Margarine and Margarine Oil, Formulation and Control

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ABSTRACT

The formulation and control of margarine and margarine oils is based primarily on an understanding of the relationships between specific physical measurements and the compositions of the oils blends and their components, and secondarily, on an appreciation of processing effects. Desirable solids-to-liquid ratios are achieved by blending and hydrogenation control. Oils are chosen for their peculiar crystal habit resulting from conditions of processing both as oils, for components, and as a finished margarine product. This presentation identifies the underlying principles directly responsible for (a) proper formulation and control to achieve desirable finished product characteristics, (b) for choosing proper testing methods and (c) for developing adequate in-process controls.

The continuing increased margarine production and per capita consumption in the United States and around the world confirms the importance of margarine as a significant food item. This broad acceptability is due primarily to the improved performance characteristics of today's margarine products available to the consumer. These products now satisfy the growing demands for "tailor-made" products to meet consumer perceived convenience, health and dietary needs. At one time, not too many years ago, margarine was available only in a stick or rigid form containing a specific level of fat. Today it is available as a plastic product both in stick and soft tub form identified as margarine or as an imitation or diet margarine, depending on fat content, and as a fluid, squeezable product.

At an earlier *Oil Processing* Short Course at this location in 1966, we discussed the subject of Margarine Oil Formulation and Control in some very specific terms (1). Since time does not allow us to broaden that presentation in the same detail, we should put these specifics in a more generalized form. As background information, several events have occured since that meeting.

Margarine as an identifiable food product celebrated its centennial in 1969, and at an AOCS symposium that year its U.S. legal and technological progress was briefly reviewed (2). A more detailed appreciation of the legislative hassle that margarine has endured over the years has been presented in a book published under the auspices of the National Association of Margarine Manufacturers (3). At the *World Conference on Oilseed and Vegetable Oil Processing Technology* in Amsterdam in 1976, the subject of margarine was given a more international perspective (4).

The most significant happening during this period was a change in the U.S. margarine standards to bring them in line with Codex (World Health Organization) and EEC regulations. This new standard was promulgated by the Food and Drug Administration in 1973 and provided significantly increased flexibility in product formulation (5). Despite the progress made with the regulation on the Codex basis, there are still differences among national legislations; however, these differences are not pertinent to our discussion, which focuses on the universal principles of manufacturing margarine products. Table I outlines the components of a typical margarine product. The most important is the fat phase, and its formulation controls the product's physical and performance attributes.

In order to qualify as a margarine under U.S. standards of identity, the product must contain a minimum of 80% fat. Any product containing less than that minimum must be labeled as an "imitation" margarine. For the past 10-12 years a diet, imitation margarine product containing 40% fat has been sold in the U.S. and in European countries. This product is considerably more popular in Europe than in the United States, probably because of their "Half-Butter," 50% butterfat product tradition. The Codex organization and its European supporters have recently proposed a standard for this product, a proposal which is not supported by U.S. margarine manufacturers. More recently the U.S. market has experimented with 60% fat products (25% fat reduction) in an attempt to provide some dietary incentive with less sacrifice in performance characteristics. Obviously the increased substitution of water for fat makes these products less applicable to baking and frying functions and only usable as a spread.

Since the Food and Drug Administration has not established the safety of fish oils for use as edible fats or oils, fats and oils of marine origin are excluded from use in U.S. margarine products. This is, of course, not true in international practice.

The second major ingredient in margarine is water. Traditionally this was added as a cow's milk product but can now be 100% water, with or without some edible protein component, undefined. The factors controlling choice from a formulator's point of view are primarily flavor considerations, and to a lesser extent on performance similar to its traditional prototype, butter. It is interesting to note that the original margarine standards promulgated in 1941 required that the aqueous phase contain 10% milk protein, a provision modeled after butter, which was then produced largely by a churning process. During the intervening years, butter production rapidly changed over to continuous processing which significantly reduced its protein or curd content to about one half that level, while margarine was required to maintain its higher content level. The new standards are essentially unrestrictive in their aqueous phase formulation requirements.

Emulsifying systems are used to hold the fat and aqueous phases together and to impart "specific" performance characteristics to the finished product. Originally these were restricted to lecithin and mono/diglycerides but are now open to any substance under the "safe and suitable" umbrella. The patent literature alleges many claims, too numerous to cover here, for their use. The best precaution is to be wary of taking them too seriously in terms of producing any significant effects.

Salt, sodium chloride, or potassium chloride for dietary margarine, is added for flavor and also acts as a preservative. This addition was always allowed, and the new standards add nutritive sweeteners as an optional ingredient. Preservatives such as sodium benzoate, benzoic acid and potassium sorbate can be used at specific levels to control microbiological growth, especially in the absence of salt.

