator.

From the deaerator the oil feed stock is pumped at a controlled rate through a heat exchanger in which heat is recovered from the hot product oil. Following the heat exchanger, the feed stock is further heated by Dowtherm before being introduced to the top tray of the deodorizing tower in which the oil is held at temperature and stripped. The deodor-

ization temperature usually is in the range of 420–480°F.

Inside of the column oil cascades downward over a series of bubble trays and is stripped of undesirable volatile constituents by a countercurrent stream of steam rising through the bubble caps. Thus the full flow of fresh steam always comes into contact with finished deodorized oil.

Volatilized fatty acids and steam are removed at the top of the column by means of a booster ejector, which discharges into a barometric condenser. A two-stage steam jet air ejector is used to evacuate the condenser. Deodorized oil is continuously removed from the tower base by a centrifugal pump which is of the internally pressure-sealed type, thereby eliminating the possibility of inward air leakage at this point. A constant rate of finished oil removal is maintained by a liquid level controller at the base of the tower.

After giving up most of its heat in the oil-to-oil heat exchanger, the finished oil is cooled to the final desired temperature by means of a shell-and-tube water cooler. The oil may then be filtered and stored.

A fully continuous deodorizer of the type described has the important advantage of recovering approximately 60% of the heat needed to raise the oil temperature to the deodorizing level. It is also a very efficient contacting medium since the stripping steam comes into intimate contact with the oil in countercurrent fashion on shallow bubble trays, thereby allowing a material reduction in processing time as compared with other forms of deodorization.

It is noteworthy that only fresh steam comes into contact with the oil leaving the base of the deodorizing tower. As the steam picks up fatty acid, it comes into contact with oil containing higher concentrations of fatty acids and other undesirables, thus assuring continuous stripping effectiveness.

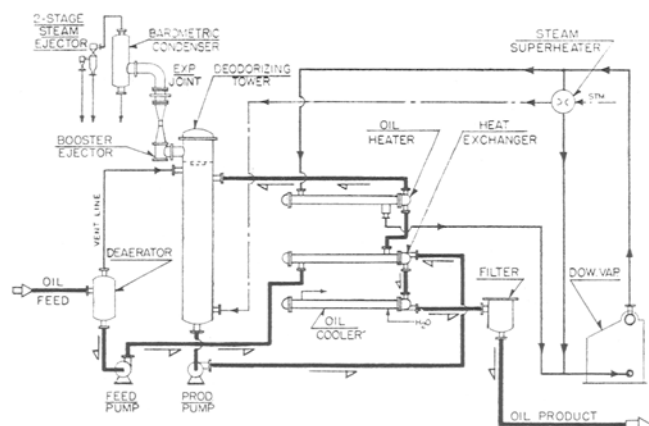
The continuous deodorizer may be arranged to permit rapid change-over of feed stocks, which has been done on recent installations.

Based upon an operating vacuum of 0.25 in. of mercury absolute, the approximate utility requirements of a typical continuous deodorizer are shown in Table I.

Another continuous deodorizer in use by Kraft Foods Inc. (12) provides for deaeration, heat exchange, and heating to about 435°F. and progressive deodorization stages at increasing temperatures until the oil is finally cooled under vacuum. Separate stripping steam connections are made to each stage, and full vacuum is maintained on each stage.

There are other continuous deodorizers although none are in common use. One of these is shown in Figure 8. It differs principally from the previous unit shown, in that all heating is accomplished by Dowtherm heated bubble trays. Thus the efficiency of steam stripping and that of heat transfer are closely tied together; both depend upon good agitation of the oil on the heated tray surfaces and intimate mixing of oil and steam. No provision is indicated for heat exchange between finished oil and feed stock.

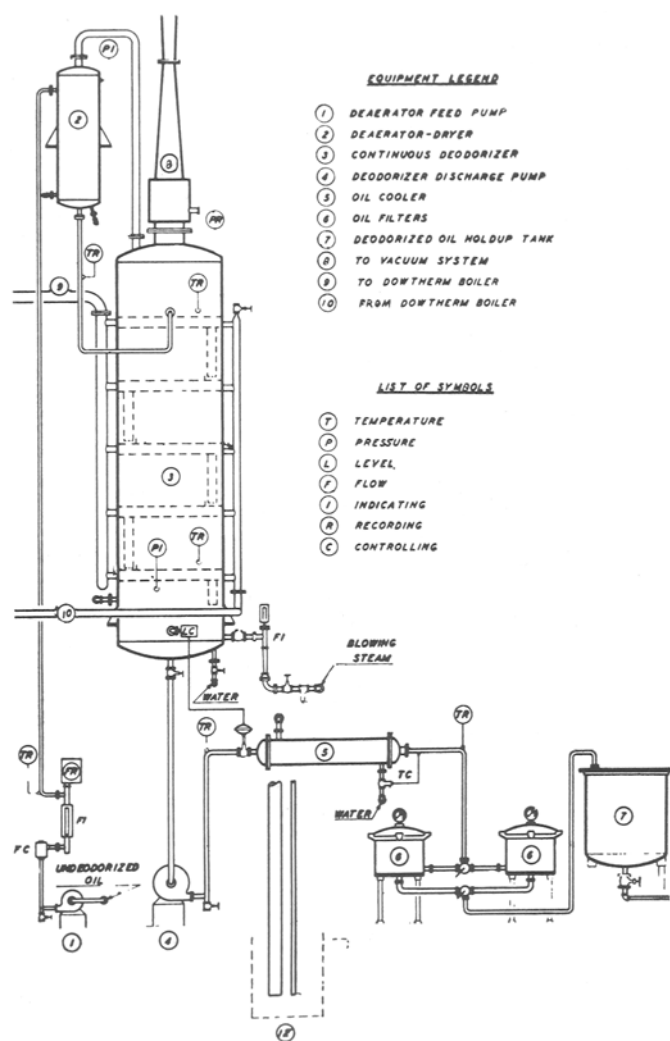
One more continuous deodorizer is illustrated in Figure 9. It differs in some details from the other continuous deodorizers described. For example, it makes no attempt at heat recovery, but all processing steps are carefully fitted into one evacuated shell to help guard against oxidation of the oil. These



CONTINUOUS DEODORIZING SYSTEM

Courtesy of Foster Wheeler Corporation

FIG. 7



Courtesy of Wurster and Sanger Inc.

