fined. For example, a crude cottonseed oil (5) contains many compounds in addition to free fatty acids and mucilaginous substances. These include chlorophyll, pentosans, peptones, phosphates, phosphatides, phospholipins, phytoseroline, phytosterols, proteoses, raffinose, resins, and xanthophyll.

b) 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.

The use of a high vacuum is not in itself sufficient insurance against oxidation. This is due to the fact that vacuum equipment should be overdesigned 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.

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 (4).

c) 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:

1. The temperature of deodorization must be sufficiently high to make the vapor pressure of volatile impurities in the oil conveniently high.

2. The absolute pressure in the deodorizer must be low enough to permit boiling of traces of impurities from the exposed oil surface.

3. Adequate stripping steam, consistent with temperature and pressure in the deodorizer, is needed.

4. 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:

$$\text{Raoult's Law: } p_a = x_a \; P_a$$

and

$$\text{Dalton's Law: } p_a = y_a \; \Pi$$

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 you will note 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. This is shown in Figure 1. This chart, which is based

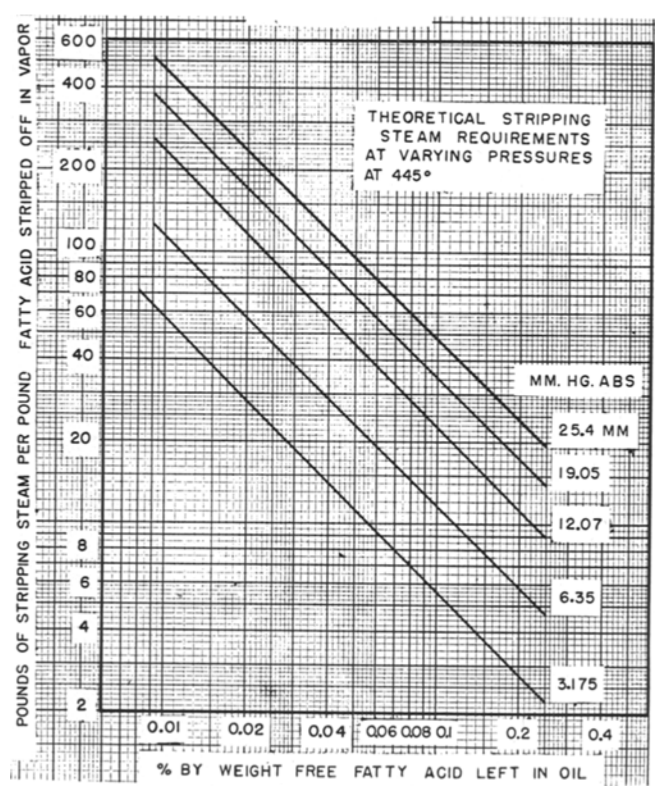


FIG. 1.

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.

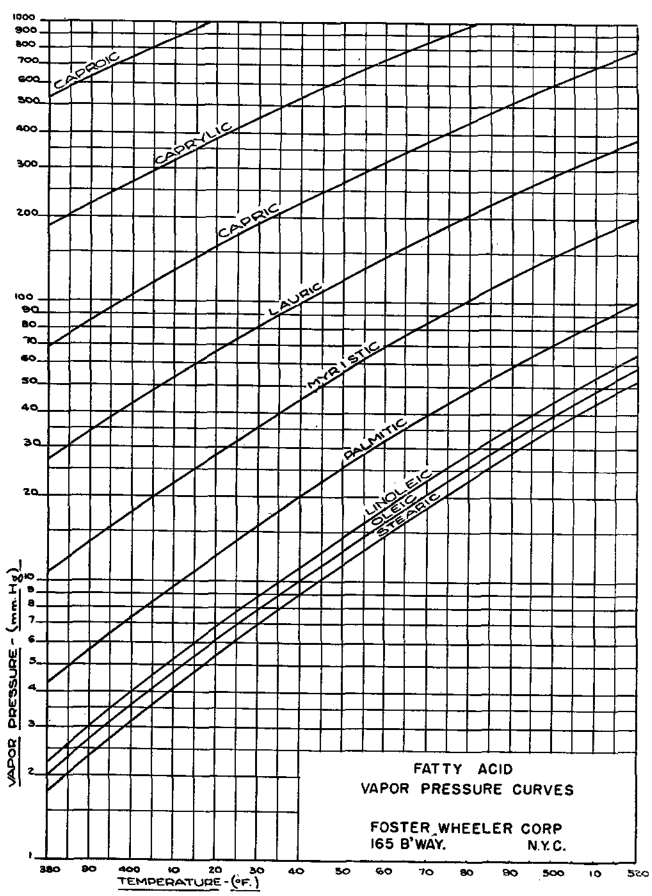


FIG. 2.

