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.

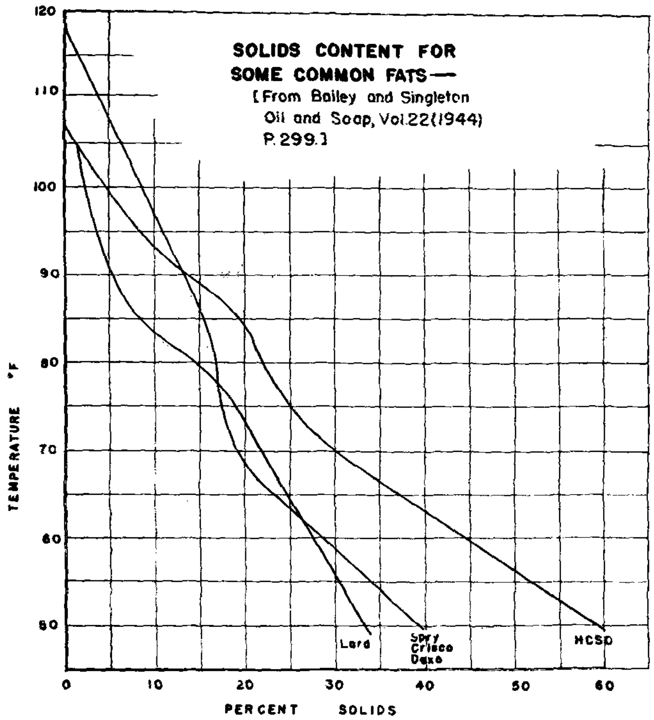

FIG. 1.

If the fat is deficient in solids content, not enough crystals will be formed to hold the liquid oil. On the other hand, if the solids content is too high, the interlocking of crystals coupled with insufficient liquid will cause the fat to be brittle and break rather than flow when the yield value is reached.

The spreading of margarine on bread or toast is an excellent example of plastic flow in a fat. Plasticity is also exemplified in the mixing of shortening into baked goods. During the creaming or mixing steps plastic fats are distributed throughout the dough or batter in thin films. Liquid shortenings, on the other hand, take a droplet shape, resist dispersion in the mixing operation, and hold no air.

Shortenings normally contain from 10 to 15% air by volume, evenly dispersed throughout the mass. Figure 2 is a photomicrograph of a commercially plasticized shortening and shows clearly the air cell distribution. It also illustrates the relative size of the air cells and the solidified fat particles. The air content contributes substantially to the volume and texture of baked products. Carlin (3) has observed that cake batters appear to be suspensions of air bubbles in fat distributed in a flour-liquid mixture with little, if any, liquid emulsified with the fat. He further observed that the fat quickly melts during baking and releases its suspended air to the flour-liquid medium. Gas generated from the leavening agent and steam from the liquid expand the air spaces already existing in the batter, and it is indicated that practically no new air cells are formed during the baking operation.

It is generally agreed that one of the objectives in the manufacture of shortenings is to make the product in such a manner that it will retain its plasticity over a wide temperature range. A realistic range is considered to be 60-90°F. The agreement with respect to margarine is not nearly so unanimous although recent developments in the industry indicate a trend to shortening-like consistency for this product.

The body or consistency of a plastic fat can be measured by either empirical or arbitrary testing procedures. Results are usually expressed numerically and are translatable in terms of "softness" or "firmness" at a specific temperature. Most commonly used tests are those for penetration, and in recent years reasonably accurate dilation procedures for estimating solids content have come into fairly widespread use.

Glyceride Distribution

It is usually true, that other factors being equal, fats made up of glycerides melting over a wide temperature range will have desirable plastic properties. Individually, the constituents of a normal shortening will melt over a temperature scale of —40° to 160°F. The high melting constituents are in a minority, and the average melting point of the blend is normally within a few degrees of body temperature. Fats consisting of glycerides which have a narrow melting range produce products with sharp softening and melting points.

Coconut oil and cocoa butter are typical examples of fatty materials with a short plastic range. In them the saturates, largely of a single class, are present in much higher percentage than lower melting point components and melt within a very narrow range. A vegetable oil shortening or margarine processed to have a high percentage of solid unsaturated component (iso-oleic) will have a relatively narrow plastic range, usually being quite firm at room temperature but softening rapidly when the temperature is raised

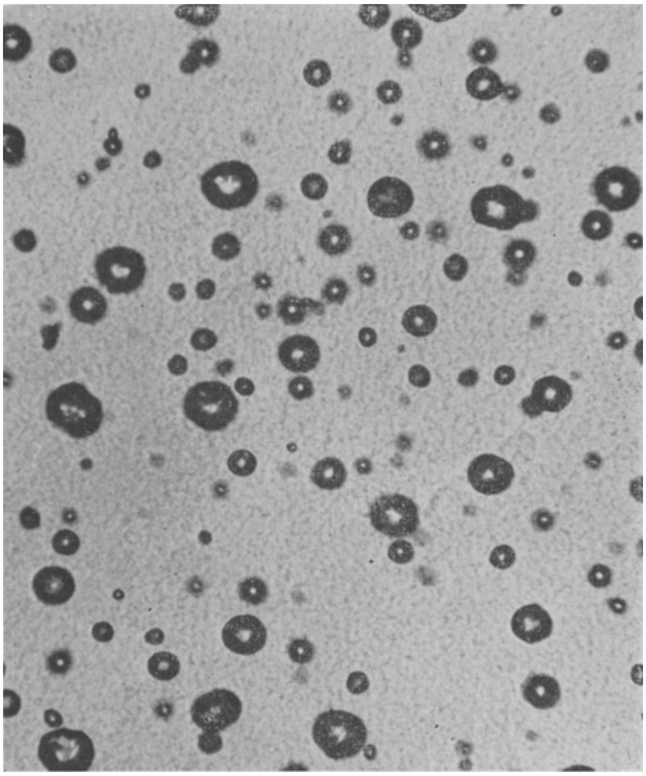

FIG. 2. Photomicrograph of commercially plasticized hydrogenated vegetable oil shortening (300 × at microscope).
Courtesy Research and Development Division, Lever Brothers Company

