hopeful of providing a stimulus to more thought and more research. We are very glad to see more literature appearing on the subject of margarine, especially new books on the subject such as that by Anderson, previously referred to, and that by M. K. Schwitzer, just recently announced. We feel that there has been a dearth of literature on this important subject and that these books will be a very valuable contribution to the field of food technology.

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Finishing and Packaging of Edible Fats

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Theoretical Considerations

Definition and Description of "Plasticity." A solid exhibiting plastic properties may be defined as one which appears to be rigid when subjected to limited deforming stress, yet when the deforming stress increases beyond the yield point, it flows considerably like a viscous liquid. In the case of plastic fats Bailey (1) has described three essential conditions.

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1. There must be two phases, one a liquid, and the other a solid.
2. The solid phase must be finely dispersed to the extent that the mass is held together by internal cohesive force.
3. The two phases must be present in the proper quantities.

If solids are deficient, not enough crystals are present to hold the liquid oil entrapped in the lattice of crystals. If liquid is deficient, the fat is brittle and will tend to break rather than flow when deforming stresses are applied beyond the yield point.

The Structure of Plastic Fats. The photomicrograph shown here (Figure 1) exhibits the structure of a plastic fat. It consists of very fine discrete crystals, no more than a few microns in length, forming a lattice work in which liquid oil is entrapped and held there by surface tension. The large cells you see are the air cells incorporated in this commercial shortening. Plastic fats at the temperature at which they are normally used usually contain from 10 to 30% of solids. This fairly wide range is the result of differences in formulation. The two most important factors governing the consistency of a plastic fat are the number and size of the crystals and the viscosity of the liquid.

The Effect of Glyceride Composition. The commercial plastic fats are made up of a mixture of glycerides which, individually, melt at widely varying temperatures. This range will be from about —40°F. to about 150°F. for the highest melting component. This mixture gives a satisfactory plastic range, with the average melting point just a few degrees above body temperature. A satisfactory plastic range may be defined as a range of temperature at which the fat may be used with good results.

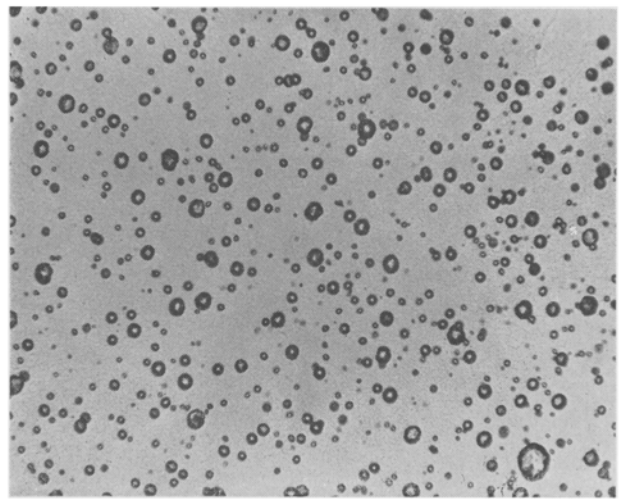

FIG. 1. Photomicrograph of a plasticized hydrogenated oil shortening (100 × at microscope).
Courtesy, Research and Development Division, Lever Brothers Company.

Fats which have sharp melting points consist of glycerides in which the saturated portion consists largely of a single class. Examples of this type of fat are cocoa butter and coconut oil. Under certain conditions of hydrogenation other vegetable oils may approach this behavior, for example, margarine oil, so hydrogenated as to have a high percentage of solid unsaturates, commonly known as iso-oleic acids. This imparts the desirable quick melting in the mouth to release milk flavors in the product.

Interesterification, or rearrangement of a mixture of glycerides, has an important effect on the consistency of the plasticized product. This is a subject of such scope that it can only be mentioned here. Consider the fact that a mixture of triglycerides will usually contain stearic, palmitic, and unsaturated fatty acids, then in a truly randomly distributed fat the distribution of the fatty acid radicals will be in accordance with the law of probabilities, based on the percentage of each component. Many natural fats, notably lard, do not have such random fatty acid distribution. The effect of random rearrangement in lard is to improve its plasticity and baking properties. Ordinary lard has the property of forming relatively large crystals, even when rapidly chilled and plasticized commercially, whereas the rearranged lard forms small crystals when processed in this manner, very similar to the structure found in hydrogenated vegetable shortenings.