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 pounds 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 pounds of steam are finally needed per pound of fatty acid. If a final free fatty acid content of 0.01% is desired, 119 pounds 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 millimeters of mercury. The data show that most existing batch deodorizers operate very inefficiently.

d) 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 metallic contamination to a safe level.

e) 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 (6). 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.

f) 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. Others are tartaric acid, phosphoric acid, and lecithin. Other compounds are

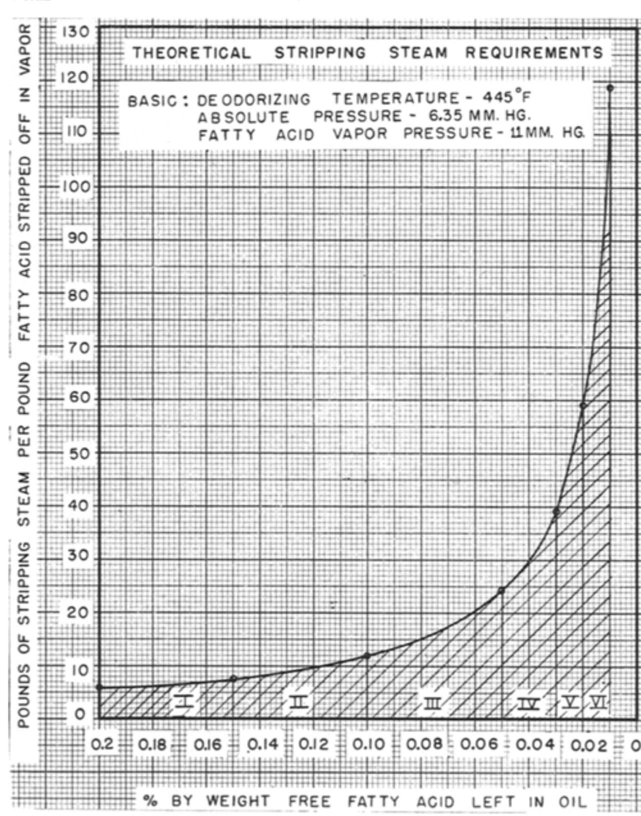


FIG. 3.

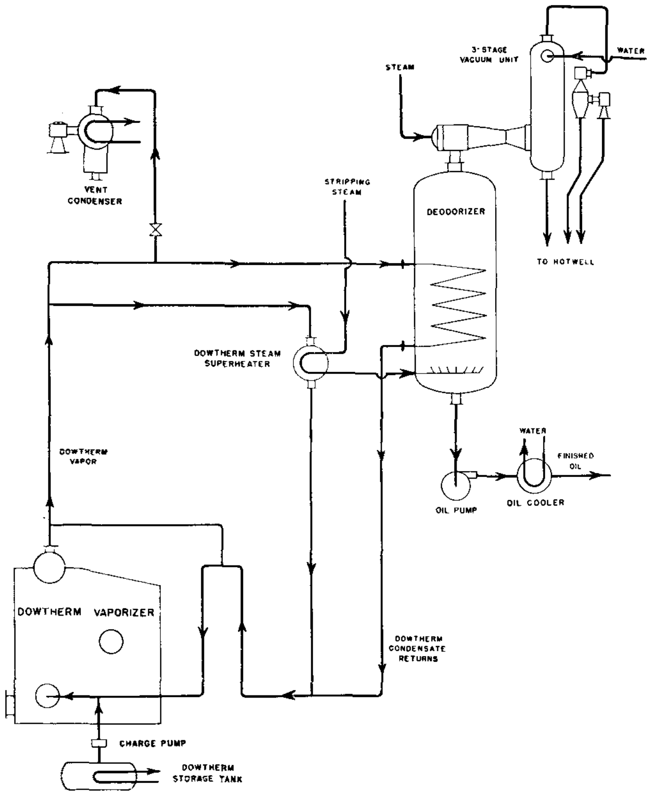


FIG. 4. Batch deodorizer **with internal heating coils.**
Courtesy of Foster Wheeler Corp.

being developed and tested for their efficiency as metal scavengers.

g) In the 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. In well-designed continuous and semicontinuous deodorizers this presents no problem whatsoever. In batch deodorizers the problem does not even exist.

