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To the Committee on Graduate Study:

I am submitting to you a thesis written by Wayne I. Tretsven entitled "Homogenization of Milk and the Properties of Homogenized Milk". I recommend that it be accepted for nine quarter hours credit in partial fulfillment of the requirement for the degree of Master of Science, with a major in Dairying.

C. C. Wylie
Major Professor

We have read this thesis and recommend its acceptance:

James D Brew

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Accepted for the Committee

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Dean of the Graduate School

HOMOGENIZATION OF MILK AND THE PROPERTIES OF HOMOGENIZED MILK

A THESIS

Submitted to
the Committee on Graduate Study
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

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by

Wayne I. Tretsven

August 1939

PREFACE

The material presented in this thesis has been collected by the writer as a graduate problem in Dairying at the University of Tennessee.

The writer wishes to express his gratitude to the members of the University of Tennessee faculty, and to investigators in other institutions for assistance rendered in this study.

Special acknowledgment is due to Professor C. E. Wylie, Professor Thos. B. Harrison, Mr. H. B. Henderson, and Miss Mildred Wall of the Dairy Department, and Dr. Dorothy E. Williams of the Department of Nutrition for their full cooperation and helpful suggestions in the preparation of this thesis.

- Wayne I. Tretsven

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CRANE MADE IN U.S.A.

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INTRODUCTION

Milk is composed of water soluble material, colloidal material, and particles in suspension. The milk fat is suspended in milk as globules, which are microscopic in size and are distributed in the milk. On standing, most of these fat globules naturally rise and collect in the upper portion called the cream layer, leaving the lower portion called the skimmilk. Often, this separation of the cream from the skimmilk is not desirable.

A mechanical process has been developed to break up the globules so that they don't rise and form a cream layer. This milk is then called homogenized milk, and the process of breaking up the globules is called homogenization.

The homogenized milk was found to have many advantages over the unprocessed milk. The color was uniform, and no mixing was necessary in order to get the fat with the skimmilk. Some consumers believe that the flavor is richer. A softer curd is formed by coagulation that makes it easier to digest. Some disadvantages of homogenized milk are that undesirable flavors may develop in the product, processing costs are high, and sediment often occurs in the bottle of homogenized milk. The utilization of unsold homogenized milk presents a problem, as it is difficult to separate the fat from the homogenized milk.

Many factors in the processing of milk have been studied in this problem. The effects of homogenizing at various pressures and temperatures were determined. Studies of homogenized milk indicate that there are changes in the curd tension, pH, acidity, viscosity, color, and bacteria count. A comparison of the feeding values and disgestibility of homogenized milk and unhomogenized milk was made.

Experimental data are given on the procedures and results of the tests made on the milk. Results, showing the efficiency of producing growth in rats, are presented with descriptive graphs comparing the digestibility of various types of milk.

DEFINITION OF TERMS USED

Curd tension - Hardness of the curd.

Hard curd milk - Milk with a curd tension above 30 grams curd tension.

Kind - Raw or pasteurized.

Lot - A division or part of a batch of milk.

Milk - Whole unprocessed lacteal secretion.

Normal - Unhomogenized (natural) milk.

Oxidized - Tallowy flavor in milk.

Particle - Fat globule, cluster, or clump.

r - Radius.

Serum - Non-solid constituents of milk.

Shattering - Act of breaking up the fat globules.

Soft curd - Milk with a curd tension less than 30 grams.

State - Liquid, gasses, solid, and semi-solid.

Types - Homogenized milk, normal soft curd, and normal hard curd milk.

PART I

REVIEW OF LITERATURE

History of Homogenized Milk

The process of homogenizing many products was practiced as early as the beginning of the twentieth century. Homogenized milk was first introduced at Lacolle, Quebec in 1910,[1] but the attempt to market the product was unsuccessful. Again in 1927 it was introduced at Ottowa and was accepted by the public. Throughout many of the Canadian Provinces its production and consumption spread, and now homogenized milk is quite common in the United States.

In Toronto and Buffalo homogenized milk is sold extensively; mainly on the basis that it is more palatable than the unhomogenized milk.[2] Whether or not this is the principal or correct reason for its rapid adoption, it has gained the preference of those people.[2] The product and its qualities have been extensively advertised. Two antagonistic views regarding the product have caused much discussion; one view sides with the general acceptance that the cream line sets the value of the milk, while the other view endorses the full meaning of the word, namely, homogenization.

The main objective in homogenizing milk is to prevent the separation of the fat into a cream layer, while the other effects are secondary. The medical profession has recommended homogenized milk for certain purposes, as it has a softer curd than the unhomogenized milk, thus making it easier to digest. The fact that it is more palatable[3] has also been used as a great selling point for homogenized milk. Regardless of its merits or faults, it

has been and is continuing to be accepted, for the consumer desires a product which always appears to be the same.

Early methods and machines used to homogenize dairy products were not very satisfactory or desirable. The methods of processing the milk were not perfected. Rancid and foreign flavors developed. A sediment often appeared and caused quite a problem. The first machines were large and complicated so that cleaning and sterilizing were impossible. Such conditions caused the public health departments to discourage the use of homogenizers. Today, processing methods are used which make the flavor pleasing and stable, the consistency and color uniform, with little or no sediment appearing in the milk.[2][3] Machines have been developed, which are very simple, with all the parts removable for cleaning and sterilizing.

As early as 1903, Butterberg[4] published an article explaining homogenization. He noted that the fat globules were broken into many smaller particles. Hammer[5] noted a great dispersion of the small fat globules, the rate of rise of the globules in the serum, and the difficulty experienced in separating milk with the finely dispersed globules.

When rennet was added to homogenized milk, it was noted by Washburn and Jones[6] that curds were not as tough as those of the unhomogenized milk. Later, the work done by Hill[7][8], Trout[9], Doan[10], and Theophilus[11] substantiated the fact that homogenization of milk causes a reduction in the curd hardness (tension).

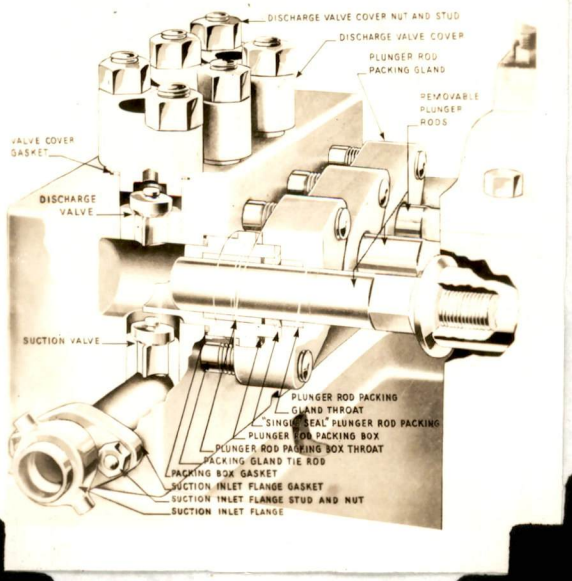
More recent research has been devoted to the properties of the milk processed by various procedures, and the work done on the various problems are discussed separately.

Mechanics of Homogenization

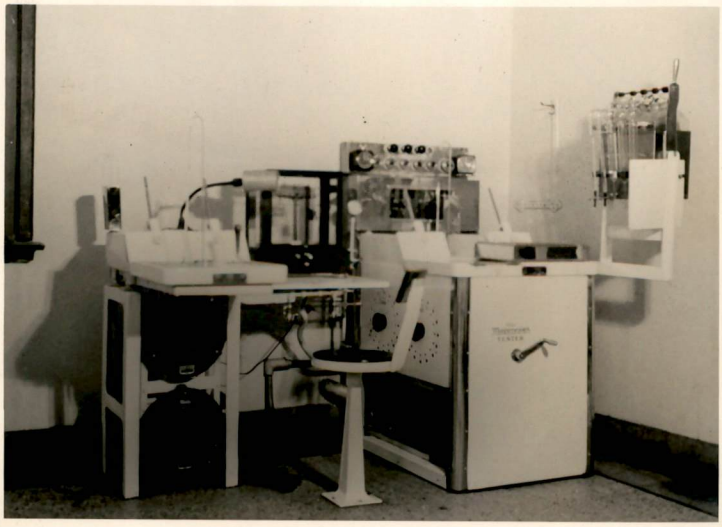
The mechanics or effect of homogenization on milk is to reduce the size of the fat globules. A reduction in the size of the globules, with the same volume or quantity of fat, necessarily brings about an increased number of globules having a much greater surface. Dorner and Widner state[12], "The surface of the fat is increased about 10 - 30 times through homogenization". The small globules, with a much greater surface as compared to their volume, do not rise as rapidly as the larger globules but remain dispersed in the liquid (serum).

A number of different methods are used to break up the fat globules. The three different types of machines used to reduce the globule size are the pressure or pump machine, the centrifugal blade-type machine, and the vibratory diaphram machine.

The pressure machines break up the fat particles by forcing the material through a very small opening.[10] Great pressures can be exerted on the liquid causing it to attain a high velocity by forcing it through a small aperture. Generally, the machines used have three or six cylinders, the pistons of which, moving on eccentrics, successively force the liquid against a release valve. See Figure No. 1, page 5. The valve constitutes the small aperture which is responsible for the homogenizing effects. The valve is usually a ground, tapered valve of the drop type, seated against a stationary seat. The size of the opening of this valve is controlled by a threaded pin, which exerts a pressure on a heavy coil spring that is in contact with the top of the ground valve. The pressure increases as the tension on the valve is increased, or as the size of the aperture is reduced. For an illustration, see Figure No. 2, page 6.



Cutaway Homogenizer



Mojonnier Milk Tester

Figure 1.

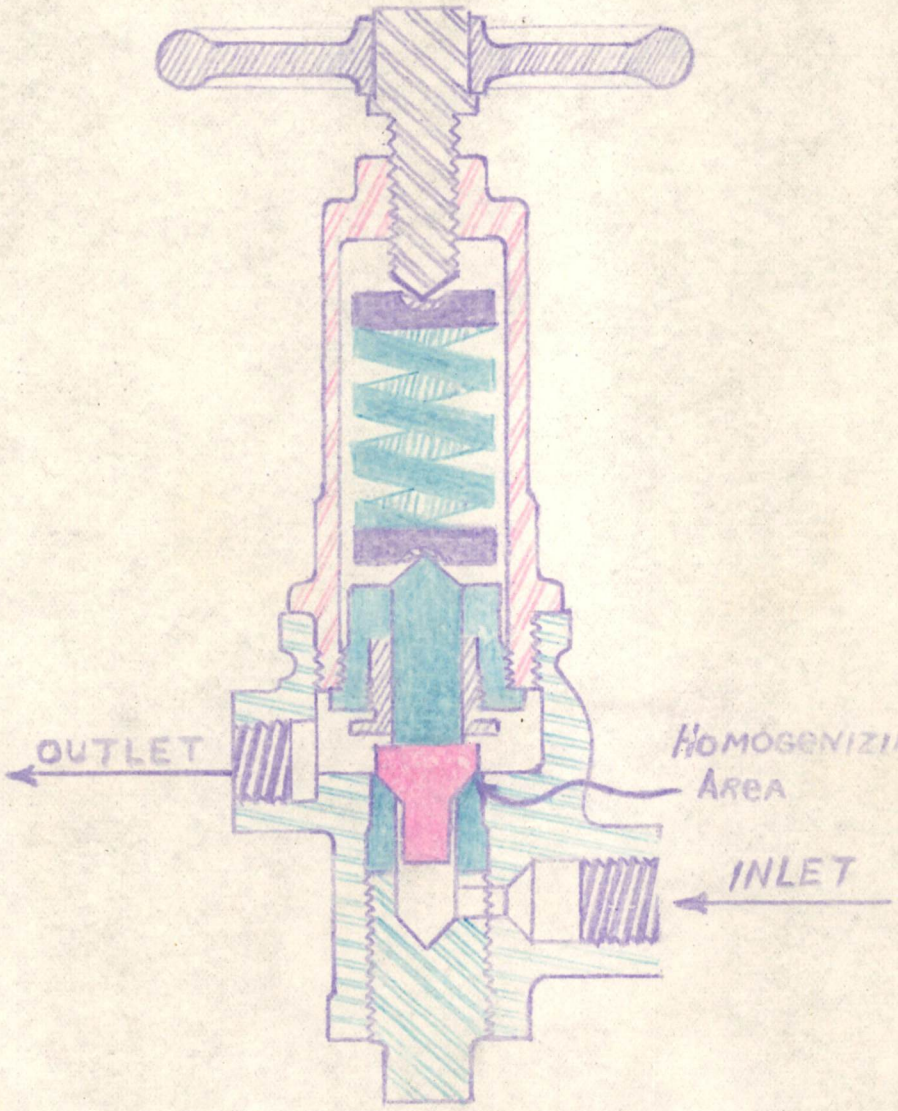


Figure (2)

Diagram Of Homogenizing Valve

At the same time, the velocity of the fluid passing through the valve is increased. Such a pressure type machine is called the homogenizer or viscolizer. Rotary or eccentric type machines are also used to attain a pressure on the liquid; however, pressures[13] much above 1,000 pounds per square inch are difficult to obtain.

Some opposing theories have been advanced regarding the physical breaking or shearing of the globules. Some maintain that the great pressure in the cylinder ruptures the surface membrane of the globule. Others believe that the high pressure so compresses the globule that the rapid reduction in pressure causes the globule to burst. Another view is that the globules are actually bigger than the clearance at the valve; therefore, they are sheared into smaller globules while passing through the restricted opening. Apparently, the two most accepted views are[14] that the fat dispersion results (1) from the shearing of the fat globules spanned across layers of liquid traveling at different velocities, and (2) from the shattering effect produced when the stream of liquid, traveling at a velocity greater than that of a rifle bullet, impinges against the side-walls of the homogenizing valve.

Centrifugal machines used to break up the fat globules operate much as a fan. The milk is slowly admitted into a container where blades, resembling a fan and traveling at a high speed, hit the inflowing milk and so agitate the liquid that a reduction in the size of the fat globules may be accomplished. Such machines are not generally used, for the results have not been very satisfactory.

A new method of reducing the size of fat globules has been developed within the last five years. The milk is passed through a narrow chamber

containing a stationary anvil and a vibrating steel diaphram. The diaphram used is either an electromagnetic or Fessenden type of oscillator producing an intense vibration. See drawings showing oscillators, Figure 3, page 9. The milk chamber is filled with milk and flows through by gravity. In operation[13] the milk flows through the center of the anvil, spreads outward through the anvil diaphram clearance, and escapes at the bottom at a controlled rate. The effect of sonic vibrations on the milk is apparently produced by fat dispersion in a manner similar to homogenization. Chambers[15] found that the milk must be 18° C. (64.5° F.) or more, as the best results are obtained when the fat is liquid. The faster the milk is allowed to flow out of the vibrating chamber, the less efficient is the globule dispersion. This method has not as yet been commercially used. The noise caused by the vibration of the oscillators is very intense.

Diagrams Showing Oscillators Used In Treating
Milk By Sonic Vibrations

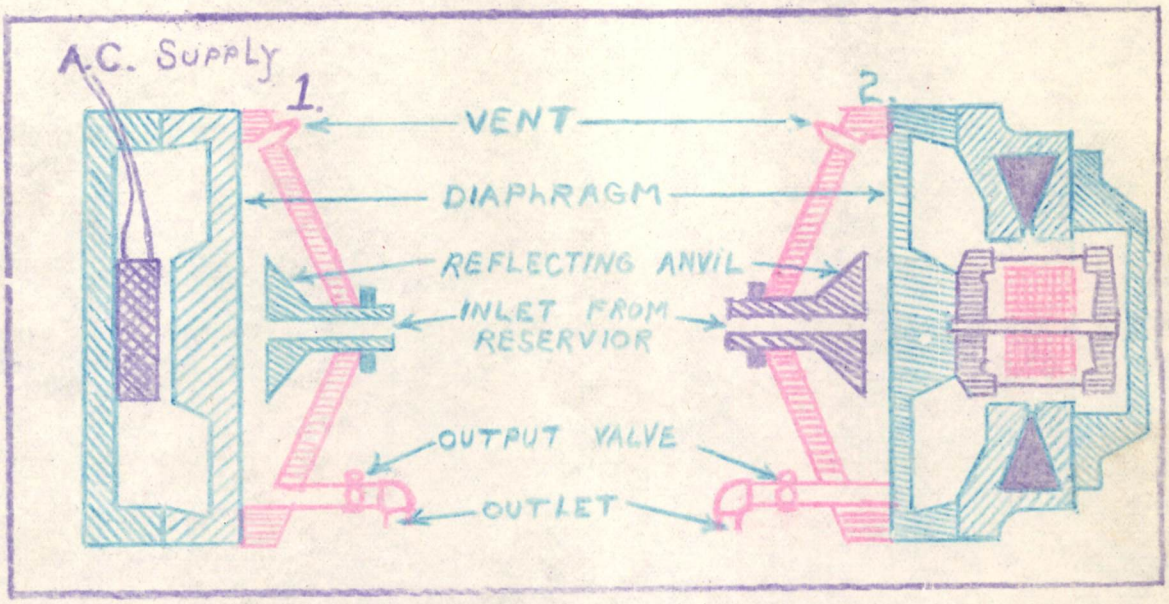


Figure (3)

1. Electromagnetic oscillator 2. Fessenden Type

Effects of Homogenization on Milk

Physical

Fat Globules. Fat globules found in milk vary considerably in size.[5][9][13][15][16] According to Fleischmann[13] they range in size from 0.1 micron to 22.2 microns in diameter; however, the general range is from 0.1 micron to 10 microns in diameter. Most of the globules fall within the range (2 microns to 6 microns in diameter). The number of fat globules in a certain amount of milk depends upon the fat content and the size of the globules. Various counts made on the number of globules in 1 c.c. of normal milk range from 1 to 8 billions. A severe agitation such as homogenization reduces the size of the globules by breaking them up. The greater the reduction in size of globules the greater the proportionate number of globules there will be. As an illustration - if one globule 10 microns in diameter is broken up into globules 1 micron in diameter, there will be 1,000 small globules; and if a globule 5 microns in diameter is broken up into globules 1 micron in diameter, only 125 small globules will be formed. Such a comparison is equivalent to the cube of the radius (r^3), as the volume of a sphere is equal to $4.189\ r^3$. By so increasing the number of globules, the combined surface area of the fat globules is also increased.

Reducing the size and increasing the number of fat globules in the milk causes a greater dispersion of the particles in the serum. According to Tracy[16], "Each fat globule is surrounded by a thin protein layer, and increasing the globule surface by breaking them into smaller particles will affect the way in which the protein is dispersed in the milk as well as the extent of fat emulsification; thus flavor and separation or cream rising

will be affected by reducing the size of the fat globules".