TABLE I

Typical Margarine Product Composition

- Fat phase
- Aqueous phase (with, W/O protein)
- Salt
- Emulsifier systems
- Preservatives/additives
- Color/flavor
- Vitamins

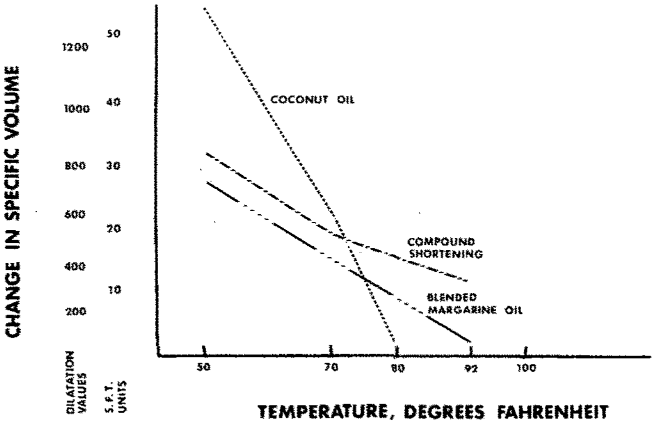

FIG. 1. Solid-liquid ratio measurement.

TABLE II

Margarine Oil and/or Component Treatments

	Patent References
Hydrogenation (selective)	15
Hydrogenation (nonselective/selective)	16
Interesterification[a]	17
Co-randomization[a]	18
Directed interesterification[a]	19
Fractionation (topped) component	20
Blending (traditional)	21
Blending, natural fat and liquid oil	22

[a]Can be hydrogenated, either before or after treatment.

The new standards also allow for the use of antioxidants, again at a "safe and suitable" level. Color and flavor substances are similarly classified.

Fortification of all margarine products with Vitamin A is mandatory; the use of Vitamin D is optional, and Vitamin E is specifically excluded under the standards of identity. The marked trend towards increased polyunsaturation in margarine products coupled with the knowledge of concomitant Vitamin E requirements suggests that Vitamin E fortification of margarines be considered. This practice is common in Europe. A good presentation of this rationale has been made by Bunnell (6).

Since the more important characteristics of finished margarines are dependent upon the physical properties of the fats and oils used in these products, it is important to consider these factors and their behavior under processing, storage and handling conditions when formulating a margarine oil blend. The physical properties of margarine are, therefore, concerned primarily with structure and its effect on consistency and plasticity. These factors depend on the melting point of component glycerides, the total solid or crystalline glycerides present at any given temperature, the distribution of these solid fats over a temperature range and the polymorphic modification or crystal habit of the fat composition. The most important characteristic is their collective response to temperature and work applied by external forces.

The hardness of a fat is usually measured by its melting point. This, however, is too empirical for good control and does not distinguish well between fats or fat systems. For a fat or fat blend to be plastic, it must consist of both solid and liquid phases. The ratio of these two phases determines its consistency, that is, its firmness or hardness characteristics. The most widely adopted method for characterizing this property of a fat or fat composition is dilatometry, the measured change in increased specific volume with increasing temperature owing to melting dilation (7). Dilatometric curves for three different fat systems are shown in Figure 1 and are plotted in terms of their solid fat indices (SFI values) as determined by the official AOCS methodology (8). These index values are not absolute terms and only refer to relative solids contents at various temperatures. The characteristics of this typical stick margarine oil curve is that its lower head end solids at 50 F, compared to coconut oil, makes it less brittle; its lower tail end solids at 92 and 100 F and its steeper slope, compared to a shortening product, provides for good eating or melt-in-the-mouth characteristics. There are many methods used for measuring and reporting melting dilations, and therefore another scale more popular in Europen practices representing dilation values (9) has been included to illustrate a comparison of numbers. The development of a broad-line Nuclear Magnetic Resonance (NMR) instrument and its ready availability offers a new approach to the determination of the solids in fats, blends and shortenings (10-12). These determinations are made in absolute solids terms and have been well adopted to practical commercial SFI control practices (13-14). Some measure of solids curve characteristics still represents the best practical means for controlling oil blending practices.

The usual guidelines for developing plastic fat compositions in general are applicable to the formulation of margarine oil blends. Since vegetable oils, as opposed to animal fats, are primarily used, hydrogenation plays an especially important role in the preparation of margarine oils. Other oil treatments are, however, employed and are identified in Table II.

By far the most common practice for the preparation of margarine oils in the United States is direct blending using selectively hydrogenated oil components. The treatment of oils other than hydrogenation and blending seems unnecessary, and there is no particular advantage to be gained by these treatments in our normal practices. These other preparative approaches are, however, useful in specific situations with regard to oil costs and availability, and where somewhat different melting properties are sought, for example, bakery margarines. The patent literature cites numerous examples of such practices, some of which are identified here.

Selective hydrogenation is characterized by high *trans* development with minimum iodine value drops, resulting in steep solids curves. Co-randomization is practiced in Europe as the only practical way of preparing highly polyunsaturated margarines from 100% sunflowerseed oil. The use of fractionated fat components and the direct blending of natural fats has again become somewhat popular with the increased availability of palm oil and palm oil stearines.