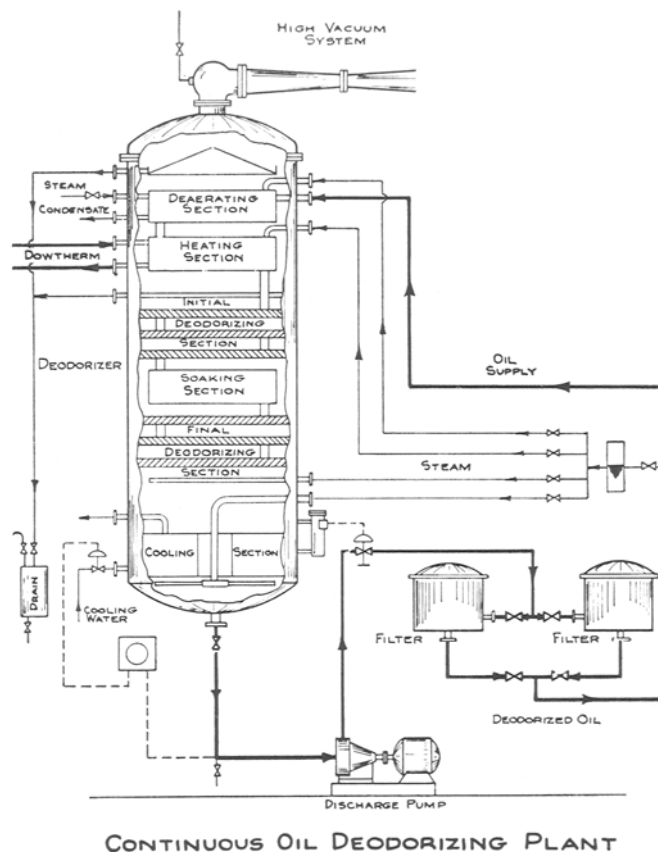
Fig. 8

steps include deaeration, steam and Dowtherm heating, deodorization and cooling. It further provides separate streams of stripping steam and separate vacuum conduits so that maximum vacuum may be maintained over each deodorizing section. This advantage is counterbalanced by some loss of simplicity and by the fact that the full supply of fresh stripping steam may not be used for the final product. Finally, the system depends upon a "soaking zone" between two deodorizing sections to provide adequate time for deodorization.

It may be concluded that all deodorizers with the exception of the standard batch unit (but including the modified batch unit) have reasonably close utility operating costs. It is up to the oil processor to decide if batch, semicontinuous, or continuous production best fits his present and projected plant operations.

When making such a decision, he may wish to know what losses of oil to expect. Information such as this is often difficult to obtain, but data have been received from a number of processors.

For simplicity these data have been averaged for each processor, and subsequently all processors in one category have been averaged although their relative capacities are unknown. However it is believed that each category of deodorizer represents a capacity



CONTINUOUS OIL DEODORIZING PLANT

Courtesy of Blaw-Knox Company

Fig. 9

of at least 10 tank cars per day of oil and at least five separate units. Data on tallow have been excluded because of its high initial free fatty acid content compared with other edible oils. Otherwise all information received is given in Table II.

Engineering Aspects of Deodorization Equipment

Consideration will now be given to the following equipment items: deodorization vessel, deaerator, oil heater, source of heat, oil cooler, oil pumps, and vacuum equipment.

A thorough analysis of deodorization equipment designs can become extremely involved since construction details must be carefully studied. Therefore it is the purpose of this paper only to emphasize the design factors which require consideration, without attempting to further specify equipment sizes or designs.

Deodorization Vessel. A study of deodorizer operation which incorporates heating with internal coils shows at least four points to which special consideration should be given.

Point 1 relates to the need for effective mixing of steam and oil. For example, in an improperly de-

TABLE II

	Batch	Semicon- tinuous ^a	Contin- ous ^b
Initial free fatty acid.....	0.10	0.11	0.13
Final free fatty acid.....	0.03	0.03	0.03
Reduction in free fatty acid.....	0.07	0.08	0.10
Total loss, including FFA.....	0.60	0.56	0.50
Net loss, excluding FFA.....	0.53	0.48	0.40

^a Type of unit shown in Figure 6.

^b Type of unit shown in Figure 7.

signed batch deodorizer, in which distribution of stripping steam is poor, it is not possible to benefit from the full effectiveness of the stripping steam. This is because of the fact that intimate contact between oil and steam is necessary for an equilibrium to be reached between vapor and liquid phases. If, to take an extreme case, all stripping steam were fed into one side of a batch deodorizer, the oil on the opposite side of the deodorizer would get less than effective stripping. Oil on the side in which the steam is actually being injected may benefit from its high proportion of stripping steam, but the average stripping effectiveness across the entire vessel is less than possible with a steam sparger of good design, which allows steam flow in a uniform portion. It should be kept in mind that this is only a generalization. Particular cases could be cited in which an unbalanced steam distribution pattern could be used to provide circulation of oil.

One very effective means for mixing steam and oil is a bubble tray. An example of this was given in the section dealing with continuous deodorizers. By the use of a well-designed bubble tray, uniformity of steam stripping is guaranteed for all of the oil. Of course, it is possible to have a poorly constructed bubble tray which allows most of the steam to concentrate on one side of the tray, but this is unlikely.

