Chilling and Crystallization of Shortenings and Margarines

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Shortening is an American invention growing out of the cotton raising industry. The first shortenings were prepared by blending refined and deodorized cottonseed oil with sufficient oleostearine, or other hard animal fat, to stiffen it to the approximate consistency of lard.

Introduction of catalytic hydrogenation into the United States about 1910 made the shortening manufacturer independent of the meat packing industry and initiated a new era into the manufacture of shortening.

A fat such as lard or shortening appears to be a soft, homogenous solid. Actually, it consists of a mass of small crystals within which is a considerable portion of liquid oil. The crystals are not joined to form a continuous structure, but each crystal is a separate and discreet particle, capable, under the proper shearing stresses, of moving independently of the other crystals. Thus, the fat has the characteristic structure of a plastic solid.

The distinguishing feature of plastic substances is their property of behaving as solids by completely resisting small stresses, but yielding at once and flowing like a liquid when subjected to deforming stresses above a certain minimal value. A firm, plastic material will not flow or deform of its own weight. However, it may be easily molded, by slight pressure, into any desired form.

The three conditions essential for plasticity are: (a) the material must consist of two phases. One of the phases must be solid, whereas the other must be a liquid; (b) the solid phase must be in a state of sufficiently fine dispersion for the entire mass to be effectively held together by internal cohesive forces. The solid particles must be small enough for the force of gravity on each to be negligible in relation to the adhesion of the particle to the mass, and the interstices, or openings, between the particles must be so small that there is negligible tendency for the liquid phase to flow or seep from the material; (c) a proper proportion must exist between the two phases. The solid particles must be few enough that the mass can flow without these particles forming interfering clots or jams. At the same time, the solid particles must not form a rigidly interlocked structure.

The hardness or firmness of any plastic is a function of the stress required to cause it to yield and flow. The predominant factor affecting this value is the volume ratio of the solid to the liquid phase. The greater the proportion of solids, the greater is their opportunity to touch and interlock, and the firmer the material. The upper limit of the solid phase is ca. 52% by vol. The lower limit varies considerably with the size of the particles and the character of the material, but generally is within the range 5-25%.

Another factor influencing the firmness of a plastic material is the size of the solid particles. With other factors constant, the material will become progressively firmer as the particle size decreases because of increasing opportunity for the particles to touch and of increased friction to be overcome in causing it to flow.

Fats also vary greatly in consistency with changes in temperature, becoming progressively firmer as the temperature decreases and softer as it increases.

The oldest apparatus for the solidification of lard and shortening is the chilling roll. It consists of a large, hollow, iron cylinder with a surface that is machined and ground smooth to true cylindrical form. The roll is internally refrigerated by the direct expansion of ammonia or other refrigerants. Turning slowly on its longitudinal, horizontal axis, the roll picks up on its surface a thin coating of the molten fat from a trough which bears against it and runs its full length. The temperature of the fat supplied to the roll varies, but it is never much above the solidification point of the fat. A blade is used to scrape off the solidified fat in the form of a thin, translucent plastic sheet. The solidified fat then drops into a picker-box, which is a trough bearing a screw conveyor. The flights of the conveyor are interspersed with blades which revolve in the partially filled trough and beat air into the fat. From the picker-box, the fat is fed into a high pressure pump, which forces it through various devices, e.g., orifices, slots, screens and valves, which create intense shearing forces, thus breaking up any aggregates of material and dispersing air throughout the mass.

The roll system of solidification generally is unsatisfactory and has been replaced by the common Votator system. With this system, molten fat is precooled slightly, then introduced under pressure with a feed pump into a refrigerated, scraped-surface heat exchanger called an "A" unit. Here, the product is rapidly chilled to ca. 15-25C, depending on the type of fat. Also customary is to whip into the fat ca. 5-25% of its own vol. of air. This air is introduced from the suction side of the product feed pump.

The supercooled fat then passes through one or more worker tubes, or "B" units, where the fat crystals are subjected to a shearing action while the heat of crystallization dissipates.

From this point, the product may pass through an extrusion valve and on to the filler, or it may be subjected to an additional special scraped-surface heat exchanger, a "C" unit.

The advantage of the process using the C unit is that the posttempering period normally required for the product to reach complete solidification can be considerably shortened. In most instances using the C unit, equilibrium is reached within 8 hr after filling, whereas it can require up to 4 days to reach equilibrium for the same shortening in conventional processing.

The final temperature range of the chilled and crystallized product is 13-24C.

Margarine was invented during the Franco-Prussian War by the French chemist Mége-Mouriés. In 1870, it won the inventor a prize offered by Napoleon III for a satisfactory butter substitute. Shortly thereafter, it appeared in a number of other countries, including the United States.

Originally, margarine was made with fat and milk; however, today's margarine may be made with fat and 100% water, rather than milk.

Milk or water in combination with fat alone does not have sufficient surface-active materials to produce an emulsion of the same stability as that existing in butter. Probably the first emulsifying agent to be used in margarine was egg yolk, but this has been essentially replaced by lecithin and synthetic emulsifying agents.

