Study of Air Cell Migration and the Effect of Whipping Temperature on the Overrun, Body and Storage Stability of a Dairy-Based Frozen Whipped Topping

William J. Locker
Utah State University

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STUDY OF AIR CELL MIGRATION AND THE EFFECT OF
WHIPPING TEMPERATURE ON THE OVERRUN,
BODY AND STORAGE STABILITY
OF A DIARY-BASED FROZEN
WHIPPED TOPPING

by
William J. Locker

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
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UTAH STATE UNIVERSITY
Logan, Utah
1972
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William J. Locker
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ABSTRACT

Study of air cell migration and the effect of whipping temperature on the overrun, body and storage stability of a dairy-based frozen whipped topping

by

William J. Locker, Master of Science
Utah State University, 1971

Major Professor: Dr. C.A. Ernstrom
Department: Food Science and Industry

A dairy-based whipped topping consisting of 22.0 percent milk fat, 7.5 percent milk solids-not-fat, 12.0 percent sucrose, 10.0 percent corn syrup solids, 0.60 percent gum arabic, 0.06 percent carrageenin, 0.19 percent polyoxyethylene sorbitan monostearate, 0.19 percent polyoxyethylene sorbitan tristearate, and 0.12 percent sodium stearoyl-2-lactylate was developed that would withstand the rigors of frozen storage. The best products were obtained when the topping was whipped on a Creamery Package 3M-30 continuous type ice cream freezer. Toppings whipped in the laboratory at temperatures higher or lower than -2.2 to -1.0 centigrade were weak and slightly wet. After 18 days frozen storage the toppings whipped at -2.2 centigrade had the best body and texture characteristics. Refrigerated storage after 18 days frozen storage resulted in an enlargement of the air cells and after about 10 days a stale flavor was detected. Commercial application of the formulation was considered feasible.
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INTRODUCTION

Over the past decade non-dairy whipped toppings have seriously cut into sales of whipping cream (13). This has happened because these products have gained certain advantages. These are: (a) cost: replacement of the milk fat with a less expensive vegetable fat, (b) convenience: the consumer is more receptive to a ready-to-use product, and (c) better physical characteristics: improved body and texture with a much longer shelf life through the use of additives not normally permitted in dairy products.

Many of the non-dairy products exhibit better physical characteristics than whipping cream. They are generally more tolerant to over-beating, have superior stability after whipping and show a greater tolerance to freezing. The advantage of being able to use stabilizers leads to a more stable foam structure. Non-dairy toppings marketed in a whipped frozen state have better keeping quality and retain their physical characteristics longer than whipped cream. In the whipped frozen state they also provide a "ready-to-use" convenience which gives the consumer additional incentive for acceptance (50,62).

Substitution of non-dairy products for whipping cream has had a significant economic impact on the dairy industry. In 1966 the use of non-dairy toppings decreased the amount of milk fat utilized in whipping cream by one-third (38). Miller (36) estimated that 6.8 million Kg of dried topping mix were produced in 1966 and that this production has expanded at a rate of 10% per year, as evidenced by the large
number of new manufacturers entering the field. The 1967 Census of Manufacturers (55) revealed that in that year approximately 110 million liters of non-dairy toppings, having a manufacturers value of $51.1 million, were produced. This production constituted over 80% of the total whipped topping market (38,54) as well as being double that production reported in 1963.

Considerable investigation has been conducted on whipping cream. However, legal standards imposed on this product have seriously limited its modification. It is difficult to consistently produce a completely satisfactory whipped cream. With the non-dairy product, using standardized ingredients and additives, a high degree of product success can be predicted. This consistency in performance reduces the high rate of returns many dairies have with whipped cream (36).

The primary objective of this investigation was to study the effect of whipping temperature on overrun and storage stability of a dairy-based frozen whipped topping, and to study the growth of air cells in the product under various conditions of frozen and refrigerated storage. It is hoped that this study will influence the development of a satisfactory dairy-based whipped topping which can be eventually marketed.
Definitions and standards of identity for whipping cream products

The composition and utilization of milk products has intrigued mankind for many years. It was known that there were many differences in milk and milk products resulting from numerous factors plus those resulting from man's unscrupulous practices in striving for profit. For the latter reason, primarily, it was necessary to develop and enforce stringent regulations for the control of milk marketing practices, and to develop a standard set of definitions for milk products that could hopefully be used throughout the country with a reliable degree of understanding.

In order to obtain an appreciation for the complexities involved in developing a dairy-based frozen whipped topping it is necessary to have a full understanding of the basic definitions for cream products.

**Cream.** Cream is the sweet fatty liquid separated from milk, with or without the addition of skimmilk, which contains not less than 18% milk fat (59).

**Whipping cream.** Whipping cream is cream that contains not less than 30% milk fat (59).

**Light whipping cream.** Light whipping cream is cream that contains not less than 30% but less than 36% milk fat (59).

**Heavy cream or heavy whipping cream.** Heavy cream or heavy whipping cream is cream that contains not less than 36% milk fat (59).

**Whipped cream.** Whipped cream is whipping cream into which air or gas has been incorporated (59).
Whipped topping. In this study the term "whipped topping" will be used to designate those products containing various additives making it illegal to identify them as whipped cream (57).

Non-dairy whipped toppings currently on the market

In order to meet the needs and demands of the consumer, numerous types of non-dairy whipped toppings have been developed.

Liquid mixtures. The first non-dairy whipped toppings were processed and packaged in liquid form. They could be refrigerated for several weeks or held indefinitely prior to whipping. The principle advantages were not all encompassing as it was still necessary to whip the product in the home prior to use.

Dry mixtures. Numerous dry non-dairy based whipped toppings have been developed (28,41). However in nearly all cases the dried non-dairy mix was combined with a specified amount of whole or skimmilk prior to whipping to the desired consistency. The primary advantage of this product was the near indefinite shelf life resulting from the stability of the dried ingredients (36). There was also the advantage of low distribution costs relative to liquid products (13).

Aerosol types. To provide the consumer with the near ultimate of convenience in whipped toppings, aerosol products were developed which were immediately ready for use. These products were packaged in liquid form under pressure using air and/or various types of gases (42,63). The most common propellant was a combination of nitrous oxide and Freon 115 (2).

Frozen whipped products. With the advent of increased refrigeration facilities in the American household, and the development of more
dependable refrigerated transportation, use of frozen whipped toppings has increased substantially. These products, composed of all non-dairy ingredients, are first whipped then held frozen until ready for use (31). The convenience gained from their superior storage stability and near immediate availability for use has resulted in their popularity.

Factors influencing foam formation and stability

The entrapment of air or gas in a liquid to form foam and the retention of the gases in a stable form, is an extremely complex physiochemical phenomenon (6). With the multitiude of ingredients in whipped toppings available for interaction, and the storage rigors encountered in the frozen state, the relationship within the gas-liquid matrix can be very complicated. This is particularly true when the liquid itself is a fat-in-water emulsion. Of prime consideration are those reactions and factors imposing attractive and opposing forces at the interface of the gas-liquid phases.