Point 2 relates to the flow of stripping steam after it has entered a deodorizer. Proper attention to detail will insure a low pressure drop for passage of vapor through the deodorizer to the vacuum system. This implies ample vapor and liquid passages, proper proportioning of bubble caps, risers and liquid down pipes in the continuous unit, and low liquid head in the path obstructing the flow of vapor.

A deeper liquid pool results in a higher liquid head and a higher pressure at the base of the pool. This makes distillation of volatile undesirables more difficult and is a common criticism of some deodorizers. In the case of a batch deodorizer there is generally a head of several feet of oil over the point at which the steam enters the batch. Thus stripping efficiency in the base of the deodorizers is considerably lower than at the liquid level. The same reasoning applies to a semicontinuous deodorizer, but in this case the liquid head is less than in the normal batch unit.

In the case of most continuous deodorizers there is very little liquid head on each tray, thus eliminating the objection just mentioned. However the absolute pressure on any tray in a countercurrent system is the summation of all the pressure drops through all of the trays above. In other words, the top tray would have full vacuum while the bottom tray would have an absolute pressure equivalent to full vacuum over the top tray, plus the pressure drop through all of the trays but the bottom one. This pressure drop is generally small. A well-designed bubble tray causes a pressure loss of only about 1 millimeter of mercury.

Point 3, entrainment, must be kept to a minimum. Some type of efficient entrainment eliminator should be installed in the vapor circuit of deodorizers. This may be located either inside of the deodorizer or between the deodorizer and the vacuum unit. It may consist of baffles or simply be a centrifugal separator. Needless to say it should have a low pressure drop. A double or triple row of inclined and opposing Venetian blind baffles gives satisfaction inside of the ves-

sel. There are a number of external centrifugal type catch-alls which can be used after the deodorizer (13).

A mathematical relationship is available to predict vapor velocities which cause entrainment, and this calculation is made for deodorizers which contain only shallow pools of oil (14). However, in the case of deodorizers with deep pools, satisfactory data for predicting the extent of entrainment at the liquid surface is not readily available. It is known that the deeper the pool, the greater the entrainment. Therefore many deodorizers are empirically selected and rely upon an entrainment eliminator to keep losses to a reasonable figure. (With the availability of a properly instrumented and equipped batch deodorizer, it should be possible to develop all data needed to predict entrainment from deep pools as well as shallow pools.)

If the top of the deodorizer is maintained at a temperature which will minimize condensation of free fatty acids upon the entrainment eliminator, there is no objection to placing the eliminator within the deodorizer itself. On the other hand, if the deodorizer is relatively cool above the oil level and, in particular, cool enough to permit condensation on a centrally located entrainment eliminator, the eliminator should be constructed of nickel or stainless steel to avoid refluxing of iron-fatty acid soaps into the oil. These soaps are less volatile, and consequently more difficult to remove from the oil than the originally distilled fatty acids.

Point 4, in the vapor outlet piping and nozzles there should be no sharp bends. Long sweeps are preferable. The number of bends should be kept to a minimum. This all harks back to the same problem. Pressure drop must be kept to the minimum to maintain distillation effectiveness of the deodorizer.

Deaerators. Deaerators are employed to remove oxygen from oil before full deodorization temperature has been reached. To accomplish this, it is necessary that the oil be exposed to vacuum in thin films before full heating.

Some types of equipment employ spray devices while others use simple flat trays which expose the oil uniformly to the vacuum system. In the case of both batch and semicontinuous deodorizers no separate deaerating unit is needed. Deaeration takes place naturally, by agitation of the batches with stripping steam during the heating cycle.

Oil Heater. This unit must be considered in the light of the heating medium (direct fire, steam, heat transfer oil, Dowtherm, etc.) since a heater may give unsatisfactory results with a poor medium; conversely a fine heating medium, particularly with excess heat transfer surface, can often compensate for a poor heater design.

Take first the problem of transferring heat into the oil. The basic heat transfer equation from metal wall to oil film is the following:

$$Q = hA\Delta T$$

or expressed differently:

$$\Delta T = Q/hA$$

where: Q = quantity of heat to be transferred, B.t.u. per hr.

h = rate of heat transfer from metal wall to oil film, B.t.u./hr. x sq. ft. x °F.

A = heat transfer surface of the metal wall, sq. ft.

ΔT = log mean temperature difference between metal wall and the main body of the oil, °F.

Looking at the second form of the equation, for any given set of conditions, Q is known, and a convenient surface (A) may be assumed.

Let $Q = 1,125,000$ B.t.u./hr.

And $A = 125$ sq. ft.

If $h = 30$ B.t.u./hr. x sq. ft. x °F.

Then $\Delta T = 150^\circ\text{F}$.

But if $h = 30$ B.t.u./hr. x sq. ft. x °F.

Then $\Delta T = 300^\circ\text{F}$.

In terms of metal wall temperature this would mean 498°F . and 625°F ., respectively. The significance of these two temperatures is apparent when it is considered that edible oils may be injured by overheating.

The flow characteristics of the heating medium used to heat the oil must be considered. The need for different types of baffling and flow patterns is obvious when comparing liquid and condensing vapor heating mediums, but even two condensing vapors need different handling. For example, the latent heat of Dowtherm is only about $\frac{1}{9}$ th that of steam so that 9 times as much condensate must be handled in the case of Dowtherm as compared with steam. This means that condensate outlet piping must be larger when using Dowtherm. The same considerations apply to heating coils. Thus a conversion of an existing steam heater or heating coil to Dowtherm would probably require some physical changes in the heater itself.

There must also be provision for differential expansion within the heater. In the case of a shell-and-tube exchanger a design must be used which permits the tubes and shell to expand independently of each other. There are a number of floating head and U-tube designs for this purpose. Similarly in a batch or semicontinuous deodorizer, heating coils must be properly supported to allow for expansion.

The general arrangement also must provide for expansion of the heater and connecting pipe in relation to other equipment and structurals. Actually this applies to all high temperature equipment but, in deodorizations systems, is most applicable to the heater.