There is, perhaps, no plastic fat product in which the matter of consistency is of such importance as in margarine. One essential quality of table margarine is that it melts readily and completely in the mouth. In this respect, there is a marked difference between margarine and shortening. Shortenings are invariably consumed in the molten form in various hot dishes, or else finely dispersed in pastries; however, stick margarine, like butter, usually is spread on bread and taken into the mouth in more or less gross portions. At ordinary temperatures, margarine should be plastic and should spread freely. At refrigerator temperatures, however, it is desirable for most margarines to be quite hard and firm.

The consistency of margarine is principally dependent on the processing techniques employed and on the fats used in its manufacture. It is influenced little by methods of emulsifying the product or by variations in the relative proportions of milk and fat.

The original method of solidifying the emulsion of milk and liquid fat in margarine making was by continuously pouring, or spraying, the emulsion into a trough, or vat, of cold, running water. The emulsion entered at one end of the vat and by the time it had reached the other end, it had solidified and floated onto the surface of the water in the form of a flaky mass which was then skimmed off.

Later, the chill roll was adapted, essentially following the same techniques as used for the solidification of shortening.

Today, of course, the Votator system is the most commonly accepted method of chilling and plasticizing margarines. The chilling unit is basically the same as that used for shortening; however, for table margarine, the worker-type B unit is replaced with a quiescent B unit to allow the emulsion to solidify so that it can be formed into a firm print. When producing soft margarine, a working B unit, similar to those used for the production of shortening, may be used to extend the plastic range of the product.

The Votator shortening plasticizing system is widely accepted by the industry and has changed little in the last 30 years.

In Spring 1979, the Groen Division of the Dover Corporation embarked on a new approach to the chilling and crystallization of shortening. The process uses their Model #DR(C) Scraped Surface Heat Exchanger (Fig. 1) for chilling the fat and commercially available static mixers for imposing the necessary shearing action on the fat crystals. They make a product quite similar to that produced by Votator's elaborate system requiring a worker tube and high pressure orifice systems. Groen has applied for a process patent on this novel system.

The new Groen process involves the replacement of a complex, high pressure system by a static mixer with no moving parts to accomplish the same end. The #DR(C) Scraped Surface Heat Exchangers are manufactured in a wide range of sizes, so that one heat exchanger can handle up to 11,350 kg (25,000 lb)/hr. This results in dramatic energy savings. For example, a Groen 11,350 kg (25,000 lb)/hr shortening plasticizing system, exclusive of product pump, requires a single 10 HP motor to drive the single heat exchanger rotor. A comparable conventional shortening plasticizing system would require over 50 HP to accomplish the same end. Electrical energy costs are reduced by 80%. In addition, the Groen system requires less than half the floor space of the conventional system.

Another novel feature is the refrigeration system. In conventional, scraped-surface cooling equipment, refrigeration is accomplished by a large volume, flooded jacket. The liquid ammonia is literally a boiling pool surrounding a central chamber of product. As heat is absorbed from the product,

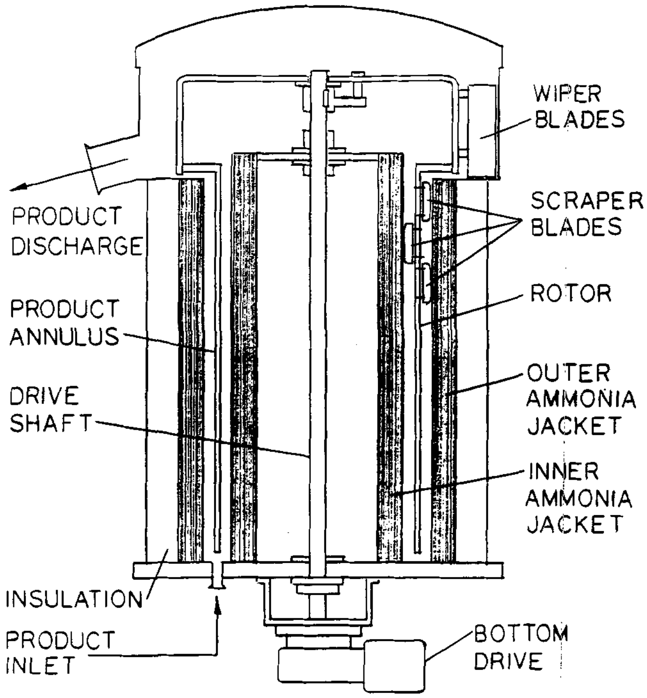

FIG. 1. Groen DR(C) series scraped surface heat exchanger.

causing the ammonia to boil, any oil that is entrained in the ammonia is concentrated and left behind, usually in the bottom of the oil leg. This is an old practice dating back to the late 1880s. Heat transfer is moderately effective, but is reduced by the lack of motion of the refrigerant over the heat transfer surface and by the formation of insulating bubbles.