The velocity which a sphere will rise or fall through a liquid can be determined by Stoke's law

$$V = r^2 \times \frac{2g\,(d_1 - d_2)}{9\,n}$$

in which

V = velocity in centimeters per second
r = radius of the sphere
d_1 = density of the sphere
d_2 = density of the liquid
g = gravitational force (981 dynes)
n = absolute viscosity of the liquid (poise)

The velocity of the rise of a fat globule varies as the square of its radius. A globule 6 microns in diameter will rise 36 times as fast as a globule 1 micron in diameter. If, however, a condition exists whereby globules adhere to one another and form a cluster, the cluster will rise much faster increasing the chances of overtaking and adhering to other globules, thus causing the cluster to rise with even a greater velocity.

The velocity of rise of these irregularly shaped clusters can not be computed. Sommer[13] states that Troy and Sharp measured the velocity of approximately spherical clusters and found that they also obey Stoke's law quite closely.

As shown in Table I on the following page, the velocities of rise would be expected for globules of fat from 1 - 10 microns in diameter according to Stoke's law.

TABLE I

VELOCITY OF RISE OF DIFFERENT SIZED FAT GLOBULES

Diameter of Globule in Microns	Velocity of rise in m.m. per hour
1	0.0834
2	0.3336
3	0.7506
4	1.3344
5	2.0850
6	3.0024
7	4.2866
8	5.3376
9	6.7554
10	8.3400

It should be noted that the larger the globule the greater is the difference in velocity of rise, while the difference in the velocity of rise of such globules is too small to cause much cluster formation. Thus (13) "The absolute size of the globules, as well as the disparity in size, is important to cluster formation".

In homogenized milk the globules are so small and the cluster formation would be so slight that any tendency toward this fat rising (creaming) is not noticeable.

Many factors[17] affect the size of fat globules in milk. The breed has much to do with the globule size. Fat globules are generally smaller in Holstein and Ayrshire milks than in Guernsey and Jersey milks. During the latter part of the lactation period, globules become much smaller than those present during the first part of the lactation period. Often it is impossible to note any cream line in such milk. According to Hunziker[18] the kind of feed fed to the animals has an effect on the size of the globules. Dry rations tend to cause the globules to be small, while succulent feed and feeds rich in oil tend to cause larger globules. When milk is frozen and melted the fat is broken up into many smaller globules.

According to Babcock[19], slow agitation of milk causes the fat globules in a solid or semi-solid state to combine or cluster (churning). Violent agitation, such as homogenization, causes the globules in a solid or semi-solid state to break up. Any agitation of globules in a liquid state breaks them up into smaller particles. Thus, the effects of agitation on the fat depend on the temperature and manner of agitation.

Doan [10] states, "Homogenization may be carried out with comparable results on either raw or pasteurized milk. However, since it should be processed warm, the raw milk is probably best treated immediately after milking while pasteurized milk can be homogenized before cooling".

The homogenizer is much more efficient if the milk is at least 90^{0} F. or higher, as a much greater force is required to break up a particle in a solid or semi-solid state than is necessary to shatter it in a liquid state. Trout reported[9] that homogenization at 145^{0} F. following pasteurization was slightly more effective in reducing the diameter of the fat globules than when the milk was homogenized at the preheating temperature

of 90° F. As the homogenization pressure was increased there seemed to be less difference in the size of globules.

Tracy[16][17] showed a relationship between the homogenizing pressure and the size of fat globules.

TABLE II

RELATION OF PRESSURE OF HOMOGENIZATION TO SIZE OF FAT GLOBULES

(Tracy)

Sample	Diameter of Fat Globule
Unhomogenized	2.25 - 11 microns (range)
Homogenized at 500 lbs. pressure	2.39 microns (average)
Homogenized at 1,000 lbs. pressure	1.75 microns (average)
Homogenized at 2,000 lbs. pressure	1.20 microns (average)
Homogenized at 3,000 lbs. pressure	.75 microns (average)

The greater the homogenizing pressure the smaller will be the globule size, as the extent of shattering depends on the velocity at which the milk passes through the pressure-valve aperture. As the aperture is reduced in size, the pressure is increased causing the milk to attain a greater velocity through the aperture.

Apparently, the process of homogenizing the milk affects the physical condition of the fat globules, the chemical changes being subsequent to the physical changes. Gould and Trout[20] studied the effects of homogenization on the Reichert-Meissl and Polenske numbers, acid degree, and refractive index of the milk fat. No appreciable differences in the Reichert-Meissl number, the Polenske number, or the refractive index of the

fat occurred when the milk was homogenized. There was no change in the acid degree of the fat when pasteurization preceded homogenization, but an immediate and rapid development of the acid degree of the fat appeared in the unpasteurized milk upon homogenization.

Homogenizing milk does not add or remove any of the constituents in the milk. The process changes the physical condition of parts in the milk, which may result in different chemical changes.

Curd Tension. Numerous investigators [9][10][14][16][17][21][22][23] found that homogenization reduced the curd tension of the milk. Hill[24], with his early study on soft curd milks, stimulated considerable interest in the curd tension of milk. Investigation of the various effects and causes of the differences in curd tension have been studied by many others.[11][16][25]

A diseased condition of the udder of cows was found to have a softening effect on the curd of milk produced from the infected quarters.[25] Hill[7][8] found that there were differences in curd tension of milk from individual cows, breeds of cows, stages of lactation, and milk of various fat contents.

Heating the milk reduces the curd tension.[13][26] Berry,[26] in his study of the curd tension of milk, found that pasteurization (holding at 142° F. for 30 minutes) had little or no effect on the curd tension, but holding milk for 15 minutes at 180° F. had a marked softening effect on the curd.

The curd tension of milk depends on the amount and condition of the constituents present in the milk. Weisberg, Johnson, and McCollum[27] concluded that the casein content is the greatest factor influencing the

curd tension. Milk with a casein content of 1.85 per cent had a curd tension of 28 grams, while milk with 4.25 per cent casein showed a curd tension of 190 grams. Welch and Doan[25] found that normal soft-curd milk usually contains less than two per cent casein; whereas, hard-curd milk contains more than two per cent casein.

It is known that the amount of calcium and phosphorus present in the milk is a factor affecting the curd tension. The ('Zeolite' or base exchange treatment)[28] is a commercial process used to make milk a soft-curd type by removing some of the original calcium and phosphorus.

A new method of reducing the curd tension of milk by the use of enzymes[13] has been developed by the Armour & Company. A slight digestion of the milk solids is accomplished by the use of a pancreatic enzyme. The curd tension of milk may also be reduced by acidification[29], dilution, and by adding certain materials (modifying) to the milk.

Homogenization is a means of increasing the concentration of fat particles (not the amount of fat) throughout the milk. The fact that the presence of fat has a softening effect on the curd tension was shown by Hill.[7][8] When the milk was skimmed, the skimmilk had a higher curd tension than the milk containing the fat portion.

Theophilus, Hansen, and Spencer[11] found that the percentage reduction in curd tension increases with an increase in homogenizing pressure. He, as well as Tracy,[16][17] Caulfield, and Martin,[22] found that the reduction in curd tension depends on the initial curd condition of the milk. The percentage reduction increases with an increase in the curd tension of the original milk.

The increase in number of fat globules present in milk homogenized at different pressures has been cited on page 14. Apparently, the great reduction in the curd tension of homogenized milk is caused by the increased dispersion of the fat[30] particles, which are points of weakness in the coagulum. The size of fat particles in milk was found by Weisberg et al[27] to have no correlation to the curd tension; however, increasing the numbers of globules, whether large or small, causes a softer coagulum.

Sommer[13] states, "A given amount of fat varies in its effect according to the size of the globules. The number of globules varies inversely with the cube of their diameter, and accordingly smaller globules cause more numerous points of weakness in the gel structure".

By homogenization, or any other treatment[15] of the milk, which increases the number of fat particles, the curd tension is reduced.

In 1923 Hill[24] proposed a test for measuring the curd tension of milk, in a study to determine the suitability of various milks for infant feeding. The original Hill test is still used today; however, criticisms and modifications of the original curd test have been made by a number of workers.[13][22][31][32][33] Hill[7][8] later modified his own test.

In the Hill test for determining the hardness of the curd, a star-shaped, ten-pronged curd knife is placed in the bottom of a mayonnaise jar. A 100 c.c. sample of thoroughly mixed milk is placed in the jar, and the jar is immersed in a water bath, and the temperature of the milk is brought up to 35° C. (95° F.) It is maintained at this temperature throughout the test. The milk is coagulated with a pepsin-calcium chloride mixture, consisting of three parts of a 0.6 per cent solution of Eimer & Amend's 1-3000 scale pepsin to one part of a saturated solution of calcium chloride. A rapidly flowing

pipette, delivering 10 c.c., is used in adding the coagulant. Immediate and thorough mixing should follow the addition of the coagulant, and the jar is then kept at 95° F. without agitation for ten minutes. After ten minutes, a spring balance is connected to the knife, and by a slow and even pull the knife is pulled through the curd. The amount of tension required can be read directly on the balance. Duplicate samples of milk should check to within 10 per cent.

Modifications of the original test include slight changes in the equipment, procedure, and coagulants.

Curd knives have been developed, which are pushed downward into the coagulum rather than pulled upward out of the curd, as fewer knives are needed and no variation in the results are possible due to differences in the sharpness or smoothness of the knife blades. The knife's downward thrust is regular, for a gradual descent is controlled by a motor drive as on the Curd Tension Tester. For illustration, see Figure 4, page 19. Such instruments as the Bloom Gelometer[34] are now adapted for determing the curd tension of milk.

A modification of the Hill[7][8] procedure was made by requiring 378 grams of dry granular calcium chloride, diluted to one liter, rather than a saturated calcium chloride solution. A pepsin-hydrochloric acid coagulant, containing 0.45 per cent dry-scale pepsin, and 0.4 per cent hydrochloric acid, was recommended by Miller.[31] Modifications of the Miller coagulant were later made and used by Flora and Doan.[35] Other coagulants used are rennet, pepsin, and hydrochloric acid. The American Dairy Science Association[32] is attempting to standardize the procedure for determining the curd tension of milk in order to eliminate the

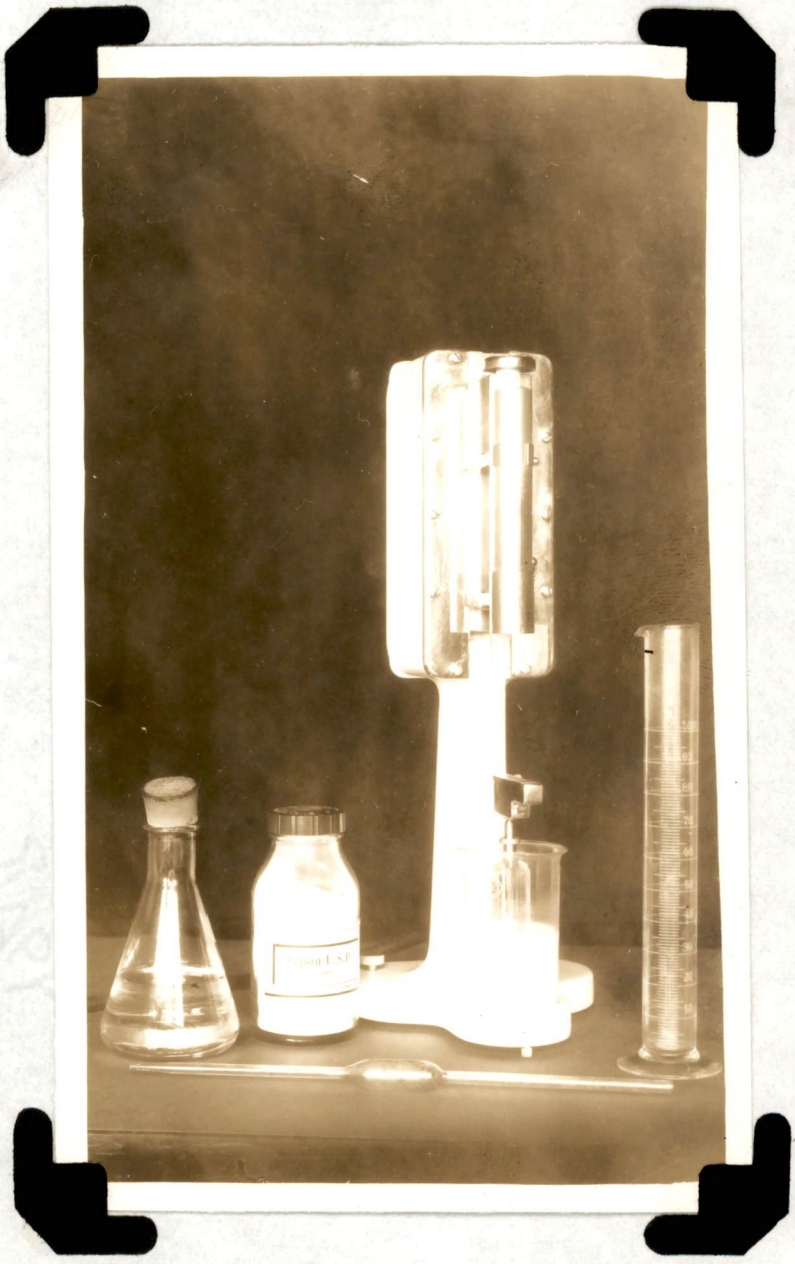


Figure 4. Curd Tension Tester

diversity of procedures. Briefly, the method substitutes N/10 hydrochloric acid containing 0.45 per cent pepsin for the calcium chloride pepsin reagent originally used.

In the proposed procedure, it is recommended that the tempered milk be added to the tempered coagulant. Minor specifications are also included in the proposed standard method for determining the curd tension.

Viscosity. Viscosity[36] is generally defined as the resistance offered by a liquid to shearing and stirring, or flow through a capillary tube. An important physical property of milk is its viscosity. Often many changes in the viscosity of milk occur which are important to the milk consumer and producer, and of interest to many investigators. If milk or cream is allowed to stand for a period of time at a low temperature, it becomes less fluid; in other words, more viscous or thick. Consumers[13] judge the richness of cream or milk by its viscosity, for they know that cream is more viscous and contains more fat than does milk. As early as 1896, Babcock[37] found that the amount of fat in cream exerts a greater influence on the viscosity than the other materials present in the cream. In milk, casein exerts a greater influence on the consistency than the fat does.

Weisberg et al[27], in their study on the viscosity of normal hard and soft-curd milks, found normal hard-curd milk to show a Relative Viscosity, approximately 15 per cent greater than that of the normal soft-curd milk. Their data are in accord with analytical data, which showed that the concentration of casein, calcium, phosphorus, and often fat was greater in hard-curd milks than in normal soft-curd milks. It is to be expected that the greater the percentage of these constituents, the greater

the viscosity.

Babcock[37] states,

> Variations in temperature have a marked effect on the consistency of milk and cream: that within moderate limits the effect is the same as with most viscous substances, it being made thinner when warmed, and the original consistency returning when cooled to the initial temperature.
>
> Pasteurized milk and cream show an apparent exception to this rule, inasmuch as the original consistency does not return after the milk or cream is thoroughly chilled. This condition is a serious objection to the use of these products on the part of the consumer, as he invariably refers this relative thinness to a lack of butterfat.

When milk or cream gradually sours, a precipitation of the casein occurs, forming a semi-solid coagulum. This slow precipitation is accompanied by an increase in consistency of the milk or cream before it shows signs of curdling.

In studying the effect upon the viscosity of milk homogenized, Trout[9] found that raw milk homogenized at 90° F. showed an increase in viscosity, and that milk pasteurized at 145° F., then homogenized at that temperature, showed a decrease in viscosity. He noted that as the pressure of homogenization was increased the viscosity of the raw milk increased, while the viscosity of the pasteurized milk decreased with increased pressure.

Trout[9] concludes that an increase in the titratable acidity, or the absorption of the proteins and salts by the increased surface of the fat globules, are factors which may have caused the increased viscosity of the raw milk. Heat of pasteurization may have possibly been the cause for the decrease in viscosity of the homogenized pasteurized milk.

Color. Homogenized milk is uniform in color. Marquardt[2] noted this characteristic uniformity in color in bottles of homogenized milk. Trout[9] compared the colors of milk before and after homogenization. He noted that homogenized milk was lighter in color than the unhomogenized milk. The color of homogenized milk was also found to be more stable and uniform because of the even distribution of fat throughout the milk. Trout noticed that a softer, lighter shade in color always appeared when chocolate milk was homogenized. Tracy[17] made a comparison of the amount of light reflected, at wave-lengths varying from 480 to 630 millimicrons, for milks homogenized at different pressures. His data indicate that the greater the particles are dispersed, the more the light is reflected. Thus, the general appearance of homogenized milk was found to be more opaque than the original milk.

Creaming. According to Trout,[9] the minimum range of homogenizing pressures required to prevent a noticeable fat rising (creaming) was between 500 and 1,500 pounds per square inch. Tracy[17] measured the amount of fat present in the upper 70 c.c. of a quart bottle of 4 per cent milk. His work indicates that the fat rising is decreased as the pressure of homogenization is increased.

Sediment. The appearance of sediment in bottles of homogenized milk has been a problem in the production of this product. A great deal of study has been done by Trout,[9] Tracy,[16] Babcock,[37] and Charles and Sommer[38] to determine the causes and methods of preventing this occurrence of sediment.

Normal milk of high quality, which was produced by clean methods, showing little or no sediment by the Sediment Test, was filtered before homogenization.[38] Sediment occurred in the homogenized milk, which leads

us to believe that the milk is either contaminated after filtering, or the filter is not efficient enough to remove the sediment material.

The sediment commonly occurs in homogenized milk, on standing 24 to 72 hours, unless special precautions are taken to avoid this defect.

The cause of the sediment was first attributed to the wearing away of the piston packings in the homogenizer. Tracy[16] and Trout et al[9] found that the deposit is not caused by worn parts of the homogenizer.

Trout[9] collected and analyzed the sediment from homogenized milk. His samples contained 9.27 per cent and 12.14 per cent fat, while solids-not-fat was 16.76 per cent and 17.98 per cent. Thus, the total solids of the residue resemble that of separator slim, but contains more fat. The studies cited indicate that the material found in the sediment is present in the milk and passes through filters. Trout and Halloran[9] found no relation between the sediment scores and the amount or occurrences of sediment in homogenized milk.

