THE UTILIZATION OF CAVITATION FOR THE HOMOGENIZATION OF MILK PRODUCTS

By

CHING CHEE LOO

A THESIS

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

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AN ABSTRACT

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CHING CHEE LOO ABSTRACT

The phenomenon of cavitation, which is the rapid formation and collapse of cavities in a liquid, has been known to have a serious damaging effect in hydraulic equipment and it is also believed by many authors to be capable of producing emulsion. It was the aim of this work to examine critically the role of cavitation in homogenization of milk products and to determine the possibility of more effective utilization of cavitation in homogenization.

By inserting a steel cylinder between the first-stage and second-stage homogenizer blocks it was possible to obtain samples of milk which had not gone through the second-stage valve and yet would show the influence of the backing up of pressure by the second-stage valve on the homogenization efficiency of the first-stage valve. It was found that back pressures lower than atmospheric or higher than 500 psi reduced the homogenization efficiency.

Two bleeding valves, which resembled the regular homogenizer valve but had tiny bleeding holes at various locations were used to show pressure variation and the progress of homogenization inside the valve clearance. Results showed that a big dip in pressure to almost atmospheric occured near the inner edge of the valve and homogenization was practically completed right beyond this location. The dip in pressure was believed to be an indication of the occurence of cavitation.

CHING CHEE LOO ABSTRACT

A homogenizer valve with the valve seat narrowed down to a knife-edge homogenized both milk and concentrated milk satisfactorily at a pump pressure of 800 to 1000 psi and a back pressure of 50 to 150 psi. Ice cream mix was not satisfactorily homogenized at similar pressures unless air at a saturation pressure of 75 psi was introduced into the mix. The air was believed to help overcome the inhibitive effect on cavitation of sugar and gelatin which were present in large quantities in the ice cream mix. A Vickers swash-plate pump was used to give very smooth pressure for these experiments.

Several other knife-edged valves were tried in a high capacity triplex type homogenizer, but results were insufficient for a reliable evaluation of the knife-edged valve when used in that type of homogenizer.

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INTRODUCTION

Homogenization has been having a widening application in the milk industry since its invention half a century ago. During this half century most of the research work in homogenization has been centered around its physical and chemical effects on the quality of the product. Very little work has been done concerning the physical process of homogenization.

Several theories, without substantial experimental support, have been advanced to explain the mechanism of homogenization. Among them the more popular ones are shearing, grinding, exploding, and impinging. A new theory was proposed by Loo, Slatter, and Powell in 1949 (16). They obtained experimental evidence showing that homogenization of milk products was partially due to a physical phenomenon known as cavitation. Cavitation, the rapid formation and subsequent collapse of bubbles in a liquid, has been known for some time as the cause of certain kinds of damage in ship propellers and other hydraulic equipment. It also has been believed to have an important role in the production of emulsion by ultrasonic means.

The action of cavitation is very much the same as water hammer. The magnitude of its hammering force was estimated by Bottomley (5) at 120 tons per square inch. Therefore, cavitation may be likened to the action of numerous minute yet powerful immaginary hammers in the liquid. In view of the fact that homogenizers designed on the conventional theories spend a great portion of the power supplied in overcoming friction it appears worthwhile to investigate the possibility of easier homogenization by better utilization of cavitation.

REVIEW OF LITERATURE

Publications concerning homogenization of milk products have been plentiful. Perhaps the most voluminous and comprehensive bibliography ever published on homogenization is the one prepared by Trout (24). However, the amount of literature concerning the physical process of homogenization has been very small, and a great portion of it was only speculative.

A paper suggesting cavitation as a factor of homogenization was published by Loo, Slatter and Powell (16). Wenrich (27) in discussing the mechanism of homogenization postulated that there should be partial vacuum at the homogenizer valve. His postulation seems to be consistent with the cavitation theory of Loo, Slatter, and Powell, because under usual conditions a partial vacuum is a necessary condition of cavitation. A considerable amount of literature on cavitation as related to emulsion formation was reviewed by Loo (15). The usual concept of cavitation procedure is that, when the hydrostatic pressure drops to vapor pressure, there will appear in a liquid, vapor cavities which will collapse instantaneously when the vapor is forced to condense by rising hydrostatic pressure (14) (21) (26).

A theory quite different from the usual concept and which had been overlooked until lately is that formulated by Van Iterson (25) in 1936. He suggested that cavitation erosion was due to the collapse of minute air bubbles in water in a state of air supersaturation. A dynamical aspect of the problem was examined with the aid of a microscope. It was found that for water saturated with air at atmospheric pressure, the bubbles originated within the boundary layer at points where the absolute pressure was about half an atmosphere in the case of clean water: the bubble then had an initial diameter of 0.6 microns. The estimated life history of such a bubble was extremely short in terms of space and time. He concluded that surface tension might exert an appreciable influence on cavitation.

Van Iterson's theory was examined by Bottomley (5) both theoretically and experimentally and was found to be more acceptable than the conventional theory of vapor condensation as the cause of bubble collapse. Bottomley was able to arrive at, by means of thermodynamical calculations, two equilibrium states of air in water that may exist under the same set of conditions. One of the equilibrium states would be one in which there were no air bubbles and the air pressure in the liquid was that of air saturation pressure. The other equilibrium state would be one where there were a definite number of bubbles formed with a definite radius and the gas pressure was capillary pressure which was higher than saturation pressure. There could be no intermediate state and the system would jump from one state into another according to whether the pressure was tending to rise or fall. He showed that the energy which produced movement in the liquid during collapse was not derived from the hydrostatic pressure but was the surface energy released due to the reduction in the surface area of the bubble less the net energy required to compress the air into solution. Maximum velocity of collapse could be that of sound in water and the instantaneous pressure 120 tons per square inch.

Lord Rayleigh (19) derived mathematically an expression of the velocity of the collapse of a vapor cavity. He based his calculation on the assumption that the cavity was round and there was a complete vacuum in the cavity at the moment of its collapse. His expression for the radial velocity of the inrushing liquid was

$$U_R = \left\{\frac{2}{3}\,\frac{P}{\rho}\left[\left(\frac{R_o}{R}\right)^3 - 1\right]\right\}^{1/2} \text{ feet per second,}$$

where U_R is the radial velocity of the inrushing liquid, feet per second,

R_o is the initial radius of the cavity, feet,

R is the radius at the moment under consideration, feet,

P is the hydrostatic pressure, poundals per square foot, and

ρ is the density of the liquid, pounds per cubic foot.

Harvey (13) studied the relation among the hydrostatic pressure, amount of dissolved air, and the destructive effect on red blood cells by cavitation produced by ultrasonic vibration. He found that "there is a rather well defined pressure at which the time of laking (of the red blood cells) becomes practically infinite, even though there is still air dissolved which cavitates under the reduced pressure." He also found that laking was prevented by a greater amount of dissolved gases, but he was unable to explain the phenomenon. His experiments indicated that "for a given sound density it would appear that the tension of a gas in solution in relation to pressure was the most important factor in determining cavitation of a fluid and consequent destruction of cells suspended in it," and that "with a lower gas tension that corresponds to equilibrium with the gas phase, increasing the hydrostatic pressure will prevent cavitation and laking; the higher the gas tension, the more the hydrostatic pressure must be increased".

Rogowski and Sollner (20) found that the emulsions produced by ultrasonics are different according as a gas is present as a third phase or not and that emulsions containing gas are much easier to produce and much more stable than those which are gas free.

Similar results were obtained by Sata (22).

Bergmann (2), explaining his production of water benzol emulsion by ultrasonic irradiation gave the supposition that the process was due to "particles of water being flung by the ultrasonic wave into the overlying benzol".

Freundlich and Söllner (12) studied the liquefaction of thixotropic gels by ultrasonics. They attributed the liquefaction effect to "the formation of cavities and their collapse in the sound beam." They proved their belief by increasing the external pressure on the liquid, thereby preventing cavitation, and liquefaction no longer took place.

Bondy and Söllner (3) (4) studied the formation of non-metallic and metallic emulsions by means of quartz piezo ultrasonic equipment and found that cavitation was necessary in the production of non-metallic emulsions, whereas cavitation was of no importance in the production of metallic emulsions. They controlled the cavitation phenomenon by either applying high pressure to the system or experimenting in vacuo.

Pease and Blink (18) made the distinction between cavitation arising from pre-existing gas nuclei and that appearing in gas-free water. They called the former false cavitation and the latter true cavitation. The true cavitation was much more difficult to produce. They also found that substances having polar groups included in the molecule and also substantial non-polar chains in the molecule offered a large degree of "protection" from cavitation (gelatin, egg albumen, sodium stearate, sulfonated soap, l-leucine, glycerine, glycerol, n-butyl alcohol, etc..)

Burger and Söllner (6) studied the action of ultrasonic waves in suspensions and found that it could cause coagulation and orientation of the dispersed phase.

Harvey (13) also observed the flocculation of coal and other particles by ultrasonics. He explained, "the coal particles stick and are forced by radiation pressure into a clump."

GENERAL STATEMENT OF PROBLEM

The problem was to seek the conditions which would allow the most efficient homogenization in the light of cavitation effect and to design the necessary mechanical device that can be readily adapted to dairy plant operation.

The methods of producing cavitation may be divided into two groups, namely,

1. methods employing sonic or ultrasonic vibration, and
2. methods in which the shape of the flow passage is designed to cause a sufficient fluctuation in hydrostatic pressure.

On account of the facilities and of the time available the methods of the second group were preferred for the investigation.

Since the mechanism of cavitation was not exactly known the whole investigation was more or less of an exploratory nature. It was very hard to set up a definite schedule beforehand, because many unexpected factors and conditions would arise. However, the problem could be generally divided into three phases: a critical examination of the theory of cavitation as a factor of homogenization, the design of a device for producing cavitation in milk or other milk products, and a study of the homogenization characteristics of this device.

EXPERIMENTAL WORK

Part I Cavitation by Partial Vacuum

Purpose

From the analysis of the flow through a pressure homogenizer it could be seen that the pump pressure has two distinct hydraulical effects on the flow at the vena contracta at the homogenizer valve. One is a tendency to raise the pressure head there, the other is a tendency to raise the velocity head there. The reduction of the pressure at the vena contracta, which is the condition necessary for the occurence of cavitation, depends on the increase of velocity. Therefore, the two effects produced by the pump pressure are in reality opposing to each other so far as the production of cavitation is concerned. This is evident from the equation for the pressure at the vena contracta derived by Loo (15) for a Cherry-Burrell 125 viscolizer. That equation when written in word form is as follows:

(pressure at vena contracta) = (pump pressure) - (velocity head at vena contracts) x (density of the liquid)

Both of the two terms on the right hand side of the equation increase as the valve is being closed. To bring about a sufficient drop of pressure at the vena contracta the valve clearance has to be very small. This in turn backs up the pump pressure to a high value. Since a conventional homogenizer valve is built primarily to create shearing and impingement, the resistance to the flow of liquid is very great and a considerable portion of the energy put into the milk is consumed in overcoming the resistance. If cavitation is a factor which alone can produce homogenization, then such resistance does not appear necessary. If suction is used to draw the milk through the valve, then in the above equation the term of pump pressure will be replaced by atmospheric pressure plus the hydrostatic pressure due to the depth of the liquid. This new term is far smaller than the normal homogenization pressure. Therefore, the velocity necessary to bring down the pressure at vena contracta would become much smaller. However, the pressure which is acting on the collapsing cavities will be greatly reduced. According to the vapor condensation theory of cavitation this reduction in pressure would seem unfavorable to the strength of collapse of a bubble. But according to the theory of Van Iterson the reduction in pressure in a supersaturated air bubble does not seem to affect the amount of surface energy released and the force of collapse, unless the trigger action of releasing the surface energy is governed by the magnitude as well as the variation of the pressure.

Method

A special homogenizer valve of curved cross-section (see Appendix I for its design and Appendix II for its capacity regulation) was connected to the suction side of a pump.

Milk was sucked through it at different degrees of vacuum. Samples of milk were collected and tested according to the definition of homogenized milk set by the United States Public Health Service (U.S.P.H.S.). A diagram showing the set-up is presented in Figure 1.

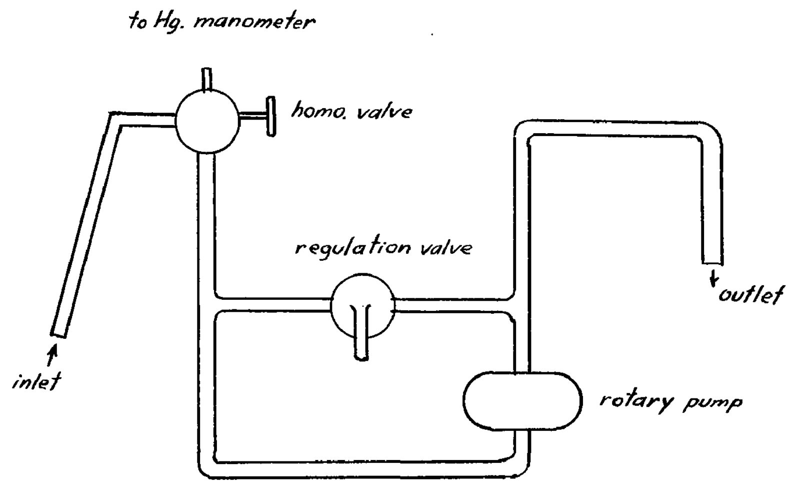


Fig. 1 Diagram showing the experimental set-up for sucking milk through a special valve of curved cross-section.

Procedure

The milk used was regular pasteurized milk from the Michigan State College Creamery. The fat test was 3.1%. The milk was placed into the supply tank of the set-up after it was warmed up to 160°F. The pump was started and the homogenizer valve was adjusted to give various degree of vacuum. The milk was collected for later determination of U.S.P.H.S. index of homogenization.

Results

Very little homogenizing effect was obtained by the afore described method and procedure as is obvious from the experimental data presented in Table I.

TABLE I

THE DEGREE OF HOMOGENIZATION OF MILK
(EXPRESSED IN U.S.P.H.S. INDEX) TREATED BY
SUCTION THROUGH A SPECIAL VALVE OF CURVED CROSS-SECTION

Sample	Temp. °F.	Vacuum In. Hg.	Fat test after 48 hours. top	bottom	U.S.P.H.S. index
			Rotary pump		
1	160	17	12.4	2.85	77
2	160	18	14.8	2.55	82.8
		Manton-Gaulin Homo. Pump			
3	130	20-1/2	11.2	2.6	76.8
4	160	12	10.0	2.8	72.0
5	160	16-1/2	9.8	2.65	73
6	160	14	10.8	2.85	73.5
7	160	19-1/2	10.4	2.6	75.0
8	160	10	10.6	2.7	74.5

Discussion

The vapor pressure of milk at 160°F. is approximately 5 psi (pounds per square inch). This means that if the suction is below 5 psi the vapor bubbles will not collapse. In this trial practically all the vacuums used were above 10 inches mercury (or less than 5 psi). Foaming due to air leakage at the pump shaft was another handicap. The milk was bipassed back into the supply tank before a steady vacuum was obtained and the milk became heavily laden with air bubbles which would interfere with cavitation procedure.

The failure to obtain homogenization effect by sucking the milk through a constriction was not sufficient to rule out the possibility of producing homogenizing cavitation by suction. However, the investigation in this direction was given up at this point, because it might require an unpredictable amount of fundamental research into the mechanism of cavitation which would be in the province of physics rather than agricultural engineering.

Part II Influence of Exit Side Hydrostatic Pressure on Homogenization Efficiency

Purpose

Since the collapse of a bubble is a pressure effect no matter which of the cavitation theories is correct a study of the relation between the hydrostatic pressure of the exit side of a conventional homogenizer valve and the efficiency of homogenization should be a valuable means of ascertaining further whether cavitation is a responsible factor of homogenization. However, it must be understood that the pressure of the exit side of a homogenizer valve is not the same as the pressure around the collapsing bubbles. The latter cannot be measured very easily in a conventional homogenizer valve.

Methods and Procedures

1. Discharging milk into a vacuum from a homogenizer

A set-up as shown diagrammatically in Figure 2 was used. To start, a vacuum was first created by running the vacuum pump with valves V4 and V1 closed and V2 and V3 opened. When a desired vacuum was reached V4 was opened and the homogenizer started immediately. The homogenizer pressure was adjusted to the desired magnitude as quickly as possible. Since V1 is closed, milk came into trap A only. When stable conditions were obtained V1 was opened and V2 and V3 closed. The milk then came into collector A. When collector A became filled the rubber hose between V4 and V1 was pulled away from V1 and inserted into collector B. So the milk in collector A was homogenized with vacuum on the exit side and the milk in collector B was homogenized with atmospheric pressure on the exit side, all other conditions being the same for both. Both samples were tested for the degree of homogenization by the U.S.P.H.S. method.

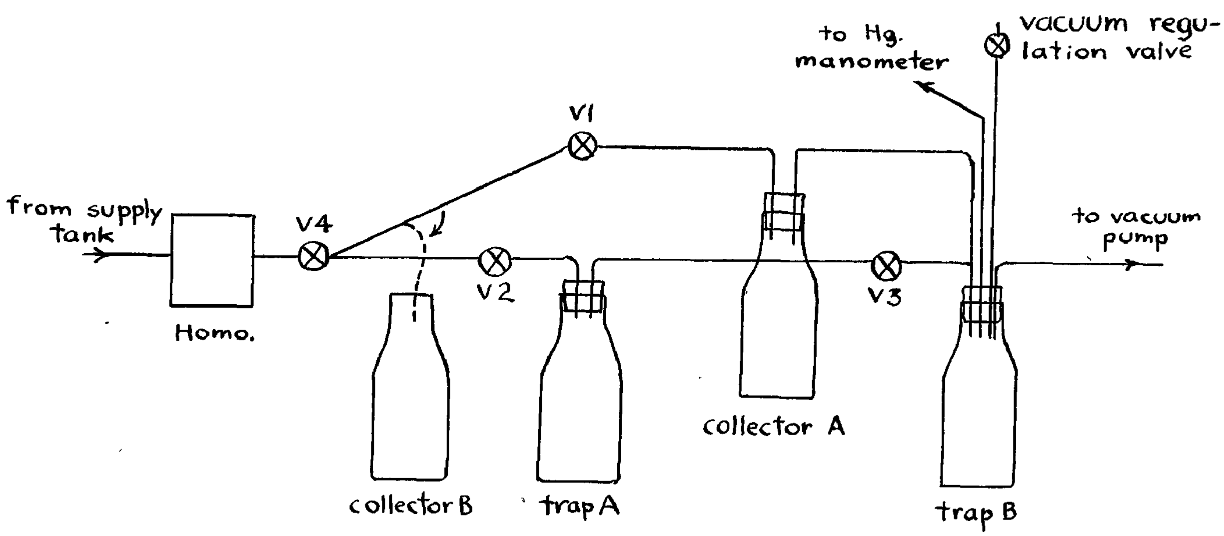
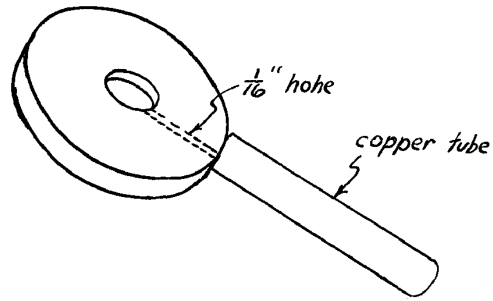


Fig. 2 Arrangement for applying vacuum to the exit side of homogenizer valve and for collecting milk samples.

2. Discharging milk into a pressure chamber

The space between the first- and the second-stage valves of a two-stage single-piston homogenizer was used as a pressure chamber in the first trials. The second-stage valve was used to back up the pressure at various levels on the exit side of the first-stage valve. A sampling disc of the construction shown in Figure 3 was inserted between the first-stage and the second-stage blocks. It was hoped that milk samples so bled from the disc would show only the homogenization effect

Fig. 3 Disc inserted between the first-stage valve block and the second-stage valve block for taking milk samples between the two valves.

