Physical and Chemical Effects of Homogenization of Milk[1]

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THE homogenization of all or part of the milk supply has become a part of the regular procedure in the processing of milk in many market milk plants throughout the country. This is the natural outgrowth of a demand for a milk of uniform richness for use in children's homes, schools, restaurants and in many homes. Although the principle of homogenization is not new to the dairy industry, its application to the market milk industry has been somewhat limited. In Canada, however, and particularly in the Province of Ontario, plants offering homogenized milk for sale report that from 10 to 90 percent of the milk sold was homogenized, the amount depending largely upon the size of the city, competition and the extent to which the sale of homogenized milk has been stressed.

Although many data were available on the effects of the homogenization process on market cream and on ice cream, the data bearing upon the homogenization of average fat content milk were not extensive. Studies were undertaken at the Michigan Agricultural Experiment Station to determine the effects of homogenization on some of the physical and chemical properties of milk. Since the inauguration of the project two years ago hundreds of samples of average whole milk have been homogenized in an endeavor to secure a representative picture of the homogenized product in comparison with the original. The milk used in the major portion of the study was mixed milk, testing approximately 3.7 to 3.8 percent fat. In some phases of the study, milk from individual cows and from individual herds was used. The milk was homogenized before and after pasteurization at various temperatures and pressures in a viscolizer of 200

[1] Credit is due to Messrs. C. P. Halloran and Ira Gould, Jr., graduate assistants at the Michigan Agricultural Experiment Station, for much of the work connected with this study.

gallons capacity. The various properties of the milk were studied according to standard recognized procedures.

A summary of the various phases studied will be presented in the following separate units.

ELIMINATION OF THE CREAM LAYER

Perhaps the destruction of the creaming ability of the milk, the aim generally sought in the homogenization process, is the most noticeable change in milk as a result of proper homogenization. The fat globules, which in normal milk are sufficiently large to be buoyed up to the surface by the heavier serum surrounding them, are broken up into globules so fine that they remain uniformly dispersed throughout the serum.

In a visit to a number of plants in which homogenization of milk was practiced, it was observed that pressures ranging from 1,500 to 3,500 pounds per square inch were being used. Also, in some plants the homogenization process was carried out on the preheated milk previous to pasteurization. Our experiments were made to determine the minimum pressure which might be used to secure a stable homogeneous product. Both raw and pasteurized milk were homogenized at pressures of 500, 1,500 and 2,500 pounds per square inch. From the data secured it would appear that pressures of homogenization higher than 1,500 pounds per square inch were unnecessary in eliminating the formation of the cream layer irrespective of whether the process was accomplished before or after pasteurization. Even when this milk which was homogenized at 1,500 pounds pressure was held for 48 hours, a cream layer of measurable volume formed in only 1 of the 24 trials run.

SIZE OF FAT GLOBULES

The principal physical effect of homogenization of whole milk is the breaking up of the fat globules into many smaller ones. Several investigators—including Buttenberg (4), Weigner (15), Baldwin (1), Sommer (14), Doan and Minster (5)—have shown that in properly homogenized milk the fat globules average less than 2 microns in diameter. It has also been shown that the size of the globules varies inversely with the pressure.

The data secured in the present study are in agreement with these observations. It was found that the fat globules were broken down from an average diameter of 3.88 microns in unhomogenized milk to an average diameter of less than 1.5 microns in the milk homogenized at 2,500 pounds pressure. Apparently both the pressure and temperature govern the size of the fat globules. The fat globules in the milk homogenized at 90° F. were not as finely divided as those homogenized at higher temperatures even though the pressure of homogenization remained the same. Although the average diameter of the globules was greatly reduced, the size of the individual globules varied. The average for the largest fat globules in unhomogenized milk was found to be 13.57 microns, while the largest for the milk homogenized at 2,500 pounds pressure was found to be between 3.4 and 4.0 microns in diameter.

FAT CLUMPING

Several investigators have studied the behavior of the fat globules in homogenized milk and cream. Doan and Minster (5) have shown that many factors affect the clumping of the fat in the homogenized product, and they found that fat clumping was more pronounced in higher fat-bearing products than in milk of normal richness. Since there appears to exist a relationship between fat clumping and instability of some proteins toward heat, clumping of fat in homogenized cream or high fat milk is of great importance. However, clumping of fat in homogenized milk of average fat content does not occur to the extent that it is a factor in the production of a high quality product. Clumping of the fat was observed at varying temperatures and pressures of processing but was not subjected to an intensive study.