Through the use of these processing techniques, the means of developing fatty composition with an extremely wide range of physical properties are available. However, before subjecting a fat or blend to one of these treatments or processing procedures, something should be known about the crystal habit of these fats. In Table III a listing of fats and oils has been made according to their characteristic crystal habit. Here the fats and oils have been separated into *beta* and the *beta-prime* categories. The desirable characteristic of margarine and shortening compositions is described by *beta-prime* crystallization. The degree to which these oils or fats will exhibit either *beta* or *beta-prime* properties will increase with increased hardness, that is, hydrogenation, and to a lesser extent on certain blending factors which we will discuss later.

A characteristic of these oils, which is responsible for their exhibiting a particular crystal habit, is their palmitic acid content. As a rule, the *beta* type oils contain relatively low, ca. 10% palmitic acid, where the *beta-*

prime-type fats contain at least twice that level of palmitic acid. The exceptions to this are lard and tallow, both with 25- to 30% palmitic acid contents. Here the *beta* characteristic of lard is attributed to the high concentration of palmitic acid in the beta or middle position of the glyceryl molecule. Distribution, therefore, of palmitic acid on the glycerine moiety is also important in providing the necessary effective concentration of *beta-prime* glycerides.

Another important aspect of predicting or choosing an oil for use in margarine formulation is its response to interesterification. Of the *beta-prime* fats. only palm oil remains unchanged in its crystal habit on interesterification. Of the oils grouped under the *beta* classification, no change in crystal habit is observed with interesterification. Corandomization can mitigate these *beta* tendencies as a result of *in situ* blending factors, resulting in a reduction and redistribution of the trisaturated triglycerides.

To the experienced product development person, fats and oils have no particular magic related to their source. A triglyceride is that, whatever its source. The basic chemistry is always the same, and the only differences are compositional. These compositional differences can manifest themselves in terms of peculiar physical properties, for example, crystal structure. Nevertheless, as we have discussed in this short course, technology exists to manipulate these differences to satisfy end product needs. Table IV (23) relates compositional and functional characteristics and forms the basis for qualifying certain fat sources, with or without some level of processing, to an end product use of function.

Natural fat systems are mixtures of mixed triglycerides. Their functional properties and quality characteristics are directly related to the type of triglycerides in the fat system. As we indicated earlier, these types of triglycerides are determined by the fatty acid composition of the triglycerides and the distribution of the fatty acids on the individual triglyceride molecules. This table shows a typical triglyceride profile for a fat or a fat blend made up of palmitic, stearic, oleic and linoleic acids. The melting points of the individual triglycerides are shown on the left hand side. The distribution of the fatty acids on the individual triglyceride molecules and the quantity of each triglyceride species, groups I through IV, depend upon the proportions of the individual fatty acids, the fat source and to a lesser extent its processing history. The trisaturated triglycerides can only provide structure; the disaturated-monounsaturated triglycerides, Group II, ~~can~~ provide both structure and lubricity; that is, they are solid at room temperature and will melt at body temperature. The lower melting, more unsaturated triglycerides, Group III and IV, can only provide lubricity. Lubricity describes imparted tenderness and adds to the richness and improved eating properties of foods; it also provides us with a feeling of satiety after eating. Structure here describes, in addition to physical structure, those structural characteristics needed for performance, for example, creaming properties in bakery applications.

Vegetable oils have no inherent structural characteristics; that is, they do not contain any significant quantity of triglycerides represented by Groups I and II. However, these structural characteristics can easily be built in by hydrogenation. The hydrogenation techniques are sufficiently flexible to provide a wide variety of compositional structures. In this manner the ratio of the structural triglycerides can be manipulated through blending to provide for the solids curves defined by specific oil formulations.

This chart also serves to illustrate some background for a later subject, that of votating or crystallizing margarine emulsions. When a fat blend, typified by this mixture of triglycerides, crystallizes, it does not do so as individual melting entities, but rather as solid solutions representing molecules with a number of different melting glycerides in the same crystalline lattice. These solid solutions assume melting and polymorphic characteristics of their own, dependent on their component triglycerides.

TABLE III

Classification of Fats and Oils According to Crystal Habit

Beta-type	*Beta prime-type*
Soybean	Cottonseed
Safflower	Palm
Sunflower	Tallow
Sesame	Herring
Peanut	Menhaden
Corn	Whale
Canbra	Rapeseed
Olive	
Coconut	Milk fat (butter oil)
Palm kernel	
Lard	Modified lard
Cocoa butter	

TABLE IV (23)

Compositional/functional Relationships[a]

	M.P. of	Glyceride Structures		
I.	149	SSS		
	142	SSP	structure @ 72 F	
	140	SPP		
	133	PPP		moisture barrier
II.	107	SSO		
	100	SPO	structure @ 72 F	
	95	PPO		
	91	SSL	lubricity @ 98.6 F	
	86	SPL		
	81	PPL		aeration
III.	73	SOO		
	60	OOP		
	43	SOL		
	42	OOO		lubricity
IV.	34	SLL		
	30	OOL		
	27	PLO	nutritional	
	22	PLL		
	20	OLL		
	8	LLL		

[a] Imposed variable is crystal habit.