Source of Heat. Similar to the film heat rate transfer formula given previously, the over-all heat transfer equation is:

$$Q = UA\Delta T$$

where: Q = heat to be transferred, B.t.u. per hr.

U = over-all heat transfer rate, B.t.u./hr. x sq. ft. x °F.

A = heat transfer surface of the heater, sq. ft.

ΔT = over-all log mean temperature difference, °F.

For any given heat load (Q) it is desirable to keep the amount of heat transfer surface (A) to a minimum. This is purely on the basis of investment cost. For the same reason as in the case of the oil heater the temperature difference (ΔT) should be at a minimum and the over-all heat transfer rate (U) at a maximum. Of course, the lower the temperature difference (ΔT), the less chance there is for burning the oil.

Assume a batch of oil is to be heated to 450°F . On this basis, various means of reaching this temperature will be outlined.

1. *Saturated Steam.* To keep the heating surface down to a reasonable figure it is necessary to have a substantial temperature difference. If a final temperature difference of 70°F . is wanted, meaning that the steam should condense at 520°F ., steam pressure would have to be over 800 lbs. p.s.i.g. Even if the condensing steam temperature is cut down to 480°F ., leaving only a final temperature difference of 30°F ., the steam pressure would have to exceed 550 lbs. p.s.i.g. This reduction of 40°F . in steam temperature would roughly have the effect of doubling the amount of heat transfer surface needed.

The cost of heat transfer surface which must withstand high pressure is appreciable. However if the plant steam supply system is such that saturated steam temperature in the neighborhood of 500°F . is available, it should by all means be used. Steam heating is a practical and satisfactory means of operation. On the other hand, if the plant boiler cannot give saturated steam pressures in the range discussed, it would be impractical to install a special high pressure steam generator for this purpose.

2. *Superheated Steam.* A rash conclusion might be reached if only the temperature of the steam available for heating a deodorizer were considered. For example, let it be assumed a deodorizer has available superheated steam at 600°F . and 150 p.s.i.g.

In the first place, no heat of vaporization would be available above a steam temperature at 150 p.s.i.g. Thus if the heat load were 900,000 B.t.u. per hour and the superheated steam were cooled 100 degrees to 500°F ., to leave an adequate temperature difference (above 450°F .), the steam requirement would be 18,000 lbs. per hour. This large quantity of steam would not only require large pipes and fittings but provision to dispose of it, after leaving the deodorizer, would also be needed. In addition, pressure drop through the deodorizer coils or heater would undoubtedly reduce the saturation steam pressure and consequently the saturation temperature as well, complicating the re-use problem.

The second serious objection to the use of superheated steam comes from the low heat transfer rate available during de-superheating. The result of low heat transfer rates, as we have seen above, is the need for a larger heat transfer surface. Thus the oil heating surface would be increased in proportion. Direct contact of superheated steam and oil would reduce the amount of steam needed for heating, but it is not customary due to high entrainment losses and the need for large vacuum equipment.

3. *Direct firing.* With this type of heating system, danger of overheating is always present, even with direct injection of steam with the oil in the heater. Temperature control is relatively poor, which may cause burning of oil. In case of power failure to the circulating pump which delivers oil in process to the direct fired heater, there undoubtedly would be carbonization of oil in the heater even if fuel is immediately cut off to the burner. There is always residual heat left in the setting, and this partly dissipates in the oil contained in the heater tubes. This disadvantage is inherent in any direct-fired liquid heating system.

4. *Circulating Oil or Liquid Dowtherm.* Liquid circulating systems are not commonly installed today in edible oil refineries. Unless the heating medium is pumped at a high velocity, the heat transfer rate from the heating medium to the edible oil is relatively low. Thus satisfactory transfer rates, in the deodorizer heater, are based upon substantial pumping charges.

The most important advantage of this type of system lies in its simplicity. Control of operating temperature is satisfactory. The circulating system, using sensible heat, does not have the advantage of a single condensing temperature, which is true for saturated steam or saturated Dowtherm vapor. This means that higher heating medium temperatures are needed for a circulating liquid than for a condensing vapor. This is not desirable in a deodorizer where a minimum wall temperature is wanted for any given bulk oil temperature.

One warning must be issued in connection with this type of system in which a liquid heating medium is circulated through a direct-fired furnace. For the same reason mentioned before in the case of direct firing, there is the danger of carbonizing the heating medium in the furnace tubes in case the circulation stops.

5. *Condensing Dowtherm.* The use of condensing Dowtherm for deodorizer service is wide-spread. Undoubtedly it is the

most popular method of heating used in modern vegetable oil deodorizer installations. Dowtherm is relatively stable and has the tremendous advantage of a low vapor pressure, when boiling at high temperatures. For example, at 522°F. the vapor pressure of Dowtherm is only 4 p.s.i.g.

Good heat transfer rates are available with condensing Dowtherm, in the neighborhood of 200 B.t.u./hr. x sq. ft. x °F. It is non-toxic but does have a distinct odor, which manifests itself immediately in case of leakage. Further information is available in the Chemical Engineers Handbook (15) and a trade publication (16).

Some deodorizers make use of cool liquid Dowtherm for cooling the oil. A condensing Dowtherm heating system may be easily combined with this method of cooling.

A superficial summary of the various means of heating follows in Table III.

Oil Cooler. The design of this unit should be such as to eliminate inward leakage of air. This means that the pressure of the oil in an external cooler must always be above atmospheric.