SPECIFIC GRAVITY

Since the homogenization process changes the form and relationships of some of the constituents of milk rather than eliminates them, it would seem that the specific gravity of milk would not be influenced by proper homogenization procedure.

Weigner (15) is of the opinion that there is no measurable change in the density of milk after homogenization. Rahn (11) concluded that any decrease in the specific gravity of milk which occurs after passing through a separator, pasteurizer, pump or cooler was due to the incorporation of air during the process.

Although the homogenized lots in both the raw and pasteurized groups averaged a trifle lower specific gravity than did the unhomogenized lots, there was no change of importance due to homogenization. As a whole, the pasteurized groups showed a slightly higher specific gravity than the unpasteurized group. This might be expected since some evaporation of water occurs during pasteurization.

FOAMING

The foaming ability of milk was measured according to the method used by Sanmann and Ruehe (13). Homogenization affected the foaming of milk differently depending upon whether the milk homogenized was raw or pasteurized. Homogenization of the raw milk decreased the foaming ability, while homogenization of pasteurized milk increased the foaming ability. The character of the foams was very different. The foam on the homogenized raw milk contained large air cells which were glossy in appearance, while the homogenized pasteurized milk showed a very fine-textured, dull-appearing foam. Homogenization of raw milk decreased the foam from 131 percent in the check sample to 75 percent in that homogenized at 1,500 pounds pressure. The pasteurized lots showed an increase in foam from 126 to 150 percent at the same pressures.

PROTEIN STABILITY

Homogenization of milk apparently decreased the stability of the proteins toward alcohol irrespective as to whether the milk was raw or pasteurized. Milk pasteurized before homogenization, however, was considerably more stable to alcohol than homogenized raw milk. As the pressure of homogenization increased the destabilizing effect became more pronounced, but this effect was far less marked in the pasteurized milk.

VISCOSITY

Twelve lots of raw milk preheated to 90° F. and 12 lots of the same milk pasteurized at 145° F. for 30 minutes were homogenized at pressures of 500, 1,500 and 2,500 pounds. The viscosity values were determined on the MacMichael viscosimeter immediately after homogenization and again after a 24-hour holding period. All viscosity determinations were made at 20° C. The results which were secured in the study of homogenization as it affects the viscosity of the product are not in perfect agreement with those reported in the literature. Our data show that homogenization of the raw milk preheated to 90° F. increased the viscosity slightly, while that homogenized at 2,500 pounds pressure after pasteurization decreased the viscosity from 2.142 in the check sample to 1.814 centipoises.

Aging the milk for 24 hours increased the viscosity both of the homogenized raw and of the homogenized pasteurized lots.

The decrease in viscosity of homogenized, pasteurized whole milk observed in these studies is in contradiction to practically all the work on viscosity as affected by homogenization. The results on homogenizing raw milk, however, are in close agreement. The milk on which these tests were made was mixed milk testing approximately 3.8 percent fat. Inasmuch as little fat clumping occurs in homogenized, normal fat-bearing milk, any increase in viscosity in homogenized milk could not be attributed to this factor as in the case of homogenized cream. The increase in viscosity of the raw milk due to homogenization as suggested by Bateman and Sharp (2) is undoubtedly due to adsorption of more of the casein to the increased surface area of the fat globules.

The results of the surface tension study indicate that the surface tension of unpasteurized milk preheated to 90° F. is always lowered by homogenization. Doan and Minster (5) have suggested that this holds true only for milk containing less than 5 to 7 percent fat. It would seem that the lowering of the surface tension of homogenized raw milk is, in part at least, the result of the activity of the lipase in bringing about the hydroly-

TABLE 1. *Effect of homogenization on the viscosity of raw and pasteurized milk immediately after processing. The viscosity is expressed in centipoises at 20° C.*