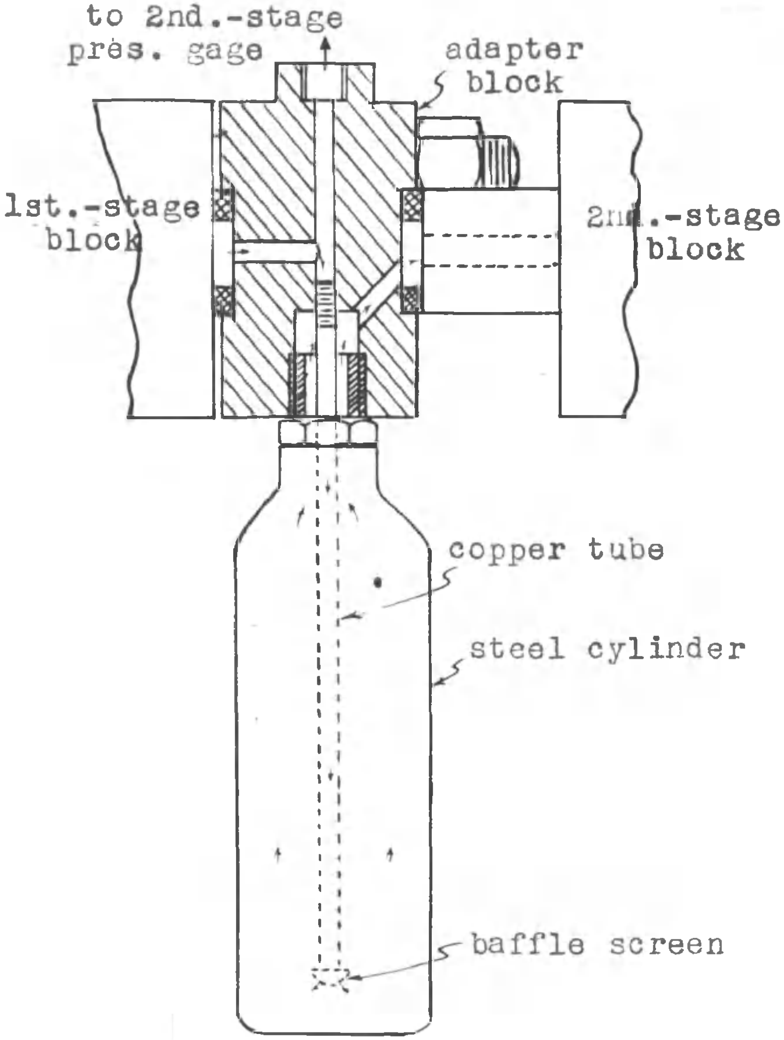


of the first-stage valve as influenced by the backing-up of pressure by the second-stage valve. However, it was found that the little bleeding hole on the disc had appreciable homogenizing effect.

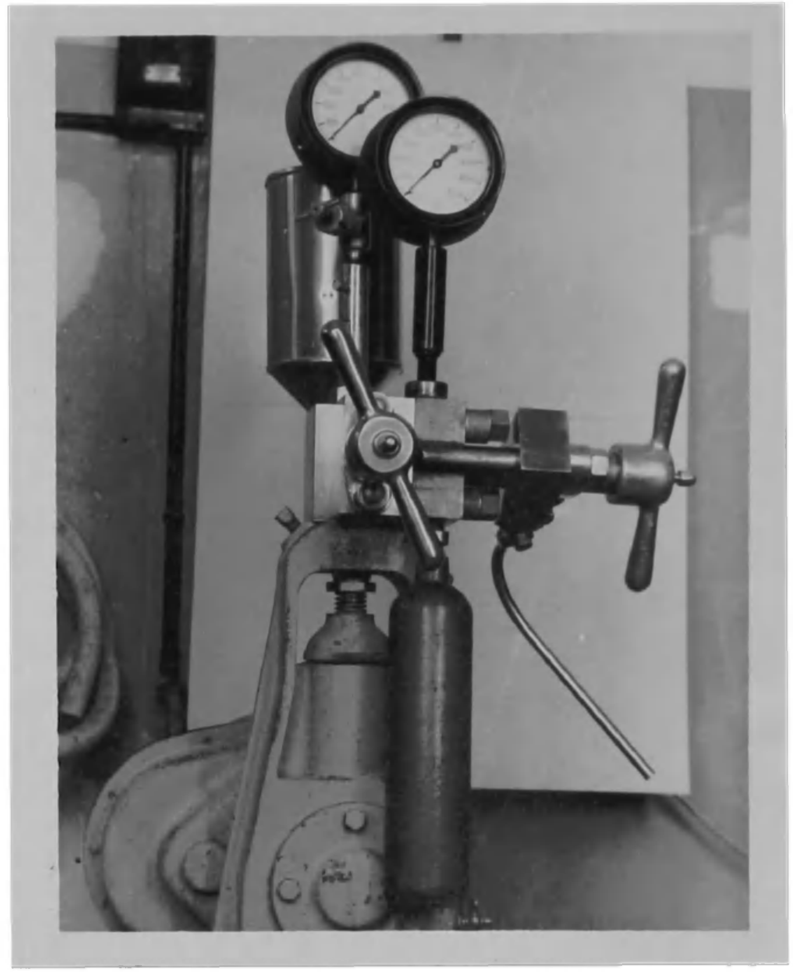
Another set-up as shown in Figure 4 was designed to provide a pressure chamber sufficiently large to catch a quart of milk sample. A medical oxygen cylinder was inserted between the first- and the second-stage blocks. Pressure in the cylinder was regulated by means of the second-stage valve. Referring to Figure 4 the tube conveying milk into the cylinder extended to the bottom of the cylinder so as to assure a continuous displacement of the content. A screen baffle was mounted at the opening of the tube so as to reduce turbulence. It was determined that representative samples could be obtained by such an arrangement after at least two quarts of milk were passed through the homogenizer after steady conditions were obtained. (See Appendix V) The particular single-piston homogenizer showed a peculiar behavior with regards to its pressure regulation. In the preliminary runs the first and the second-stage pressures were adjusted in the following conventional manner: With the first-stage valve open the second-stage valve was adjusted until the pump pressure gage indicated the desired second-stage pressure, then the first-stage valve was turned in until the pump pressure gage showed the sum of the desired first- and second-stage pressures. However, it was noticed that the pump pressure gage did not fall to the desired first-stage pressure when the second-stage valve was released, being considerably higher. A second pressure gage was added in between the two valves so that the second-stage pressure could be measured independently and that the real pressure difference across the first-stage valve could be determined. The peculiar behavior became more obvious after the second pressure gage was added. (See Appendix VI.)

This peculiarity might be an indication that there was some form of energy loss at the first-stage valve dependent on the second-stage pressure or that the first-stage valve opening was affected to some extent by the second-stage pressure. So two methods of manipulation of the first-stage valve were tried for the purpose of leaving cavitation as the only variable at the first-stage valve.

The first method was to assume that the size of the valve opening could be kept constant by using constant pressure difference across the valve. The second method was to assume that the size of the valve opening could be kept constant by using the same valve hand-wheel position. Under the first method the valves were adjusted to give constant pressure



(a)



(b)

Figure 4 Inserting a steel cylinder between the first-stage and the second-stage of a homogenizer. (a) Adapter block cross-sectioned. (b) Homogenizer with the steel cylinder inserted in position.

difference across the first-stage valve for several different second-stage pressures (chamber pressures). Under the second method the first-stage valve was regulated first and let set at that position for all the various second-stage pressures (chamber pressures).

To obtain milk samples the homogenizer was stopped after three quarts of milk had passed through it under stable conditions and without releasing either of the valves. The milk left in the steel cylinder was supposed to show only the effects of the first-stage valve as influenced by the backing up of the pressure by the second-stage valve. It was then emptied into a quart bottle to be tested for U.S.P.H.S. homogenization index. With the first-stage valve remaining in the same position and the steel cylinder removed the homogenizer was started again. Milk now discharged from the first-stage valve into free atmosphere and was collected into another quart bottle to be tested for U.S.P.H.S. homogenization index. This index served as the control.

Three levels of chamber pressure were used, namely, 500 psi, 1000 psi, and 1500 psi. The corresponding pump pressures under the first method of first-stage valve manipulation (constant pressure difference) were 3000 psi, 3500 psi, and 4000 psi. Under the second method (constant valve handwheel position) the corresponding pump pressures were 2650 psi, 2750 psi, and 2900 psi.

Results

1. Discharging milk into a vacuum from a homogenizer

The results presented in Table II show that in all the nineteen comparisons the homogenization efficiency was lowered by applying vacuum to the discharge side of a homogenizer. Practically all the control samples were up to the U.S.P.H.S. requirements for homogenized milk while eleven out of the nineteen collected in vacuum had indices above the U.S.P.H.S. upper limit of 10.

TABLE II

DEGREE OF HOMOGENIZATION (EXPRESSED AS U.S.P.H.S. INDEX) AS INFLUENCED BY APPLYING VACUUM TO THE EXIT SIDE OF A HOMOGENIZER VALVE

Homogenizer: Manton-Gaulin Lab. Model CGB (single piston, 25 gal./hr.)
Homogenization Pressure: 2500 psi
Homogenization Temperature: 160°F.

With breaker ring			Breaker ring removed		
Vacuum "Hg.	U.S.P.H.S.index of milk discharged into vacuum	U.S.P.H.S.index of control sample (no vacuum)	Vacuum "Hg.	U.S.P.H.S.index of milk discharged into vacuum	U.S.P.H.S.index of control sample (no vacuum)
24	16.7	5.4	25	10.0	5.16
22	8.75	2.63	24	16.7	7.7
20	12.2	2.7	22	7.7	5.16
18	5.1	2.63	22	14.7	7.7
14	7.5	2.63	20	7.7	5.16
10	14.8	10.3	20	11.3	7.7
5	12.5	10.3	18	3.9	5.16
			18	10.9	5.62
			17	12.8	5.62
			14	11.75	5.62
			10	8.7	5.62
			5	7.9	6.6

2. Discharging milk into a pressure chamber from a homogenizer

(a) Constant pressure difference across homogenizer valve

TABLE III

DEGREE OF HOMOGENIZATION OF MILK (EXPRESSED AS U.S.P.H.S. INDEX) AS INFLUENCED BY APPLYING PRESSURE TO THE EXIT SIDE OF THE HOMOGENIZER VALVE

The pressure difference across the homogenizer valve was kept constant (Temperature of milk 140 to 145 F.)

Homo. pump press.		2500 psi	3000 psi	3500 psi	4000 psi
Chamber press.		0 (control)	500 psi	1000 psi	1500 psi
Homo. pump press. on the release of chamber press.		2500 psi	2850 psi	3200 psi	3600 psi
U.S.P.H.S. indices	Run 1	8.75	15.3	14.8	14.6
	Run 2	8.4	12.9	12.3	10.9
	Run 3	7.6	13.8	13.1	11.6
	Mean	8.25	14.0	13.4	9.28

Statistical analysis of the results (See Appendix VII for the mathematical procedure):

Least significant difference between treatment means at 1% level = 5.98

Least significant difference between treatment means at 5% level = 3.94

(b) Constant valve handwheel position

TABLE IV

DEGREE OF HOMOGENIZATION OF MILK (EXPRESSED AS U.S.P.H.S. INDEX) AS INFLUENCED BY APPLYING PRESSURE TO THE EXIT SIDE OF THE HOMOGENIZER VALVE

The homogenizer valve was kept at a constant setting which gave a homogenization pressure of 2500 psi on the release of exit side pressure

Pump press. psi		2500	2650	2750	2900
Second-stage press. psi		0	500	1000	1500
U.S.P.H.S. indices	Run 1	14.4	16.4	20.0	20.4
	Run 2	6.7	9.63	13.2	17.0
	Run 3	12.3	14.5	15.9	24.4
	Run 4	8.65	12.2	14.1	23.0
	Mean	10.51	13.13	15.80	21.18

Statistical analysis of the result (See Appendix VII for the mathematical procedure):

Least significant difference between means at 1% level = 4.27

Least significant difference between means at 5% level = 2.97

Least significant difference between means at 10% level = 2.41

Discussion

It is very obvious from the experimental results that applying either vacuum or pressure to the exit side of a homogenizer valve will cause some definite influence on the homogenization efficiency. In the case of the particular magnitudes of vacuum and pressure used the homogenization efficiency was lowered. This seems to be consistent with Freundlich and Söllner's experiments (12) in which they prevented ultrasonic cavitational liquefaction of thixotropic gels by increasing the hydrostatic pressure.

The results not only serve as an evidence of cavitation being a factor of homogenization but also point to a possible optimum collapse pressure of the cavities for smashing the fat globules in milk.

Part III "Bleeding Valve" Experiments

Purpose

The purpose of using a "bleeding valve", the description of which will be presented later, was to examine further the role of cavitation in homogenization by investigating the pressure distribution in the valve clearance and also the variation of the degree of homogenization of the milk as it travels through the valve.

Apparatus

A Manton-Gaulin 125 gallons-per-hour triplex two-stage homogenizer was procured for this experiment. The valves were ground to give good fit and all gaskets and packings were replaced by new ones.

The "bleeding valve" was a valve duplicating the original first-stage valve but with a number of small holes drilled at various radial positions for taking milk samples or measuring the pressures at such locations. Its exact details and method of installation are shown in Figures 5 and 6. Plastic tubings, capable of standing vacuum or mild pressure, were connected to the holes for taking samples and measuring pressures. Two such valves were used. One had eight holes located at equal radial intervals between the inner and outer edges of the valve. The other one had four holes drilled at the following locations:

1. tangential to the inner edge of the valve,
2. two thirds of the hole diameter (about 0.01 inches) from the inner edge,

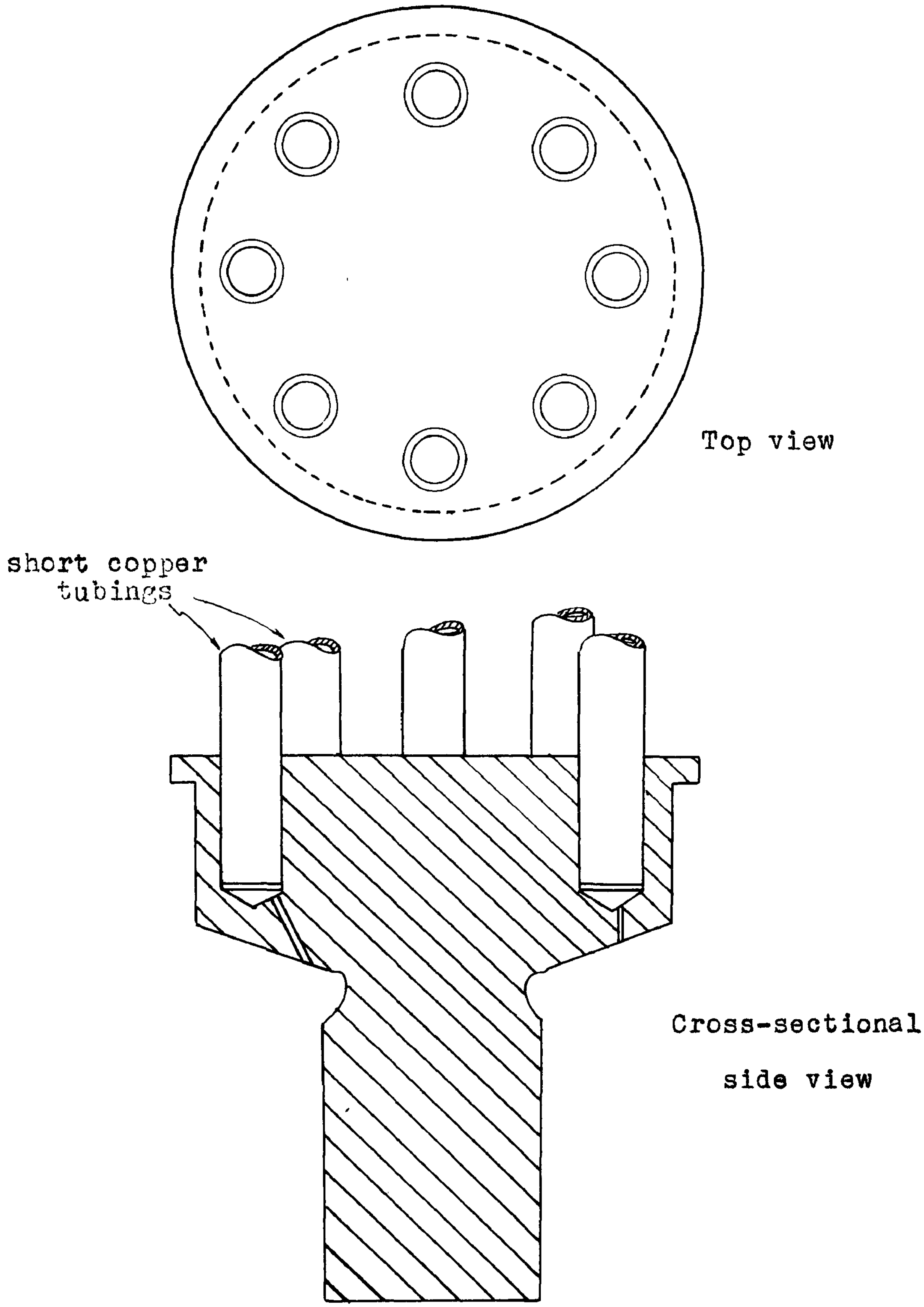


Figure 5 Enlarged views of the "bleeding valve".

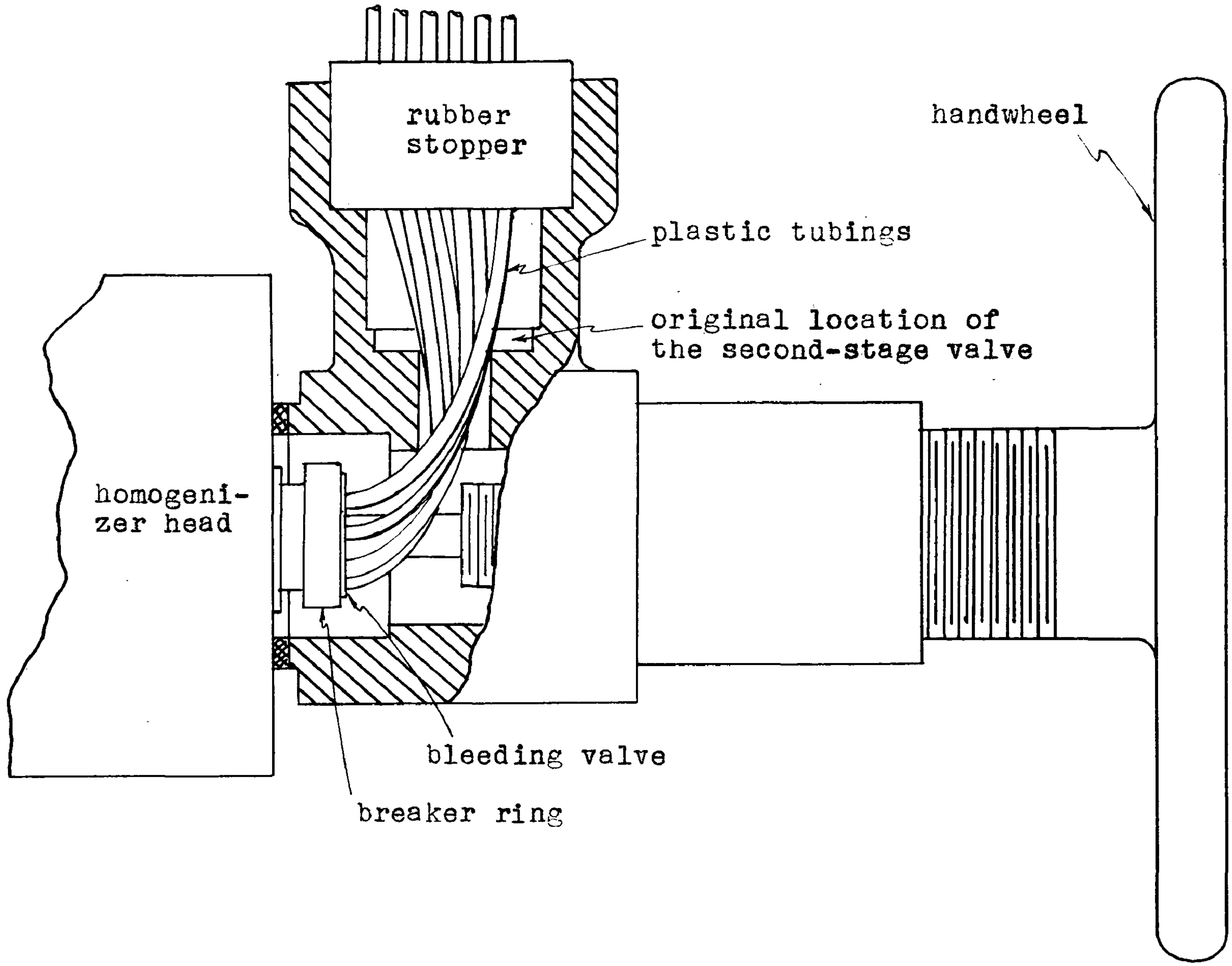


Figure 6 Cut-away view of the valve block of a Manton-Gaulin homogenizer showing the bleeding valve in position.

3. five sixths of the hole diameter from the inner edge, and
4. one diameter of the hole from the inner edge.

Procedure

(a) Measuring the pressure at the holes of the bleeding valve: It would have been very desirable if the absolute values of the pressures at the holes could have been measured. Because of the alignment of the valves strong tubings that could stand pressure could not be used to connect the holes to a pressure measuring device. On the other hand plastic tubings had good flexibility but could not stand pressure. Hence, it was decided to measure the pressures by measuring the heights of the water columns ejecting from the ends of the plastic tubings when water was being pumped through the valve.

