THE ROLE OF ADDED NONFAT DRY MILK SOLIDS AND THE PRESSURE OF HOMOGENIZATION ON THE STABILITY, VISCOSITY, AND OTHER PROPERTIES OF HALF-AND-HALF HOMOGENIZED MILK

By

Eiler Shirley Humbert

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Dairy

Year 1954

Approved ____

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ABSTRACT

Investigations encompassing 5 to 7 series and involving 105 different samples were conducted on various physical, chemical, and organoleptic properties of half-and-half homogenized milk processed under various conditions. Data obtained indicated that the viscosity and heat stability of 10.5 percent half-and-half, without added nonfat dry milk solids, were similar to those previously reported for homogenized milk.

As the fat percentage increased, the product became increasingly more sensitive to homogenization so far as the resultant stability of the samples was concerned.

Extensive trials showed that half-and-half was stable in coffee made with hard, tap water. However, when the coffee was made with distilled water, the half-and-half occasionally feathered. Although the addition of nonfat dry milk solids to half-and-half provided some buffering action against the effects of the destabilizing ions, fortification with these solids did not improve the stability of half-and-half against feathering in hot, distilled-water coffee.

The rate of migration of the fat globules in an electrical field increased as the result of homogenization.

EILER SHIRLEY HUMBERT ABSTRACT

When homogenized-induced fat clumping was evident, the addition of the emulsifier, sorbitan monostearate, reduced the viscosity and increased the heat stability of half-and-half and cream.

The dry-weight analysis of the feathered material from half-and-half and cream indicated that, in addition to 81 to 94 percent fat, over 40 percent of the original colloidal casein was present in the precipitate. However, only a small percentage of the heat-coagulable protein fraction was found in this feathered material.

It may be concluded that homogenization of half-and-half testing 10 to 11 percent fat does not produce the instability as has been experienced with table cream. If feathering of half-and-half does occur in coffee, the factors which should be considered, in order of importance, are: (1) quality of ingredients in the half-and-half; (2) pH of the coffee brew; and (3) pressures of homogenization.

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ACKNOWLEDGMENTS

The author wishes to express his sincerest appreciation to Dr. G. M. Trout, Research Professor of Dairying, for his valuable direction and encouragement during the course of this study, and for his assistance in the preparation of this manuscript. The author is deeply indebted to Dr. J. R. Brunner, Assistant Professor of Dairying, for his helpful suggestions and assistance in many of the techniques used in this study.

Grateful acknowledgment is due Dr. Earl Weaver, Head of the Dairy Department, for making available a graduate assistantship and the facilities that were necessary in the fulfillment of this investigation.

The author also wishes to express his deepest gratitude to his wife, Jean, for her encouragement, assistance, and many sacrifices that she has made, without which this thesis might never have been possible.

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INTRODUCTION

Half-and-half homogenized milk, a product testing between 10 and 13 percent fat and 8 to 10 percent solids-not-fat, was introduced into the State of Michigan in 1952. Half-and-half was defined by the Michigan Department of Agriculture (1952) as "a homogenized product resulting from combining or mixing milk and cream, with or without the addition of nonfat milk solids, and shall contain not less than 10.0 percent butterfat and shall have a specific gravity at 60 degrees Fahrenheit not greater than 1.033."

While this product is still relatively new in Michigan, it has been distributed in many other states for some time. It has been sold in these areas under such names as "breakfast cream," "cereal cream," "cereal treat," and "cereal milk." Trade names also commonly associated with this product are "Mel-O-Rich" and "Tasty-Rich" (Trout and Weinstein, 1950). Nevertheless, this product was not recognized by the United States Public Health Service until 1953, when it was defined as "a product consisting of a mixture of milk and cream which contains not less than 11.5 percent fat."

The importance of this product in the dairy industry cannot be minimized. Although only a few reports are available (Colebank, 1953; Coles, 1952a, 1952b, 1952c), these have emphasized its increasing importance during the past few years.

Among the advantages suggested, the chief one seems to be its palatability. Due to the lower butterfat content, the product does not have too rich a taste; hence, more of the public seems to prefer its use on cereal. Half-and-half, when properly processed, also competes favorably with table cream so far as coloring ability in coffee is concerned. In addition, many creamery operators feel that this product has merit in its lower cost, thus opening new fields for selling. At the same time, the product can still take the place of table cream successfully.

On the other hand, some possible potential disadvantages have been mentioned. Many creamery operators fear that, through the introduction of half-and-half, a decline in total butterfat sales might occur. These operators feel also that they are merely adding a new product to their already long list of small operations in their plants. Some consumers dislike this lower-fat product because it lacks richness in taste, and does not color the coffee in the same manner as table cream.

Although half-and-half has been on the market in various areas for some time, while being introduced only recently in others, limited research has been undertaken in this field. Voluminous studies, however, have been conducted with the 18-percent-fat product, table cream. Unfortunately, the results obtained on the latter product sometimes have been applied directly to half-and-half. With such a difference in composition between the two products, this would certainly not seem advisable in all cases.

The manufacture and introduction of half-and-half have not been without their problems, one of which has been feathering in coffee. The physico-chemical properties of this reaction, as applied to a high solids-not-fat to fat product, such as half-and-half, have not been satisfactorily explained. In addition, the influence of variations in specific processing techniques also seemed to require further exploration. To these ends the present study was made.

REVIEW OF LITERATURE

Little available information regarding the properties of half-and-half homogenized milk appears in the literature at this time. However, extensive studies have been conducted on both the higher-fat product, table cream, and upon regular- and high-fat milks. The general findings of these studies which might pertain to half-and-half have been included so that the review on the subject might be as thorough as possible.

Viscosity

Definition. Davies (1939) defined the viscosity of a liquid as follows:

> The internal friction or its resistance to shear, agitation or flow, measurable in absolute units--the poise--which may be defined as the force required to produce a difference in the velocity of flow of a liquid 1 cm. per sec. when this force is exerted on 1 sq. cm. between two parallel planes, each 1 sq. cm. in area and 1 cm. apart. The viscosity is usually expressed in centipoises, the standard being that of water at 20° C. (= 1.005 centipoises).

Viscosity of homogenized milk and cream. Bishop and Murphy (1911) conducted one of the earliest organized investigations on homogenized milk and cream. Using a glass plate held at an angle, they observed greater viscosities in creams homogenized at 140° F. than at 70° F. Babcock and Russell (1896) had previously suggested that casein exerted a greater influence on consistency than fat, and, in milk, was the chief factor, while in cream, the fat assumed a more important role because of its high percentage.

Doan (1938) stated that the viscosity of homogenized milk was higher than unhomogenized. This was attributed to the clumping phenomenon (Doan and Swope, 1927), but it was noted that this did not become apparent until about 4 to 6 percent fat was present. Doan (1927) further explained that when fluid milk or cream containing 8 percent or more fat was homogenized at a pressure of 2,000 to 3,000 pounds, the globules were greatly reduced in size and tended to clump together with the clumps showing a tendency to arrange themselves in such a fashion that they occupied the greatest possible space. Doan (1929a) added that this clumping of the small fat globules in homogenized mixtures was greatly stimulated by an increased fat content, and also by increased homogenization pressures.

Investigating the influence of temperature on homogenization, Trout and Scheid (1941) stated that little or no dispersion of the fat globules occurred until the fat approached a liquid state. Moreover, Trout, Halloran, and Gould (1935) found that the reduction in size of the fat globules was greater when the homogenization was done at 145° F. than at 90° F. at any given pressure of homogenization.

From the results of similar studies, Whitaker and Hilker (1937) indicated that no clumping of fat globules was noted in any of the homogenized milks processed at 90° F. or less, with very slight clumping being noted above 100° F. Doan and Minster (1933) obtained the greatest degree of fat clumping in very-high-fat homogenized milk, when the sample was preheated at 145° F. and processed at 100° F. or lower. This led to the conclusion that, in general, the greater the drop in temperature between preheating and homogenizing, the greater was the clumping tendency. However, when the preheating and homogenizing temperatures were increased to 180° F., no fat clumping was found in the samples containing up to 10 percent fat.

Doan (1929a), in studying the effect of plasma solids in clumping, postulated that a limiting factor in the fat clumping phenomenon was the ratio of the amount of plasma solids to the amount of fat in the mixtures processed. A critical ratio was suggested above which no clumping was obtained, but below which clumping was evident or even pronounced.

Trout and Weinstein (1952) noted that single-stage homogenization induced varying degrees of fat clumping when the fat was 10 percent or more, and that a pronounced increase in viscosity was present after 48 hours of storage at 40° F. With two-stage homogenization, however, fat clumping was reduced to a minimum and very little change in viscosity occurred after the same length of storage. Doan (1931a) also pointed out that, while dual homogenization made it possible to use a much higher total pressure, thus increasing the efficiency of homogenization, it also reduced the viscosity.

Factors Affecting the Stability of Milk and Cream

Introduction. The variability of milk towards heat coagulation was noted by Holm, Webb, and Deysher (1932). From an investigation of milk from individual cows during their lactation periods, wide variation was observed. These authors emphasized that a wide difference existed in the properties of milk as indicated by the lack of correlation in their data. Cole and Tarassuk (1946) reported much the same results. They found considerable variation between the samples of cows' milk so far as coagulation time at a given temperature was concerned.

Homogenization. Whittier and Webb (1950) suggested that the heat stability of milk and cream was affected by the temperature, pressure of homogenization, and by the fat and solids-not-fat content.

A report by Doan (1929a) noted that protein stability in homogenized mixtures decreased with increasing pressures of homogenization. He added that the fat-clumping tendency was found to parallel very closely the stability of the proteins, with a decrease being noted as the clumping increased. This was verified by a subsequent report of Doan (1931a), when he concluded that the degree of fat clumping in normal, sweet, homogenized cream was probably the most important single factor affecting the stability of the cream towards heat.

Webb (1931) explained that coagulation of such a hydrophilic colloid as casein depended upon the destruction of its water-holding capacity and upon the flocculation of the denatured particles. Using a cryoscope to determine bound water, Pyenson and Dahle (1938) showed that homogenization of ice cream mixes, with one pressure, produced an increase in viscosity, but decreased the bound-water content. Dual homogenization, they pointed out, increased both bound water and viscosity.

An endothermic reaction was shown by Leighton and Mudge (1923) to have accompanied the coagulation of casein of milk, when this coagulation was brought about by heat. This phenomenon was attributed to the precipitation of calcium and magnesium as citrates and phosphates.

However, tests conducted by Sullam (1942) with alcohol, acetone, and neutral salts indicated that homogenization increased the stability of milk.

Solids-not-fat. The solids-not-fat apparently play an important role in the heat stability of milk and cream. Doan and Minster (1930) reported that, under some conditions, added solids increased the stability of cream as compared with the product homogenized at a normal solids content. However, Webb (1931) stated that an increase in the concentration of milk-solids-not-fat greatly decreased the coagulation time, expressed as heat stability, of both the untreated and homogenized creams. The conclusion was drawn from this investigation that as the solids content increased, the stability of the homogenized sample tended to approach that of the untreated cream. Furthermore, Doan (1931a) cautioned against using excessive amounts of condensed skimmilk or skimmilk powder, as this could cause a loss of stability.

Processing temperatures. Whittier and Webb (1950) felt that the actual temperature of homogenization was more important than the prehomogenization heat treatment when nonconcentrated, high-fat products were used.

Trout, Halloran, and Gould (1935) reported that, while homogenization decreased the protein stability of milk toward alcohol, the milk pasteurized before homogenization was considerably more stable to alcohol than homogenized raw milk.

Doan (1929b) attributed this heating effect possibly to the reduced amount of soluble calcium, thus making the protein more stable to the effect of homogenization. Working with homogenized milks ranging from 0 to 10 percent, Doan and Minster (1931) found that a high preheating temperature tended to inhibit or limit fat clumping which consequently reduced the loss of stability upon homogenization. This, they continued, would not eliminate fat clumping in any of the mixtures containing over 7 percent fat, if the mixture was subsequently processed at the low temperature of 100° to 120° F. This indicated to these investigators that the precipitation of calcium ions was probably not as important as had been thought.

Webb and Holm (1928) suggested that the maximum heat stability for any percentage of butterfat as high as 30 percent could be attained by having cream preheated to 80° C., with the exception of those with low fat content and low homogenizing pressures, where 90° C. slightly increased the stability.

In general, Doan (1931a) thought that cream should not be homogenized at a temperature lower than that at which it was preheated unless this was 170° F. (76.6° C.) for 30 minutes, or 180° F. (82.2° C.) flash. In order that the heat stabilities of creams containing more than 15 percent fat be increased, Webb (1931) stated that double homogenization at 80° C. (176° F.), with the second stage in the vicinity of 500 pounds, would be beneficial. These results were verified by the work of Whittier and Webb (1950), who contended that if the creams were heated to the optimum homogenizing temperature, 176° F., and then cooled and homogenized at a lower temperature, such as 140° F., their heat stabilities would be almost as low as if both heating and homogenizing were done at 140° F.

The results of Pyenson and Dahle (1938) indicated that the heating of milk to high temperatures decreased the bound-water content, but increased the stability towards alcohol.

Effect of Salts on Stability of Milk and Cream

State of components in milk. Rogers (1935) reported that casein was entirely in suspension. This author pointed out, however, that whether casein existed in combination with calcium alone, with calcium phosphate, whether the aggregate was a combination of calcium caseinate with calcium phosphate, or whether sodium was involved, was a question still in doubt at that time.

In an early study, Van Slyke and Bosworth (1914) stated that the protein combined with calcium amounted to 3.20 percent. In 1915, these same investigators noted that the belief at that time suggested that milk casein was combined with calcium (about 1.07 percent), which formed a calcium caseinate salt, and in addition, the casein was believed to be chemically combined directly with calcium phosphate and that this protein was a double compound of calcium caseinate combined with calcium phosphate.

This calcium caseinate-calcium phosphate complex was isolated from milk by Ramsdell and Whittier (1944), through the use of an ultracentrifuge. On this basis, the complex was found to contain 4.80 percent tricalcium phosphate and 95.20 percent calcium caseinate. The calcium caseinate fraction of the complex was reported to contain 1.18 percent calcium.

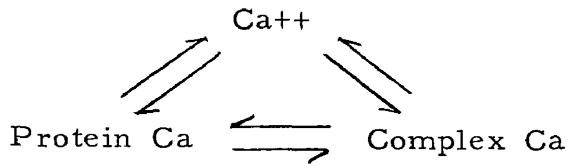
Previously, Pyne (1932) had suggested that calcium caseinogenate and the colloidal phosphate of milk existed in some form of chemical combination. Subsequent results of Pyne (1934) showed that this double salt consisted of calcium caseinogenate and tricalcium phosphate. Ter Horst (1947) added that the calcium combined with the phosphate in milk was in a quantity exceeding the solubility product of tricalcium phosphate.

Van der Burg (1947) postulated that this calcium caseinate kept in solution an amount of colloidal calcium and phosphate with the molecular ratio of this calcium and phosphate varying, being about 1 to 50 on the average. It was also believed that the calcium, united with the organic phosphate of the casein, formed the calcium caseinate.

Recently, Haurowitz (1950) reported that proteins combined particularly with calcium, magnesium, phosphate, and bicarbonate ions and the linkage they formed was so stable that the ions were removed neither by dialysis nor by electrophoresis, although they could be possibly removed by electrodialysis. In addition, this author explained that the stability of the bond formed was due to the high electrostatic attraction of the bivalent inorganic ions, whereas univalent ions were less firmly bound. Hence, it was reasoned that the cations were attracted to the negatively charged carboxyl groups, while the anions were bound to the positively charged group of the protein. Van der Burg (1947) added that the positive amino group of lysine took part in the binding of the negative phosphate groups; consequently only the negative carboxyl groups were left for the colloidal calcium.

Early investigations by Van Slyke and Bosworth (1916) suggested that the insoluble calcium in fresh milk was in combination with phosphoric acid as $CaHPO_4$ and with casein as Ca_4 caseinate. Ling (1936) reported that it was generally agreed that the major part of the colloidal inorganic phase consisted of calcium phosphate, but he noted that opinions were divided as to whether it was the di- or tricalcium phosphate. The results of his investigations showed that tricalcium phosphate accounted for almost all the colloidal inorganic phosphate of milk. Pyne and Ryan (1950) concurred by stating that about 88 percent of the colloidal phosphate appeared to be tricalcium phosphate with the remainder thought to be in the dicalcic form.

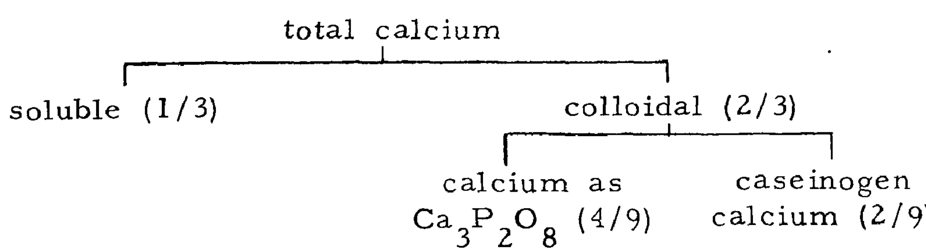
As Leighton and Deysher (1923) noted, the calcium and magnesium were probably present in milk in combination with proteins, as ions, or in un-ionized molecules and in an insoluble form. Seekles (undated) pictured the presence of calcium in milk as follows:



Seekles and Smeets (1947) explained the presence of calcium on the basis of its ultrafilterability; that is, an equilibrium existed between (1) ultrafilterable calcium bound to protein, (2) ultrafilterable calcium ions, and (3) calcium bound to ultrafilterable organic and inorganic complexes such as citrates and phosphates.

Nordbo (1939) calculated that only about 20 percent of the calcium was present in ionic form. As for magnesium, it was reported that a total of 0.4 to 0.5 mM. of magnesium ions were present in the ultrafiltrates of fresh market milk, while the total diffusable magnesium amounted to about 2.5 mM. per liter.

The state of calcium in milk was represented by Ling (1937) to be approximately as follows:



Effect of heating on state of components. When skimmilk was heated to 62°, 77°, and 100° C. for 30 minutes, and to 100° F. for 30, 60, and 90 minutes, Harmon and Slatter (1950) showed that in all cases the rate of diffusion of the calcium, phosphorus, and magnesium was decreased markedly, whereas the citric acid was apparently unaffected. These results substantially agreed with those of Bell (1925), who had previously reported that, with an increase in temperature, there was a corresponding loss of the soluble calcium and phosphorus content of skimmilk. He noted also that when the temperature of 170° F. was reached, no measurable amounts of these substances were removed from solution.

Verma and Sommer (1950) found a decrease in the amount of soluble calcium after pasteurization, but this tended to come to normal on cool aging, and at the end of 24 hours of storage at 45° F., the amount of soluble calcium in milk was higher than that contained in raw milk. Similar results were noted by Hilgeman and Jenness (1951), who, when using a heat treatment of 80° C. for 30 minutes, reported a 12 to 18 percent decrease in the dissolved calcium and inorganic phosphorus of skimmilk. A slow reversal of the effect was shown to occur on cool storage.

Van der Burg (1947) explained that by heating milk the colloidal calcium and phosphate were split off from the casein. In whey serum these salts were precipitated as tricalcium phosphate. This investigator also suggested that under these conditions, they were readsorbed by the casein.

As early as 1918, Sommer and Hart (1918) showed that citric acid was not destroyed on the heating of milk, even in an autoclave at 15 pounds pressure for one hour. Hence, it was concluded that the citric acid salts were not converted to the insoluble tricalcium citrate on heating.

Effect of salt balance. Some of the first significant investigations concerning the salt balance in dairy products were accomplished by Sommer. This investigator (1929a) considered the main factor in the alcohol coagulation test with milk to be the salt balance; that is, the amount of calcium and magnesium salts in the milk, as opposed to the amount of citrates and phosphates. Earlier, Sommer and Hart (1919) had explained that casein apparently required an optimum calcium content for its maximum stability, and, in addition, the calcium distributed itself chiefly to the citrates and phosphates. Hence, they postulated that if milk were high in citrates and phosphates, more calcium was necessary in order that casein could retain its optimum calcium content. In addition, they felt that if milk was high in calcium, there possibly would not be enough citrates and phosphates to compete with the casein in order to lower the calcium to the optimum. The function of magnesium was explained as a replacement of calcium in the citrates and phosphates.

Webb and Holm (1932) considered milk to have a certain critical salt concentration, beyond which rapid sensitization of the sol to heat occurred. They understood that the value of the critical salt balance depended on the solids content of milk and the precipitating ion. The action of added calcium was not considered to be the result of calcium itself, but rather that of the positive charge it carried. From their results it was concluded that the criterion for maximum stability was a critical balance of strongly positive cations as opposed to the action of heavy anions.