Lot	Raw (90° F.)				Pasteurized (145° F.)			
	Pounds pressure of homogenization				Pounds pressure of homogenization			
No.	0	500	1500	2500	0	500	1500	2500
1.	1.58	1.73	1.88	2.15	2.18	1.85	1.82	1.85
2.	2.12	2.09	2.24	2.24	2.06	2.03	1.87	1.81
4.	2.18	2.21	2.33	2.51	2.27	2.18	2.00	1.64
5.	2.24	2.18	2.12	2.33	2.24	1.82	1.79	1.82
6.	2.12	2.00	2.09	2.06	2.00	1.79	1.79	1.67
7.	2.13	2.26	2.26	2.23	1.97	1.90	1.83	1.70
8.	2.30	2.20	2.13	2.00	2.37	1.80	1.77	1.77
9.	2.27	2.30	2.37	2.43	2.27	2.03	1.90	2.00
10.	2.33	2.40	2.57	2.57	2.20	2.17	1.93	1.87
11.	2.17	2.33	2.40	2.47	2.23	2.13	2.13	2.13
12.	2.23	2.26	2.26	2.47	1.83	1.80	1.73	1.70
Ave.	2.152	2.178	2.241	2.315	2.142	1.954	1.869	1.814

sis of the fat. When the milk was pasteurized before homogenization, the surface tension was slightly increased.

CURD TENSION

Much information is availale in the literature showing the reduction in curd tension of whole milk as a result of homogenization. The data secured in this study substantiate those findings. They indicate that the curd tension of both raw and pasteurized milk is lowered by homogenization in proportion to the pressure used. The extent of change in the toughness of the curd obtained from different samples seemed to be dependent upon the fat content of the milk. Homogenization of skim milk showed no change in curd tension.

SEDIMENT IN HOMOGENIZED MILK

Those practicing homogenization of the milk supply have observed from time to time a defect in the bottled product which was often so evident as to merit serious complaints from customers. This defect appeared as a smudgy, dirty deposit in the bottom of the bottle after the milk had been held at a low temperature for 24 to 48 hours. The amount of this deposit varied greatly. Sometimes it manifested itself as a very fine, hair-like ring at the base and side of the bottle from 1/16 to 1/8 of an inch from the bottom. Occasionally it was so serious as to give the bottom of the bottle a dark appearance. In such cases, the discolored material may occur in several forms. It may be evenly distributed over the entire surface, may be flocculent or may be chunky. The distribution of this material appears to depend to some extent upon the position of the bottle during storage. This material readily remixes with the milk upon slight shaking of the bottle, after which it does not resettle for some time.

When sediment discs were secured from pint samples of milk which had shown a deposit and which had been remixed, the sediment discs were clean and were in no way indicative of the nature of the milk from which the discs were taken. The sediment was so fine that it passed readily through the disc. By syphoning the liquid above the sediment and concentrating the material from 90 quarts of milk in which the defect was quite apparent, some of the material was obtained, dried and examined under the microscope. Before it was dried the material appeared as very dirty separator slime. After it was dry it was quite hard and tenacious. Under the microscope it appeared to be composed of extremely fine silt, which was possibly associated to some extent with the proteins of the milk. These dirt particles ranged from 2 to 10 microns in size and were irregularly shaped.

A total of 28.9 grams were obtained from the 90 one-quart samples, or, approximately, one-third of a gram of sediment per quart. Although the deposits varied somewhat in intensity of color, two distinct types of color appeared, grayish-black and yellow. The dark precipitate appeared to contain foreign particles, detritus, while the light precipitate appeared creamy and cheesy as if it were high in fat and casein. Generally, when the yellow color predominated, the precipitate was small in quantity. The composition of the sediment is presented in table 2.

TABLE 2. *The composition of sediment in homogenized milk as determined by the Mojonnier method*

Color of sediment	Water percentage	Fat percentage	Solids—not fat percentage	Total solids percentage
Dark gray to black	73.97	9.27	16.76	26.03
Yellow	69.88	12.14	17.98	30.12

In all cases where this defect appeared the check, unhomogenized sample showed a clear white bottom in the bottle. If any sediment specks did appear, they were coarse and of sufficient size to be filtered out.

Trials were run to determine whether the pressure of homogenization had any influence upon the amount of sediment settling out of the milk. Pressures of 1,500, 2,500 and 3,500 pounds were used at 145° F. with no consistent difference showing between any two pressures.