The slimy deposit contains large numbers of leucocytes and body cells.[9][16] A direct relationship of the leucocyte and cell count of the milk to the appearances of sediment in the homogenized milk was made by Tracy.[16] However, Charles and Sommer[38] state the following:

> The white sediment was found to be present in samples homogenized from milk produced under the finest conditions. This was from normal, healthy udders that were being studied for mastitis in connection with another problem: hence an abnormal cell content is very unlikely. The sediment therefore might be present in the original milk and merely made manifest by homogenization or actually caused by the homogenizer.

The possibility that homogenization affects the milk proteins, or removes material surrounding the fat globules, was cited by Charles and

Sommer.[38]

Clarification of the unhomogenized or homogenized milk was shown to reduce the occurrence of sediment.[9][13][16][38]

Chemical

Acidity and pH. Halloran and Trout,[39] Dorner and Widner,[12] Doan,[40] Caulfield and Martin,[22] Gould and Trout,[20] and Trout et al[9] have studied acidity changes when milk is homogenized. It was found[9][12][22] that an increase in titratable acidity occurred immediately after homogenizing raw milk, but pasteurization tends to prevent this immediate increase in acidity. Doan and Minster[41] observed similar changes in making pH determinations.

Doan states[40] that Sharp and de Tomasi noted that the rapidity of development of non-lactic acidity (rancidity) increases with increases in pressure of homogenization, and with holding the temperature up to 37 degrees C. (99° F.) Gould and Trout[20] found that the acid degree of the fat of raw homogenized milk was increased fourfold to sixfold within a few minutes after homogenization, and continued to increase on standing. Milk pasteurized before homogenizing did not show the rapid change in the fat that occurred in the homogenized raw samples.

Holding milk[12] 30 minutes at 53° C. (127.4° F.) reduces the development of non-lactic acidity, and holding for 30 minutes at 55° C. (131° F.) was found to be the critical heating temperature needed to prevent the occurrence of this change in the fat.

Flavor and Aroma. Many flavors have been found in milk. Sommer[13] states: "Homogenized milk has a richer flavor than untreated milk. This is due to the increased number and surface area of fat globules". Some undesirable flavors found in milk have been shown[12][13][17][20][22][40][42][43][44][45][46] to be affected by homogenization.

A rancid flavor developing in raw homogenized milk has been studied by Dorner and Widner,[12] Doan,[40] Caulfield and Martin,[22] and Gould and Trout.[20] They all conclude that this flavor is prevented by heating to destroy the causitive agent (lipase) of rancidity. By homogenization, the surface of the fat is greater, allowing the lipase to attack it better. It was also shown that increases in the rancidity parallel the non-lactic acidity increases, which are measured as titratable acidity or pH. Critical temperatures, inhibiting the action of the enzyme in milk, were determined by Dorner and Widner,[12] and Doan.[40] The rancid flavor was attributed to the splitting of the fat, by lipase, to give free fatty acids.

A flavor, called oxidized, was found in pasteurized milk or milk which had been placed in a strong light. In practice, such metals as copper and iron, which contaminated the milk by contact (coolers, cans, pipes, etc.), were found to cause the oxidized flavor. Tracy et al,[42] Thurston et al,[43][44] and Trout and Gould[46] found that the oxidized flavor seldom occurred in homogenized milk. The problem was studied,[17][42][43][44][45][46] and homogenization at high pressures was found to prevent the occurrence of an oxidized flavor in milk which was highly contaminated with the causitive agents (copper and iron). Trout and Gould[46] contaminated homogenized milk with copper, and found that this milk did not develop an oxidized flavor. A hypothesis was advanced by Ross[45] that the prevention

of oxidized flavor in milk by homogenization may possibly be due to the formation of a film around the fat globule. Thurston et al[43] state: "Lecithin, rather than butterfat, appears to be the constituents of milk affected when oxidized flavor develops. These results indicate that so-called oxidized flavor is not identical with the tallowy flavor of oxidized butterfat". A minimum homogenizing pressure of 1,500 pounds per square inch is advocated[45][46] to prevent the occurrence of oxidized flavor.

Microscopic Studies

Cell Counts. It has been known for many years that homogenizing milk tends to increase the bacteria counts. Tracy's[17] data indicate that the process of homogenizing increases the bacteria counts for two possible reasons. He found that groups (chains, clusters, or pairs) of cells are disrupted into smaller groups or individual cells, thus accounting for an increase in count. Contamination of the milk by the equipment was also studied and was found to be another contributing factor for the higher counts.

Apparently, leucocytes found in normal milk have never been associated with any bad qualities of the milk. The sediment,[9][47] which occurred in homogenized milk, resembled separator slim, and contained many leucocytes and body cells. Work done at the University of Illinois Creamery[16] indicates that milk with a high leucocyte count, if homogenized, will show a greater amount of sediment than will milk having a lower original cell count.

Costs of Homogenizing Milk

The cost of homogenization must include such items as the initial investment, depreciation of equipment, interest on the investment, and power for operation and labor. Sommer cites[13] the unpublished data of Bruhn and Thomsen on the costs of homogenizing ice cream mix at 3,200 pounds pressure, using a 250-gallon per hour machine:

Data on Operation

Capacity per hour	2,417 pounds.
Current per hour	9,134 Kw. Hrs.
Current per 100 lbs. of mix	0.377 Kw. Hr.
Current used for washing	0.09 Kw. Hr.

Costs on the Basis of a Five-hour Day

Depreciation and upkeep per day (10% annually)	$0.93
Interest per day	0.30
Power 45.76 Kw. Hrs. at 1.75 cents	0.80
Labor 7 hours at 55¢ (allowing for cleaning)	3.85
Total daily cost	$5.88
Cost per 100 lbs. of mix	$0.048

Farral[48] made a survey of the power required to homogenize mix. The power consumption varied almost directly with changes of pressure at which the machine operated. He found that the average power consumption necessary to homogenize 100 pounds of mix was approximately 1/3 Kilowatt Hour. From a study of these data, one may estimate the cost of homogenizing milk to be approximately 0.1 cent per quart.

Feeding Qualities of Homogenized Milk

Digestibility

Many statements are to be found in literature proclaiming the superiority of homogenized milk. Such statements were based on the facts that the fat globules are much smaller, having more surface exposed to digestive agents, and the milk curds are much softer than those of ordinary milk. Few investigators have studied and compared the digestibility of homogenized milk to that of ordinary milk.

Studies in Vivo. Washburn,[6] in a study of the values of different grades of milk for infant feeding, found the homogenized milk curds in the stomachs of pigs to be flocculent and friable, while a tough curd was found when unhomogenized milk was fed. Espe and Dye[49] state: "Doubling the curd tension of milk increases the digestive period from 30 to 65 per cent". Advertising material[50] used to advance the use of homogenized milk contained the following statement: "Homogenized milk curds formed in the stomach are smaller and softer; hence more easily handled by the digestive tract". The rapidity with which milk (made soft curd) is digested was shown by Mortenson et al.[51] Heating milk to make it a soft-curd milk did not coagulate in a calf's stomach as rapidly as the raw hard-curd milk. Although the heated and raw milks passed through the stomach in about the same length of time, the heated milk began to leave the stomach quicker than raw milk. Pigs[6] fed milk containing dyes of different colors retained a colored curd in the stomach as long as 39 hours. Washburn[52] states:

> If a husky pig requires 39 hours or even one-tenth of that number of hours to dispose of natural milk curd, we certainly must expect human infants to have similar but more serious difficulties - and they do.

Morris and Richardson[53] report: "The stools of infants fed on soft-curd milk are more frequent than those fed on boiled diluted cow's milk and may often contain large casein curds".

Doan and Welch[23] used calves, rats, and human beings in their studies, and found that a normal soft-curd milk formed a definite large curd lump in the digestive system, but was softer and looser than that formed by hard-curd milk. Evaporated milk coagulated and formed a loose, fine-particle curd, while buttermilk failed to form a curd structure.

Studies in Vitro. Doan and Welch[23][35] have done practically all of the work made in vitro on the digestibility of milk curds. Coagulation similar to that found in the stomach has been attempted. An improved technique of studying the problem by this method is needed. Such a method should prove to be very useful in studying the digestibility of milk of various types.

Nutritive Qualities

Comparative studies of the nutritional qualities of soft-curd and hard-curd milks have been made by Washburn,[6] Berry,[26] and Morris and Richardson.[53]

In feeding pigs, Washburn's results[6] indicate that the growth depends upon the composition and consumption. The milk containing the higher percentage of fat (greater nutritive ratio) produced greater gains for the amount consumed. In viewing his results from the standpoint of energy supplied and retained as growth, a greater proportion is utilized from the homogenized milk than from the unhomogenized milk.

Washburn[6] states:

> The homogenization of the fat does not seem to be helpful in feeding of the young, if we may judge by the clinical evidences. The pigs fed the milks thus treated ate their food less greedily and, whenever the fat content of their ration was increased, went off feed more quickly than did those receiving milk containing normal fat. However, the curds formed from milk, the casein of which had been homogenized, were made so much more flocculent and friable as a result of this process that the writers are led to feel that perhaps benefit may be expected from such treatment.

Berry[26] fed rats and noted the consumption and growth when fed hard-curd, normal soft-curd, hard-curd heated, and hard-curd homogenized milks. Rats fed normal soft-curd milk showed no tendency toward producing a larger gain in weight than rats fed normal hard-curd, or hard-curd milk rendered soft-curd by heat or homogenization. The average daily consumption of normal soft-curd milk was greater than the hard-curd milk, and less than the hard-curd milk treated to render it soft-curd.

Morris and Richardson[53] noted a greater constant gain in weight for infants fed normal soft-curd milk than when fed evaporated milk.

Public Opinion of Homogenized Milk

Homogenized milk has been accepted in Canada and parts of the United States. Companies manufacturing dairy equipment attempted to promote homogenizing by issuing advertising material to the public.

The medical profession[2] has recommended homogenized milk for certain purposes because it has a softer curd than unhomogenized milk. Milk plants either sell homogenized milk at a higher price than ordinary milk, or sell it at the price of ordinary milk and attempt to make up the difference in cost by the increased sales of the milk and cream.

Tracy,[16] by a consumer questionnaire, found that the consumers liked homogenized milk for the following reasons:

1. Looks and tastes richer.
2. No cream adheres to bottle cap and top of milk bottle.
3. No mixing necessary.
4. Better for breakfast foods.
5. There is no temptation to remove the cream.
6. Easy to prepare for infant feeding.
7. No cream rises to top of glass standing in refrigerator.
8. Makes fine milk drinks.
9. Children like it better.
10. Babies do better on homogenized milk.
11. Does not churn out when it freezes.
12. Adults would never drink other types of milk.

Apparently, the factors leading to the adoption and gradual increase in sales of homogenized milk are (1) the benefits derived from the consumption of this milk, (2) the quality product that has been offered to the public, and (3) proper advertising.

Summary of Review of Literature

The following conclusions may be drawn from the literature cited:

1. Homogenization of milk has been practiced since 1910.

2. The process of homogenizing milk consists of breaking up the fat globules into many smaller globules. Nothing is added to or removed from the milk by homogenizing.

3. Various machines and procedures are used in order to homogenize milk.

4. The smaller the fat globules the slower is the fat rise (creaming).

5. Homogenization of milk reduces the curd tension.

6. Homogenization may affect the viscosity of the milk, depending upon the treatment and milk composition.

7. The color of homogenized milk is uniform.

8. Sediment may occur if proper treatment of the milk is not practiced.

9. A rancid flavor develops in raw homogenized milk.

10. Homogenization may stabilize the milk against an oxidized flavor.

11. Bacteria counts are higher after homogenizing.

12. The expense of homogenizing is approximately 0.1 cent per quart.

13. Homogenized milk is easier to digest.

14. The public has accepted the introduction of homogenized milk.

PART II

ORIGINAL INVESTIGATION

PART II

ORIGINAL INVESTIGATION

Objects of Investigation

1. To compare the procedures as to cost, efficiency, and adaptations.
2. To study some of the effects (physical, chemical, and bacteriological) of various procedures on the milk.
3. To compare the palatability of homogenized, normal soft-curd, and normal hard-curd milks.
4. To determine the feeding value of homogenized milk as compared to normal soft and hard-curd milks.
5. To compare the speed and ease of digestion of homogenized, soft-curd, and hard-curd milks.

Plan of Investigation

The plan of this investigation is to determine the effects of various methods and procedures in homogenizing milk, and to compare the qualities of the milk processed by the various procedures.

Detail data were collected for each procedure used. The operation of processing the milk and determining its qualities was done by the author. Capable milk judges aided in comparing and criticizing the flavors of the milk. Standard lines of modern high-quality equipment were used in the experimental work. The approved procedures for making the various tests on the milk were followed. Individual record sheets for each batch of milk processed were prepared and the results were recorded when the test was made. All data sheets were filed. To compare some of the nutritional qualities of the three types of milk, rats were used. The homogenized milk used was the standardized normal hard-curd milk which was homogenized. The soft-curd milk was collected weekly from selected cows producing such milk. Weights of the rats were recorded weekly, and the consumption of the milk was recorded on the cage when the milk was fed.

General Procedure In Processing the Milk

This investigation was conducted in the Dairy Department of the University of Tennessee. The facilities of the University Creamery were used in processing the milk. The study of the products was done in the Dairy Laboratories.

Some of the equipment used in processing the milk was designed especially for this work; however, most of the equipment was used in the commercial processing of milk by the Creamery. All of the instruments,

materials, and equipment needed in this study were of a high quality and standard make.

Most of the milk was obtained from the college herd and farm herds that supply the market milk needs of the Creamery. Such milk was graded, and met the City Health requirements for the production of Grade "A" pasteurized milk. Generally, mixed milk was used unless otherwise stated.

Preheating to approximately 110° F. was accomplished by a horizontal steam-jacketed tubular preheater. All of the milk was filtered through a standard in-the-line flannel milk filter. This process generally followed the preheating.

The pasteurization of most of the milk was done in a stainless steel spray pasteurizer (Cherry-Burrell, Model 35 CC). When trials were made to determine the effects that various processing temperatures and treatments had on the milks, representative samples (split lots) of the milk were heated in shot-gun cans. The cans of milk were immersed in a hot water bath, and the milk was agitated by hand stirring rods.

A De Laval, number 32, power-driven separator and a McCormick Deering, number 4, power-driven separator were used to separate and clarify the milk at the various stages and temperatures given.

Cooling of the milk was accomplished by immersing the container of milk in an iced water bath.

Most of the milk was homogenized with a Cherry-Burrell sanitary viscolizer of 100-gallon capacity, fitted with a single-stage homogenizing valve. In some cases, homogenization was attempted by using a 'Marvel' centrifugal homogenizer.

In every case, two samples of milk were taken for the various tests. The samples were taken in quart bottles and 100 ml. graduated cylinders, and kept in storage at approximately 40 - 45 degrees F. until tested.

The curd tension determinations were made by two different procedures. The first procedure consisted of adding 1 ml. of a rennet solution (equal parts by volume of water and rennet) to 100 ml. of milk tempered to 95° F. plus or minus 1° F. The milk was held at this temperature for ten minutes before measuring the curd tension. The second method was the procedure recommended by Hill,[7][8] except that the 100 ml. of tempered milk was added to 10 ml. of the tempered coagulant. This coagulant consists of one part by volume of a calcium chloride solution and three parts by volume of a pepsin solution. The calcium chloride solution was made by dissolving 378 grams of dry granular calcium chloride in distilled water and diluting to one liter. The pepsin solution was made by dissolving 0.6 gram of dry scale pepsin (U.S.P. 1-5,000) in distilled water and diluting it to 100 ml. Duplicate tests were always made on the milk.

The instrument used to determine the curd tension was the Curd Tension Tester designed by the Submarine Signal Company. This machine was fitted with the improved curd knife. A gradual descent of the knife assembly is controlled by a motor drive. The knife is floated by the buoyancy of a calibrated rod extending into a column of mercury. The knife assembly is always self-adjusting, and the curd tension is measured directly in grams by reading the position of the mercury meniscus on the calibrated rod. The average of the readings of the duplicate trials was recorded and the difference in curd tension readings was never greater than 10 per cent. Curd tension determinations were made 2 hours after processing

and 24 hours after processing.

The Mann's procedure was used to determine the titratable acidity of the milks. N/10 normal sodium hydroxide was used to neutralize the acid. An alcoholic solution of phenolphthalein was the indicator. The acidity, calculated as the per cent of lactic acid, was titrated on the samples of milk before processing and at various times after processing.

A Beckman pH meter was used to determine the hydrogen-ion concentration of the milk samples. This instrument uses the glass-electrode method of determining the pH of the solution. The instrument was frequently standardized to a standard buffer solution (a pH of 6.0 at 20° C.) The pH was determined before and after processing the milk samples.

Viscosity of the milk was determined by recording the length of time required for a definite volume of liquid to flow through the Borden flow meter. The Relative Viscosity was not determined, as only a comparison of the apparent viscosities of milk treated by various procedures was desired. Thus, the length of time measured in seconds and fractions of seconds by a stop watch provided a direct means of comparioan. The samples of milk were kept in storage until one-half hour before making the viscosity tests. The samples were slowly tempered until a temperature of 15.5° C. (60° F.) was reached. The discharge tube used on the flow meter was two inches long and 1.97 mm. in diameter. The time of flow was measured from the first appearance of the milk flowing out of the discharge tube until the steady flow ceased.

One hundred ml. samples of milk were placed in 100 ml. glass graduates. The creaming ability of the milks was found by noting the volume

in c.c. of cream on the milk. The number of c.c. of cream was easily expressed as the per cent of creaming, since a sample of 100 ml. was used.

Comparisons of the color were made between the milk in one graduate and milk in another graduate, etc.

Sediment occurring on the bottom of the graduate was noted and the percentage recorded. Generally, the occurrence of sediment was found in the quart sample of milk.