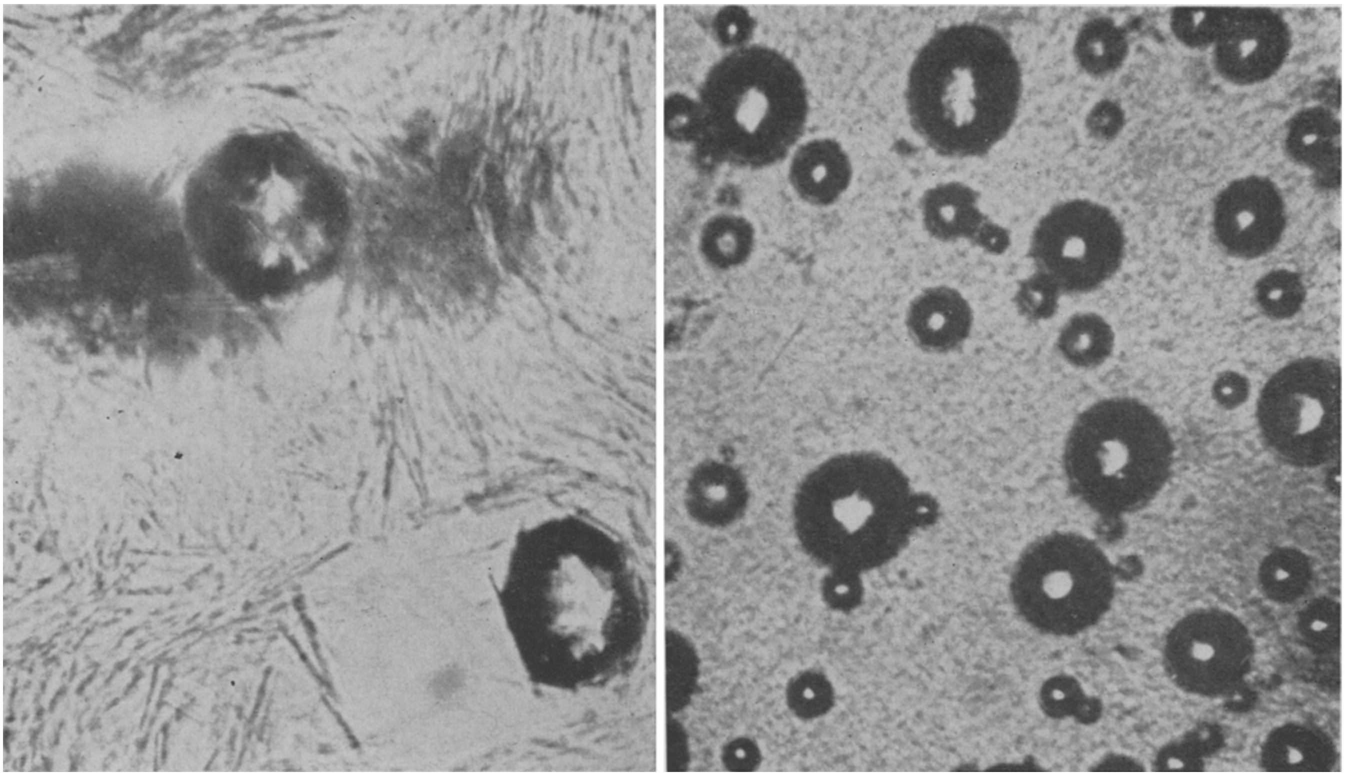

FIG. 3. Effect of random rearrangement on crystal structure of commercially solidified lard. Section on left untreated lard; on right same lard rearranged.

Courtesy Humko Company

a few degrees. The rapid softening is desirable for margarine since it is an indication of sharp melting point characteristics and is associated with a fast "get away"—or quick melt—when placed in the mouth. Unfortunately such a margarine usually will be quite hard at refrigerator temperature and also have poor spreadability.

Crystal Size

The body of plastic fats is influenced significantly by the size of the crystals formed during solidification. A product becomes progressively firmer as the average size of the solids decreases and softer as the crystal size increases. A fat which has been melted and allowed to crystallize slowly under static conditions will contain many large crystals plainly visible to the eye. Crystals formed in the same fat by rapid chilling methods will be microscopic in size. Since the quickly chilled product has very small crystals, it will be firmer. Therefore its consistency range will be much wider than that of the fat which has been slowly crystallized.

These fine crystals are credited with being responsible for a rather remarkable phenomenon in plastic fats. It appears that when a crystal is once established following solidification under recognized commercial practice, it is almost indestructible short of complete melting of the fat mass. This is true despite the constant melting and recrystallization taking place over the range in which the fats are plastic. Apparently no new crystals are formed, but existing crystals simply decrease or grow in size as the temperature changes.

Hydrogenated vegetable oils form fine crystals when subjected to rapid chilling. The crystals are of uniform size and approximately 4 microns in all dimensions. Under similar chilling conditions lard or hydrogenated lard crystallizes in particles approaching 20 microns in dimension. If we assume that at 75°F. a vegetable oil shortening and a lard shortening have the same solids content and that both have been rapidly chilled under optimum conditions, it is probable that the individual crystals in the vegetable oil product outnumber those in the lard by a ratio of 100:1 at least. This difference in crystal size is responsible for lard's relative lack of body and probably contributes to its poor behavior in certain baked goods.

Hydrogenation and subsequent rearrangement with an interesterification catalyst inhibit the growth of large crystals in lard upon quick chilling and result in a crystal structure and size almost indistinguishable from vegetable oil shortenings. Figure 3 shows the effect of random rearrangement on the crystal formation of lard. The section on the left is untreated lard; that on the right is the same lard after rearrangement with an interesterification catalyst. Rearranged lards also exhibit improved baking properties and in this respect compare favorably with vegetable oil shortenings. This is the reason why the production of modified lard has assumed such importance in the oils and fats industries today.

Supercooling

A very critical and oftentimes complicating factor in plasticizing of edible fats is the supercooling property of triglycerides. The degree of supercooling and the temperature at which the supercooled product is allowed to reach crystal equilibrium is directly related to the temperature range over which it is workable. The extent to which a fat is supercooled can affect not only its consistency but also the melting point of the solidified product.

