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A. C. DAHLBERG AND J. C. MARQUARDT

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BULLETIN NO. 591

HOW THE CREAM LAYER FORMS ON MILK[1]

A. C. DAHLBERG AND J. C. MARQUARDT

ABSTRACT

The volume of cream which forms on milk is of special commercial importance. It is used as a sales advantage, as a source of sweet cream, and as a very crude and often inaccurate method of estimating the richness of milk. The subject of cream rising can best be understood from a practical standpoint by a consideration of the fundamental principles involved.

The volume of the cream layer depends upon (1) the percentage of fat in the original milk, (2) the percentage of fat remaining in the skimmilk, and (3) the percentage of fat in the cream layer. The distinctness of the cream line depends upon (1) the completeness of creaming, (2) the color of the butterfat and skimmilk, (3) the percentage of fat in the cream layer, and (4) the smoothness of the bottom edge of the cream layer.

Fat rises in milk at speeds which can be readily calculated and experimentally observed. The individual fat globules rise too slowly to explain creaming as it actually occurs. Clusters of fat globules form in cold milk during creaming and these clusters rise with sufficient rapidity to account for the formation of a cream layer from 1 to 4 hours after the cooling of the milk.

It is difficult to explain the cause of the formation of fat clusters, but a theory based upon the influence of calcium ions on the fat globules fits the observed facts. The details of this theory of fat clumping are presented.

INTRODUCTION

The amount of cream which forms on milk has always been considered to be of much practical importance. Prior to the invention of

[1]This bulletin is a popular presentation of a portion of Technical Bulletin No. 157 of this Station to which the reader is referred for a review of the literature on the subject and for the experimental data substantiating this publication.

the cream separator, the hand skimming of the cream layer from milk was the only method of obtaining cream for churning or for other purposes. After the centrifugal cream separator was invented gravity skimming became of little significance. Since the introduction of glass milk bottles, the cream layer has always been of commercial importance, milk salesmen having stressed the volume of the cream layer. The consumer often attempts to judge the richness of milk by the depth of the cream layer and the sharpness of the cream line. There has always been some tendency toward the removal of the cream layer from the milk bottle by the consumer to secure sweet cream for table use.

The creaming of milk has been very intensively studied and the value of these studies has been emphasized by the fact that the temperature necessary to destroy pathogenic bacteria during pasteurization approaches the critical temperature above which milk cannot be heated without detrimental effects on creaming.

SOME CHARACTERISTICS OF THE CREAM LAYER

There is some confusion in the use of the terms "cream layer" and "cream line." The cream layer is the distinctly evident layer of cream which forms on the top of milk. It is distinguished from the skimmilk not only by location and color, but also by a distinct line of demarcation between the two which is known as the cream line.

There are several factors to bear in mind in considering the depth of the cream layer and the distinctness of the cream line. The volume of the cream layer is influenced by the percentage of fat in the milk, because, as will be shown in a subsequent publication, the volume of the cream layer is directly related to the percentage of fat in the milk, providing the milk forms a cream layer in an average way. The volume of the cream layer is also affected by the amount of fat which remains in the skimmilk layer. These two factors affecting the volume of cream are generally recognized.

It is not so well understood that the volume of the cream layer is also greatly affected by the percentage of fat which this layer contains. The fat content of the cream layer increases with age up to approximately 24 hours, due to packing of the fat globules. The upward force is greatest near the top so that the cream tests most at the extreme top and is rather thin near the skimmilk layer. It also increases in richness with increased temperatures of creaming.

Under ordinary circumstances the cream layer contains an average of approximately 25 per cent of fat, but newly formed layers may contain as low as 20 per cent of fat and creamed milk which has been stored at 50° or 60°F for 24 hours may have a cream layer containing as high as 30 per cent of fat.

The absence of a cream line does not necessarily indicate that the cream has not risen in the milk, altho this may be true. A pronounced cream line is due to two conditions, namely, that the color of the cream contrasts with that of the skimmilk, and that the lower edge of the cream layer is uniform and smooth. The contrast in color is affected by the thoroness of creaming, the color of the butterfat, and the color of the skimmilk. If the lower edge of the cream layer is rough and irregular, the cream will blend into the skimmilk and there will be no sharp cream line, even tho there is good volume in the cream layer.