Directed interesterification differs from random interesterification in that the reaction is carried out at a temperature below the melting point of the fat. Under these conditions the trisaturates precipitate out of the reaction zone as they are formed, upsetting the equilibrium and driving the reaction toward the formation of more trisaturates than are formed in random rearrangement. This has a marked effect on the consistency of the plasticized finished product. Hawley and Holman (2) described in detail the commercial process.

The Effect of Crystal Size. When once a crystalline structure is attained in a fat, it appears that nothing short of complete melting and recrystallization will change the pattern of the structure. However during the tempering of a shortening it is postulated that the make-up of the individual crystal may change with respect to the saturated and unsaturated fat molecules in the crystal.

In general, a solidified fat allowed to cool and crystallize slowly in a static condition will have fewer and larger crystals than if it were cooled and crystallized rapidly. The slowly crystallized fat will be softer than the rapidly crystallized fat. The quick-chilling method is invariably followed in the commercial production of plastic fats. In this way a firmer product can be made with a given solids content, at a temperature in the normal usage range, with no change in the melting point.

The Effect of Supercooling. Because of the fact that fats are polymorphic the solidification and plasticizing of them requires careful control. The conditions of supercooling have a very marked effect on the consistency of the product at the temperature at which it is normally used.

An extreme example of what differences can be brought about in consistency of a compound type shortening by persistent supercooling is the following:

> If the molten fat is rapidly chilled in equipment such as "Votator" shortening apparatus to a temperature of about 65°F., passed through a "B" unit or worker, and packaged at the usual packaging temperature of about 75 to 80°F., it will quickly set and resemble an all-hydrogenated shortening with respect to plastic range, perhaps have a wider plastic range. If, on the other hand, the same fat is rapidly chilled in the same equipment to about 40 to 45°F., packaged at low temperature, and stored at 40 to 45°F., it will be so liquid as to pour. If this product is then stored at 85°F., it will gradually come to about the same consistency as the product rapidly chilled to the usual temperature of about 65°F. A possible explanation is that because of the polymorphic nature of the fat, the lower melting unstable type of crystal is formed and maintained. When the storage temperature is raised, due to partial melting and recrystallizing, the higher-melting, more stable crystalline form results, and the product can then withstand quite wide variations in temperature and still be a workable plastic shortening.

In commercial practice the temperature to which a fat is supercooled, worked, and packaged is controlled so that the product has the widest possible plastic range for a given formulation.

The Effect of Mechanical Work During Crystallizing. If a supercooled fat is allowed to solidify without agitation while crystallizing, it will be quite firm and have a narrow plastic range. Also it will not have the desired smoothness of texture and appearance.

Without mechanical work the supercooled fat will, upon crystallization, form a lattice work of somewhat longer crystals, so interlocked as to give a structure of greater strength than the same amount of crystals broken into smaller discrete particles. So it is important to the manufacturer of plastic fat products to provide means for working the fat while it is crystallizing from the supercooled state.

In the case of margarine the working of the supercooled emulsion is held to a minimum, primarily to have a product sufficiently firm to be handled in the packaging equipment. Other important considerations are to prevent too fine a dispersion of the aqueous phase and to induce larger crystal formation. This latter prevents a "waxy" sensation in the mouth and hastens the liberation of the aqueous phase which contains the milk flavors.

The Effect of Tempering. The exact mechanism of the process known as tempering is not known. In a system containing many components of different melting points, equilibrium is difficult to establish. In these systems where we have solid solutions, the crystal composition varies. We attempt to hasten the attainment of equilibrium by storing the plasticized fat product, such as shortening, at a temperature somewhat higher than the temperature at which it was packed. Bailey (3) characterizes the process as an "unmixing" operation, that is to say, when plastic fats are stored at tempering temperatures slightly higher than packing temperature, there is a partial melting of the low melting components followed by slow recrystallizing of other glycerides in a stronger and more homogeneous crystal structure.