TABLE V

Component Blending

– Hi level Hi IV oil	+	Low level Low IV fat
– Intermediate level Hi IV oil	+	Intermediate level Intermediate IV fat
– Low level High IV oil	+	High level Intermediate IV fat
– Blend of intermediate IV fats		

Table V illustrates the basic types of oil blends used to formulate margarine products. Relating to the previous table, the high iodine value oils are characteristic of Group IV, exhibiting no significant structural tendencies. They are, in fact, antistructural, in the sense that they solubilize the solids or higher melting triglycerides. The low iodine value and intermediate iodine value fats do contribute structural characteristics.

The first group, blending a high level of a high iodine value oil plus a low level of a low iodine value fat, is typically used to formulate fluid margarines, high, 75-80%

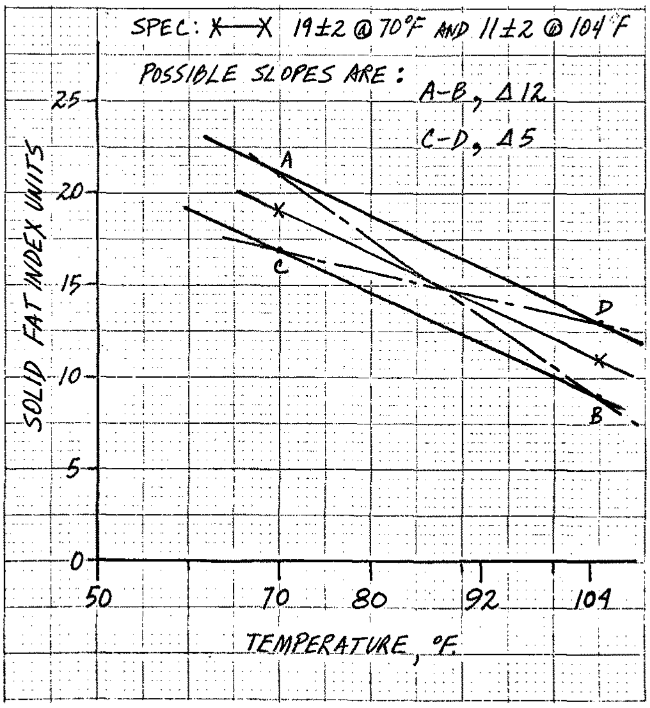

FIG. 2. Slope "unawareness."

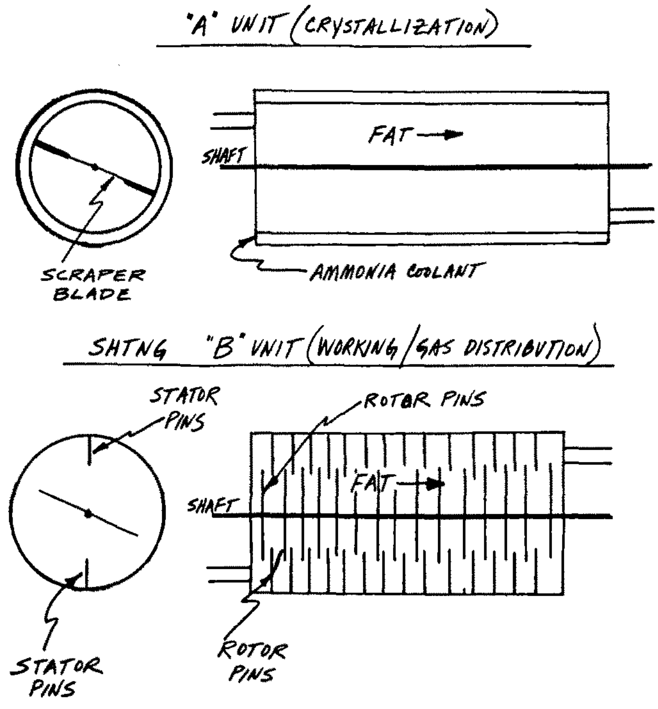

FIG. 3. Margarine crystallization and working units.

liquid oil stick products, and certain high, polyunsaturated, soft tub products. Co-randomizing this blend is typically used to prepare a soft tub product from 100% sunflowerseed oil.

The second group, utilizing an intermediate level of a high iodine value oil plus an intermediate level of an intermediate iodine value fat, is used to prepare high polyunsaturated, 50% liquid oil stick products and is typically used for soft tub products.