A good example of the effect of persistent supercooling is illustrated by compound vegetable oil shortenings (10-20% of highly hydrogenated fat blended with liquid or soft oil). If, in commercial solidification, such a blend is chilled to the proper temperature and then is stored at a temperature which is optimum for rapid crystal equilibrium, the consistency will be firm and the product workable over a wide temperature range. However if the chilling temperature is low and the filled packages are stored at a low temperature, the product will remain soft almost indefinitely and often can be poured from the container at temperatures where ordinarily it would be quite firm. Even though the chilling temperature may be lower than normal, subsequent storage at about the equilibrium temperature, where the crystal growth is rapid, imparts a normal consistency to the product.

One explanation for the foregoing behavior in shortenings is that supercooling is more likely to be persistent as the saturation of the triglycerides increases and as the saturated glycerides approach a single class. Thus compound shortenings in which the saturated portion is largely palmitodistearin derived from highly hardened cottonseed oil reach a solids-liquid equilibrium more readily than do products containing highly hydrogenated soybean oil, which consists largely of tristearin.

Mechanical Working

If solidification of the supercooled mass takes place under quiescent conditions, the fat will be abnormally firm, and its plastic range will be adversely affected. The product will also lack the smoothness of texture and uniformity in color associated with commercially packaged plastic fats. Rapid solidification in the absence of mechanical work causes crystals to grow together, and a crystal lattice is formed, which is of far greater strength than the same proportion of solids in the form of discrete crystals. In order to prevent the growing together of crystals, plastic fats must be mechanically worked during supercooling and solidification, for during this time crystal formation is most rapid. It is customary to apply some degree of work to chilled fat until substantially all of the latent heat of crystallization has been dissipated.

The degree of work applied to shortening and margarine differs primarily because of packaging considerations. Margarine must be firm enough to be handled in the print-forming and wrapping apparatus whereas shortenings can be and preferably are in a semi-fluid condition when they reach the filling lines. Margarine is therefore allowed to reach crystal equilibrium under the minimum amount of work to produce a homogeneous mixture. On the other hand, the supercooled shortenings are subjected to mechanical agitation and shearing action during the time they solidify. Lards also require mechanical working but, because of their relative softness, cannot be worked as much as vegetable oil shortenings.

Solidification Apparatus

Up to this point we have considered the effect of the following variables on the plasticity of edible fats: proportion of solids, size of crystals, supercooling, and mechanical work.

All of these variables are more or less dependent upon the solidification process and the equipment used to carry out the solidifying operations. Since any one of these variables affects not only the consistency but also the use properties of the fat, it is obvious that precise control of solidifying conditions is essential to insure uniformity of production. Slaughter and McMichael (4), Bailey (5), and James (6) have given excellent descriptions of the various systems used for solidification of plastic fat, including margarine.

The system utilizing Votator continuous processing apparatus provides means for the exact control of the foregoing variables and has been almost universally adopted by manufacturers in the United States and Canada. Essentially the apparatus consists of a scraped surface heat exchanger, jacketed for a direct expansion refrigerant system, and an unrefrigerated worker unit wherein crystallization of the supercooled fat is substantially completed.

Chilling Unit

Figure 4 shows a longitudinal and cross-sectional view of the Votator scraped surface heat exchanger for chilling edible fats. This heat exchanger is referred to as an "A" unit. On the larger shortening and lard units the cylinders are 10 in. in diameter; they are mounted vertically to facilitate easy and safe removal of the shafts. Diameters of the shafts are approximately 9 in. In the margarine unit the cylinders are 4 in. in diameter, and the shafts are approximately 3¼ in. in diameter. Product cylinders on shortening units are constructed of carbon steel, which is chrome-plated to minimize cylinder wear and to prolong the life of the scraper blades. The margarine cylinder is constructed of commercially pure nickel, which is also chrome-plated; all other parts

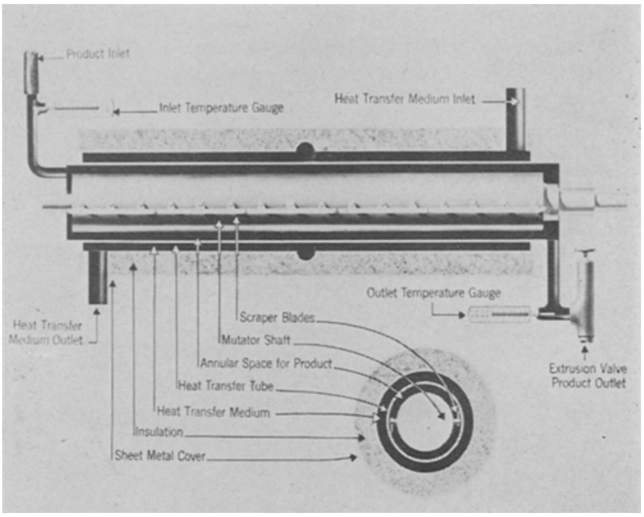

FIG. 4. Longitudinal and cross sectional view of the Votator Heat Exchanger for chilling edible fats.

coming into contact with the product are of stainless steel. The design provides a compact closed system, in which a minimum of product is in contact with maximum heat transfer surface. The unit employs scraper blades to remove the product film from the heat transfer wall, and the blades also prevent crystal build-up on the walls. The shaft has two rows of blades; they are not rigidly fixed but are thrust against the cylinder wall by plowing action and centrifugal force. In general, shaft speeds are in the range of 400 to 700 r.p.m., depending upon the size of the cylinder.

Agitation is vital in the rapid chilling of fats, and a feature of the Votator "A" unit is the violent agitation afforded by the rapidly rotating shaft. The agitation also helps maintain a fine and uniform crystal structure, which is necessary for maximum plasticity. The blade velocity will be upwards of 700 feet a minute, and the two rows of blades will scrape the surface clean about 1,500 times a minute. In order to prevent build-up of crystals on the shaft, hot water may be circulated through it to insure a clean surface at all times.

In the chilling of plastic materials, where there is a rapid increase in solids and at the same time the liquid phase becomes more viscous with temperature drop, a critical shaft speed is reached. Beyond this speed no additional mixing is obtained, and the power input required to rotate the shaft at the higher speed will more than offset any heat transfer benefits resulting from more frequent scraping of the cylinder wall.