HOW THE FAT GLOBULES RISE IN MILK

The formation of the cream layer on milk has always been very puzzling for it has not been very well understood. It is necessary to have a fair knowledge of the manner in which the cream layer is formed to be able to understand intelligently those practices on the farm and in the milk plant which affect the cream layer volume.

It is well recognized that fat exists in milk as very small round particles or globules which are approximately 0.0015 of an inch in diameter. These small globules rise to the surface of the milk because they are slightly less than 0.9 as heavy as the skimmilk. The rate at which these fat globules rise as individuals in milk can be readily calculated from an equation which has general application and which has proved accurate when applied to the rising of fat in milk.

This calculation shows that the average fat globule rises in milk at the rate of approximately 0.03 of an inch per hour. If it is assumed that the fat globule shall rise 7 inches in the milk bottle to reach the cream layer, then approximately 226 hours, or 9½ days, will be required for the creaming of the milk. These figures have been experimentally verified and, since milk readily creams in a couple of hours, it is self-evident that the fat cannot rise in milk as individual globules. This point is of commercial importance for the fat in milk must be held in clusters to secure a cream layer, and commercial practice should be so adjusted as to reduce to a minimum the destruction of these very fragile clusters of fat globules or of their reformation.

When milk is creaming rapidly the fat exists as clusters which are very irregular in shape and size. They are loosely held together by some unknown force. Observations indicate that in milk of good creaming properties the most numerous clusters have an average diameter of approximately 0.2 mm which is slightly less than 0.01 of an inch. Much larger clusters may be present, but it is the rate of rise of the smallest clusters that determines the time of the creaming period because these small clusters must be in the cream layer before creaming is completed and before a distinct cream line is evident.[2]

The presence of these clusters is clearly illustrated by Fig. 1 which shows a sample of milk creaming rapidly 30 minutes after the cooling of the milk. The fat clusters are clearly evident thruout the skimmilk and a cream layer has commenced to form, but this would not be evident in a milk bottle because there is no distinct cream line. Fig. 1 has not been magnified, except for the slight magnification under the hand lens, so that the true size of the clusters is shown.

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[2]The equation used for calculating the rate at which a fat globule rises in milk is as follows: $V = \frac{2r^2(d_s - d_f)g}{9v}$, where V = velocity of the rise in cm per second; r = radius of fat globules or clusters in cm, assuming them to be round; d_s = density of skimmilk (1.0365 at 41°F); d_f = density of a fat globule (0.9612 at 41°F); d_f for a fat cluster

$$= \frac{(\% \text{ fat in cluster} \times d_f) + (\% \text{ skimmilk in cluster} \times d_s)}{100};$$

g = gravitational constant (980 dynes); and v = viscosity of skimmilk (0.0296 at 41° F).

Altho this equation may seem somewhat complicated, its application can be easily made if one understands the units of measurements involved, as shown by the following illustration: Assuming the average fat globule in milk to be 4 microns in diameter, the rate at which it rises in milk at 41° F can be calculated by making substitutions directly in the formula. It is first necessary to know that 4 microns are 0.0004 of a cm which gives a radius of 0.0002 of a cm. In the example, the rate at which the fat globule rises in milk has been changed from cm per second to inches per hour. The calculations are as follows:

$$V = \frac{2 \times 0.0002^2(1.0365 - 0.9612)980}{9 \times 0.0296} = \frac{2 \times 0.00000004 \times 0.0753 \times 980}{0.2664}$$

$$= \frac{0.00000008 \times 73.794}{0.2664} = \frac{0.00000590352}{0.2664} = 0.0000221 \text{ cm per second} = 0.0000221 \times$$

$$3600 \text{ (seconds per hour)} = 0.07956 \text{ cm per hour} = \frac{0.07956}{2.54 \text{ (cm per inch)}} = 0.031 \text{ inch}$$

per hour.

The rate at which a fat cluster with a diameter of 0.2 mm (0.01 inch) rises in milk at 41° can be shown by calculation to be equivalent to 19.1 inches per hour.[3]

On this basis, it would require approximately one-third of an hour for creaming to be completed after the fat clusters had formed in the milk. Observations on the particular sample of milk shown in Fig. 1 demonstrated that 31 minutes were actually required for creaming to be completed. The sample of milk shown in Fig. 2 is the same as that illustrated in Fig. 1 after creaming was completed and when a distinct cream line was evident. A period of only 17 minutes elapsed between the taking of these two photographs.