(b) Determining the variation of the degree of homogenization of milk as it travels through the valve: Five gallons of milk were warmed up to 140 F. and pumped through the homogenizer at 2500 psi. Milk coming out from the plastic tubings was collected in test tubes when a reasonable time had elapsed after the homogenizer pressure became steady. Because of the small size of the samples obtained, only microscopic examinations of them were done to judge their degree of homogenization. The microscopic method employed was that devised by Farrall, Walt, and Hansen (11). Two slides were made from each sample and four readings (five fields for each reading) were taken from each slide. The results were then analyzed statistically.

Results

(a) Measurement of pressures at the holes of the bleeding valve.

There was a sharp reduction in the height of the water jet at about 0.015 inches to 0.03 inches from the inner edge of the bleeding valve. It then rose to a new height at about 0.045 inches from the inner edge and then tapered off to almost no water issuing at the outermost hole.

The results shown in Table V are plotted in Figure 7.

(b) Results of microscopic examination of milk samples taken from the bleeding holes of the bleeding valves.

Statistical analysis of the results showed that the milk samples from the three innermost holes were highly different from the milk sample taken at the homogenizer outlet. Milk samples from the other eleven holes were insignificantly different from the milk sample taken at the homogenizer outlet.

TABLE V

HEIGHTS OF WATER JETS ISSUING
FROM THE PLASTIC TUBINGS OF THE
BLEEDING VALVES IN INCHES OR FEET AS INDICATED

Distance from inner edge of valve, 1/100 in.		4-hole valve				8-hole valve							
		0.8	1.0	1.3	1.6	2.2	4.5	6.7	8.9	11.2	13.4	15.7	17.9
Homo. pump press., psi	500	5"	2"	1"	¼"	0.5"	3/4"	¼"	+	+	+	+	+
	1000	1'	8"	3"	1"	3/4"	1½"	½"	¼"	¼"	¼"	+	+
	1500	1½'	8"	4"	1½"	1"	2-3/4"	½"	¼"	¼"	¼"	¼"	+
	2000	2'	1½'	8"	2"	2"	3½"	½"	¼"	¼"	¼"	¼"	+
	2500	3-4'	3-4'	3"	3"	4"	5"	½"	¼"	¼"	¼"	¼"	+

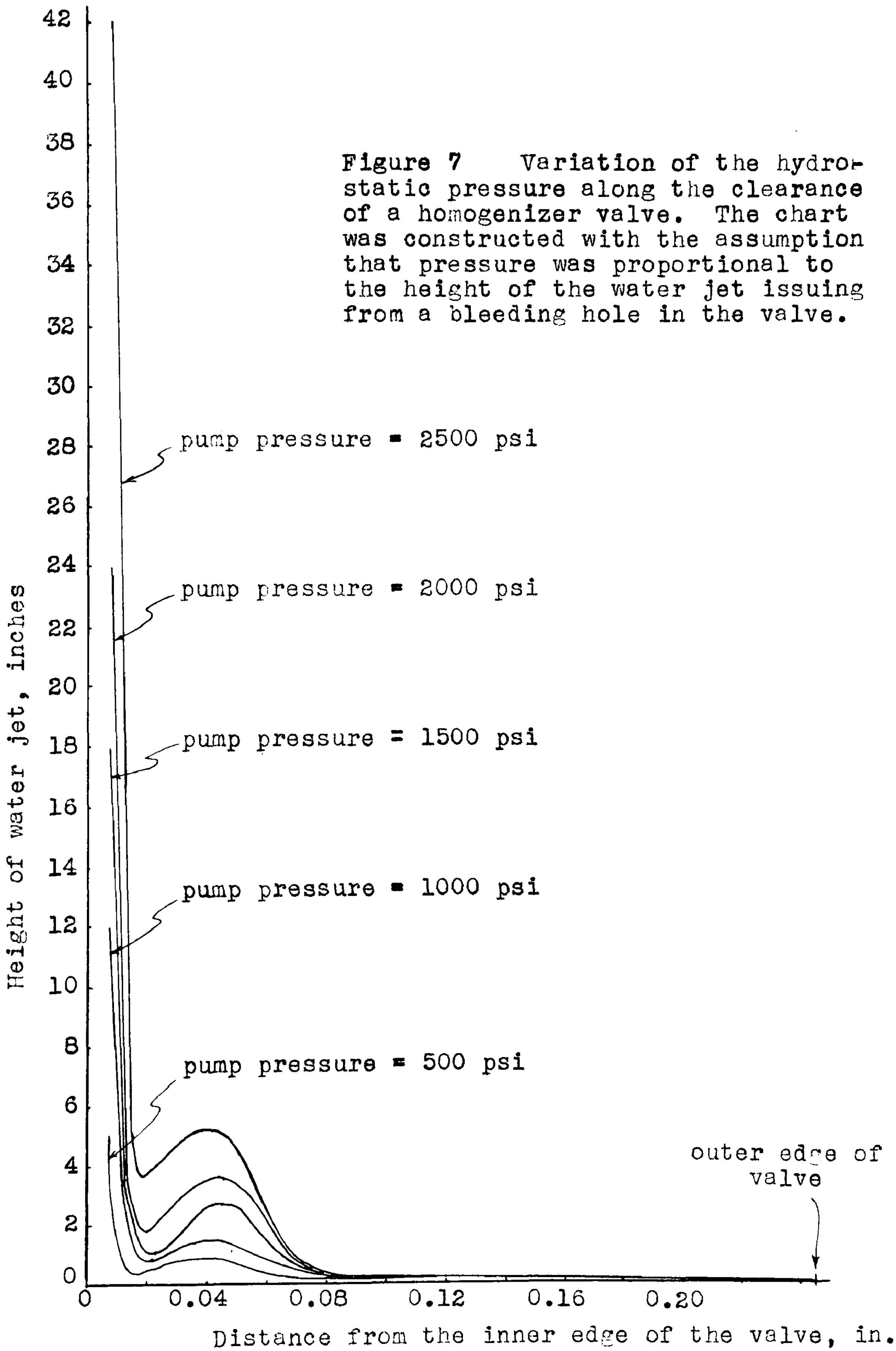


Figure 7 Variation of the hydrostatic pressure along the clearance of a homogenizer valve. The chart was constructed with the assumption that pressure was proportional to the height of the water jet issuing from a bleeding hole in the valve.

1. 4-hole bleeding valve

TABLE VI

DEGREE OF HOMOGENIZATION (EXPRESSED IN FARRALL'S INDEX) OF MILK TAKEN AT DIFFERENT LOCATIONS OF A 4-HOLE BLEEDING VALVE

	Distance from inner edge of valve				homo. outlet
	0.008"	0.010"	0.013"	0.016"	
	77.8	42.4	29.2	8.0	5.2
Slides	94.6	23.8	97.4	2.6	7.8
Series I	78.4	26.4	32.4	2.6	10.6
	67.6	34.2	15.6	5.2	5.2
	57.4	7.8	57.8	5.2	5.2
Slides	86.2	32.6	34.4	5.2	13.6
Series II	61.4	26.2	44.4	2.6	15.6
	45.2	15.6	24.4	10.8	13.0
Mean	71.07	26.12	41.95	5.27	9.52

Least Significant difference between means at 5% level = 14.70

Least significant difference between means at 1% level = 19.80

The mathematical operations of the statistical analysis are contained in Appendix VIII

TABLE VII

DEGREE OF HOMOGENIZATION (EXPRESSED IN FARRALL'S INDEX) OF MILK TAKEN AT DIFFERENT LOCATIONS OF AN 8-HOLE BLEEDING VALVE

	Distance from inner edge of valve								Outlet of homo.
	0.022"	0.045"	0.067"	0.089"	0.112"	0.134"	0.157"	0.179"*	
	23.8	10.6	18.8	24.6	13.0	7.8	7.8		23.8
Slides	31.4	13.4	10.4	15.8	21.0	18.8	2.6		13.2
Series I	0	20.8	21.0	15.6	18.6	15.8	26.2		23.8
	18.6	5.2	23.8	10.4	29.0	18.4	18.6		15.8
	26.2	29.2	18.4	28.8	44.6	5.4	15.8		36.6
Slides	26.4	13.0	23.8	47.4	63.2	44.6	18.6		34.4
Series II	31.6	29.0	18.4	26.6	49.8	31.6	13.0		29.6
	39.4	10.6	18.4	20.8	26.2	31.6	18.2		21.4
Mean	24.67	16.48	19.13	23.75	33.13	21.75	15.10		24.83

* The pressure at this hole was negative, no sample was obtained from this hole.

2. 8-hole bleeding valve

A statistical analysis (Appendix VIII) of the results shown in Table VII reveals that there were no significant differences between any of the samples collected from the bleeding holes and the sample collected at the outlet of the homogenizer.

Discussion

The results of the bleeding valve experiments also yield evidence that cavitation occurs and is a responsible factor in homogenization of milk. The sudden dip in pressure to almost atmospheric at the third hole was a good indication of the occurrence of cavitation there. Though the pressure at that hole did not go below atmospheric, the true pressure at the vena contracta could have been below atmospheric, because the hole (0.0156 inches in diameter) was very probably several times bigger than the distance between the top and the bottom halves of the valve and undoubtedly covered a radial distance bigger than the contracted part of the flow at the vena contracta. It did not measure the pressure at the very neck of the vena contracta but measured the gross pressure of a region around the vena contracta.

The microscopic examination of the milk samples from the bleeding holes revealed that only those samples coming from the three innermost holes were significantly different, in degree of homogenization, from the milk collected at the outlet of the homogenizer. Since cavitation was very likely to occur at about the third hole as was manifested by the sharp dip in pressure there, the high degree of homogenization of milk samples coming out from the fourth and the following holes strongly indicated that davitation was an important responsible factor of homogenization. Of course, there existed also the effect of shearing due to the bleeding holes themselves. Shearing due to the hole itself should be maximum at the innermost hole where the milk passed through it at a speed higher than at any of the other holes. Yet the lowest degree of homogenization was found in the milk from this hole. Therefore, the factor of shearing due to the holes could be neglected.

It was observed that a negative pressure existed near the outer edge of the valve when milk was pumped through it (see Table VII). The lowering in pressure here probably was the same as that happening in a radial flow between any two parallel discs under ordinary conditions. This drop in pressure indicated that cavitation could occur near the outer edge of the valve also. A cavity that grows so large as to include several globules in its shell may bring the globules together on its collapse. If the conditions favor a weak collapse of the cavity (such as the collapse under equilibrium comditions hypothesized by Bottomley (5)) the globules might have the chance to agglomerate instead of becoming smaller or remaining the same size. If cavitation of this kind occurs at the negative pressure region near the outer edge of the valve, globules that have just been broken up near the inner edge would form clumps.

The advantageous effect of a second-stage valve in the prevention of clumping in a conventional homogenizer might be due to its backing up of pressure and eliminating the cavitation phenomenon near the outer edge of the homogenizer valve. Of course, when a second-stage pressure of 500 psi or higher is used there could be some homogenizing effect in the second-stage valve itself also.

Part IV The Construction of an Experimental Knife-edged Homogenizer Valve

The "bleeding valve" experiments showed that reduction in fat globule size was virtually completed at about only one one-hundredth of an inch from the inner periphery of the valve surface. Since the homogenizing region is so close to the inner periphery, one might think that that part of the valve surface beyond the homogenizing region has little contribution to the process of homogenization. On the basis of shearing theory this hypothesis would appear justified. On the other hand, in the light of cavitation theory, the surfaces beyond the homogenizing region should exert an important influence on the intensity and quality of cavitation at the homogenizing region due to its backing up of the pressure there.

If the valve surface of a homogenizer valve is reduced to a knife-edge, a great deal of the flow resistance could be removed. Thus the knife-edged valve becomes a device that will generate cavitation more easily and at the same time, through the use of a second-stage valve, the collapse pressure on the cavities can be regulated. Such a regulation of the collapse pressure on the cavities is not attainable in a wide-surfaced valve, because the resistance due to the wide surface constantly backs up a high collapse pressure.

Based on this theory a knife-edged homogenizer valve and a valve for controlling the collapse pressure (the exit side pressure of the homogenizer valve) were designed and are shown in Figures 8 and 9 respectively. The valve for controlling the collapse pressure consisted essentially of two rubber rings pressed together to form a variable smooth constriction.

In order to obtain a uniform steady pressure, a Vickers swash-plate pump was used to pump the milk through the valve. By means of proper speed reduction a sanitary motor was used to drive the pump to deliver 25 gallons per hour. This particular capacity was chosen because it would allow the coupling of the pump to the valve blocks of the existing 25 gallon-per-hour Manton-Gaulin laboratory homogenizer. At this capacity, one-twentieth of the rated capacity of the Vickers pump, very little fluctuation in pressure was observed. Very low exit side pressure could be easily and quite accurately read.

Since the amount of dissolved gases has been pointed out by several investigators (3)(4)(13)(20)(22) as a very essential factor in the production of emulsion by cavitation, the knife-edged valve was also used to investigate the effect of gas concentration on homogenization efficiency. Two series of experiments using the knife-edged valve and various pump pressures and collapse pressures were carried out. In one of them no air was added to the milk product to be homogenized. In the other series the milk product to be homogenized was saturated with air at various levels.

In order to provide a means of introducing air into the milk product, the suction side of the Vickers pump was vented and the vent was controlled by a small needle valve. The regulation of the needle valve served as a controlling device for the amount of air going into the liquid. When the air came with the liquid into the high pressure side of the pump it would dissolve completely into the liquid unless it exceeded the amount necessary to saturate the liquid under the pump pressure.

The essential features of the experimental homogenizer having a knife-edged valve may be summed up as follows.

1. Its pressure was more uniform.
2. It was supposed to generate cavitation more easily.
3. It allowed the control of the collapse pressure of the cavities.
4. It allowed the introduction of controlled amount of air into the milk product being homogenized.

The above features made the experimental homogenizer a very desirable equipment for the study of cavitation homogenization.

An assembled view of the experimental homogenizer is shown in Figure 10.

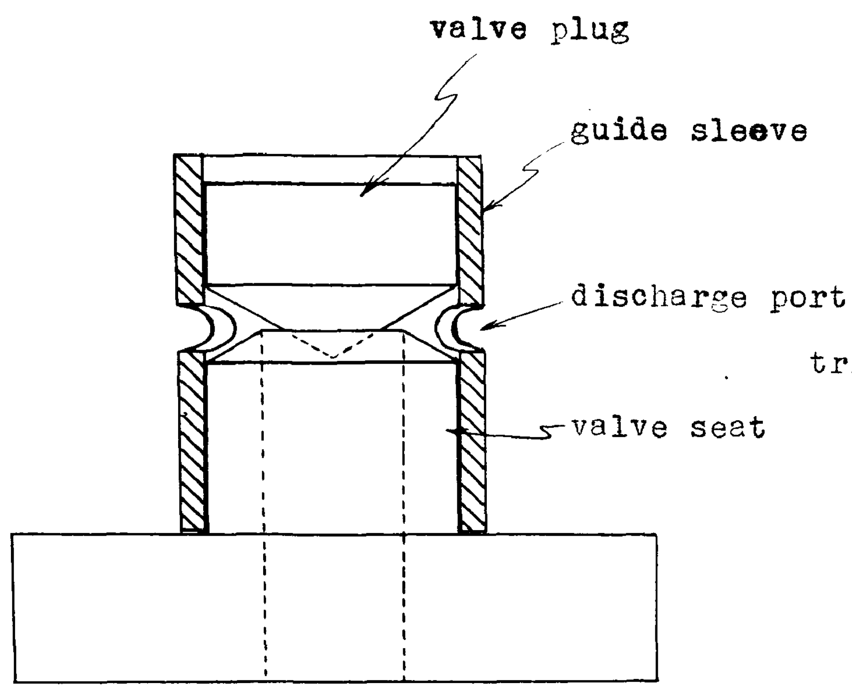


Figure 8 Knife-edged homogenizer valve.

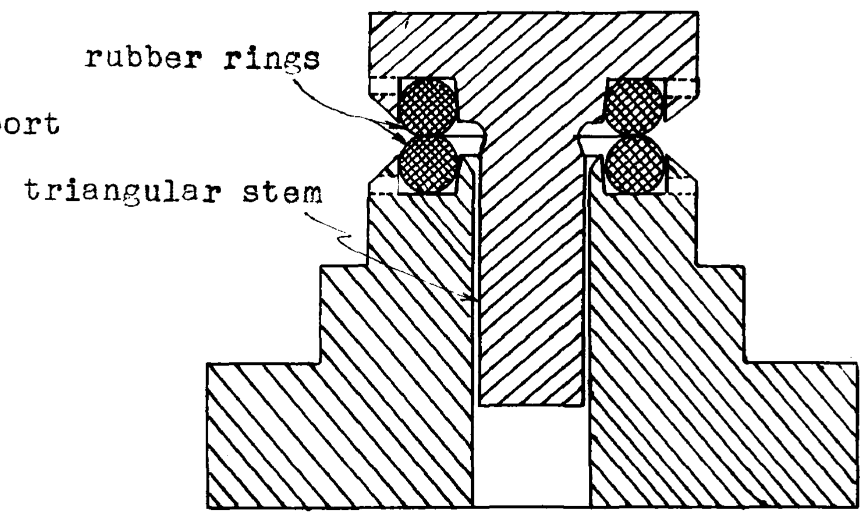
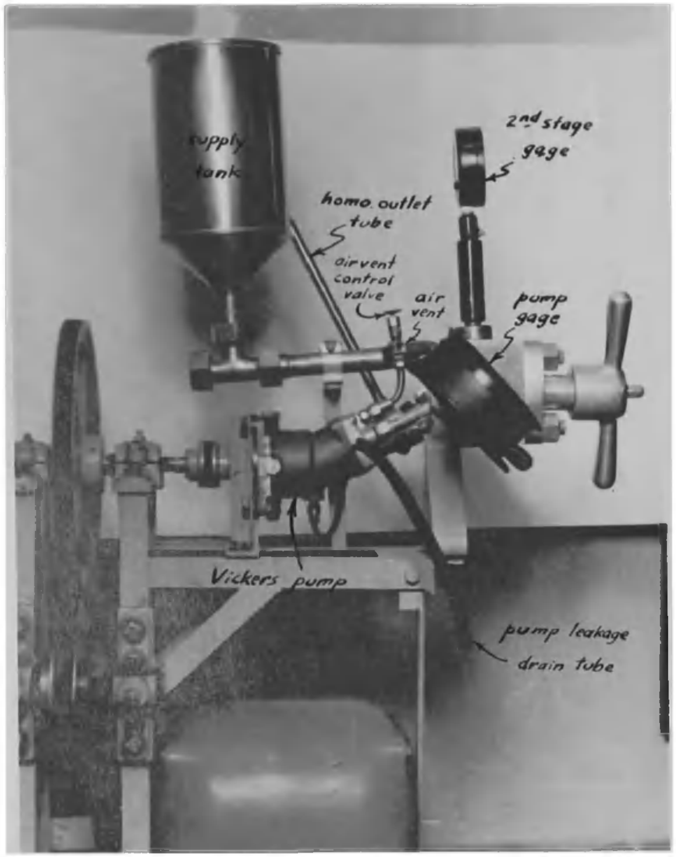
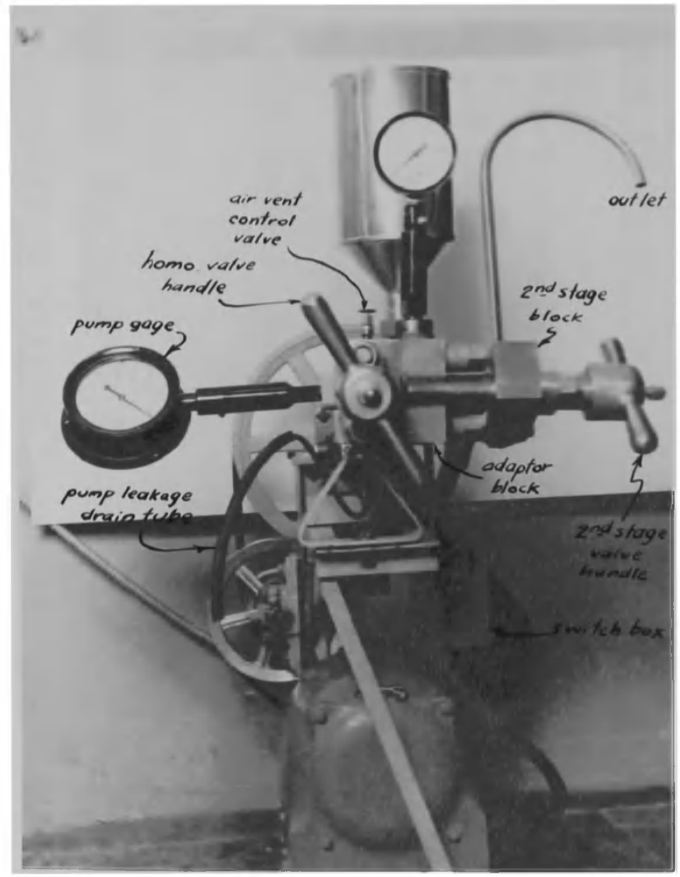


Figure 9 Cavity collapse pressure control valve for use in connection with the knife-edged homogenizer valve.