The seven factors affecting deodorization may be summarized as follows:

1. Correct preparation of oil before deodorization
2. Elimination of oxygen
3. Provision of proper conditions for distillation
   a) High temperature
   b) Low absolute pressure
   c) Adequate stripping steam
   d) Careful distribution of stripping steam
4. Materials of construction
5. Elimination of fatty acid condensation and refluxing
6. Use of metal scavengers
7. Insurance of full deodorization treatment

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.

At the present time there is one question relating to deodorizers which should not be overlooked in any economic study of deodorizer operating costs. This relates to patent number 2,621,196 assigned by B. H. Thurman to the Kraft Foods Company. Since there is the possibility of a licensing program based on this patent, consideration of how this could affect the final cost of deodorized oil must be 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 to storage.

The cycle of operations 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

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.

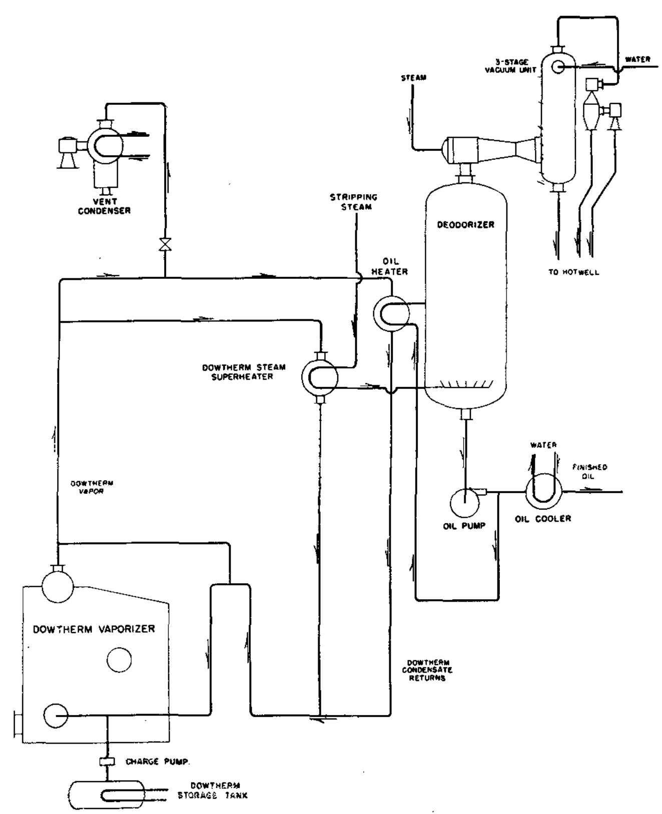


FIG. 5. Batch deodorizer with external oil heater.
Courtesy of Foster Wheeler Corp.

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 draining 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.

TABLE I

Typical Utility Requirements for Deodorization of 100 lbs. of Oil

Type of deodorizer	Steam at 125 psig.	Water at 85°F.	Power	Fuel Oil
	lbs.	*gal.*	*kwh.*	*gal.*
Standard Batch	80.4	963	0.03	0.278
Modified Batch	41.8	530	0.07	0.206
Semicontinuous	37.4	296	0.041	0.093
Continuous	38.6	468	0.114	0.11

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.

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. From the point of view of mechanical equipment it has 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 20 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 batch-deodorizer utility costs are relatively high. However these high costs must be balanced against the possibility of any royalty or licensing charges which might be levied against a more modern type of deodorizer. Capitalization and labor costs must also be taken into account.

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 trays of either nickel or stainless steel. In the top tray oil is heated by means of steam which simultaneously helps deaerate the feed. In the second tray heating of the oil is continued by means of condensing Dowtherm. The third and fourth trays are normally unheated deodorizing trays 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 trays to compensate for heat loss due to radiation and other causes and thus to maintain the deodorization temperature. The holding time in each tray is approximately one-half hour, and stripping steam is injected into all of the trays. The larger proportion of the steam is introduced into the two deodorizing trays for stripping purposes.