Refrigerant System

The "A" unit is designed for direct expansion refrigerants such as ammonia, Freon, propane, etc., and advantage is taken of the high rate of heat transfer due to surface boiling. Figure 5 illustrates the refrigerant system on the vertical Votator "A" unit for lard and shortening. In principle the same system is used for chilling margarine although the arrangement is different. Lard and shortening units have the refrigerant system mounted above the "A" unit assembly; on margarine apparatus it is housed below the horizontal "A" unit cylinder assembly primarily for the sake of added sanitation. The location of the refrigerant system does not affect the overall heat transfer properties of the unit.

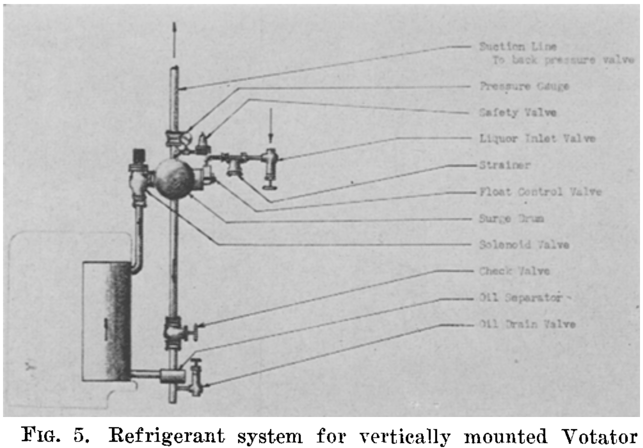

FIG. 5. Refrigerant system for vertically mounted Votator "A" unit chilling cylinders.

On vertical units the liquid refrigerant from the surge drum is fed by gravity to the bottom end of the cylinder and around its periphery. On contacting the outer wall of the heat transfer cylinder, the liquid which is maintained at the desired back pressure (normally 15 pounds), will begin to vaporize with the subsequent evolution of gas. The vapors are removed from an outlet which is located at the top of the cylinder.

Actually this arrangement might be termed a "thermal pump." The controlled liquid level in the surge drum establishes a constant head at the bottom of the cylinder assembly. A considerable proportion of the liquid vaporizes upon contact with the heat transfer tube, and the velocity of the gas carries a relatively high percentage of liquid ammonia back to the surge drum, thus assuring complete flooding of the heat transfer surface at all times. The surge drum is equipped with baffles, which efficiently separate gas and liquid. Since the return lines are mostly filled with vapor, the liquid leg will continue to supply refrigerant to the "A" unit. The baffle arrangement assures that only gas will be returned to the compressor.

By means of a solenoid valve it is possible to go from a full refrigeration load on the cylinder assembly to one completely devoid of refrigerant in a matter of seconds. A relay de-energizes the coil, which in turn closes the return line, whereupon the warm heat transfer tube will vaporize enough refrigerant to build up pressure sufficient to force any liquid remaining in the cylinder back through the liquid feed line into the surge drum. The solenoid valve is connected also through a magnetic overload with the motor on the shaft drive. Upon reaching a predetermined load setting, the relay will de-energize the solenoid valve and cause the liquid refrigerant to be returned from the cylinder to the surge drum. When the power load returns to a safe operating range, the valve opens again. This control protects the Votator apparatus against freeze-ups, which might damage the equipment. Rapid changes in processing conditions can be made by regulating the back pressure valve.

In the refrigerant system designed for the margarine "A" unit the gravity feed arrangement has been replaced with a storage tank and liquid recycle pump. A constant liquid level is maintained by means of a float valve, and the liquid is pumped to the cylinder at the bottom center, where it enters a trough immediately surrounding the heat transfer cylinder. The trough is open at the top but high enough to permit complete flooding of the cylinder surfaces. Vapors together with a high percentage of liquid overflow the trough and are returned also at the bottom center of the cylinder. The solenoid valve has been omitted. Protection against freeze-ups is assured by connecting the liquid recycle pump through a relay to the motor of the shaft drive. Any mechanical failure or overload will stop the refrigerant pump, and the liquid in the cylinder will drop down into the storage tank. Figure 6 is a photograph of a 10,000-pounds-an-hour lard or shortening plasticizing apparatus.

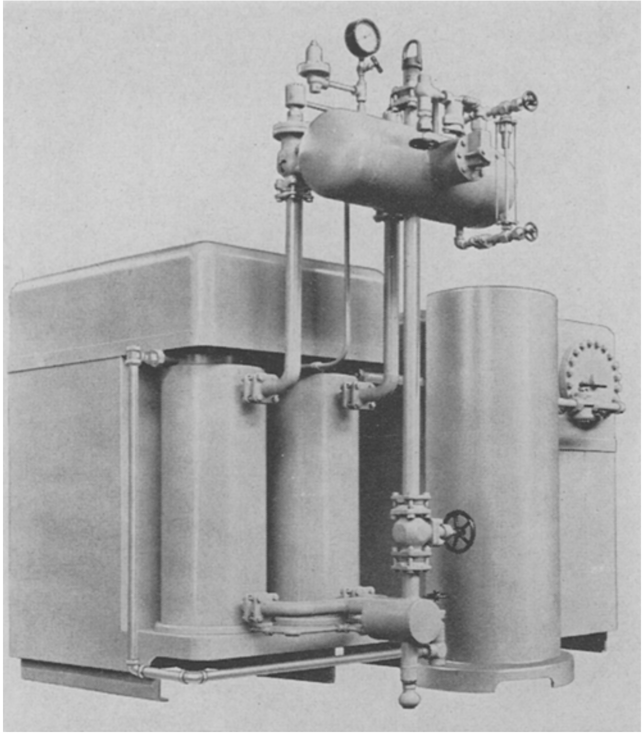

Fig. 6. Two-cylinder, 10", Votator lard or shortening apparatus with rated capacity of 10,000 pounds per hour.

Operation of Votator Apparatus for Plasticizing Lard and Shortenings

The flow diagram shown in Figure 7 covers the complete sequence of operations in the plasticizing of lard or shortening. The diagram represents apparatus having a nominal capacity of 10,000 pounds an hour. Systems having capacities of 3,500 and 5,000 pounds an hour are available also.

The molten oil at temperatures of 130°-140°F. is fed from holding tanks to a small float controlled feed tank and is pumped by a gear pump through an oil to water coil type of precooler. The temperature of the fat is lowered to 115°-120°F. in the precooler. The purpose of the precooler is threefold: first, to insure that the material entering the Votator "A" unit is at a constant temperature; second, to reduce the heat load on the "A" unit; and third, by having the fat at a temperature close to its melting point, to insure the presence of the largest number of crystal nuclei as the fat is chilled in the "A" unit.