Surface tension. Surface tension can most aptly be described as the attraction between molecules of a liquid at its surface; the greater the attraction between the molecules the higher the surface tension value, and the less the attraction between the molecules the lower the surface tension value will be (3). This phenomenon was first noted and identified as "surface tension" in the mid 1700's when workers noted that two drops of a like liquid placed close to each other tended to coalesce (7). The tendency of a liquid surface to contract and assume the smallest area possible is due, primarily, to the fact that molecular forces within the bulk have a short range of action compared to molecular forces on the surface, and the concentration of matter in the gas
phase, as a rule, is much smaller than in the liquid (7). The kinetic chemistry of the physical system dictates that work must be accomplished or energy expended to raise a molecule, or particle of substance, from the interior of its bulk to the surface. When the surface area is extended, more molecules must be raised. The free energy residing in the extended surface is the work spent on moving the particles from the bulk to the surface (7). Early concepts of the term "surface tension" were that the surface of a liquid had a stretchable (1) or contractile (5) skin. In the bulk of a liquid the net attraction between neighboring molecules is fulfilled most completely, whereas the attraction of molecules at the surface, not being completely surrounded by other liquid molecules, is less complete than those in the bulk (5,9). The net effect is an attractive force directed into the liquid from the surface, thus, the smaller the surface the lower the net force or energy (5). As the natural tendency of a system is to minimize free energy (1,39), the surface of a liquid has a "tendency" to spontaneously contract (5,9). The term "surface free energy" as applied to that work required to move molecules from the bulk to the surface, thus extending the surface area, is a more apt and descriptive term when referring to the surface tension at a gas-liquid interface (1).

**Vapor pressure.** Vapor pressure can be defined as the pressure exerted when a solid or liquid is in equilibrium with its own vapor. The pressure is a function of the temperature and the concentration of constituents of the system (61), and is a direct result of the surface free energy of the system interface (39). Very little investigation has been conducted on the influence of vapor pressure on a complex system such as whipped toppings.
Viscosity. As a bubble in a foam approaches a neighboring bubble, it is necessary to push intervening liquid aside. This pushing is slowed by the viscosity, or resistance to flow, of the liquid. Real foam is produced when the viscosity of a liquid is low enough to enable a gas bubble to quickly move toward a neighboring gas bubble, but as they approach, the viscosity of the thin layer of liquid between the bubbles becomes very high (6). Therefore the bubble crossing the last part of the distance to its neighbor is greatly retarded (6). The normal Newtonian viscosity, however large, can only retard bubble coalescence, not prevent it. In fruit juice foams the viscosity decreases as the bubble size increases with time (29).

Temperature. Temperature during the foaming process is critical; it may affect the rate of foam formation and the amount of foam stabilizer required. Foam should be formed at the lowest temperature at which the system is sufficiently liquid (15). The surface tension of most liquids decreases with increasing temperature (5), thus affecting their ability to retain gas bubbles. By whipping cream at various temperatures between 4.4 and 10C, Smellie (44) showed that there was a marked relationship between the temperature of whip and overrun; the lower the temperature the higher the overrun. He did not detect any relationship between whipping temperature and firmness of the foam. He did show that lower overrun was generally indicitative of greater product firmness. Babcock (4) stated that the chance of obtaining a successful whip in cream rapidly diminishes as the whipping temperature goes beyond 10C.
Role of ingredients in whipped toppings

Regardless of formulation nearly all whipped toppings are similar in composition. They generally all contain varying proportions of fat, some type of protein, a combination of sugars to enhance flavor and the possible addition of buffers, stabilizers and emulsifiers to improve body and stability (25,36). Legal restrictions limit the use of non-dairy ingredients in dairy products. The Filled Milk Act of 1923 (58) forbids the inclusion of any additive to a dairy product that is not provided for in the standard of identity for that product. The exception is sodium casienate which may be used with non-dairy products (64).

Fat. The major non-aqueous ingredient in whipped topping formulations is fat (25). It provides richness, body and texture to the final product. Many different fats are available for use in whipped toppings. Oils may even be used if they are emulsified in such a manner that they are completely encapsulated within a protective layer of surfactants (26). Knightly (25) investigated several types of fat, differing basically in their melting point, for whipped topping formulations. His studies showed that for fats within the melting point range of 35.6 to 48.9°C there was no significant effect on aeration. He indicated that most fats designed for use in simulated cream have a relatively high solids content index, regardless of melting point, when compared to shortening type fats. In an earlier study Knightly (25) indicated that highly unsaturated fats may decrease the aereating ability of protein foams. This is somewhat explained in subsequent work where he indicated that oils and low melting fractions of fats, if not properly emulsified tend to diffuse into the protein of the food,
seriously detracting from the aerating ability and colloidal solubility of the protein (25, 26). Thus, he emphasizes that fats and oils with a low solids content index are rarely used in topping formulations. Overall fat selection should be based primarily on flavor stability and palatability (25). Fats with a high melting point generally leave a greasy aftertaste in the mouth, thus for flavor and palatability considerations a low melting point fat is preferred (36). The fat selected for whipped toppings should have a solids content index (solid fat index) such that none of its fractions remain solid at body temperature, melting point less than 36.7°C, yet possess a high solids index at the anticipated critical storage temperature (25). A comparison of the general composition of milk fat with that of a typical non-dairy topping fat was made by Miller (36) and is shown in Table 1.

Table 1. Comparison of fatty acid composition of milkfat with that of a typical non-dairy whipped topping fat

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Carbon number</th>
<th>Points of unsaturation</th>
<th>Milk fat (%) wt</th>
<th>Non-dairy fat (%) wt</th>
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<tr>
<td>Butyric</td>
<td>4</td>
<td>0</td>
<td>3.0</td>
<td>--</td>
</tr>
<tr>
<td>Caproic</td>
<td>6</td>
<td>0</td>
<td>1.8</td>
<td>Tr</td>
</tr>
<tr>
<td>Caprylic</td>
<td>8</td>
<td>0</td>
<td>1.4</td>
<td>4</td>
</tr>
<tr>
<td>Capric</td>
<td>10</td>
<td>0</td>
<td>3.0</td>
<td>3</td>
</tr>
<tr>
<td>Lauric</td>
<td>12</td>
<td>0</td>
<td>3.4</td>
<td>32</td>
</tr>
<tr>
<td>Myristic</td>
<td>14</td>
<td>0</td>
<td>12.4</td>
<td>12</td>
</tr>
<tr>
<td>(15 branched)</td>
<td>14</td>
<td>1</td>
<td>0.8</td>
<td>--</td>
</tr>
<tr>
<td>15 carbons</td>
<td>15</td>
<td>0</td>
<td>2.1</td>
<td>--</td>
</tr>
<tr>
<td>(16 branched)</td>
<td>16</td>
<td>0</td>
<td>Tr</td>
<td>--</td>
</tr>
<tr>
<td>Palmitic</td>
<td>16</td>
<td>0</td>
<td>33.3</td>
<td>11</td>
</tr>
<tr>
<td>(17 branched)</td>
<td>16</td>
<td>1</td>
<td>1.6</td>
<td>Tr</td>
</tr>
<tr>
<td>17 carbons</td>
<td>17</td>
<td>0</td>
<td>1.6</td>
<td>--</td>
</tr>
<tr>
<td>Stearic</td>
<td>18</td>
<td>0</td>
<td>11.3</td>
<td>12</td>
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<td>1</td>
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<td>10</td>
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<tr>
<td>Elaidic</td>
<td>18</td>
<td>1</td>
<td>----</td>
<td>13</td>
</tr>
<tr>
<td>Linoleic</td>
<td>18</td>
<td>2</td>
<td>1.5</td>
<td>2</td>
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</table>