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

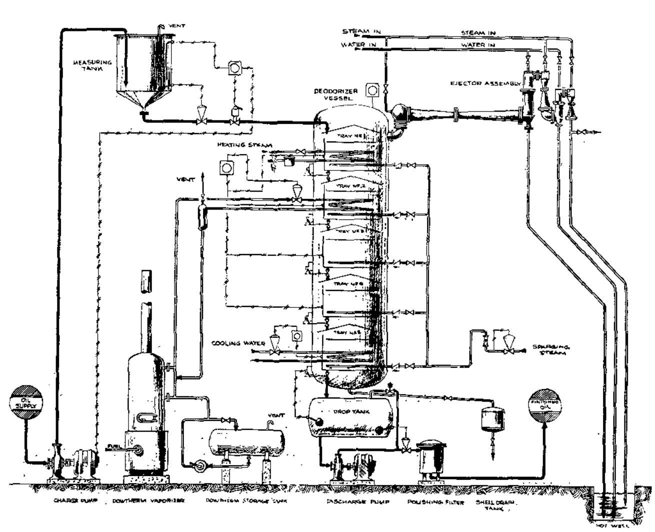
The principal advantage of this system derives from the fact that all trays of the deodorizing system are under the same relatively high vacuum. All oil receives substantially identical treatment, and the annular space between the trays and the shell provides some insurance against oxidation due to inward 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, 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 Deodorizers. In the continuous deodorization process one type of which is shown in Figure 7, the oil is continuously charged to a deaeration section, which is maintained under high vacuum. Some volatile matter and moisture are thus removed at low temperature. From the deaerator the oil passes through a heat exchanger, in which it is partially preheated by means of hot discharging finished oil.

Final processing temperature is reached by heating the oil in a Dowtherm heater, from which it flows to the top tray of the deodorizing tower. The usual temperature is in the range of 420-480°F.

Inside of the column oil cascades downward over a



SEMI-CONTINUOUS DEODORIZER SCHEMATIC FLOW DIAGRAM

FIG. 6.

Courtesy of Girdler Corp.

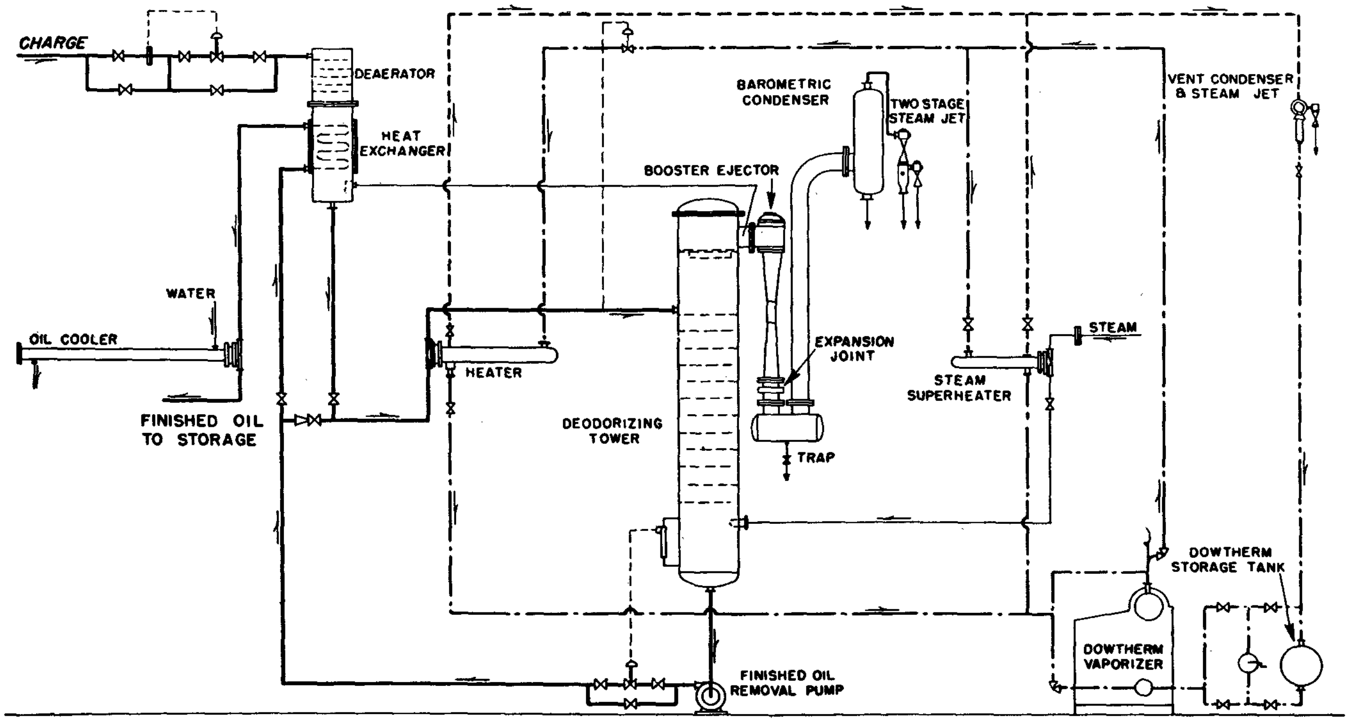


FIG. 7. Continuous deodorizer.