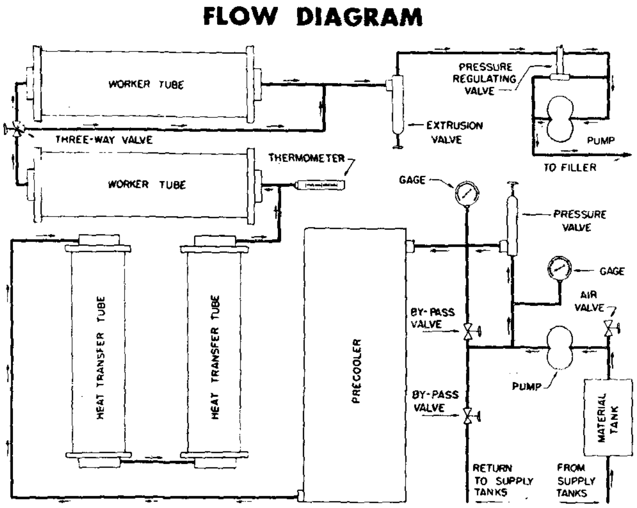

Fig. 7. The Votator system for plasticizing edible fats.

Air or preferably an inert gas, such as nitrogen, is drawn into the melted fat on the suction side of the product pump in precise amounts regulated by flow meters. Pressure throughout the entire Votator solidification system is maintained by means of a pressure regulating valve placed in the hot oil line between the product pump and the precooler.

The precooled oil enters the "A" unit or chilling assembly, where, in a residence time of approximately 18 seconds, the fat is cooled to 60°-65°F. Two "A" unit cylinders, each 10 in. in diameter, are connected in series for production of approximately 10,000 pounds an hour. They provide 18 sq. ft. of heat transfer surface. One cylinder for chilling is sufficient when production rate is 5,000 pounds an hour.

Worker Unit

The supercooled fat leaves the Votator "A" unit in a semi-liquid condition having a higher viscosity than the hot oil and passes directly into an unrefrigerated cylindrical unit called, for the sake of simplicity, a "B" unit. A cutaway view of this equipment is shown on Figure 8. These worker cylinders are somewhat larger than the "A" unit tubes, being 13 in. in diameter for the larger unit, and are provided with beaters or pickers, which keep the supercooled fat under mild agitation during solidification. The shaft revolves at approximately 125 r.p.m. and contains ½-in. diameter pins fixed in a spiral position along the length of the shaft. The pins mesh with stationary fingers attached in comb form to the top of the cylinder wall. Residence time of the chilled fat in the "B" unit is approximately 3 minutes. During this time the temperature of the fat rises approximately 10°-15°F., mostly due to latent heat of crystallization. Agitation during this period of final solidification serves not only to form fine discrete crystals but also to distribute the heat of crystallization uniformly throughout the product.

The worked fat from the "B" unit is forced through an extrusion valve which contains a slot or other form of constriction to aid in making the product homogeneous by breaking up under intense

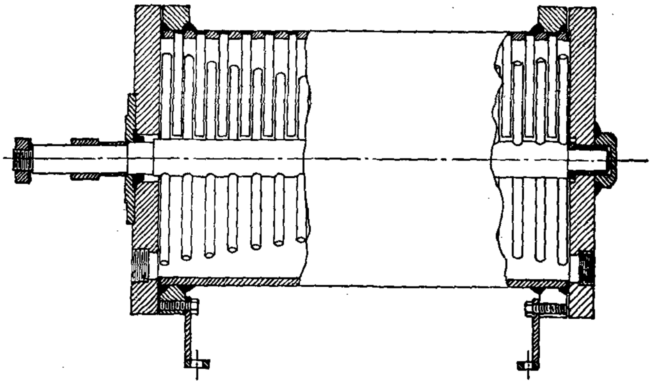

Fig. 8. Cutaway view of Votator "B" unit used to supply work to superchilled edible fats.

shearing action any remaining crystal aggregates. A rotary pump takes suction from the "B" unit and delivers the substantially solidified fat at pressures in the range of 300-400 p.s.i.g. to a second extrusion valve located near the filling station. The shearing action of the valves forces the air or inert gas out of solution into the occluded phase. It is necessary to maintain a minimum pressure of about 300 p.s.i.g. at the second extrusion valve to prevent loss of air and resulting streaked appearance of the product. A crystal structure for maximum plastic range has been established by shock chilling and rapid dispersion of heat of crystallization under controlled agitation. The product is now ready for the filling operation. The temperature rise in the container should not be more than 1 or 2°F. Increases above this are indicative of substantial crystallization under static conditions and still cause the consistency to be firmer than desired.

Tempering

Immediately after packaging, the lard or shortening is stored for 24-72 hours at a temperature slightly above the packing temperature. This conditioning period is referred to as "tempering." The primary purpose of tempering is to condition the plasticized shortening so that it will withstand wide temperature variations in subsequent storage and still have a uniform consistency when brought back to 70°-75°F., which is the accepted optimum temperature range for bakery use.

Considerable confusion exists as to what happens to the structure of plastic fats during the tempering period. The prevailing theory seems to be that low melting point glycerides are eliminated from crystals by melting at the conditioning temperature. It is believed that this melting and the forming of firmer crystals produce a structure that is more homogeneous and stronger mechanically. Such a theory fits in with the increased creaming qualities of a tempered fat and also with the ability of a plastic fat to retain uniform consistency at a specific temperature regardless (within reason) of interim storage conditions. As would be expected, hydrogenated vegetable oil shortenings, due to their wide melting point range, require longer tempering times than do compound shortenings or lard.

Effect of Chilling Temperature and Mechanical Work on Consistency

Just how critical the degree of supercooling and mechanical work applied to the supercooled mass is on the body of a shortening is illustrated in the curves shown on Figure 9. The glyceride composition of the shortenings represented by Curves X and Y is identical, and both products were processed in similar apparatus. Shortening X was chilled to a temperature of 68°F. in the "A" unit at a rate of 10,000 pounds an hour, and the equilibrium temperature was 84°F. Shortening Y was chilled at 64°F. at 8,000 pounds an hour, and equilibrium temperature was 78°F. Both shortenings were tempered for 72 hours slightly above their respective packing temperatures. The 70°F. penetration of shortening X was lower (indicating a firmer product) than that of product Y.