Doan (1929b) indicated that the calcium ion concentration, or amount of soluble calcium, was a prime factor which affected both fat clumping and protein stability. For stabilization purposes, Doan (1929b) showed that additions of sodium citrate, disodium phosphate, and sodium carbonate stabilized the proteins in both the homogenized and nonhomogenized samples, with the greatest increase in stability being shown in the homogenized portions. He thought it reasonable to suppose that some of the effect of these salts in stabilizing the protein was due to the fact that they precipitated soluble calcium. Doan (1931b) suggested that these salts should be added prior to homogenization.

Sommer and Binney (1923) noted that a slight increase in the magnesium or calcium content would cause a positive alcohol test, while increases in potassium, sodium, chlorides, citrates, and phosphates would not give a positive test.

A phosphate test, developed by Ramsdell, Johnson, and Evans (1931), showed that if milk, when mixed with a phosphate solution, coagulated upon immersion in boiling water, then this product was found to be of low heat stability.

Effect of acid on state of components. Doan (1929c) reported that the stability of the proteins was decreased by larger amounts of soluble calcium and higher hydrogen-ion concentrations. However, a report by Sommer and Hart (1919) had stated that in fresh milk, there was no relation between titratable acidity and heat coagulation, and it was concluded that the hydrogen-ion concentration was not the determining factor in fresh-milk coagulation.

Webb and Holm (1932) suggested that two different types of milk existed with respect to the effect of the hydrogen-ion concentration upon its heat stability. These investigators explained that an addition of acid, or a bacterial development of acid, in a milk either could increase or decrease its stability. The final effect, they explained, could be dependent on securing in the milk the optimum pH for the particular sample in question.

Miller and Sommer (1940) found milk to be very sensitive to pH changes, especially within two ranges; namely, from approximately 6.4 to 6.2 and to a lesser extent between pH 5.4 and 5.2. Between pH 6.6 and 6.4, the coagulation temperature showed very little change with pH.

Lampitt and Bushill (1934) reported that an increase in acidity by bacterial action materially increased the proportion of dialyzable calcium and inorganic phosphorus.

Benton and Albery (1926), using the alcohol test, suggested that whether the alcohol test was positive or negative did not prove anything as to the heat stability of that milk. They explained that by turning an alcohol-positive milk negative by the addition of citrates or other buffers did not increase the stability, unless the optimal combination of pH and salt balance was approached.

Effect of milk evaporation. A study of various processing techniques and their significance in evaporated milk would be of definite importance in the study of salts and heat stability in milk. Deysher, Webb, and Holm (1929) considered the heat stability of an evaporated milk to be dependent upon several factors, the most important of which was the temperature of forewarming, while homogenization affected stability to a lesser degree. Forewarming of a normal milk, according to Leighton and Deysher (1923), made the nonconcentrated milk less stable towards heat, but, if the milk had been concentrated after having been forewarmed, a much more stable product would result.

Rogers, Deysher, and Evans (1921) understood the effect of high forewarming in raising the coagulation temperature of evaporated milk as evidently being due to the precipitation of part of the calcium. If, however, the forewarming temperatures were much below 95° C. (203° F.), little effect was noted on the coagulation temperature. The results of Webb and Bell (1942) were in agreement, in that the stability of their test samples, which were forewarmed over a temperature range of 101° C. (213.8° F.) to 165° C. (329.0° F.) was increased as much as six times over that of the control samples forewarmed at 95° C. (203° F.).

As Deysher, Webb, and Holm (1929) had previously mentioned, homogenization appeared to be of secondary importance in the heat stability of evaporated milk. These investigators homogenized evaporated milk containing 18 percent solids-not-fat and 8 percent fat at pressures up to 4,000 pounds, and found that this treatment only slightly affected the heat stability.

However, Sommer and Hart (1922) considered the main factor in the heat coagulation of evaporated milk to be the salt composition in the milk. Other factors in order of importance according to Sommer (1923) were albumin content, acidity, and rennet-forming organisms. This investigator suggested that heat coagulation was more prevalent in winter because most cows were freshening or drying off at that time, and as a result, the albumin and calcium content of the milk were higher. The lower citric acid content of the milk in the winter was attributed to the lack of green feed. Sommer and Hart (1926) postulated that the high forewarming treatment not only precipitated a larger amount of calcium salts, but also coagulated the albumin to a greater extent.

Webb (1928) suggested that for every milk there was an optimum pH, the attainment of which would result in maximum heat stability for the system involved. Rogers, Deysher, and Evans (1921) pointed out, however, that there was no very definite relation between the coagulation of evaporated milk and the true acidity, although if a small increase in acidity occurred, a distinct lowering of the coagulating temperature of the evaporated milk was noted. According to Sommer and Hart (1926), the effect of a slight increase in acidity on the coagulation of evaporated milk was not due to the hydrogen-ion concentration as a direct factor, but rather to the indirect effect of the conversion of the secondary to primary phosphate.

Taking all factors into consideration, Webb and Bell (1942) indicated that the use of optimum high-forewarming temperatures brought about, in the milk tested, a greater increase in heat stability in the evaporated product than could be attained by the addition of an optimum quantity of stabilizing salts to a normally forewarmed milk.

Feathering

Characteristics. Doan (1931b) reported that feathering was characterized by the appearance of a flocculent, feather-like precipitation upon the admixture of unstable cream with hot coffee. This phenomenon of feathering of homogenized table cream and the coagulation of sterilized cream were both regarded as a heat coagulation of the casein similar to that encountered in the processing of evaporated milk. Sommer (1952) suggested that the scum which floated to the surface of the coffee, when added cream feathered, consisted of "coagulated proteins with enough occluded fat to float the particles."

Effect of quality of ingredients. From the results of their studies, Atherton and Bradfield (1952) thought that feathering of cream in coffee appeared as a result of an interplay of several factors, rather than by any one single effect. Webb and Holm (1928) pasteurized pure, fresh cream, testing 20 percent fat and 0.15 percent acidity, from 65° to 85° C., and homogenized at pressures up to 3,000 pounds with the general result that no feathering occurred. The opinion of these investigators was that the basic criterion as to whether or not cream would feather was quality.

Effect of pasteurization and homogenization. Dahlberg (1944) considered homogenization of 18-percent cream advantageous in that it increased viscosity, richness of taste, and coloring in coffee. In addition, cream plugs and skimmilk layers were eliminated, and fat losses by adherence to the bottle were reduced. The only objection voiced was increased feathering in coffee, a fault which he felt could be liminated by high-temperature pasteurization, low-pressure homogenization, and the use of very fresh cream of fine quality.

Burgwald (1923), however, had previously pointed out that pasteurization only had but little effect on feathering, although there was a tendency for pasteurized cream to feather at a slightly lower acidity than the same cream not pasteurized.

Maximum stability was obtained when Webb and Holm (1928) preheated cream at 80° C., but when the sample was pasteurized at 70° to 74° C. for 30 minutes, prevention of feathering was only partially successful. Tracy and Ruehe's (1930) suggestion was that cream should be pasteurized at 155° F. for 30 minutes, heated to 165° F., and then cooled to 145° F. for homogenization.

Doan (1929a) concluded from his work that as a general rule the tendency for homogenized cream to feather paralleled the degree of fat clumping, but in an inverse fashion.

Henderson (1944) reported that homogenized cream would feather quicker than nonhomogenized cream because of the decreased protein stability. With 25-percent cream, Henderson suggested an optimum homogenization pressure of 1,000 pounds. Atherton and Bradfield (1952) suggested 600 pounds pressure. Doan (1931b) preferred 1,000 pounds if a single-stage homogenizer were used; but with a two-stage machine, he recommended that the pressure on the second stage should not be greater than that put on the first valve.

For a single-stage homogenizer, Tracy and Ruehe (1930) recommended a pressure of 500 to 1,000 pounds. If, however, two stages were used, they suggested a total pressure of 1,500 to 2,500 pounds, with 500 to 1,000 pounds being placed on the second valve.

Tracy and Ruehe (1928) thought it possible that the effect of homogenization would be an increase in the amount of fat-adsorbing surfaces with the result that an increased amount of protein would be adsorbed on the fat-globule membrane, which, according to Titus, Sommer, and Hart (1928), consisted mostly of casein. Tracy and Ruehe (1928) also considered it probable that some of the phosphates and citrates were removed from the colloidal solution and had become fixed to the fat globule, which resulted in a calcium excess in the remaining serum.

Tracy and Ruehe (1930b) further theorized that this localizing of the casein on the fat globule made the casein more susceptible to heat coagulation, and they thought it possible that through molecular orientation of the casein molecule in the adsorbed film, the stability of the protein in the presence of soluble calcium was lessened. These postulations were substantiated by Doan (1938), who believed that the loss of mobility of the casein was one of the first stages of coagulation.

King (1953) noted that the stability of the protein phase decreased with increased pressures of homogenization and fat content with nonsterilized cream. The same was true with sterilized homogenized cream, although these effects were not shown as clearly.

Effect of coffee. Another important factor in the feathering of cream in coffee is that of the coffee itself. Ruehe (1948b) pointed out that some brands of coffee were more likely to cause feathering than others, as some contained a high percentage of soluble acids. In a study of curing beans and their effects, Tracy and Corbett (1938) found that the method of curing the beans had no relation to the pH of the brew on feathering. However, according to these investigators, the degree of roast to which the bean was subjected did affect feathering; as more roasting occurred, the higher would be the pH of the brew, and, consequently, lesser the degree of the feathering. In the same study, it was noted that the concentration in the brew had no definite relation to feathering. A further point was noted by Ruehe (1948b) in that the brew made from aged coffee had a higher acidity.

Slightly more feathering was noted by Tracy and Corbett (1938) with brew made from the dripolator method than from that of the percolator or the boiling method. These investigators also pointed out that more feathering could result when the coffee was added to the cream, rather than when the cream was added to the coffee. The slow, rather than fast additions of small quantities of milk to the coffee, according to Whitaker (1931), enhanced the feathering of evaporated milk in hot coffee.

In isolated cases, Doan (1931b) was able to attribute feathering to the hard water used in making the coffee. Sommer (1929b) explained that if the cream was of good quality, properly pasteurized, homogenized at a low pressure and yet showed trouble with feathering, the cause was almost certain to be in the hardness of the water and the salt content of the cream.

Another method for the prevention of feathering of cream in coffee would be the addition of certain salts. Doan (1931b) and Mulder (1949) suggested that if other procedures failed to help, salt stabilizers such as sodium citrate, sodium bicarbonate, or disodium phosphate would be beneficial, with the former investigator suggesting the rate of 0.025 to 0.1 percent. Tracy and Ruehe (1930a) recommended using these salts at the rate of 8 to 20 pounces per 1,000 pounds of cream. This investigator added that these sodium salts should be added before any processing occurred.

To prevent dry milk from feathering in coffee, Kempf and Blanchard (1953) added disodium phosphate to the milk just prior to condensing.

Coloring Ability of Cream in Coffee

The coloring ability of the cream in coffee, according to Mack (1939), depended upon (1) solids-not-fat, and (2) size of the fat globules. To increase this coloring power, he suggested that the serum solids of the cream should be built up and fat globules subdivided by homogenization, which Henderson (1944) explained increased the surface of the fat, hence more light was reflected.

Neither aging the cream nor the development of acidity, according to Whitaker (1934), had any influence on the quantity of cream required to color coffee. In addition, he pointed out that the pasteurization of cream by the usual holding method also had no influence on the color of the coffee-cream mixture.

Half-and-Half Homogenized Milk

As this study is primarily concerned with the preparation and testing of different types of half-and-half homogenized milk, a review of the processing techniques as used by other investigators would, at this point, be advantageous.

Preparation. Ruehe (1941, 1948a) recommended that milk and cream should be standardized from 10 to 10.5 percent fat. In addition, he suggested that the solids-not-fat content should be increased by about 2 percent by adding either high-quality skimmilk powder or concentrated skimmilk.

Roadhouse and Henderson (1941) proposed that half-and-half should be pasteurized and homogenized at 145° F. Ruehe (1941), however, had recommended cooling to 115° to 125° F. for homogenizing, but later (1948a) raised this temperature to 145° to 150° F. for 30 minutes.

This product, half-and-half, should be homogenized at a pressure under 2,500 pounds, according to Ruehe (1941, 1948a). However, Roadhouse and Henderson (1941) felt that pressures of 1,000 to 1,500 pounds would be sufficient. In the study of Trout and Weinstein (1952), both single and double stages were utilized. When using only the single stage, a pressure of 2,500 pounds was used; and for dual homogenization, 500 pounds pressure was placed on the second valve. They suggested that two stages should be used in order that a product of uniform viscosity might be obtained.

Theories Regarding Fat Clumping in Milk and Cream

Introduction. Sommer (1952) reported that when milk left the cow's udder, the fat globules were in suspension as separate, individual globules, but on standing for a short time these globules gathered into clusters, while still having retained their identity. This clustering of fat globules was noticed by Babcock (1889), and Woll, Babcock, and Russell (1903), with the latter attributing the holding together of the clusters to some invisible material. Babcock and Russell (1896) suggested that these aggregations of fat globules had a very important influence in determining the consistency of milk and, especially, cream.

Increased viscosity in creams when aged were attributed to clumping of fat globules by Sherwood and Smallfield (1926) and Dahlberg and Hening (1925). This viscosity, however, was shown by Nair and Mook (1933) to have been reduced by agitation.

Palmer (1923) noted that the rise of fat globules was due primarily to the difference between the specific gravity of milk fat and the plasma in which it was dispersed. However, it was indicated by Palmer, Hening, and Anderson (1926) that the differences in densities of fat and plasma did not determine the volume of cream nor the rise of fat, but was determined largely by the plasma colloids. Palmer and Anderson (1926) and van Dam and Sirks (1922) essentially agreed that the properties which influenced the separation and volume of the cream were determined largely by the plasma, and not by the fat.

Doan (1926) added solids-not-fat in the form of plain condensed skimmilk and skimmilk powder, but found they gave no increased creaming power either to raw or to pasteurized milk. The results of Skelton and Ellenberger (1939) tended to minimize the importance hitherto placed upon fat-globule clumping as a major factor influencing cream viscosity.

Troy and Sharp (1928) calculated the rise of fat globules and reported that they were in accordance with Stoke's Law. From their results, they concluded that the individual fat globules rose so slowly that it would have required many times the normal creaming time of milk for them to reach the cream layer. However, they showed that clusters did rise rapidly enough to account for the normal creaming time.

Hammer (1916) had postulated that the size of the fat globules, the percentage of the total amount of fat present in globules of varying size, and the constitution of the fat-globule clusters must all be of importance in the creaming ability of milk. No simple relation between the viscosity of milk and the rate of formation of cream was found by Rahn (1921).

Agglutinin theory. Babcock (1889) attributed the clustering of fat globules to "a principal in milk when is analagous or identical with blood fibrin," which, through spontaneous coagulation, clotted and thus entangled the fat globules, which consequently prevented efficient creaming. However, Hekma (1922) pointed out that fibrin was not a normal constituent of milk.

Mulder (1949) noted that creaming was stimulated by the agglutination of the fat globules, which combined into clusters. Sharp and Krukovsky (1939) had previously concluded that this agglutinating substance was adsorbed on the surface of the solid or solidifying fat globules, and not on the surface of the liquid fat globules. Further evidence was supplied by Dunkley and Sommer (1944), who pointed out the similarity of the mechanisms involved in the agglutination of bacteria and the clustering of fat globules in milk.

Rowland (1933) reported that the heating of normal milk caused a denaturation of the albumin and globulin, but not their coagulation. Later, Rowland (1937) was able to postulate that globulin probably was the major factor in the reduction of the creaming power of heated milk. The amount of albumin and globulin coagulated at a pasteurization temperature of 143° F. for 30 minutes was calculated by Shahani and Sommer (1951) to be 9 and 5 percent, respectively.

Brouwer (1924), meanwhile, had fractionated globulin into euglobulin and pseudoglobulin, and demonstrated that the euglobulin was very effective in improving the creaming properties of milk, while pseudoglobulin had very little effect.

Stickiness. When cream was cooled, King (1950) explained that the fat globules became clumped as a certain amount of the liquid fat was squeezed out from the globules and served as adhesive material between the globules. King (1951) also suggested that at very low temperatures the fat globules failed to clump since the amount of the liquid fat fraction in the globules was too small for clump formation. However, Brunner and Jack (1950) pointed out that even at temperatures of 0° to 10° C. for 18 hours, the degree of solidification in cream ranged from 48 to 68 percent solidified fat.

Theory of electrokinetics. North and Sommer (1935) theorized that the potential at the fat-liquid interface was the net result of reversible and irreversible ions with the film of irreversible adsorbed milk colloids playing the dominant role in determining the potential. Previously, Sirks (1923), who had assumed that the electrophoretic mobility of the fat globules was proportional to their surface potential and charge, found that this mobility showed no relationship to the extent of clustering of the fat. Hence, this investigator was able to conclude that the charge on the fat globule was not important in determining the extent to which fat globules clustered. Somewhat different results were obtained by North, Courtney, and Sommer (1935), who observed a general relationship between the charge, and both cluster formation and cream volume.

Jack and Dahle (1937a) were unable to find any significant difference in the mobility of fat globules from cows of different breeds. The electrophoretic mobilities of fat globules were shown to be constant up to a fat content of 65 percent by these same investigators (1937b), but above this, there was a rapid increase. By increasing the temperature above the pasteurization point, Dahle and Jack (1937) stated that there was an increase in the mobility of the fat globules. This phenomenon had been previously explained by North, Courtney, and Sommer (1935) to be an increase in the charge on the fat globules.

Electrostatic theory. The most plausible reason for the creaming of raw and pasteurized milk, according to Dahlberg and Marquardt (1929, 1931), was the action of the calcium ions on the clustering of fat globules. These investigators suggested that the positively charged calcium ions were attracted by the negative charge of the fat globules in sufficient amounts so as to cause an electric attraction of one fat globule for another, hence the formation of clusters. Doan (1932) thought this theory to be logical with the exception that it did not explain the effects of homogenization.

Interfacial tension. Fat clumping seemed to be best explained according to Doan (1929a) on the basis of an interfacial tension effect. He theorized that the fat and water interface gave rise to relatively high interfacial tensions, and since this free energy could be diminished by a decrease in surface area, coalescence occurred. However, he continued, coalescence would not take place probably because an adsorbed layer prevented an intimate contact of the globules. Still the investigator realized that the complete explanation of such a complex phenomenon would probably be based on more than one effect.

North, Courtney, and Sommer (1935) and Dunkley and Sommer (1944) disagreed with this hypothesis, as they were unable to find any relationship between interfacial tension at the fat-serum interface and the extent of fat-globule clustering. The latter investigators did state, however, that this free energy, while not being a cause in clustering, could play a part through its influence on the adsorption by the fat.

The present-day knowledge of the relationship between fat-globule clustering and viscosity in cream was utilized by Hening and

Dahlberg (1932); Wiese, Nair, and Fleming (1939); Smith and Dean (1948); and Snyder (1948), as a method of increasing cream viscosity through various separating and heating techniques.

SECTION I

THE INFLUENCE OF VARIATION IN COMPOSITION AND PRESSURES OF HOMOGENIZATION UPON SOME CHEMICAL AND PHYSICAL PROPERTIES OF HALF-AND-HALF HOMOGENIZED MILK

Experimental Procedure

Factors affecting the physical, chemical, and organoleptic properties of half-and-half. Fresh raw milk was obtained from the Michigan State College Creamery. The milk was warmed to 90° F., and separated. The resultant skimmilk was placed immediately into the milk-storage room, held at 37° F. Meanwhile the cream was placed in cold, running water (53° F.). A period of approximately 30 minutes was required from the time the separation was completed until the beginning of the pasteurizing process. Three separate series were conducted with each varying in composition as follows:

Series 1. Skimmilk and cream standardized to 10.5 percent fat.

Series 2. Skimmilk and cream standardized to 10.5 percent fat plus the addition of 2 percent low-heat, spray-process skimmilk powder.

Series 3. Skimmilk and cream standardized to 10.5 percent fat plus the addition of 5 percent low-heat, spray-process skimmilk powder.

Each series was heated in a 30-gallon, stainless-steel univat and pasteurized at 150° F. for 30 minutes. The product was then homogenized at 150° F. in a Manton-Gaulin (Model E) two-stage homogenizer with a capacity rated at 75 gallons per hour.

The homogenization pressures used with the single stage were 2,500 and 5,000 pounds per square inch. However, when the samples were subjected to dual homogenization, in addition to the above pressures on the first stage, 500 pounds per square inch pressure was placed on the second valve. This gave homogenization pressures of 0, 2,500, 5,000, 2,500 + 500, and 5,000 + 500 pounds per square inch for each series.

The samples were cooled to 60° F. with running water, bottled by hand into half-pint bottles, and placed in cold storage at a temperature of 37° to 38° F.