(a)



(b)

Fig. 10 Assembled views of the experimental homogenizer using a Vickers pump. (a) Side view. (b) Front view.

Part V Homogenization Characteristics of the Knife-edged Valve with No Air Injection

The knife-edged valve was tried on milk, concentrated milk and ice cream mix without any addition of air to the product. The procedure of the experiment and the method of judging the degree of homogenization were not all the same for the three products. Hence, they are described separately below.

Procedure for milk

A total of sixteen runs using milk were carried out at various levels of first-stage pressure (pump pressure) and second-stage pressure (collapse pressure or exit side pressure). The first four runs had second-stage pressures varying from 0 to 500 psi. They yielded evidence that there was an optimum second-stage pressure somewhere around 100 psi. So the following twelve runs were concentrated around this optimum region. Also, in these twelve runs, valves of four different diameters were tried to study the effect of valve diameter on homogenization efficiency. The samples were tested for U.S.P.H.S. homogenization index and the results were analyzed statistically. One sample of milk homogenized with the knife-edged valve at 1000 psi first-stage pressure and 100 psi second-stage pressure was tested for protein stability and curd tension. The results were then compared with those of unhomogenized milk and milk homogenized with the Manton-Gaulin laboratory homogenizer at 2500 psi.

Two methods of determining protein stability were used. One was the heat stability test according to Cole and Tarassuk's method (7). The other was the alcohol test, that is, noting the strength of alcohol solution (percent of 95% alcohol) needed to cause flaking of the milk (5 ml. milk to 10 ml. alcohol solution). Curd tension was tested according to the method adopted by the American Dairy Science Association in 1941. The tester was of the Submarine Signal Company design.

For the purpose of comparison, the original Manton-Gaulin valve was used in the Vickers pump set-up to homogenize milk at 1000 psi pump pressure, and several different second-stage pressures. The samples of milk so homogenized were tested for U.S.P.H.S. index.

<u>Procedure for concentrated milk</u>

The concentrated milk was prepared by mixing proper amounts of 30% cream and water into 3-to-1 condensed skim milk to a composition of 7.9% fat and 20.6% milk solids-not-fat. Part of the concentrated milk was homogenized by means of the Manton-Gaulin laboratory homogenizer at 2500 psi. The rest of it was homogenized by means of the knife-edged valve in the experimental homogenizer using 1000 psi first-stage pressure and 100 psi second-stage pressure. Samples from both machines and a sample of unhomogenized concentrated milk were tested for Farrall's index, protein stability and curd tension. Protein stability was tested according to the method of Cole and Tarassuk (7) and also according to the alcohol method as described previously for milk. The curd tension test was done for both concentrated milk and diluted concentrated milk (one part concentrated milk to one part water).

Procedure for ice cream mix

Two runs of plain ice cream mix and one run of chocolate ice cream mix of usual composition (see Appendix IX) were carried out using various combinations of first-stage pressure and second-stage pressure. The ice cream mix to be used in the experiment was taken from the College Creamery ice cream pasteurizer just before it was to be homogenized. A sample of the same batch of ice cream mix homogenized by the College Creamery was used as a control. All the samples were tested and compared for viscosity with a Brookfield viscosimeter and for fat globule size in terms of Farrall's index.

Results of the homogenization of milk using the knife-edged valve

a. Runs 1 to 4. The pressures used were as follows.

Runs 1 and 3, first-stage 900 psi
second-stage 0 to 500 psi.

Runs 2 and 4, first-stage 1400 psi
second-stage 0 to 500 psi.

The results are tabulated in Table VIII. From these results an operation chart of the knife-edged valve was constructed as shown in Figure 11. The operation chart shows clearly that the degree of homogenization increased rapidly (lowering of U.S.P.H.S. index) as the second-stage pressure was increased to around 100 psi. Further increase in second-stage pressure produced no significant change in degree of homogenization when first-stage pressure was 1400 psi, but definitely reduced the degree of homogenization (rising of U.S.P.H.S. index) when the first-stage pressure was 900 psi.

b. Runs 5 to 16.

The U.S.P.H.S. indices obtained by using knife-edged valves of four different diameters, three different first-stage pressures and four different second-stage pressures are tabulated in Table IX and plotted in Figure 12.

It was noted that the index obtained for the three-sixteenths valve at P_1 = 800 psi and P_2 = 50 psi and the index for the one-half inch valve at P_1 = 600 psi and P_2 = 50 psi seemed to be erroneous, being outstandingly too high. This would be especially obvious if the results of the twelve runs were plotted and compared. So in the statistical analysis the two values were replaced by values obtained by the method of estimating missing values in a randomized block experiment (2) (23). The other two missing values, represented by asterisks in the table, were estimated in like manner. The total degrees of freedom and degrees of freedom for error were correspondingly reduced by four. Before applying the formulas for estimating missing values, the experimental data were divided into three two-way tables, one for each first-stage pressure. Then the formula for one missing value or

TABLE VIII

U.S.P.H.S. INDICES OF FOUR RUNS OF HOMOGENIZATION OF MILK USING A KNIFE-EDGED VALVE

Run No.	1st.-stage Press.,psi	2nd.-stage Press.,psi	U.S.P.H.S. Index
	900	0	20.4
	900	50	10.5
1	900	100	8.1
	900	300	15.2
	900	500	26.1
	1400	0	12.6
	1400	50	4.1
2	1400	100	4.1
	1400	300	6.7
	1400	500	4.8
	900	0	17.5
	900	50	8.0
3	900	100	10.2
	900	300	13.1
	900	500	25.6
	1400	50	5.12
	1400	100	4.5
4	1400	300	3.1
	1400	500	7.2

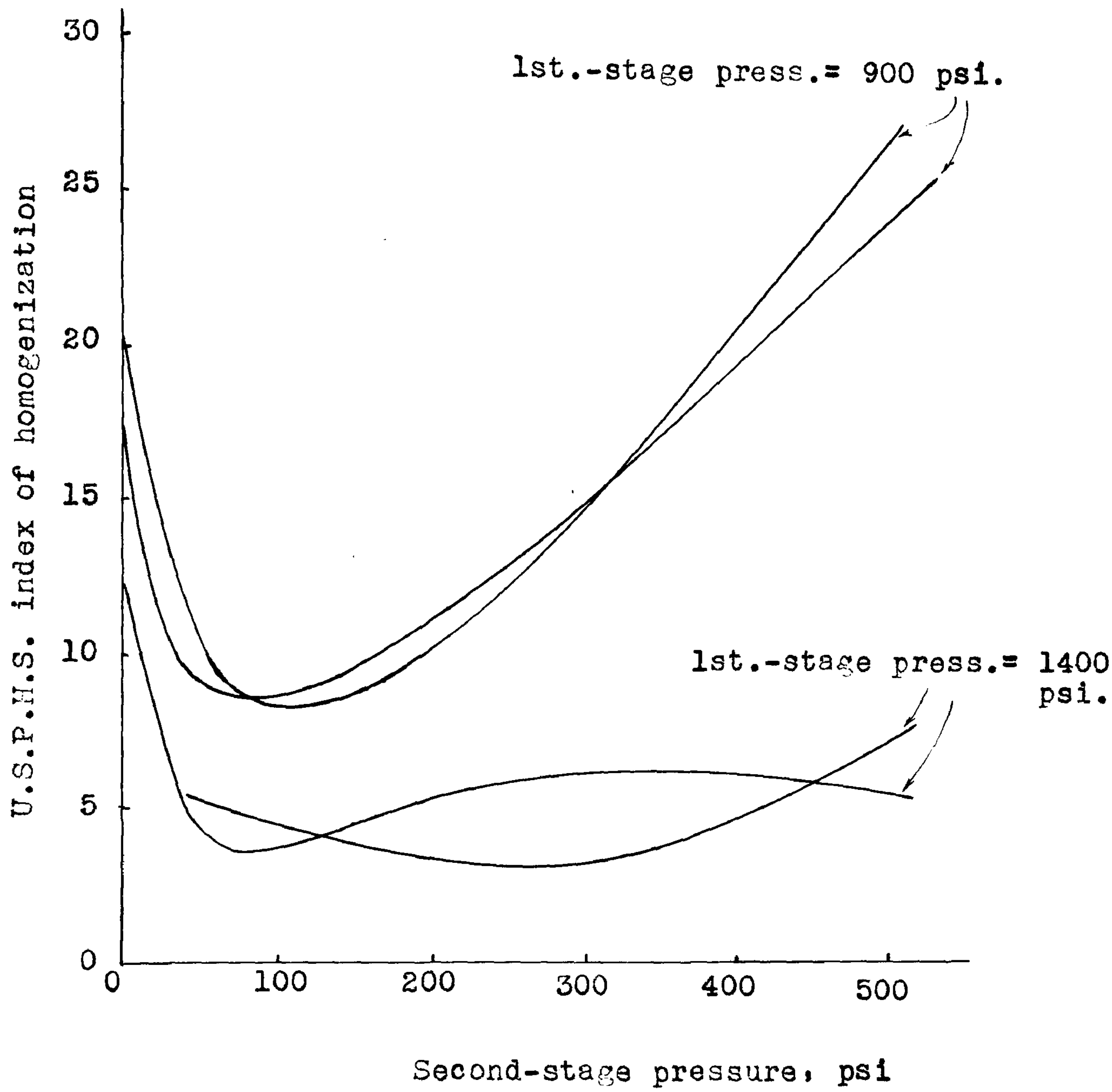


Figure 11 Operation chart of the knife-edged valve for 0 to 500 psi second-stage pressure with no air injection.

TABLE IX

U.S.P.H.S. INDICES OF TWELVE RUNS OF HOMOGENIZATION OF MILK USING FOUR KNIFE-EDGED VALVES OF FOUR DIFFERENT DIAMETERS

Valve Dia. d, inches	First-stage Press., P_1, psi	2nd.-stage Press., P_2			
		0 psi	50 psi	100 psi	150 psi
3/16	600	39.8	32.2	34.2	*
	800	12.7	19.4	8.0	10.9
	1000	18.1	9.2	8.5	6.7
1/4	600	39.5	28.3	27.0	33.3
	800	16.1	8.7	11.4	12.8
	1000	17.2	11.4	9.2	6.7
3/8	600	35.0	29.2	28.3	29.2
	800	15.2	12.0	11.0	11.5
	1000	16.9	9.2	5.4	5.9
1/2	600	36.5	45.0	35.2	43.3
	800	18.5	13.9	14.9	14.5
	1000	16.4	10.3	8.0	*

*Samples were not obtained because of running out of milk during the experiment.

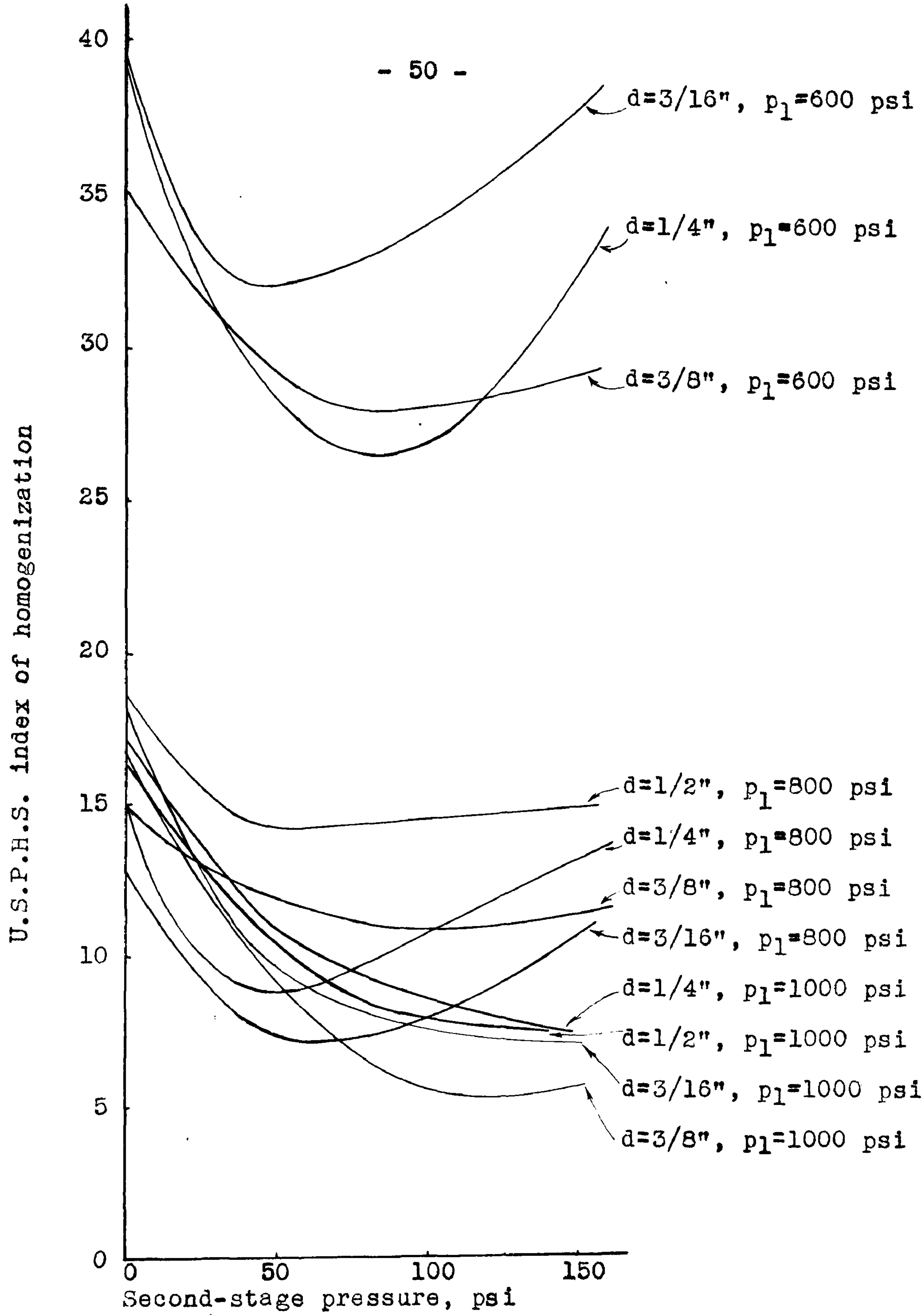


Figure 12 Operation chart of the knife-edged valve for 0 to 150 psi second-stage pressure with no air injection.

two missing values was applied accordingly. Hence, the following values were obtained.

For P_1 = 600 psi, P_2 = 150 psi, and d = 3/16" the estimated index was 38.1.

For P_1 = 800 psi, P_2 = 50 psi, and d = 3/16" the estimated index was 9.0.

For P_1 = 600 psi, P_2 = 50 psi, and d = 1/2" the estimated index was 34.4.

For P_1 = 1000 psi, P_2 = 150 psi, and d = 1/2" the estimated index was 6.3.

A statistical analysis, of which the mathematical operations are presented in Appendix X, showed that there was significant difference at 1% level between the half inch valve and the other valves, and between zero second-stage pressure and the other second-stage pressures.

The results of protein stability tests and curd tension test of milks homogenized by the knife-edged valve and by the Manton-Gaulin homogenizer are presented in Table X. They show that the knife-edged valve at 1000 psi first-stage pressure and 100 psi second-stage pressure produced practically the same effects on the protein stability and curd tension as the Manton-Gaulin homogenizer at 2500 psi operation pressure.

TABLE X

EFFECTS OF HOMOGENIZATION BY MEANS OF THE KNIFE-EDGED VALVE AND THE MANTON-GAULIN VALVE ON THE PROTEIN STABILITY AND CURD TENSION OF MILK

	Control (Unhomo. milk)	Milk Homo. by Manton-Gaulin Valve[1]	Milk Homo. by Knife-edged Valve[2]
Heat stability test	No coagulation after 80 min.	Curdled at 69 min. Set at 80 min.	Set at 69 min.
Alcohol test	90%	85%	85%
Curd tension	26 gm.	14 gm.	14 gm.

1. The homogenization pressure was 2500 psi.
2. The homogenization pressures were 1000 psi pump pressure and 100 psi second-stage pressure.

Results of the homogenization of milk using the Manton-Gaulin valve in the Vickers pump set-up

As stated previously the Manton-Gaulin valve was used in the Vickers pump set-up at the same pressures as the knife-edged valve for the purpose of comparison. The results of the test showed that none of the samples of milk homogenized by the Manton-Gaulin valve in the Vickers pump set-up were up to the U.S.P.H.S. requirements for homogenized milk. All of them had a sticky cream layer of various thicknesses after 48 hours standing in a cooler.

TABLE XI

DEGREE OF HOMOGENIZATION OF MILK HOMOGENIZED BY THE MANTON-GAULIN VALVE IN THE VICKERS PUMP SET-UP

Pump pressure, psi	1000	1000	1000	1000
Second-stage pressure, psi	0	50	100	150
Run 1	41.5	35.0	37.0	45.0
Run 2	22.3	35.8	29.2	27.4
Run 3	26.8	24.2	24.8	30.0

Results of the homogenization of concentrated milk using the knife-edged valve

The results of protein stability test, curd tension test, and microscopic examination of the unhomogenized concentrated milk and homogenized concentrated milk from both Manton-Gaulin laboratory homogenizer and the knife-edged valve homogenizer are tabulated in Table XII. Both the heat stability test and alcohol test revealed practically no difference among the three samples. The curd tension test of diluted concentrated milk showed about the same reduction in curd tension in the homogenized samples, but the curd tension test of undiluted concentrated milk failed to show any significant differences among the three samples. The microscopic examination showed a somewhat better fat globule size reduction in the sample homogenized by the knife-edged valve homogenizer at 1000 psi pump pressure and 100 psi second-stage pressure than in the sample homogenized by the Manton-Gaulin laboratory homogenizer at 2500 psi pump pressure.

TABLE XII

EFFECTS OF HOMOGENIZATION BY MEANS OF THE KNIFE-EDGED VALVE AND THE MANTON-GAULIN VALVE ON THE PROTEIN STABILITY, CURD TENSION AND FAT GLOBULE SIZE OF CONCENTRATED MILK

	Control (Unhomo. conc. milk)	Conc. Milk Homo. by Manton-Gaulin Valve[1]	Conc. Milk Homo. by Knife-edged Valve[2]
Heat stability test	Curdled at 6 min. Set at 7 min.	Curdled at 6 min. Set at 7 min.	Curdled at 6 min. Set at 7 min.
Alcohol test	70%	70%	70%
Curd tension (sample undiluted)	38 gm.	37 gm.	38 gm.
Curd tension (sample diluted)	21 gm.	11 gm.	9 gm.
Farrall's index	661	72.5	45.9

1. The homogenization pressure was 2500 psi.
2. The homogenization pressures were 1000 psi first-stage and 100 psi second-stage.

Results of the homogenization of ice cream mixes using the knife-edged valve

Results of two runs using plain ice cream mix and one run using chocolate ice cream mix are shown in Table XIII. They show that the knife-edged valve homogenizer operating at pump pressures from 700 to 1400 psi and second-stage pressure from 50 to 200 psi definitely did not homogenize so well as the Cherry-Burrell Superhomo operating at 2300 psi pump pressure and 800 second-stage pressure, though viscosity of the samples seemed to be in favor of the knife-edged valve. Clumping of fat globules was observed in some of the samples from both machines, but no definite trend was discerned.

TABLE XIII

EFFECTS OF HOMOGENIZATION BY MEANS OF THE KNIFE-EDGED VALVE AND THE CHERRY-BURRELL VALVE ON THE VISCOSITY AND FAT GLOBULE SIZE OF ICE CREAM MIXES

Ice Cream mix	Homogenizer	Homogenization Pressures, psi 1st. stage	Homogenization Pressures, psi 2nd. stage	Absolute viscosity, centipoise	Farrall's index
Plain	Knife-edged valve	700	50	14.6	190.2
		700	100	14.7	350.5
		850	50	19.4	342.5
		850	100	19.0	437.3
		1000	50	20.7	94.9*
		1000	100	19.3	515.0
	Cherry-Burrell Superhomo.	2300	800	23.0	31.1*
Plain	Knife-edged valve	800	100	20.8	108.2*
		800	200	20.8	97.7
		1000	100	21.5	125.5
		1000	200	21.2	96.6
		1200	100	24.3	66.2*
		1200	200	22.6	70.6
		1400	100	23.6	132.5
		1400	200	24.6	79.0
	Cherry-Burrell Superhomo.	2300	800	26.6	16.2
Chocolate	Knife-edged valve	500	50	76.2	423.2
		500	100	68.0	389.4
		700	50	86.0	272.8
		700	100	77.0	472.5
		1400	100	66.0	153.4
	Cherry-Burrell Superhomo.	1500	600	172.4	63.8*

*Sample showed clumping of fat globules.