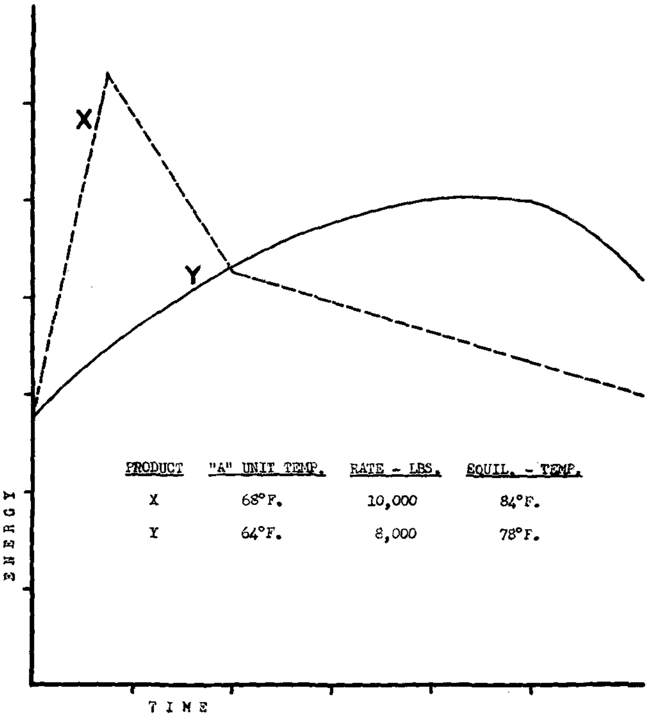

FIG. 9. Effect of temperature and mechanical work in plasticizing vegetable oil shortening on energy requirements for mixing.

The initial energy applied to shortening X to cause plastic flow was considerably in excess of that for Y. Once the yield value had been reached however, energy requirements for continued mixing of product X became much less than those for the softer-appearing product Y. If these two shortenings were subjected to creaming volume tests (shortening, sugar, and eggs), product X would increase in specific volume very rapidly and reach its maximum in about ½ to ⅓ the time required for product Y. However shortening Y would maintain maximum volume over a longer mixing period than would X. These effects simply emphasize the necessity for close control of solidification conditions in order to assure uniform behavior in the product at time of use.

Calculation of Percentage of Solids Crystallized in Solidification Process

From the actual operating data and the pertinent thermal constants for vegetable oil shortenings the percentage of solids crystallized in the "A" unit and the "B" unit can be calculated.

Heat Transfer Data—Shortening

Feed temperature to "A" unit	120°F.
"A" unit outlet temperature	70°F.
Equilibrium temperature	86°F.
Rate	10,000 lbs./hr.
Power input, "A" unit motor and drive	17 kw.
Power input, "B" unit motors	9 kw.
Ammonia back pressure	25 p.s.i.g.

Thermal Constants

Specific heat	0.5
Heat content per pound	35.0 B.T.U.
Latent heat of crystallization	45.0 B.T.U./lb.

In making the calculations, it has been assumed that the B.T.U. removed per pound of product by the "A" unit is 35.0. This figure has been experimentally determined and its accuracy established in production units on numerous occasions. It includes an allowance of 10% for radiation losses in the compressor. The latent heat of crystallization for vegetable oil shortenings is approximately 45 B.T.U. per pound, and this constant has been used in calculating the percentage of solids crystallized in the solidification process. It is assumed also that the efficiency of the motors is 70%. The calculations appear as follows:

Tabulation Showing Heat Loads and Percentage Solids Crystallized in "A" and "B" Units

In "A" Unit

Total Heat Load $Q_t = 35 \times 10{,}000 = 350{,}000$ B.T.U./hr. of which

Sensible Heat $Q_s = (120 - 70) \times 0.5 \times 10{,}000 = 250{,}000$ B.T.U./hr.

Mechanical Heat $Q_m = 17 \times 3{,}413 \times .7 = 40{,}600$ B.T.U./hr.

Radiation Losses $Q_r = .10 \times 350{,}000 = 35{,}000$ B.T.U./hr.

Latent Heat $= Q_t - (Q_s + Q_m + Q_r)$

Latent Heat $= 350{,}000 - 325{,}600 = 24{,}400$ B.T.U./hr.

$$\text{\% Crystallized in ``A'' Unit} = \frac{24{,}400}{45} \times \frac{100}{10{,}000} = 5.4$$

In "B" Unit

Total Heat Load Q_t in "B" unit derived from Latent Heat Q_l plus

Mechanical Heat Q_m (Radiation Losses are Negligible)

$\therefore$ Latent Heat $= Q_t - Q_m$

$Q_t = (86 - 70) \times 0.5 \times 10{,}000 = 80{,}000$ B.T.U./hr.

$Q_m = 9.0 \times 3{,}413 \times .7 = 21{,}500$ B.T.U./hr. ,

Latent Heat $= 80{,}000 - 21{,}500 = 58{,}500$ B.T.U./hr.

$$\text{\% Crystallized in ``B'' unit} = \frac{58{,}500}{45} \times \frac{100}{10{,}000} = 13\%$$

% Total Crystallized $= 5.4 + 13.0 = 18.4$ at 86°F.

Solidification Processes for Margarine

Votator Process. The fact that margarine contains only 80% of plastic fat, with the remainder being predominantly water, does not present any undue complications in the solidification process. Most margarine manufactured in the United States is solidified in Votator continuous margarine processing apparatus. In general, the system is similar to that used for the solidification of lard and shortenings. There is one exception. The margarine "B" unit differs radically in design from the one used for working shortenings in that no provision is made for mechanical agitation. The margarine "B" unit is a good deal smaller in diameter and considerably longer. Solidification of the supercooled margarine emulsion therefore takes place under almost static conditions. The purpose of limiting the amount of work given the product in the "B" unit is threefold: first, to produce a product that is not too soft to be handled in automatic print-forming and wrapping equipment; second, to prevent the aqueous phase from being dispersed in an extremely fine state of subdivision; and third, to induce growth of larger crystals from the supercooled mass. If the same amount of mechanical work applied to shortening were used on margarine, the aqueous phase would be dispersed in exceedingly small droplets, the solid portion of the fat would be crystallized in minute particles, and a long resting period would be required for the product to become firm enough for packaging.