The sediment test proved to be of little value in the selection of milk for homogenization insofar as its relation to the degree of sedimentation was concerned. Even when milk was filtered through two thicknesses of filter cloth and then homogenized, the defect was very evident after 24 hours. It appeared practically as intense as that in the unfiltered homogenized sample.

Power clarification before homogenization was sufficient to overcome the defect.

TITRATABLE ACIDITY

An interesting phenomenon observed in the studies on homogenization was the effect of homogenization upon the increase in the percentage of titratable acidity. When raw milk was homogenized, an increase in the titratable acidity occurred in every case. The greater the pressure of homogenization, the greater was the increase.

Subsequent pasteurization did not reduce the acidity. When the milk was pasteurized previous to homogenization, there was no change in the percentage of acidity due to homogenization irrespective of the pressure employed. These observations are in agreement with those made by Dorner and Widner (7) and have been further substantiated by Ramsey and Tracy (12) and Doan and Minster (5). This increase in acidity may be the result of hydrolysis of the fat by the activity of the lipase brought about, in part at least, by the increase of the surface area of the fat globules as a result of homogenization. Pasteurization exposures inactivated the enzyme.

DEVELOPMENT OF RANCIDITY

Homogenization affected the development of rancidity in the milk to an extent depending upon the heat treatment to which the milk had been subjected previous to homogenization. Dorner and Widner (7) have shown that homogenized raw milk develops rancidity within 15 minutes to 4 hours. These findings have been substantiated by recent work of Halloran and Trout (8), Ramsey and Tracy (12) and Doan and Minster (5). The development of rancidity is associated with an increase in the titratable acidity. As the pressure of homogenization increases, the development of rancidity is accelerated. The agent of rancidity seems to be an enzyme, lipase, which hydrolyzes the milk fat, the increase in surface area of the fat globules apparently accelerating the hydrolysis.

In our studies on rancidity several hundred samples of milk, both mixed and from individual cows, have been homogenized at the preheating temperature of 90° F. In every case, rancidity developed to the extent that the milk was very repulsive to the taste. Usually the rancidity was pronounced after two hours; however, some milk upon homogenization showed rancidity 15 minutes after homogenization. Trials were run to ascertain if pasteurization immediately after homogenization would yield a desirable flavored milk. Fifty gallons of raw milk were heated to 90° F., homogenized at 2,500 pounds pressure and pasteurized at 145° F. for 30 minutes. Although the resulting product did not become as pronouncedly rancid as the unpasteurized samples, the flavor was distinctly off. It would seem that, where vat pasteurization was employed, homogenization of the milk previous to pasteurization would be undesirable unless the milk were preheated to a temperature sufficiently high to inactivate the enzyme. Dorner and Widner (7) and Ramsey and Tracy (12) have shown that heating milk to 130° or 131° F. materially reduces the activity of the agent producing rancidity.

BABCOCK FAT TEST OF HOMOGENIZED MILK

As a result of some disagreement among investigators on the subject, the Babcock fat test was made the object of special study.

Hudson (10) and Hollingsworth (9) stated that dealers have come to realize that a 3.6 percent pasteurized milk will not yield a 3.6 percent homogenized milk by the Babcock test. The reason given for this discrepancy is that the fat globules are so finely divided that the smaller ones cannot rise with the fat column in the Babcock test bottle. Doan and Swope (6) disagreed with the majority of investigators and stated that homogenization of whole milk or cream, even at high pressures, exerted but little influence on the Babcock test.

If the size of the fat globule directly influenced the Babcock fat test, it would be expected that the butterfat content as shown by the Babcock test would be lowered as the pressure increased.

Even at the higher pressures of homogenization, no difficulty was experienced in forcing up the finely divided globules into the fat column.

TABLE 3. *The effect of various strengths of sulphuric acid upon the elimination of charred material from the Babcock fat test of homogenized milk*[1]

Lot No.	Sp. gr. H_2SO_4	H_2SO_4 purity percentage	Observation
I.	1.815	89.0	Greyish plug at the base of most fat columns although the fat columns were easily readable. The plug was not very heavy, being from 1/32 to 1/64 of an inch in thickness.
II.	1.820	90.0	About the same as in lot I. If any difference, it was in favor of the 1.820 acid. Plug thin but darker in appearance.
III.	1.825	91.0	Plug or scum at base of practically all fat columns. Fairly heavy. Dark.
IV.	1.830	92.0	Plug in all fat columns. Worse than that in any of the above lots. Black and charred.