Discussion

The experiments of the knife-edged valve with no air injection revealed that, in the case of milk, there was an optimum second-stage pressure around 50 to 150 psi. Milk could be satisfactorily homogenized at 1000 psi pump pressure and 50 to 150 psi second-stage pressure. A satisfactory explanation of the phenomenon of optimum second-stage pressure is that the optimum pressure is just high enough that on the one hand it intensifies the striking effect of the collapsing cavities and yet on the other hand it does not cause any unfavorable effect on the generation of cavities.

From the analysis of the effect of valve diameter on the efficiency of homogenization the valve diameter did not seem to be very critical within certain limits. If this is true, three possible advantages might be derived, namely,

1. flexibility in the capacity of a valve,
2. "finger-tip" manipulation of the homogenizer valve, and
3. less mechanical abrasion due to grits present in the flow.

The first advantage is obvious. The second advantage is due to the fact that the pressure force on a smaller valve plug requires smaller effort to turn the valve handwheel. It is common experience that quite an effort is needed to turn the valve handwheel to get the pressure up to 2000 psi in a conventional homogenizer. The third advantage is possible, because a smaller diameter would require a bigger valve clearance, and a bigger valve clearance would allow grits to go through with less abrasive effect.

The operation chart probably can be applied to the conventional poppet type homogenizer valves too. However, because of the constant high collapse pressure due to wide valve surface the operation region will be limited to an area somewhere away on the right side of the optimum region on the operation chart.

The protein stability of the concentrated milk was very low as the curdling time was only six minutes at 120°C. Since all the three samples, one unhomogenized and two homogenized, showed practically the same stability it is quite likely that the lowering of stability of the proteins in concentrated milk was chiefly caused by treatments other than homogenization.

With a conventional homogenizer, the pressure used to homogenize ice cream mix generally is lower than that used to homogenize milk. With the knife-edged valve homogenizer, it was found that ice cream mixes could not be homogenized satisfactorily at pressures equal to or even 400 pounds higher than that which yielded satisfactory homogenization of milk. A possible reason why the cavitation homogenizer valve (knife-edged valve), when compared to the shearing homogenizer valve (poppet-type valve), did not homogenize ice cream mixes so easily as it did milk was that the ice cream mixes contained large quantities of sugar and some amount of gelatin. Sugar and gelatin consist in their chemical structures of many polar groups (molecular groups and double and triple bonds that show a strong attraction for water). Such polar groups were found to hinder cavitation by Pease and Blinks (18). Therefore, the experiment of using a knife-edged valve to homogenize ice cream mix yielded two significant points.

First, it showed that unaerated ice cream mix (later tests were made with aerated mix) is more easily homogenized than milk in the case of the poppet type valve, but the reverse is true in the case of the knife-edged valve. Second, based on Pease and Blinks's observation, the key to successful homogenization of ice cream mixes may lie in determining how to overcome the interference of polar groups of sugar and gelatin.

Part VI Homogenization Characteristics of Knife-edged Valve with Air Injection

Purpose

From the literature reviewed it appeared that dissolved gases had a very significant place in the phenomenon of cavitation. According to Harvey (13), Rogowski and Söllner (20), Pease and Blinks (18), and Sata (22) the dissolved gases had direct relation to the ease of producing cavitation. According to Van Iterson (25) and Bottomley (5) the amount of dissolved gases would determine how low a hydrostatic pressure would be needed to produce destructive cavitation.

In ordinary milk products such as milk and ice cream mixes which are in constant contact with air the amount of dissolved air should be quite close to saturation under atmospheric pressure. By means of the experimental homogenizer it was possible to add a controlled amount of air into the milk product just before it was to go through the homogenizer valve. Hence it was possible to investigate the effect of varying the amount of dissolved air on the efficiency of homogenization.

Procedure

The only part of the procedure that needs description is the procedure of regulating the amount of gases in the milk product, the rest of the procedure being the same as described in Part V.

In the following description of the procedure P_1, P_a, and P_2 are used to represent the desired pump pressure, air saturation pressure and second-stage pressure respectively. The air vent was first closed and the machine started. After the first-stage valve was adjusted to obtain P_1 on the pump pressure gage and the second-stage valve was adjusted to obtain P_a on the second-stage pressure gage, the air vent valve was opened up gradually until a distinct rattling noise could be heard. At the same time the pointer of the first-stage gage began to show erratic vibration. Then the vent valve was turned back just far enough to reduce the rattling noise to a smooth hissing noise and the gage pointers just ceased erratic vibration. The second-stage valve was then tightened to get P_2 on the second-stage gage. The procedure of obtaining P_1, P_a, and P_2 was then completed. After a reasonable time had elapsed a sample could be collected at the outlet of the homogenizer.

Since it was found that optimum second-stage pressure existed around 100 psi, the values of P_2 used in the present series of experiments were up to only 200 psi. P_a, the air saturation pressure or the pressure at which the air would come out from solution to form cavities, was necessarily smaller than P_2 in order that the cavities would collapse.

Also since it was found that, without adding air, a pump pressure of 800 psi would homogenize milk just up to the limit of the U.S.P.H.S. requirement, effects in either direction should be more easily detected if this pump pressure was used.

So five of the seven runs using milk were carried out using 800 psi pump pressure. In the remaining two runs the pump pressures were 1000 psi and 600 psi respectively.

In the case of ice cream mix, there were three runs using 1000 psi pump pressure and three other runs using 800 psi pump pressure. Only plain ice cream mix was used.

In the case of concentrated milk the air saturation pressures used ranged from below atmospheric to 75 psi. Samples with air saturation pressure below atmospheric were used for the purpose of imitating the conditions of concentrated milk in actual production process in which the concentrated milk receives deaerating effect in the vacuum pan and is not appreciably exposed to atmospheric air before going into the homogenizer. Partially deaerated milk was obtained by spraying the concentrated milk at 145° F. into a container at 17 to 18 inches vacuum. It was reheated to 140° F. and transferred to the supply tank of the homogenizer with care not to incorporate air into it.

Results

(a) Milk.

The degrees of homogenization of milks homogenized by means of the knife-edged valve with air injection are shown in Table XIV. Run 1 shows a very noticeable undesirable effect of the large amount of air and some slight improvement at medium amount of air. Run 2, consisting of three replications, was analyzed statistically (See Appendix XII). The analysis showed no significant difference among the effects of various amounts of air (from 0 to 25 psi). Runs 3 and 4 did not seem to show any significant difference either.

TABLE XIV

EFFECTS OF ADDING AIR TO MILK ON HOMOGENIZATION EFFICIENCY

(U.S.P.H.S. indices of milk homogenized by the knife-edged valve at 140°F.)

Run No.	Homo. Pump Pres. psi	2nd.-stage Pres. psi	Air Saturation Pressure, psi							
			0	10	20	25	50	75	150	200
1	600	100	26.0					18.7		
	600	200	27.3				23.0	22.3	33.3	
	600	300	41.0							51.3
2	800	50	10.2	11.5	12.3	11.9				
	800	50	11.4	10.9	11.9	9.8				
	800	50	11.7	7.8	12.5	14.1				
3	800	100	13.5			12.5	15.2	13.1		
	800	200	18.7			16.3	18.0	18.4		
4	1000	100	9.9			9.2	10.9	9.9		

(b) Ice cream mix.

Results of the homogenization of ice cream mix using the knife-edged valve with air injection are presented in Table XV.

TABLE XV

EFFECTS OF ADDING AIR TO ICE CREAM MIX ON HOMOGENIZATION EFFICIENCY AND VISCOSITY

(Farrall's indices and viscosity in centipoise of ice cream mix homogenized by the knife-edged valve at 150° F.)

Homo. Pump Pres. psi	2nd.-stage Pres. psi	Air Sat. Pres. psi	Run 1 Index	Run 1 Vis. cps.	Run 2 Index	Run 2 Vis. cps.	Run 3 Index	Run 3 Vis. cps.	Average Index
800	100	0	239.2	27.0	191.7	26.5	153.2	22.0	194.7
800	100	50	212.1	29.5	88.2	22.5	168.1	20.0	156.1
800	100	75	97.1	23.5	56.8	22.0	80.9	19.0	78.3
800	200	0	277.1	25.0	118.3	24.5	138.9	20.5	178.1
800	200	50	241.0	27.0	97.4	23.5	84.0	20.0	140.8
800	200	75	147.5	24.0	55.2	19.0	95.8	21.0	99.5
1000	100	0	212.6	61.0	31.1	21.5	52.0	19.0	98.5
1000	100	50	62.5	23.0	25.4	19.5	236.9	20.0	108.3
1000	100	75	60.6	23.0	5.7	20.5	35.2	20.0	33.8
1000	200	0	173.1	52.0	36.5	19.0	90.6	20.0	100.1
1000	200	50	57.5	22.0	20.0	20.0	56.2	21.0	44.6
1000	200	75	33.3	21.5	24.1	19.0	66.9	21.5	41.4

Control sample*: Farrall's indices = 36.5, 42.5, 73.1, 14.9
Average Farrall's index = 41.7
Fiscosity = 73 cps.

*Control sample was homogenized by Cherry-Burrell Superhomo at 2300 psi pump pressure and 500 psi second-stage pressure.

The statistical analysis (Appendix XIII) showed an improvement of homogenization efficiency at 1% level of significance when the air saturation pressure was 75 psi. Also there was a difference at 5% level of significance between 75 psi and 50 psi saturation pressures. The use of 50 psi air saturation pressure was insignificantly different from adding no air. No significant difference was observed between the two second-stage pressures.

The average indices of samples homogenized at 1000-75-100 psi (pump pressure-air saturation pressure-second-stage pressure), 1000-50-200 psi and 1000-75-200 were comparable to the average index of a sample homogenized by a Cherry-Burrell Superhomo at 2300 psi pump pressure and 500 second-stage pressure. The viscosities of the knife-edged valve samples were all appreciably lower than the Cherry-Burrell sample.

(c) Concentrated milk.

Results of homogenizing concentrated milk at various concentrations of dissolved gases using the knife-edged valve are presented in Table XVI. A statistical analysis of the results (see Appendix XIV) revealed that the deaerated samples were less homogenized than all the others at a significance level of 1%. All the samples with air injection were insignificantly different from each other. Only 20 and 75 psi air saturation pressures produced improvement over atmospheric saturation pressure at a significance level of 5%.

TABLE XVI

EFFECTS OF ADDING AIR TO CONCENTRATED MILK ON HOMOGENIZATION EFFICIENCY

(Farrall's indices of concentrated milk homogenized by the knife-edged valve at a homogenizer pump pressure of 900 psi and second-stage pressure of 100 psi at a temperature of 140° F.)

	Deaerated sample	Air Saturation Pressure, psi					
		Atmos.	10	20	25	50	75
Replication I	188.0 166.8	127.8 114.4	63.1 66.3	43.1 53.9	64.0 40.6	99.6 92.6	79.6 64.4
Replication II	213.0 172.2	91.4 102.7	125.3 124.0	117.9 85.9	133.5 117.0	93.5 91.0	65.0 65.5

Conclusion

The fact that adding a certain amount of air into ice cream mix raised the homogenization efficiency to satisfactory value was a likely indication that air helped overcome the previously postulated inhibitive effect of sugar and gelatin on cavitation in ice cream mix. However, in the case of milk the addition of a similar amount of air did not yield any significant effect on the efficiency of homogenization. A larger amount of air only reduced the homogenization efficiency. This might mean that the natural amount of dissolved gases in milk is not insufficient as far as the production of cavitation is concerned and that the addition of air to milk only tends to cushion the hammering effect of collapsing cavities.

The fact that deaerated concentrated milk was much harder to homogenize not only is a confirming evidence of the role of cavitation in homogenization but also may have importance in the actual production of evaporated milk. It seems that allowing milk to take up a sufficient amount of air when going from the vacuum pan to the homogenizer will insure good homogenization of the product. However, amounts more than saturation at atmospheric condition does not seem necessary.

It was believed that more uniform results could be obtained by using a more sensitive device for controlling the amount of dissolved air in the experiments. It was quite likely that much of the variation due to error came from the lack of precision in controlling the air.

There was considerable variation among runs when homogenizing ice cream mix. One possible reason was that oiling-off of the fat in the supply tank was rather heavy. The mix in the supply tank could be agitated only mildly because too strong agitation might incorporate air bubbles into the mix and hence would ruin the purpose of the experiment.

Part VII Durability Test of the Knife-edged Homogenizer Valve

Purpose

Since the knife-edged homogenizer valve was designed to produce cavitation which is very damaging, it was necessary to determine how well the valve could stand cavitation action under continuous operation conditions. It was not expected that the knife-edged valve might be made to last as long as the conventional poppet type stellite valve. However, it was hoped that it might be made into an item which might be very inexpensively replaced as soon as it began to show reduction in its efficiency.

Procedure

A study of the durability of the knife-edged valve under continuous cavitation action was carried out in the following manner. The valve used had a seat similar to the one shown in Figure 9, but its plug was a polished flat disc instead of a cone. While such a construction was not expected to be different in effectiveness its polished surface would allow cavitation to produce clear markings of erosion. The material used for making the valve was brass, which was very soft. An emulsion of mineral oil (SAE No. 50 motor oil) and water in a volumetric ratio of 1:4 with 10 grams of Ivory soap to a gallon of mixture was run through the homogenizer and recirculated. The machine was stopped, cleansed and used to homogenize a gallon of milk in the usual manner at certain time intervals. The degrees of homogenization of the milk samples served as an indication of the efficiency of the valve. Pressures were maintained at 1000 psi pump pressure and 100 psi second-stage pressure throughout the experiment. Temperature of the emulsion varied from 120 to 150° F. with 140° being most common. A stream of tap water washing down the outside of the return tube of the homogenizer helped dissipate the heat added into the recirculating emulsion by the pump. The capacity of the pump was checked occasionally.

Result

The result of the durability test of the knife-edged valve shown in Table XVII shows that there was practically no reduction in efficiency of the valve during the entire five hours operation. There were faint radial erosion markings on the valve plug.

TABLE XVII

DURABILITY OF THE KNIFE-EDGED HOMOGENIZER VALVE

(U.S.P.H.S. indices of samples taken at various time intervals during five hours operation)

Time, Minute	U.S.P.H.S. index
0	5.05
30	6.72
60	6.90
120	4.50
180	5.00
300	6.20

Conclusion

Though the durability test was not carried out long enough to determine actually how long the useful life of the knife-edged valve would be, the ability of the brass knife-edged valve to maintain high efficiency during the test period of five hours was a good basis on which to predict a useful life of, say, 100 hours if the valve were made of harder material such as stainless steel. A valve stamped out from stainless steel sheet like the one shown in Figure 13a could be cheaply made for frequent replacement.

Part VIII Trial of the Knife-edged Valve in High Capacity Triplex Homogenizer

Purpose

Since the knife-edged valve homogenized milk very satisfactorily at 1000 psi pump pressure and 100 psi second-stage pressure in a small experimental homogenizer it was desired to determine whether the same principle could be readily applied to high capacity commercial homogenizers.

Though it was found that in the experimental homogenizer the size of the valve did not seem to be critical, it must be realized that the flow rate per inch of valve diameter in the experimental homogenizer was very small, being about 65 gallons per hour per inch diameter. If this ratio were adopted in designing a knife-edged valve for a commercial homogenizer of 500-gallons-per-hour capacity, a diameter of about seven and a half inches would be necessary. Such a size would be undoubtedly impractical. In order to make a knife-edged valve that could be readily fit into an ordinary commercial homogenizer a high flow rate per inch diameter would have to be used. Also commercial homogenizers are, almost as a rule, of the triplex type. A triplex pump exhibits some degree of pressure fluctuation believed to be bigger than that of the swash-plate pump of the experimental homogenizer. Differences like these might affect the performance of a knife-edged valve in a commercial homogenizer.

Procedure

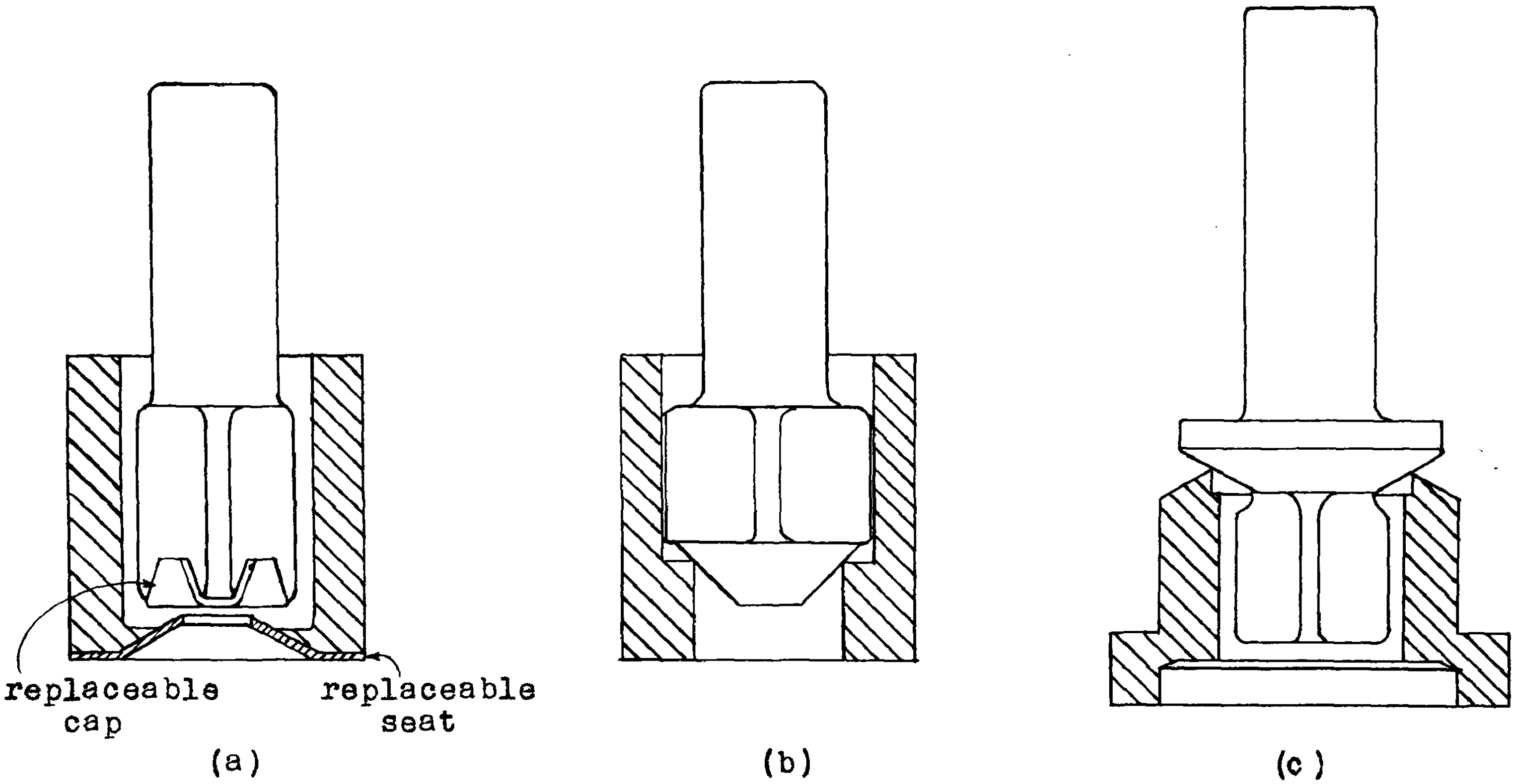
The commercial homogenizer used was a Cherry-Burrell 500-gallons-per-hour triplex type which was used daily by the Michigan State College Creamery to homogenize fluid milk. It was thoroughly overhauled to operate satisfactorily before three knife-edged valves of different sizes were tried in it.

Since it was a single-stage machine a needle valve similar to the ball valve shown in Figure A1 was added to the outlet of the homogenizer to control the pressure at the exit side of the knife-edged valve. A sanitary pressure gage that read up to 200 psi was inserted between the original homogenizer outlet and the second-stage valve (the needle valve).

As a measure against air leak along the supply line the supply tank was elevated about one foot above the homogenizer inlet and a paper gasket was inserted in each pipe joint.

The machine was tempered with hot water before the milk at 140° F. was pumped through it at 1000 psi pump pressure and 100 psi second-stage pressure. About 10 gallons of milk was used for the trial of one valve. A quart of milk near the end of the 10 gallons was collected for the determination of U.S.P.H.S. index. This index was compared with that of a sample taken from the creamery production line in the same day.