WHY FAT CLUSTERS FORM IN MILK

No one has ever furnished conclusive experimental evidence to prove any contention concerning the cause of the aggregation of the fat globules into clusters, yet it is well established that fat clusters are formed. As a result of the numerous observations on the creaming of milk made at this Station, a theory of the cause of this aggregation has been presented which is very helpful in understanding conditions which affect creaming. Several assumptions need to be made in this theory, altho all assumptions have circumstantial evidence to support them.

Whenever fat globules are suspended in a watery solution they assume a negative electric charge. Since similar electric charges repel each other and opposite charges attract, it is self-evident that all of the fat globules must be negatively charged or they would immediately aggregate into clusters firmly held together. Milk contains consider-

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[3]The following calculation shows the rate at which fat clusters with a diameter of 0.2 mm will rise in milk at 41°:

$$V = \frac{2 \times 0.01^2 \left[1.0365 - \frac{(25 \times 0.9612) + (75 \times 1.0365)}{100}\right] 980}{9 \times 0.0296}$$

$$= \frac{0.0002 \left[1.0365 - \frac{(24.030 + 77.7375)}{100}\right] 980}{0.2664}$$

$$= \frac{0.196(1.0365 - 1.017675)}{0.2664} = \frac{0.0036897}{0.2264} = 0.0138 \text{ cm per second}$$

$$= 0.0138 \times 3600 = 49.68 \text{ cm per hour} = \frac{49.68}{2.54} = 19.1 \text{ inches per hour.}$$

FIG. 1.—PHOTOGRAPH OF PASTEURIZED HOLSTEIN MILK HELD IN A THIN LAYER BETWEEN GLASS PLATES WITH A STRONG LIGHT ON THE BACK SIDE.

The reading glass gives a small magnification inside the circle. The photograph was taken 26 minutes after the pasteurized milk was cooled to 40°F. The fat clusters rising into the cream layer are clearly evident, in fact, the milk looks so filled with butterfat clusters that one might doubt that this is really milk.

able quantities of calcium salts, in fact the amount of calcium salts present is so great that they are not all dissolved but exist to a considerable extent as suspended particles of the salts which can be removed by pressure filtration thru a porous earthen filter. A small amount of calcium salts dissolves and breaks up into component