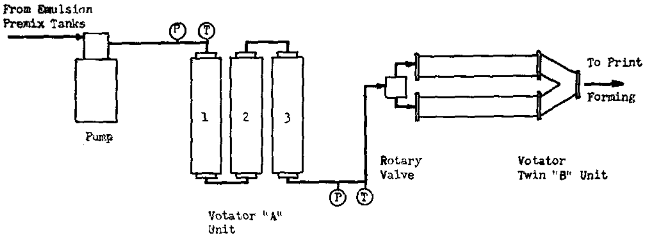

FIG. 10. Flow diagram. Votator margarine solidification system.

In general, a tight emulsion and a fine crystal structure delay melting of the product in the mouth and leave a "waxy" impression with the consumer and at the same time fail to yield the desirable milk and salt flavors before the product has been swallowed. A tight emulsion and a fine crystal structure are also partly responsible for brittleness or hardness, which is reflected in lack of spreadability at refrigerator temperatures.

A typical flow diagram for a Votator margarine solidification system is shown on Figure 10. Three chilling cylinders make up the "A" unit with a total heat transfer area of approximately 12 square feet and a rated capacity of 4,500 pounds an hour. The product cylinders are constructed of commercially pure nickel, chrome-plated. Stainless steel is used otherwise, and all fittings and interconnecting piping are sanitary. Refrigeration requirements are 22 standard tons at 15 pounds ammonia back pressure. The system provides for continuous flow of the material from the emulsion premix tank through the print-wrapping operation. It is totally enclosed, and the product is not exposed tc the atmosphere until it reaches the print-forming equipment.

Molten fat and cold milk are brought together in the premix tank, where mixing is sufficient to keep the milk from settling out. The margarine mixture enters the "A" unit at approximately 100°F. and in a residence time of 16 seconds is chilled to about 50°F. At this stage the mixture is quite fluid since it is in a supercooled condition. The "B" unit is 7 in. in diameter and is made up of flanged sections approximately 18 in. long to permit length to be varied in accordance with the physical characteristics of the fat being solidified. While in the "B" unit the temperature rises 10°-15°F., primarily due to latent heat of crystallization. Normally there is no further temperature increase.

The supercooled mass solidifies as it is slowly forced through the "B" unit by the pressure of the feed pump. Actual resting can be obtained by using two "B" units connected in parallel. When one section has been filled, a motor-actuated rotary valve automatically switches the flow of product to the second section. The product in one section remains static until the second section has been filled. The solidified margarine is extruded in noodle form from the unit through a perforated plate located at the "B" unit discharge. This work together with that applied to the product in the feed hopper of the print-forming mechanism is sufficient to produce a margarine which is uniform in structure and color but firm enough to be form-retaining.

The internal structure of margarine manufactured in Votator apparatus following the foregoing procedures is coarser than that of shortening, as can be seen from Figure 11. It is known that for the same solids content coarser emulsions accelerate melting in the mouth with consequent quick release of milk and salt flavors. Considerable research has been carried out in the past decade and is undoubtedly continuing in efforts to improve the physical characteristics of margarine. Several approaches have been followed, and three developments which have been the subjects of patents are of interest. One depends on opening the structure of margarine by dispersing part of the aqueous phase in larger droplets; another selectively crystallizes a high percentage of glycerides melting at or slightly below body temperature; and a third involves growing of large aggregates by churning. Votator apparatus is used in the first two processes.

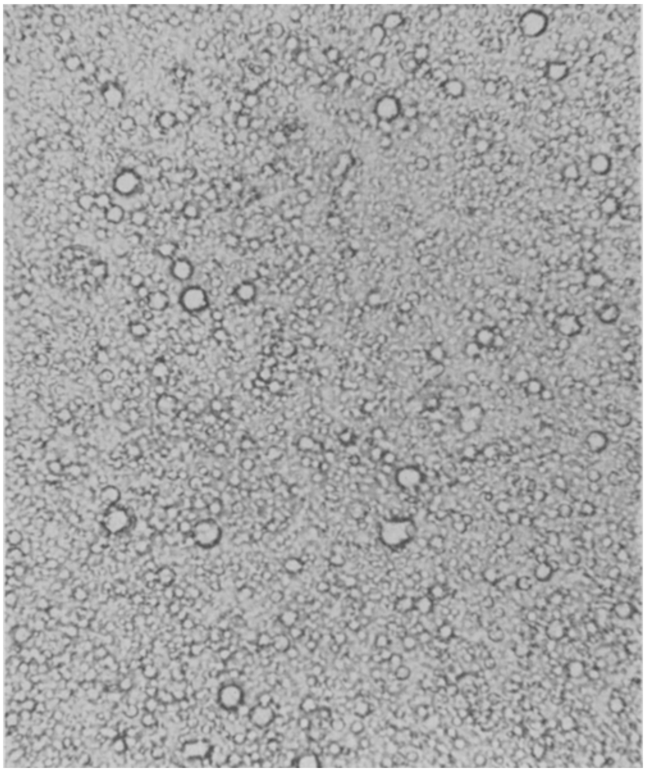

FIG. 11. Photomicrograph of margarine commercially solidified in Votator apparatus (300 × at microscope).

Courtesy of Research and Development Division, Lever Brothers Company

Milk Injection Process. Miller (7) has patented a process for opening the emulsion, wherein part of the milk is proportioned into the chilled emulsion emerging from the "A" unit. A 5-cylinder piston pump of sanitary design serves as the product pump and also as a proportioning device for introducing the milk into the chilled emulsion. In this system all of the fat and approximately 25% of the milk is chilled in the "A" unit. The supercooled fat-milk blend then enters a blender installed between the "A" and "B" units. The blender is similar in design to a shortening "B" unit although it is greatly reduced in size. The shaft is set with pins and rotates at a speed of about 700 r.p.m. As the chilled fat-milk portion enters the blender, it meets a stream consisting of the remainder of the milk containing all of the salt. It is the usual practice to chill the milk-salt mixture (approximately 30°F.) in a coil type cooler prior to blending it with the supercooled fat-milk portion. Mixing action in the blender must be sufficient to keep the aqueous phase from "weeping," a condition encountered when water droplets visibly separate from the mass, but agitation should not be violent enough to disperse the milk-salt mixture too finely in the fat.