The three knife-edged valves are shown in Figure 13. Though they differed in construction, they all had the same basic feature - a sharp edge against a smooth surface.



Valve diameter = 3/8" Valve diameter = 3/4" Valve diameter = 1.0 in.

Figure 13 Cross-sectional views of knife-edged homogenizer valves of three different diameters designed to fit into a Cherry-Burrell 500-gallons-per-hour homogenizer. Scale, full size.

Results

Results of using knife-edged valves of three different diameters in a 500-gallons-per-hour triplex homogenizer are presented in Table XVIII.

TABLE XVIII

PERFORMANCE OF KNIFE-EDGED VALVE IN A 500-GALLONS-PER-HOUR TRIPLEX HOMOGENIZER

Valve Diameter, inch	Pump Pres., psi	2nd.-stage Pres., psi	U.S.P.H.S. Index	U.S.P.H.S. Index of Control Sample*
3/8	1000	100	19.4	8.9
3/4	1000	100	12.6	9.2
1	1000	100	16.2	9.5

*Control sample was homogenized by the regular Cherry-Burrell valve at 2000 psi pump pressure.

In all the three trials the knife-edged valve working at 1000 psi pump pressure and 100 psi second-stage pressure did not homogenize as well as the original valve working at 2000 psi pump pressure. There was no definite indication of the relation between the valve diameter and the efficiency of a knife-edged valve.

Conclusions

More trials designed for a good analysis of variance would be needed for a reliable evaluation of the knife-edged valve when used in a commercial homogenizer. From the meager experimental data, the following conclusion might be drawn with reservation.

There were several possible reasons why the result of using the knife-edged valve in a commercial homogenizer was not satisfactory. The lack of a definite relationship between the efficiency and the diameter might mean that physical factors other than valve diameter were responsible. These physical factors might include the shape and the workmanship of the valve, and the pressure fluctuation that existed. Fluctuation in pressure, especially the second-stage pressure, would have a pronounced influence on the efficiency as could be observed in the operation chart of a knife-edged valve (Figure 12). Poor workmanship might cause uneven fluid speed distribution around the valve and hence uneven cavitation effect. With regards to the shapes of the valves, though they all had a sharp edge against a smooth surface, there was the difference of the angle between one side of the edge and the surface. As can be seen in Figure 13, the angles on the approaching sides were 90°, 45°, and 60° in the 3/8", 3/4" and 1" valves respectively. The corresponding angle in the knife-edged valve used in the experimental homogenizer was 60°.

Another possible source of error might have been the amount of milk used in each trial run. The amount of ten gallons for one run might have been insufficient. One and two-tenths minutes was all the time that was required to pump the ten gallons through. Allowing time for the adjustment of the pressures, there might be only twenty seconds or so left.

CONCLUSIONS

Among the various experimental results the more significant ones are those concerning the location of the homogenizing region in a poppet type homogenizer valve, the influence of back pressure in both the poppet type and the knife-edged valves, and the effects of dissolved gases on the homogenization efficiency. They established very well the place of cavitation in homogenization of milk products and were made use of in the design and operation of the knife-edged homogenizer valve which showed a very satisfactory performance in the experimental set-up.

This investigation of cavitation in homogenization was, however, by no means exhaustive. An investigation, relative to cavitation, of other eminent factors such as the temperature and the composition of the product being homogenized, and the shape of the constriction of the valve might yield information for even more effective and wiser utilization of cavitation for the purpose of homogenization. Some physical and chemical changes associated with homogenization such as the clumping of the fat globules after they have been broken up, the development of anti-oxidation effect, the occasionally observed pasty appearance of homogenized ice cream mix, etc., might have their explanation in cavitation. With due effort the adaption of the principle of cavitation homogenization to commercial operation should be possible.

APPENDIX I

Design of the Vacuum Homogenization Valve

The vacuum homogenization valve used in Part 1 of the experimental work was designed to provide a smooth constriction which would cause the hydrostatic pressure to drop to about 5 psi when the milk was being sucked through at the rate of 25 gallons per hour.

The procedure of the design was in four steps: to find the velocity of the flow at the valve needed for the pressure drop, to find the corresponding valve clearance, to determine the specification of the valve spring, and to design the accessory parts for housing the valve in a $1\frac{1}{2}$ inch sanitary pipe cross.

a. To find the velocity of the flow at the valve that would reduce the hydrostatic pressure to the vapor pressure of milk

The experimental set-up for vacuum homogenization is diagrammatically shown below.

$P_1 = 14.7$ psi. $\quad P_2 = 4.8$ psi.

$V_1 = 0 \quad V_2 = ?$

P_1 = pressure at the supply tank

= atmospheric pressure, approximately

= 14.7 psi.

P_2 = vapor pressure of milk at homogenization temperature 160°F.

= vapor pressure of water at 160°F., approximately

= 4.8 psi.

density of milk = 66 lbs./cu. ft.

Applying Bernoulli's equation to the supply tank and the homogenizer valve,

$$\frac{P_1}{m} + \frac{V_1^2}{2g} = \frac{P_2}{M} + \frac{V_2^2}{2g}$$

$$\frac{14.7 \times 144}{66} + 0 = \frac{4.8 \times 144}{66} + \frac{V_2^2}{2g}$$

Solving for V_2, $\quad V_2 = 37.6$ fps.

b. To find the valve clearance

Assuming a pump capacity of 25 gallons per hour, or 0.00093 cubic feet per second.

A = cross-sectional area of the flow at the valve

$= Q/V_2$

= 0.00093/37.6

= 0.0000247 sq. ft.

= 0.00356 sq. in.

Assuming a 3/8 in. effective diameter of the valve,

valve clearance = $0.00356/\pi \times 0.375$

$= 0.00302$ in.

c. Design of the valve spring

Assuming that the valve should open when the pressure in the valve chamber drops down to 10 psi and that during operation the pressure in the valve chamber is around 5 psi, then

the change of load on the spring = $(10-5)(\frac{3}{8})^2 \frac{\pi}{4}$

$= 0.55$ lbs.

valve clearance = 0.00302 in.

therefore, spring rate = 0.55/0.003 = 183 lbs./in.

Let G = torsional modulus of elasticity

= 11,500,000 psi

D = diameter of the spring

= 9/16 in.

n = number of coils in the spring

= 6

d = diameter of the wire of the spring

Then

$$183 = 11{,}500{,}000\ d^4 / 8 \times 6 \times D^3$$

Solving, d = 1/8 in., approximately.

Hence, the specification of the spring should be as follows:

wire size = 1/8 in. dia.

spring diameter = 9/16 in.

no. of coils = 6

pitch = 3/16 in.

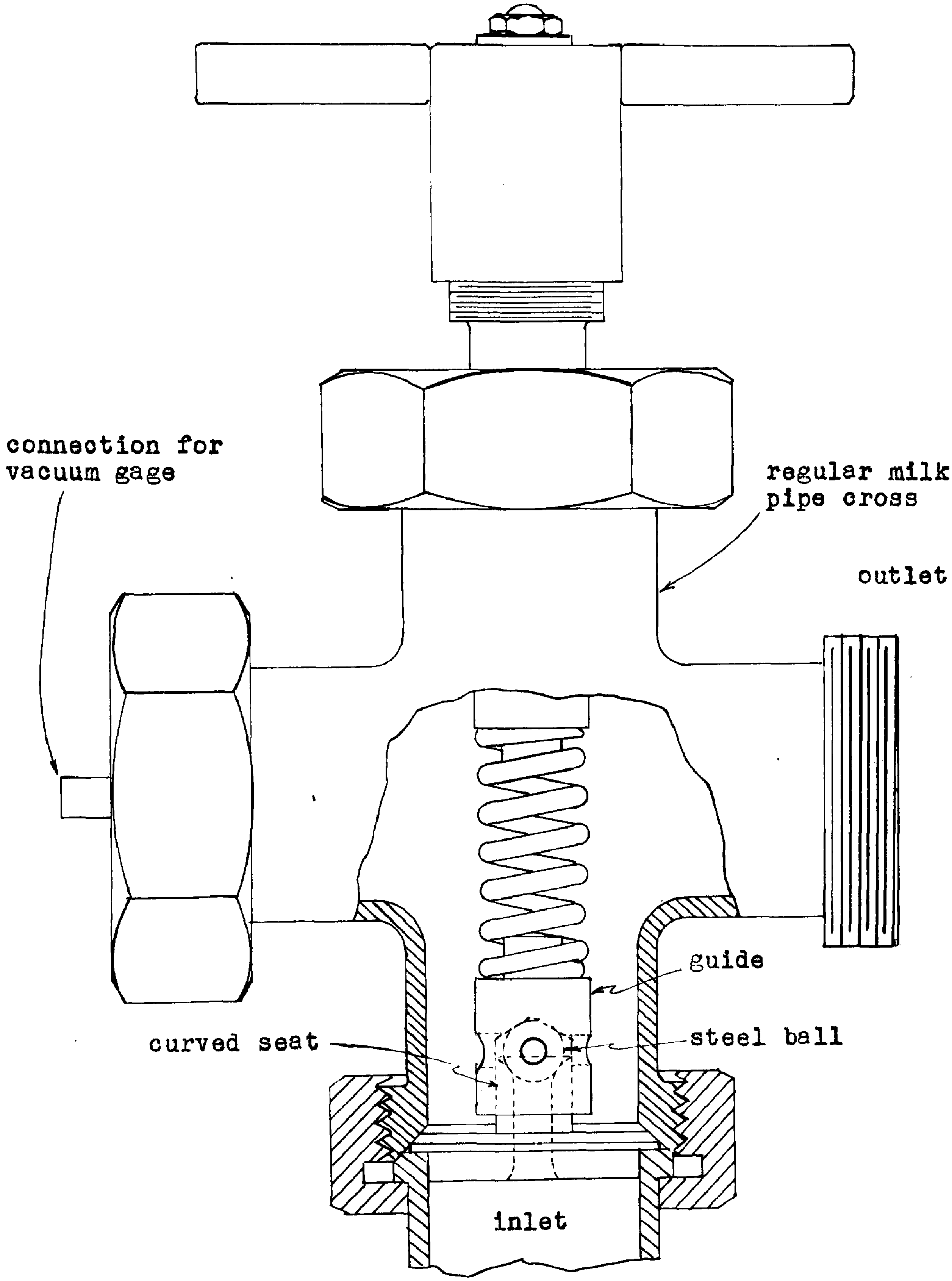


Figure A1 Cross-sectional view of the experimental vacuum homogenization valve.

APPENDIX II

The Calibration of the Capacity Regulation Valve of the Rotary Pump Used in the Experiment of Vacuum Homogenization

Since the rotary pump available for the experiment of vacuum homogenization had a capacity of 375 gal. per hour, a by-pass valve was used to cut down the capacity to the desired value, namely 25 gallons per hour. The arrangement is shown in Figure A3. The by-pass valve was a 1 inch sanitary valve. Marks were stamped on the valve as shown for graduation purpose. But the valve was found to be insensitive for the purpose. A thin slot was cut on the valve plug as shown in Figure A4 to allow more precise control. The valve was set at different positions and the time required to pump one gallon of water at various degrees of vacuum was noted. The capacity corresponding to different valve settings was calculated and plotted to construct a calibration chart for the capacity regulation valve. However, the reliability of the results was rather doubtful, because the pump was leaking at the shafts.

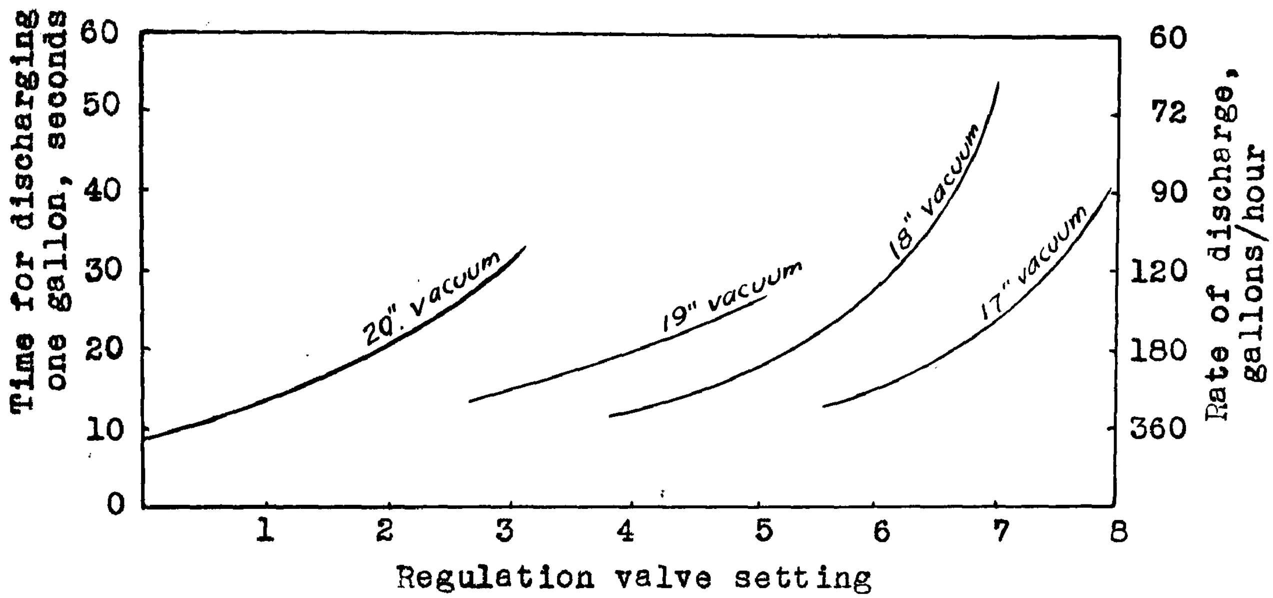


Fig. A2 Calibration chart of the capacity regulation valve of the rotary pump used to produce vacuum for the vacuum homogenization valve.

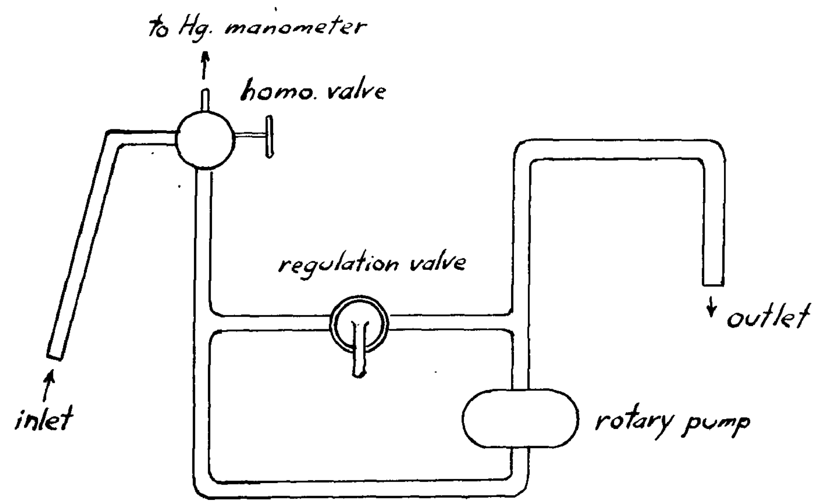


Fig. A3 Pipe line connection of the vacuum homogenization valve, the regulation valve, and the rotary pump.

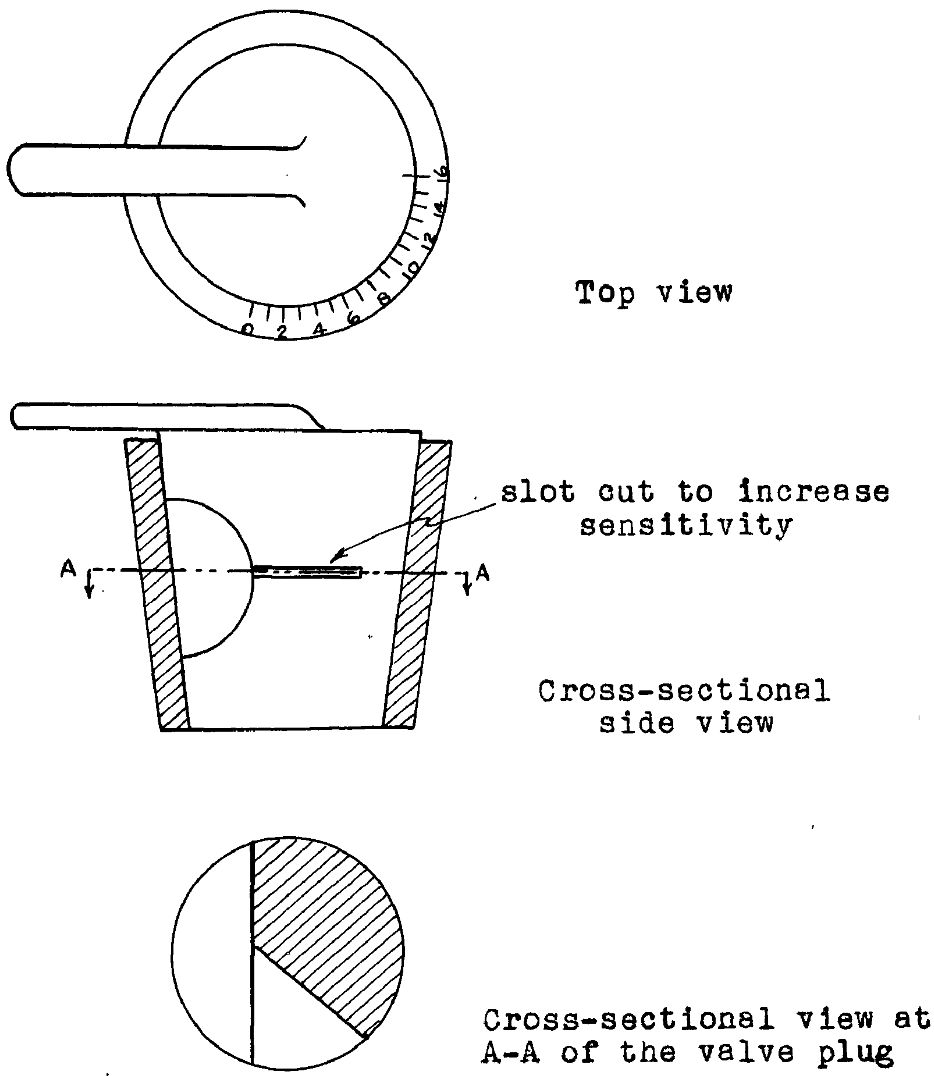


Fig. A4 Views of the regulation valve showing the slot cut to increase its sensity.

TABLE AI

THE CAPACITY OF THE ROTARY
PUMP AT VARIOUS DEGREES OF VACUUM
AND SETTINGS OF THE REGULATION VALVE

Reg. valve setting	Vacuum in. Hg.	Amount of water delivered, gal.	Time, sec.	Capacity gal./hr.
0	20	1	12	300
1	20	1	15	240
2	20	1	17	212
3	19	1	14	257
3	20	1	32	112
4	18	1	15	240
4	19	1	22	164
5	18	1	15	240
5	19	1	23	156
6	17	1	14	257
7	18	1	52	69
7	17	1	27	133
7	16	1	17	212
8	17	1	35	102

APPENDIX III

A Mathematical Study of the Magnitude of the Force Necessary to Break a Fat Globule

Though the exact manner in which a fat globule is broken up in the process of homogenization is uncertain, the force necessary to break a fat globule into two halves may be calculated hypothetically by assuming that the globule is broken in one of the three possible ways, namely, breaking into two halves along a meridian plane, by gradual narrowing down at the middle (i.e. gradual reduction in equatorial diameter), or by shearing along a meridian plane. The effects of the enveloping serum, the electrostatic charges, and the elasticity of the liquid fat are neglected in the following calculations.

1. Breaking open along a meridian plane

The force may be calculated from the equation for force between two plates separated by a thin layer of a liquid fat, which is

$$F = 2AS\left(\frac{\cos\theta}{d} - \frac{1}{2R}\right) + BS\sin\theta \quad \text{dynes} \qquad (17)$$

where θ = angle of contact

d = distance between the two plates

R = radius of curvature of the meniscus

A = area of each plate

S = surface tension

B = circumference of the plate.

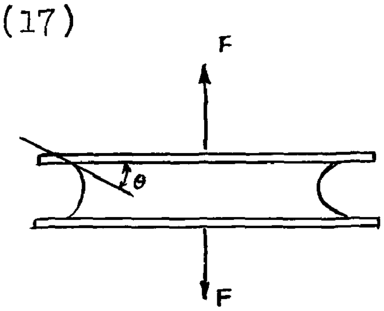


Fig. A5 Two plates separated by a drop of liquid.