The remaining two groups are used for the preparation of low, polyunsaturated soft tub products and all hydrogenated stick products respectively. One of the potential defects in margarine texture is graininess (24,25). The higher melting triglycerides melt out of their non-grainy condition (stable solid solution) and crystallize as large, discreet particles, hence the term "sandy" margarines. This problem can be resolved by a proper choice of hard component(s) or the use of a multiplicity of components. Earlier work demonstrated that this graining was attributable to polymorphic transformation with the formation of triglycerides in the *beta* form (26). Earlier blending practices used two component systems, a hard and a softer component blend, and since extremes in hardness will accentuate grain formation (25), one obvious cure would be to use a strong *beta-prime* fat as the harder component. The use of a third component of intermediate hardness will, for constant SFI values, reduce the hardness or potential *beta* contribution of the hard component and thereby help stabilize the oil blend toward the prevention of grain formation.

The use of multiple components not only controls grain formation, but more importantly, leads to improved product consistency control and product flexibility. This "blending" factor provides the basis for the successful formulation of a 100% soybean oil stick product using an oil with a high propensity towards *beta* crystallization.

A number of years ago when speaking on the subject of finished margarine quality, I had occasion to use an illustration that I would like to repeat here (27). The illustration is a quote from a book review concerning traditional Scottish foods; it reads in part, as follows: "The first time I ever saw Scots porridge eaten *properly* was at an inn on the Isle of Islay, where a bearded and irascible sea captain astonished me by sipping it dry from a dish and only occasionally dipping his spoon into a separate bowl of milk. Further, he salted each spoonful individually with a twist of his finger from a salt dish, and from time to time washed it down with whiskey." The article continued: "I was used to porridge pre-salted, without whiskey, but with milk on top of it; also, the porridge I knew was hot, and semiliquid. The captain's was cold and so constructed that when some of it fell on the floor it bounced. It occured to me then that there was no single authentic recipe for anything; plainly, true porridge could vary from a sugary-gruel to alcohol-reinforced cement. It was a discovery that has made me cautious about traditional recipes ever since."

Margarine too is a traditional recipe for which we can be equally cautious, from a margarine manufacturer's point of view of consistently making the product he wants. We have indicated the importance of solid fat indices (SFI) as the primary measurement for oil formulation control, and there is yet another aspect of this measurement that we need to appreciate if we are to do justice to this traditional recipe.

Figure 2 illustrates a subject which we entitle "Slope Unawareness" and is responsible for a high degree of lost control in oil blending operations. The figure describes a typical SFI specification for an oil or an oil blend providing typical plus and minus factors for the head and tail ends. The desired slope of this product is described by the solid line through the two specification points, 19 units at 70 F and 11 units at 104 F, the slope of the line Δ 8. The plus and minus values associated with each point suggests that product integrity will be defined by a series of similarly sloped lines falling within the region bordered by Lines A-D and C-B. However, a good many (perhaps most) formulators will interpret the plus and minus to mean that a product's specifications are satisfied as long as the head value falls somewhere between A and C and the tail value somewhere between B and D. This jeopardizes the traditional recipe, allowing for such ranges in slope as described by the dotted line A-B and C-D with slopes of Δ 12 and Δ 5 respecitvely. These represent significant departures from the intended specifications and identify a real problem in oil formulation work as it is practiced today for the preparation of components as well as oil blends. Slope integrity as defined by the prime specification numbers is necessary for consistent finished product quality.

Margarines are usually processed by quick chilling through a swept surface heat exchanger, followed by quiescent solidification prior to molding or forming. If a supercooled fat composition is allowed to solidify without agitation, it will be quite firm and exhibit a narrow plastic range. This is the manner in which stick margarines are formed. Where specific body characteristics are desired, a treatment similar to that employed in shortening manufacture is applied, namely, the use of a working "B" unit after supercooling.

The scraped surface heat exchanger of "A" unit is shown in Figure 3. It consists of a steel shaft rotating in a tube which is cooled externally by boiling ammonia. The rotating shaft is fitted with scraper blades which at high rotation speeds are pressed against the cooled inner surface by centrifugal force. High internal pressures and shearing actions induce fast nucleation and crystallization during the short residence time of about 5-10 sec. In general, fats require crystallization times of about 5-7 min. In the case of stick margarines, 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 and to provide a product with a short plastic range to ensure better "melt-down" on eating. In practice, this quiescent crystallization occurs in large diameter crystallization tubes situated between the "A" unit and the molding or forming machines. Sufficient crystallization or "set" is strictly a function of time and temperature. Since some fats supercool more than others, that is, require longer crystallization times, the length of the crystallization tubes will vary depending on the fat compositions used in the formulation.

The plastic range of a fat composition can be altered by mechanically working the fat while it is crystallizing from the supercooled state. This is usually done in a shortening "B" unit (Figure 3), which is a large diameter tube fitted with stator pins on the cylinder walls and a rotating shaft fitted with rotor pins, which at high speeds mechanically work the fat as it passes through the unit. This mechanical working extends the plastic range of the product and is the practice used for packing soft tub and industrial pak margarine products.