The fat tests used were the Babcock test for fat and the ether extraction method as specified by the Mojonnier testing manual.(54)

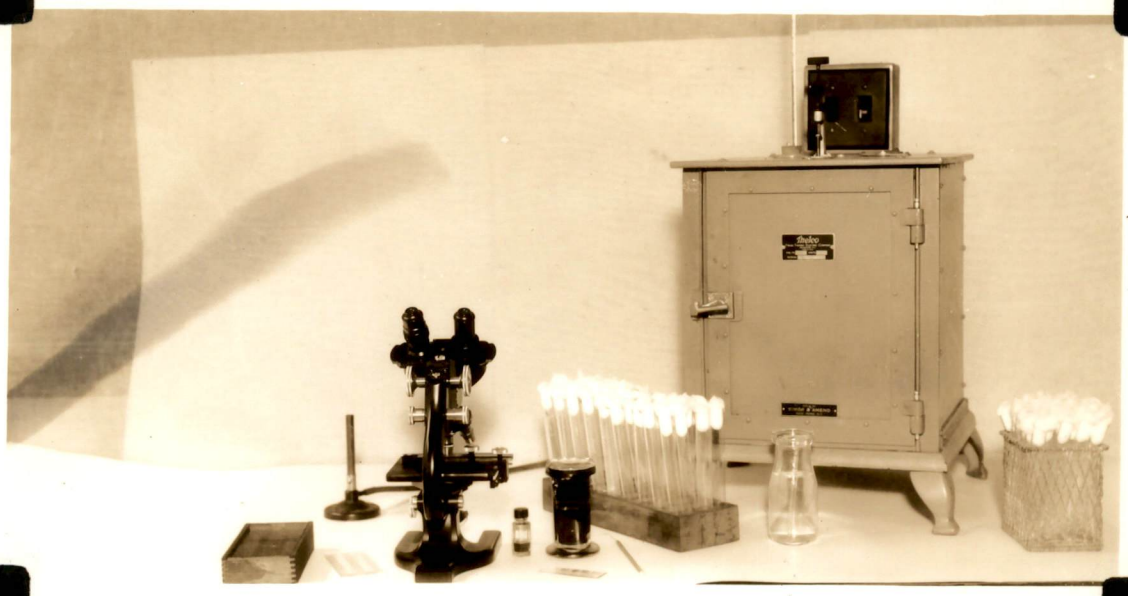
The total solids content was determined by the evaporation of moisture from the milk by the Mojonnier method.(54)

The specific gravity was measured by a Quevenne lactometer and the Westphal balance.

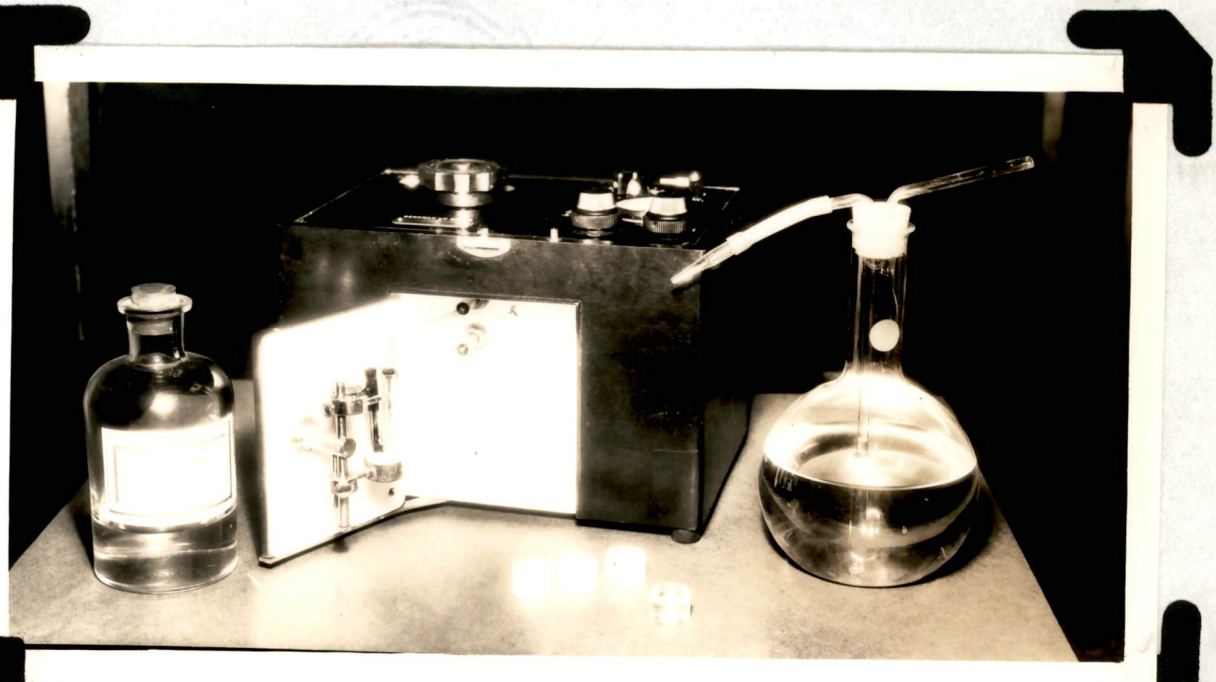
Samples of milk were examined organoleptically for the various flavors by milk judges working independently .

The Hortvet cryoscope was used to determine changes in the freezing points of the milk processed by the various procedures.

Microscopic examination of the fat globules was done by observing diluted milk in a hanging drop. The size of the fat globules was determined by the use of a stage micrometer. Bacteria and leucocyte counts were made by the Breed Direct Microscopic Method of counting cells. The Modified Newman-Lampert stain was used to stain the milk smears on the slides.



The Equipment Used For the Bacteriological Study



The Potentiometer for Determining pH

Physical Effects of Homogenization on Milk

Size of Fat Globules

In the various milks studied the sizes of the fat globules were noted. The average globule size was determined microscopically by counting the number of globules of each diameter and deriving the average globule size by dividing the sum of all the globules' diameters by the number of globules observed in the field.

Table III, page 41, shows the effect of different pressures of homogenization on raw milk homogenized at 120° F. These data show that there is a great variation in the size of fat globules in samples of milk. The average size of the fat globules becomes smaller as the homogenizing pressures are increased; however, homogenization does not reduce the fat globules to a common size. For an illustration, see Figure 5, page 42. Globules under one micron in diameter were listed as being one micron. The reduction in the size is not directly an inverse proportion to the pressure applied, for it is quite apparent that the efficiency in reducing the average globule size is much less for the higher pressures than for the lower homogenizing pressures.

From the data presented in Table IV, page 43, it is evident that the greater the homogenizing pressure the smaller is the average fat globule size in both raw and pasteurized milks. The small differences in the average globule size when the milk was homogenized at the various temperatures are insignificant, for such small differences were within the limits of experimental error. From the data of this one trial, no conclusion can be made; however, they may indicate that a difference in the average fat globule sizes exists.

TABLE III

EFFECT UPON THE SIZE OF THE FAT GLOBULES WHEN RAW MILK WAS HOMOGENIZED AT 120° F.

Pressure of Homogenization	Range of Fat Globule Size		Average Fat Globule Size
	Number	Diameter in Microns	Diameter in Microns
4,000 pounds	46 24 2	1 2 3	1.38
3,000 pounds	26 15 4 1	1 2 3 5	1.41
2,000 pounds	35 20 6 2	1 2 4 5	1.73
1,000 pounds	22 28 16 21 12 5	1 2 3 4 6 7	3.01
Unhomogenized	6 3 5 6 5 6 4 5 8 6 6 4 2 2	1 2 3 4 5 6 7 8 9 10 12 13 14 16	7.29

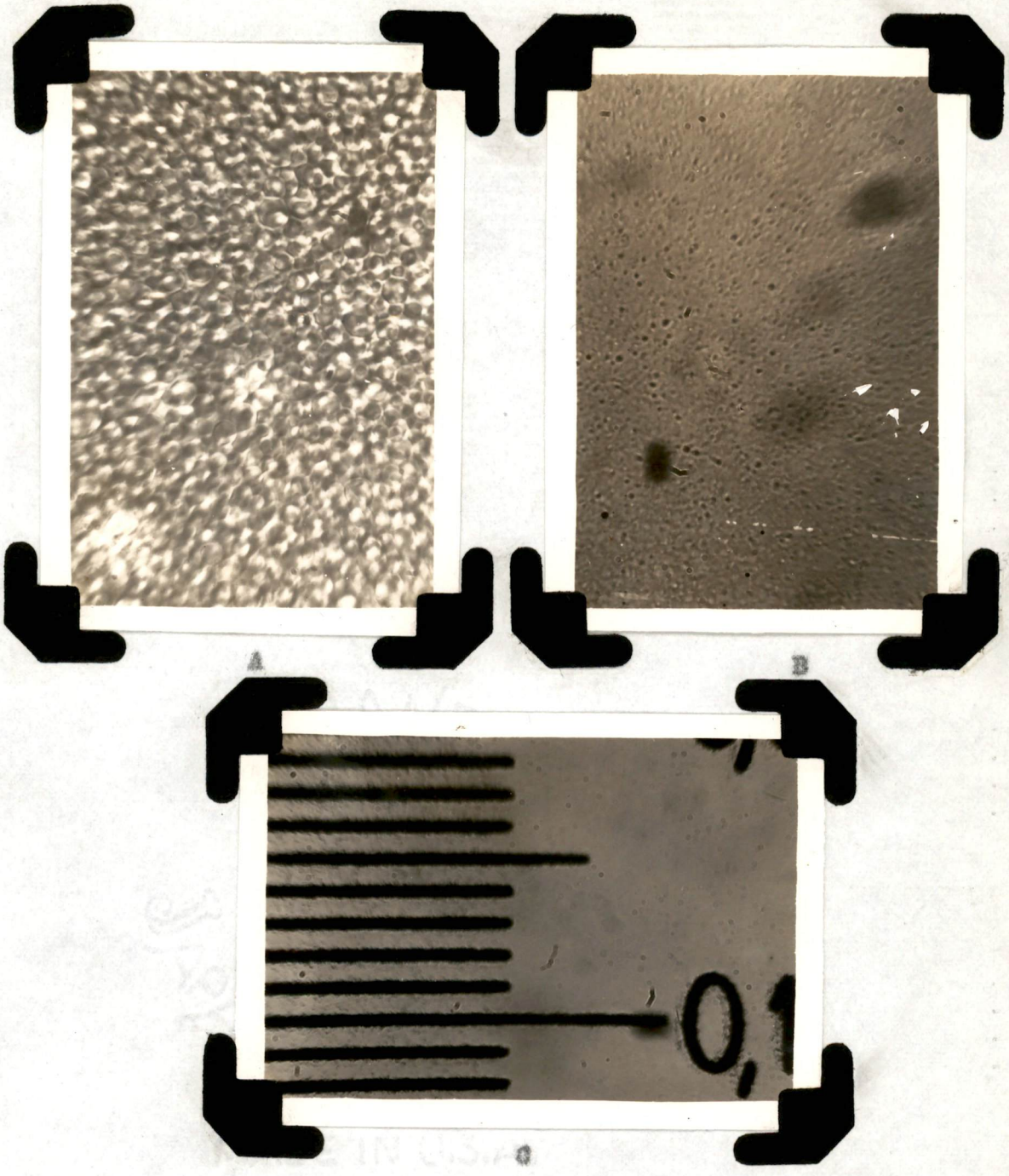


Figure 5. Photomicrographs (Magnification 625 times)

A Fat globules in normal milk
B Fat globules in homogenised milk
C Stage micrometer

TABLE IV

EFFECT OF HOMOGENIZING RAW AND PASTEURIZED MILK AT DIFFERENT TEMPERATURES ON THE SIZE OF FAT GLOBULES

Pressure of Homogenization	Average Diameter of Fat Globules (Microns)					
	Raw			Pasteurized		
	Homogenizing Temperatures					
	90° F.	120° F.	143.5° F.	90° F.	120° F.	143.5° F.
500	5.02	4.98	4.88	3.85	4.04	3.93
1,000	3.90	4.04	3.84	3.14	3.44	3.76
2,000	3.00	2.96	2.81	2.43	2.43	2.51
3,000	2.48	2.56	2.24	1.85	2.12	2.08
4,000	2.34	2.22	2.71	1.92	1.61	1.88
Average	3.54	3.55	3.29	2.63	2.72	2.83
	Average size of fat globule before homogenizing: 7.29 microns			Average size of fat globule before homogenizing: 6.82 microns		

Fat Tests

To determine whether or not any change occurs in the fat tests of milk homogenized, the Babcock sulfuric acid method and the Mojonnier ether extraction method of testing for fat were used. The data in Table V are the average tests of samples from six lots of milk. The samples were both raw and pasteurized (143.5° F. for 30 minutes).

TABLE V

FAT TESTS (BABCOCK) OF SAMPLES OF RAW AND PASTEURIZED MILK HOMOGENIZED AT THE VARIOUS TEMPERATURES AND PRESSURES (AVERAGE 6 LOTS OF MILK)

Homogenizing Temperature	90° F.		120° F.		143.5° F.	
Treatment	Raw	Pasteurized	Raw	Pasteurized	Raw	Pasteurized
Pressure of Homogenization Lbs. per sq. in.	Per Cent Butterfat					
0	4.31	4.32	4.31	4.32	4.31	4.32
500	4.28	4.30	4.30	4.32	4.31	4.32
1,000	4.29	4.29	4.30	4.30	4.30	4.30
2,000	4.29	4.28	4,29	4.31	4.29	4.30
3,000	4.26	4.27	4.29	4.30	4.29	4.29
4,000	4.26	4.27	4.28	4.29	4.29	4.30
Average	4.281	4.289	4.295	4.306	4.298	4.305

It is apparent from the data obtained and shown in Table V, page 44, that homogenizing at higher pressures tends to lower the Babcock fat tests. The average of the samples of six lots of milk is more representative of the variations in tests, as the average tends to reduce any variation between the individual tests. Variations between the individual fat tests were all within the normal limits of error permitted by standard regulations governing the fat tests.

Homogenizing the pasteurized and raw milk at various pressures had little or no more effect on one kind of milk than on the other. It is evident that in every case the pasteurized milk showed a greater fat test than did the raw milk; however, no apparent difference in fat test between raw and pasteurized was caused by homogenization.

Lower homogenizing temperatures caused lower Babcock fat tests than did the higher homogenizing temperatures.

No significant difference in the fat tests determined by the Mojonnier method were found when four lots of pasteurized milk were homogenized at different temperatures. Table VI, page 46, showed no appreciable difference in fat test by the Mojonnier method for milk homogenized at the different pressures.

It is questionable as to the extent that the fat globule dispersion influences the Babcock test. Trout et al[9] also found that higher pressures of homogenization lowered the Babcock test; and pasteurized milk, homogenized at 145° F. had a lower fat test than raw milk homogenized at 90° F.

TABLE VI

FAT TESTS (MOJONNIER, ETHER EXTRACTION) OF PASTEURIZED MILK HOMOGENIZED AT THE VARIOUS TEMPERATURES AND PRESSURES (AVERAGE OF 4 LOTS OF MILK)

Homogenizing Temperature	90° F.	120° F.	143.5° F.
Pressure of Homogenization Lbs. per sq. in.	Per Cent Butterfat		
0	4.35	4.35	4.34
1,000	4.35	4.35	4.35
2,000	4.34	4.36	4.36
3,000	4.33	4.36	4.35
4,000	4.36	4.35	4.36
Average	4.346	4.354	4.351

It may be assumed that the fat globule dispersion in the milk reduces the fat column, as more centrifugal force is needed to raise the tiny globules. It is shown in Table IV, page 43, that a greater dispersion of the globules and less globule clumping is found when raw milk is homogenized at the higher temperatures. The fat globule dispersion in pasteurized milk is more pronounced at 90° F. than at 143.5° F. Such differences in the Babcock fat test were not apparent when the Mojonnier ether extraction method was used to determine the fat content of the milk.

Specific Gravity and Total Solids

No change whatsoever was found in the specific gravity of milk when it was homogenized. Determinations of the specific gravity were made with Quevenne lactometer and the Westphal balance.

The total solids content was determined directly by the Mojonnier method of evaporating the moisture to get the total solids, and by calculating the per cent of total solids from the fat test and specific gravity. No change was found in the specific gravity when milk was homogenized.

Curd Tension

The studies of the curd tension of various milks indicate that many factors affect the curd tension of milk.

Table VII, page 48, shows the effect that pressures of homogenization have on the curd tension of normal hard-curd, medium curd, and low curd milks. These data are the average of four separate trials. The three types of milk were selected on their curd tension properties. All of the milk was obtained from the University dairy herd; generally, each type was the mixed milk from two or more cows producing milk with a curd tension within the desired range. The three types of milk were standardized as to fat content (Babcock test) by removing enough of the top cream of the richer milks to make them equal to the fat content of the type with the lowest test. The average test was 3.85 per cent fat. All of the milks were handled alike. The raw milks were rapidly brought up to 90°, 120°, and 143.5° F. and immediately homogenized at the various pressures. Quart samples of the milk were collected at the homogenizer outlet and cooled by immersing the bottles in ice water.

TABLE VII

EFFECTS OF HOMOGENIZING NORMAL HARD, MEDIUM, AND LOW CURD MILKS ON THE CURD TENSION (AVERAGE OF 4 TRIALS)

Type Of Milk	Homogenizing Temperature	Unhomogenized	Homogenizing Pressure - Lbs. per sq. in. 500	1,000	2,000	3,000
			(Curd Tension in Grams)			
Hard Curd	90° F.	176.5	58.0	48.75	46.5	45.0
	120° F.	174.0	55.25	44.0	44.0	41.75
	153.5° F.	175.25	55.0	46.5	42.75	41.75
	Average	171.9	56.0	46.4	44.4	42.8
	% Reduction	0	67.5	72.8	74.2	75.0
Medium Curd	90° F.	121.0	72.75	57.75	50.0	42.25
	120° F.	118.0	64.5	55.5	48.5	38.0
	143.5° F.	118.5	60.25	54.25	48.0	35.25
	Average	119.1	65.8	55.8	44.8	38.5
	% Reduction	0	44.7	53.2	62.4	67.7
Low Curd	90° F.	48.0	42.25	38.0	34.75	30.5
	120° F.	45.75	40.0	38.5	33.25	30.5
	143.5° F.	44.5	41.25	39.0	30.25	26.75
	Average	46.0	41.1	38.5	32.75	29.2
	% Reduction	0	10.7	16.3	28.1	36.6

As evidenced by Table VII, the greater the pressure of homogenization the greater is the percentage reduction in curd tension. This is in accordance with Theophilus et al[11] and Doan[10]. By comparing the percentage reduction in curd tension of the three types of milk, it may be noted that a greater percentage reduction is obtained in the milk with higher curd tension. This fact is not in agreement with that of Caulfield and Martin[22] who obtained a greater percentage reduction in the milks of lower curd tensions. However, Theophilus et al[11] found a greater

percentage reduction in the milk of higher curd tension. The reduction in curd tension of the milk is not proportional to the increase in pressure. This is probably due to the fact that the reduction in the size of the fat globules is not proportional to the increase in pressure, as shown in Table III. When the samples were homogenized at 2500 and 3000 pounds per square inch, the differences in the curd tension were not as great, indicating that the greater homogenizing pressures are not proportionally as effective in reducing the curd tension or the size of the fat globules. Hard-curd milks generally contain a greater total solids content with a higher fat percentage than do normal soft-curd milks, and the average size of the fat globules are larger in hard-curd milks than in normal soft-curd milks. If, by homogenizing milk with larger fat globules, a greater percentage of dispersion and reduction in globule size occurs than when smaller globules are homogenized (Table III), it is reasonable to believe that the percentage reduction in curd tension of milk depends directly upon the amount of dispersion of the fat globules.