Courtesy of Foster Wheeler Corp.

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 easily be designed to permit rapid change-over of feed stocks, although its principal use so far has been for extended runs.

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

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.

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.

Engineering Aspects of Deodorization Equipment

In this portion of the paper consideration will be given to the following equipment items:

a) Deodorization Vessel
b) Deaerator
c) Oil Heater
d) Source of Heat
e) Oil Cooler
f) Oil Pumps
g) 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, with-

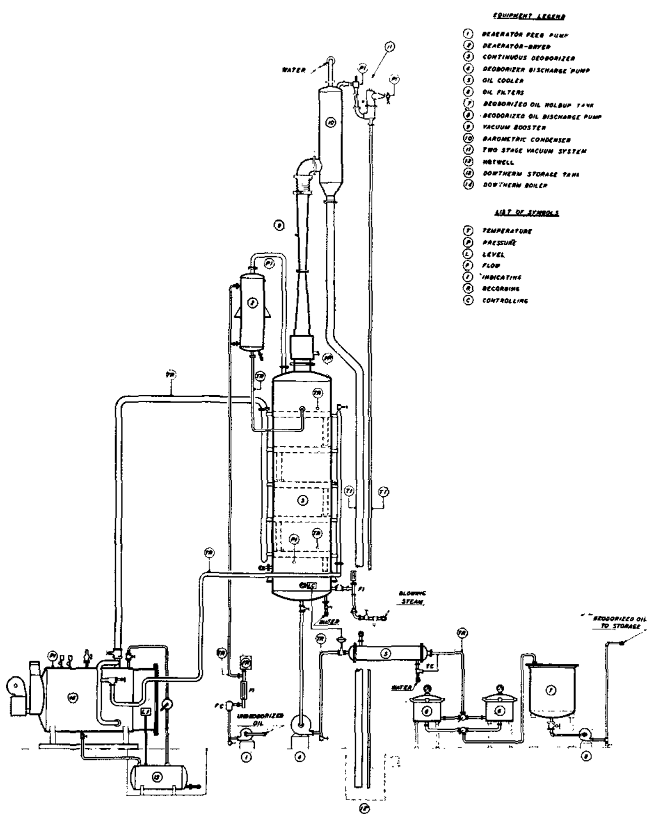


FIG. 8.
Courtesy of Wurster & Sanger Inc.

out attempting to further specify equipment sizes or designs.

A. 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. This relates to the need for effective mixing of steam and oil. For example, in an improperly designed 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 due to 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 pattern. Please keep 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. The second important factor in design of deodorization vessels relates to the flow of stripping steam after it has entered a deodorizer. Proper attention to detail will insure 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 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. However 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 down to a minimum figure. 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 vessel. There are a number of external centrifugal type catchalls which can be used after the deodorizer (8).

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. 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; instead 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.

B. 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.

One very effective form of deaerator has been used frequently in continuous deodorizing systems. It incorporates a flat type of tray for deaeration of the oil feed stock before any heating takes place. Subsequent to this low temperature deaeration, the oil flows downward over a nest of tubes, through which finished deodorized oil flows in a countercurrent fashion. Thus the raw oil is steadily deaerated at progressively increasing temperatures, the heat coming from the finished oil stock which represents an important heat economy. Since the raw oil is always exposed to high vacuum flowing over the heat exchange bundle, undesirable vapors are removed as quickly as is possible by distillation. This minimizes the harmful effects of dissolved gases and volatiles which would otherwise be present in the oil during the heating-up period.

C. Oil Heater

This unit must be considered in the light of the heating medium (direct fire, steam, 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.