It is also necessary to look into the danger of oil congealing on the water-cooled tube surface. If con-

TABLE III

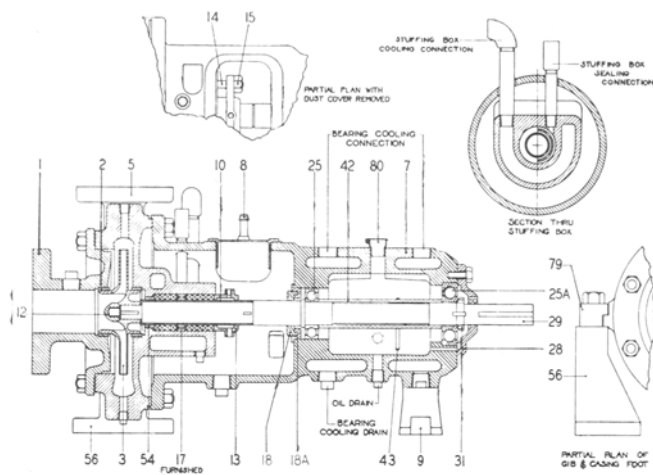
	Saturated steam	Superheated steam	Direct firing	Liquid circulation	Condensing dowtherm
Simplicity	Good	Good	Very good	Good	Good
Temperature control	Very good	Fair	Poor	Good	Very good
Power consumption	Very good	Very good	Poor	Poor	Good to very good
Cost of equipment	Fair to good	Good	Very good	Good	Good
Reliability	Good	Good	Fair	Fair	Good
Heat transfer rates	Very good	Poor	Poor	Fair to very good	Good
Flexibility	Very good	Fair	Poor	Very good	Very good
Minimum tube-wall temperature	Very good	Fair	Poor	Good	Very good

gealing does occur, the surface becomes essentially inoperative, and the cooler will be found to operate more efficiently with warmer water, which will not tend to congeal the oil.

If the congealing temperature of the oil is known, an estimate may be made for a given cooler of the amount and temperature of water required for the cooling operation. This is accomplished by making film heat transfer calculations on both water and oil sides of the exchanger. Since the actual film temperatures are inversely proportional to the heat transfer rates on the oil and water sides of the cooler, the temperature of the oil film may be calculated. If this oil film is above the congeal point, the cooler should operate satisfactorily.

Oil Handling Pumps. A pump, which handles edible oils at high vacuum and high temperature, must be very carefully selected. First of all, to accommodate these conditions, it preferably will be center-line supported to minimize the effect of piping expansion, placing a strain on the pump shaft and stuffing box or seal. If a stuffing box is used, it should be reasonably long. Both stuffing box or seal and bearings should be water-cooled.

To avoid inward leakage of air through a pump stuffing box, the pump of general design shown in Figure 10 may be used. The impeller has no pressure equalizing holes near the hub. Thus the stuffing box is subjected to a positive lateral pressure which

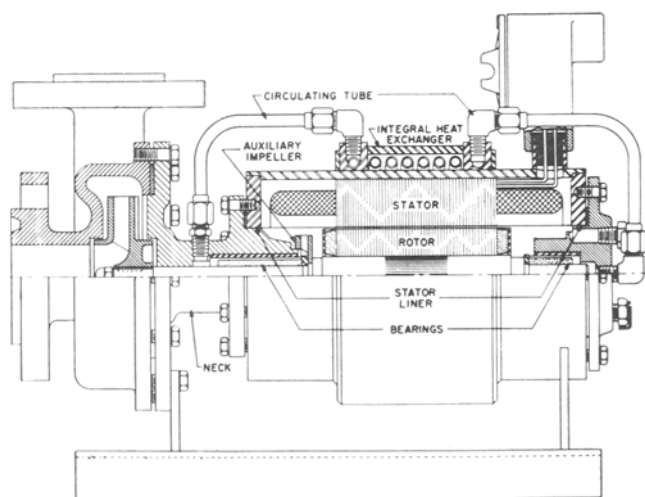


Courtesy of Dean Brothers Pump Company
Fig. 10

originates from the pump discharge pressure in the impeller casing. Oil is forced past the pump wearing rings, where it leaves and enters the end of the stuffing box. Thus leakage of oil is outward, which prevents inward leakage of air. In a properly designed pump which is well packed and accurately aligned, the oil drips from the pump at a very low rate, which should be only a few drops per minute.

In the past few years there has been a tendency to make use of mechanical pump seals in place of stuffing box packing. At some additional cost, the pump shown in Figure 10 can be fitted with such a seal, either inside or outside the stuffing box. The seal should be arranged to permit differential pressure, whether caused by internal oil pressure or external atmospheric pressure, to help force the seal faces together.

Another pump, one type of which is illustrated in Figure 11, has also been developed recently. This is the so-called "canned" pump which encases the motor within the pump. Speaking broadly, the pump impeller encloses the rotor of the motor and the pump casing, the external windings of the motor. With such a pump there is no possibility whatsoever of inward air leakage since there is no stuffing box or mechanical seal. This pump ordinarily operates at lower hydraulic and electrical efficiencies than



Courtesy of Chemumpump Inc.
Fig. 11

standard pumps, and it may be subject to higher maintenance of pump bearings in some services. These problems are being worked out however, and the pump merits consideration.

Vacuum Equipment. The most reliable and flexible type of equipment, to produce the high vacuum needed in deodorizer service, is the steam jet air-ejector. It is rugged, has no moving parts to get out of order, and gives continuous satisfactory service with little or no maintenance. Service records of 20 years or more are commonplace.

In the range of absolute pressures normally required in modern deodorizers, up to 0.25 in. Hg, the handling capacity of a steam jet air-ejector is appreciably higher than other types of vacuum units in proportion to capital cost. This is an additional reason for its almost universal use in deodorizer service.

Cast iron or steel construction, with 18-8 stainless steel steam nozzles, are the usual selections for material of construction. A typical three-stage air-ejector, of the type used in deodorization service, is shown in Figure 12.

On the basis of an absolute pressure of 0.25 in. of mercury, with water available at a maximum temperature of 85°F., a practical combination of ejectors and condensers calls for a compression ratio of 8 to 1 in the first (or booster) stage. This means that the absolute discharge pressure of the booster ejector will be 2.0 in. of mercury. With this pressure 85°F. condensing water can be used conveniently and efficiently. For example, if the water is heated 11 degrees to 96°F., just 5°F. temperature difference automatically is allowed to force condensation of the

ejector steam because water itself has a vapor pressure of 2.0 in. Hg absolute at 101°F.