In order to determine the viscosity of the various series, a Brookfield Synchro-Lectric viscometer was employed. The viscosities were measured at temperatures of 20° C. (68° F.) and 3° C. (37.4° F.), with the results being expressed in centipoises. When the readings were taken at 20° C., the half-pint samples were removed from cold storage and placed in a water bath, held at 20° ± 1° C. for 30 minutes prior to the determination of the viscosity. The samples examined at 3° C. were taken directly from cold storage and readings were made immediately. All samples were held in cold storage for a period of six hours prior to the initial determinations. Other readings were obtained at intervals of three and seven days.

The heat stability of the samples was determined at the same time the viscosity results were obtained. One-milliliter samples were sealed in 8-milliliter Pyrex glass tubing and immersed in an oil bath held at a temperature of 120° C. (248° F.). The submerged tubes were rotated at a constant rate of seven revolutions per minute. The time interval between immersion of the samples and the appearance of the first signs of precipitation in the glass tubes was recorded, in minutes, as the measurement of heat stability.

Titratable acidity and pH determinations were conducted on all samples. A Beckman (Model G) pH meter was used for recording the pH. Titratable acidity was expressed as percentage lactic acid.

The percentage total solids and fat was determined as outlined by Mojonnier and Troy (1925) for cream testing 25 percent and under. The procedure of Brunner (1952) was used to determine total nitrogen. A factor of 6.38 was used to convert total nitrogen into total protein.

The specific gravity was determined by means of a Quevenne lactometer at 60° F., the samples being tempered for 30 minutes in water.

The percentage of ash was determined by evaporating 10 grams of half-and-half to dryness on a steam bath. The dried product then was placed in a muffle furnace, held at a temperature no higher than 550° C. (1,022° F.) until free of carbon. The ashed sample was cooled finally in a desiccator, weighed, and the percentage of ash then calculated.

In order that the stability of half-and-half in coffee might be determined, several trials were conducted. Five milliliters of the product was pipetted first into a beaker to which 50 milliliters of hot coffee, ranging in termperature from 195° to 205° F., was added. The mixture was allowed to remain quiescent for two minutes, after which the feathering ability of the samples was observed and recorded. The coffee used in the trials for the detection of feathering was prepared by adding 3 grams of regular-grind coffee to 50 milliliters of boiling water containing the various concentrations of calcium ions. The brew was allowed to boil for one minute, after which it was filtered through a piece of cheesecloth and then added to a beaker containing the 5-milliliter sample. Trials were run also with the coffee made by the percolator method. Here, directions as recommended by the manufacturers were followed for the preparation of the coffee. The proportions used were 15 grams of regular-grind coffee per cup (150 ml.) of water. Both distilled and hard water were used in this method of coffee making.

The organoleptic qualities of half-and-half were determined by a panel of experienced dairy judges. The samples were judged when they were from three to five days old. Special emphasis was placed on the body and flavor of the products.

Influence of added nonfat dry milk solids and pressures of homogenization on the stability of half-and-half. With the view of studying the effect of added solids-not-fat and pressures of homogenization on the stability of half-and-half homogenized milk, ionic solutions of calcium, magnesium, and citrate were prepared in distilled water. Concentrations of each group of ions ranged from 0 to 500 parts per million, in graduations of 100 parts per million.

Five milliliters of each specific concentration was pipetted into a test tube. To this, 1 milliliter of the sample of half-and-half under study was added. The contents were inverted five times. To this mixture, various increments of N/100 HCl were added from a burette, after which the tube was inverted five times and observed. This technique was continued until the first signs of a fine precipitate in the test tube were noted, at which point the number of milliliters of N/100 HCl were recorded as the relative stability of the sample.

Results

The results, obtained from the first section of this study, were secured from three series of half-and-half homogenized milk. Five to seven trials were conducted on each series. These samples were standardized at 10.5 percent fat, with the milk-solids-not-fat content ranging from 8.73 to 12.38 percent (Table 1) by the addition of low-heat, spray-process skimmilk powder. The data are presented in Tables 1 to 9, inclusive, and are shown graphically in Figures 1 to 12, inclusive.

Viscosity. The data from Table 2, illustrated in Figure 1, may be divided into two major categories: (1) the effect of single and double homogenization; and (2) the effect of added milk-solids-not-fat on the viscosity of half-and-half. The viscosity measurements recorded in this table were obtained after the samples had been held in storage for six hours.

In general, the viscosity did not exceed 17.8 centipoises, even when homogenized at 5,000 pounds per square inch pressure with one stage. The greatest increase in viscosity occurred when only one stage was used, the greatest being 11.2 centipoises at 5,000 pounds per square inch pressure. When 500 pounds per square inch pressure was applied to the second valve, the viscosity increased only slightly as the pressure of homogenization increased. With the two stages in operation, the greatest increase in viscosity was only 1.5 centipoises over that of the nonhomogenized control sample (Table 2).

Further inspection of Table 2 shows that the addition of nonfat dry milk solids did increase the viscosity slightly. With one exception, there appeared to be a small but definite increase in viscosity as a result of adding skimmilk powder. This occurred when the samples were homogenized at a pressure of 5,000 pounds per square inch, single stage, resulting in an increase in viscosity of 4.3 centipoises. The remaining samples showed only an increase of from 1.0 to 1.8 centipoises.

Only slight increases in viscosities were noted, even after the samples were held in storage for seven days. This is clearly illustrated in Table 3. As these data indicate, the general increase in viscosity was very small, and in most cases would not be considered as being significant. This was true whether nonfat dry milk solids were added or not. With only two exceptions, the largest increase in viscosity noted in seven days was only 2.5 centipoises. The reason for the abnormally high viscosity shown in the second trial in Series 1 (Table 3) cannot be explained. The sample was normal in all other respects. This was the only time this deviation occurred in all the trials conducted on half-and-half in the current study.

Heat stability. The effect of various additions of nonfat dry milk solids on the heat stability of half-and-half is presented in Table 4 and Figure 2. From these results, several different facts may be noted. The first is that the maximum heat stability occurred in the nonhomogenized samples to which no skimmilk solids had been added. As the percentage of milk-solids-not-fat increased in these nonhomogenized samples, there appeared a definite decrease in heat stability. In all cases, homogenization, whether single or double stage, also decreased the heat stability of the half-and-half homogenized milks.

However, a distinct difference appeared between single- and double-stage homogenization. The result of placing 500 pounds per square inch pressure on the second valve more than doubled the heat stability over the samples which were subjected to the same single-stage pressures. It might well be pointed out that in the series where the skimmilk powder was added, the heat stability at the two different pressures with the single-stage process was identical. The results obtained from the dual-homogenized samples, although not identical with each other, were very close. The series where no powder was added showed a gradual decrease in stability as the pressure increased, with the single-stage homogenized samples being the least stable.

Titratable acidity and pH. The information supplied in Table 5 and Figure 3 is of considerable importance when considering use of added milk-solids-not-fat in half-and-half. Perhaps the most significant information that is shown by these data is the definite increase in titratable acidity as the percentage of milk-solids-not-fat increased. As shown in Figure 3, for every percentage increase in the solids-not-fat, up to 5 percent, the calculated increase in titratable acidity amounted to 0.0189 percent. However, adding milk-solids-not-fat appeared to produce no significant difference in pH of the samples used in this study.

Specific gravity. The specific gravity was found to increase directly as increments of milk-solids-not-fat were added to the samples.

Feathering of half-and-half in coffee. The data showing the stability of the samples of half-and-half in coffee are compiled in Table 6. Perhaps the most significant factor in this study was that, with one exception where the viscosity was abnormally high (Series 1, Trial 2, Table 6), no sample of half-and-half prepared in this study feathered when the coffee was made with hard tap water. The hardness of this water was calculated to be 419.2 parts per million calcium carbonate. However, as indicated in Table 6, when the coffee was made with distilled water, different results were obtained. The nonhomogenized samples were quite stable when added to this coffee. When the samples were homogenized, this stability against feathering dropped sharply. The dual-homogenized samples showed slightly more stability than those treated with the single stage. Under the conditions of this study the addition of skimmilk powder did not improve significantly the stability of the half-and-half in coffee when made with distilled water.

When coffee was made either with distilled or with tap water, a difference in the pH of the brews was noted. The coffee made with distilled water had a pH range from 5.18 to 5.65, while that made with hard water was much higher, ranging from 6.00 to 6.32.

A panel of experienced dairy-product judges considered the samples from an organoleptic point of view. The nonhomogenized products were criticized because of their salvy type of cream plug, which formed upon storage. In addition, these samples were considered to lack the flavor and body which is desired in half-and-half.

The samples to which 2 percent skimmilk powder were added were considered to have a good body and excellent flavor. However, when the additions were increased to 5 percent (although the products were considered to have a desirable, heavy body), they had a definite, undesirable salty taste.

Occasionally, when the samples were homogenized at the lower pressures used in this study, they were criticized for the appearance of a fat ring around the top of the bottle. This was noticeable both with single- and with double-stage homogenization. When the higher pressures were used, this defect did not occur.

The influence of added nonfat dry milk solids and pressure of homogenization on the stability of half-and-half. The data presented in Tables 7, 8, and 9, show the influence of various concentrations of calcium, magnesium, and citrate ionic solutions on the stability of different types of homogenized milks, as measured by acid precipitation. Three separate trials were conducted. The first trial was made in January (Figures 4, 7, and 10), the second in March (Figures 5, 8, and 11), and the third in May (Figures 6, 9, and 12).

Perhaps the most significant point that might be noticed from these three tables is that acid was not required to precipitate the nonhomogenized samples when they were mixed with distilled water. Although the three different types of ionic solutions of varying concentrations were added to half-and-half, these samples were still readily precipitated upon mixing. However, when the samples of half-and-half were homogenized, the addition of acid was necessary to give this precipitation, thus suggesting increased stability.

The general effect of adding milk-solids-not-fat to half-and-half was that, as the percentage increased, more acid was required to produce a precipitate, thus indicating a greater stability. Furthermore, when these samples were homogenized at higher pressures, including both single and double stage, additional acid usually was necessary for precipitation. This was especially noticeable in the first two trials.

The effects of the calcium, magnesium, and citrate ions on the stability of the different series of half-and-half proved interesting. The effect of the calcium ions was that of destabilization (Figures 4, 5, and 6). Magnesium tended to have but little effect, for as the concentration of these ions increased, the amount of acid required for precipitation remained fairly constant (Figures 7, 8, and 9). The addition of citrate ions, however, tended to increase slightly the stability of the samples as the ionic strength was increased (Figures 10, 11, and 12). The above effects of these ions were most noticeable in the two series which contained added increments of 2 and 5 percent milk-solids-not-fat, especially when they were homogenized at 5,000 and 5,000 + 500 pounds per square inch pressures.

Of interest also is a comparison of the data from the three separate trials. When comparing the trials in which no solids were added, it may be seen that the trial conducted in January appeared to be rather unstable, as little acid was required to give a precipitate. The other two trials, which were run in March and May, did give somewhat higher readings. The addition of skimmilk powder tended to minimize the differences in the results of the three trials, as was noticed in the first series.

A marked difference occurred between the data obtained from the first two trials and those of the third. The results from this last trial showed that, although the different homogenization pressures were used in each series, the results were almost identical. However, in the first two trials, the data were more erratic, there being a marked difference in the findings, due to the different pressures of homogenization. As in all three trials of every series, little significant difference could be detected between single- and double-stage homogenization.

Table 1. The influence of added solids-not-fat on the composition of half-and-half homogenized milk.

Series No.*	Added Increments of Solids-Not-Fat	The Composition of Half-and-Half Homogenized Milk When Various Amounts of Solids-Not-Fat Were Added				
		Fat	Protein	Ash	Solids-Not-Fat	Total Solids
	(pct.)	(pct.)	(pct.)	(pct.)	(pct.)	(pct.)
1	0	10.58	3.36	0.6967	8.73	19.20
2	2	10.47	4.18	0.8353	10.05	20.53
3	5	10.28	4.66	1.0168	12.38	22.57

* Five to seven trials on each series.

Table 2. The influence of added solids-not-fat on the viscosity of half-and-half when homogenized at various pressures.

Series No.*	Added Increments of Solids-Not-Fat	Temperature of Viscosity Measurements	The Viscosity of Half-and-Half When Homogenized at:				
			0 lbs./sq.in.	2500 lbs./sq.in.	2500 +500 lbs./sq.in.	5000 lbs./sq.in.	5000 +500 lbs./sq.in.
	(pct.)	(°C.)	(centipoises)	(centipoises)	(centipoises)	(centipoises)	(centipoises)
1	0	20	4.9	6.7	5.4	8.9	5.8
		3	6.7	8.9	7.0	13.5	7.5
2	2	20	5.7	8.0	6.3	10.4	6.7
		3	6.6	9.3	7.5	17.8	8.1
3	5	20	5.9	7.8	6.7	9.1	7.2
		3	7.9	10.3	8.6	15.9	9.3

* Five to seven trials on each series.

Table 3. The influence of length of storage and added solids-not-fat on the viscosity of half-and-half homogenized at various pressures.

Homogenization Pressures	Viscosity of Half-and-Half When Stored at 3° C. for:								
	0 days			3 days			7 days		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(lbs./sq.in.)	(centipoises)*			(centipoises)			(centipoises)		
	Series 1: No Solids-Not-Fat Added								
0	4.6	4.7	4.9	4.8	5.1	5.3	5.6	5.9	5.7
2500	7.4	7.5	6.8	7.0	-	-	7.6	7.8	7.2
2500+ 500	5.1	39.3	5.4	5.5	78.4	5.5	5.8	82.6	5.5
5000	9.2	8.6	9.5	10.0	-	-	10.4	8.9	10.0
5000+ 500	5.0	79.8	5.7	6.3	169.8	5.1	6.8	209.6	5.6
	Series 2: Added Solids-Not-Fat (2%)								
0	5.4	5.4	5.6	5.5	5.6	5.2	6.1	6.0	6.0
2500	8.2	8.7	8.1	7.9	-	-	8.4	9.6	8.3
2500+ 500	5.8	7.9	6.2	6.1	8.2	5.4	6.0	8.9	6.0
5000	9.3	8.3	11.9	9.8	-	-	10.3	8.8	14.4
5000+ 500	6.7	15.2	6.5	7.5	18.2	6.7	7.1	21.4	6.8
	Series 3: Added Solids-Not-Fat (5%)								
0	9.9	5.8	5.8	10.7	7.5	6.3	11.9	6.8	6.5
2500	7.5	7.8	8.2	10.4	-	-	7.6	8.6	8.1
2500+ 500	7.6	7.1	6.5	8.3	7.3	6.4	9.2	7.6	7.2
5000	8.4	10.5	8.4	8.6	-	-	8.6	12.0	8.9
5000+ 500	7.6	7.8	6.8	8.3	7.9	7.4	9.2	8.2	7.6

* Readings made at 20° C.

Table 4. The influence of added solids-not-fat on the heat stability of half-and-half homogenized milk when subjected to various pressures.

Series No.*	Added Increments of Solids-Not-Fat	The Heat Stability of Half-and-Half When Homogenized at: 0 lbs./sq.in.	2500 lbs./sq.in.	2500 +500 lbs./sq.in.	5000 lbs./sq.in.	5000 +500 lbs./sq.in.
	(pct.)	(minutes)	(minutes)	(minutes)	(minutes)	(minutes)
1	0	97	28	80	15	76
2	2	92	11	59	11	58
3	5	76	15	33	15	37

* Five to seven trials on each series.

Table 5. The influence of added solids-not-fat on the specific gravity, pH, and titratable acidity of half-and-half homogenized milk.

Trial No.	Specific Gravity	The Acidity of Half-and-Half Homogenized Milk as Measured by: pH	Titratable Acidity
	Series 1: No Solids-Not-Fat Added		
1	1.0261	6.55	0.180
2	1.0242	6.67	0.155
3	1.0255	6.52	0.180
4	1.0268	6.65	0.185
5	1.0263	6.67	0.160
6	1.0259	6.68	0.155
	Series 2: Solids-Not-Fat Added (2%)		
7	1.0319	6.78	0.205
8	1.0330	6.58	0.205
9	1.0320	6.49	0.210
10	1.0313	6.53	0.195
11	1.0310	6.62	0.195
12	1.0302	6.59	0.190
13	1.0302	6.58	0.195
	Series 3: Solids-Not-Fat Added (5%)		
14	1.0405	6.43	0.275
15	1.0422	6.50	0.270
16	1.0410	6.57	0.245
17	1.0438	6.59	0.235
18	1.0428	6.64	0.265

Table 6. The influence of calcium-ion concentration, composition, and pressures of homogenization on feathering of half-and-half in coffee.

Calcium-Ion Concentration	Occurrence of Feathering in Half-and-Half when Homogenized at:														
	0 lbs./sq.in.			2500 lbs./sq.in.			2500 +500 lbs./sq.in.			5000 lbs./sq.in.			5000 +500 lbs./sq.in.		
	Series 1*	2	3	Series 1	2	3	Series 1	2	3	Series 1	2	3	Series 1	2	3
(ppm)															
Hard**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-
50	-	-	-	+	?	-	-	-	-	+	+	+	?	-	+
75	-	-	-	+	+	?	?	-	-	+	+	+	+	?	+
100	-	-	-	+	+	+	+	-	+	+	+	+	+	+	+
125	-	-	-	+	+	+	+	?	+	+	+	+	+	+	+
150	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+
200	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+
300	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
400	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
500	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

* Two trials conducted on each series.

** Hard, tap water, testing 419.2 ppm calcium carbonate.

\- No feathering.

? Questionable.

\+ Definite feathering.

Table 7. The influence of various concentrations of ionic solutions of calcium on the stability of half-and-half homogenized milk, as measured by acid precipitation.

Calcium-Ion Concentration	Acid Required to Precipitate					
	0 lbs./sq.in.			2500 lbs./sq.in.		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ppm)	(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added						
0	0	0	0	0.715	1.305	2.050
100	0	0	0	0.500	0.875	1.915
200	0	0	0	0.195	0.930	-
300	0	0	0	0.210	0.750	1.180
400	0	0	0	0.135	0.825	-
500	0	0	0	0.000	0.545	1.030
Series 2: Added Solids-Not-Fat (2%)						
0	0	0	0	1.305	1.900	3.520
100	0	0	0	1.130	1.935	3.435
200	0	0	0	0.715	2.020	-
300	0	0	0	0.870	2.220	2.380
400	0	0	0	0.490	1.780	-
500	0	0	0	0.000	1.610	1.915
Series 3: Added Solids-Not-Fat (5%)						
0	0	0	0	1.375	2.620	4.375
100	0	0	0	1.845	2.680	4.135
200	0	0	0	1.935	3.380	-
300	0	0	0	1.930	2.920	3.140
400	0	0	0	1.665	2.725	-
500	0	0	0	2.415	2.455	2.370

Table 7 (Continued)

Half-and-Half when Homogenized at:								
2500+500 lbs./sq.in.			5000 lbs./sq.in.			5000+500 lbs./sq.in.		
Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ml. N/100 HCl)			(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added								
0.655	0.865	0.990	0.680	0.800	2.810	1.130	1.305	1.515
0.430	0.785	0.815	0.470	0.590	2.400	0.910	1.890	2.545
0.360	0.970	-	0.450	0.710	-	0.745	1.915	-
0.400	1.420	0.530	0.425	0.350	1.710	0.600	1.455	2.005
0.120	1.320	-	0.205	0.410	-	0.630	1.490	-
0.000	0.985	0.555	0.190	0.670	1.290	0.550	1.460	1.430
Series 2: Added Solids-Not-Fat (2%)								
0.955	1.790	3.575	3.240	3.240	3.760	3.525	3.435	3.650
1.215	1.815	3.500	2.980	2.900	3.015	3.085	3.225	2.805
1.625	1.890	-	2.500	2.585	-	2.800	3.225	-
2.165	2.290	2.815	1.985	2.000	2.645	2.580	2.730	3.130
0.635	2.085	-	1.620	1.460	-	2.170	2.495	-
0.595	1.680	2.090	1.225	1.495	2.100	1.665	2.420	2.410
Series 3: Added Solids-Not-Fat (5%)								
2.275	2.740	4.205	4.345	4.425	4.210	4.810	4.605	4.520
1.760	2.365	3.840	4.070	3.960	3.830	4.505	4.340	4.110
1.965	2.910	-	3.580	3.615	-	4.275	3.795	-
1.610	3.115	3.315	2.985	3.460	3.370	3.970	3.140	3.220
1.735	2.755	-	2.865	2.870	-	3.700	2.950	-
1.650	2.840	2.470	2.665	2.710	2.800	3.290	2.720	2.575

Table 8. The influence of various concentrations of ionic solutions of magnesium on the stability of half-and-half homogenized milk, as measured by acid precipitation.