*From Miller*
It is easy to see that milk fat is unique in that it contains many different types of fatty acids compared to non-dairy fat. Miller (36), lists only the most prevalent fatty acids. Jensen et al., (16) indicated that over 142 different fatty acids have been reported in milk fat. Processing techniques and special blending can provide non-dairy fats that are specialized for non-dairy toppings. This can give a high degree of predictable success from batch to batch. In contrast, dairy products, limited to a single fat system--milk fat, with a high degree of unsaturated fatty acids, are highly susceptible to processing, handling and compositional changes. This quite often results in a large number of dairy returns. The fat globules in normal milk fat range from 0.8 to 20μ in diameter. Globules of this size have a tendency to cluster together causing a rapid creaming, or migration of the globules to the upper surface, in unhomogenized milk products (3). In a homogenized mix the fat globules range in size from 1 to 2μ or less in diameter (60). Sommer (46) described the forces that tend to drive the fat globules apart during the homogenization process as the force applied by shattering, shearing or explosion effect of the homogenizing valve and the natural repulsion of the fat globules due to their electrical charge. He concluded that the factors which tend to bring the globules together were the collision of the globules as they emerged from the valve of the homogenizer, the Brownian movement of the small globules, the cohesion of the adsorptive layer surrounding the globules, the interfacial tension between the globules in close proximity, and the concentration of the fat in the serum. Loo, Slatter and Powell (30) have presented evidence supporting cavitation or implosion as a primary cause of homogenization. The clumping or reag-
glomeration of the fat globules as they pass from the homogenization valve may, if marked, cause excess viscosity and reduce the whipping properties (3). This viscosity can be prevented by using low homogenization pressures, 800 to 1000 psig on the first stage and 500 psig on the second stage, and insuring that the mix is homogenized at, or slightly below, the pasteurization temperature. Knightly (24) has shown that the state of dispersion of fat in ice cream mixes is a combination of small individual globules, small clumps, some agglomerated clusters and coalesced clumps. Microscopic examination has shown that in ice cream the individual homogenized fat globules and clumps are dispersed in the serum lamella material in chain like arrangements surrounding the air cells (8). The state of the dispersed fat appears to have a direct correlation with the degree of foam structural stability. It has been shown that surface dryness in soft serve ice cream and novelties is highly desirable due to the good standup properties which usually accompany it. A considerable amount of evidence has been presented to show that the attainment of a desired degree of dryness in whipped milk fat products is accompanied by a partial and carefully controlled destabilization of the fat emulsion (51). Keeney (17) has shown that dryness in ice cream can be directly correlated with emulsion instability, and that the greatest dryness and stiffness was obtained where the maximum amount of clustering had taken place just short of churning. Kloser and Keeney (20) found that meltdown characteristics of an ice cream with a high proportion of destabilized and/or churned fat was very poor. The product would not melt to a smooth creamy consistency, but retained its original shape and structure even when exposed to temperatures which caused a complete thawing
of the ice crystals. This characteristic may very well be an advantage to frozen whipped toppings where stability of the foam after thawing is highly desired. Serum drainage can be controlled by using stabilizing agents; carrageenin has proven very good for this. Even though many investigators have recognized the destabilization phenomenon, primarily in recommending kinds of stabilizing and emulsifying agents, little data is available indicating the full degree of relevance it has on the ultimate product stability. Griffin, Amundson and Richardson (13) conducted extensive research on the effects of homogenization pressures on the production of a dairy-based dried whipped topping mix. They indicate that there are two major opposing factors resulting from the extent of homogenization. First, homogenization pressures dictated the fat globule size which was shown to have a direct influence on product overrun and stability. Large fat globules increase the foam stability, yet foster a low overrun, whereas small fat globules increase the overrun but develop a poor foam stability. The second and opposing effect is based on the assumption that the ratio of adsorbed surface active material per unit area of fat surface compared to that in solution remains constant. Thus if the fat globules are quite large resulting from low homogenization pressures, there would be less surface area exposed thus more surface active agent would be adsorbed per unit area. This would be conducive to high emulsion stability resulting in poor foam structure. Conversely, small fat globules resulting from high homogenization pressures, would have a large surface area thus there would be less surface active agent adsorbed per unit area, decreasing emulsion stability and influencing good foam structure. If this is the case, then a compromise must be reached to obtain the
homogenization pressure that will best optimize the overrun and stability of both effects. Griffin, Amundson and Richardson (13) indicate that an "intermediate" homogenization pressure was found to be preferable. Knightly (25) found that optimum topping properties were obtained when homogenization pressure was sufficient to produce fat globules of 2 to 3 in diameter. This pressure was found to be 100 psig on the first stage and 500 psig on the second stage. Thalheimer and Rusch (51) indicated that fat globules of 3 to 5 gave best topping properties. No data was found indicating optimum homogenization temperatures, however, nearly all processing techniques call for the topping mix to be homogenized at or near the pasteurization temperatures.

Protein. Protein serves several functions in the formulation of whipped toppings. Dissolved in the serum it forms a film which entraps the aerated gases and aids in the emulsification (33). It imparts body to the product and is a major contributor to flavor (25). In formulating a topping mix the protein quality and quantity is extremely important as it determines the strength and resilience of the lamella that surrounds the entrapped gases. Natural milk proteins have an added advantage in that they contain many lipoproteins including phospholipids and other neutral surface active materials adsorbed to the fat globule surface (25). Sodium casienate is the most common protein used in simulated dairy products (27). The Federal Filled Milk Act of 1923 (58) prohibited the use of milk solids in conjunction with non-dairy fats. In a study conducted by Knightly (26) it was indicated that sodium casienate leaves something to be desired when compared to non-fat dry milk (NDM) as a source of protein. He stated that vegetable fat toppings prepared from NDM form a more stable
emulsion with less syneresis and will aerate more readily to a higher peak overrun than similar toppings made with sodium caseinate as a source of protein.