Whatever the mechanism, tempering a plastic fat product like shortening extends its plastic range. It also improves the creaming qualities of the shortening. The tempering time required varies primarily with container size but also with formulation. Lard and compound type shortenings require less tempering time than do the hydrogenated vegetable shortenings.

The Effect of Gas Incorporation. Commercial plasticized shortening agents all contain from 10 to 15% air or nitrogen. The reasons for this are several.

1. It improves texture.
2. It makes for homogeneity.
3. It makes the product less dense, and hence easier to handle.
4. It contributes a substantial part of the leavening gas in the course of baking.

Operating Procedures

Plasticizing of Lard and Shortening. One of the early methods of plasticizing lard and shortening involved the use of a chill roll which was internally refrigerated by circulating cold brine through the chill roll. The liquid lard or shortening was fed into a trough which supplied feed to the roll. A thin film of the liquid feed was picked up by the roll as it revolved and was crystallized to a semi-solid state in the course of a portion of one revolution. A doctor blade removed the film of chilled fat in the form of a sheet which fell into a trough known as a picker box. This trough was equipped with a rotating shaft, upon which were mounted fingers or paddles to whip the lard or shortening to make it homogeneous and to incorporate air. In some cases two picker boxes in series were employed, and in other cases a single one. The lard or shortening was then picked up by a pump and delivered to the filling machine where the product was packaged. This process has now become obsolete except for a few specialty products. The reason of course is that the variables mentioned above were too difficult to control properly to give a uniform finished product.

Probably 90% of the plasticized lard and shortening produced in the United States and Canada is made in closed continuous systems employing Votator equipment. Such systems permit very close control of all of the variables which effect the texture and plasticity of these products that stem from the method and conditions of the plasticizing operation. Figure 2 shows a longitudinal and cross-sectional view of the Votator scraped surface chilling unit known as an "A" unit. The principles of operation of this unit are no doubt known, and it is sufficient to mention that the combination of chilling the fat in a very thin film and the removal of that film by the scraper blades results in very high over-all heat transfer coefficients and very close control of the temperature to which the fat is chilled. The high degree of agitation during the chilling makes a very homogeneous chilled fat. The rotational speed of the shaft in this unit is between 500 and 700 r.p.m.

In the chilling of such plastic fat products as lard and shortening there is a critical shaft speed. When these products are chilled, there is a rapid increase in solid content and a coincident increase in viscosity of the liquid. When this critical speed has been reached, no additional mixing is obtained. To rotate at higher speeds will require more power and offset heat transfer benefits resulting from more frequent scraping of the cylinder wall.

Figure 3 is a flow diagram of a Votator system for plasticizing lard and shortening. This diagram happens to represent a system with a nominal capacity of 10,000 lbs. per hour. Other systems are available for 3,500 and 5,000 lbs. per hour. A brief

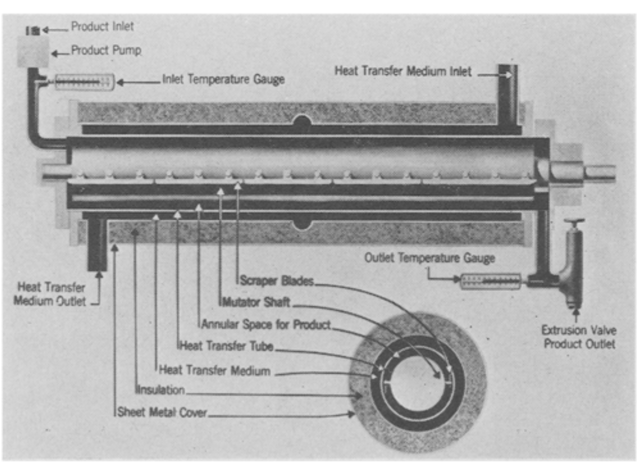

FIG. 2. Longitudinal and cross-sectional view of Votator chiller for edible fats.
The Girdler Company.