Magnesium-Ion Concentration	Acid Required to Precipitate					
	0 lbs./sq.in.			2500 lbs./sq.in.		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ppm)	(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added						
0	0	0	0	0.790	1.480	2.170
100	0	0	0	0.560	1.610	2.115
200	0	0	0	0.370	1.710	-
300	0	0	0	0.280	1.920	1.820
400	0	0	0	0.160	1.450	-
500	0	0	0	0.180	1.485	1.870
Series 2: Added Solids-Not-Fat (2%)						
0	0	0	0	1.940	2.220	3.575
100	0	0	0	1.885	2.770	3.130
200	0	0	0	1.480	3.245	-
300	0	0	0	0.885	3.345	3.075
400	0	0	0	0.865	3.240	-
500	0	0	0	0.540	3.310	3.100
Series 3: Added Solids-Not-Fat (5%)						
0	0	0	0	1.970	1.995	4.380
100	0	0	0	1.890	2.330	3.940
200	0	0	0	2.125	2.420	-
300	0	0	0	2.425	3.545	3.935
400	0	0	0	2.325	3.795	-
500	0	0	0	2.115	3.930	3.970

Table 8 (Continued)

Half-and-Half when Homogenized at:								
2500+500 lbs./sq.in.			5000 lbs./sq.in.			5000+500 lbs./sq.in.		
Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ml. N/100 HCl)			(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added								
0.640	1.110	1.650	0.750	3.280	2.825	0.700	3.120	2.900
0.535	1.420	1.975	0.460	2.930	2.665	0.485	3.210	2.600
0.175	1.040	-	0.275	2.980	-	0.745	3.165	-
0.135	1.370	2.135	0.370	2.970	2.300	0.520	3.140	2.685
0.130	1.660	-	0.370	2.645	-	0.695	3.115	-
0.060	1.480	2.580	0.270	2.785	2.415	0.945	2.995	2.745
Series 2: Added Solids-Not-Fat (2%)								
0.640	1.685	3.655	3.890	3.660	3.325	3.830	3.245	3.800
0.905	1.745	3.600	3.760	3.445	3.415	4.005	3.855	3.450
1.405	1.405	-	3.695	3.420	-	3.790	3.880	-
1.005	1.775	3.025	3.660	3.425	3.385	4.170	3.820	3.190
1.240	1.775	-	3.455	3.340	-	3.975	3.600	-
1.275	1.490	3.355	3.560	3.500	3.210	3.815	3.685	3.280
Series 3: Added Solids-Not-Fat (5%)								
1.370	2.035	4.555	4.245	4.475	4.315	4.430	3.805	4.725
2.005	1.995	4.410	4.070	4.430	4.070	4.365	4.400	4.290
2.325	1.910	-	4.010	-	-	4.300	4.205	-
1.870	2.305	3.930	3.640	4.420	3.935	3.920	4.020	4.115
1.700	2.165	-	3.630	4.320	-	4.140	4.260	-
1.620	2.135	3.985	3.775	4.290	4.080	3.970	4.315	4.120

Table 9. The influence of various concentrations of ionic solutions of citrate on the stability of half-and-half homogenized milk, as measured by acid precipitation.

Citrate-Ion Concentration	Acid Required to Precipitate					
	0 lbs./sq.in.			2500 lbs./sq.in.		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ppm)	(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added						
0	0	0	0	0.495	0.920	1.955
100	0	0	0	0.715	1.345	2.745
200	0	0	0	0.385	1.585	-
300	0	0	0	0.365	1.805	2.815
400	0	0	0	0.290	1.690	-
500	0	0	0	0.290	1.740	3.330
Series 2: Added Solids-Not-Fat (2%)						
0	0	0	0	1.215	2.600	3.985
100	0	0	0	1.195	2.885	4.185
200	0	0	0	1.045	2.765	-
300	0	0	0	1.170	2.910	4.415
400	0	0	0	1.350	2.865	-
500	0	0	0	1.950	2.815	5.180
Series 3: Added Solids-Not-Fat (5%)						
0	0	0	0	1.800	2.045	4.300
100	0	0	0	1.580	2.155	4.805
200	0	0	0	1.620	2.220	-
300	0	0	0	1.780	2.415	5.320
400	0	0	0	2.430	2.395	-
500	0	0	0	2.370	2.335	5.590

Table 9 (Continued)

Half-and-Half when Homogenized at:								
2500+500 lbs./sq.in.			5000 lbs./sq.in.			5000+500 lbs./sq.in.		
Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
(ml. N/100 HCl)			(ml. N/100 HCl)			(ml. N/100 HCl)		
Series 1: No Solids-Not-Fat Added								
0.520	1.570	1.975	0.780	2.785	2.960	1.130	3.475	2.980
0.430	1.960	2.800	1.110	3.795	3.040	1.295	3.275	3.185
0.380	1.680	-	1.270	3.145	-	1.655	3.200	-
0.345	1.770	3.690	1.520	2.805	3.200	1.330	3.135	3.460
0.175	1.865	-	1.620	3.360	-	2.015	3.130	-
0.160	1.715	4.070	1.630	2.850	3.710	2.220	3.295	3.625
Series 2: Added Solids-Not-Fat (2%)								
1.190	1.945	3.985	3.775	3.610	3.510	3.750	3.720	3.890
1.425	2.475	4.250	4.210	3.855	3.815	4.220	4.060	4.290
1.240	2.420	-	4.505	4.455	-	4.665	3.700	-
1.840	2.590	4.680	4.280	4.500	4.240	4.715	3.700	4.610
1.375	2.265	-	4.485	4.350	-	4.630	3.870	-
1.760	2.385	4.795	4.655	4.165	4.550	5.100	3.910	4.940
Series 3: Added Solids-Not-Fat (5%)								
1.835	1.765	4.185	4.475	4.305	4.225	4.500	4.445	4.185
1.780	1.975	4.550	4.990	4.785	4.335	5.130	5.215	4.685
1.785	1.990	-	5.310	4.925	-	5.515	5.355	-
2.455	2.225	4.990	5.320	5.335	4.980	5.555	5.575	4.820
2.495	2.435	-	5.455	5.620	-	5.620	5.730	-
2.260	2.630	5.250	5.575	6.125	5.195	6.205	6.295	5.285

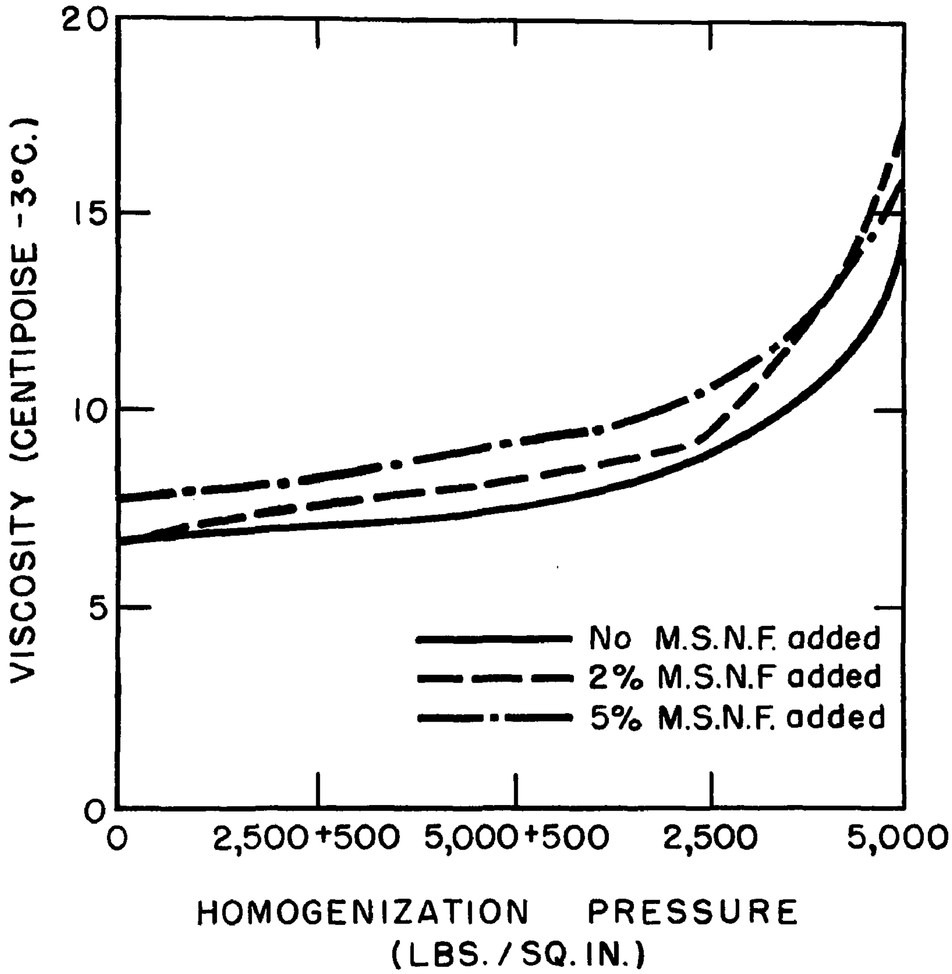


Figure 1. The effect of single- and double-stage homogenization on the viscosity of half-and-half homogenized milk.

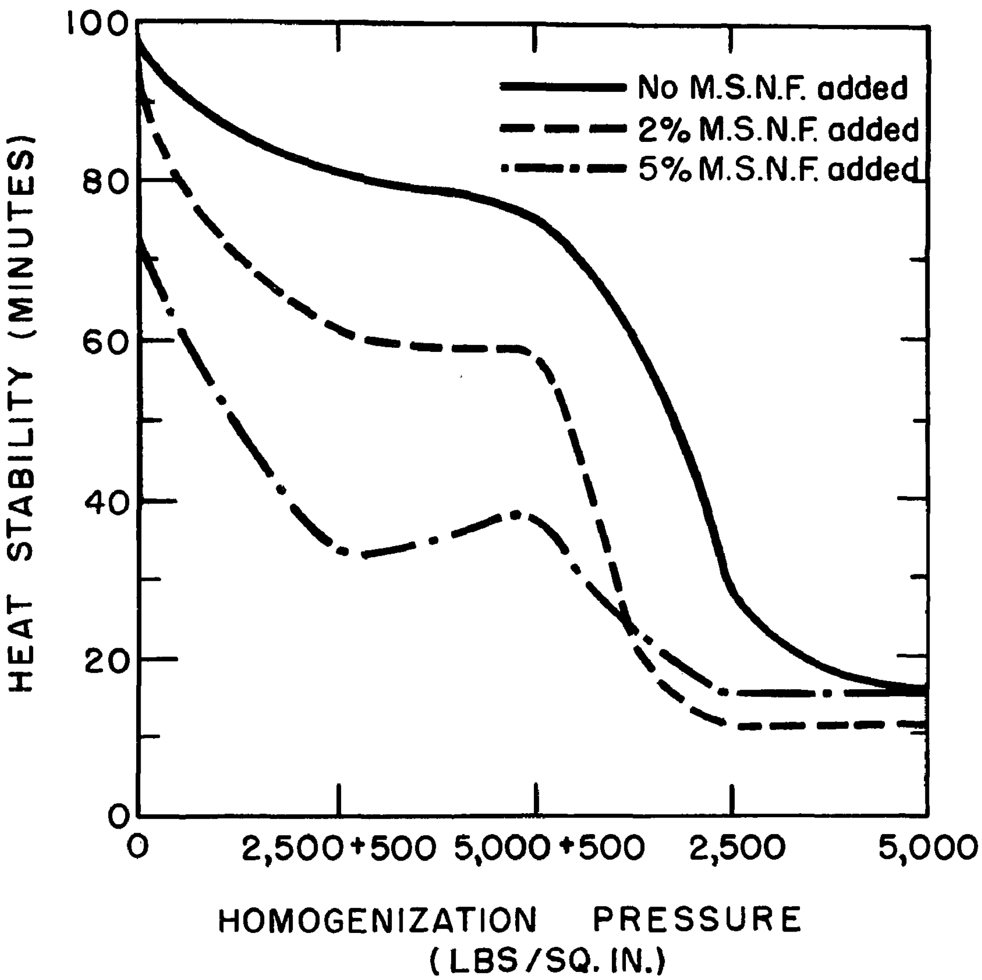


Figure 2. The effect of single- and double-stage homogenization on the heat stability of half-and-half homogenized milk.

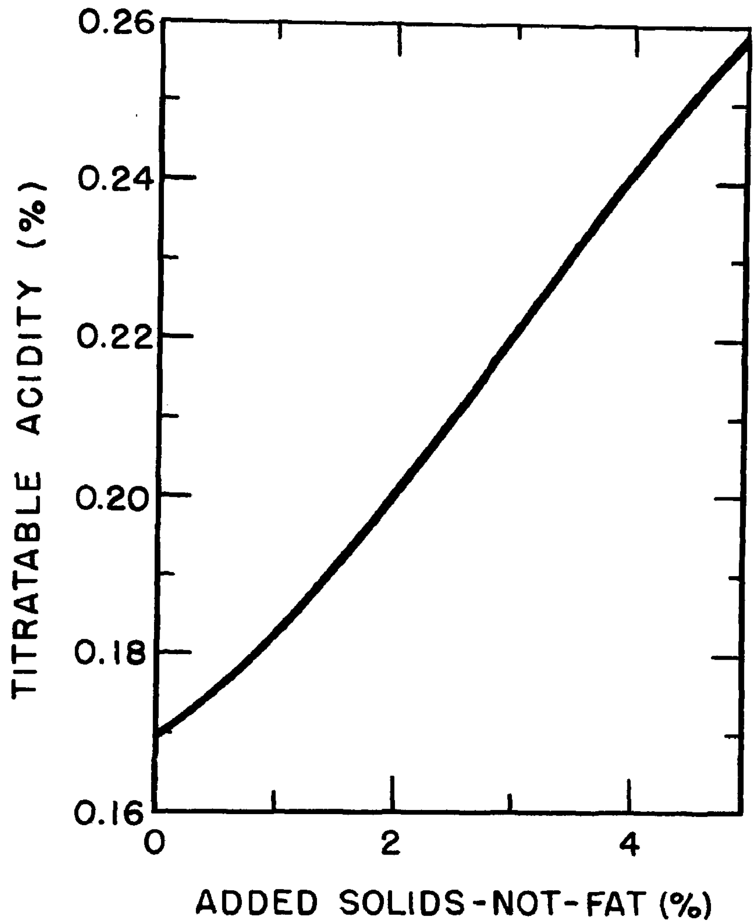


Figure 3. The influence of added increments of low-heat, spray-process skimmilk powder on the titratable acidity of half-and-half homogenized milk.

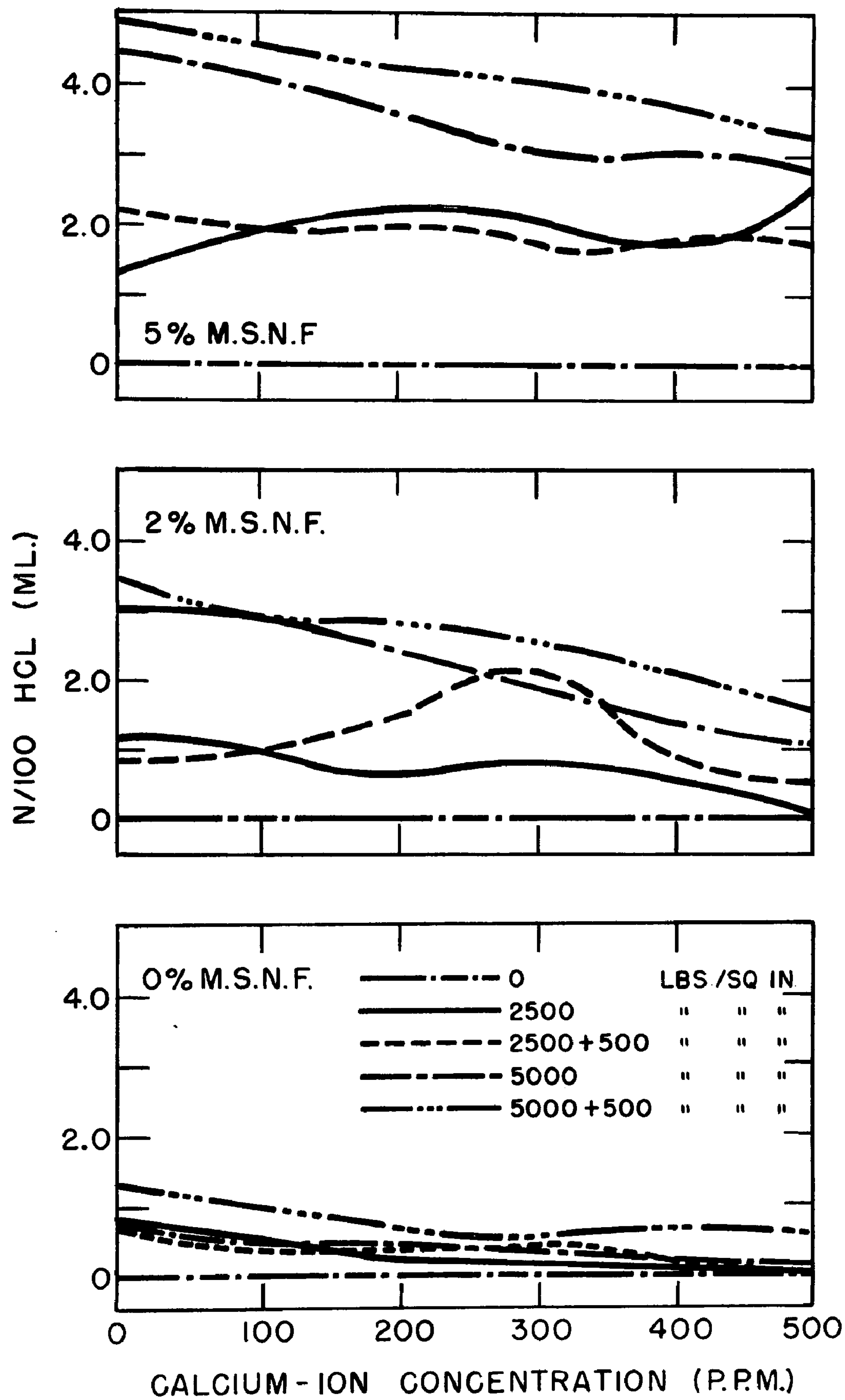


Figure 4. The influence of increasing amounts of calcium-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 1, January).

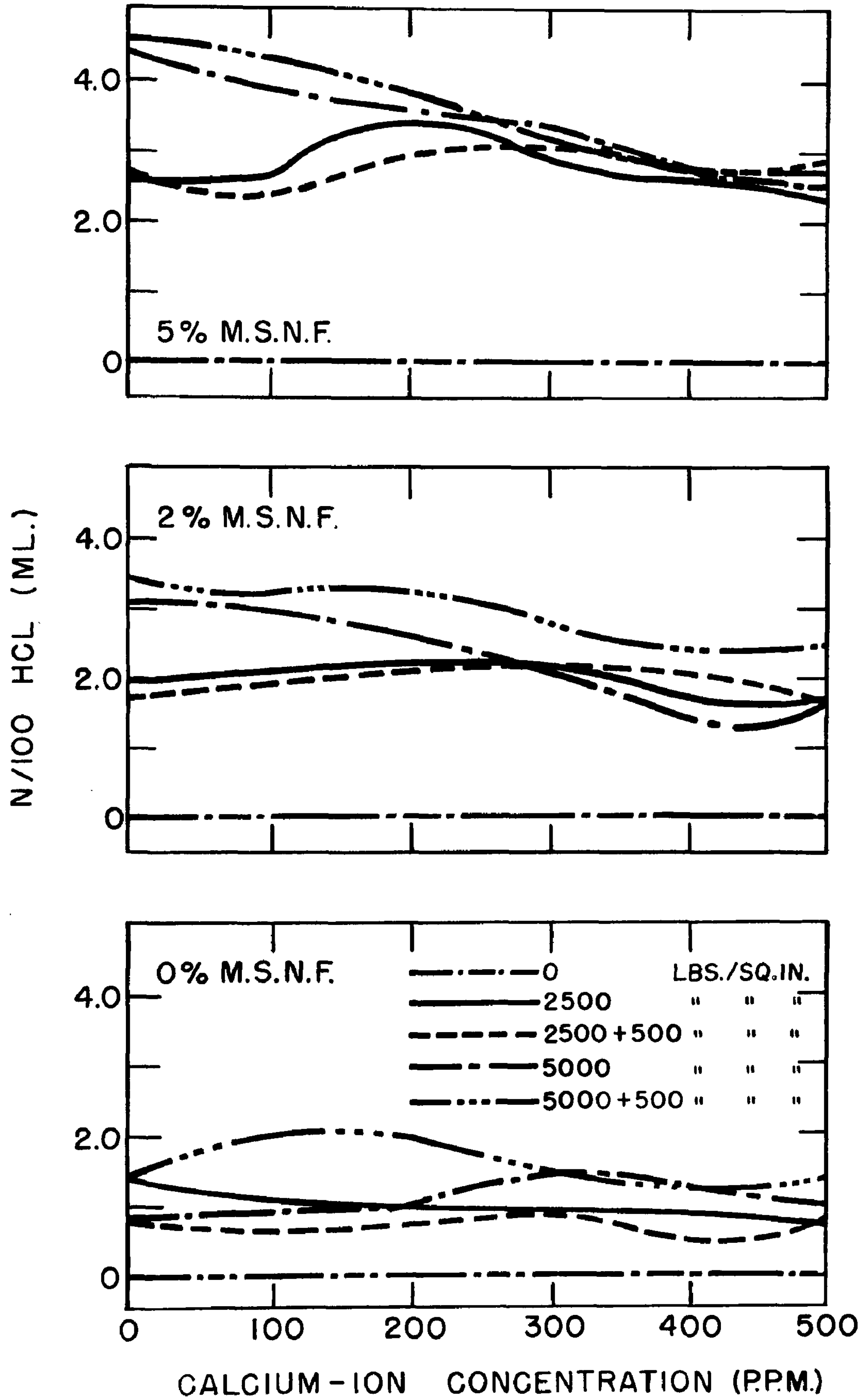


Figure 5. The influence of increasing amounts of calcium-ion concentration on the stability of half-and-half homogonized milk of varying composition, as measured by acid precipitation (Trial 2, March).