**Sweeteners.** The primary function of sweeteners in whipped toppings is to impart flavor and body characteristics and provide a low-cost source of solids (25,26). Most commercially sweetened whipped creams contain about 7% sucrose (25), whereas non-dairy toppings may contain as much as 20 to 30% sweetening agent (31). Corn syrup solids are commonly used in dairy-type products due to their low-cost (26), and may be added to increase solids without appreciably increasing sweetness. Low conversion corn syrups may be used to impart additional viscosity and body (25,32). The level of sweeteners in a topping may have an effect on the degree of fat destabilization and dryness of the product. Kloser and Keeney (20) found that fat in ice cream mixes, containing 13% sucrose, was more easily destabilized than that in mixes containing more sucrose. They explained that mixes with a 13% sucrose concentration had a high initial freezing point, and thus were frozen to a critical stiffness at freezer operating temperatures of -5°C. This caused a marked acceleration of fat destabilization. Other mixes, with more sucrose, had lower freezing points, and did not have as much frozen water at the operating temperatures. Therefore they were not sufficiently stiff or concentrated to adversely affect the fat stability. In whipping cream it has been found that sugar has the least deleterious effect on overrun and stability if added after whipping has commenced (40). No work was found indicating any significant effect on whipped topping mixes caused by time of adding sugar.
Stabilizers. Hydrophilic colloidal gums are used to control viscosity, improve body and texture, inhibit the growth of ice crystals, improve freeze-thaw stability in frozen products and prevent syneresis (26). In toppings of low fat or total solids content the need for colloidal gums to improve body and gas retention by strengthening the air cell structure is great (25). Many colloids are available (11), however, carrageenin, a seaweed extract, is unique for use with dairy products because of its reaction with casein. This improves the colloidal protein dispersibility (14,43). Complexing of carrageenin with casein improves protein solubility and aids in the prevention of syneresis and protein precipitation (25). In aerosol whipped toppings carrageenin is used to produce a more persistent foam and a product with a stiffer drier texture (11). Whipped toppings made with methyl, hydroxypropyl methyl (Methocel \textsuperscript{R}, Dow Chemical Co.) (10), and hydroxypropyl (Klucel \textsuperscript{R}, Hercules Inc.) (23) ethers of cellulose exhibit very good body and texture characteristics when compared to toppings with other colloids (25,26). These colloids generally impart excellent overrun and stability, however, their combination with carrageenin is recommended for toppings with firm stable foams (45). The level of stabilizers used in a topping will vary considerably depending upon the solubility of the protein, processing techniques and salt balance of the emulsion. The level of colloids used for improving body and texture is primarily dependent upon the percent total solids in the mixture, particularly the fat (25). Common gums such as carboxymethylcellulose and the alginates, which do not adversely affect milk protein stability (14), are excellent colloids for this purpose (11). In frozen toppings where ice crystallization can destroy emulsion
stability, the level of colloids will generally be high. This is needed to improve the freeze thaw stability. Stabilizing colloids reduce the amount of water available for freezing and aid in inducing the formation of fine ice crystals (25). Experimentation has shown that it is most desirable to blend or combine several colloids to obtain the desired characteristics. This permits capitalization on the advantages of each and on their synergistic characteristics (11,45).

**Emulsifiers.** One of the most important considerations in a whipped topping formulation is emulsification. The term "emulsifier" as it is used in the food industry today, is actually a misnomer as emulsification agents generally act as whipping agents and as surfactants for promoting dryness (21,47,51). Knightly (25) indicated that surfactants are necessary to induce stable emulsions and to improve the rate and degree of aeration during whipping. Adsorption of the surfactant at the fat globule surface reduces the fat-water-interfacial tension, and enhances the film forming ability of the protein solution. Food surfactants can be categorized by function, source, ionization tendency, chemical type and solubility tendency (50). However, they are most commonly divided into two categories: (a) glycerols or sorbitan esters of fatty acids and (b) polyoxyethylene derivatives of fatty acids, or their glycerol or sorbitan esters (21). It has been shown that dryness and stiffness in aerated emulsions result from partial destabilization of the emulsion and agglomeration of the fat (19). Kloser and Keeney (20) found that the polyoxyethylene derivatives were very effective fat destabilizers and drying agents, with polyoxyethylene sorbitan monooleate being the most effective. Stistrup and Julin (48) indicate that lactylated distilled monoglycerides also pro-
moted effective fat destabilization. The degree of saturation of the fatty acid radical was extremely important in determining the effect of the emulsifier. Unsaturated fatty acids, because of their effect on the protein in the emulsifier system, are very effective in destabilizing the emulsion (25) and imparting dryness and melting resistance (47). Because of this weakening effect on the protein film strength (27) the use of surfactants with unsaturated fatty acid radicals should be approached with caution. The best concentration of surfactants will vary depending upon the overall formulation of the mix and the qualities desired in the topping (25). It has been the general consensus of the food industry that for most applications a blend of lipophilic and hydrophilic surfactants usually provides better results than the use of either type alone. Recent studies have challenged this concept (34,35,52). Mickle (34) contends that a single emulsifier, with the proper solubility, can lend the same properties to a food product as the blend of emulsifiers regularly used. This theory is based on the fact that the most important single factor governing an emulsifier's performance is its water-fat solubility ratio. The measurement of the water-fat solubility of an emulsifying agent is difficult. Precise techniques involve the use of gas chromatography (32). A more common expression of the emulsifier solubility is the hydrophilic/lipophilic balance (HLB). Knightly (27) and Thalheimer and Rusch (50) described the HLB on a scale of 1 to 20, which is an indication of the percentage by weight of the hydrophilic portion of the molecule divided by five. This provides a range of numbers that are easy to work with. Surfactants with low HLB numbers are generally lipophilic, more soluble in lipids than in water, and those with high numbers are generally
Table 2. Hydrophilic-lipophilic balance (HLB) as an indication of non-ionic surfactant function\textsuperscript{a}

<table>
<thead>
<tr>
<th>HLB Range</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - 6</td>
<td>W/O emulsifier</td>
</tr>
<tr>
<td>7 - 9</td>
<td>Wetting agent</td>
</tr>
<tr>
<td>8 - 18</td>
<td>O/W emulsifier</td>
</tr>
<tr>
<td>13 - 15</td>
<td>Detergent</td>
</tr>
<tr>
<td>15 - 18</td>
<td>Solubilizing agent</td>
</tr>
</tbody>
</table>

\textsuperscript{a}From Thalheimer Part I

hydrophilic, more soluble in water than in oil.

Investigations have shown that for whipped toppings a blend of surfactants that is predominately lipophilic results in optimum product body and texture characteristics. Knightly (27) explained that only a small amount of hydrophilic surfactant is needed to reduce the surface tension whereas a large amount of lipophilic surfactant is necessary to cover the fat globule surface. The more finely emulsified the fat the greater the surface area per unit weight of fat, thus the more surfactant required. He further indicated that blends in the HLB range of 6 to 9 were best for whipped toppings. In studies conducted by Titus et al., (53) and Govin and Leeder (12) it was shown that the fat content has a more decided effect on the emulsion stability than the HLB number or concentration of emulsifier. Titus et al., (53) found that for systems containing 15 to 30\% fat, which would include most whipped toppings, the optimum HLB number would be between 9 and 11. The HLB number should be used as a guide with other factors, such as chemical compatibility and ionization potential in selecting surfactants. As was the case with stabilizers,
high levels of surfactants must be used in frozen toppings to attain freeze thaw stability. The use of highly hydrophilic surfactants such as sorbitan esters and polyoxyethylene derivatives is governed by federal regulation (56) and cannot exceed 0.4 percent of the total topping mix in non-dairy products.