Further compression to atmospheric pressure is customarily handled by two smaller ejectors in series interconnected by a barometric intercondenser since the ratio of compression from 2.0 in. to 3.0 in. Hg absolute is too great for efficient operation of a single jet. By condensing the actuating steam from the booster jet and the second-stage jet in barometric condensers, the work of both second and third-stage jets is decreased tremendously. They need only handle the noncondensable gases, saturated with water vapor.

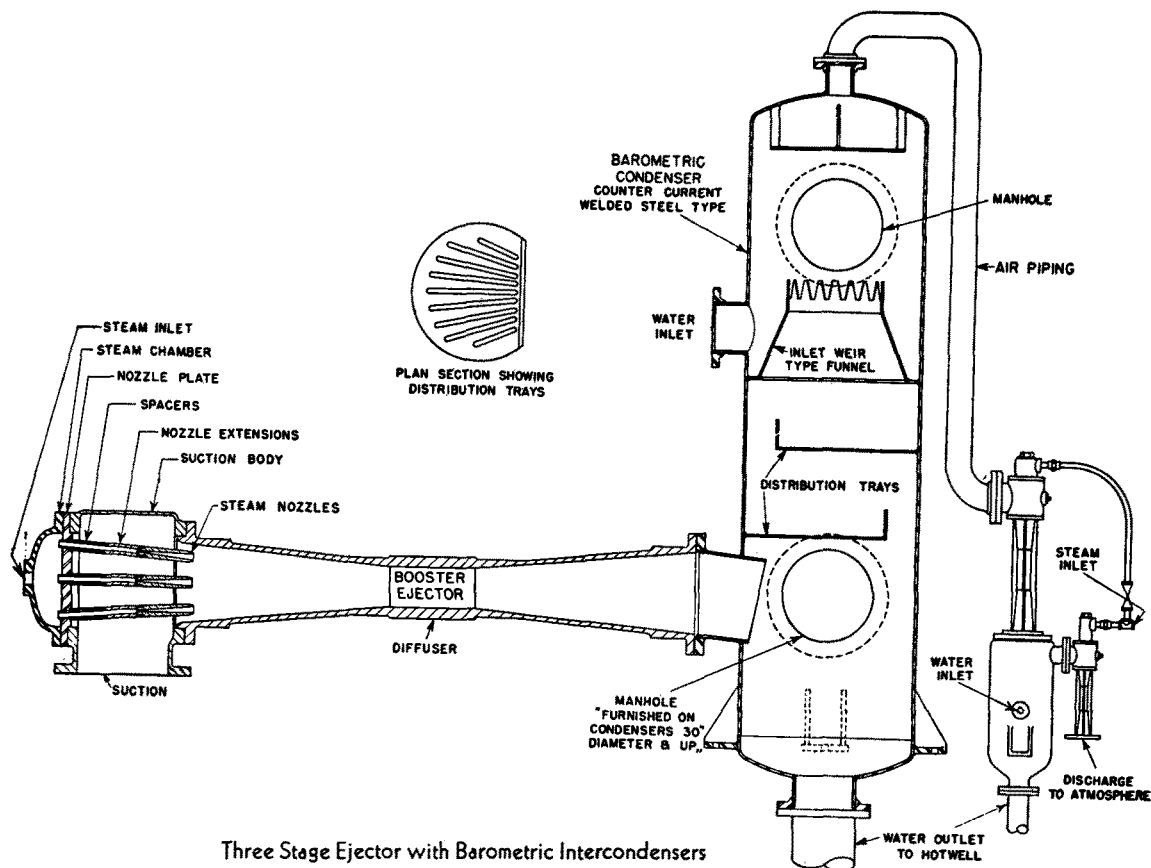
The foregoing figures and those tabulated below in Table IV show why it is impossible to obtain very high vacuums in condensers without refrigerated water or booster ejectors.

The use of this table permits the determination of condensing water requirements. Obviously if the design can permit heating the condensing water to 95°F., twice as much water will be needed at 85°F. as at 75°F. However the usual practice in the design of ejectors takes advantage of the lower water tem-

TABLE IV

Water temperature ^a in °F.	Water vapor pressure in inches mercury
40	0.25
50	0.36
60	0.52
70	0.74
80	1.03
90	1.42
100	1.93
110	2.60

^a The equilibrium water temperature in a condenser will generally be 10-20°F. higher than the entering water temperature.



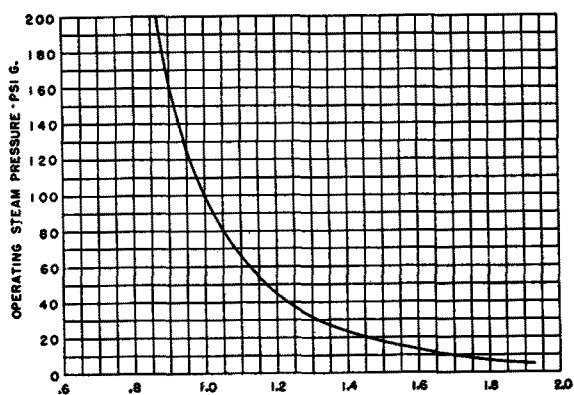
Three Stage Ejector with Barometric Intercondensers

peratures by setting the main barometric condenser temperature and consequent absolute pressure at a lower level, thus saving on the steam requirements.

The effect of steam pressure upon the steam requirement of simple ejectors is significant although not as great as a superficial guess might infer. If, arbitrarily, it is assumed that 100 lbs. of steam at 100 p.s.i.g. are needed for an ejector, then only about 90-91 lbs. will be needed at 150 p.s.i.g. and about 117 lbs. at 50 p.s.i.g. This relationship is shown in Figure 13.