Fats have a tendency to supercool, that is, to remain liquid when rapidly chilled below their melting point. Because of this fact and the fact that fats are polymorphic, the solidification of plastic systems requires careful control. Figure 4 illustrates another control factor we need to appreciate if we are to do justice to our traditional recipe. There is not much point in controlling blending operations, as we discussed earlier, only to lose product integrity by not adequately controlling its crystallization process. Figure 4 is a simple phase diagram for two substances, *A* and *B*. Natural fat systems are complicated mixtures which contain a large number of different melting triglycerides; however, this simple diagram can serve to illustrate what occurs during the crystallization of a natural mixture of mixed triglycerides.

This diagram plots temperature, vertically, vs. crystalline composition in terms of *A* and *B*, horizontally. At any temperature, *t*, the composition of the liquid phase, is defined by the solid line, and the composition of the crystalline phase is described by the dotted line. If the temperature is lowered to a point *a*, the composition of the crystallizing fat will be defined by *b* on the dotted line. If the temperature drops to *c*, its intersection with the dotted line defines a new composition for the solid or crystallizing phase. Since fats do not crystallize as individual entities, but rather as mixtures of solid solutions, any variation in temperature, for example, from *a* to *c*, will deposit a range of crystalline compositions represented by those two points on the compositional axis, c^1-b. These compositions are not simple admixtures of *A* and *B* but intimately crystallized solid solutions having identities, that is, crystal and thermal properties, unique to themselves.

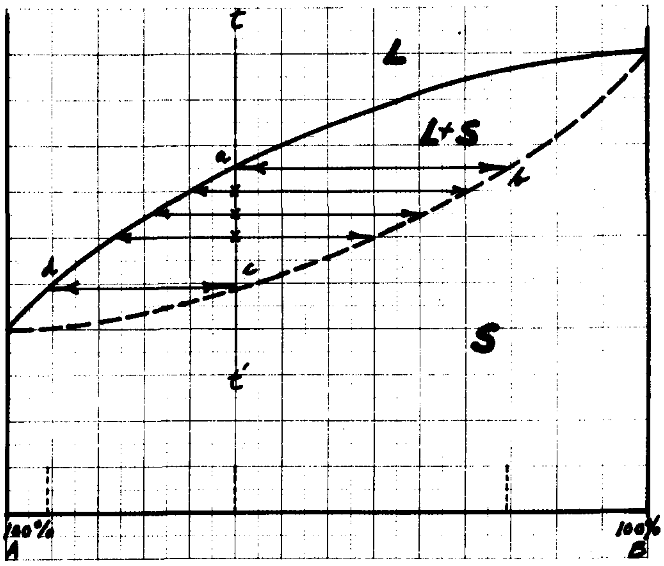

FIG. 4. Simple Phase diagram for two substances illustrating solid solution formation (composition vs. temperature).

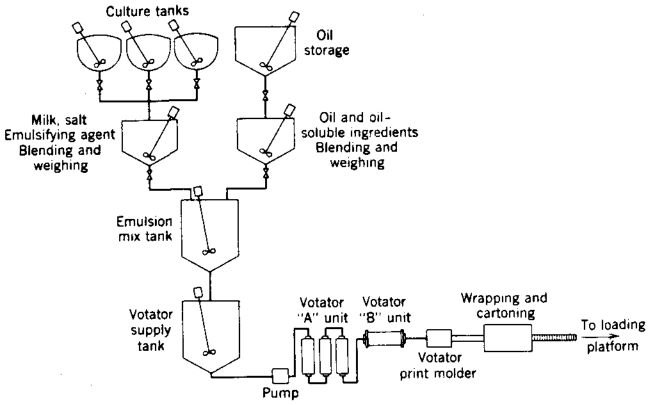

FIG. 5. Flow diagram for batch-continuous margarine production.

In a votator situation, there always exists some temperature differential across the product flow with the lowest temperatures existing on the outside or chilled walls. As a result, votation will not result in a single crystalline composition but rather in some range of compositions. Each temperature differential for the same oil blend passing through the votator will produce a different mixture of solid solutions, each with its own peculiar melting characteristics.

Assuming that good votation temperature control is represented by plus or minus one degree, we would have a compositional variance corresponding to lines where the three *x's* intersect the dotted line, x^1-x. Allowing the votator temperature to vary with less control, over a greater temperature range, for example, *a* to *c*, would triple the possible solid solution compositions. Each instance represents a different finished product and suggests one of

TABLE VI

Typical SFI Values for U.S. Margarines

	10 C	21.1 C	26.7 C	33.3 C	37.8 C
	50 F	70 F	80 F	92 F	100 F
Stick (3 Components)	28	16	12	2-3	0
80% liquid oil print	15	11	9	5	2
Soft tub products	13	8	6	2	0
Liquid oil + 5% hard fat	7	6	6	5.4	4.8
Bakers	27	18	16	12	8
Roll-in	29	24	22	16	12
Puff paste, veg./A-V	26	24/21	23/20	22/16	21/15

TABLE VII

Evaluation of Physical Properties of Margarine

Testing techniques	References
Appearance	---
Oral melting characteristics	28,
Oil-off (bleeding)	28, 28 b
Slump (collapse)	28 b
Get-away	---
Penetrations	29, 30
Spreadability	28b
Rheological properties. . . Hardness/spreadability	
a. Penetration	31, 32
b. Extrusion	33, 34
c. General	35

TABLE VIII

Factors Influencing Consistency/Plasticity

- Proportion of Solid-liquids
- Viscosity of the liquid
- Temperature treatment
- Mechanical working
- Super cooling
- Polymorphism
- Properties of crystals
  - Size
  - Number
  - Composition

the important variables that enters into the manufacturing of shortening and margarine products. For margarines, especially industrial types, this poses a real source for finished product quality problems and indicates why tight and continuous temperature control is so necessary.