Salts. In processing whipped toppings there is sometimes encountered a "whey ing off" or syneresis. Syneresis may be defined as the separation of the protein from the serum due to lack of colloidal solubility of the protein (25). Certain salts such as calcium and/or magnesium can have a detrimental effect on the protein solubility. Other salts, primarily solubilized phosphates and citrates, have the ability to sequester calcium and magnesium reducing their effect on the protein stability and may, at low pH levels, react directly with the protein to aid its colloidal stability. In topping mixes where protein is important for emulsion stability the salt balance can be very critical. According to Keeney (18), ice cream mixes containing 0.2% citrate or phosphate showed the least amount of fat agglomeration. Klotzek and Leeder (22) showed that added citrates and phosphates retarded fat destabilization but would not prevent it. However, as Knightly (27) cautions, maximum emulsion stability is not always desirable as fat agglomeration has a decided effect on the dryness and stiffness of the product. His studies show that if more than the minimum stabilizing salts are used in the topping formulation the product will appear wet and slick. Templeton and Sommer (49) indicated that the addition of sodium citrate to whipping cream before pasteurization or after homogenization will decrease the product whipping time.
METHODS OF PROCEDURE

Source of ingredients

**Fat.** Sweet cream, standardized to 35% fat, obtained from the Utah State University (USU) Dairy Products Laboratory was used in the dairy-based toppings. Non-dairy fat used in the study was a commercial vegetable fat blend (CO-Freez A), with a melting point of 37.2 to 39.5°C, manufactured and distributed by Drew Chemical Corp. This blend is commonly used in frozen whipped toppings and coffee whiteners.

**Solids not fat.** Skim milk obtained from the USU Dairy Products Laboratory and NDM were combined in the appropriate ratio to provide the desired serum solids in the formulation.

**Sucrose.** Commercial fine granulated beet sugar was used.

**Corn syrup solids.** A 42 DE, regular conversion, corn syrup containing 80% solids was used.

**Stabilizer.** A combination of carrageenan and gum arabic was used.

**Emulsifier.** A laboratory blend of 0.19% polyoxyethylene monostearate (Tween 60), 0.19% polyoxyethylene tristearate (Tween 65) and 0.12% sodium stearoyl-2-lactylate (Emplex® Patco Products), based on the total weight of the mix, was used.

Processing procedures

Laboratory batches were processed and whipped in such a manner as to simulate as close as possible commercial conditions. The following procedures were used in all experimental trials except where indicated otherwise.
1. Stabilizer, NDM and sugar were dry blended to facilitate their solubilization.
2. The dry blend was added to the cream and skimmilk at 38 to 55°C.
3. The emulsifiers were melted in a hot water bath and added to the warm mix.
4. The mix was pasteurized at 74°C for 30 minutes.
5. The mix was homogenized, at or near pasteurization temperature, at 1800 psig total with 500 psig on the second stage.
6. The mix was cooled to 4.4°C or below and allowed to age for at least 4 hours, generally overnight.
7. Vanilla was added prior to whipping the mix to the desired consistency in a ten-quart Emery Thompson batch ice cream freezer.
8. Samples were packaged in plastic cups with snap lids, frozen and stored at -28.8°C.

**Physical measurements**

**Overrun.** The weight of the samples taken from the mixer was compared with the weight of the mix, and overrun was computed from the following formula:

\[
\text{Percent overrun} = \frac{\text{wt of mix} - \text{wt of same volume of topping}}{\text{wt of same volume of topping}} \times 100
\]

**Storage stability.** Whipped samples were immediately frozen after whipping and stored at -28.8°C for at least two weeks. Upon thawing the following changes are observed and recorded;

1. Changes in relative size of air cell
2. Foam shrinkage and/or weeping
3. Organoleptic changes in the general body and texture of the foam.
Product stability was also evaluated in terms of its ability to withstand several freeze thaw cycles.

**Foam structure.** The air cells of the samples were examined microscopically and recorded by means of photomicrographs. Foam smears about 1 mm thick were made on glass slides by placing a drop of foam between two parallel strips of double sticky Scotch tape, then covering with a glass cover slip pressing the foam to a uniform thickness. The slides were photographed at 100X magnification with a microscope mounted Polaroid camera (Polaroid Model ED-10) using fast ASA 3000 film with transmitted light through a blue filter lens.

**Flavor evaluation.** The flavor and acceptability of the whipped toppings were evaluated by a panel of three members of the Department of Food Science and Industries who were trained and experienced in sensory evaluation. Comparisons were made with whipped cream and commercial non-dairy frozen whipped toppings. Figure 1 shows the evaluation form. Overall acceptance was evaluated on a nine point hedonic scale with limits of "like extremely" to "dislike extremely." A + four point scale was used to determine any differentiation in sweetness compared to a sample of commercial frozen whipped topping. The foam structure of the product was compared with the preference of the judge on a five point scale with the limits of "dry, stiff" and "wet, weak."
# Whipped Topping Evaluation

**Overall Acceptability**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
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<tbody>
<tr>
<td>9</td>
<td>Like extremely</td>
</tr>
<tr>
<td>8</td>
<td>Like very much</td>
</tr>
<tr>
<td>7</td>
<td>Like moderately</td>
</tr>
<tr>
<td>6</td>
<td>Like slightly</td>
</tr>
<tr>
<td>5</td>
<td>Neither like or dislike</td>
</tr>
<tr>
<td>4</td>
<td>Dislike slightly</td>
</tr>
<tr>
<td>3</td>
<td>Dislike moderately</td>
</tr>
<tr>
<td>2</td>
<td>Dislike very much</td>
</tr>
<tr>
<td>1</td>
<td>Dislike extremely</td>
</tr>
</tbody>
</table>

**Sweetness**

<table>
<thead>
<tr>
<th>Difference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+4</td>
<td>Large difference</td>
</tr>
<tr>
<td>+3</td>
<td>Moderate difference</td>
</tr>
<tr>
<td>+2</td>
<td>Slight difference</td>
</tr>
<tr>
<td>+1</td>
<td>Very slight difference</td>
</tr>
<tr>
<td>0</td>
<td>No difference</td>
</tr>
<tr>
<td>-1</td>
<td>Very slight difference</td>
</tr>
<tr>
<td>-2</td>
<td>Slight difference</td>
</tr>
<tr>
<td>-3</td>
<td>Moderate difference</td>
</tr>
<tr>
<td>-4</td>
<td>Large difference</td>
</tr>
</tbody>
</table>

**Foam Structure**

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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>Wet &amp; Weak</td>
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<td></td>
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</tbody>
</table>

**Comments Please**
RESULTS

Formulation development

Variations in fat, total solids, sweeteners, stabilizers and emulsifiers were evaluated in developing a dairy-based whipped topping that would withstand the rigors of frozen storage. Table 3 shows the formula and ingredients necessary for a 100-lb batch. Most laboratory batches were from 25 to 60 lb, depending on the number of trials needed. The 25-lb batch was considered the minimum amount to process and still obtain adequate homogenization on the commercial equipment in the USU Dairy Products Laboratory. A similar formula was developed using vegetable fat instead of milk fat (Table 4). The experimental vegetable fat formulation was used as a control to compare with body and texture characteristics of the experimental milk fat formulation.