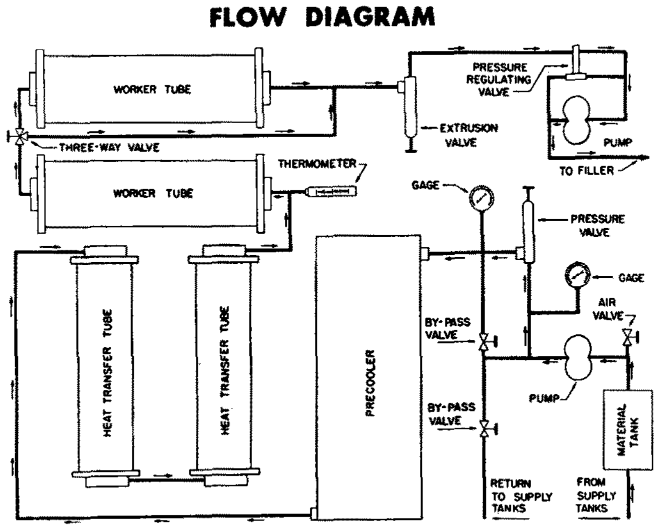

FIG. 3. Votator system for plasticizing lard and shortening.
The Girdler Company.

description of this plant follows. The liquid lard or shortening is kept in the holding tanks at a temperature of about 125 to 140°F. This liquid fat is delivered to a small feed tank which is equipped with a level control. Then it is moved by a gear pump through a water-cooled pre-cooler where the temperature is reduced to about 110 to 120°F. The use of the pre-cooler insures that the material entering the Votator "A" unit or chiller is at a constant temperature, and it provides a large number of crystal nuclei in the fat as it is introduced into the "A" unit. It also reduces the heat load in the "A" unit.

Air, or preferably gas, such as nitrogen, is introduced into the liquid oil at the suction side of the product pump in precisely controlled quantities. A pressure regulating valve is supplied on the discharge of this pump to maintain a constant pressure throughout the solidification system. The pre-cooled fat, together with the incorporated nitrogen or air, is introduced into the "A" unit where it is chilled to about 60 to 65°F. during a residence time of approximately 18 to 20 seconds. In this case there are two chilling cylinders in series for this high production rate of 10,000 lbs. per hour. In the smaller sizes only one chilling tube is required.

The semi-liquid, cooled fat then passes directly into the worker unit called a "B" unit. Stationary fingers are attached to the cylinder walls and other fingers are affixed to the shaft in spiral fashion and intermesh with the stationary fingers. As the supercooled fat starts to crystallize, considerable heat is liberated and this unit dissipates the heat very rapidly, at the same time working the fat to provide the very fine crystals which are desirable in products of this kind. It is desirable to dissipate most of the heat of crystallization, but not quite all of it. Some temperature rise in the package is desirable to assure rapid setting of the finished product in the tempering room. The temperature rise in the package should be about 1 to 2°F. The worked fat from the "B" unit passes through an extrusion valve which makes an homogeneous product, is picked up by a pump, and is delivered to the filling station at about 300 to 400 p.s.i.g. At the filling station it passes into another extrusion valve into the filling machine or into the drum as the case may be. This system has the following advantages over old chill roll system: no exposure of the product to air during process, positive control of gas incorporation, positive control of temperatures and pressure at critical states in the process, and relatively small heat losses. These advantages result in a product which is more uniform in color and texture, a product which is completely homogeneous, and one which is more stable.

The Solidification of Margarine. The trend in the production of margarine is toward a product which spreads easily at ice box temperatures and yet is form-retaining at room temperature. The manufacture of margarine to meet these requirements is more a function of the formulation and control in the hydrogenation step rather than in the solidification and finishing of the product. These so-called "soft" margarines do pose problems in the solidification step which requires very close control of the critical steps in that process.

Here again, about 90% of the margarine made in the United States and Canada is produced with Votator continuous processing systems. The chilling step is similar to that employed in the manufacture of plasticized lard and shortening. The subsequent steps however are different. Even though there is considerable water present in margarine, the product is amenable to supercooling because the fat is the continuous phase. The supercooled emulsion is allowed to crystallize in an almost static condition in order that the product is not too soft to be handled, extremely fine dispersion of the aqueous phase is prevented, and the growth of larger crystals in the product is induced.