Figure 5 shows a simplified diagram for batch-continuous margarine production. In today's practice a "milk" is prepared by adding dried protein to water and after pasteurization is stored cooled in milk hold tanks. The water soluble ingredients, salt and preservative, are added to the milk, and the oil soluble ingredients, mono/diglycerides and lecithin, are added to the oil blend. The oil and aqueous phases are scaled into the emulsion mix tank or "churn" and mixed under high agitation with flavor and vitamin/color premix. It is a normal procedure to check moisture and fat content before pumping to the emulsion hold tank feeding the "A" unit. Automatic proportionating equipment is available to make this a continuous process. After chilling through the "A" unit, the product flows through a "B" unit, either quiescent or working, before printing or filling.

A number of patented procedures exists for processing margarines in which the process differs somewhat from the normal practice of crystallizing an emulsion of the fat and aqueous phases. Special product properties have been claimed for these processes. One is the use of a double emulsion, an oil-in-water-oil system, in which the dispersed phase is an oil-in-water emulsion, that is a cream, for which a longer plastic range is claimed for the finished product (36). Improved melting and eating characteristics are also claimed for precrystallization and milk injection processes (37). In these practices a portion of the chilled emulsion from the votator is cycled back into the votator feed, or a portion of the aqueous phase is fed into the crystallized mass and loosely mixed or blended by the action of flow through the lines to the print or filling machines. The whipping of margarines up to 50% overruns will also increase the hardness, allowing for the use of softer oil blends, and it changes the texture of the finished products (38). The rate of cooling the emulsion, the type of working during and subsequent to chilling, and the condition of the emulsion to the chilling unit all have a marked effect on finished product characteristics. Processing, therefore, is equally important as the oil blend in describing the physical and performance properties of the margarine product. Table margarines are usually sold without any tempering or heat treatment after packaging. Margarines to be used for baking purposes are usually placed at elevated temperatures for varying lengths of time. Tempering conditions used depend on the type of product, and they are done to improve the plasticity and creaming properties of the margarine products.

Whereas plastic systems depend on rapid crystallization for *beta-prime* structural stability, fluid systems depend on slower crystallization for *beta* crystal form stability. This *beta* crystallization can be accomplished by either direct or indirect means (39). Liquid margarine formulations have been described in the patent literature (40), using both *beta* and *beta-prime* type hard fats. Unlike shortening systems, *beta-prime* crystallizing hard fats are more suitable for the direct crystallization of a fluid margarine product into its package. Fluid margarine products formulated with *beta* hard fats require the indirect approach of tempering a supercooled mass at an elevated temperature for a period of time under agitation. While this will produce a more fluid, less structured product, it does result in increased production costs, which in terms of product performance are not easily justified.

Some typical SFI values for various United States margarines are shown in Table VI. The first four products are representative of margarines available in the retail market and illustrate the wide range of solids contents which are employed today. The last three margarines are illustrative of industrial/institutional products. The Baker's and Roll-In margarines are usually prepared by blending a standard stick margarine oil formulation with added hard fat and/or monoglycerides. Puff-Paste products will require, because of their specialized applications, special crystallization and tempering steps to develop a high level of malleability. Processes of multiple, in series votation with quiescent crystallization in between, are used to produce these products directly and replace the classical chill roll technology which required overnight tempering before subsequent working in a forming machine.

The formulation and processing of industrial margarines for the food processing industry have become significantly more sophisticated with their need to perform in high speed, high shear and high pressure equipment. Here we are concerned with thixotropy and syneresis or "watering-out" during movement and application procedures. This starts with emulsion temperature control and carries through the entire process, through tempering of the crystallized product. It has been demonstrated, for example, that rheological properties are substantially evolved in the first 48 hr of tempering (41).

Testing techniques for the evaluation of physical properties of finished margarine products are shown in Table VII. The evaluation of table grade products is comparatively straightforward and depends primarily on sensory or organoleptic evaluation. Industrial margarine products require some better assessment of their rheological properties. Some of these methods are grouped under rheological properties for determining hardness and spreadability (Table VII). An evaluation of this methodology has been detailed elsewhere and will not be discussed here, suffice to say that the sophistication of instrumental designs for the measurement of these rheological properties lags far behind the need for these tools (1, 42).