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. × sq. ft. × °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. Take the case of an oil to be heated from 150°F. to 450°F. with a 125-sq. ft. heater. If the heat load is 1,125,000 B.t.u. per hour and the film transfer rate (h) is 60 B.t.u./hr. × sq. ft. × °F., then an average log mean temperature difference (ΔT) of 150° would be required. On the other hand, if h were only 30, the average log mean temperature difference would have to be 300. 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 ⅑th 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 to 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 heat 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 deodorization systems, is most applicable to the heater.

D. Source of Heat

Similar to the film heat rate transfer formula given previously the overall heat transfer equation is:

$$Q = UA\Delta T$$

where:

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

U = overall heat transfer rate, B.t.u./hr. × sq. ft. × °F.

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

ΔT = overall 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 overall 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. per sq. in. gauge. 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. per sq. in. gauge. 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 of 366°F. This is the saturated 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 reuse 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 Heating.* Systems of circulating mineral oil are not commonly installed today in edible oil refineries. Unless the heating medium oil is pumped at a high velocity, the heat transfer rate from the heating medium oil to the edible oil is relatively low. Thus satisfactory transfer rates, in the deodorizer heater, are based upon substantial pumping charges.

The basic advantage of this type of system lies in its simplicity. Control of operating temperature is satisfactory. However the mineral oil is subject to some decomposition upon heating and after a period of time must be replaced. A circulating oil does not have the advantage of a single condensing temperature, which is true for saturated steam or for Dowtherm which is discussed below.

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 for 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. × sq. ft. × °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 (10) and a trade publication (11).

E. Oil Cooler

The design of this unit should be such to eliminate inward leakage of air. This means that the pressure of the oil in the 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 congealing 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.

F. Oil Handling Pumps.

A pump, which handles edible oils at high vacuum and temperature, must be very carefully selected. First of all, to accommodate these conditions, it must be center-lined supported to minimize the effect of piping expansion, placing a strain on the pump shaft and stuffing box. The stuffing box should be long. Both stuffing box and bearings are preferably water cooled.

To avoid inward leakage of air through the pump stuffing box, a pump of the general design shown in Figure 9 may be used. Note that the impeller has no pressure equalizing holes near the hub. Thus the stuffing box is subjected to a positive lateral pressure

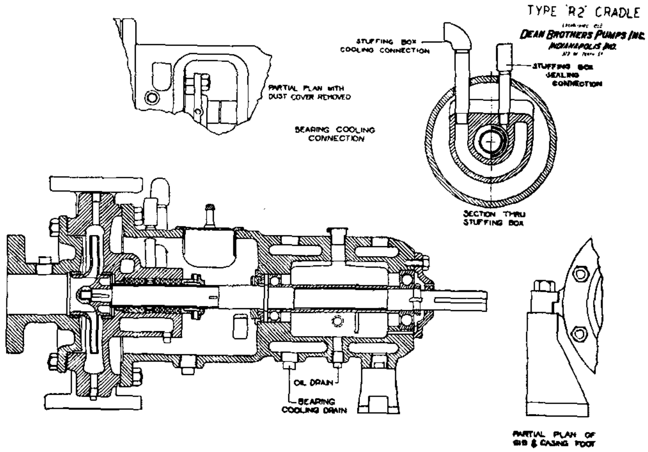


FIG. 9.

which 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.

G. 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 15 to 20 years or more are commonplace.

In the range of absolute pressures normally required in modern deodorizers, namely 3 to 8 mm. of mercury, 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 10.

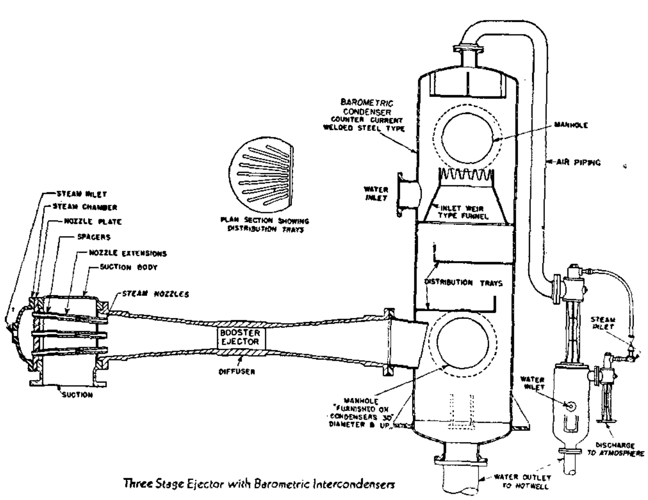


FIG. 10.
Courtesy of Foster Wheeler Corp.