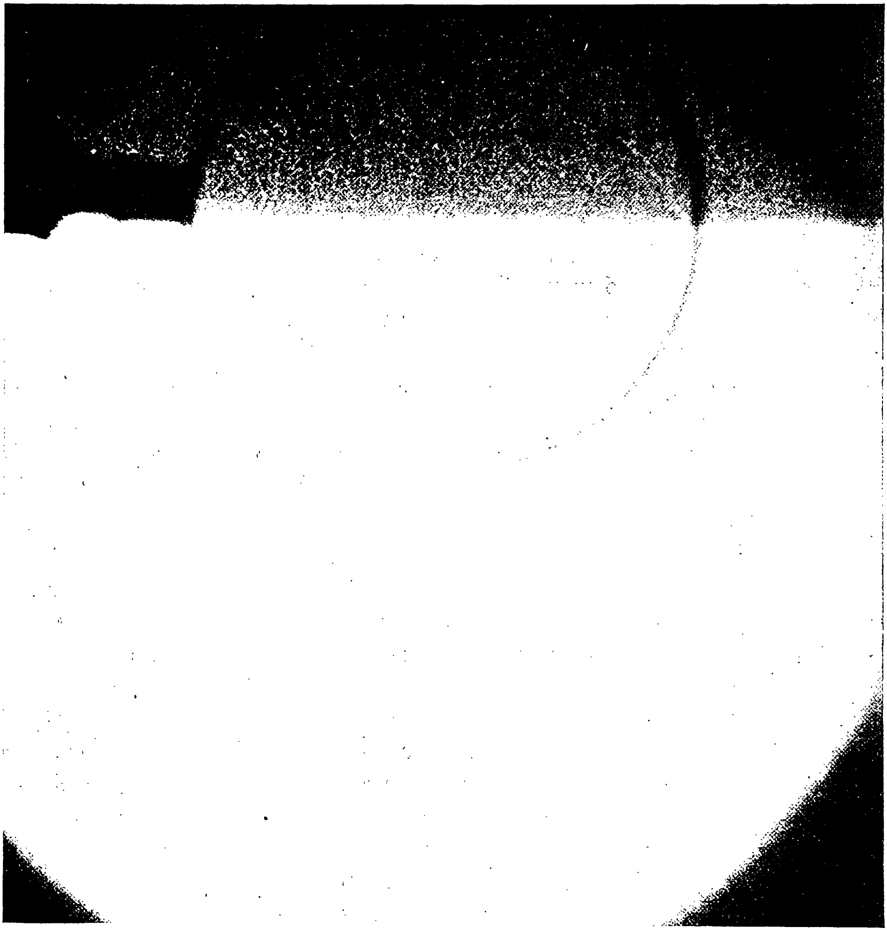

FIG. 2.—THE SAME MILK AS SHOWN IN FIG. 1 AFTER 47 MINUTES' COOLING. The cream layer has completely formed and the cream line is distinct. At this point the cream layer would be visible in a milk bottle. Note that the skimmilk is practically free from fat clusters so prominent in Fig. 1 and that these clusters can still be seen in the cream layer.

parts which are called ions. These calcium ions carry a positive electric charge which is attracted by the negative charge of the fat globules. If conditions are proper the calcium ions will neutralize a sufficient amount of negative charges on the fat globules to cause an electric attraction of one fat globule for another. Under these circumstances the fat globules come together into clusters.

Several conditions affect the solubility of the calcium ions and the possibility of coalescence of the fat globules. For example, fat globules always possess more or less motion which is called "Brownian movement." Brownian movement is a rapid vibration of a small particle without motion in any general direction. If Brownian movement is pronounced, fat clusters cannot form as the movement tears the clusters apart. The smaller the fat globule, the greater its Brownian movement will become, and for this reason the smallest fat globules, which are 1 micron or less in diameter, possess so much Brownian movement that they do not enter the fat cluster and remain in the skimmilk after milk has creamed.

According to present teachings of physics, all particles are in motion and the speed of this motion increases with temperature. In milk at warm temperatures, i. e., 100° or more, Brownian movement of the fat globules is so great that there is little opportunity for the formation of fat clusters.

When milk is warm, there is a maximum number of calcium ions carrying a maximum number of positive charges because the maximum solubility increases with increases in temperature. There is little possibility of the calcium ions producing fat clusters at warm temperatures because Brownian movement is too excessive. If the milk is quickly cooled to 35° or 40° Brownian movement of all the fat globules, except the excessively small ones, ceases instantly because this movement was due to the motion of molecules caused by warmth. The prevention of this motion makes it possible for fat clusters to form because they are not torn apart by Brownian movement. The effect of the greatly reduced temperature on the calcium ions is exceedingly slight because the solution of calcium is not quickly affected by changes in temperature. Under these circumstances conditions are ideal for neutralization of a part of the negative electric charges on the fat globules by the positively charged calcium ions and the fat globules are in a suitable condition for clumping. It is known that calcium ions tend to bring about such an aggregation of other suspended oils in water and it is logical to assume that the same situation occurs in milk.

This theory of the formation of fat clusters in milk means that the best creaming is secured when warm milk is quickly cooled to 35° or 40° and allowed to cream without further agitation.

When milk is held for several hours at 35° to 40°, the dissolved calcium ions slowly change to insoluble calcium salts which remain suspended as very fine particles in the milk. The force which assisted in the formation of fat clusters has now been partially removed and for this reason there is less tendency to hold the fat clusters intact and to reform them in case they are broken up by agitation. Consequently, if cold, aged milk is thoroly mixed it recreams slowly and poorly the second time. On the other hand, it is possible to restore the creaming ability of this milk by warming to temperatures of 120° to 140°, with momentary holding, or to 100° to 110° with holding for approximately 1 hour. Under these conditions the calcium is again slowly dissolved to reach maximum solubility and if the milk is again quickly chilled to 35° or 40° good creaming qualities will be secured.

It is generally recognized that the heating of milk to excessively high temperatures, as in too high temperature of pasteurization, produces a permanent precipitation of calcium salts which do not re-dissolve when the temperature is lowered. There is no known method of restoring the creaming properties of milk which has been heated above 145° for 30 minutes or momentarily to temperatures in excess of 165°. The permanence of the destruction of the good creaming properties of milk by excessive heat can readily be explained on the basis of the permanent removal of calcium ions from milk.