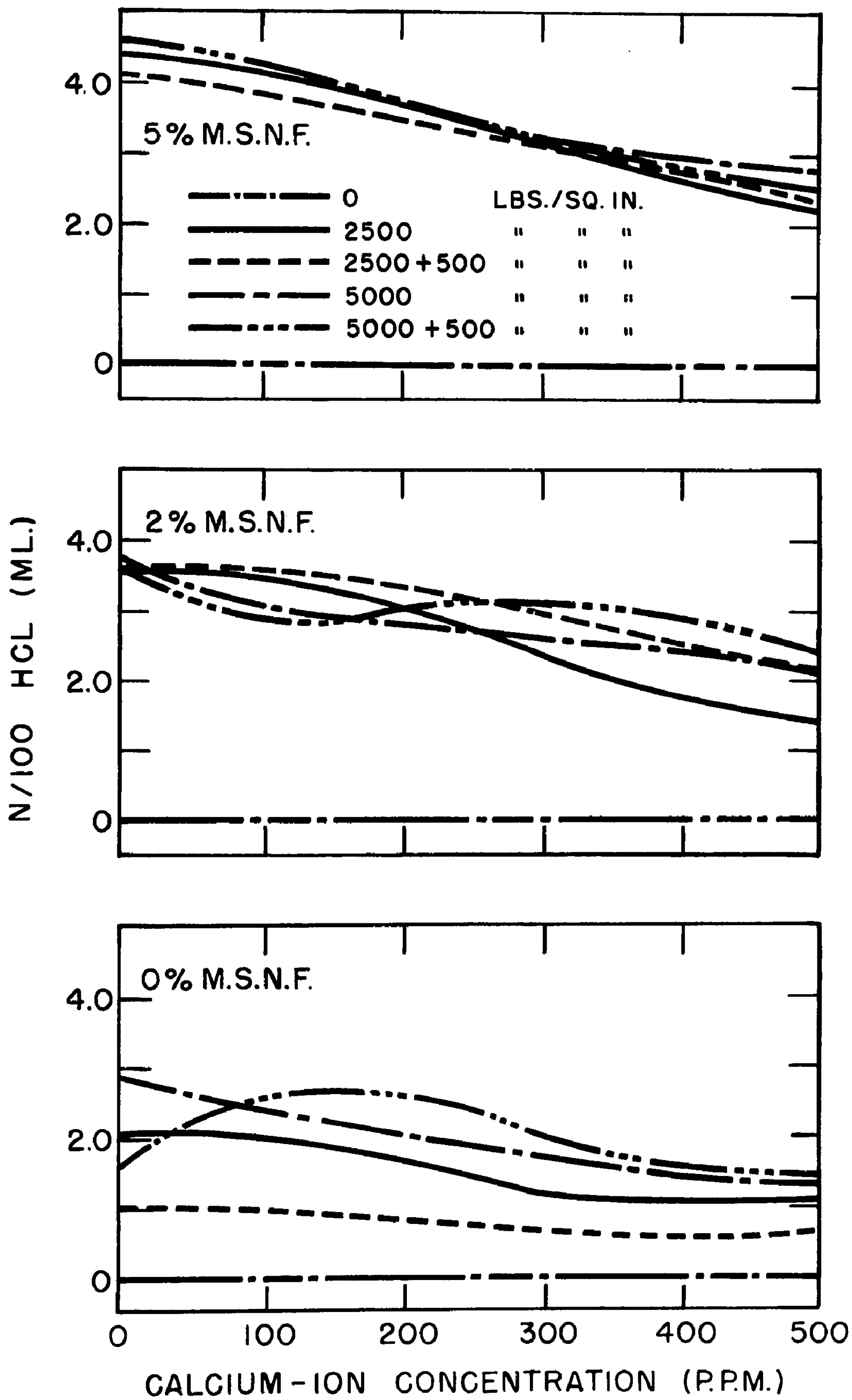


Figure 6. The influence of increasing amounts of calcium-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 3, May).

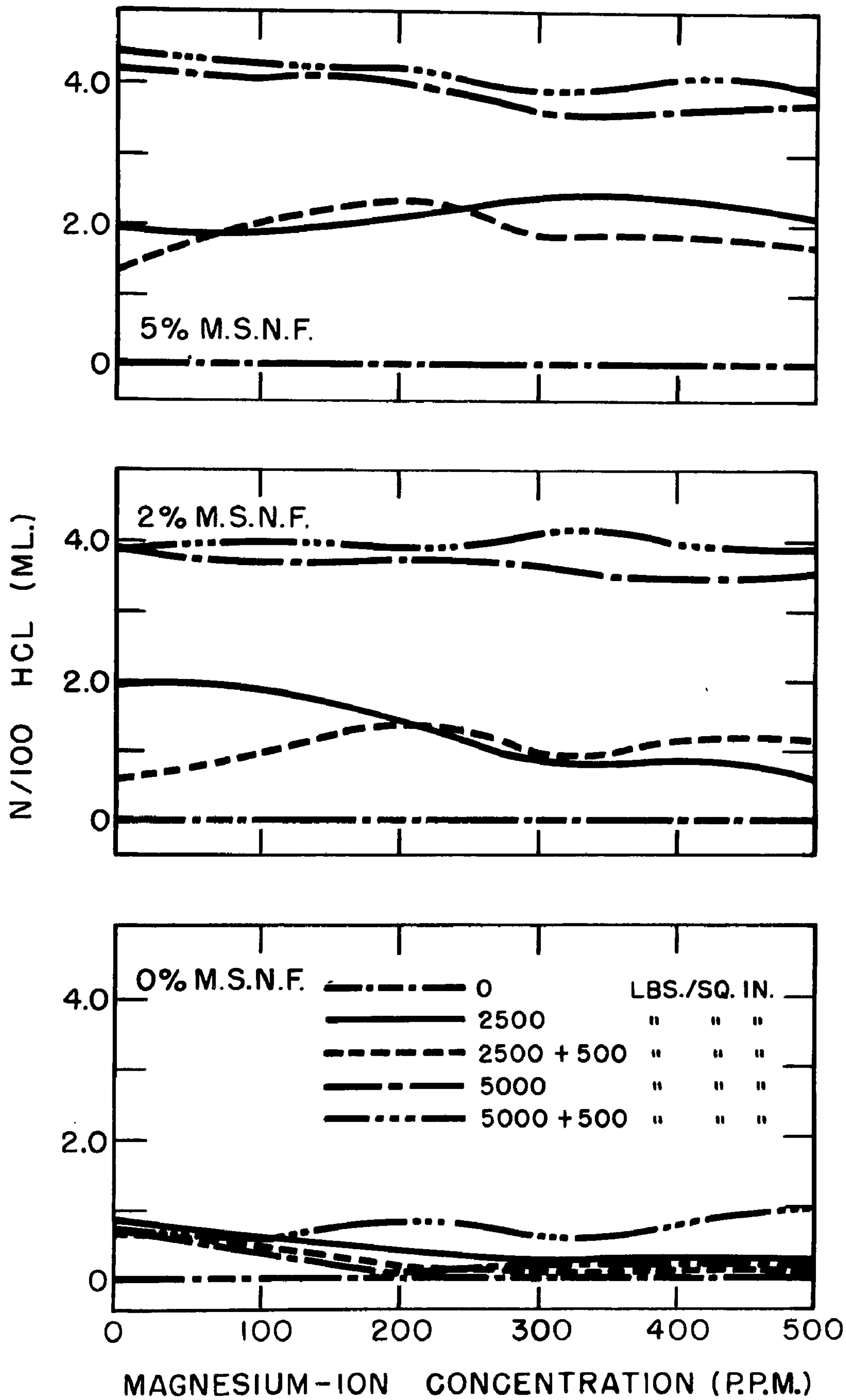


Figure 7. The influence of increasing amounts of magnesium-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 1, January).

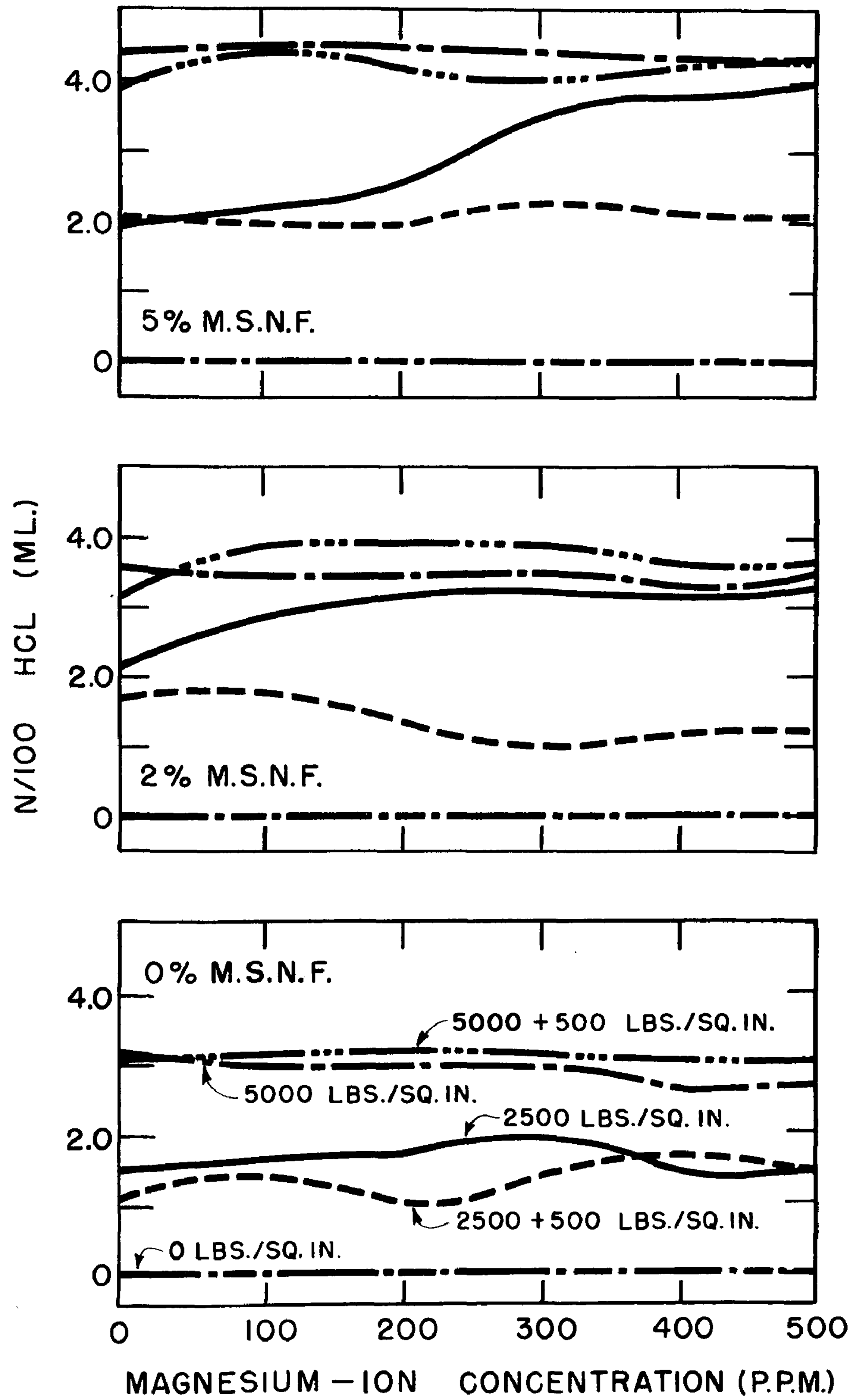


Figure 8. The influence of increasing amounts of magnesium-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 2, March).

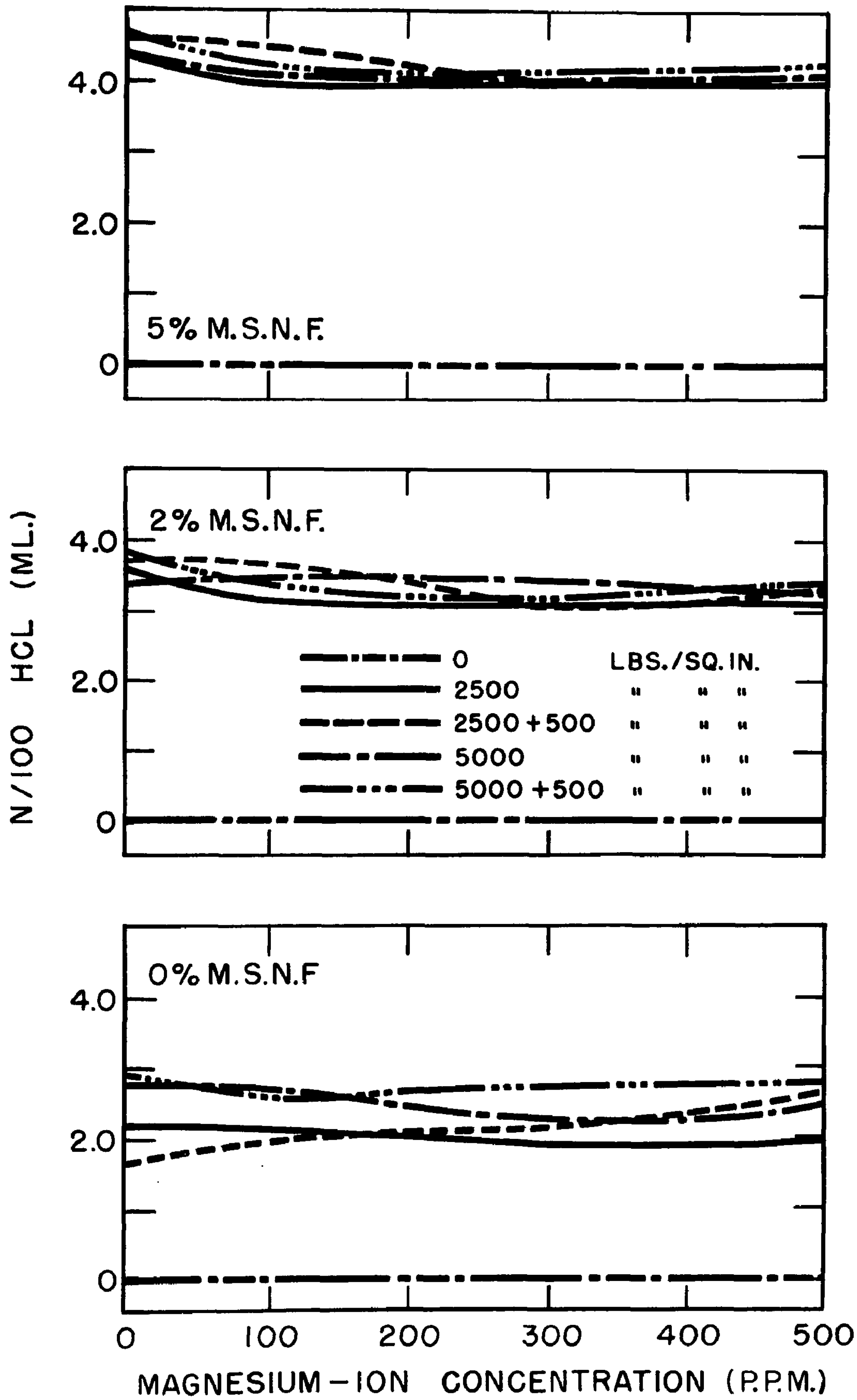


Figure 9. The influence of increasing amounts of magnesium-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 3, May).

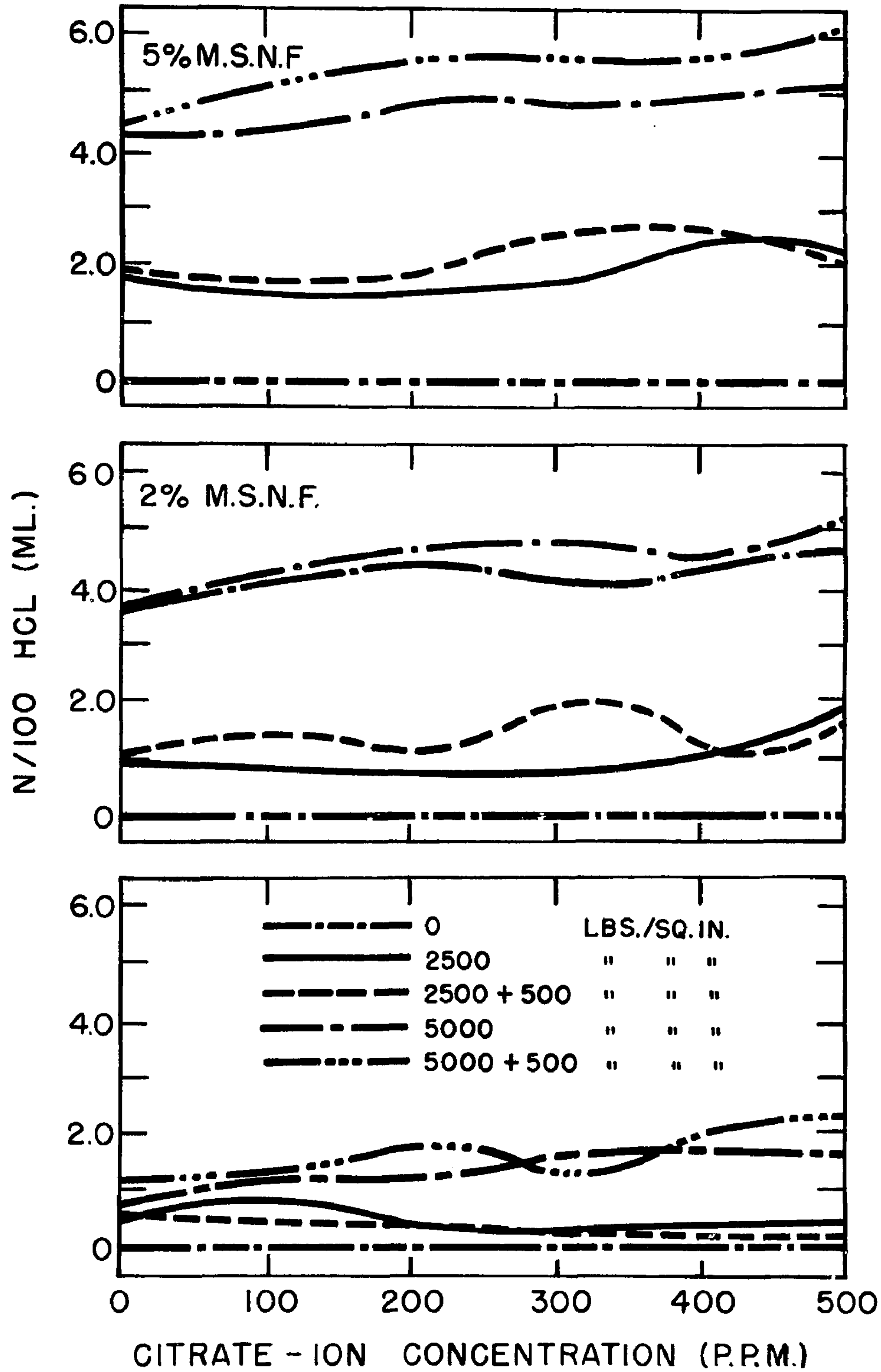


Figure 10. The influence of increasing amounts of citrate-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 1, January).