Increasing the homogenizing temperature of raw milk reduced the curd tension of the milk, as shown in Table VIII, page 50. As the temperature of homogenization is increased, the size of the fat globules tends to be smaller (Table V, page 44), thus causing a greater dispersion of the fat globules. Possibly the effects of heating the milk to higher temperatures may cause a lower curd tension of the milk. Berry[26] found that heating milk to high temperatures reduced the curd tension of the milk.

TABLE VIII

EFFECTS OF TEMPERATURE OF HOMOGENIZATION ON THE CURD TENSION OF RAW MILK (AVERAGE OF 4 TRIALS)

Temperature of Homogenization	Type of Milk	Unhomogenized	Homogenizing Pressure - Lbs. per sq.in.			
			500	1,000	2,000	3,000
			(Curd Tension in Grams)			
90° F.	Hard-Curd	176.5	58.0	48.75	46.5	45.0
	Medium Curd	121.0	72.75	57.75	50.0	42.25
	Low Curd	48.0	42.25	38.0	34.75	30.5
	Average	115.1	57.6	48.1	43.4	39.2
	% Reduction	0	49.1	59.2	62.3	66.0
120° F.	Hard-Curd	174.0	55.25	44.0	44.0	41.75
	Medium Curd	118.0	64.5	55.5	48.5	38.0
	Low Curd	45.75	40.0	38.5	33.25	30.5
	Average	112.5	53.2	46.0	41.9	36.7
	% Reduction	0	52.8	59.2	62.8	67.4
143.5° F.	Hard-Curd	175.25	55.0	46.5	42.75	41.75
	Medium Curd	118.5	60.25	54.25	48.0	35.25
	Low Curd	44.5	41.25	39.0	30.25	26.75
	Average	112.0	52.1	46.5	40.2	34.3
	% Reduction	0	53.4	58.5	64.2	70.2

A mixed lot of fresh milk was used to determine the effects that the fat percentage had on the curd tension of milk homogenized. The lot of milk was separated at 105° F. The skimmilk and cream was combined to make products having various fat percentages. Each product was heated alike to 120° F. and homogenized at the various pressures. Samples were taken and the curd tensions determined.

Data in Table IX, page 51, indicate that the fat percentage of the milk has a marked softening effect upon the curd.

TABLE IX

EFFECT OF HOMOGENIZATION UPON THE CURD TENSION OF RAW MILK OF VARIOUS FAT PERCENTAGES (BABCOCK)

Raw Product	Unhomogenized	Homogenized at 120° F.				
		500	1,000	2,000	3,000	4,000
		(Curd Tension in Grams)				
Skim .04% fat	121	118	120	115	118	115
Milk 2.2% fat	105	95	95	82	80	75
Milk 4.1% fat	95	80	68	65	58	52
Milk 5.8% fat	88	75	62	55	48	45
Milk 8.3% fat	55	42	40	36	25	22
Milk 12.6% fat	36	32	30	22	25	18
Cream 24.5% fat	28	15	15	15	12	10
Cream 32.0% fat	20	18	15	15	0	0

In every case, the milk with a higher fat percentage had a lower curd tension. Hill[7][8] found that the curd could be made softer by adding cream to the milk. Homogenization affected the curd tension of milks, and the greatest effects were noted in milks containing 2.2 per cent fat to 12.6 per cent fat. The curd tension of the skimmilk was high, and homogenization had little or no effect upon it as the amount of fat available for dispersion was nil. A reduction in the curd tension of cream was noted; however, the test was not very significant, as the curd tension of the unhomogenized sample was very low and a great variation normally occurs in samples with such soft curds.

Borden Body Flow Meter

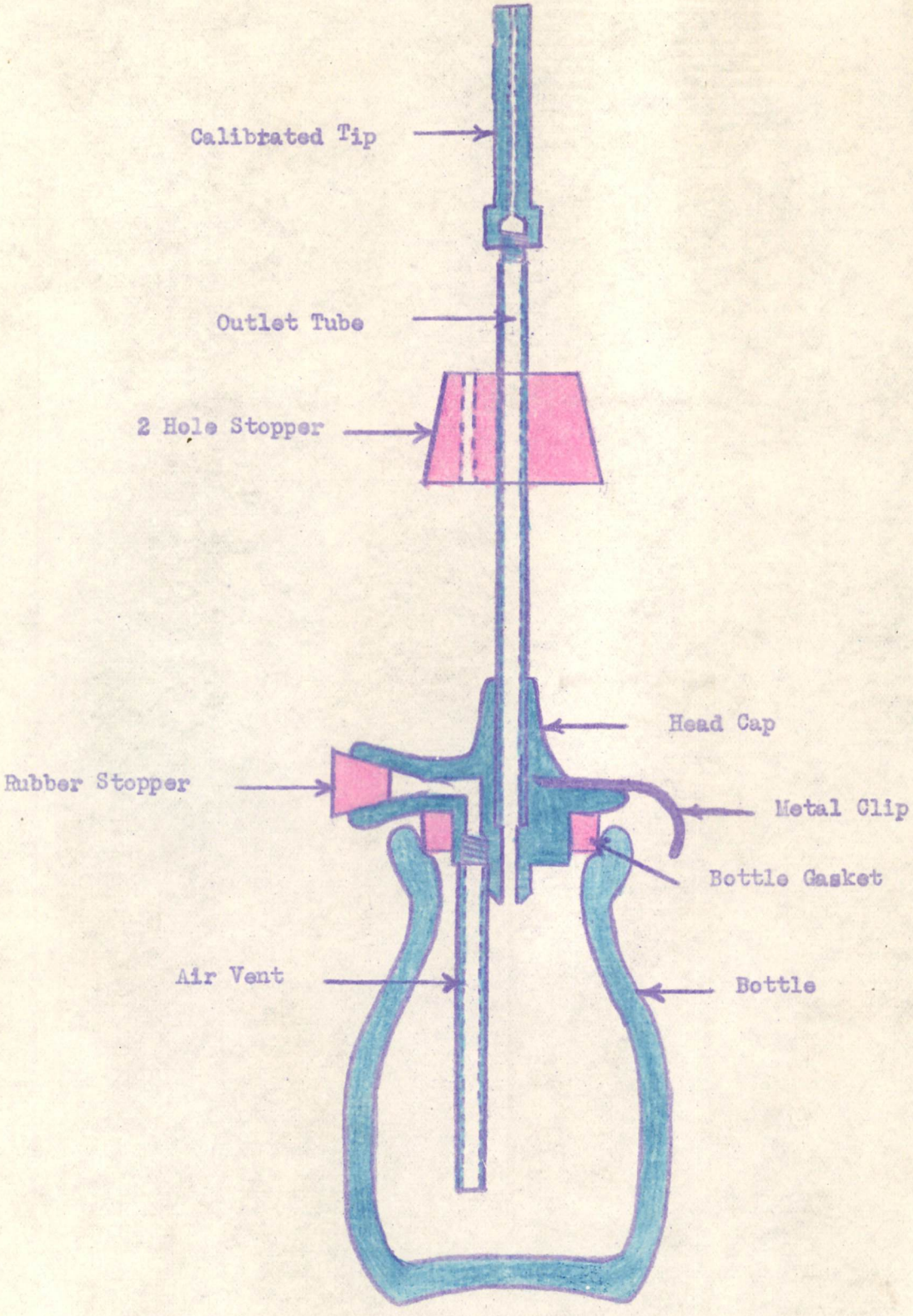


Figure (6)

Viscosity

The Borden Flow Meter was used to determine the viscosity of the milk processed by different methods, and the relative viscosity was expressed only in seconds of flow. From the data shown in Table X, page 54, it is evident that the viscosity of raw milk was increased by homogenization. No significant changes in viscosity occurred when pasteurized milk was homogenized. The increase in viscosity may be due to the increased number of fat globules together with a greater surface area of adsorptive film, which relatively increases the effective radius of the fat globules. Any adsorption of the serum materials to the globules, or clumping of the fat into irregular clusters, tends to increase the friction of the particles, thus increasing the viscosity.

Babcock and Russell[37] found that the viscosity of milk was decreased by pasteurization. They explained this decrease as being caused by the breaking up of the clusters.

Homogenizing a cultured buttermilk produced a marked decrease in the viscosity, and the product was made extremely smooth. There was no tendency toward a wheying off. The product remained very smooth even after two weeks of storage at 40° F.

No significant change was noted in the viscosity of skimmilk after homogenizing.

Homogenizing cream at a low temperature (120° F.) causes a great increase in viscosity, as the concentration of the fat is much more than in milk. There is a greater tendency toward fat clumping in cream than in milk.

TABLE X

EFFECT UPON THE VISCOSITY WHEN VARIOUS KINDS OF MILKS WERE HOMOGENIZED AT 120° F.

Kind of Milk	Unhomogenized	Pressure of homogenization Lbs.per sq.in.			
		500	1,000	2,000	3,000
	Time of Flow in Seconds at 60° F.				
Raw (Average 4 trials)	64.25	67.42	67.52	67.30	67.53
Pasteurized (Average 6 trials)	62.15	62.61	62.23	63.40	63.87
Buttermilk	1203.0	542.0	410.0	282.0	184.0
Skimmilk	59.1	---	59.7	61.7	61.2
Raw Cream 35% fat	90.0	164.0	285.0	342.0	361.0

Figure 7. Borden Body Flow Meter

Creaming

To determine the temperatures and pressures required for the efficient dispersion of the fat globules, samples of the processed milk were placed in 100 ml. graduates and examined after 24 hours, 48 hours, 72 hours, and 168 hours for the formation of a cream layer. See Figure 8, page 59.

As shown in Table XI, page 57, a cream layer was generally found on raw milk homogenized at 500 pounds per square inch. When milk at 143.5° F. was homogenized at 1,000 pounds pressure, a cream line seldom appeared. However, a pressure of 1,000 pounds per square inch should not be considered sufficient to homogenize milk, as a slight creaming occurred upon standing. When the milk at 90° or 120° F. was homogenized even at 1,500 pounds pressure, a slight creaming occurred. When milk was preheated to 90° F. or 120° F., the fat globules were probably still in a solid or semi-solid state, and 1,500 pounds pressure was not great enough to completely disperse them. A pressure of 1,500 pounds per square inch is sufficient to homogenize milk at 143.5° F.; however, pressures in excess of 1,500 pounds are advised.

The data in Table XII, page 58, indicate that pasteurizing milk reduces the cream volume in both unhomogenized and homogenized milks.

TABLE XI

PERCENT OF CREAMING OF RAW MILK HOMOGENIZED AT THE VARIOUS TEMPERATURES
(AVERAGE OF 4 TRIALS)

Pressure of Homogenization (Lbs. per sq. in.)	After (Hours)	Percent of Cream Rising on Raw Milk Homogenized at Various Temperatures		
		90° F.	120° F.	143.5° F.
Unhomogenized	24	16 %	14.5 %	14.0 %
	48	15.50	14.5	13.5
	72	15.50	14.25	13.0
	168	15.25	14.25	12.25
500	24	2.5	2.5	2.25
	48	2.75	2.5	2.50
	72	2.75	2.75	2.25
	168	3.0	2.5	2.25
1,000	24	1	---	---
	48	1.25	0.75	---
	72	1.25	1.0	0.75
	168	1.25	1.0	1.0
1,500	24	---	---	---
	48	.25	---	---
	72	0.5	0.50	---
	168	0.75	0.50	---

TABLE XII

PER CENT OF CREAMING OF RAW AND PASTEURIZED MILK
HOMOGENIZED AT 143.5° F.
(AVERAGE OF 4 TRIALS)

Pressure of Homogenization (Lbs. per sq. in.)	Per Cent Cream Rising					
	Raw			Pasteurized		
	After 24 hours	After 48 hours	After 72 hours	After 24 hours	After 48 hours	After 72 hours
Unhomogenized	14.0 %	13.5 %	13.0 %	13.25%	13.25%	13.0 %
500	2.25	2.50	2.25	1.75	2.0	2.0
1,000	--	--	0.75	--	0.5	0.5
1,500	--	--	--	--	--	0.25
2,000	--	--	--	--	--	--

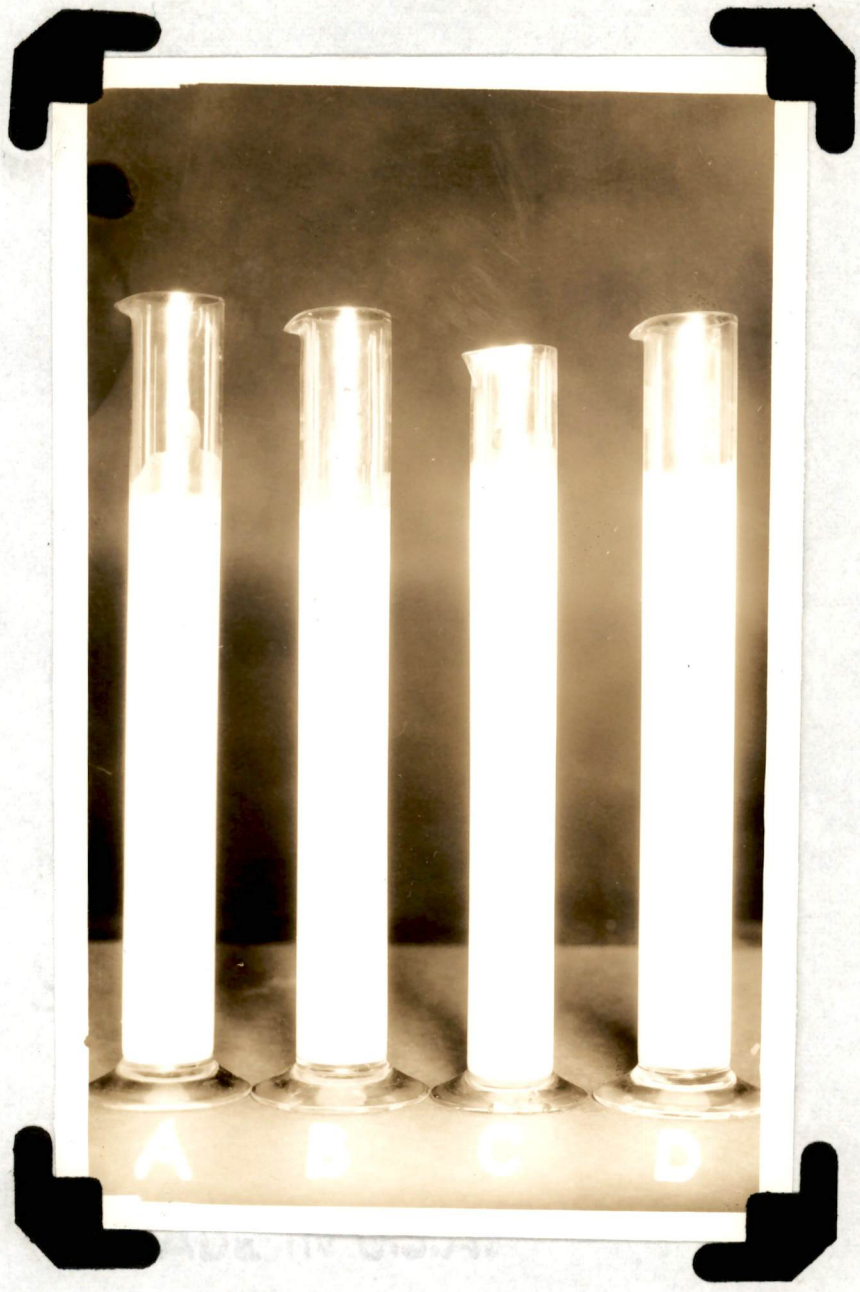


Figure 8. Graduate to Show Creaming, Color, and Sediment

A Unhomogenized milk
B Milk homogenized at 500 pounds per square inch
C Milk homogenized at 1,000 pounds per square inch
D Milk homogenized at 2,000 pounds per square inch

Color

One important characteristic of homogenized milk is that it has the same color throughout; no dark cream or blue skimmilk layers exist. It was noted, by comparing the 100 ml. graduates of milk used to determine the creaming (Figure 8), that the homogenized milk was lighter in color, being more opaque. It was also noted that higher pressures of homogenization made the milk even whiter. This effect on the color was due to the great dispersion of the smaller fat globules that reflect the light from their surface. However, skimmilk that was homogenized appeared to be lighter in color than the unhomogenized skimmilk. A color analyzer was not available for this work, and it was questioned as to the practical value of determining the effects of various procedures on the color of the milk in this study.

Sediment

A study of the occurrence and cause of sediment in homogenized milk was made in connection with a bacteriological problem, which was being carried out on the University dairy herd. In the early part of this study the homogenized milk samples were observed for sediment. Samples of milk were purposely contaminated with separator slime and other materials in an attempt to produce sediment in homogenized milk. No sediment was noted in such samples until Professor G. M. Trout of Michigan State College pointed out an occurrence of sediment in one particular sample. This sediment in appearance was nearly the same color as the milk, the difference being that it was a white powdery material approximately one-half inch thick. A slight movement of the bottle caused this material to be dispersed in the milk.

This sediment reappeared when the bottle was undisturbed for a short time. Sediment occurring in milk has been noted since. Many milk treatments and procedures in processing have been tried in an attempt to eliminate this difficulty. In this study, the equipment (homogenizer, pipes, etc.) definitely was not the source of the contamination (sediment). One milk was processed immediately after another, and sediment might be noted in one sample and not in the other. If the equipment was the source of the sediment, samples treated alike would tend to be the same in this respect. The milk or the materials contained therein were then suspected as being the cause of the sediment.

Milk was homogenized both before and after pasteurization, and at various temperatures and pressures. Milk when pasteurized seemed to have slightly more sediment than did the raw milks. There was no apparent difference in the sediment when homogenizing pressures of 500 pounds or more were used at the various temperatures.

On three occasions, milk was divided into two lots. One lot was machine separated at 100 degrees Fahrenheit, and the other lot was allowed to cream by gravity and then hand skimmed. Both lots of skimmilk were homogenized, and no sediment occurred in the samples. A small amount of separator slime was added to the skimmilk, and then rehomogenized. Sediment occurred in these samples. This homogenized skimmilk containing sediment was mixed with both unhomogenized milk and cream, and homogenized-clarified milk and cream to a fat concentration of approximately 4 per cent. No sediment appeared in the mixed samples containing the unhomogenized milk and cream, but sediment did appear in the samples with the homogenized milk and cream.