Over-all utility requirements of three-stage vacuum units, consisting of three steam jets, and two inter-condensers of the type shown in Figure 10, are given in Figures 14, 15, and 16.

The life and efficiency of a jet depends not only upon the manufacturer but also upon the user. In the first place, the manufacturer must properly place the steam nozzles in the booster ejector nozzle plate.



Comparative steam consumption of booster ejectors for various steam pressures
Courtesy of Foster Wheeler Corporation
FIG. 13

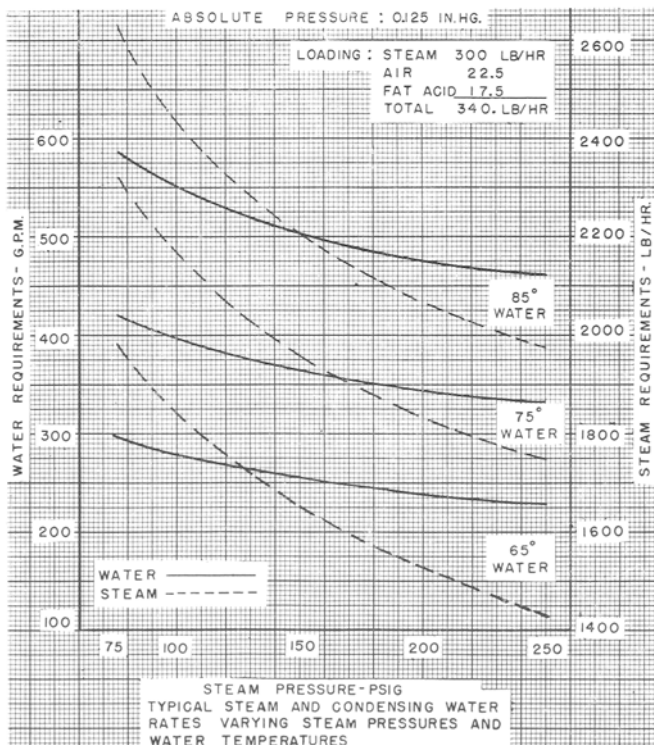


FIG. 14

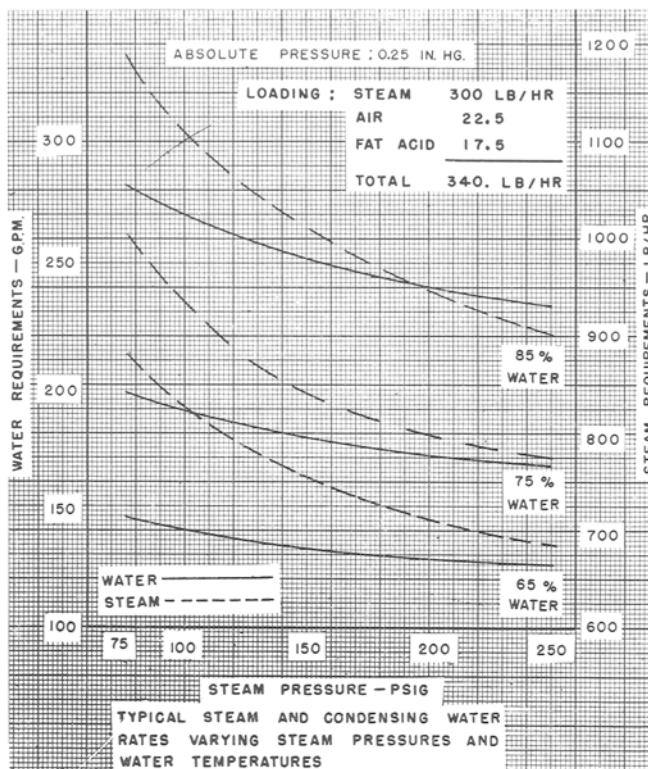


FIG. 15

Small variations in position (as little as 1/4 in.) have a significant effect upon the ejector characteristics. This placing is determined by careful tests. It is the user however who can do most to prolong life and maintain efficiency.

From the point of view of ejector life one important factor is the steam quality. This should not be wet since impinging water will cut a sharp groove in the diffuser of an ejector. The presence of water will also hurt the efficiency of operation, possibly making it impossible to reach design vacuum.

All factors influencing ejector operation can be studied by deodorizer operators. For this purpose a check list of common reasons for poor operation is given here.

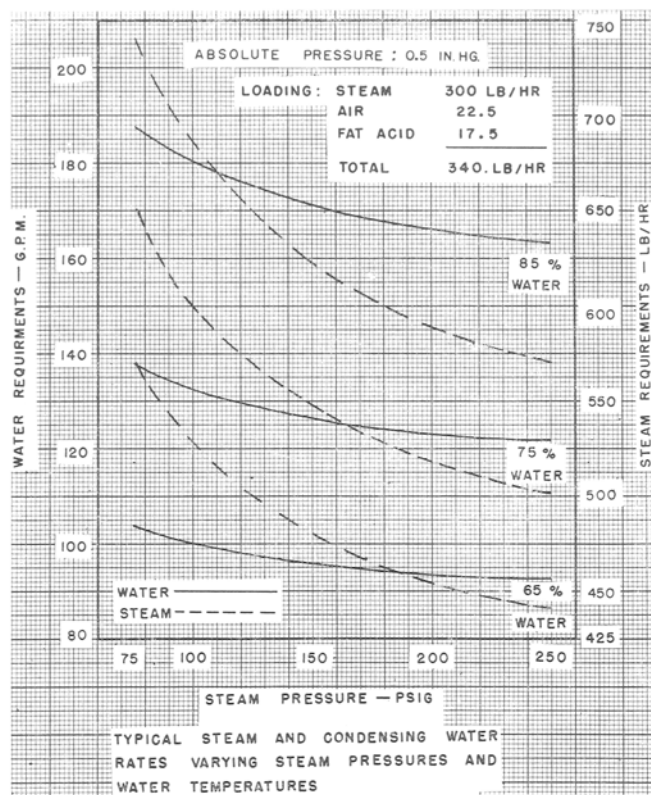
1. *Low Steam Pressure.* This may be caused by clogging of the steam strainers or orifice plates with pipe scale or sediment, improper operation of the steam pressure regulating valve, or low boiler pressure. The steam pressure gauge, for measuring the operating pressure, should be installed at a point close to the ejector steam inlet in order to determine the true operating pressure.