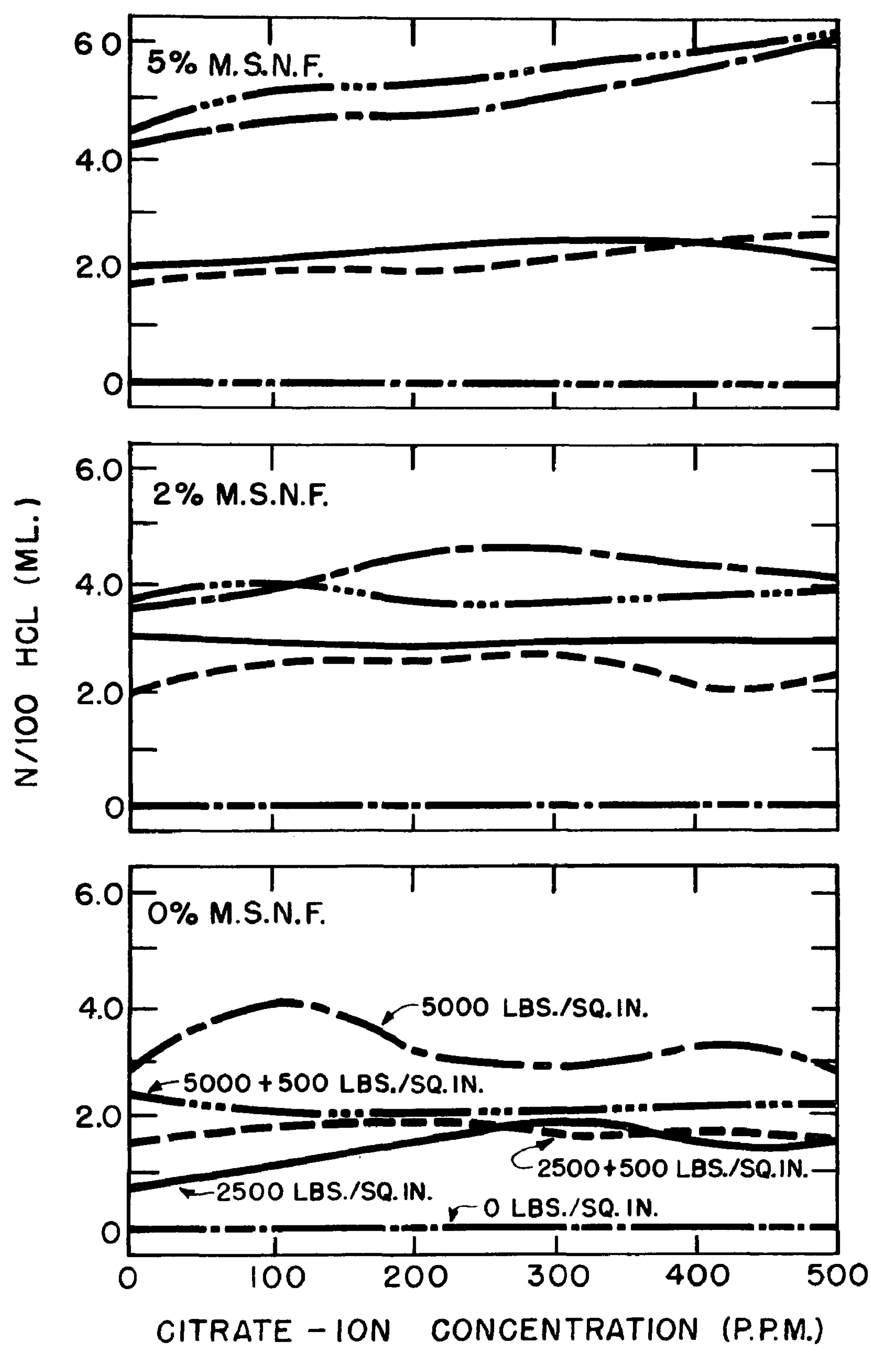


Figure 11. The influence of increasing amounts of citrate-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 2, March).

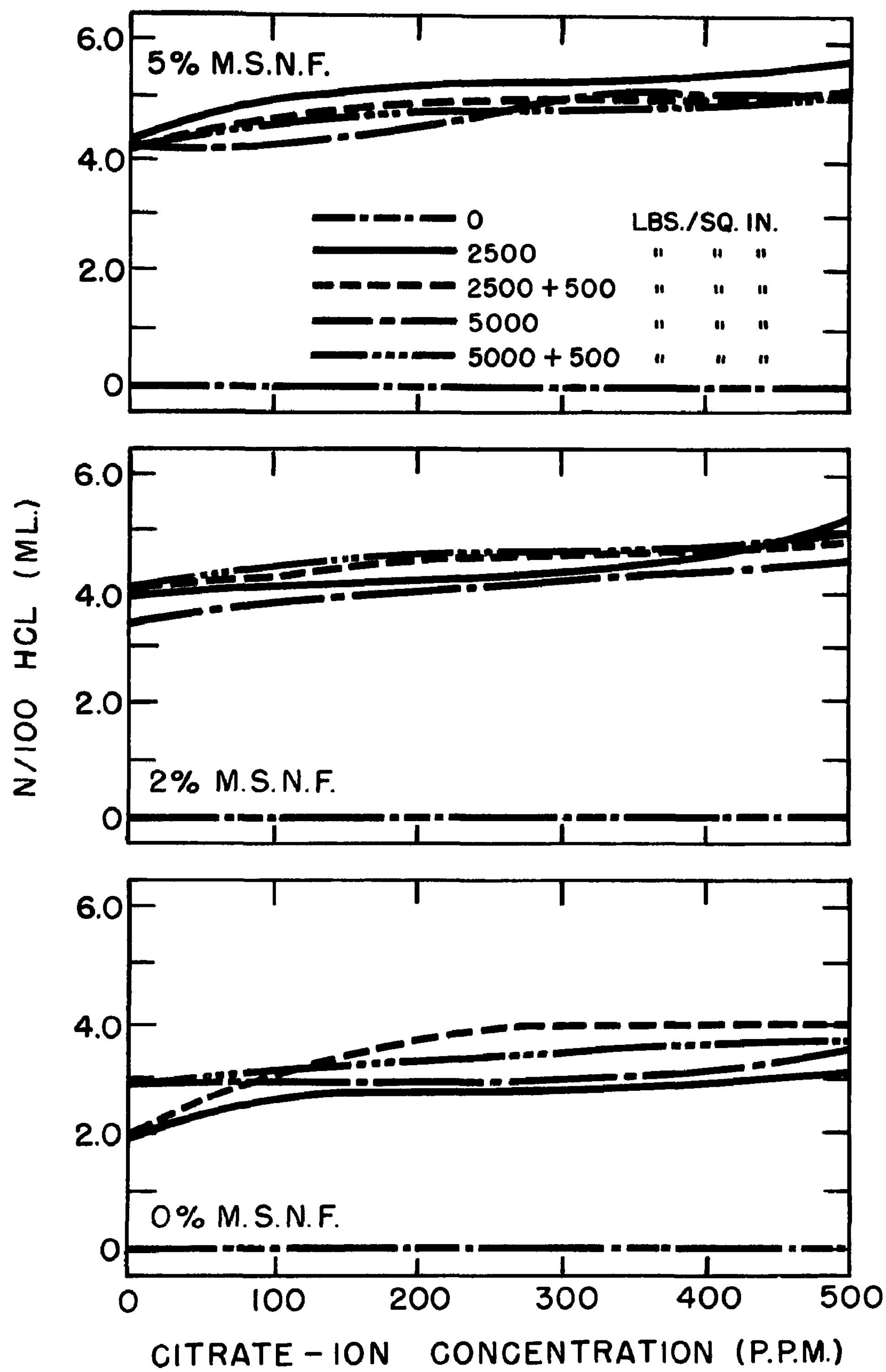


Figure 12. The influence of increasing amounts of citrate-ion concentration on the stability of half-and-half homogenized milk of varying composition, as measured by acid precipitation (Trial 3, May).

Discussion

The studies undertaken in the first section of this investigation were designed to gather information on some of the physical and chemical properties of half-and-half homogenized milk. Factors considered were (1) the effect of varying the composition through the addition of low-heat, spray-process skimmilk powder, and (2) noting whether homogenization was a significant factor in a product testing 10 to 11 percent fat.

These series of half-and-half were standardized to 10.5 percent fat. This was in accordance with the laws of the State of Michigan (1952), which specified that the amount of butterfat should not be less than 10 percent. As the purpose of introducing half-and-half was to present to the public a low-fat, cream-like product, the percentage of fat was reduced to 10.5 percent, thereby retaining a safety margin of 0.5 percent.

Viscosity. In the opinion of this investigator, the most significant fact noted in this study was the relatively small increase in viscosity, regardless of homogenization or additions of nonfat dry milk solids. Nevertheless, the effect of adding skimmilk powder did increase the viscosity of the half-and-half slightly. This increase was consistent, whether the product was homogenized or nonhomogenized. These observations were essentially in agreement with those of Trout and Weinstein (1952) and Babcock (1931). However, these investigators, by adding different types of nonfat dry milk solids, did obtain a greater increase in viscosity.

Of considerable importance also was the contrasting effect of single- versus double-stage homogenization on the half-and-half homogenized milk. The greatest increase in viscosity occurred as the result of single-stage homogenization. When the pressure was increased to 5,000 pounds per square inch, the increase in viscosity was erratic, the greatest increase being 11.2 centipoises. However, when a pressure of 500 pounds per square inch was placed on the second valve, the greatest increase was only 1.5 centipoises. Although the viscosity readings were higher when the determinations were made at 3° C., no significant difference in the increase in viscosity as a result of processing could be distinguished from those readings recorded at 20° C.

Information concerning viscosities of half-and-half-type products are somewhat scarce. However, these results are in reasonable agreement with those of Trout and Weinstein (1952), who had made investigations on similar types of products. Using milk testing 3.7

to 4.1 percent, Demott (1954) obtained a maximum viscosity of 4.3 centipoises at 6,000 + 500 pounds per square inch pressure when using the same homogenizer as was used in this study. In milk testing up to 6 percent fat, Brunner (1952), using a homogenization pressure of 3,500 pounds per square inch, obtained viscosity values up to 6.2 centipoises. Hence, in this latter case, although using a different homogenizer, the results were close to some of the readings observed in this investigation.

The general consensus of opinion among investigators (Doan, 1938; Bateman and Sharp, 1928; and Trout, Halloran, and Gould, 1935) is that, although there may be a slight increase in the viscosity of milk as a result of homogenization, this increase could not be considered as significant. There is, however, some disagreement as to the percentage of fat necessary in order for clumping to be produced upon homogenization. Doan and Swope (1927) suggested from 4 to 6 percent fat; whereas Doan (1927) believed 6 to 8 percent fat to be the critical percentage to bring about clumping. Later, Doan and Minster (1931) showed that high preheating temperatures would eliminate clumping when the product contained less than 7 percent fat.

When homogenizing at a temperature of 37° C. (100° F.), Doan (1929) suggested that the threshold point of clumping occurred when a product containing from 10.5 to 10.6 percent fat was homogenized at 3,500 pounds per square inch pressure. Using the same processing technique, Doan considered the critical ratio of plasma solids to fat to be 0.60 to 0.85 when the fat concentration was from 8 to 18 percent.

The ratios of plasma solids to fat used in this study were 0.83, 0.96, and 1.2 for Series 1, 2, and 3, respectively. Under the conditions of this investigation, where the homogenizing temperature was 150° F., some fat clumping was evident, especially in those samples homogenized at 2,500 and 5,000 pounds. However, the clumping in these latter cases was relatively light. Therefore, although a good homogenizing temperature was used, and the plasma solids-to-fat ratio was above that of Doan's (1929a), fat clumping was evident at a pressure of 2,500 pounds per square inch.

Doan (1931a) also thought that fat clumping could be reduced by increasing the amount of plasma solids in homogenized cream, thus lowering the viscosity. The data presented in this study, however, do not show any decrease in viscosity as a result of adding nonfat dry milk solids. Hence, it might be assumed that the samples in the first series, where no solids were added, had a sufficient amount of solids in the plasma for adsorption onto the new surfaces of the homogenized fat globules. Probably the main effect of adding nonfat dry milk solids to half-and-half was a slight increase in the viscosity due to the presence of additional solids in the plasma phase.

As evidenced by the small degree of clumping, the three series studied had relatively low viscosities. Therefore, as might be expected, little increase in viscosity occurred when the samples were stored for 7 days. This was in accordance with the views of Sherwood and Smallfield (1926), who noted that when viscosity increased upon storage, the clumps of fat globules were larger. It should be noted that the initial determinations were made after the samples were stored for 6 hours.

Heat stability. The maximum heat stability was found to be in the nonhomogenized control samples of Series 1, in which skimmilk powder was not added. As the solids-not-fat content was increased by the addition of this powder (Series 2 and 3), the stability of the nonhomogenized samples decreased. This destabilizing effect of skimmilk powder occurred also in the homogenized samples. However, the addition of skimmilk powder to the samples homogenized at a pressure of 5,000 pounds per square inch produced no further decrease in the heat stability.

In all cases, homogenization of half-and-half decreased the heat stability. A distinct difference could be detected between the stabilities of those samples processed with a single and with a double stage. However, once the solids had been added, and the pressure of 2,500 pounds per square inch was reached, no further decrease in heat stability was noticeable with increased pressures. In addition, once the samples, with the added solids, were homogenized at pressures of 2,500 + 500 pounds per square inch, any increase in pressure on the first valve did not produce any further destabilization.

The heat stability of the nonhomogenized products to which no powder was added (97 minutes) appeared to be within reasonable agreement with that found on mixed-herd milk, where the heat stability varied from 50 to 120 minutes, depending upon the time of year (Osborne, 1953). Demott (1954), in determining the effect of dual-homogenization on milk, found that by using pressures up to 6,000 + 500 pounds per square inch, the heat stability ranged from 128 to 154 minutes for 3.7 percent milk, and 98 to 128 minutes for 4.1 percent milk. In both cases, pressures of homogenization did not affect the results significantly. Webb and Holm (1928), who had previously reported data for 5- and 10-percent products, indicated that, while some reduction in heat stability did occur in milk as a result of homogenization, a greater decrease was found when the fat content was increased to 10 percent.

Hence, the relatively small decrease in heat stability that occurred in Series 1 as a result of homogenization appeared to be in reasonable agreement with the values obtained for both milk and the 10-percent-fat product. The lowering in heat stability of products containing abnormally large amounts of milk-solids-not-fat was borne out by the results of Webb (1931) and Whittier and Webb (1950), although the findings in this investigation were not in agreement with those of Doan and Minster (1930).

As yet, the reason why homogenized products have a lower heat stability appears to be not fully understood. This instability has been explained by Doan (1931a), Tracy and Ruehe (1930b), and Webb and Holm (1928) as due to the clumping of the fat in homogenized cream. Webb (1931) felt that the fat clumps in cream could provide a suitable nuclei around which flocculation could proceed. Doan (1931a) believed that the casein adsorbed on the fat globules, as a result of homogenization, would lose its mobility and hence be more susceptible to agents of coagulation. If this were true, he postulated, then the fat clumps could bring such easily precipitated casein into intimate contact, thus presumably favoring coagulation.

That the membrane-protein of the homogenized fat globules is different from the nonhomogenized material has been indicated by Brunner, Duncan, and Trout (1952) and Brunner, Duncan, Trout, and MacKenzie (1953). In addition, the results of their work show that this membrane-protein material on the homogenized fat globule differed markedly from any of the recognized proteins.

In low-fat products, where clumping is not so pronounced, other factors may be involved. As a result of homogenization, some of the serum protein becomes adsorbed onto the new fat surfaces (Brunner, Lillevik, Trout, and Duncan, 1953), thereby leaving a high proportion of salts to the protein remaining in the serum. If this left a higher proportion of calcium in the serum, then instability would result. This instability would increase as homogenization became more efficient.

Titratable acidity, pH, specific gravity, and organoleptic properties of half-and-half. The addition of skimmilk powder resulted in a definite increase in titratable acidity. When 5-percent solids were added, the calculated increase in acidity for each percent was 0.0189 percent lactic acid. There was no significant change in pH as a result of these additions. The solids-not-fat, present in milk, contains the constituents which are responsible for the apparent acidity of milk (Sommer, 1952). Hence, the addition of nonfat dry milk solids to half-and-half would increase the titratable acidity. However, as these constituents have a low ionization constant, little effect on the pH would be expected by adding skimmilk powder.

The increase in specific gravity was in proportion to the amount of nonfat dry milk solids added. The maximum specific gravity allowed in half-and-half homogenized milk in Michigan is 1.032 (Michigan Department of Agriculture, 1952). Therefore, according to the results of these trials (Table 5), with half-and-half containing between 10 and 11 percent fat, the maximum amount of powder that might be added legally would be approximately 2 percent, for at this solids-not-fat to fat ratio, the specific gravity varied from 1.0302 to 1.0330.

When considering the preference for the products of the three series of half-and-half based on their organoleptic properties, the series which contained no added increments of milk-solids-not-fat was omitted from further consideration due to the salvy cream plug, thin body, and lack of flavor. The addition of skimmilk powder yielded a heavier body and enhanced the flavor of the product. However, when 5 percent skimmilk powder was added, although the body was considered as being very desirable, the flavor was undesirable, being distinctly salty. Consequently, for desirable body and flavor, the series containing 2 percent added skimmilk powder was preferred.

The stability of half-and-half in coffee. The most unexpected fact noted was that half-and-half did not feather in coffee made with hard, tap water, while in some cases feathering did occur in coffee made with distilled water.

With this problem of feathering, the pH of the brew appears to be of considerable importance. Investigators such as Ruehe (1948b) and Tracy and Corbett (1938) were concerned with the methods of preparation and the use of different types of coffee on the pH of the brew. Their opinion was that brews with higher acidities, or lower pH values, would have a greater tendency to feather. The point that should be noted in this study was that the pH of the brews made from hard water were much higher than those made with distilled water. The lack of any buffering action of the salts, which are present in hard water, may be one explanation for the decreased pH in the brews made with distilled water.

The fact that no feathering occurred in coffee made with hard water need not seem too startling. Previously Doan (1931b) was able only in isolated cases to attribute feathering to the hard water used in the coffee making. Sommer (1929b) agreed by stating that if all other processing techniques were satisfactory and feathering still resulted, then the cause was almost certain to be in the hardness of the water and the salt content of the cream. Other investigators (Tracy and Ruehe, 1930a; Burgwald, 1923; and Atherton and Bradfield, 1952) tended to agree that, although the hardness of water might be a factor in the feathering of cream in coffee, other factors such as quality of ingredients in the cream, occurrence of fat clumping as a result of homogenization, and pH of the brew were considered to be of greater importance.

The influence of added nonfat dry milk solids and pressures of homogenization on the stability of half-and-half. The reason why acid was not required to bring about precipitation of the nonhomogenized samples, when mixed with distilled water, is open to considerable speculation. It is rather improbable that this precipitation was due to churning, since the agitation was limited before the observation was made (the tubes were inverted only five times). Furthermore, the report of Palmer and Wiese (1932), that the layer of adsorbed material was so firmly held at the fat surface that rich creams could be repeatedly diluted with distilled water and reseparated without breaking the emulsion, would lend support against churning as the possible cause of precipitation.

One conjecture in favor of dilution as contributing to precipitation is that of the dilution of the salts themselves. As the protein requires an optimum quantity of salts (Sommer and Hart, 1919; Tracy and Ruehe, 1930b), the effect of dilution would be a destabilizing factor, due to the removal of some of the salts from the protein. This destabilization occurred even when the various concentrations of the three ions, calcium, magnesium, and citrate, were used as a diluent. Hence, it might be supposed that a concentration of 500 parts per million of these ions was not adequate for proper stabilization.

The addition of acid was necessary to produce precipitation in all the homogenized samples. A possible explanation of this effect might be in the formation of new membrane-protein layers as a result of homogenization. This protein component of the fat globule membrane of homogenized milk was altered due to the addition of milk plasma proteins to the normal complement of the membrane protein complex (Brunner, Duncan, Trout, and MacKenzie, 1953; Brunner, Lillevik, Trout, and Duncan, 1953). Doan (1931a) had previously described this altered-membrane protein as having lost its mobility. Therefore, under the conditions of this experiment, the altered membrane might possibly be more resistant to this dilution effect.

When skimmilk powder was added to half-and-half, more acid was necessary to bring about precipitation (Tables 7, 8, and 9). This amount of acid increased as additional increments of the powder were added to the half-and-half. These additions of skimmilk powder would increase the concentration of the plasma solids and hence provide a buffering action, not only for the various ions, but also against the additions of acid. Consequently, the assumption might be made that as more nonfat dry milk solids were added to the samples, as in Series 2 and 3, more acid would be required to precipitate the protein. In all the trials carried out, this was shown to be the case. Therefore, it may be said that when low-heat, spray-process skimmilk powder is added to half-and-half, increased stability of the product is indicated.

With the exception of the May trial, more acid was required to produce precipitation when the higher pressures of homogenization were used. This was especially noticeable in the series wherein 2 and 5 percent skimmilk powder were added. One possible explanation of this apparent increase in stability might be associated with the fat-globule membrane as previously explained for the difference of stability between homogenized and nonhomogenized samples in distilled water. In this instance, the increase in pressure would create a greater number of fat globules, which would result in a greater amount of protein being incorporated in the fat-membrane layer. Therefore, this greater proportion of altered protein conceivably could require more acid for precipitation than that of the samples homogenized at the lower pressures.