[1] The Minnesota test reagent was used in making 24 fat tests of milk homogenized at 2,500 pounds pressure at 145° F. Although not all of the fat columns were free from the plug, most of them were. Those which showed the presence of the plug compared favorably in appearance with the best results obtained by the Babcock test.

The Babcock test seemed to be as effective with the raw homogenized milk as with the pasteurized. In only one case was there a variation in the fat percentage as great as two-tenths of 1 percent. This occurred at the beginning of the study when considerable difficulty was experienced at the time in securing clear tests, because of the use of too strong acid. After standardizing the sulphuric acid to a specific gravity of 1.82 to 1.825 such variations were eliminated.

A plug of foreign material was observed at the base of the fat columns in practically all the Babcock tests made on homogenized milk. This defect was subjected to a more intensive study. The results are presented in tables 3 and 4.

The nature and composition of the plug is difficult to explain. Its specific gravity was slightly greater than that of butterfat but less than the serum-water-acid mixture in the test bottle. Its appearance resembled, to a remarkable degree, that of curd which is sometimes observed in the fat columns of tests made from unhomogenized milk, when the Babcock test was improperly made. There appeared, however, to be a fineness of texture in the former which was lacking in the latter. The plug was tenacious and compressed. As the fat column receded upon cooling, the plug adhered to one side of the glass, where it appeared as a thin disc.

CENTRIFUGAL SEPARATION OF HOMOGENIZED MILK

Since the size of the fat globules varied with the pressure and since some creaming was observed at the lower homogenization pressures, the centrifugal separation of homogenized milk was made the subject of special investigation. Six lots of milk, consisting of 50 gallons each, were pas-

TABLE 4. *Effect of various temperatures of acid and milk upon the elimination of charred material from the Babcock fat test of homogenized milk*

Lot No.	Sp. gr. H_2SO_4	Temp. of acid (°F.)	Temp. of milk (°F.)	Observation
I.	1.815	65-70	65-70	Grayish plug at the base of most fat columns, although the fat columns were easily readable. The plug was not very heavy, being from 1/32 to 1/64 of an inch in thickness.
II.	1.820	50	50	Grayish plug.
III.	1.820	75	75	About the same as testing with acid having specific gravity of 1.815.
IV.	1.820	50	75	About the same as testing with acid having specific gravity of 1.815.
V.	1.820	50	100-105	Samples badly charred. Very poor.

TABLE 5. *The efficiency of centrifugal separation of milk homogenized at various pressures*

(The milk was pasteurized at 145° F. and was separated at 120° F.)

Lot No.	Fat test of milk (%)	Fat test of cream (%) Pressure of homogenization (lbs. per square inch)					Fat test of skim milk (%) Pressure of homogenization (lbs. per square inch)				
		0	500	1,500	2,500	3,500	0	500	1,500	2,500	3,500
I.	3.80	33.0	32.0	32.0	21.5	23.5	.02	.05	1.0	1.8	2.5
II.	3.60	32.5	29.0	22.0	18.0	......	.01	.06	1.0	1.7	....
III.	3.75	35.0	32.0	25.0	20.0	15.0	.01	.08	1.1	2.0	2.4
IV.	3.70	41.5	41.5	30.0	27.0	18.0	.01	.09	1.2	1.8	2.4
V.	3.20	37.0	33.5	26.5	20.5	16.0	.01	.05	1.0	1.7	2.2
VI.	3.65	40.5	38.0	32.0	30.0	21.0	.01	.07	....	1.1	2.1

teurized at 145° F. for 30 minutes, homogenized at various pressures and then separated at 120° F. Ten gallons of milk from each lot were homogenized at a given pressure. The results are tabulated in table 5.