From these results, it was evident that creaming of the milk tends to prevent sediment. The sediment material adheres to the large fat particles when these particles rise, and the sediment material is found in greater concentrations in the cream layer. See Figure 9, page 63.

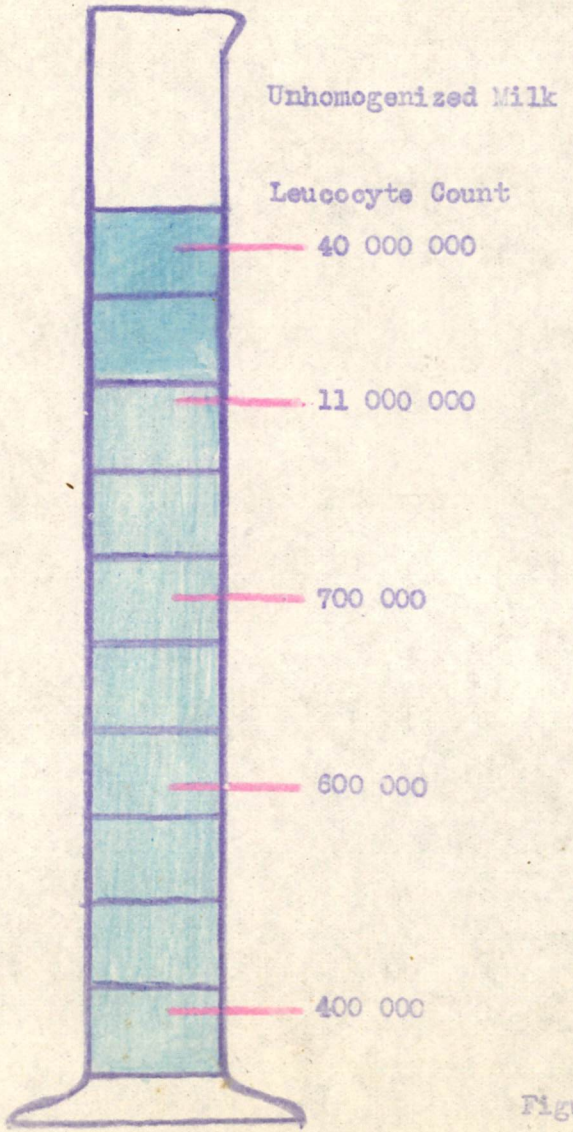
Samples of cream, obtained by centrifugal separation and by hand skimming, were homogenized; these samples showed a great amount of sediment, especially in the richer creams containing 40 per cent fat or more. It appears that the material responsible for the typical sediment found in milk or cream is either a part of the fat globule covering, or some other material which adheres to the fat particles.

A fine dust was added to one batch of milk. The milk was filtered and divided into five lots. The processing treatments and results are shown in Table XIII, page 64.

Filtering the milk removed some of the fine silt, as some of the silt was retained in the flannel filter. Clarifying removed still more of silt, as the clarifier slime was colored by this dark material. It is apparent that clarifying at a higher temperature is slightly more effective in preventing the sediment. Clarifying after homogenization was very effective in the removal of the sediment material from the milk. Apparently, the sediment material was held to the fat particles, and was liberated to a greater extent by breaking up the globules by homogenizing.

On several occasions, milk was selected from a few cows in the University herd producing milk with very high leucocyte counts, and from others producing milk practically free of leucocytes. Both milks were treated alike and homogenized. The milks with the high leucocyte counts always contained more sediment than did those with a very low leucocyte

Leucocyte and Tissue Cells In The Various Portions of Samples Of Milk



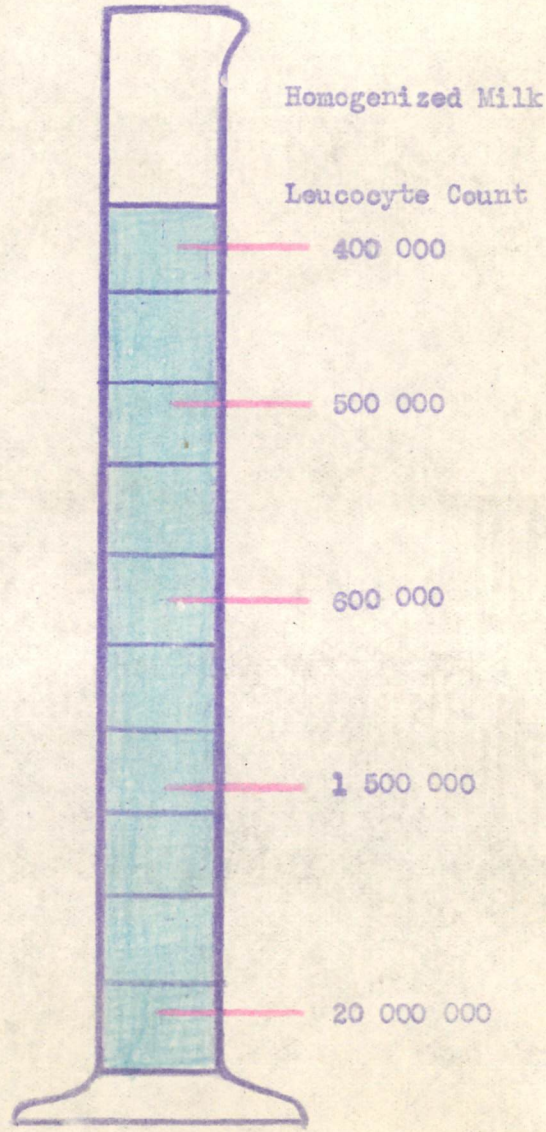


Figure (9)

TABLE XIII

EFFECT OF THE PROCESSING PROCEDURE UPON THE OCCURRENCE OF SEDIMENT IN HOMOGENIZED MILK

Milk	Processing Procedure	Sediment
Lot 1	Clarified at 100° F., then pasteurized at 143.5° F. for 30 minutes, and homogenized at 143.5° F.	++
Lot 2	Pasteurized at 143.5° F. for 30 minutes, then clarified at 143.5° F., and homogenized at 143.5° F.	+
Lot 3	Pasteurized at 143.5° F. for 30 minutes, then homogenized at 143.5° F., and clarified at 143.5° F.	-
Lot 4	Clarified at 100° F., homogenized at 143.5° F., and pasteurized at 143.5° F. for 30 minutes.	+++
Lot 5	Homogenized at 143.5° F., then clarified at 143.5° F., and pasteurized at 143.5° F. for 30 minutes.	-

Key: - No sediment ++ Moderate sediment

\+ Slight sediment +++ Much sediment

count. Once, bloody milk was homogenized, and the sediment of the unclarified sample was pink while the sample clarified before homogenization had only a trace of white sediment. When clarified after homogenizing, the sample did not show any sediment.

It was found that homogenized milks with a low pH generally had more sediment than milk with a higher pH.

Sediment found in homogenized milk was possibly due to particles in normal milk that are changed by pressure and precipitate, or are in milk as silt and cells that are liberated from the large buoyant fat particles.

Centrifugal clarification is effective in preventing sediment in homogenized milk when used at high temperatures and after the milk is homogenized.

Chemical Effects of Homogenization on Milk Flavor and Aroma

Rancid and oxidized flavors were noted in this study. However, since previous investigators[9][12][40][44][45][46] have studied this subject quite extensively, no work on this problem was attempted at this time.

Homogenized raw milk was found to have a rancid flavor which substantiates the works of Trout,[9][20] Dorner and Widner,[12] and Doan.[40] An oxidized flavor was not found in homogenized milk pasteurized at 158° F. and held for 25 minutes, while the same milk unhomogenized had a pronounced oxidized flavor. This brief study indicates that homogenization tends to prevent the development of oxidized flavor in milk pasteurized at a high temperature.

The effects of homogenization on the wild onion-flavored milk were studied. Wild onions were fed to two cows in the University herd and the milk collected from these cows had an onion flavor. This milk was divided into two lots and treated as follows:

Lot (1) was heated to 143.5° F. and homogenized at pressures of 500, 1000, and 2000 pounds per square inch. This homogenized milk was then heated to 165° F. for 15 minutes, and immediately cooled by immersing the bottles of milk in ice water. It was found that after homogenization the onion flavor was more pronounced. Higher pressures of homogenization made the flavor even more pronounced. Allyl-sulfide,[55] which is the potent aromatic onion-flavored material in the onion tops, is fat soluble and is readily absorbed by the butterfat. The dispersion of the fat by homogenization increases the surface of the fat globules containing the allyl-

sulfide. This causes a more pronounced onion flavor in the milk. By pasteurizing the homogenized milk at the high temperature, much of the onion flavor was removed.

Lot (2) was pasteurized at 165° F. for 15 minutes, then homogenized at 143.5° F., and cooled the same as Lot 1. The onion flavor of samples in Lot 2 was not as pronounced as in the original milk. However, the onion flavor of samples in Lot 2 was much more pronounced than in Lot 1. As has been stated, the milk in Lot 1 had only a slight onion flavor.

To determine whether or not strong onion-flavored milk could be rendered free of this objectionable flavor, this study was continued. In order to get a strong onion flavor, milk was contaminated with clean wild onions suspended in a can of milk for 12 hours. This strongly flavored milk was then heated to 143.5° F. and homogenized prior to pasteurization. The homogenized milk was heated to 160° F. and 170° F. for 15 minutes. The onion flavor in the milk heated to 170° F. was not as pronounced as that heated to 160° F. Both samples had a peculiar bitter taste and a slight onion flavor.

Granulated brimstone, a sulfur compound sometimes advertised to remove slight onion flavor in milk, was placed on the milk filter pads. Both the unhomogenized and homogenized samples with the onion flavor were allowed to flow through the granulated brimstone. The onion flavor in both cases seemed to be just as pronounced after contact with the brimstone as before.

Homogenization increases the intensity of the fat soluble flavor, allyl-sulfide, in the milk. Heat treatments of 160°F. or higher after homogenization reduce this onion flavor more than heat treatments prior to homogenization.

Acidity and pH

The acidity and pH of the milk were noted throughout most of the study. Homogenized raw milks showed an increase in titratable acidity, while no change in the titratable acidity was noted when the pasteurized milks were homogenized. This was in agreement with the work of Trout,[9] Dorner and Widner,[12] and Doan.[40]

It was found that raw milk of a pH of 6.2 or less before homogenizing did not show as marked decrease in the pH as milk having a pH of 6.2 to 6.8. Milk of a pH of 6.8 - 7.1 showed a decided decrease in pH when homogenized. See Table XIV, page 69. As shown in Table XV, page 70, a greater decrease in the pH was found when raw milk containing a higher percentage of fat was homogenized. This increase was possibly due to the greater number of fat globules having more surface exposed to the lipolytic enzyme.

In every case, when the titratable acidity was increased or the pH decreased due to homogenization of the raw milk, a rancid flavor was noticeable.

The causative enzyme for the development of rancidity was found to be present in raw skimmilk, even though the pH was not decreased or the acidity increased by homogenizing. Raw skimmilk was mixed with pasteurized homogenized milk (5.8 per cent fat), which had not developed an increase in titratable acidity or a decrease in pH immediately after homogenization. Soon after mixing the two, the titratable acidity had increased, while the pH decreased, and the mixed milk slowly developed a rancid flavor.

The heat treatment necessary to suppress the action of the lipolytic enzyme was found to correspond closely to that determined by Dorner and Widner[12], and Doan.[40]

TABLE XIV

EFFECT OF HOMOGENIZATION UPON THE CHANGES IN TITRATABLE ACIDITY AND pH OF MILK IMMEDIATELY AFTER HOMOGENIZING

Kind of Milk	Per Cent Acidity and pH of Milk (4 per cent fat)									
	Unhomogenized		Homogenized (pounds per square inch)							
			0		1,000		2,000		3,000	
	pH	acidity	pH	acidity	pH	acidity	pH	acidity	pH	acidity
Raw	6.12	.22%	6.10	.22%	6.10	.23%	6.05	.23%	6.02	.23%
	6.32	.24	6.30	.25	6.28	.24	6.28	.25	6.28	.26
	6.45	.18	6.44	—	6.48	—	6.40	—	6.43	—
	6.64	.14	6.61	—	6.61	—	6.62	—	6.61	—
	6.84	.15	6.80	.15	—	—	6.78	.17	6.74	.17
	7.08	.11	6.92	.12	6.86	.14	6.82	.15	6.75	.15
Pasteurized	6.14	.22	6.15	.21	6.14	.22	6.18	.24	6.15	.22
	6.31	.24	6.30	—	6.30	—	6.30	—	[illegible]	—
	6.45*	.18	6.45	.18	6.48	.18	6.46	.19	6.47	.18
	6.64	.14	6.62	.14	6.63	.14	6.62	.14	6.63	.14
	6.84	.15	6.82	.15	6.84	.15	6.90	.14	6.84	.15
	7.05	.11	7.0	—	7.05	—	7.04	—	7.02	—

* Due to an experimental error the pH of the raw milk was given.

TABLE XV

EFFECT UPON THE pH AND TITRATABLE ACIDITY WHEN RAW MILK, STANDARDIZED TO VARIOUS FAT PERCENTAGES, WAS HOMOGENIZED (AVERAGE OF 3 TRIALS)

Raw Milk Fat Per Cent	Per Cent Acidity and pH							
	Pressures of Homogenization (Lbs. per sq. in.)							
	0		1,000		2,000		3,000	
	pH	Acidity	pH	Acidity	pH	Acidity	pH	Acidity
0	6.47	.16%	6.47	.16%	6.46	.16%	6.45	.16%
2.1	6.46	.16	6.44	.17	6.44	.17	6.44	.17
4.15	6.46	.16	6.44	.17	6.40	.18	6.40	.18
5.8	6.48	.17	6.44	.18	6.43	.18	6.44	.18
8.65	6.47	.16	6.41	.18	6.40	---	6.41	---

Bacteriological Effects of Homogenization on Milk

Bacteria Counts

The routine experimental procedures used in studying the effects of homogenization on the milk were not suitable for a bacteriological study of this problem. Irregular and varying results were obtained as a result of using small amounts of milk in large commercial equipment. A local commercial milk plant cooperated in a study on the bacterial counts of the homogenized milk.

The regular milk was homogenized both before and after pasteurization. Direct microscopic bacteria counts made on the milk before homogenizing and after homogenizing indicate that the process of homogenizing increases the count. It was found by making a count of every cell, whether in individual or in groups, that there was practically no difference between the counts of milk unhomogenized and homogenized. See Table XVI, page 72.

The study indicated that the clean, sanitary-type homogenizer was not a source of much bacterial contamination, but broke up the groups of cells into individual cells so that by the standard methods developed by Breed and Brew,[56] a higher count occurred.

An active culture of Streptococcus lactis, testing 0.94 per cent acidity (calculated as lactic acid), and having long chains of bacterial cells, was added to highly pasteurized skimmilk with 0.18 per cent acidity for the production of commercial buttermilk. This mixed skimmilk, testing 0.20 per cent acid, and containing 5 per cent culture, was divided into three lots and maintained at the same incubation temperatures.

TABLE XVI

EFFECTS OF HOMOGENIZATION OF MILK UPON THE BACTERIA COUNTS

Milk	Standard Direct Microscopic Bacteria Count	
	Unhomogenized	Homogenized
	Cells per c.c.	Cells per c.c.
Raw	570,000	1,140,000
Pasteurized	680,000	950,000
Cultured Buttermilk	22,000,000	150,000,000
	Direct Microscopic Count of Each Cell	
	Unhomogenized	Homogenized
	Cells per c.c.	Cells per c.c.
Raw	1,040,000	1,200,000
Pasteurized	1,300,000	1,260,000
Cultured Buttermilk	125,000,000	175,000,000

Lot (1) was homogenized at 2,000 pounds per square inch. This sample coagulated and developed an acidity of 0.80 per cent acid in 7½ hours.

Lot (2) was homogenized at 2,000 pounds per square inch, five hours after the culture had been added. Eight and three-quarters hours of incubation were required for the acidity to reach 0.80 per cent.

Lot (3) was allowed to incubate naturally, and the acidity did not reach 0.80 per cent until 16 hours.

No difference in the flavor of the three lots of cultured buttermilk was noticed. Samples of Lot 3 were slightly less viscous than were the samples in the other lots. The decrease in the length of time required for the acid development of the homogenized lots was attributed to the breaking up of the chains of cells into many individual cells and to a slight increase in temperature. Homogenizing the products at 2,000 pounds per square inch was found to cause an increase in temperature of 7.4° F. This increase in temperature was due to compression by the homogenizer.

Apparently, by microscopic examination of the milk, each individual cell was the source of a chain of cells, thus accounting for the faster acid development in these lots of milk.

Feeding Qualities of Hard and Soft Curd Milks

Comparative Feeding Values

The comparative feeding values of homogenized, normal hard-curd, and normal soft-curd milks were determined by feeding trials with albino rats. The feeding values were measured by noting the growth and food consumption of growing rats.

Two separate feeding trials were used in this experiment. The procedure in one trial consisted of feeding three groups of rats, each group receiving only one type of milk for a 28-day period. A rotational procedure was used in the second trial. The groups of rats were fed the three types of milk. Group I was fed only one type of milk for the first 7-day period. Another type of milk was fed to this group the second 7-day period, and the third type of milk was fed during the third 7-day period. The fourth 7-day period, the group was fed the same type of milk that it received during the first 7-day period. One group was being fed one type of milk while the other groups were being fed the other types of milk.

These two separate feeding procedures were run at the same time. While a particular type of milk was fed to a group of rats in one procedure, it was also being fed to a group in the other procedure.

Normal, hard-curd, and soft-curd milks were selected from cows in the University herd that produced milk corresponding to the type desired. A weekly survey was made on the milk of the cows in order to select the desired type of milk. The milk was selected from healthy cows that were non-reactors to the tuberculin and abortion tests. The milk of at least two or more cows was obtained once each week.

The milk selected for homogenizing was the mixed pasteurized milk obtained from the University Creamery. This milk was standardized to approximately 4 per cent fat and homogenized at a pressure of 3,000 pounds per square inch.

The total solids and fat percentages of the three types of milk varied considerably. As it was impossible to standardize the three selected types of milk for all the constituents without changing their physical properties, only the fat was standardized.

The three types of milk were kept in storage at 40° F. and fed during the following week. The total solids, fat percentage, and curd tension of each type of milk fed are shown in Tables XVII, XVIII, and XIX.