Fat content. Mixes ranging from 18 to 24% fat were studied. As the fat content increased from 18 to 24% the following occurred: the stiffness and dryness of the whipped product increased, higher overrun was reached with shorter whipping time, the product tasted richer, destabilization of the fat increased during whipping, thus increasing the tendency of shrinkage in the frozen product and the cost of ingredients increased. The 24% fat exhibited some shrinkage after thawing, whereas the 22% fat did not. The fat content selected was a compromise between the desirable and undesirable factors above. It was concluded that 22% fat was the desirable amount to use.
Table 3. Composition of dairy-based frozen whipped topping

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount (lb)</th>
<th>Fat (lb)</th>
<th>Solids not fat (lb)</th>
<th>Total solids (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cream, 35% fat</td>
<td>62.86</td>
<td>22.00</td>
<td>3.68</td>
<td>25.68</td>
</tr>
<tr>
<td>Skimmilk</td>
<td>8.28</td>
<td>0.72</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Non-fat dry milk (NDM)</td>
<td>3.20</td>
<td>3.10</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>12.00</td>
<td></td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>Corn syrup solids</td>
<td>10.00</td>
<td></td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Emulsifier</td>
<td>0.50</td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>0.19% polyoxyethylene sorbitan monostearate</td>
<td>(86.25 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.19% polyoxyethylene sorbitan tristearate</td>
<td>(86.25 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.12% sodium stearoyl-2-lactylate</td>
<td>(54.50 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stabilizer</td>
<td>0.66</td>
<td></td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>0.60% gum arabic</td>
<td>(272.40 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.06% carrageenin</td>
<td>(27.25 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>22.00</td>
<td>7.50</td>
<td>52.65</td>
</tr>
</tbody>
</table>

Table 4. Composition of frozen whipped topping containing vegetable fat

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount (lb)</th>
<th>Fat (lb)</th>
<th>Solids not fat (lb)</th>
<th>Total solids (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable fat</td>
<td>22.00</td>
<td>22.00</td>
<td></td>
<td>22.00</td>
</tr>
<tr>
<td>Skimmilk</td>
<td>48.94</td>
<td>4.21</td>
<td>4.21</td>
<td>4.21</td>
</tr>
<tr>
<td>NDM</td>
<td>3.40</td>
<td>3.29</td>
<td>3.29</td>
<td>3.29</td>
</tr>
<tr>
<td>Sucrose</td>
<td>12.00</td>
<td></td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>Corn syrup solids</td>
<td>10.00</td>
<td></td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Emulsifier</td>
<td>0.50</td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>0.19% polyoxyethylene sorbitan monostearate</td>
<td>(86.25 g)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.19% polyoxyethylene sorbitan tristearate</td>
<td>(86.25 g)</td>
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<tr>
<td>0.12% sodium stearoyl-2-lactylate</td>
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<tr>
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</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>22.00</td>
<td>7.50</td>
<td>52.65</td>
</tr>
</tbody>
</table>
**Total solids content.** A high solids content in the mix was desirable in that it provided stiffness and a basis for stable foam structure at high overruns (250 - 280%). Ingredients, other than fat, most suitable for increasing the solids content were sugar, corn syrup solids and milk solids-not-fat. It was considered desirable to keep the level of milk solids-not-fat relatively low so that the product would not have the flavor and mouth feel of ice cream. The sucrose content was somewhat limited by excessive sweetness. The corn syrup solids contributed a characteristic "corn" flavor. High and low DE corn syrup solids were evaluated without definite conclusions as to which was the more desirable. The liquid syrups were generally better from the flavor, or lack of flavor, standpoint than the dried syrup products. The low DE corn solids gave products with a higher freezing point. However, this did not appear to make any difference in foam stability during frozen storage. A slight advantage of a lower freezing point is that the product melted faster and was at a desirable eating consistency sooner after being taken from the freezer. Considering the above factors it was concluded that a good balance of ingredients was 12.0% sucrose, 10.0% corn syrup solids from liquid 42 DE syrup and 7.5% total milk solids-not-fat.

**Stabilizers.** The most important function of the stabilizer system is to prevent syneresis or serum separation of the topping after it has thawed. Other functions include increased stiffness and foam stability during freezing and storage. A limiting factor in the amount of stabilizer used is excess viscosity of the mix. This not only presents problems in physical handling of the mix during the heating and cooling process, but also retards whippability and limits
overrun. This is particularly true where air is not forced into the mix under pressure during whipping. Hydroxypropyl and methyl celluloses were used in combination with carboxymethylcellulose (CMC) in a number of trials. The general observation was that they did not contribute appreciably to the stability of a milk serum system. Toppings made with CMC had a tendency to synerese or allow serum separation after thawing. This was controlled by using carrageenan at concentrations of 0.04% or above, however, this combination yielded a mix with high viscosity making it undesirable to handle and whip. Guar gum, locust bean gum, gelatin and some alginate derivatives were tried in several combinations with varying degrees of success. The stabilizer combination found to give good results was a mixture of gum arabic and carrageenan. Gum arabic was used at relatively high concentrations without causing excessive viscosity and carrageenan appeared to contribute to protein stability and aid in preventing syneresis. Concentrations of 0.5 to 0.6% gum arabic and 0.05 to 0.06% carrageenan gave good results.

Emulsifiers. A number of emulsifier combinations including monoglycerides, mono-diglycerides, sorbitan monostearate, sorbitan tristearate, stearoyl lactylate and polyoxyethylene derivatives of sorbitan (Tween 40, Tween 60, and Tween 65) were evaluated. A combination similar to that used by Min (37) was selected. It consisted of 0.19% polyoxyethylene sorbitan monostearate (Tween 60), 0.19% polyoxyethylene sorbitan tristearate (Tween 65) and 0.12% sodium stearoyl-2-lactylate (Emplex, Patco Products). This combination gave a rapid whipping mix and provided a product with high overrun and firm foam structure.
Homogenization. Proper homogenization was considered essential for a good whipped topping. Fat globules should be less than 2 or 3 μ in diameter. Some clumping or clustering of small globules is desirable to promote rapid whipping and good product body. Homogenization at 500 psig on the second stage with 1500 to 2000 total psig gave satisfactory results. Higher pressures, 3500 psig, caused excessive viscosity in the mix which was undesirable.