Little difference was noted in acid stability of the samples subjected to single- and to double-stage homogenization. However, on close observation of the trials conducted in January and March, the products homogenized at pressures of 5,000 + 500 pounds per square inch generally were found to be slightly more stable than the other samples. No difference could be distinguished between the two samples homogenized at the lower pressures of 2,500 and 2,500 + 500 pounds per square inch. The above results might seem contrary to those which have been previously reported both in this and in oth r investigations (Doan, 1931a; Webb, 1931). Therein the stability of high-fat products were reported as having been decreased markedly as a result of single-stage homogenization. The decrease in stability was attributed to the clumping of fat globules. If, however, these clumps were broken up as a result of low-pressure homogenization or agitation (Doan, 1929a), a resultant increase in stability occurred. Therefore, because of the dilution and agitation factors used in the procedure of this study, these fat clumps would be broke up in large part. Consequently, this technique would not show any significant differences in the stabilities of the single- and dual-homogenized samples.

When comparing the effects of the calcium, magnesium, and citrate ions on the stability of the various types of half-and-half, some definite trends were indicated. Calcium ions tended to destabilize the products. The magnesium ions, in the concentration used, apparently did not affect the stability of the samples. On the other hand, the citrate ions tended to act as a stabilizing ion, for as the ionic concentrations were increased, more acid was required to produce a precipitate. These results were in agreement with those previously reported by such investigators as Doan (1931b), Seekles and Smeets (1947), Sommer (1929b), and Tracy and Ruehe (1930b), who noted that calcium ions helped destabilize products and the citrates were used for stabilization purposes. Little information has been reported on the stability of products, as affected by the magnesium ion.

Three separate trials were conducted in this phase of the experiment, the first in January, the second in March, and the third in May. The results obtained from the first trial, on the series in which no solids were added, indicated an unstable product (Figures 4, 7, and 10). Whether calcium, magnesium, or citrate ions were added, very little acid was required for precipitation. Comparing this same series to Trial 2 (Figures 5, 8, and 11) and Trial 3 (Figures 6, 9, and 12), a gradual stabilization of half-and-half was seen to occur. This would seem to agree with the work of Sommer and Hart (1926) and Hunziker (1949), who believed that the citric acid content in milk was increased when the cows were turned to green spring pasture. However, Osborne (1953) suggested that the citric acid content of milk might increase or decrease in the spring, depending on such factors as the cow and type of pasture. In addition, these results were in agreement with those of Jacobsen and Wallis (1939) and Ellenberger, Newlander, and Jones (1950), who found the calcium and phosphorus values to be low for milk during the summer, but reaching their highest level in the winter months of November through February.

In Series 2 and 3, wherein 2 and 5 percent skimmilk were added, respectively, this difference in stability of the three trials was minimized. When 5 percent powder was added, only a little difference in the relative stabilities of the three trials was noted, especially when the samples were homogenized at the higher pressures.

In Trial 3, although the samples were homogenized at the usual high and low pressures, very little difference in the results was observed. One possible explanation may be that at the lower pressures, the necessary dispersion of the fat globules to bring about stability against the effect of acid was attained.

SECTION II

1. THE EFFECT OF DECREASING RATIOS OF SOLIDS-NOT-FAT TO FAT ON SOME CHEMICAL AND PHYSICAL PROPERTIES OF HALF-AND-HALF AND CREAM

2. ANALYSIS OF FEATHERED HALF-AND-HALF AND CREAM

Experimental Procedure

The effect of decreasing ratios of solids-not-fat to fat on some chemical and physical properties of half-and-half and cream. Fresh raw milk was received by the Michigan State College Creamery, where it was separated at 40° F. with a cold-milk separator. The resultant cream and skimmilk were utilized to standardize various series of half-and-half and creams. A total of six different series was prepared with each varying in composition as follows:

Series A. Skimmilk and cream standardized to 10.5 percent fat.

Series B. Skimmilk and cream standardized to 10.5 percent fat plus the addition of 2 percent low-heat, spray-process skimmilk powder.

Series C. Skimmilk and cream standardized to 10.5 percent fat plus the addition of 5 percent low-heat, spray-process skimmilk powder.

Series D. Skimmilk and cream standardized to 13.0 percent fat.

Series E. Skimmilk and cream standardized to 18 percent fat.

Series F. Skimmilk and cream standardized to 23 percent fat.

Hence, Series A to C were prepared in the same manner as Series 1, 2, and 3 in Section I, and Series D, E, and F were standardized so as to produce samples of increasing fat content. Each series was pasteurized, homogenized, and bottled as stated in Section I.

The viscosity, heat stability, titratable acidity, pH, percentage total solids, and fat also were determined as outlined in the Experimental Procedure under Section I.

An attempt was made to note whether an emulsifying agent would have any effect on the clumping phenomenon of homogenized half-and-half and cream. The emulsifying agent used for this study was sorbitan monostearate. This agent was added, at the rate of 0.05 percent, just prior to the holding time of pasteurization. All other factors in the preparation of the samples were kept as similar to the control as possible. The effect of the emulsifier was determined by heat stability and viscosity.

A preliminary investigation was undertaken with the view of studying the migration of fat globules in an electrical field as affected by various pressures of homogenization and by differences in composition of the samples.

A phosphate buffer, standardized to a pH of 7.6 and an ionic strength of 0.02, was prepared by dissolving 0.309 gram of monobasic sodium phosphate and 6.36 grams of dibasic sodium phosphate in a liter of distilled water. The Mudd modification of the Northrop-Kunitz Cataphoresis Apparatus was used in this experiment.

The samples were prepared by first tempering the product and the buffer to 70° F., or room temperature, and then suspending 0.15 milliliter of the product in 50 milliliters of the buffer. The migration of the fat globules was observed under a microscope at a fixed-focus depth in the cataphoretic cell, in a fixed electrical field. The time for the fat globules to migrate 234.6μ was recorded, and the results were then calculated on the basis of time, in seconds, required for the globules to move 100μ under the above conditions. Five to six readings were made for each sample.

Preparation and analysis of feathered half-and-half and cream. A sample of feathered material was prepared through the use of a 300 parts per million calcium-ion solution, and hard, tap water with the hardness calculated to be 419.2 parts per million calcium carbonate. The calcium-ion solution was used in the first two trials, with the hard water being employed for the third trial. Fifty milliliters of the water was heated to boiling (200° to 205° F.), removed from the source of the heat, and then 5 milliliters of the sample to be tested was added. The precipitated material was removed by filtering through a number 42 filter paper.

The resultant filtrates and the original samples were analyzed for total nitrogen, noncasein nitrogen, nonheat-coagulable nitrogen, and nonprotein nitrogen according to the procedure as given by Brunner (1952).

The percentage of casein nitrogen was obtained by subtracting the noncasein nitrogen from the total nitrogen, and the heat-coagulable nitrogen was obtained by subtracting the nonheat-coagulable nitrogen from the noncasein nitrogen.

The percentage total solids and fat were determined both on the parent sample and on the material precipitated from it.

Experimental Results

A total of six series of samples was prepared in this phase of the study. The first three series, A, B, and C, were standardized at 10.5 percent fat. Increments of 2 and 5 percent nonfat dry milk solids were added to Series B and C, respectively. As these products were similar to those investigated in Section I, only one trial for each series was conducted. The remaining three series, D, E, and F, were prepared with increasing percentages of fat, and were standardized on the basis of their solids-not-fat to fat ratio. The results of the analyses of these products are included in Table 10.

Viscosity. The results, as shown in Table 11 and illustrated in Figure 13, indicated that, as previously reported in Section I, Table 2, homogenization of the three series testing 10.5 percent fat produced only a relatively small increase in viscosity, even when subjected to very high pressures. Furthermore, as a result of single-stage homogenization, viscosity of the samples, testing 13 percent fat, still did not exceed 50.9 centipoises at a pressure of 5,000 pounds per square inch. When the percentage of fat was increased to 18, a sharp increase in viscosity appeared as a result of single-stage homogenization. This increase was even more significant when the 23-percent cream was homogenized. This cream, homogenized at 5,000 pounds per square inch pressure, was not only viscous, but almost solid at 3° C.

When dual homogenization was used, very little increases in the viscosity of the products testing up to 18 percent fat were noted (Table 11, Figure 13). However, by increasing the fat to 23 percent, a definite increase was shown as a result of homogenizing at the pressure of 5,000 + 500 pounds per square inch.

<u>Heat stability</u>. Data presented in Table 12 and shown graphically in Figure 14 show the effect of increasing percentages of fat on the heat stability of the samples. Again, the results of the first three series were found to be similar to those recorded in Section I, Table 4. This confirmed the findings that (1) a decrease in heat stability occurred in the nonhomogenized and in the dual-homogenized samples, when the percentage of solids-not-fat was increased, and (2) the heat stability of the dual-homogenized samples was between that of the relatively stable nonhomogenized products and the unstable, single-stage homogenized samples.

A striking observation made on the final three series, in which the fat content was increased, was the increase in the heat stability of the nonhomogenized samples (Table 12). One factor which should be noted in this connection is that the data presented in this second section were observed in May and June, while the results in Section I were recorded mainly in December, January, and February.

However, as was shown previously, once these high-fat products were homogenized, a significant decrease in the heat stability occurred. This stability became more apparent as the percentage of fat was increased. Hence, a reduction in the heat stability occurred in the dual-homogenized samples as the result of both increasing pressures and increasing percentages of fat. When the products were subjected to one pressure only, the series testing 13 percent fat and over were almost immediately coagulated by the heat. This differed from the series containing 10.5 percent fat, which required at least 10 minutes for coagulation.

Effect of an emulsifier on fat clumping as measured by viscosity and heat stability. An emulsifier, sorbitan monostearate, was added to various samples of half-and-half and cream to note its effect on the clumping phenomenon. The first trial was conducted, using extremes in homogenization pressures, to see what differences, if any, occurred in the viscosity and heat stability (Tables 13 and 14). The second and third trials then were run, using higher-fat products in order that any differences as a result of adding the emulsifier could be more readily detected. These data indicated little significant differences between the control and the treated samples in non-homogenized and dual-homogenized trials. However, when a high degree of clumping occurred, as produced by single-stage homogenization, the addition of 0.05 percent sorbitan monostearate produced a significant decrease in viscosity in all the trials conducted.

The effect of this emulsifier on heat stability is recorded in Table 14. These findings showed that the addition of the emulsifier made no definite changes in the heat stability of the nonhomogenized samples. Furthermore, no significant differences in this property were noted with the single-stage homogenized, 18-percent sample. This was undoubtedly due to their rapid coagulation when subjected to heat. However, when the percentage of fat was decreased to 10.5, a difference was discernible with this single-stage treatment.

When the products were homogenized at 2,500 + 500 pounds per square inch pressure, the addition of sorbitan monostearate definitely increased the stability of the samples. At a pressure of 5,000 + 500 pounds per square inch, one of the trials did show increased stability, while the other remained apparently unaffected.

The migration of fat globules as affected by homogenization and composition. The data showing the migration of fat globules in an electrical field, under fixed conditions, are presented in Table 15. These results were obtained after a period of from four to five days of storage, when it was assumed that ample opportunity was provided for the samples to reach a state of equilibrium. Trials 6 and 7 were determined under the same relative conditions, but through the process of recalibration, probably a slightly different focal length was obtained in the Mudd Cell.

These results indicate that the fat globules of the nonhomogenized samples require a longer period to migrate 100μ than those of the homogenized product. In this respect no significance could be attached to any differences in pressures whether with a single- or with double-stage treatment. In addition, these data would indicate that composition had no effect on migration of fat globules. However, this could not be considered as conclusive.

Analysis of feathered half-and-half and cream. Apparently, little information has been supplied regarding the composition of the feathered material in coffee. In order that this problem may be more thoroughly understood, various samples of half-and-half and cream were subjected to feathering treatment, and this precipitated material, as well as the original products, were then analyzed. The techniques selected to form the precipitate involved such factors as heat, presence of calcium ions, and instability of the product due to homogenization, since these factors were probably most conducive to feathering in coffee.

Four separate trials were conducted. The data are presented in Tables 16 and 17. The results, presented for each trial in these two tables, were obtained from the same series of samples. The analysis of the feathered material showed that, on a dry-weight basis, the percentage of fat ranged from 81.02 to 94.11, with the increase corresponding to a similar increase in the percentage of fat in the original products.

The distribution of the nitrogen in the filtrate and parent material is shown in Table 16. Here th results are expressed as milligrams of nitrogen per 100 milliliters of parent product. Since 5 milliliters of the parent product was added to 50 milliliters of water, a dilution factor of eleven was had. Therefore, the nitrogen values, obtained in the filtrates, were converted onto the same basis as that of the parent material, by multiplying by this dilution factor. The nitrogen may be converted into protein simply through multiplying by 6.38.

While the results from the analysis of the original samples appeared to be rather consistent, those obtained from the filtrate are inconsistent. As a result of precipitating the feathered material with water containing the calcium ions, a higher percentage of the casein apparently was precipitated. For Trial 2 (Table 17), a negative value was calculated for the casein nitrogen in the filtrate. The results of Trial 3 showed that approximately 91 percent of the casein was precipitated. However, in the fourth trial, in which hard water was used, only about 43 percent of the casein was feathered. Undoubtedly this was due to the high degree of fat clumping in the parent product.

With the technique used in this study, little of the heat-coagulable fraction was precipitated. Of the calculated values obtained (Trials 2 and 3), only about 19 to 31 percent of the heat-coagulable fraction of the parent material was present in the feathered material.

From the above results, several general trends may be noted. When the samples were precipitated with calcium ions, a large proportion of the casein was present in the precipitate. The addition of a sample, homogenized at a pressure of 2,500 pounds per square inch, to hot, hard water produced a precipitate with a much smaller amount of casein. In the samples studied, less of the heat-coagulable fraction was present in the precipitated material than in the original sample.

Table 10. The influence of added solids-not-fat and increasing percentages of fat on the composition of half-and-half homogenized milk and cream.

Series No.	Added Increments of Solids-Not-Fat	Analyses of Half-and-Half and Cream When Treated With Various Increments of Solids-Not-Fat and Fat			
		Fat	Solids-Not-Fat	Total Solids	S.N.F./Fat
	(pct.)	(pct.)	(pct.)	(pct.)	
A*	5	10.54	11.61	22.15	1.101
B*	2	10.71	9.68	20.39	0.904
C*	0	10.50	8.08	18.58	0.770
D**	0	12.76	7.87	20.63	0.617
E**	0	18.44	7.50	25.94	0.407
F**	0	22.74	7.16	29.90	0.315

* One trial.

** Two trials.

Table 11. The influence of variations of temperature and composition on the viscosity of half-and-half and cream when homogenized at various pressures.

Series No.	Added Increments of Solids-Not-Fat	Temp. of Viscosity Measurements	The Viscosity of Half-and-Half When Homogenized at: 0 lbs./sq.in.	2500 lbs./sq.in.	2500 +500 lbs./sq.in.	5000 lbs./sq.in.	5000 +500 lbs./sq.in.
	(pct.)	(°C.)	(centipoises)	(centipoises)	(centipoises)	(centipoises)	(centipoises)
A	5	20	6.7	7.0	6.1	8.6	7.0
		3	8.1	8.9	8.1	14.6	9.3
B	2	20	5.9	7.1	5.5	9.3	6.3
		3	6.9	8.1	6.8	14.8	8.1
C	0	20	5.3	6.5	5.0	8.1	5.7
		3	6.5	7.9	6.3	11.0	7.1
D	0	20	6.1	19.6	5.7	37.9	6.8
		3	7.2	22.5	7.1	50.9	8.2
E	0	20	7.6	114.7	7.5	231.0	8.9
		3	9.3	202.3	8.7	331.0	11.1
F	0	20	11.2	172.4	9.9	1,593.0	26.0
		3	18.0	1,053.0	16.3	4,665.0	44.0

Table 12. The influence of variations in composition on the heat stability of half-and-half and cream when homogenized at various pressures.

Series No.	Fat	Added Increments of Solids-Not-Fat	The Heat Stability of Half-and-Half and Cream When Homogenized at: 0 lbs./sq.in.	2500 lbs./sq.in.	2500 +500 lbs./sq.in.	5000 lbs./sq.in.	5000 +500 lbs./sq.in.
	(pct.)	(pct.)	(minutes)	(minutes)	(minutes)	(minutes)	(minutes)
A	10.54	5	90	15	31	13	30
B	10.71	2	106	12	43	10	44
C	10.50	0	130	12	107	10	94
D	12.76	0	156	3	55	2	48
E	18.44	0	148	1	38	1	6
F	22.74	0	166	1	10	-*	1

* Sample too viscous for a determination.

Table 13. The influence of sorbitan monostearate upon the viscosity of half-and-half and cream when homogenized at various pressures.

Trial No.	Fat	Solids-Not-Fat	The Viscosity of Half-			
			0 lbs./sq.in.		2500 lbs./sq.in.	
			Con-trol	Emul-sifier Added	Con-trol	Emul-sifier Added
	(pct.)	(pct.)	(centipoises)		(centipoises)	
		Viscosity Measured at 20° C.				
1	10.87	7.50	5.9	6.0	-*	-
2	18.20	7.39	7.9	7.8	47.4	26.7
3	18.67	7.61	7.2	8.0	180.0	33.8
		Viscosity Measured at 3° C.				
1	10.87	7.50	7.0	6.8	-	-
2	18.20	7.39	8.4	9.9	56.6	26.7
3	18.67	7.61	10.1	10.4	358.0	41.4

* Values not determined.

Table 13 (Continued)

and-Half and Cream When Homogenized at:					
2500+500 lbs./sq.in.		5000 lbs./sq.in.		5000+500 lbs./sq.in.	
Control	Emulsifier Added	Control	Emulsifier Added	Control	Emulsifier Added
(centipoises)		(centipoises)		(centipoises)	
Viscosity Measured at 20° C.					
-	-	12.9	8.5	-	-
7.6	7.2	194.0	120.0	9.1	8.5
7.5	7.6	266.0	74.9	8.7	8.6
Viscosity Measured at 3° C.					
-	-	15.2	10.1	-	-
8.1	8.6	253.0	145.0	11.0	11.4
9.2	9.0	406.0	84.4	13.0	11.9

Table 14. The influence of sorbitan monostearate upon the heat stability of half-and-half and cream when homogenized at various pressures.

Trial No.	Fat	Solids-Not-Fat	Heat Stability of Half-and-Half and Cream When Homogenized at:				
			0 lbs./sq.in.	2500 lbs./sq.in.	2500 +500 lbs./sq.in.	5000 lbs./sq.in.	5000 +500 lbs./sq.in.
	(pct.)	(pct.)	(minutes)	(minutes)	(minutes)	(minutes)	(minutes)
			No Emulsifier Added				
1	10.87	7.50	95	-	-	3	-
2	18.20	7.39	116	1	66	1	7
3	18.67	7.61	190	2	10	1	5
			Emulsifier Added (0.05%)				
1	10.87	7.50	105	-	-	7	-
2	18.20	7.39	111	2	78	1	18
3	18.67	7.61	190	2	74	1	5

Table 15. The effect of various pressures of homogenization and composition of half-and-half and cream on the movement of fat globules in an electrical field.

Trial No.	Fat	Added Increments of Solids-Not-Fat	Time for Fat Globules in Half-and-Half and Cream to Migrate 100μ When Homogenized at:				
			0 lbs./ sq.in.	2500 lbs./ sq.in.	2500 +500 lbs./ sq.in.	5000 lbs./ sq.in.	5000 +500 lbs./ sq.in.
	(pct.)	(pct.)	(seconds)	(seconds)	(seconds)	(seconds)	(seconds)
1	10.54	5	3.51	3.41	3.36	3.37	3.41
2	10.71	2	3.43	2.85	2.94	2.93	3.09
3	12.70	0	3.70	3.56	3.58	3.57	3.45
4	18.20	0	3.70	3.58	3.29	3.41	3.51
5	22.74	0	3.60	3.39	3.50	-*	-
6	12.82	0	3.28	2.78	2.92	2.90	3.09
7	18.67	0	3.13	2.93	2.75	2.81	2.66

* Values not determined.

Table 16. The composition of half-and-half and cream, as compared to the resultant feathered material.

Trial No.	Comparison in Composition of the Parent Product Against the Resultant Feathered Material: Fat		Solids-Not-Fat		Total Solids		Fat per 100 grams Solids	
	Parent	Feathered	Parent	Feathered	Parent	Feathered	Parent	Feathered
	(pct.)		(pct.)		(pct.)		(grams)	
1	10.68	28.21	7.70	5.42	18.38	33.63	58.10	83.88
2	10.87	21.09	7.81	4.94	18.68	26.03	58.19	81.02
3	18.67	67.29	7.61	4.21	26.28	71.50	71.04	94.11
4	22.69	61.65	6.55	6.17	29.24	67.83	77.59	90.90

Table 17. The nitrogen distribution of half-and-half and cream, as compared to the resultant feathered material.