All of the animals were young, healthy rats approximately 35 days of age at the beginning of the experiment. The groups were evenly divided as to numbers, and consisted of both male and female rats. The initial weight of each group of rats was approximately the same. Groups in procedure I consisted of 10 rats, while those in procedure II were composed of 9 rats each.

The rats were quartered in cages made of galvanized netting with raised bottoms to prevent the animals from having access to the feces. The cages of rats were kept in a light room, free from drafts, at 80° - 85° Fahrenheit.

The rats were weighed at the beginning of the feeding trials and at the end of each 7-day period. The milk was fed in shallow glazed porcelain dishes holding 250 ml. The milk was fed ad-libitum, and was before the rats at all times. The amount of milk consumed was recorded on each cage. Small amounts of milk were placed as frequently in the shallow

dishes as the rats would clean-up the milk. This was done to prevent the rats from getting only the cream portion and to prevent the milk from souring.

Three days before the feeding experiment began, the rats were taken off the stock diet, and given commercial pasteurized milk. They had free access to water. However, they soon refused the water probably due to the high percentage of water in the milk. To prevent any possible change in the physical curd properties of the milk by dilution with water, drinking water was not provided during the experimental period.

Feeding Experiment - 28-day Period. Data of the growth, consumption of milk, curd tension, and total solids of the milk for each group of rats fed one type of milk for 28 days are shown in Table XVII, page 77.

As shown in Table XVII and in Figure 10 by the ratio of the gain in weight per 100 ml. of milk consumed, rats fed hard-curd milk made the most gain per 100 ml. of milk consumed, while rats fed homogenized milk made the least gain for the amount consumed. These data indicate that normal hard-curd milk was more efficient in producing a gain in weight in growing rats. It is interesting to note that rats in Group I, fed homogenized milk, consumed the most milk, and made the smallest gains in weight. When the normal soft-curd milk was fed to Group II, the greatest gain in growth was made. The rats consumed more normal soft-curd milk than the other types of milk. However, it may be noted that the per cent total solids of the normal soft-curd milk was less than the other types of milk fed. Such a fact should be considered when analyzing the data. The rats in each group seemed to be very healthy and active throughout the experimental period.

TABLE XVII

COMPARISON BETWEEN GROWTH AND MILK CONSUMPTION OF GROUPS OF RATS, EACH GROUP FED A DIFFERENT TYPE OF MILK FOR 28 DAYS

7-Day Period	Weight of Animal Grams	Gain in Weight Grams	Consumption of Milk ml.	Ratio: Grams gain per 100 ml. of milk consumed	Milk Curd Tension Grams	Milk Total Solids %
GROUP I. Average of 10 Animals Fed Homogenized Milk						
	*59.6					
1st	71.6	12.0	215	5.59	7	13.04
2nd	94.1	22.5	297	7.56	5	13.61
3rd	105.9	11.8	262	4.50	18	13.40
4th	125.0	19.1	281	6.80	24	13.20
Total		65.4	1055	6.19 Ave.		
GROUP II. Average of 10 Animals Fed Soft-curd Milk						
	*54.0					
1st	77.2	23.2	200.2	11.58	26	12.94
2nd	101.3	24.1	283.4	8.47	28	12.60
3rd	118.1	16.8	324.2	5.18	33	13.21
4th	133.6	15.5	308.8	5.01	28	12.40
Total		78.6	1116.6	7.13 Ave.		
GROUP III. Average of 10 Animals Fed Hard-Curd Milk						
	*53.1					
1st	75.8	22.7	183.1	12.40	78	13.80
2nd	99.8	24.0	218.3	10.99	112	13.51
3rd	114.5	14.7	287.8	5.11	130	13.60
4th	122.3	7.8	245.9	3.17	158	13.54
Total		69.2	935.1	7.41 Ave.		

*Average Initial Weight of Rats at Beginning Feeding Trials.

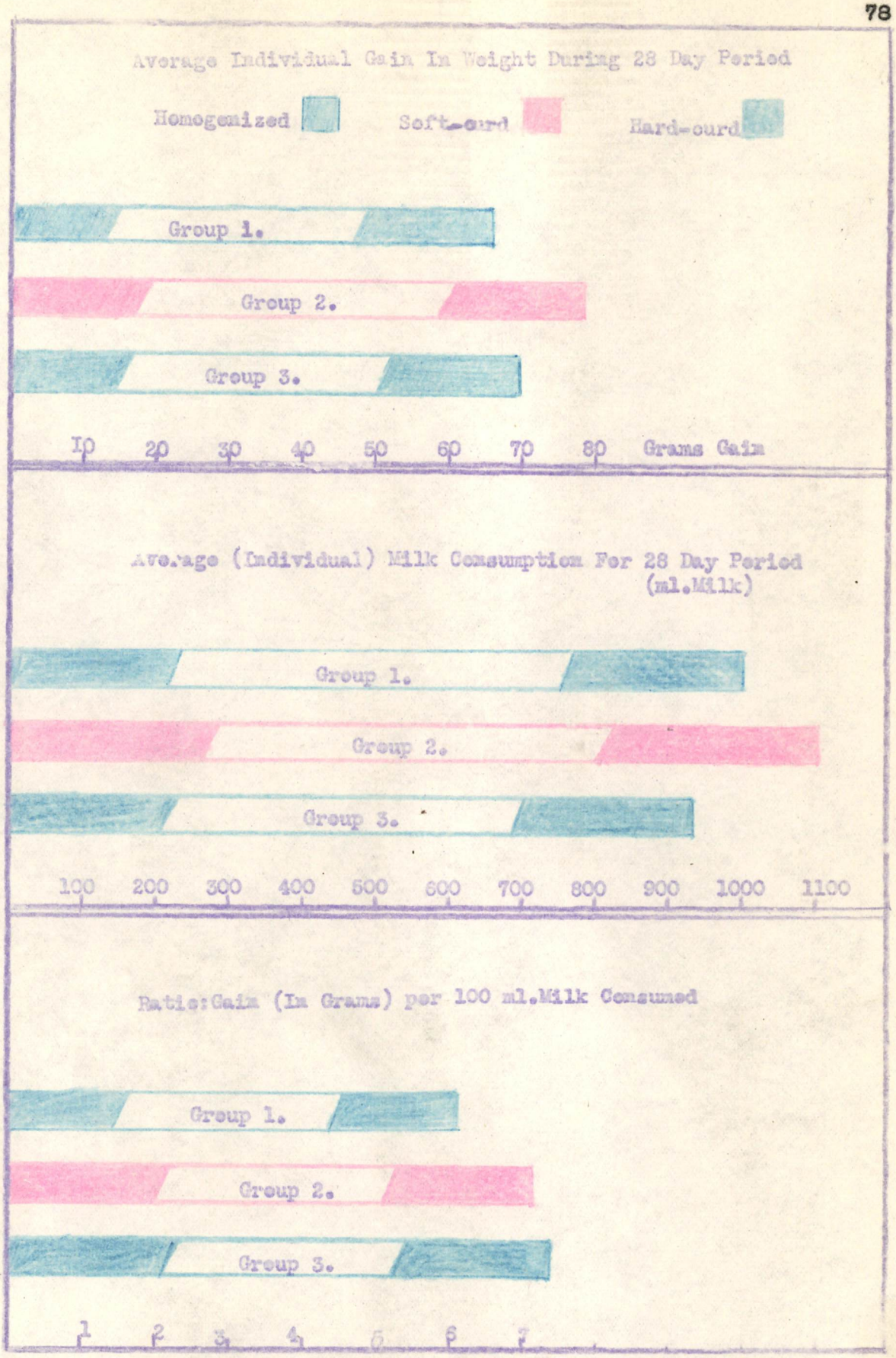


Figure (10.) Comparison Of Each Group Of Animals Fed One Type Of Milk For 28 Days

Rotational Feeding Experiment, Four 7-Day Periods. The growth and milk consumption data of rats fed three types of milk are presented in Table XVIII. No outstanding differences in the gain or total milk consumption were noted between groups IV, V, and VI.

By classifying all of the rotating groups fed a particular type of milk for the 7-day feeding periods, it was possible to determine the gain in weight, milk consumption, and gain in weight per 100 ml. of each type of milk consumed. Table XIX and Figure 11 show that the greatest gain in weight was made on the hard-curd milk, while the normal soft-curd milk produced the smallest gain. More homogenized milk was consumed than either the normal hard-curd or normal soft-curd milks. Normal hard-curd milk produced a gain of 8.39 grams per 100 ml. of milk consumed, while the homogenized milk produced a gain of 6.86 grams per 100 ml. of milk fed. Normal soft-curd milk produced only 5.88 grams gain in weight per 100 ml. of milk consumed.

By comparing the data on the two experimental procedures, it is interesting to note the similarity of the results obtained. Greater gains per 100 ml. of milk consumed were obtained from the feeding of normal hard-curd milk. However, the rats consumed less hard-curd milk than either of the other two types. The rats consumed large amounts of homogenized and normal soft-curd milks. In one experimental procedure, slightly more normal soft-curd milk was consumed; while in the other procedure, more homogenized milk was consumed.

In practically every case(Tables XVII, XVIII, XIX) regardless of the type of milk fed, or the group of rats, there was a decided decrease in the amount of gain in weight per 100 ml. of milk consumed as the experiment

progressed. The animals were approaching maturity, thus accounting for the inefficiency of the milk in producing large gains in growth.

The per cent total solids of the normal milks was apparently the main factor for the greater gains on the normal hard-curd milk than on the normal soft-curd milk. However, it is possible that the per cent total solids is not the only factor, because the per cent total solids of the homogenized milk approached that of the normal hard-curd milk while a marked difference in the gains in weight was noted. This would imply that the physical condition of the milk affects its efficiency in producing a gain in weight.

TABLE XVIII

RESULTS OF FEEDING THREE GROUPS OF RATS THREE DIFFERENT TYPES OF MILK IN ROTATION

7-Day Period	Weight of Animal Grams	Gain in Weight Grams	Consumption of Milk ml.	Ratio: Grams gain per 100 ml. of milk consumed	Milk Curd Tension Grams	Milk Total Solids %
GROUP IV. Average of 9 Animals in Group						
	*59					
1st Homogenized	79.2	20.2	251	8.0	7	13.04
2nd Soft-curd	100.4	21.2	300	7.0	28	12.60
3rd Hard-curd	116.6	16.2	248	6.56	130	13.60
4th Homogenized	** 136.7	20.1	320	6.28	24	13.20
Total		77.7	1119	6.94 Ave.		
GROUP V. Average of 9 Animals in Group						
	*57.5					
1st Soft-curd	77.2	19.7	200	9.82	26	12.94
2nd Hard-curd	100.4	23.2	237	9.78	112	13.51
3rd Homogenized	115.5	15.2	299	5.08	18	13.40
4th Soft-curd	125.2	9.6	278	3.44	28	12.40
Total		67.7	1014	6.66 Ave.		
GROUP VI. Average of 9 Animals in Group						
	*66.0					
1st Hard-curd	84.8	18.8	190	9.75	78	13.80
2nd Homogenized	111.1	26.3	321	8.31	5	13.61
3rd Soft-curd	124.2	13.1	307	4.26	33	13.21
4th Hard-curd	149.0	24.8	314	7.87	158	13.54
Total		83.0	1133	7.33 Ave.		

*Average Initial Weight of Rats, Beginning of Feeding Trials.

**Average for 8 Animals, One Animal Being Killed at Beginning of Period.

TABLE XIX

COMPARISON BETWEEN THREE TYPES OF MILK WHEN FED TO THREE ROTATING GROUPS OF ANIMALS

7-Day Period	Group	Gain in Weight Grams	Consumption of Milk ml.	Ratio: Grams gain per 100 ml. of milk consumed	Milk Curd Tension Grams	Milk Total Solids %
GROUPS IV, V, and VI Fed Homogenized Milk During the Various 7-day Periods						
1st	IV	20.2	251	8.0	7	13.04
2nd	VI	26.3	321	8.31	5	13.61
3rd	V	15.2	299	5.08	18	13.40
4th	IV	20.1	320	6.28	24	13.20
Total		81.8	1191	6.86 Ave.		
GROUPS IV, V, and VI Fed Soft-curd Milk During the Various 7-day Periods						
1st	V	19.7	200	9.82	26	12.94
2nd	IV	21.2	300	7.00	28	12.60
3rd	VI	13.1	307	4.26	33	13.21
4th	V	9.6	278	3.44	28	12.40
Total		63.6	1085	5.88 Ave.		
GROUPS IV, V, and Vi Fed Hard-curd Milk During the Various 7-day Periods						
1st	VI	18.8	190	9.75	78	13.80
2nd	V	23.2	237	9.78	112	13.51
3rd	IV	16.2	248	6.56	130	13.60
4th	VI	24.8	314	7.87	158	13.54
Total		83.0	989	8.39 Ave.		

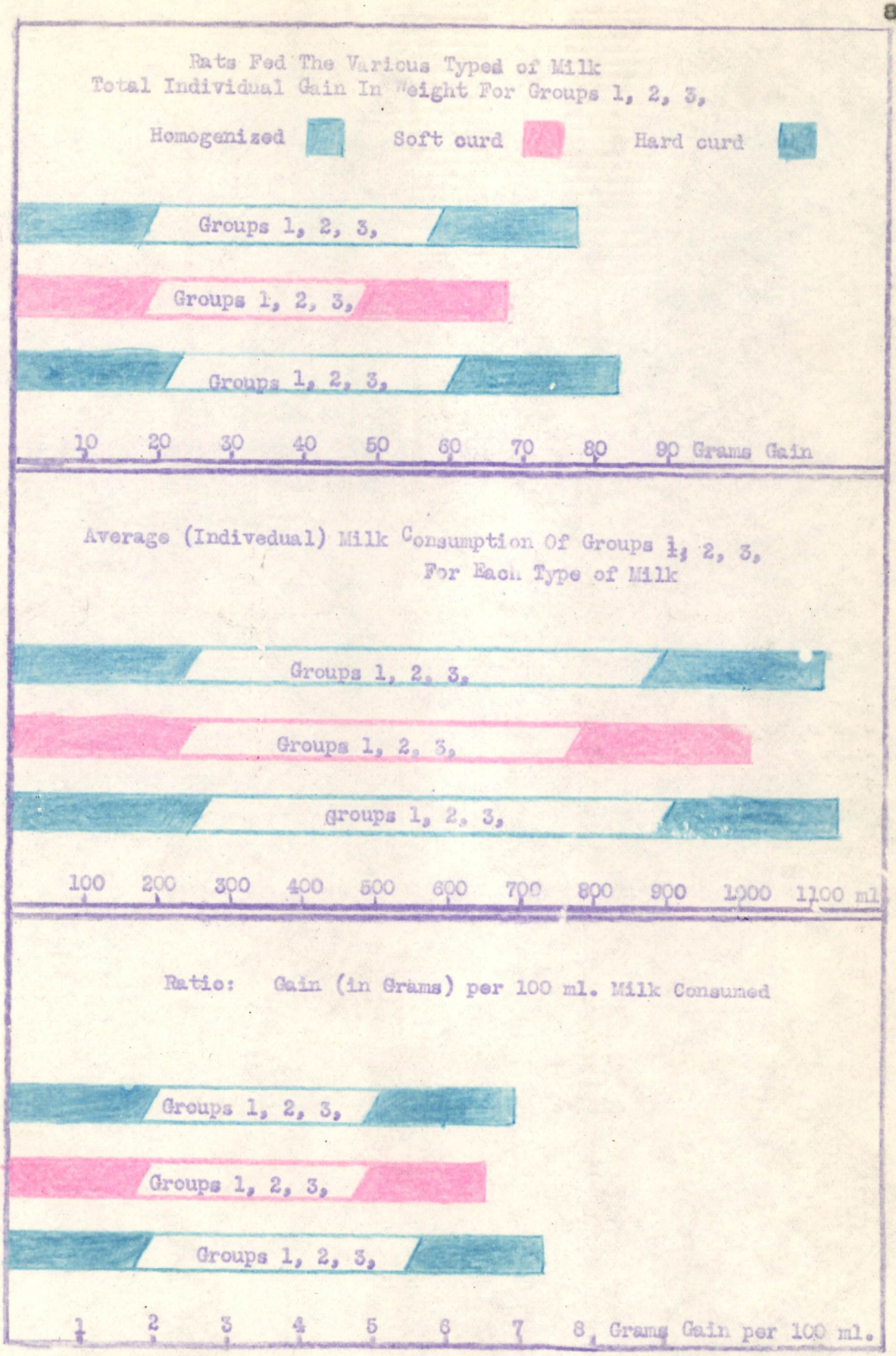


Figure (11) Comparison Between Three Types Of Milk When Fed To Three Rotating Groups Of Animals

Comparison of the Apparent Digestibility of the Three Types of Milk

The digestibility of the types of milk fed was not determined from a nutritional standpoint. The nutritive qualities of the various constituents in milk fed to rats have been determined by Nevens and Shaw.[57] The digestibility of milk was found to be affected by the size of the curd particles.[1][49] However, the data regarding the digestibility of normal hard-curd milk made soft-curd by homogenization are limited.

Rats fed the three types of milk in the feeding trials were used in observing the apparent digestibility of the milks. It was noted early in the experiment that the feces of rats fed the normal hard-curd milk were compact and quite solid in consistency. Feces of rats fed the homogenized milk were copious, soft, and voluminous. Many times the feces were so soft in consistency that it was difficult to differentiate between individual feces. When normal soft-curd milk was fed, the feces appeared more solid in consistency than the feces of rats fed homogenized milk. However, the rats fed normal soft-curd milks appeared to excrete more urine than rats fed either of the other types of milk.

An experiment to compare the time required for rats to digest the various milks was attempted. Immediately following the feeding trials, the animals were not fed for 12 hours. Each group of animals was again fed the same type of milk fed during the last 7-day period of the feeding trial.

The milks contained a harmless dye which did not alter the palatability or physical curd tension properties of the milk. The dyes, carmine, colloidal-carbon, and methylene blue were selected because they would appear in the feces of the rats.

TABLE XX

COMPARISON OF THE TIME REQUIRED FOR THE THREE TYPES OF MILK TO PASS THROUGH THE DIGESTIVE TRACT OF RATS (AVERAGE OF 3 TRIALS)

Type of Milk Fed To Groups of Rats	Time After Feeding Milk With Dye to Rats	
	First Appearance of Dye in Feces	Last Appearance of Dye Occurring in Feces
	Hours	Hours
Homogenized	10.75	28
Normal Soft-curd	13.0	41
Normal Hard-curd	17.5	62

The animals were allowed to consume the milk with the dye for only one-half hour. After four hours the animals were fed milk without the dye.