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 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., we automatically allow just 5°F. temperature difference 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 30.0 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 non-condensable gases, saturated with water vapor.

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

TABLE II

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.

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 usual practice in the design of ejectors takes advantage of the lower water temperatures 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 11.

Overall utility requirements of three-stage vacuum units, consisting of three steam jets, and two intercondensers of the type shown in Figure 10, are given in Figures 12, 13, and 14.

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 position the steam nozzles in the booster ejector nozzle plate. Small variations in position (as little as ¼ in.) have a significant effect upon the ejector characteristics. This positioning is determined by careful tests. It is the user however who can do most to prolong life and maintain efficiency.

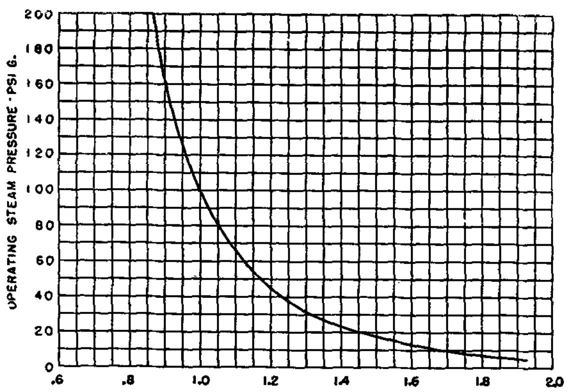


FIG. 11. Comparative steam consumption of booster ejectors for various steam pressures. Courtesy of Foster Wheeler Corp.

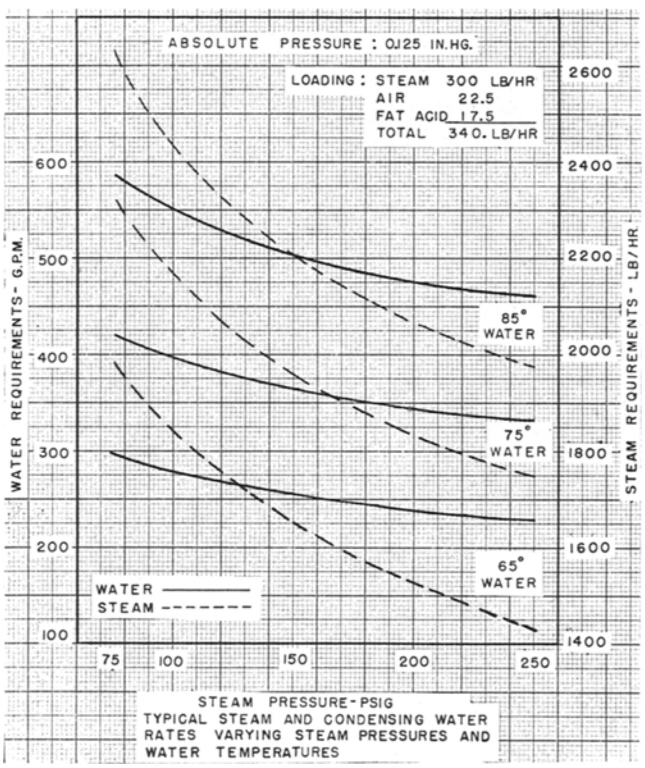


FIG. 12.

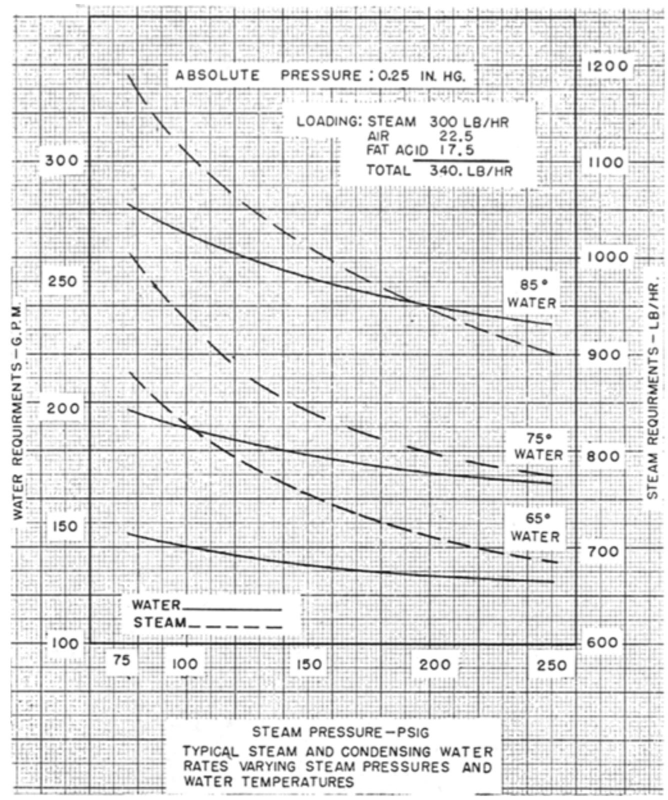


FIG. 13.