Effect of whipping temperature and time on overrun

The data in Figure 2 show the effect of three different whipping temperatures on the overrun of the experimental milk fat formulation whipped for a period of time. By controlling the refrigerant of the freezer it was possible to maintain the product in the freezer at the desired temperature. This was accomplished by precooling the freezer to the desired temperature, then turning the refrigerant on and off for 3 seconds and 5 to 10 seconds respectively, depending upon the temperature being maintained, as the product was being whipped. The graph represents an average overrun obtained from two separate trials, each whipped at -2.2, 0.0 and 3.4°C. A fourth sample was whipped at -4.4°C, however, at this temperature the highest overrun obtained was 140%. Previous investigations had shown that this level of overrun was unacceptable for a whipped topping. The body was heavy and the texture was generally quite weak and slack. Though these data were not included in Figure 2, product samples were retained for further comparative study. Samples were taken for overrun evaluations at 5, 7, 9, 11, 13, 15, and 25-minute intervals providing a profile of the whippability at each temperature for that period of time. Figure 2
shows that overrun generally increased with whipping temperature. The highest overrun obtained was 187% from the product whipped at 3.4°C. This is compared to 182 and 171% respectively for samples whipped at 0.0 and -2.2°C. Organoleptic evaluations of the four samples after 18 days frozen storage indicated that the mix whipped at -2.2°C had the best body and foam structure. The body and foam structure of the product whipped at 0.0°C was only slightly less acceptable. The body of the product whipped at 3.4 and -4.4°C was quite weak. After three freeze-thaw cycles the product whipped at -2.2°C still exhibited the best body and texture.

Air cell configuration

Photomicrographs (100X) were taken of four types of toppings, (Figure 3) to show the significance of air cells. (A) Air cell structure of a freshly thawed commercial non-dairy frozen whipped topping¹, (B) Air cell structure of freshly whipped cream, (C) Air cell structure of experimental formulation containing milk fat, (D) Air cell structure of the experimental formulation made with vegetable fat. The four toppings are further illustrated in Figure 4 showing a general comparison of foam structures and the relative stiffness of each. The products in Figure 4, except for the fresh whipped cream, had been held in frozen storage for at least a month. There was little difference between the air cells in fresh whipped cream and the experimental milk fat formulation. The experimental vegetable fat formulation, however, contained a considerable number

¹ Commercial non-dairy frozen whipped topping used in this study was Cool Whip, distributed by Birds Eye Div., General Foods Corp.
Figure 4. A. Freshly thawed commercial non-dairy whipped topping  
B. Fresh whipped cream,  
C. Freshly thawed experimental milk fat formulation  
D. Freshly thawed experimental vegetable fat formulation.
of very small air cells. This was in contrast to those found in both milk fat products, but quite similar to the commercial non-dairy product. The commercial non-dairy topping was whipped on commercial equipment to about 250 to 280% overrun, while the fresh whipped cream was whipped on a kitchen model Hobart mixer to about 150% overrun. The two experimental toppings were whipped on an Emery Thompson batch ice cream freezer. In evaluating the body and texture of these four types of topping it was interesting to note that the dryness and firmness of the commercial non-dairy topping was quite similar to that of the fresh whipped cream. The experimental vegetable fat topping had a slightly wet but firm foam, while the experimental milk fat topping appeared slightly wetter with a weaker foam than any of the others. This characteristic of the experimental milk fat topping was not overly objectionable because the stability of the foam after thawing was still quite good.

Effect of whipping temperature on air cell structure of dairy-based whipped topping

The difference in the air cell structure between the freshly whipped experimental dairy-based topping whipped at four temperatures is shown in Figure 5. As the whipping temperature was increased from \(-4.4{\degree}C\) (A), through \(-2.2{\degree}C\) (B) and \(0.0{\degree}C\) (C) to \(3.4{\degree}C\) (D) the size of the major air cells also increased. Thus, air cells in the product whipped at \(-4.4{\degree}C\) were the smallest while those in the product whipped at \(3.4{\degree}C\) were the largest. Samples were removed from the freezer after 18 days frozen storage. One set was thawed and subjected to 24 hours refrigerated storage (10C), while another set was subjected to 24 hours storage at room temperature (27C). Photomicrographs (100X) were
taken of each set at 2, 8, 16, and 24 hour intervals to show the relative growth of the air cells with time. The growth of the air cells in the sample whipped at -4.4C is shown in Figure 6, at -2.2C in Figure 7, at 0.0C in Figure 8, and 3.4C in Figure 9. The growth of air cells during the frozen storage period appeared negligible. When stored at 10C, following thawing, there appeared to be little discernable difference in the rate of air cell growth between the samples whipped at the different temperatures. Photomicrographs (100X) of the samples subjected to storage at 27C for 8 hours after thawing are shown in Figure 10. Accelerated growth of the air cell was evident. This can be seen by comparing air cell sizes of samples shown in Figure 10, whipped at the same temperatures, but stored at 10 and 27C respectively for 8 hours, (the B pictures of Figures 6 through 9 respectively). Air cell growth at 27C was so accelerated that beyond the 8 hour interval the air cells were so large that the technique used to prepare the slides did not reveal the true size of the air cells. There was a flattening of the air cell by the cover slip which exaggerated their size. A further demonstration of the effect of storage at 27C is shown in Figure 11. A sample of the product whipped at -2.2C (A) was removed from the 18-day frozen storage, thawed and kept at 10C for 24 hours. The sample was refrozen overnight, then rethawed and stored another 24 hours at 10C. A second sample (B) was treated in the same manner but held at 27C following each freezing cycle. As can be seen in Figure 11 a complete collapse of the foam structure occurred when the sample was subjected to storage at 27C.
Figure 11. Shrinkage of experimental milk fat formulation subjected to two freeze-thaw cycles after 18 days frozen storage:
(A) Held 24 hours at 10°C following each freeze cycle,
(B) Held 24 hours at 27°C following each freeze cycle.
Experimental vegetable fat formulation

The vegetable fat formulation was used primarily for comparison of body and texture characteristics with that of the milk fat topping. Overruns obtained with this formulation were generally comparable with those of the milk fat formulation whipped at -4.4°C. The photomicrographs (100X) shown in Figure 12 indicate significant differences between the air cell structure of the vegetable fat compared to that of the milk fat formulation. Air cells of the freshly whipped product are shown in A. After being frozen for 18 days the sample was thawed and stored at 10°C for (B) 4 hours, (C) 8 hours, and (D) 16 hours. The vegetable fat product contained a considerable larger number of very tiny air cells than did the milk fat product. This was evident in the freshly whipped product. In the milk fat topping the air cells appeared to grow in size and decrease in number while those in the vegetable fat product appeared to increase in number and decrease in size. There was a noted proliferation of the very tiny air cells while the larger air cells continued to grow, similar to those in the milk fat topping. Further comparison of the vegetable fat and milk fat topping is shown in Figure 13. The milk fat sample (A) and the vegetable fat sample (B) were subjected to one freeze thaw cycle following 18 days frozen storage. The vegetable fat sample had a more course structure, and the air cells were similar to those shown in (D) of Figure 12. The milk fat sample was slightly wet and weak, yet, it was still a highly desirable product.
Figure 12. Air cells (100X) in whipped experimental vegetable fat formulation, (A) Fresh whipped, (B) After 4 hours storage at 10C following 18 days frozen storage, (C) After 8 hours storage at 10C following 18 days frozen storage, and (D) After 16 hours storage at 10C following 18 days frozen storage.
Figure 13. Comparison of experimental milk fat formulation (A), and experimental vegetable fat formulation (B), after one freeze-thaw cycle at 10°C following 18 days frozen storage.
DISCUSSION AND CONCLUSION

A dairy-based whipped topping was developed that would satisfactorily withstand the rigors of frozen storage. The best formulation consisted of 22% milk fat, 7.5% milk solids-not-fat, 12% sucrose, 10.0% corn syrup solids, and 1.16% stabilizer/emulsifier. The total solids in the formulation was 52.65%. The levels of fat and stabilizer/emulsifier system were considered the most critical factors in the development.