If margarine were worked like shortening, a long tempering period would be required before it could be handled in the print forming and wrapping machines. As a matter of fact, when margarine was packed in the so-called squeeze bag, a shortening "B" unit was employed in the place of the regular margarine "B" unit. A simplified flow diagram of a Votator margarine system is shown in Figure 4. This system happens to be one with a nominal capacity of 4,500 lbs. per hour. There are other smaller capacity systems. In this case there are three chilling units, or "A" units, and a divided "B" unit. Because of the presence of moisture and salt sanitary fittings are used throughout the plant and the material-contacting parts of the Votator chiller are made of commercially pure nickel, chrome-plated.

The liquid margarine oil and cold milk are mixed in a pre-mix tank to make a loose emulsion. The oil-soluble additives, such as vitamin and lecithin, are in the fat phase and water-soluble ones such as the salt and preservatives are in the milk mix. This loose emulsion is maintained at about 100 to 105°F. and is introduced in the "A" unit, where it is chilled to about 50°F. in a residence of approximately 16 seconds. From the "A" unit it passes to the "B" unit, which is simply a tube about 7 in. in diameter, made up in flanged sections so that the required length for setting can be attained by adding sections or taking out sections to give it the desired residence time, which depends upon formulation. The supercooled mixture is allowed to set in practically a static condition, and the temperature usually rises from 10 to 15° during this tempering period. The feed pump forces the product through the entire system and into the hopper of the print-forming machine. The discharge from the "B" unit is usually through a perforated plate so that the margarine falls into the print-forming hopper in the form of noodles. It is then picked up by the feeding screws of the print-forming machine and forced into the volumetric forming chamber. The noodling and the work imparted by the screws is sufficient to insure uniformity of texture and color but not so much as to make it too soft to handle in the printing machine.

In margarine it is desirable to have a comparatively loose structure with large crystals so that when taken into the mouth it melts quickly, thereby releasing the milk and salt flavor.

Controlling the structure of margarine to achieve these desirable features has been the subject of much research. A Miller *et al.* patent (4) describes a process for opening the emulsion, which features proportioning a portion of the milk into chilled emulsion coming from the "A" unit. A five-cylinder piston pump proportions the milk into the chilled emulsion as well as serves as a production pump which forces the milk through the entire system. The mixture of chilled emulsion and milk then passes through a small blender, which is similar in design to a very small shortening "B" unit where homogeneity is attained, then it passes to the quiescent "B" unit and out through screens or perforated plates to the packaging equipment. In this way that portion of the milk which is introduced after the "A" unit is dispersed in relatively large globules as contrasted with that which is introduced with the fat which goes through the "A" unit. It is claimed that this releases the milk flavor much more rapidly than the conventional method of processing.

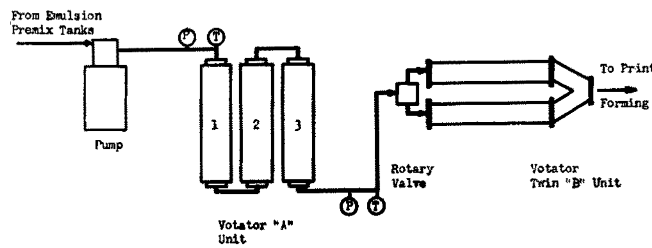

Fig. 4. Simplified flow diagram Votator margarine process.

A Wilson *et al.* patent (5) describes a process for improving spreadability and quickness of melt which features large-size fat crystals which melt at body temperature or slightly lower. A portion of the chilled emulsion discharged from the "A" unit is recycled back into the warm stream before it enters the "A" unit. In the recycle operation the warm stream and the chilled stream pass through a blender similar to a small shortening "B" unit and then into the "A" unit for complete chilling. It is claimed that the lower melting crystals in the chilled stream are melted by the warm stream, leaving a high percentage of crystals that melt at or near body temperature. These crystals serve as nuclei which will promote the growth of larger crystals. It is believed that the larger crystal particles are imbedded in a matrix of small crystals of lower melting point, which holds the liquids. The chilled portion enters this pre-crystallizer at a temperature of about 50 to 55°F. while the warm stream is about 100°F. The mixture enters the "A" unit then at about 85°F. The chilled material which is not recycled passes through screens or plates to give the product some amount of work and then is allowed to set in the quiescent "B" unit before going to the printing and packaging machine.