The object is to produce two intermixed dispersions of the aqueous phase, one of which is in a very fine state of subdivision as represented by the 25% portion incorporated with the fat while the other phase consists of relatively large water droplets. The source is the milk mixture proportioned into the chilled emulsion. The blender discharges into a quiescent "B" unit fitted with screens or perforated plates to supply work necessary for a homogeneous structure in the finished product.

Precrystallization Process. A recent patent issued to Wilson *et al.* (8) describes a method for improving the quickness of melt and the spreadability of margarine by a method which induces growth of a higher percentage of large size crystals melting at body temperature or slightly below. Essentially the method involves introducing part of the chilled and emulsified mixture discharged from the "A" unit into the warm emulsion entering the "A" unit. Both streams are brought together in apparatus quite similar to a shortening "B" unit, the discharge of which is connected to the chilling cylinder. When used in this manner, the "B" unit is referred to as a precrystallizer. As the stream of chilled fat emulsion is mixed with the warm emulsion of identical composition, it is claimed that the crystals of the lower melting point glycerides melt, leaving a high percentage of crystals that melt at or near body temperature. It is probable that these solids also act as seed crystals and induce growth of larger sized crystals. Internally it is believed that the larger crystallized particles are imbedded in a matrix of minute crystals of lower melting point which hold the liquid components. Because of this, melting in the mouth is claimed to be very rapid and considerably faster than that of margarine manufactured in the conventional Votator system. Spreadability of margarine made by the precrystallization process is also said to be improved at ice box temperature.

Practical ratios of chilled emulsion to unchilled fat and milk mixture are said to lie between 0.5:1 and 1:1. The temperature of the "A" unit discharge may vary from 50° to 60°F., depending upon the composition of the fat blend. The warm fat emulsion enters the precrystallizing unit at approximately 100°F., and the mixed streams enter the "A" unit at a temperature of about 85°F. The portion of the chilled emulsion not returned to the precrystallizing unit is passed through a series of screens described in a recent British patent (9). The screen device is designed in such a manner that obstructions cause sudden changes in direction of flow, thus assuring thorough mixing action and sufficient work to produce a smooth-appearing product. From the screens the worked fat goes to a quiescent "B" unit, the discharge of which is connected directly to the print-forming apparatus.

Steam Injection and Churn Process. In efforts to simulate the fracture and melting characteristics of butter Turgasen (10, 11) has patented a process for margarine solidification that closely follows the churn procedure used in the dairy industry. The process was developed on the premise that each globule of milk fat is coated with loose protective phospholipid-protein film. Lack of film continuity exposes fat surfaces, and during churning globules adhere together at the point of film interruption to form granules.

To accomplish this in margarine Turgasen brings together the melted fat and milk in proportions of about one part fat to two parts milk. The mixture is pumped into a vessel, and steam is injected in the direction of flow. The injected steam raises the temperature to about 250°F. and disperses the continuous oil phase into a fat-in-milk emulsion. The heated mixture is flashed into a vessel held under about 25 in. vacuum, where the dispersion of fat in the milk is completed and a heavy cream-like emulsion is obtained. The emulsion is cooled over a milk cooler to a temperature well below the melting point of the fat. At this point milk cultures may be added to the cooled emulsion for flavoring purposes.

The emulsion is then agitated in conventional butter churns at a temperature favorable to aggregation of the fat globules. When the aggregates reach a specific size, the emulsion suddenly breaks, and the fat separates into a plastic mass containing about 14% moisture. The excess milk is drained off and the aggregates washed with cold water. Adjustments are made to bring the moisture content to the standard figure, salt is added, and the mixture is churned until the desired body and texture are obtained. The product is removed from the churn and is placed in trucks which are held under controlled temperature conditions for several hours prior to packaging.

In 1952 4,220,000,000 pounds of lard and vegetable oil shortenings were produced in the United States; probably well over 95% of this total was commercially solidified. In the same year margarine production was 1,271,000,000 and for the first time exceeded the pounds of butter sold. Long-range forecasts indicate a steady increase in margarine consumption. It is certain that the solidification process has contributed heavily to consumer acceptance of these products, for no matter what system is used for plasticizing edible fats, each one has as its objective an improved product quality. Further advances can be expected from the application of the ever increasing knowledge of the chemical and physical structure of fats and oils to the solidification process.

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The Basket Extractor—The Universal Extractor

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The basket extractor originated in Germany, and its design is one of the most successful exports from that country. In this country the basket type of extractor was early adapted and perfected to an unusual degree for the particular requirements of the solvent extraction industry. It has been modified in many ways and is still the most satisfactory and most widely used of the many types of extractors. About 40% of the cottonseed tonnage that is extracted in this country is handled in basket extractors. Over 70% of all the soybean tonnage that is extracted is handled in basket extractors, and the figure is at least 70% for corn germ and 80% for flaxseed. The basket extractor handles a great deal more tonnage of oil seeds in this country than all other types of extractors combined. There are currently seven basket extractor installations in various stages of construction in the United States, out of the total of nine or ten such active projects that exist at this time. Apparently basket extractors are maintaining their predominant position in the oil seed extraction industry.

R. P. Hutchins

Such popularity of one type of extraction system merits a close look at its advantages, which are: a) an unusual degree of mechanical perfection, b) low maintenance, c) maximum number of operating days in a year, d) miscella clarity, e) efficient extraction, f) universal application, and g) low operating costs.

The basket extractors have been perfected to an unusual degree because of their wide application. A large number of skilled engineers of leading oil seed processors in this country have applied their best thoughts to mechanical and processing improvements. It is seldom that a single machine is applied, corrected, reapplied, and recorrected again and again as this machine has been. This mechanical improvement has resulted in an extremely low maintenance cost and also results in a maximum number of operating days in a year, or a minimum number of days required for maintenance.

The miscella clarity is an advantage that apparently is little understood by many processors. Miscella clarity is a relative term and is often discussed in relation to counter-current or immersion types of extraction systems in which a great reduction in fines in miscella is claimed but which is completely out of range of the discussion when basket extractors are referred to. For instance, an installation of two ex-