If we have two imaginary parallel planes very close together at a meridian plane of a fat globule, we have

$\theta = 90^o$

$R = -r = -$(radius of the fat globule)

$A = \pi r^2$

$B = 2\pi r$

Then,

$$F = 2\pi r^2 S(\frac{\cos 90^o}{d} + \frac{1}{2r}) + 2\pi r\ S \sin 90^o$$

or $$F = 2\pi r^2 S(\ 0 + \frac{1}{2r}) + 2\pi r S$$

or $$F = 3\pi r S \text{ dynes}$$

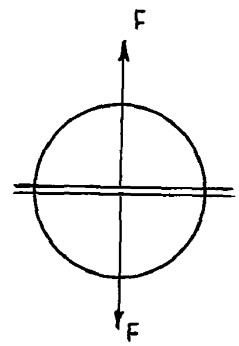


Fig. A6 A liquid sphere breaking into halves along a meridian plane.

2. Breaking a fat globule by reducing the equatorial diameter to zero

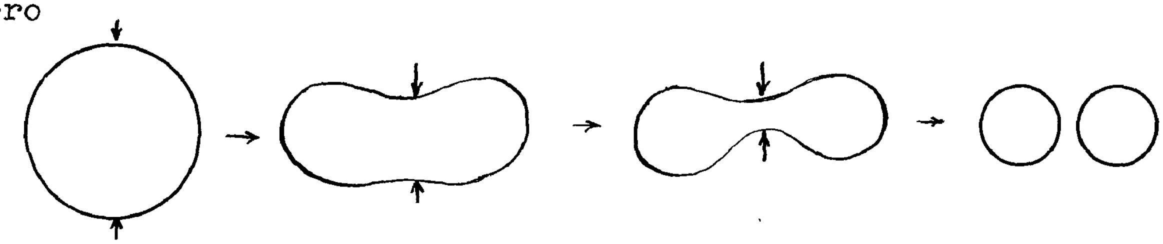


Fig. A7 Hypothetical process of breaking a liquid sphere by reducing the equatorial diameter to zero.

Since a sphere has the minimum surface area with respect to volume, any deformation must be accompanied by an increase in surface area. If the elasticity of the liquid is neglected, the work necessary to deform the globule equals the corresponding increase in surface energy.

Let W be the work necessary to deform a sphere of fat into two halves. Then

W = increase in surface energy

$= 2S\pi(2r_1)^2 - S\pi(2r)^2$ ergs

where r = radius of the original globule

r_1 = radius of the resultant half-volume globules $= (\frac{1}{2})^{\frac{1}{3}} r$

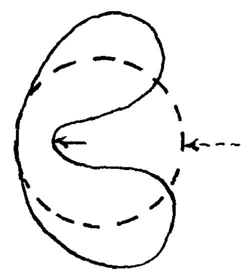
Therefore, $W = 2S\pi(2\sqrt[3]{\tfrac{1}{2}}\, r)^2 - S\pi(2r)^2$

$= 1.04\ S\pi r^2$ ergs

Assuming that this work is done by a force travelling all across the diameter of the globule, as shown in Figure A8, then

$F = 1.04\ S\pi r^2/2r = 0.52\ S\pi r$ dynes

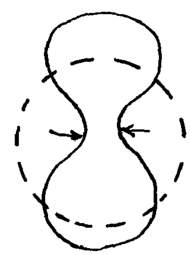
Fig. A8



If the distance travelled by the force is r as shown in Fig. A9 then

$F = 1.04\ S\pi r^2/r = 1.04\ S\pi r$ dynes

Fig. A9



3. Breaking a fat globule by shearing

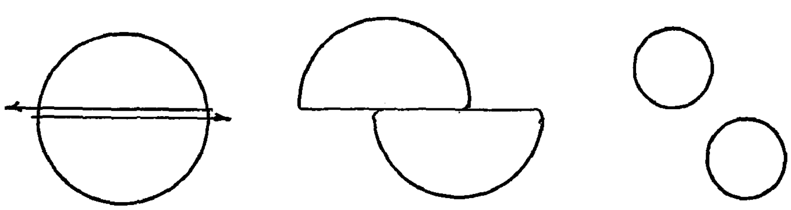


Fig. A10 Hypothetical process of shearing a liquid sphere.

Since the fat is assumed to have no shearing elasticity the work done in shearing should be the same as that calculated for breaking by reducing the equatorial diameter to zero. Hence,

$F = 0.52\ S\pi r$ dynes

APPENDIX IV

A Mathematical Study of the Size of the Cavity Which is Capable of Breaking a Fat Globule on its Collapse

Since the force necessary to break a fat globule into two halves has been found hypothetically in Appendix III the size of the cavity necessary to produce such a force on its collapse may be calculated by the use of the water hammer equation and Rayleigh's equation (19).

Assuming that the force F acts over an area on the fat globule equal to $k\pi r^2$, k being a constant, the impact pressure P due to the water hammer action upon the collapse of a cavity is

$$P = 1.04\ S\pi r/k\pi r^2$$

$$= \frac{1.04}{k} \cdot \frac{S}{r} \text{ dynes/cm}^2.$$

The average size of milk fat globules is around 4 microns, and S at 160°F is around 5 dynes/cm.

Hence, $P = 1.04 \times 5/0.0002k$

$$= 26000\ k^{-1} \text{ dynes/cm}^2.$$

$$= 26.6/k \text{ gms./cm}^2.$$

$$= 0.37/k \text{ psi.}$$

From the water hammer equation,

$$P = \frac{\rho c U}{144} \text{ psi*}$$

*Adapted from the water hammer equation on page 395 Hydraulics 2nd Ed., by Schoda & Dawson, McGraw Hill Book Co., New York. 1934.

where ρ = mass density of liquid, slugs/cu.ft.,

r = specific density of liquid, lbs./cu.ft. (66 for milk),

c = velocity of sound in liquid (assumed to be the same as in water, 4700 ft./sec.), and

U = velocity of the in-rushing liquid,

The velocity of in-rushing liquid is

$$U = 144\ P/\rho c$$

or

$$= 144 \times 0.37 \times 32.2/(66 \times 4700k)$$

$$= 0.0055/k \text{ ft. per sec.}$$

If it is assumed that the cavity is a perfect vacuum at the moment of collapsing (i.e. all the vapor condenses and no other gases present), Rayleigh's formula for the velocity of contraction of cavity (19) can be used to determine the size of the cavity necessary to produce a sufficient force at its collapse. Rayleigh's formula states,

$$U = \left\{ \frac{2P}{3\rho} \left[\left(\frac{R_o}{R} \right)^3 - 1 \right] \right\}^{\frac{1}{2}}$$

where P = the hydrostatic pressure,

ρ = density of the liquid, (66 lb./cu.ft. for milk)

R_o = initial radius of the cavity,

R = radius of the cavity at the moment under consideration.

Putting the value of U obtained on the top of this page into Rayleigh's formula,

$$\frac{R_o}{R} = \sqrt[3]{1 + \frac{0.003}{Pk^2}}$$

Remembering that $k\pi r^2$, or $k(\frac{1}{4}$ x surface area of a fat globule), is the area on the fat globule over which the water hammer acts, it can be readily seen that the value of k is somewhere between 0 and 4. If the hydrostatic pressure is near atmospheric (2.12×10^3 lbs./sq/ft.) then the term $0.003/Pk^2$ will be significant only when the value of k is in the order of 10^{-2} or less. Therefore, the ratio $\frac{R_0}{R}$ should be not very far from 1 if the assumptions are correct, i.e. the collapse of the cavity is instantaneous and there is no resistance due to uncondensed vapor or undissolved gases.

The actual conditions can be expected to deviate greatly from what have been set forth in the above calculations.

1. The formation of the cavity requires the expenditure of energy to evaporate the water and to work against the hydro static pressure. Since it is a constant presspure process in a steady flow the source of energy would be the thermal energy of the surrounding milk. Hence, there must be a reduction in the temperature of the shell of the cavity. The reduction in temperature raises the surface tension and also may harden the fat globule to some extent. The force necessary to break the fat globule would thus be greater than just calculated.

2. It is known that in rapid operation, the elasticity of the liquid becomes significant. The work done in deforming the fat globule may not be negligible.

3. Unless the milk is thoroughly deaerated, there are bound to be some gases present in the cavity, and unless the free gases go back into solution instantaneously as the Van Iterson (25) theory postulates such gases may serve as cushion at the moment of collapse of the cavity. Hence, the hammering action would be much weaker than calculated.

4. In the homogenization of milk the fat globules are supposed to break into more than just two smaller ones. The actual situation would be much more complicated than what is assumed in the calculations.

5. The fat globules in milk have a surface adsorption layer of proteinous material which no doubt affects the magnitude of the force necessary to break the fat globule.

APPENDIX V

Determining the Representativeness of the Milk Collected in the Steel Cylinder Inserted between the First- and Second-stage Valve Blocks of a Manton-Gaulin Laboratory Homogenizer

In the investigation of the influence of exit side hydrostatic pressure on homogenization efficiency a steel cylinder which had a capacity of about one quart was inserted between the first- and the second-stage valve blocks of the homogenizer. It was necessary to determine the proper length of time that must elapse for getting a representative milk in the steel cylinder after the pressures were adjusted. To do this, successive quarts of milk discharging from the homogenizer were collected after the pressures became steady and tested for U.S.P.H.S. index and Farrall's index. The results, tabulated in Table AII and plotted in Figure All, show that milk in the cylinder can be taken as a representative sample after at lease two quarts of milk have been discharged from the homogenizer after the pressures become steady.

TABLE AII

DEGREE OF HOMOGENIZATION OF SUCCESSIVE QUARTS OF MILK DISCHARGED FROM A MANTON-GAULIN LABORATORY MODEL CGB 25 GPH HOMOGENIZER WITH A STEEL CYLINDER INSERTED BETWEEN THE FIRST AND THE SECOND-STAGE VALVE BLOCKS

Sample	1st.qt.	2nd.qt.	3rd.qt.	4th.qt.	5th.qt.	6th.qt.
U.S.P.H.S. index	41.3	18.1	11.0	11.0	11.0	12.0
Farrall's index	362	161	47	62.3	37.1	43.1

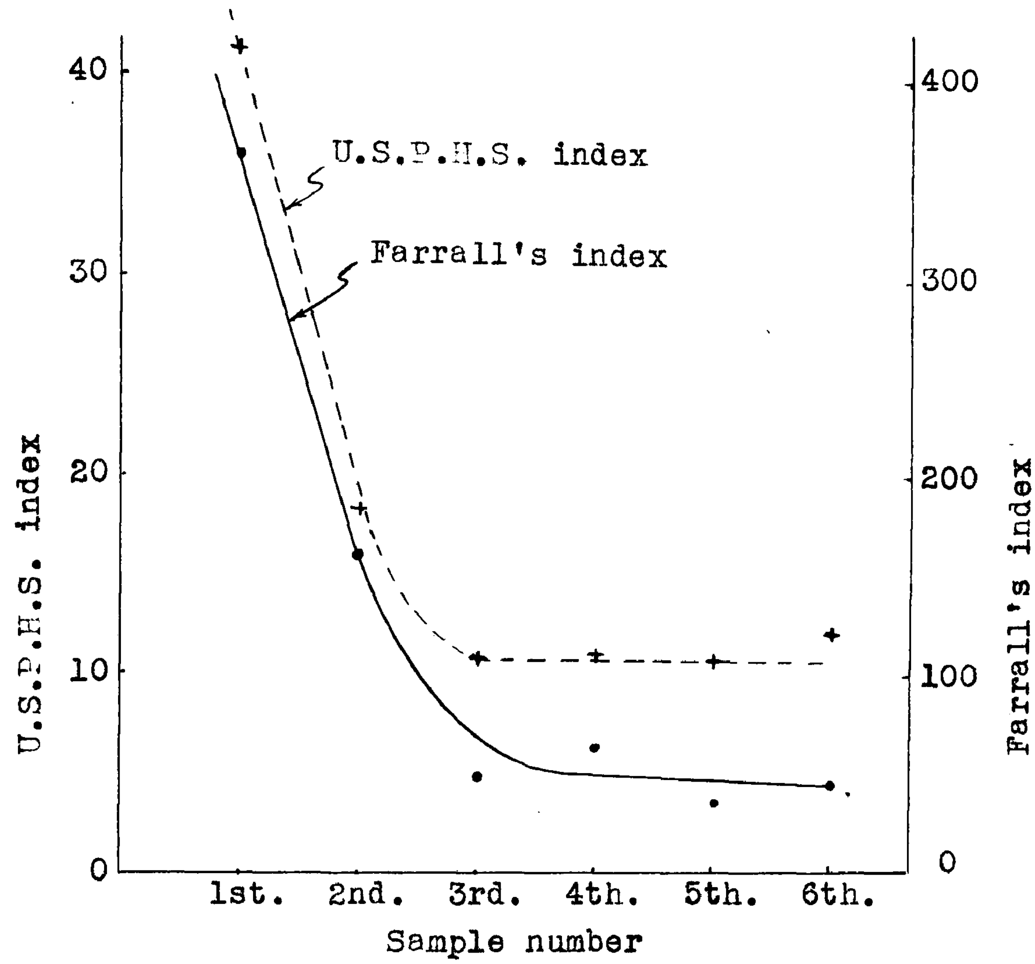


Figure A11 Degree of homogenization of successive quarts of milk discharged from the Manton-Gaulin laboratory homogenizer with a steel cylinder inserted between the first-stage and the second-stage blocks.

APPENDIX VI

Some Peculiarities in the Pressure Adjustment of the Single-piston Two-stage Laboratory Model Homogenizer

It is almost a rule that a two-stage homogenizer is provided with only one pressure gage, though there are two pressures to be regulated. Because of this fact the customary way of adjusting the first- and the second-stage pressures is as follows: With the first-stage valve open, the second-stage valve is adjusted until the pressure gage indicates the desired second-stage pressure, then the first-stage valve is turned in until the pressure gage indicates the sume of the desired first- and second-stage pressures. However, in one of the experiments using the Manton-Gaulin laboratory model homogenizer it was accidentally noticed that this conventional way of using one pressure gage for regulating two pressures did not seem to be reliable. It was noticed that after the pressures were adjusted the pressure gage did not fall to the desired first-stage pressure on the release of the second-stage valve, being higher than what was expected. Upon closer investigation, it was found that the higher the second-stage pressure the more greatly the first-stage pressure differs from the desired on the release of the second-stage valve. Table AIII shows such differences.

Such differences might be an indication that the conventional way of using the pressure gage in a two-stage homogenizer was not correct. Since the customary way of using a single pressure gage in a two-stage homogenizer is based on the constant delivery nature of the homogenizer pump, the next item checked was the rate of delivery at different pressures. The results are shown in Table AIV. The average capacity was 21.0 gallons per hour. The maximum fluctuation was less than 5% from the average.

TABLE AIII

PRESSURE READINGS INDICATED BY A SINGLE PRESSURE GAGE OF A TWO-STAGE SINGLE-PISTON HOMOGENIZER WHEN THE VALVES WERE ADJUSTED IN THE CONVENTIONAL WAY

Desired 2nd.-stage pressure, psi	500	1000	1500
Desired 1st.-stage pressure difference, psi	2500	2500	2500
Gage reading when 2nd.-stage valve was adjusted, psi	500	1000	1500
Gage reading when 1st.-stage valve was also adjusted, psi	3000	3500	4000
Gage reading when the 2nd.-stage valve was released, psi	2700	3050	3500
Difference from desired 1st-stage pressure difference, psi	200	550	1000

TABLE AIV

CAPACITY OF THE TWO-STAGE SINGLE-PISTON LABORATORY HOMOGENIZER AT VARIOUS PRESSURES

Pump press., psi	1500	2000	2500	3000	3500	3000	3500	4000
2nd.-stage press., psi	0	0	0	0	0	500	1000	1500
Time for delivering one gallon, sec.	180	177	167	167	168	170	170	173
Capacity, gal./hr.	20.0	20.3	21.5	21.5	21.4	21.2	21.2	20.8

TABLE AV

BEHAVIOR OF THE READINGS OF TWO PRESSURE GAGES OF A TWO-STAGE SINGLE-PISTON HOMOGENIZER - I

(Method of manipulating the valves: The second-stage valve was adjusted first, then the first stage valve was adjusted to get a gage reading on the pump gage equal to the sum of the desired pressures, then the second-stage valve was released.)

2nd.-stage gage reading when the 2nd.-stage valve was adjusted, psi	500	1000	1500
Pump gage reading when 1st.-stage valve was also adjusted, psi	3000	3500	4000
1st.-stage pressure difference, psi	2500	2500	2500
Pump gage reading when 2nd.-stage valve was released, psi	2850	3200	3600

TABLE AVI

BEHAVIOR OF THE READINGS OF TWO PRESSURE GAGES OF A TWO-STAGE SINGLE-PISTON HOMOGENIZER - II

(Method of manipulating the valves: The first-stage valve was first adjusted to get the desired pump pressure, then the second-stage valve was adjusted until the second-gage indicated the desired second-stage pressure, then the pump gage reading was again noted.)

Pump gage reading when the first-stage valve was adjusted, psi	2500	2500	2500
Second-stage gage reading when the second-stage valve was adjusted, psi	500	1000	1500
Pump gage reading after the second-stage valve was adjusted, psi	2650	2750	2950
Pump gage reading when second-stage valve was released, psi	2500	2500	2500

The next item investigated was to insert a pressure gage between the first-stage and the second-stage valves in addition to the one at the homogenizer pump and to note the behavior of the gage readings for different pressure combinations. The results are shown in Tables AV and AVI.

Table AV seems to show that the valve clearance of the first-stage valve changes with different first- and second-stage pressure combinations though the pressure across the valve is maintained the same. Table AVI seems to show that though the valve hand-wheel was kept at the same setting the pressure difference across the valve changes as the second-stage pressure changes. Such behavior of the homogenizer makes it difficult in the experiments to maintain constant shearing and impingement and to vary the factors of cavitation. An investigation of such behavior was carried out on a different machine, a Manton-Gaulin triplex two-stage homogenizer at 125 gallons per hour capacity. The results shown in Table AVII are quite different from that obtained by using the single-piston homogenizer. The differences between the desired pump pressure and the gage reading upon the release of the second-stage valve were not so large as in the case of the single-piston homogenizer.

TABLE AVII

BEHAVIOR OF THE READINGS OF A SINGLE PRESSURE GAGE OF A TWO-STAGE TRIPLEX HOMOGENIZER

(Method of manipulating the valves: The second-stage valve was first adjusted to get the desired second-stage pressure, then the first-stage valve was adjusted until the pressure gage indicated the sum of the desired first- and second-stage pressures, then the second-stage valve was released and pressure gage reading again noted.)

Gage reading when second-stage valve was adjusted, psi	500	1000	
Gage reading when first-stage valve was also adjusted, psi	3000	3500	
Pressure difference across the first-stage valve, psi	2500	2500	
Gage reading when the second-stage valve was released, psi	2500	2600	(trial 1)
	2550	2700	(trial 2)

The principal structural differences between the single-piston homogenizer and the triplex homogenizer are listed below.

Single-piston homogenizer	Triplex homogenizer
1. Single piston, pressure unsteady.	1. Three pistons, pressure relatively steadier.
2. The outlet valve of the pump was also used as the first-stage valve.	2. Separate pump valves and homogenization valve.

Comparing the figures in Table AVII and Table AV, it can be seen that such behavior of the homogenizer is likely an individuality of a particular type of homogenizer.

APPENDIX VII

Statistical Analysis of the Results Obtained from the Experiments of Applying Pressure to the Exit Side of a Homogenizer Valve in a Manton-Gaulin Single-Piston Homogenizer

Part 1 Pressure difference across the homogenizer valve kept constant.

TABLE AVIII

EFFECT OF THE APPLICATION OF PRESSURE ON THE EXIT SIDE OF A HOMOGENIZER VALVE ON HOMOGENIZATION EFFICIENCY - I

(Milk samples were collected in a steel cylinder inserted between the first- and the second-stage blocks and their degrees of homogenization were expressed in terms of U.S.P.H.S. index, pressure difference across the homogenizer valve being maintained at 2500 psi.)