The length of time that the animals were given the dyed milk until the first appearances of the colored feces was recorded. The time required for the occurrence of feces not containing the dye material was also recorded.

As shown in Table XX above, the homogenized milk passed through the digestive tract 1.25 times as fast as did the normal soft-curd milk, and 1.6 times as fast as did the normal hard-curd milk. The normal hard-curd milk remained in the digestive tract 2.2 times as long as the homogenized milk, and 1.5 times as long as the normal soft-curd milk. By these data, it is apparent that soft-curd milks pass through the digestive tract faster than milks having a harder curd.

Each group of rats was given access to their particular type of milk for thirty-minute periods spaced four hours apart. After the animals had been fed the milks dyed black, red, and blue in rotation for three days,

they were chloroformed, and the entire digestive tract removed. The digestive tracts were washed and mounted, as shown in Figures 12, 13, 14, and 15. A physical curd condition of the material in the tracts was noted.

As shown in Figure 12, the digestive tracts of rats fed homogenized milk contained only the milk fed within the previous twelve hours. The material in these tracts was quite soft, and no definite division between milk of one color and that of another color was observed.

Figure 13 is a drawing of the average digestive tract of rats fed normal soft-curd milk. The drawing shows that milk fed at four 4-hour intervals was still in the system. In many tracts it was difficult to determine just how far the milk of one color had passed and where another had progressed, as there was a considerable mixing of the soft-curds in the stomach and remained as such until they reached the latter part of the small intestine.

A drawing of a digestive tract of a rat fed normal hard-curd milk is shown in Figure 14. Hard-curd milk produced such a compact curd that there was little or no mixing of the coagulated and liquid milk in the stomach. The progress of the colored materials in the tracts was easily noted. In the small intestine the progress of normal hard-curd milk fed at six different intervals was noted in the average tract. The curds were very small and tough. A curd-like material was noted in the caecum. The feces found in the large intestine were solid and distinct.

In all digestive tracts observed, the material in the caecum was quite soft, and it was difficult to note any differences in color.

Illustration Of The Digestive Tract Of A Rat Fed

Homogenized Milk

(Average Of 31 Tracts)

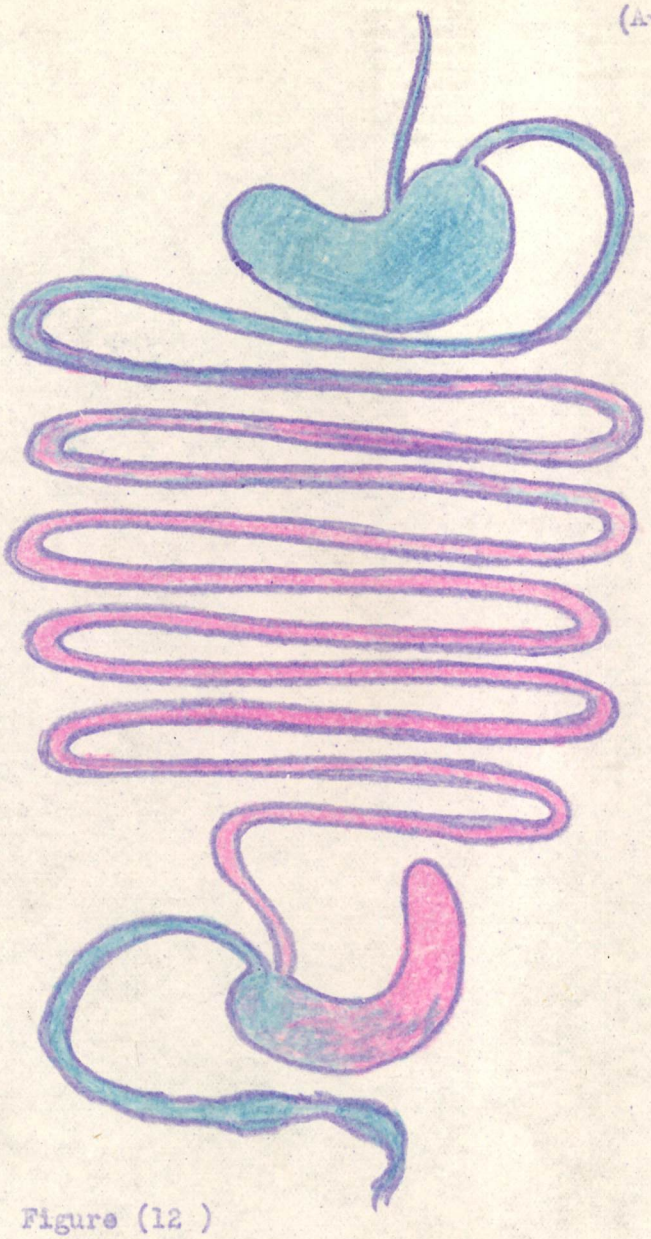


Figure (12)

Every 4 Hours The Rats Were Fed Homogenized Milk Containing A Different Colored Dye.

The Distance Traveled And The Condition Of The Material Within The Digestive Tract May Be Noted.

Soft curd Milk Fed At 3 Feeding Intervals Are Shown

Illustration Of The Digestive Tract Of A Rat Fed

Soft Curd Milk

(Average of 24 Tracts)

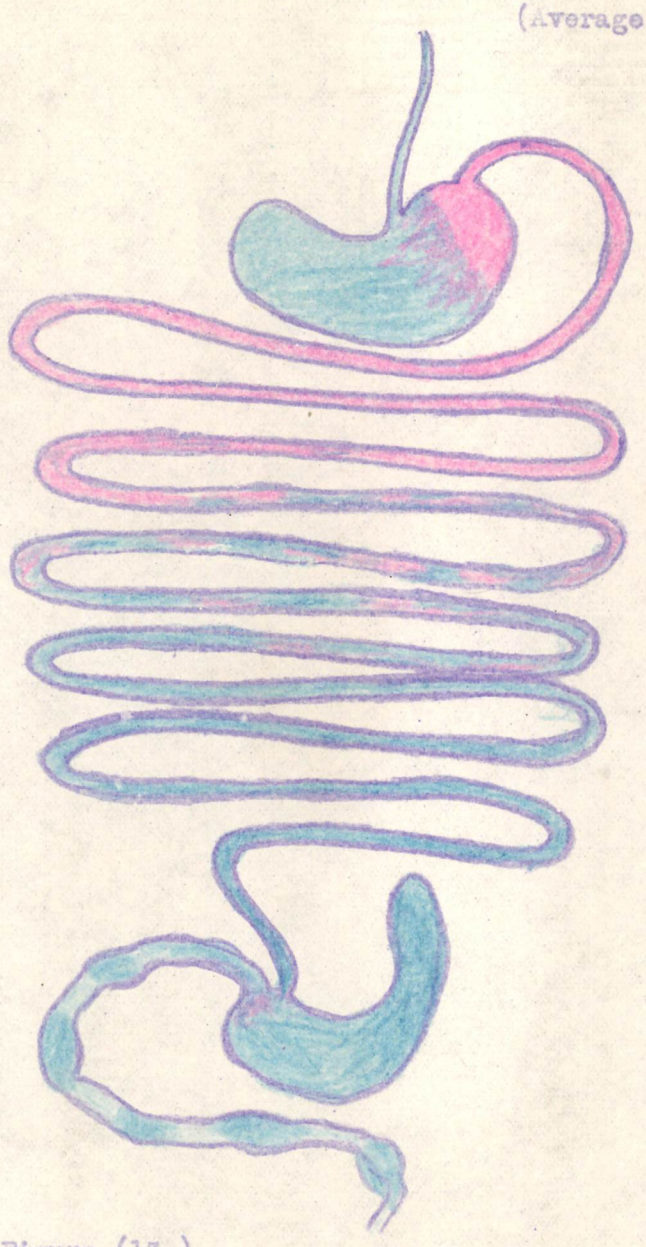


Figure (13)

Every 4 Hours The Rats Were Fed Soft curd Milk Containing A Different Colored Dye.

The Distance Traveled And The Condition Of The Material Within The Digestive Tract MayBe Noted

Soft curd Milk Fed At 4 Feeding Intervals Are Shown

Illustration Of The Digestive Tract Of A Rat Fed

Hard Curd Milk

(Average of 27 Tracts)

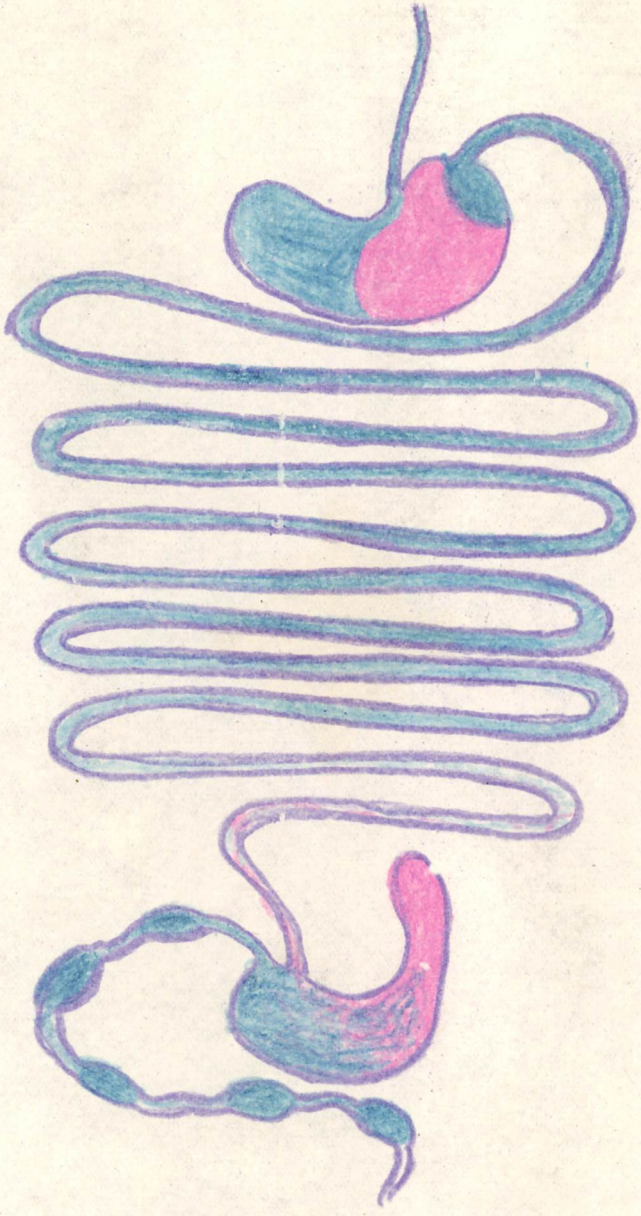
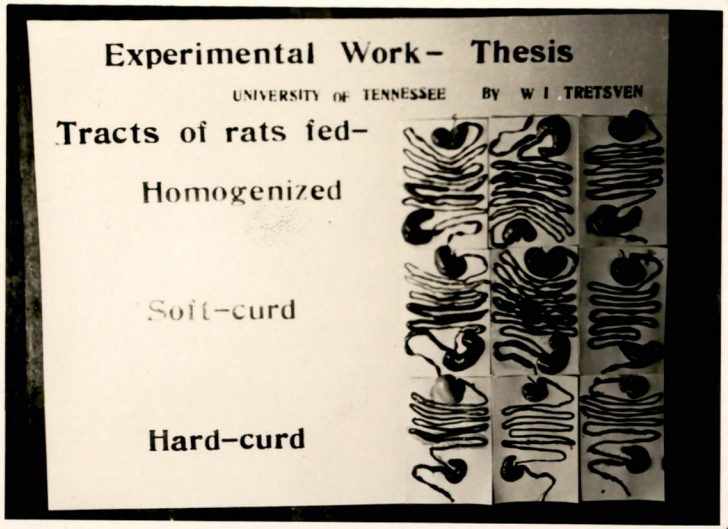
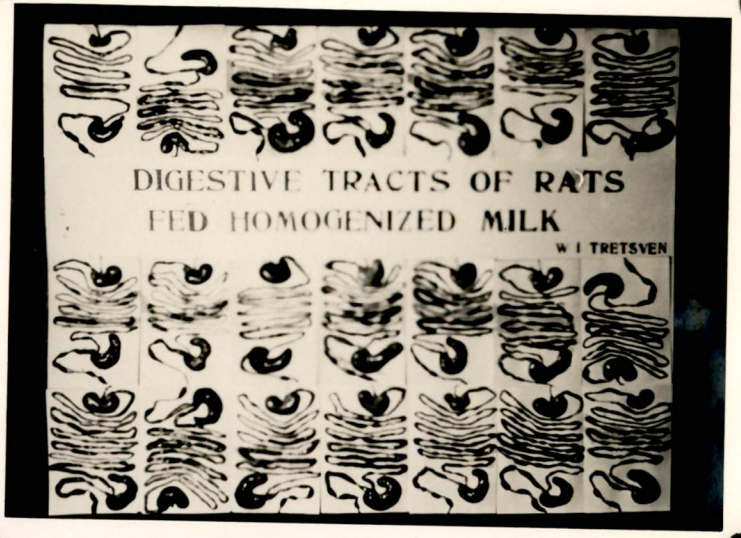


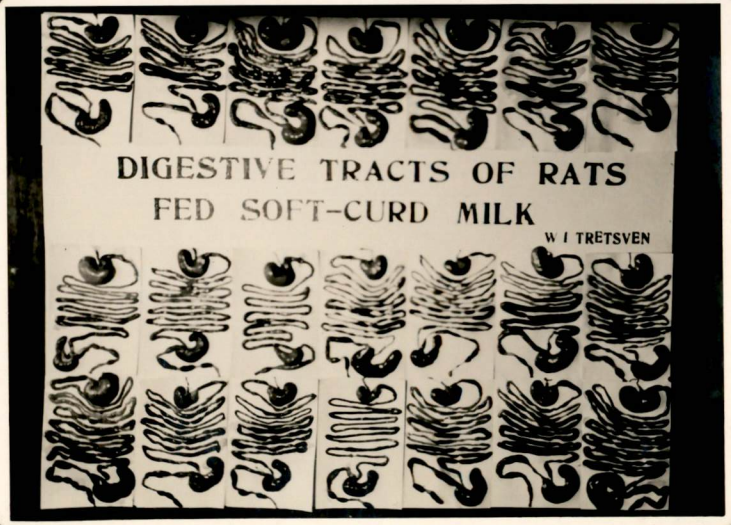
Figure (14)

Every 4 hours The Rats Were Fed Hard curd Milk Containing A Different Colored Dye.

The Distance Traveled And The Condition Of The Material Within The Digestive Tract May Be Noted. Hard curd Milk Fed At 6 Feeding Intervals May Be Noted.


Experimental Work- Thesis
UNIVERSITY OF TENNESSEE BY W I TRETSVEN
Tracts of rats fed-
Homogenized
Soft-curd
Hard-curd


DIGESTIVE TRACTS OF RATS
FED HOMOGENIZED MILK
W I TRETSVEN


DIGESTIVE TRACTS OF RATS
FED SOFT-CURD MILK
W I TRETSVEN

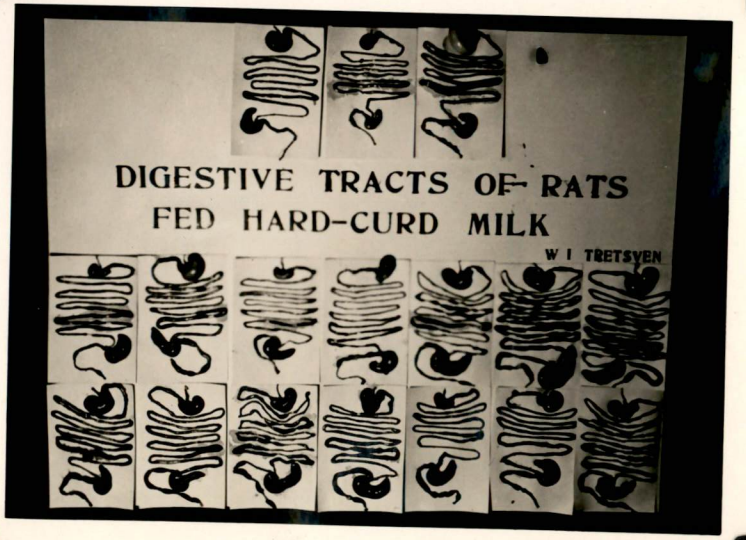

DIGESTIVE TRACTS OF RATS
FED HARD-CURD MILK
W I TRETSVEN

Figure 15

CONCLUSIONS

1. The greater the homogenizing pressure the smaller is the average fat globule size.
2. Temperatures of homogenization have little effect on the average fat globule size.
3. Homogenization tends to lower the Babcock fat test of milk. No apparent changes in the Mojonnier fat tests of homogenized milk were found.
4. The specific gravity of milk was not affected by homogenization.
5. Milks of a higher curd tension showed a greater per cent reduction in the curd tension by homogenization.
6. The per cent reduction in curd tension of milk homogenized is influenced directly by the fat percentage of the milk. Milk having a higher fat percentage had a greater per cent reduction in the curd tension.
7. The viscosity of homogenized milk is affected by the fat percentage of the milk and the temperature of homogenization.
8. A pressure of 1,500 pounds per square inch or higher is advised to prevent the formation of a cream layer on milk.
9. Sediment in homogenized milk is probably due to extraneous materials such as cells and dirt, and to a precipitation of some milk constituents caused by homogenization.
10. Centrifugal clarification is quite effective in preventing occurrences of sediment in homogenized milk. Clarifying after homogenization is more effective in preventing occurrences of sediment than clarifying before homogenization.

CONCLUSIONS (Continued)

11. The process of homogenizing increases the intensity of the fat soluble flavor, allyl-sulfide, in the milk.

12. Raw milk of a pH of 6.2 or less did not show as marked decrease in the pH after homogenization as raw milk of a higher pH.

13. The causitive enzyme responsible for the development of rancidity in homogenized raw milk is present in homogenized raw skim milk.

14. Raw milk having a high percentage of fat showed more change in pH and titratable acidity than raw milk of a lower fat percentage after homogenization.

15. Homogenization increases the Bacteria Count of milk as the groups of bacteria are broken up into the individual cells by homogenizing.

16. In the feeding trials, rats consumed more homogenized milk than normal hard-curd or normal soft-curd milk. Rats fed normal hard-curd milk made a greater gain per 100 ml. of milk consumed than when fed either of the other types of milk.

17. Homogenized milk was found to pass through the digestive tract much faster than unhomogenized milk. Normal soft-curd milk passed through the digestive tract faster than normal hard-curd milk.

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