Trial No.	Comparison in Nitrogen Distribution of the: Total Nitrogen		Noncasein Nitrogen		Nonheat-coagulable Nitrogen	
	Parent	Filtrate	Parent	Filtrate	Parent	Filtrate
	(mg./100 ml. product)*		(mg./100 ml. product)		(mg./100 ml. product)	
1	480.50	108.46	86.86	67.76	44.66	40.70
2	522.20	67.76	87.50	108.46	43.12	44.44
3	417.60	284.57	68.99	84.70	25.56	103.29
4	434.30	141.90	-***	-	-	-

* Readings based on 100 milliliters of parent product.

** Values calculated were negative.

*** Values not determined.

Table 17 (Continued)

Parent Product Against the Resultant Filtrate					
Nonprotein Nitrogen		Casein Nitrogen		Heat-coagulable Nitrogen	
Parent	Filtrate	Parent	Filtrate	Parent	Filtrate
(mg./100 ml. product)		(mg./100 ml. product)		(mg./100 ml. product)	
29.42	30.14	393.60	40.70	15.24	10.56
27.00	29.70	434.70	-**	16.12	14.74
28.65	23.76	348.60	199.87	-**	79.53
-	-	-	-	-	-

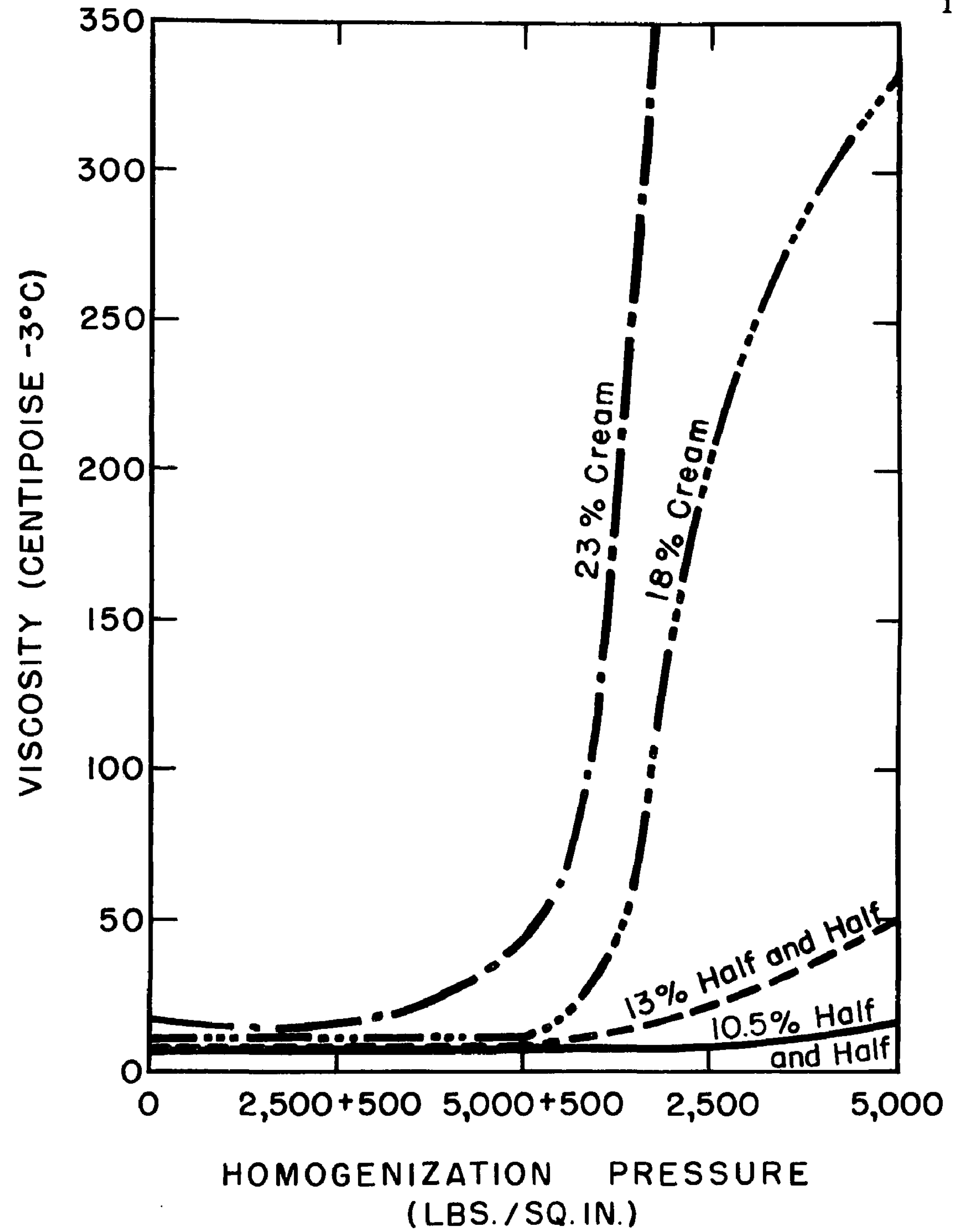


Figure 13. The effect of increasing percentages of fat on the viscosity of half-and-half and cream when homogenized at various pressures.

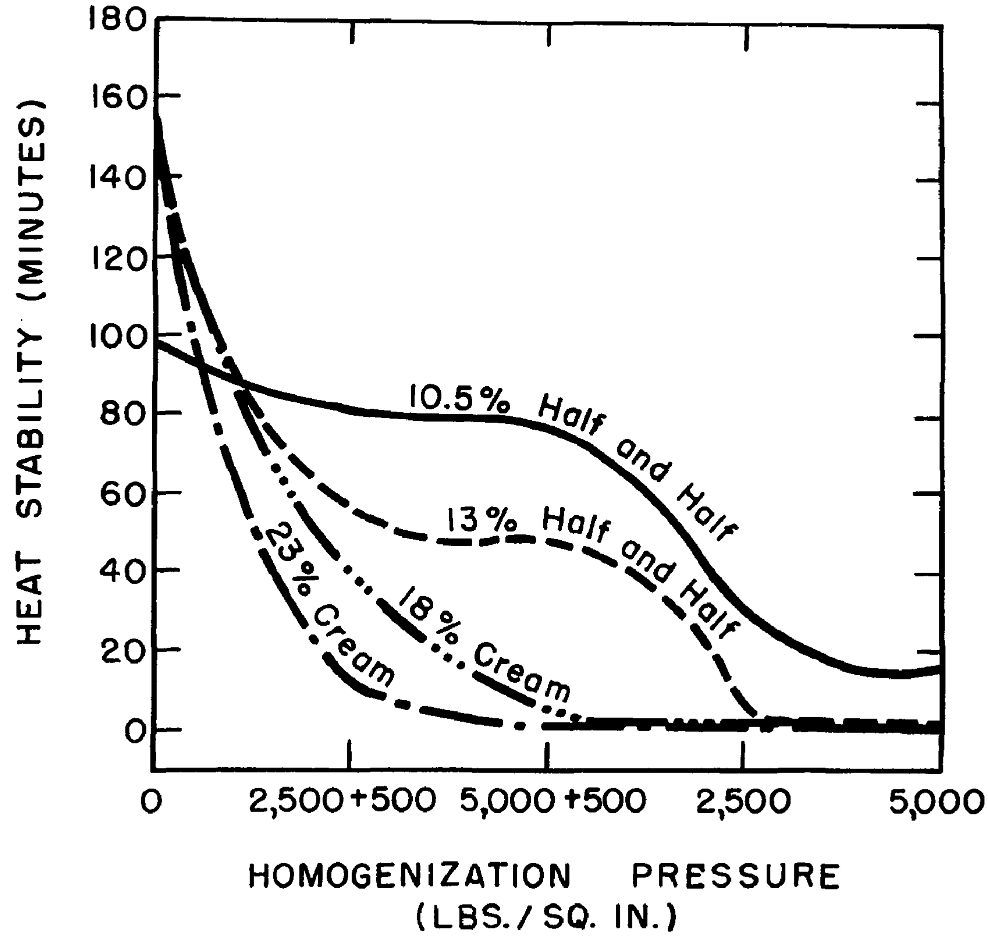


Figure 14. The effect of increasing percentages of fat on the heat stability of half-and-half and cream when homogenized at various pressures.

Discussion

The data presented for the 10.5-percent series, in which solids were not added, were obtained from Section I. These results were compared with the series testing 13, 18, and 23 percent fat (Figures 13 and 14). The latter three series were prepared in two separate trials, the results of which were reported in duplicate.

Viscosity. An increase occurred in the viscosity of half-and-half and cream, nonhomogenized, and homogenized, as the percentage of fat increased. With dual-homogenization, the products testing up to 18 percent fat showed very little, if any, increase in viscosity. Apparently, the addition of 500 pounds per square inch pressure on the second valve was sufficient to break down a large proportion of the viscosity-contributing clumps of fat globules which were formed as a result of the higher pressures on the first valve. However, when the amount of fat was increased to 23 percent, the viscosity increased rather sharply when a pressure of 5,000 + 500 pounds per square inch was applied.

With single-stage homogenization, increased pressures resulted in little increase in viscosity in the 10.5-percent-fat series (Figure 13). When the amount of fat was increased to 13 percent, a relatively slight increase in viscosity was noted at a pressure of 5,000 pounds per square inch. However, on homogenization of the 18-percent series, a sharp increase in viscosity could be seen with pressures of 2,500 and 5,000 pounds per square inch. This increase became still more apparent when the fat was increased to 23 percent.

Therefore, with double-stage homogenization, the sharp increase in viscosity appeared when the fat was between 18 and 23 percent. When considering the solids-not-fat to fat ratio, the above sharp increase in viscosity would be between the ratios of 0.407 and 0.315. With single-stage homogenization, the critical ratio for excessive clumping of fat globules was found to be between 0.617 and 0.407. These values are below the critical ratios of 0.60 to 0.85, as suggested by Doan (1929a). Hence, although different homogenizing temperatures were used, pronounced clumping of the fat globules would be expected at these low ratios used in this study.

Heat stability. A gradual decline occurred in the heat stability of the homogenized products, as the percentage of fat increased (Figure 14). The heat stability of the nonhomogenized samples apparently increased as the percentage of fat increased. Osborne (1953) noted that the highest heat stability of mixed-herd milk occurred in

June, which might indicate why these higher-fat products had a greater degree of stability than the half-and-half samples.

In all the trials conducted, the heat stability of the samples was reduced as a result of homogenization. With dual-homogenization, the heat stability, although sharply reduced, still was definitely above the stabilities as found in the samples homogenized with a single pressure. With dual-homogenization there appeared to be no point where a definite break in the heat stability of the samples occurred as a result of increased percentages of fat. A distinct difference in the heat stability between each series was noted, but this difference was reduced when the 18- and 23-percent cream was homogenized at pressures of 5,000 + 500 pounds per square inch. When these high-fat products were homogenized with dual-stages, very little time was needed for the samples to coagulate.

With single-stage homogenization, however, there did appear to be a definite break in the heat stability once the fat content was increased to 13 percent (Figure 14). The series testing 10.5 percent did not coagulate until the sample was submerged in the oil bath for at least 10 minutes. However, by increasing the fat to 13 percent, only 2 to 3 minutes were required for coagulation.

When comparing viscosity with heat stability, as has been noted previously (Doan, 1931a; Webb, 1931), an inverse relationship was found to exist, for, as the viscosity increased, a decrease in the heat stability was observed. When the second stage was used, due to the breaking up of the clumps of fat globules, the viscosity was decreased while the heat stability was increased.

Effect of an emulsifier on the fat-clumping phenomenon. The action of sorbitan monostearate was determined by the effect of this emulsifier on the viscosity and heat stability of the treated samples (Tables 13 and 14).

This emulsifier had little to no effect on the viscosity of the nonhomogenized and dual-homogenized samples. If anything, as the result of adding this emulsifier, the viscosity tended to increase in the nonhomogenized products at 3° C. However, when these samples were homogenized with a single stage, substantial reduction in clumping appeared evident. Here the addition of 0.05 percent sorbitan monostearate reduced the viscosity 33.5 percent with the 10.5-percent product, while this reduction amounted to 88.4 percent with the 18-percent table cream. This emulsifier had no apparent effect on the samples homogenized at pressures of 2,500 + 500 and 5,000 + 500 pounds per square inch.

When considering the heat stabilities of the same samples, an inverse relationship existed between the viscosity and the heat stability. Once more, no significant difference could be attached to the nonhomogenized samples as a result of adding the emulsifier. With heat stability, the significance is not with the samples homogenized with a single stage, as with viscosity, but with the dual-homogenized products where the clumping was not so heavy. The pressure showing the greatest effect of this emulsifier was at 2,500 + 500 pounds per square inch, for at this pressure the heat stability definitely increased as a result of adding the emulsifier.

On close inspection of these data, the addition of sorbitan monostearate appeared to emulsify the fat globules in such a manner that they were less susceptible to clumping. This might indicate that the plasma solids, in normal cream, did not contribute appreciably to the stability of the fat globule emulsification of the homogenized products, since they tended to form clumps. Therefore, these observations appear to lend support to the theory that once clumping of the fat globules occurs, as the result of homogenization, there is a corresponding decrease in heat stability. If this clumping were reduced, however, a resultant increase in the stability of the product would occur (Doan, 1931a).

Migration of fat globules as affected by homogenization and composition. Indications are that once the samples were homogenized, less time was required for the fat globules to move a certain distance than that required for the fat globules of the nonhomogenized products (Table 15). This, however, appeared to be contrary to the finding of Jack and Dahle (1937b), who reported that neither single- nor double-stage homogenization had any effect on the electrophoretic mobility of the fat globules.

However, once the samples were homogenized, increased pressures of homogenization produced no difference in the migration rate of the fat globules. Although clumping was evident in the samples homogenized with a single stage, the movement of the clumps were similar to those individual fat globules present in the dual-homogenized samples.

From this preliminary investigation, increased percentages of fat in half-and-half and cream did not appear to affect the migration rate of the fat globules. This had been noted previously by Jack and Dahle (1937a), who reported that the electrophoretic mobilities of fat globules of nonhomogenized samples were constant up to a fat content of 65 percent.

Analysis of feathered half-and-half and cream. The reduced proportion of solids-not-fat found in the precipitate indicated that some of these solids-not-fat were lost in the filtrate. The determination of the distribution of nitrogen in the feathered material showed this to be true.

As the methods selected for obtaining the feathered material were arbitrary, no definite references were found in the literature regarding the composition of this material. However, the values obtained in the parent sample were in reasonable agreement with the findings of Shahani and Sommer (1951) and Menefee, Overman, and Tracy (1941), although the heat-coagulable fraction appeared to be much lower than the values obtained by these investigators.

The analysis of the filtrate indicated that where calcium ions were a prominent factor in feathering, a larger proportion of casein appeared in the precipitated material. If, however, the instability of the samples were due to a high degree of fat clumping, as produced by single-stage homogenization, then the amount of precipitated casein would be somewhat less.

Only a small proportion of the heat-coagulable fraction of the parent sample appeared in the feathered precipitate. With the technique used in this study, the water was heated to boiling (200° to

205° F.), removed from the heat, at which point 5 milliliters of the sample was added, and the sample was then filtered within 2 minutes. From the work of Rowland (1933), it might be quite possible that not too much of this fraction was precipitated. This investigator found that 31.4 percent of the total albumin and globulin was denatured at 75.0° C. (167° F.) in 8.2 minutes, whereas if the time interval was decreased to 1.2 minutes, only 13.7 percent was denatured at this same temperature. Therefore, as these samples were subjected to a high temperature for only a short time, incomplete precipitation of the heat-coagulable fraction might be expected.

SUMMARY

Investigations were conducted on the effect of variations in composition of product and in pressures of homogenization on the viscosity, heat stability, occurrence of feathering in coffee, the action of calcium, magnesium, and citrate ions, as measured by acid precipitation, and the organoleptic properties of half-and-half homogenized milk and cream. In addition, the effect of an emulsifier on the clumping of fat globules, the effect of homogenization on the migration of fat globules in an electrical field, and the composition of feathered half-and-half and cream were studied.

The addition of skimmilk powder produced only a slight increase in viscosity of the nonhomogenized and homogenized samples. These additions of powder apparently did not hinder the formation of the fat clumps.

Increases in the percentages of fat produced increases in the viscosity of the nonhomogenized and homogenized samples.

Homogenization, either single- or double-stage, did not produce a significant increase in the viscosity of 10.5-percent half-and-half. The first marked increase in viscosity resulted from single-stage

homogenization when the fat percentage of the samples was between 13 and 18 percent. When 23-percent products were homogenized at a pressure of 5,000 pounds per square inch and stored at 3° C., a plastic-like product was obtained. With dual homogenization, no significant increase in viscosity was observed in the products testing less than 18 percent fat. However, as a result of increasing the fat content above 18 percent, the viscosity increased sharply at a pressure of 5,000 + 500 pounds per square inch.

The addition of nonfat dry milk solids decreased the heat stability of both the nonhomogenized and homogenized samples. The heat stability was found to increase slightly as the percentage of fat in the nonhomogenized samples increased.

On the other hand, homogenization decreased the heat stability of all the products. The samples subjected to single-stage homogenization had the least stability against heat. However, when 500 pounds pressure was placed on the second valve, an improvement in the heat stability was observed. As the percentage of fat increased in the homogenized samples, a gradual decrease in the heat stability occurred. When the percentage of fat was increased from 10.5 to 13 percent, a sharp decrease in the heat stability was observed in the single-stage homogenized samples. No such definite decrease was observed in the heat stability of the dual-homogenized samples.

The addition of nonfat dry milk solids increased the titratable acidity of the samples, whereas the pH remained largely unaffected.

For half-and-half testing between 10 and 11 percent, the addition of 2 percent skimmilk powder was judged to be the most desirable from the viewpoint of body and flavor.

Coffee made with hard, tap water did not feather half-and-half, whereas that made with distilled water occasionally did show feathering. The difference in stability was believed to be due to the lower pH of the brew made with distilled water. The addition of skimmilk powder to half-and-half did not improve significantly the stability of the samples against feathering when the coffee was made with distilled water.

Generally, half-and-half, homogenized at the higher pressures, appeared to be more stable against the effect of acid than that homogenized at the lower pressures. This increased stability against acid precipitation was attributed to the altered membrane protein of the homogenized fat globule.

The addition of nonfat dry milk solids apparently provided a buffering action not only against the action of the calcium, magnesium, and citrate ions, but also against precipitation by acid. This would indicate increased stability of these products. The calcium ions tended to destabilize the samples; the magnesium ions had little to no effect; while the action of the citrate ions was one of stabilization.

Where homogenized-produced fat clumping was evident, the addition of the emulsifier, sorbitan monostearate, reduced the viscosity and increased the heat stability of half-and-half and cream. These effects were not observed with the nonhomogenized control samples.

Less time was required for the fat globules of homogenized products to migrate a certain distance, in a fixed electrical field, than for those in nonhomogenized products. Once the samples were homogenized, no difference could be detected in the migration rate of the fat globules either due to increasing pressures or to single- versus double-stage homogenization.

The feathered material of half-and-half cream was found to contain approximately 81 to 94 percent fat, calculated on a dry-weight basis. Over 40 percent of the original colloidal casein was precipitated with the actual amount depending upon the method of denaturation. Only a small percentage of the heat-coagulable protein fraction appeared in the feathered material.

CONCLUSIONS

The viscosity of half-and-half homogenized milk is affected favorably by such factors as (1) pressures of homogenization; (2) single- as opposed to double-stage homogenization; (3) percentage of fat, and (4) percentage of solids-not-fat.

The heat stability of half-and-half is decreased by (1) homogenization; (2) single- as opposed to double-stage homogenization; and (3) additions of nonfat dry milk solids. It is increased by (1) low-pressure homogenization; (2) dual homogenization; and (3) addition of an emulsifying agent.

Each percentage of nonfat dry milk solids added to half-and-half increases the acidity, titrated as lactic acid, 0.0189 percent. These additions produced no significant change in the pH of the product.

The rate of migration of the fat globules in a fixed electrical field is accelerated by homogenization. Once the samples are homogenized, no further differences in the migration rate may be detected, either as a result of increased pressure or single- versus double-stage homogenization.

Feathered material from half-and-half and cream contained from 81 to 94 percent fat, calculated on a dry-weight basis. This material also contained at least 40 percent of the original colloidal casein, but only a small percentage of the heat-coagulable protein fraction.

Homogenization of half-and-half, testing 10 to 11 percent fat, does not produce the instability as has been experienced with table cream. If feathering of half-and-half does occur in coffee, the factors which should be considered in order of importance are (1) quality of ingredients in the half-and-half; (2) pH of the coffee brew; and (3) pressures of homogenization, with special reference to single- versus double-stage.

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