A Turgasen patent (6) describes a process which does not use the closed continuous internal chiller. It resembles the churning procedure used for making butter. Melted fat and milk in a ratio of about 1 part fat to about 2 parts milk are pumped into a tank; steam is injected into the line in the direction of flow. This steam injection raises the temperature to about 250°F. and disperses the oil phase into a fat-in-milk emulsion. This mixture is introduced into a vacuum vessel where the emulsification action is completed and a heavy creamy emulsion results. This emulsion is cooled, employing a regular milk cooler, to a temperature below the melting point of the fat. This emulsion is then churned in conventional butter churns at a temperature favorable to the aggregation of the fat globules. When the aggregates reach the proper size, the emulsion breaks and the fat separates into a plastic mix containing about 14% water. The excess milk is drained off, and the fat portion may be washed with cold water. The moisture content is adjusted, salt is added, and this plastic product is churned until the desired texture is obtained. The product is then removed from the churn, placed in trucks, and tempered for several hours before printing and packaging.

The Packaging of Edible Fat Products. In the case of lard and shortening, fillers are positive displacement volumetric machines. They are made in a high-pressure type and a low-pressure type. The high-pressure type fillers employ a pump which fills a calibrated cylinder and, with the proper valving, forces the product out of the cylinder by the incoming product on the opposite side of the piston. At the completion of the stroke the action is reversed. The product is delivered through an extrusion valve to the package. The low-pressure type filler also employs volumetric displacement, but it does not rely on a product pump to operate the measuring cylinders. This type of filler employs a rotating table onto which the empty tin is fed. A feed hopper rotates above it. The plastic feed is delivered to this hopper at about 300 to 400 p.s.i.g. and is discharged into this hopper at substantially atmospheric pressure through an extrusion valve. The hopper is equipped with stationary plow-type arms to prevent the fat from setting up. The measuring cylinders are located in the bottom periphery of the hopper and deliver an exact volume product through the operation of a cam-actuated piston. Many manufacturers fill the outage of the can with nitrogen to improve the keeping quality of the product by excluding oxygen from the package.

When filling bulk packages, it is customary to fill from the "B" unit directly into the package through an extrusion valve with the package resting on a scale.

In the case of margarine a very high percentage is packed in quarter-pound prints individually wrapped and placed four to a carton. The machine for accomplishing this involves twin screws which force the product into the measuring and forming chamber, from which it is removed and wrapped and automatically packaged four to a carton which may or may not be over-wrapped with paper, foil, or cellophane. In the last few years there have been many improvements in the packing of margarine for protection of the product and for consumer eye-appeal.

There have been no fundamental changes in the process of solidifying and plasticizing edible fat products in the past few years. Rather, product improvement has come from other processing steps, such as bleaching, hydrogenation, interesterification, deodorization, and improved methods of control.

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Fat-Splitting

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FAT-SPLITTING OR HYDROLYSIS is the term applied to the operation in which a fat or oil is reacted with water to form glycerine and fatty acid. The splitting process is important commercially because of the extensive use of fatty acids in preparing soaps, synthetic detergents, plasticizers, coatings, greases, and many miscellaneous organic derivatives. Although in soapmaking and certain other uses either fats or fatty acids can be used for the same purpose, the initial conversion of fats to fatty acids has the advantage of allowing the upgrading of poor stocks by distillation. Various physical separations of the fatty acids can also be carried out to give special properties to the products made from them.

Hydrolysis Reaction

Hydrolysis is a reversible reaction which will approach completion only if a large excess of water is used or if one of the products can be removed from the reaction mixture. In certain continuous processes