An additional factor in the flooded ammonia system is maintenance. Oil has to be drained from the equipment periodically, and some ammonia always escapes. During clean-up, the refrigerant has to be removed from the barrel of the heat exchanger in some fashion to allow the surfaces to be properly heat-sterilized. The Groen System provides the higher efficiency of the modern pump-recirculated ammonia refrigeration system. Instead of flooding a large volume jacket, liquid ammonia is introduced to numerous, very thin jackets, surrounding the product channel on two sides. The liquid ammonia boils violently as it is forced through the thin film evaporator, carrying any entrained oil with the ammonia, and returns the oil to the refrigeration system suction accumulator, where it can be automatically recovered or dumped, depending on the design of the central refrigeration system.

Heat transfer is dramatically improved. The space taken up in the plant is reduced, the complexity of the refrigeration system is reduced, and, perhaps most important, maintenance requirements are reduced or eliminated.

An additional advantage is that a small amount of ammonia is required, and with the control panel, it is easy to apply hot ammonia gas to the evaporator to either warm the heat transfer surface to free a stuck rotor (which can happen in a system upset), or, to rapidly pump the refrigerant out of the heat exchanger during clean-up.

A 680 kg (1,500 lb)/hr shortening and crystallizing unit similar to that just described, was installed in a plant in Chicago where it produced commercial products for ca. 60 days. Based on this demonstration, a 11,500 kg (25,000 lb)/hr system has been ordered.

PROCESSING—Summary of discussion

SESSION IIA

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Panelists were A.G. Gonzalez-Uriarte, K. Bader, W.M. Barger, Phillipe Van Dosselaere, D. Mendizabal, R.D. Moen, G.R. Thomas, L. Shoemaker, V. de Oliveira Shurmann and Chairman Frank Khym, all of whom had been introduced earlier in Plenary Session II or as a speaker in Round Table Discussion II A.

Phillipe Van Dosselaere opened the session with a paper on the storage of soybeans under a controlled atmosphere. He emphasized minimal humidity requirements of some stored-products insects and gave data on the consumption of nitrogen during purging of wheat bulks as affected by filling ratio in bins. He also discussed insect kill, utilizing carbon dioxide with exposures to 14 days and at varying concentrations.

Germination of soybeans and its modifying effects on the quality of full-fat soya flour was discussed by D. Mendizabal. The advantages of the process were evaluated by determining protein dispersibility, trypsin inhibitor, lipoxygenase activity, milling capacity and flavor scores during the different stages of the process. The study confirms the works of earlier researchers—i.e., that germination improves the quality of full-fat soya flour for food applications.

Near infrared reflectance spectroscopy instrumentation, and its applications in a soybean processing plant for better quality control, was discussed by R. Moen. Examples were given on how protein levels are monitored to provide information about the performance of the process.

The art of soybean meal and hull grinding was discussed by G.R. Thomas. This process step may be considered an art rather than a pure science, due to the need to properly blend all of the factors involved to produce the desired finished product. The grinding of soya meal as a protein supplement to animal feed is best achieved by using a side-fed mill, with plenty of air throughput and a large screen area. However, for the fine grinding of soya meal or isolate products (50 mesh or finer), an impact turbo mill with closely controlled clearance is generally used. Soybean hull grinding requires a mill with a high hammer tip speed, wear-resistant grinding elements, good air flow, and again, a large screen area.

Solvent safety in soybean extraction was discussed by L. Shoemaker. Nonflammable solvents other than hexane were mentioned, and reasons were given as to why these have not been used in the soybean industry. Normal hexane has the best compromise of solubility, low latent heat of vaporization, and boiling point range. Until another solvent that is not flammable meets these requirements, we will continue to have to work with the hazards of flammable solvents. The use of inert gases during the shutdown process, the explosive range of hexane in air, static electricity, and fire-fighting equipment were areas emphasized. A thought provoking comparison dramatizing the potential hazards of hexane was given by the speaker, who stated that 20 gallons of hexane is equivalent to 1 lb of TNT in explosive power.

SESSION IIB

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A wide range of intense interests was shown in round table papers on processing. The bleaching operation was reviewed not only in regard to classical refining, but was also discussed in regard to its role in physical refining, in pre- and post-hydrogenation steps, and in relation to energy and other economic factors.

Preliminary experiments are raising new questions concerning selectivity of nickel hydrogenation catalysts as affected by the concentration of catalysts. The effects of variations in the oils to be hydrogenated upon catalyst selectivity were also observed. Extensions of the results presented may be expected at future meetings of the AOCS.

In addition to these theoretical considerations of hydrogenation, practical application of the hydrogenation unit operation was discussed particularly in relation to the characteristics of nickel hydrogenation catalysts that are critical in plant practice.

Physical refining (steam refining) seems to hold numerous advantages over classical caustic refining in terms of economics and in directly yielding free fatty acids (85%), which are immediately marketable.

Novel twists in the time-honored methods of chilling and crystallization appear to be on the horizon. New designs, static mixers and simplified refrigerant systems are among the features to be incorporated in unit operations of the future.

Soybean oil of high quality can be and has been produced by a small plant in Venezuela for over a decade and this success should encourage other small business operations throughout Latin America to turn to soybeans as a reliable source of raw material.

Whereas the use of soybean oil in inedible applications amounts to less than 5% of its consumption in the United States, there are expanding outlets for soybean oil as a source of industrial chemicals, and new research products