2. *Steam Nozzles.* In addition to the possibility of a nozzle clogging from pipe scale or dirt, a scale deposit might occur in the throats of the steam nozzles from impurities in the steam. When this occurs, it is necessary to clean out the nozzles with nozzle reamers or drills of the proper size, being careful not to mar the internal surfaces of the nozzles. The proper size of drill to be used can be obtained from the manufacturer upon request.

3. *Insufficient Cooling Water.* The temperatures of the water entering and leaving the ejector condensers should be measured. If the temperature rise is not excessive (see Table III), the cooling water supply is adequate and the trouble should be sought elsewhere.

4. *High Back Pressure at Ejector Discharge.* This can be determined by a pressure measurement at the exit of the final stage. Where this is found to be excessive, the piping must be changed to reduce the discharge pressure.

5. *Nozzle and Diffuser Wear.* When ejectors are operated with extremely wet steam or are required to handle corrosive gases or vapors, the steam nozzle and diffuser should be checked periodically to determine whether excessive wear



has increased the flow area and produced a rough wall surface. The throat diameter of the diffuser and nozzle should be compared with the original sizes. If any scale deposits are found in the nozzle or diffuser, they should be carefully removed.

Margarine Production

LEO C. BROWN, Swift and Company, Research Laboratories, Chicago, Illinois

MARGARINE PRODUCTION in the United States for the last 10 years has been at about an average rate of 1 billion lbs. per year. It is a big industry, a tremendous outlet for the products of American farms. It supplies jobs not only for those directly engaged in the production of margarine but also for those engaged in supplying the necessary equipment for that production. It supplies Mr. and Mrs. America with a nutritious palatable food at low cost.



L. C. Brown

Margarine was introduced into the United States according to Snodgrass in 1874 (1), after its invention in France by Mege-Mouries during the Franco-Prussian war of 1870. Figure 1 will show that the volume of the material produced grew slowly through economic and legislative trials spurting

The operation of any deodorizer is naturally dependent upon continuous high vacuum. However it is not always the vacuum equipment which is faulty in case of either poor product, insufficient vacuum, or both. Air leaks should be found if they exist, and this can be done with a leak detector during operation (17).

An alternate means of locating leaks may be carried out when the deodorizing system is shut down. It calls for sufficient ammonia (from bottled gas or aqueous ammonia) to build up a pressure in the deodorizer system of about 1 p.s.i.g. The pressure is then raised to about 20 p.s.i.g. with air or inert gas.

All suspected points of leakage can be checked by passing a burning sulfur taper within about 12 in. of the point in question. If a leak exists, a white fume will form instantly, and it will seem to issue from the leak.

REFERENCES

1. Bates, R. W., J. Am. Oil Chemists' Soc., 26, 601-606 (1949).
2. Morris, C. E., J. Am. Oil Chemists' Soc., 26, 607-610 (1949).
3. Bailey, A. E., "Industrial Oil and Fat Products," Interscience (1951).
4. Baldwin, A. R., J. Am. Oil Chemists' Soc., 25, 33-35 (1948).
5. Jamieson, G. S., and Baughman, W. F., J. Oil and Fat Ind., 3, 347-355 (1926).
6. Spannuth, H. T., J. Am. Oil Chemists' Soc., 26, 618-622 (1949).
7. Phelps, G. W., and Black, H. C., (to Industrial Patents Corporation) U. S. Patent No. 2,407,616 (1946).
8. Technical Bulletin No. 72, Citric Acid-Edible Oil, Chas. Pfizer and Co. Inc.
9. U. S. Patents 2,485,631 to 2,485,640 inclusive and 2,523,792 to The Best Foods Inc.
10. Schwab, Cooney, Evans, Cowan, J. Am. Oil Chemists' Soc., 39 (5), 177 (1953). (Editor reference incorrect ? ? ? ? ?)
11. Gearhart and Stuckey, J. Am. Oil Chemists' Soc., 32, 386-390 (1955).
12. Thurman, B. H., (to Kraft Foods Inc.) U. S. Patent 2,621,196 (1952).
13. Lawrence, E. A., Chem. Eng. Prog., 48, No. 5, 241-246 (1952).
14. Souders and Brown, Ind. Eng. Chem., 26, 98-103 (1934).
15. Perry, John H., "Chemical Engineers Handbook," 3rd ed.
16. Processes Using Dowtherm, Bulletin ID-50-1, Foster Wheeler Corporation.
17. White, F. B., J. Am. Oil Chemists' Soc., 28, 438-40 (1952).

during World War I. The scarcity of fats in World War II and the economic desirability of producing margarine gave the American consumer the opportunity to become better acquainted with the modern version of this spread. The reaction of the consumer was favorable, ultimately resulting in the passage of a federal law permitting the sale of yellow margarine tax-free. This provided the impetus for greater growth of the industry, and margarine has retained its position since that time.

The improvement in quality of the product, while a gradual process, has been influenced most greatly by discoveries and inventions and through legislative enactments. If the history of margarine production in the United States is traced, there are certain milestones of progress, which are about as follows:

1. introduction from Europe of margarine made principally from fractionated beef fat;
2. the invention of the processes of alkali-refining, deodorization, and hydrogenation, making the use of vegetable oils possible;
3. development of the continuous closed system of crystallization and texturization, as illustrated by the Votator process;
4. standardization of the product through the promulgation of the standard of identity under the Food and Drug Administration; and