Since the milk was homogenized immediately after the pasteurization exposure and separated as quickly as the milk could be lowered to 120° F., the efficiency of separation was probably greater than if the temperature of the milk had been raised from below 100° F. to the separating temperature. According to these data, 98.2 percent of the fat was recovered in separating homogenized milk when the milk was homogenized at 500 pounds pressure; 70.7 percent at 1,500 pounds; 63.5 percent at 2,500 pounds, and 36.1 percent at 3,500 pounds as compared with 99.7 percent recovered when the milk was unhomogenized. From these figures it would seem that, when milk was homogenized at pressures not exceeding 1,500 pounds, the fat loss in skim milk during centrifugal separation should not exceed 30 percent.

CHURNING OF HOMOGENIZED CREAM

Since the separation of milk homogenized at 1,500 pounds pressure recovered 70 percent of the fat, several trials were run to determine the churnability and the exhaustiveness of churning homogenized cream. Sufficient quantities of sweet cream for churning in the 200-pound laboratory churn were secured and pasteurized at 145° F. for 30 minutes.

Following pasteurization, this cream was divided into three lots of 20 gallons each. Lot I was unripened and unhomogenized; lot II was unripened and homogenized at a pressure of 900 pounds per square inch; lot III was homogenized the same as lot II and ripened to a cream acidity of approximately sixty one-hundredths of 1 percent calculated as lactic acid. Homogenization pressures of 900 pounds were used since a survey of dairy practices showed that table cream homogenization was usually

TABLE 6. *Showing the churnability of ripened and unripened cream homogenized at 900 pounds pressure at 145° F.*

Lot No.	Treatment of cream	Weight (lbs.)	Fat test (%)	Acidity at time of churning (%)	Churning temp. (°F.)	Time to churn (min.)	Fat test of buttermilk (%)
				Trial I			
I.	(Check) Unhomogenized	155	33.0	0.15	50	27	0.17
II.	Homogenized Unripened	155	33.0	0.15	49	51	5.50
III.	Homogenized Ripened	155	33.0	0.55	49	59	3.30
				Trial II			
I.	(Check) Unhomogenized	160	32.5	0.12	51	33	0.30
II.	Homogenized Unripened	160	32.5	0.12	51	35	7.10
III.	Homogenized Ripened	160	32.5	0.60	52	25	2.60
				Trial III			
I.	(Check) Unhomogenized	160	33.0	0.12	50	21	0.35
II.	Homogenized Unripened	160	33.0	0.12	50	55	6.40
III.	Homogenized Ripened	160	33.0	0.62	50	37	4.40

carried out at pressures ranging from 800 to 1,000 pounds. The results are presented in table 6. Ripening of the homogenized cream resulted in more exhaustive churning than was obtained in similar cream unripened. The buttermilk obtained from the churning of the homogenized cream, both the ripened and the unripened, was of excellent quality, possessing a heavy, viscid body, but was relatively high in butterfat content as compared with that from unhomogenized milk.

The butter made from homogenized cream showed no inclination toward defects during the working process, but yielded a firm, waxy body, similar to that from unhomogenized cream.

Since the utilization of surplus homogenized milk and cream is a problem of great importance to those homogenizing milk and cream, the more exhaustive churning as a result of ripening should be of special commercial interest.

Brown (3) has shown that when homogenized cream was mixed with unhomogenized cream in the proportion of one to eight, and then churned, excessive fat losses in the buttermilk did not occur.

MORE RESEARCH NEEDED ON HOMOGENIZED MILK

Although several phases of the problem have been studied, there appears to be a need for more research upon the homogenization of market milk. Some questions have suggested themselves in this study. Just where does the homogenizer best fit into the processing of market milk, before or after pasteurization? Does homogenized milk upon souring show an abnormal fermentation which would lead the consumer to look upon the product with suspicion? Does homogenized milk seem richer to the average person than similar milk unhomogenized? Can experienced judges of milk recognize homogenized milk by the "feel" of the sample as it passes over the tongue? Are there any advantages of high pressure homogenization when low pressure homogenization is sufficient to render the product homogeneous? Can the temperature of the milk be raised after homogenization rapidly enough under practical plant conditions to inactivate the enzyme responsible for rancidity so that an off flavor does not result? Are there any advantages to the homogenization of milk at higher temperatures than those of the ordinary pasteurization exposure? These and other questions have arisen in connection with the work herein reported.

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