As the fat was increased from 18 to 24% there was a marked increase in dryness and stiffness of the whipped product. Dryness and stiffness were essential for good foam stability, especially during frozen storage, and were necessary characteristics of a satisfactory whipped topping. Other investigators have shown that fat destabilization is conducive to the dry stiff effect, consequently increased fat levels apparently contributed to an increase in fat clumping and clustering. A critical point of destabilization was reached at a level of 24% fat, where there was a considerable amount of visible churned fat accumulated around the hub of the beaters. This was evidence of excess fat destabilization which caused rupture of air cells and product shrinkage during storage. Frozen whipped samples containing 24% fat exhibited up to 25% shrinkage when thawed. A level of 22% fat gave a product with satisfactory dryness and stiffness with no significant shrinkage after thawing. Whipping temperatures less than -4.4°C appeared to enhance fat destabilization and caused shrinkage in the final product.
The primary consideration in selecting 12% sucrose and 10% corn syrup solids was to provide adequate, but not excess sweetness, yet make a substantial contribution to the overall total solids of the mix. Dried syrup products imparted a slight "corn syrup" flavor which was considered quite objectionable. Of the various liquid syrups evaluated, the 42 DE syrup with 80% solids gave good results and contributed no detrimental flavor. At overruns of 250 to 280%, sweetness was toned down considerably and volatile flavors were enhanced.

The selection of stabilizers was based primarily on their compatibility with a milk serum system. Knightly (25) claimed that hydroxypropyl and methyl celluloses exhibited unique characteristics in stabilization of non-dairy whipped toppings, primarily because of their film-forming characteristics. These stabilizing agents were used in combination with carboxymethylcellulose (CMC) in a number of trials. The general observation was that they did not add appreciably to the stability of a milk serum system. Toppings containing CMC tended to syneresis or allow serum separation after thawing. When carrageenin was added to control syneresis, the viscosity of the mix increased to undesirable levels. The mix was hard to handle during processing and did not aerate readily. Other combinations of guar gum, locust bean gum and various alginates were evaluated with little success. A combination of 0.06% carrageenin and 0.60% gum arabic gave good results. The advantage of gum arabic was that it was highly soluble in aqueous solutions and could be used in high concentrations without causing excess viscosity. Carrageenin could be used in higher concentrations with gum arabic than was possible with most other stabilizing colloids.
Probably the most important factor in the mix formula was emulsification. The physical as well as the chemical aspect of emulsification was considered. High homogenization pressures (3500 psig) and double homogenization caused excessive viscosity in the mix, and in some instances induced a consistency of a thick pudding. Homogenization at 500 psig on the second stage and 1500 to 2000 psig on the first stage gave satisfactory results. A number of emulsifying agents were used and evaluated. The combination that appeared to promote the proper degree of fat destabilization (at the 22% fat level), yet not permit excessive churning, was 0.19% Tween 60, 0.19% Tween 65 and 0.12% sodium stearoyl-2-lactylate (Emplex, Patco Products).

The temperature at which the product was whipped had little effect on the rate of aeration, but did affect the amount of overrun. Increasing whipping temperature from -4.4 to 3.4°C stimulated higher overrun. Evaluation of the final product indicated that a whipping temperature in the range of -2.2 to 0.0°C was satisfactory. Samples of the mix whipped at -4.4°C then subjected to frozen storage and thawed, appeared quite wet and weak, as did samples whipped at 3.4°C, though not as pronounced. Earlier experiments indicated that freezing of the product in the mixer resulted in excess destabilization of the fat and shrinkage of the final product during storage.

There was little apparent change in the configuration of the air cells during frozen storage, regardless of the temperature at which the product was whipped. However, upon thawing several undesirable changes took place. The first of these was an enlargement of the air
cells to form a course looking product with frothy mouth feel. The photomicrographs illustrated this change very well. Air cells in products thawed and held at room temperature (27°C) enlarged at a much faster rate than did those in products kept in the refrigerator (10°C) after thawing. Toppings made with vegetable fat were more resistant to this change than were the milk fat toppings. In fact, the vegetable fat toppings appeared to exhibit an inverse of the tendency of air cell growth which was noted in the milk fat toppings. In this product there was an apparent proliferation of smaller air cells with time in storage instead of the usual enlargement of air cells with storage time as noted in the milk fat samples. The most likely explanation for this phenomenon is that a portion of the gases were actually dissolved in the serum phase. As the product warmed during thawing, and 10°C storage, the natural tendency for air cell growth took place. However, the air cells grew from submicroscopic size to a visible range which appeared in the photomicrographs. The interfacial tension between the gas phase and liquid serum phase is apparently sufficient to retard the normal coalescence of small cells with larger air cells, thus as the new air cells grew to a certain size they appeared to increase in number rather than in size. In the milk fat system the coalescence of the air cells was apparently not as restricted, thus as the dissolved gases formed new air cells they were immediately absorbed into larger air cells.

Another undesirable change that took place in the thawed milk fat sample was the development of a stale flavor after about 10 days refrigerated storage. This factor could have a significant impact on ultimate consumer acceptance.
Several samples were whipped on a Creamery Package 3M-30 continuous type ice cream freezer. Overruns of 260 to 280% were obtained with a discharge temperature of -2.2 to -1.0°C. The machine had a separate air pump to force air into the mix and provided considerably more whipping action in the barrel than was obtainable in laboratory trials. After 10 months frozen storage the only undesirable defects noted in the product upon thawing was a stale flavor and some drying around the wall of the container. The body and texture were similar to the product thawed after 18 days frozen storage. This provides considerable evidence of the feasibility of eventual commercial application of this experimental formulation.

Additional studies should be made to determine the exact degree of fat destabilization present in the product whipped at different temperatures. It has been shown that the formulation will withstand frozen storage, however, more critical methods of analysis of foam stiffness and texture preference may provide a more satisfactory product. Other combinations of stabilizers and emulsifiers may be found to provide better results. In light of Mickle's (34) recent contentions, there may very well be a single emulsifying agent that will give satisfactory results. This would lend considerable economic advantage.
LITERATURE CITED


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