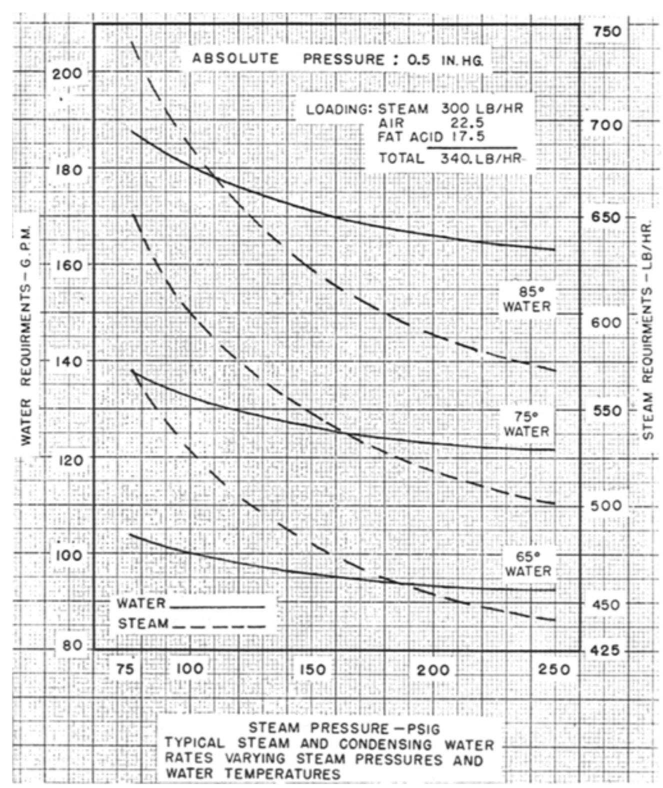


FIG. 14.

From 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 de-

posit 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 II), 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.

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 (12).

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.

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The Plasticizing of Edible Fats

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TO the consumer, commercially solidified edible fats appear to be solids which are relatively soft to the touch at room temperature. The chances are that the percentage of solids present is not over 20% by weight. In some instances as little as 5% solids content is sufficient to produce a product which is form-retaining at 70-80°F. Practical limits however lie somewhere between 10 and 30%. We are dealing with materials melting over a very wide temperature range, which are therefore extremely temperature dependent. A change of a few degrees in temperature at which the products are solidified, stored, or used may lead to a significant change in the solids-liquid ratio and consequently affect the mixing and baking behavior of a shortening or the spreadability and melting characteristics of a margarine. Figure 1 (1), showing the solids contents for lard, a typical all-hydrogenated vegetable oil shortening, and a hydrogenated cottonseed oil, is indicative of solids change with respect to temperature.

N. T. Joyner

Plastic Properties of Fats

The body or consistency of commercially solidified fats depends upon three factors: first is oil formulation, which determines the glyceride distribution; and second is the process of solidifying the molten fat. The solidifying process is critical, and the equipment used as well as the conditions of solidification play an important part in determining the culinary behavior of the finished product. The third factor is the influence of hydrogenation on the consistency of edible fats. It is a subject in itself and cannot be fully treated in this article.

Actually commercially solidified fats in the quiet state are a mass of interlocked, discrete crystals which entrap and hold by surface tension a high percentage of liquid oil. The crystals move independently of one another when a sufficient shearing force is applied to the mass. This property places the material in the class of true plastic solids.

Plastic solids act like rigid solids until force applied is sufficient to cause permanent deformation. At this point they differ radically from rigid solids for as the force is increased, plastic solids yield and flow in the pattern of viscous liquids. Bailey (2) has listed three essential conditions for plasticity. First, there must be two phases, and one of the phases must be solid and the other liquid. Second, the solid phase must be so finely dispersed that the mass will be held together by internal cohesive forces. The third condition is a proper proportion between the two phases.