Everything that we have discussed influences and is important to finished product integrity. Achieving desired finished product characteristics requires an appreciation of the factors that influence and give rise to those characteristics. The achievement of those finished product characteristics uniformly, time after time, requires control of those factors. Table VIII summarizes our subject:

1 Need to properly choose and then control oil formulation.

2 Formulate emulsion, and

3 Subject it to proper thermal and working treatments.

It is interesting to note that our industry has provided both the retail and industrial customer with a long list of innovative products in spite of what appears to be the obvious restrictiveness of regulatory standards governing the composition of margarine products.

REFERENCES

1. Wiedermann, L.H., JAOCS 45:515A (1968).
2. Miksta, S.C., JAOCS 48:169A (1971).
3. Riepma, S.F., "The Story of Margarine," Public Affairs Press, Washington, D.C., 1970.
4. Gander, K.F., JAOCS 53:417 (1976).
5. Federal Register, Vol. 38, No. 85 Thursday, May 3, 1973, pp. 10952-10955.
6. Bunnell, R.H., B. Borenstein, and G.W. Schutt, JAOCS 48:175A (1971).
7. Braum, W.Q., Ibid 32:633 (1955); Fulton, N.D., et al, Ibid. 31:98 (1954).
8. Official and Tentative Methods of the AOCS, Solid Fat Index Method Cd 10-57.
9. U.S. 3,240,608 (1966); British 1,017,091 (1966).
10. Ferren, W.P., et al, Food Tech. 17:1066 (1963).
11. Chapman, D., et al, Nature 183:44 (1959); Chapman, D., et al, JAOCS 37:243 (1960).
12. Taylor, J.R., et al, Ibid. 41:177 (1964); Pohle, W.D., et al, Ibid. 42:1075 (1965).
13. Haighton, A.J., et al, Ibid.48:7 (1971).
14. Haighton, A.J., et al, Ibid.49:153 (1972).
15. U.S. 2,167,113 (1939).
16. U.S. 2,814,633 (1957).
17. U.S. 3,099,564 (1963).
18. U.S. 2,855,311 (1958); U.S. 2,874,056 (1959); U.S. 2,921,855 (1960). British 832,377 (1960); U.S. 3,006,771 (1961); British 1,020,826 (1966).
19. U.S. 2,442,532; -537; -538 (1948).
20. U.S. 3,189,465 (1965); British 1,017,091 (1966).
21. U.S. 1,070,331 (1913); U.S. 2,718,468 (1955); Candian 713,512 (1965); Canadian 718,861 (1965); British 1,014,068 (1965); U.S. 3,240,608 (1966).
22. Anderson, A.J.C. and P.N. Williams, "Margarine," 2nd Ed., Pergamon Press, 1965.
23. Cochran, W.M., "Size and Functional Implications of Edible Oil Markets as a Basis for Selecting Research Programs," A.E. Bailey Award Lecture, North Central AOCS Meeting, March 19, 1975, Unpublished.
24. Struble, D.H., JAOCS 31:34 (1954).
25. Kozin, H.I., et al, Maslob. Zhir. Prom. 29:11 (1963); Kozin, H.I., et al, Tr. Mosk. Inst. Nar. Knoz. 24:56 (1963).
26. Merker, D.R. and L.H. Wiedermann, JAOCS 35:130 (1958).
27. Wiedermann, L.H., Ibid.49:478 (1972).
28. U.S. 2,754,213 (1956); Canadian 718,372 (1965); British 1,014,068 (1965).
29. U.S. 3,240,608 (1966); Canadian 718,861 (1965).
30. Clardy, L., et al, JAOCS 29:591 (1952).
31. British 1,005,802 (1965); Haighton, A.J., Ibid. 36:345 (1956).
32. Naudet, M., et al, Grasas y Aceites 10:20 (1959); Naudet, M., et al, Rev. Franc. Corps Gras 6:4 (1959).
33. Prentice, J.H., Lab Pract. 3:186 (1954); Loska, S.J., et al, JAOCS 34:495 (1957); Haighton, A.J., Ibid.42:27 (1965).
34. Soltoft, P., "On the Consistency of Mixtures of Hardened Fats," Thesis, Copenhagen, H.K. Lewis & Co., Ltd., London, 1947.
35. Scott-Blair, G.W., J. Sci. Food Agric., 5:401 (1954); Green, "Industrial Rheology and Theological Structure," Wiley & Sons, Inc., 1949.
36. U.S. 2,575,874 (1951); Japanese 8638 (1960).
37. U.S. 2,325,393 (1943); U.S. 3,745,750 (1956): U.S. 2,772,976 (1956).
38. Canadian 560,273 (1958); U.S. 2,937,093 (1960).
39. Bednarcyk, N.E., "Edible Oils and Fats," Food Processing Review No. 5, Noyes Development Corp., N.J., 1969.
40. U.S. 3,338,720 (1967).
41. Sambuc, E., and M. Naudet, Rev. Fr. Corps Gras 12:239 (1965).
42. Haighton, A.J., JAOCS 53:397 (1976).