Homo. pump press. psi.		2500	3000	3500	4000	Sum
Cylinder pressure psi.		0	500	1000	1500	
U.S.P.H.S. indices	Run 1	8.75	15.3	14.8	14.6	53.45
	Run 2	8.4	12.9	12.3	10.9	44.5
	Run 3	7.6	13.8	13.1	11.6	46.1
Sums		24.75	42.0	40.2	37.1	144.05
Means		8.25	14.0	13.4	9.28	

Correction term = $(144.05)^2/12 = 1729.2002$

Total sum of squares = $8.75^2 + 8.4^2 + \ldots\ldots + 11.6^2$ - correction term

$= 95.0923$

Treatment (cylinder pressure) sum of squares = $(24.75^2 + 42.0^2 + 40.2^2 + 37.1^2)/3$ - correction term = 60.4706

Run sum of squares = $(53.45^2 + 44.5^2 + 46.1^2)/4$ - correction term = 11.3904

Discrepance = 95.0923 - 60.4706 - 11.3904 = 23.2313

TABLE AIX

ANALYSIS OF VARIANCE OF THE EXPERIMENT OF APPLYING PRESSURE TO THE EXIT SIDE OF A HOMOGENIZER VALVE WHILE THE PRESSURE DIFFERENCE ACROSS IT WAS KEPT CONSTANT

Sources of Variance	Degree of Freedom	Sums of Squares	Mean Squares	F ratio
Total	11	95.0923		
Treatments (cylinder pressures)	3	60.4706	20.157	5.21*
Runs	2	11.3904	5.695	1.46
Discrepance	6	23.2313	3.872	

*Significance level equal to 5%.

For six degrees of freedom $t_{.01} = 3.707$

$t_{.05} = 2.447$

Least significant difference between treatment means at 1% level

$= \sqrt{2 \times 3.872/3} \times 3.707 = 5.98$

Least significant difference between treatment means at 5% level

$= \sqrt{2 \times 3.872/3} \times 2.447 = 3.94$

Hence, when keeping the pressure difference across the homogenizer valve constant and discharging the milk into a pressure chamber of 500 psi and 1000 psi there was a significant lowering of homogenization efficiency. This was not true when the chamber pressure was at 1500 psi.

<u>Part 2</u> Homogenizer valve setting kept constant.

TABLE AX

EFFECT OF THE APPLICATION OF PRESSURE ON THE EXIT SIDE OF A HOMOGENIZER VALVE ON HOMOGENIZATION EFFICIENCY - II

(Milk samples were collected in a steel cylinder inserted between the first- and the second-stage blocks and their degrees of homogenization were expressed in terms of U.S.P.H.S. index, homogenizer valve setting being kept constant.)

Homo. pump press. psi.		2500	2650	2750	2900	Sums
Cylinder pressure psi.		0	500	1000	1500	
U.S.P.H.S. INDICES	Run 1	14.4	16.2	20.0	20.4	71.0
	Run 2	6.7	9.63	13.2	17.0	46.53
	Run 3	12.3	14.5	15.9	24.4	67.10
	Run 4	8.65	12.2	14.1	23.0	57.95
Sums		42.05	52.53	63.2	84.8	242.58
Means		10.51	13.12	15.80	21.18	

Correction term = $242.58^2/16 = 3677.816$

Total sum of squares = $14.4^2 + 6.7^2 + \ldots + 23.0^2$ - correction term

$= 370.193$

Treatment (cylinder pressure) sum of squares = $(42.05^2 + 52.53^2 + 63.2^2 + 84.8^2)/4$ - correction term = 250.405

Run sum of squares = $(71.0^2 + 46.53^2 + 67.10^2 + 57.95^2)/4$ - correction term = 88.847

Discrepance = 370.193 - 250.405 - 88.847 = 30.941

TABLE AXI

ANALYSIS OF VARIANCE OF THE EXPERIMENT OF APPLYING PRESSURE TO THE EXIT SIDE OF A HOMOGENIZER VALVE WHILE ITS SETTING WAS KEPT CONSTANT

Sources of Variance	Degree of Freedom	Sums of Squares	Mean Squares	F Ratio
Total	15	370.193		
Treatments (cylinder pressures)	3	250.405	83.468	24.478*
Runs	3	88.847	29.616	8.614
Discrepance	9	30.941	3.438	

*Significance level equal to 1%.

For 9 degrees of freedom $t_{.01} = 3.250$

$t_{.05} = 2.262$

Least significant difference between treatment means at 1% level

$$= \sqrt{2 \times 3.438/4} \times 3.250 = 4.27$$

Least significant difference between treatment means at 5% level

$$= \sqrt{2 \times 3.438/4} \times 2.262 = 2.97$$

Hence, the samples obtained when the cylinder pressure was 1000 psi or 1500 psi were very significantly different from the sample when the cylinder pressure was zero (atmospheric).

APPENDIX VIII

Statistical Analysis of the Results Obtained from the Bleeding Valve Experiments

Part 1 Four-hole valve.

TABLE AXII

DEGREES OF HOMOGENIZATION (IN TERMS OF FARRALL'S INDEX) OF MILK AT FOUR DIFFERENT LOCATIONS IN THE HOMOGENIZER VALVE

		Locations: Distance from Inner Edge of Valve 0.008"	0.010"	0.013"	0.016"	Homo. Outlet	Sums	Means
Slides series I	Farrall's indices	77.8 94.6 78.4 67.6	42.4 23.8 26.4 34.2	29.2 97.4 32.4 15.6	8.0 2.6 2.6 5.2	5.2 7.8 10.6 5.2		
	sum	318.4	126.8	174.6	18.4	28.8	667.0	
	mean	79.6	31.7	43.65	4.6	7.2		33.35
Slides series II	Farrall's indices	57.4 86.2 61.4 45.2	7.8 32.6 26.2 15.6	57.8 34.4 44.4 24.4	5.2 5.2 2.6 10.8	5.2 13.6 15.6 13.0		
	sum	250.2	82.2	161.0	23.8	47.4	564.6	
	mean	62.55	20.55	40.25	5.95	11.85		28.23
Sum		568.6	209.0	335.6	42.2	76.2	1231.6	
Mean		71.07	26.12	41.95	5.27	9.52		30.79
Diff. between series sums		68.2	44.6	13.6	5.4	18.6		

Correction term = $1231.6^2/40 = 37920.964$

Total sum of squares = $77.8^2 + 94.6^2 + \ldots + 13.0^2$ - correction term = 30476.88

Location sum of squares = $(568.6^2 + 209.0^2 + \ldots + 76.2^2)/8$ - correction term = 22979.24

Series sum of squares = $(667.0^2 + 564.6^2)/20$ - correction term = 262.14

Subclass sum of squares = $(318.4^2 + 250.2^2 + \ldots + 47.4^2)/4$ - correction term = 23879.3

Location x series interaction = 23879.3 - 22979.24 - 262.14 = 637.92

Slide sum of squares = $(68.2^2 + 44.6^2 + 13.6^2 + 5.4^2 + 18.6^2)/8$ - correction term = 900.06

TABLE AXIII

ANALYSIS OF VARIANCE OF THE BLEEDING VALVE EXPERIMENT USING A FOUR-HOLE VALVE

Source of variance	Degree of freedom	Sum of squares	Mean square	F ratio
Total	39	30476.88		
Locations	4	22979.24	5744.81	27.81*
Slides	5	900.06	180.01	0.87
Series	1	262.14	262.14	1.27
Location x series interaction	4	637.92	159.48	0.77
Discrepance	30	6197.29	206.57	

*Significance level equal to 1%.

If the hypothesis is that all the samples came from the same population, the mean square of location may be compared with that of the slides. Then

$$\text{F ratio for location} = \frac{\text{location mean square}}{\text{slide mean square}}$$

$$= 5744.81/180.01$$

$$= 31.913$$

$F_{.01} = 11.39$ for 4 and 5 degrees of freedom

Hence the hypothesis that all samples were from the same population cannot be established. The next step is to use t test to compare the samples from the bleeding holes with the sample collected at the outlet of the homogenizer.

$t_{.05}$ for 30 degrees of freedom = 2.042

$t_{.01}$ for 30 degrees of freedom = 2.750

Standard error of difference between means = $\sqrt{2 \times 206.57/8}$

$= 7.2$

Therefore,

least significant difference between means at 5% level

$= 7.2 \times 2.042 = 14.7$

least significant difference between means at 1% level

$= 7.2 \times 2.750 = 19.8$

Samples from the first and the third holes were significantly different from the sample from the homogenizer outlet at 1% level. Sample from the second hole was significantly different from the sample from the homogenizer outlet at 5% level. Sample from the fourth hole was insignificantly different from the sample from the outlet of the homogenizer.

Part 2 Eight-hole valve

TABLE AXIV

DEGREES OF HOMOGENIZATION (IN TERMS OF FARRALL'S INDEX) OF MILK AT EIGHT DIFFERENT LOCATIONS IN THE HOMOGENIZER VALVE

		Locations										
		Distance from Inner Edge of Valve, 1/100"								Homo. Outlet	Sum	Mean
		2.2	4.5	6.7	8.9	11.2	13.4	15.7	*17.9			
Slides Series I	Farrall's indices	23.8	10.6	18.8	24.6	13.0	7.8	7.8		23.8		
		31.4	13.4	10.4	15.8	21.0	18.8	2.6		13.2		
		0	20.8	21.0	15.6	18.6	15.8	26.2		23.8		
		18.6	5.2	23.8	10.4	29.0	18.4	18.6		15.8		
	Sum	73.8	50.0	74.0	66.4	81.6	60.8	55.2		76.6	538.4	
	Mean	18.45	12.50	18.50	16.60	20.40	15.20	13.80		19.15		16.825
Slides Series II	Farrall's indices	26.2	29.2	18.4	28.8	44.6	5.4	15.8		36.6		
		26.4	13.0	23.8	47.4	63.2	44.6	18.6		34.4		
		31.6	29.0	18.4	26.6	49.8	31.6	13.0		29.6		
		39.4	10.6	18.4	20.8	26.2	31.6	18.2		21.4		
	Sum	123.6	81.8	79.0	123.6	183.8	113.2	65.6		122.0	892.6	
	Mean	30.9	20.45	19.75	30.90	45.95	28.3	16.4		30.5		27.894
Sum		197.4	131.8	153.0	190.0	265.4	174.0	120.8		198.6	1431.0	
Mean		24.67	16.48	19.13	23.75	33.13	21.75	15.10		24.83		22.359
Series difference		49.8	31.8	5.0	57.2	102.2	52.4	10.4		45.4		

*No sample was obtained from this location because of the negative pressure there.

Correction term = $1431^2/64$ = 31996.26

Total sum of squares = $23.8^2 + 31.4^2 + \ldots. + 21.4^2$ - correction term

= 8611.29

Location sum of squares = $(197.4^2 + 131.8^2 + \ldots. + 198.6^2)/8$ - correction term

= 1828.07

Series sum of squares = $(538.4^2 + 892.6^2)/32$ - correction term

= 1960.27

Subclass sum of squares = $(73.8^2 + 123.6^2 + \ldots. + 122.0^2)/4$ - correction term

= 4596.58

Location x series interaction = 4596.58 - 1960.27 - 1828.07 = 808.24

Slides sum of squares = $(49.8^2 + 31.8^2 + \ldots. + 45.4^2)/8$ - correction term

= 2768.51

TABLE AXV

ANALYSIS OF VARIANCE OF THE BLEEDING VALVE EXPERIMENT USING AN EIGHT-HOLE VALVE

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Total	63	8611.29		
Locations	7	1828.07	267.15	3.122*
Slides	8	2768.51	346.06	4.137*
Series	1	1960.27	1960.27	23.437
Location x series interaction	7	808.24	115.46	1.380
Discrepance	48	4014.71	83.64	

*Significance level equal to 1%

Since the variation due to slide difference was significant, the slide mean square is used to compare the location mean square to judge the significant of location variations. Then

$$\text{F ratio for location} = \frac{261.15}{346.06} = 0.754$$

Which is insignificant.

Hence all samples seemed to have come from the same population.

APPENDIX IX

Composition of the Plain Ice Cream Mix and Chocolate Ice Cream Mix Used in the Experiments

Composition of the plain mix:

Skimmilk powder	134 lbs.
Milk (3.5% fat)	175 gal.
White Sugar	273 lbs.
Corn sugar	70 lbs.
Gelatin	7.6 lbs.
Sweetose	86 lbs.
50% cream	518 lbs.

This mix contains 12.4% milk fat, 12.3% milk solids, and 40% total solids.

Composition of the chocolate ice cream mix:

White sugar	225 lbs.
Water	15 lbs.
Skimmilk powder	67 lbs.
Corn sugar	35 lbs.
Gelatin	4 lbs.
Milk (3.5% fat)	756 lbs.
50% cream	117 lbs.
Swiss maid nugget	150 lbs.

This mix contains 6.5% milk fat, 10.6 milk solids, and 49% total solids.

APPENDIX X

Statistical Analysis of Twelve Runs of Homogenization of Milk Using Knife-edged Valves of Four Different Diameters

TABLE AXVI

U.S.P.H.S. INDICES OF HOMOGENIZATION OBTAINED BY USING FOUR SIZES OF KNIFE-EDGED VALVES, THREE FIRST-STAGE PRESSURES, AND FOUR SECOND-STAGE PRESSURES

Valve Diameters	Homo. Pump Pressures psi	Second-stage Pressures, psi				Sums	Means
		0	50	100	150		
3/16"	600	39.8	32.2	34.2	38.1*	144.3	
	800	12.7	9.0*	8.0	10.9	40.6	
	1000	18.1	9.2	8.5	6.7	42.5	
		70.6	50.4	50.7	55.7	227.4	18.9
1/4"	600	39.5	28.3	27.0	33.3	128.1	
	800	16.1	8.7	11.4	12.8	49.0	
	1000	17.2	11.4	9.2	6.7	44.5	
		72.8	48.4	47.6	52.8	221.6	18.5
3/8"	600	35.0	29.2	28.3	29.2	121.7	
	800	15.2	12.0	11.0	11.5	49.7	
	1000	16.9	9.2	5.4	5.9	37.4	
		67.1	50.4	44.7	46.6	208.8	17.4
1/2"	600	36.5	34.4*	35.2	43.3	149.4	
	800	18.5	13.9	14.9	14.5	61.8	
	1000	16.4	10.3	8.0	6.3*	41.0	
		71.4	58.6	58.1	64.1	252.2	21.0
Total		281.9	207.8	201.1	219.2	910.0	
Mean		23.45	17.3	17.6	18.3		18.95

*Values are estimated by using the formulas for calculating missing values in a randomized block layout. (1)(23)

TABLE AXVII

TWO 2-WAY TABLES, SUMMARY OF THE RESULTS OF TWELVE RUNS OF HOMOGENIZATION OF MILK USING KNIFE-EDGED VALVES

A	2nd.-stage Pressure					
1st-stage press., psi	0	50	100	150	Sum	Mean
600	150.8	124.1	124.7	143.9	543.5	34.95
800	62.5	43.6	45.3	49.7	201.1	12.5
1000	68.6	40.1	31.1	25.6	165.4	10.3
Total	281.9	207.8	201.1	219.2	910.0	

B	Valve Diameter					
1st-stage press., psi	3/16"	1/4"	3/8"	1/2"	Sum	Mean
600	144.3	128.1	121.7	149.4	543.5	34.95
800	40.6	49.0	49.7	61.8	201.1	12.5
1000	42.5	44.5	37.4	41.0	165.4	10.3
Total	227.4	221.6	208.8	252.2	910.0	

To determine the missing values the data are divided into three 2-way tables, one for each first-stage pressure with four diameters versus the four second-stage pressures. Then the appropriate formula for one missing value or two missing values was applied.

The formulas for two missing values in different treatments and blocks are

$$X = \frac{(r-1)(s-1)(sP_i + rQ_h - T) - (sP_j + rQ_k - T)}{[(s-1)(r-1)]^2 - 1}$$

$$W = \frac{(r-1)(s-1)(sP_j + rQ_k - T) - (sP_i + rQ_h - T)}{[(s-1)(r-1)]^2 - 1}$$

Where X is the estimate of the missing value in the i^{th} treatment and h^{th} block,

W is the estimate of the missing value in the j^{th} treatment and k^{th} block,

P_i and P_j are the sums of the known values in the i^{th} and j^{th} treatments respectively,

Q_h and Q_k are the sums of the known values in the h^{th} and k^{th} blocks respectively,

T is the sum of all known values, and

s and r the numbers of treatments and blocks respectively.

There are two missing values in the group of data under a first-stage pressure of 600 psi, namely, when d = 3/16" and P_2 = 150 psi and when d = 1/2" and P_2 = 50 psi, Hence,

$s = r = 4$

$P_i = 33.3 + 29.2 + 43.3 = 105.8$

$P_j = 32.2 + 28.3 + 29.2 = 89.7$

$Q_h = 39.8 + 32.2 + 34.2 = 106.2$

$Q_k = 36.5 + 35.2 + 43.3 = 115.0$

Substituting into the above formulas, the following values are obtained.

$X = 38.1$ (for $P_1 = 600$ psi, $P_2 = 150$ psi, and $d = 3/16"$)

$W = 34.4$ (for $P_1 = 600$ psi, $P_2 = 50$ psi, and $d = 1/2"$)

The formula for one missing value is

$$X = \frac{tT-bB-S}{(t-1)(b-1)}$$

where t is the number of treatments,

b is the number of blocks,

T is sum of items with same treatment as missing item

B is sum of items in same block as missing item,

S is sum of all observed items.

To estimate the index for $P_1 = 800$ psi, $P_2 = 50$ psi, and $d = 3/16"$

$t = b = 4$

$T = 34.62$

$B = 31.55$

$S = 183.77$

Putting these values into the above formula,

$X = 8.99$ or 9.0, say.

To estimate the index for $P_1 = 1000$ psi, $P_2 = 150$ psi, and $d = 1/2"$

$t = b = 4$

$T = 19.3$

$B = 34.7$

$S = 159.1$

Putting these values into the above formula,

$X = 6.3$

Following is the statistical analysis of the results.

Correction term (C.T.) = $(910)^2/48 = 17252.08333$

Total sum of squares = $39.8^2 + 12.7^2 + \dots + 6.3^2 - \text{C.T.}$

$= 6197.27667$

2nd.-stage pressure sum of squares

$$= \frac{(281.9^2 + \dots + 219.2^2)}{12} - \text{C.T.}$$

$= 342.77500$

1st.-stage pressure sum of squares

$$= \frac{(543.5^2 + \dots + 165.4^2)}{16} - \text{C.T.}$$

$= 5447.33042$

Valve diameter sum of squares = $\frac{227.4^2 + \dots + 252.2^2}{12} - \text{C.T.}$

1st. and 2nd-stage pressures interaction sum of squares

$$= \frac{150.8^2 + \dots + 25.6^2}{4} - P_1 \text{ sum of sqs.}$$

$- P_2$ sum of sqs. - C.T.

$= 123.98125$

Interaction between diameter and 1st.-stage pressure

sum of squares = $\frac{144.3^2 + \dots + 41.0^2}{4}$ - diam. s.s.

$- P_1$ s.s. - C.T.

$= 109.77792$

TABLE AXVIII

ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Total	43	6197.27667		
1st.-stage pressure	2	5447.33042	2723.66	691
2nd.-stage pressure	3	342.77500	114.26	29.0
Valve diameter	3	82.88333	27.62	7.01
Interaction between 1st. and 2nd.-stage pressures	6	123.98125	20.66	5.25
Interaction between 1st.-stage press. and valve diameter	6	109.77792	18.29	4.63
Error	23	90.52875	3.94	

All the F ratios are significant at the 1% level.

t-test for diameter and second-stage pressure

For error of 23 degrees of freedom

$$t_{.05} = 2.069$$

$$t_{.01} = 2.807$$

The standard diviation of the mean for either the second-stage pressure or the diameter is

$$S = \sqrt{2(3.94)/12} = 0.811$$

Hence, the least significant differences are

$$L.S.D._{.05} = 0.811 \times 2.069 = 1.68$$

$$L.S.D._{.01} = 0.811 \times 2.807 = 2.28$$

Using these values to check the mean indices of the various diameters and second-stage pressures, it is found that there was significant difference at 1% level between the 1/2" valve and the rest, and between $P_2 = 0$ and the other second-stage pressures.

APPENDIX XI

A Comparison of the U.S.P.H.S. Method and Farrall's Method of Judging the Degree of Homogenization of Milk

In the "bleeding valve" experiments the samples of milk obtained were small. It was necessary to have some method of determining the degree of homogenization of very small samples. The microscopic method devised by Farrall, Walts, and Hanson (11) seemed to be the answer. A number of milk samples were tested for the purpose of getting familiar with the operations of this method and at the same time providing some idea of the relationship between this microscopic method and the U.S. P.H.S. method. The results of eleven samples over a wide range of degree of homogenization are presented in Table AXIX and plotted in Figure A12.

TABLE AXIX

THE DEGREE OF HOMOGENIZATION OF ELEVEN SAMPLES OF MILK MEASURED BY THE U.S.P.H.S. AND FARRALL'S METHODS

Sample No.	Fat Test,%	U.S.P.H.S. Index	Farrall's Index
1	3.7	41.3	362
2	3.7	18.1	161
3	3.70	11.0	47
4	3.70	11.0	62.3
5	3.70	11.0	37.1
6	3.70	12.0	43.1
7	3.65	8.47	28.2
8	3.65	14.8	34.8
9	3.65	8.86	18.8
10	3.65	14.6	38.8
11	3.65	15.6	47.0

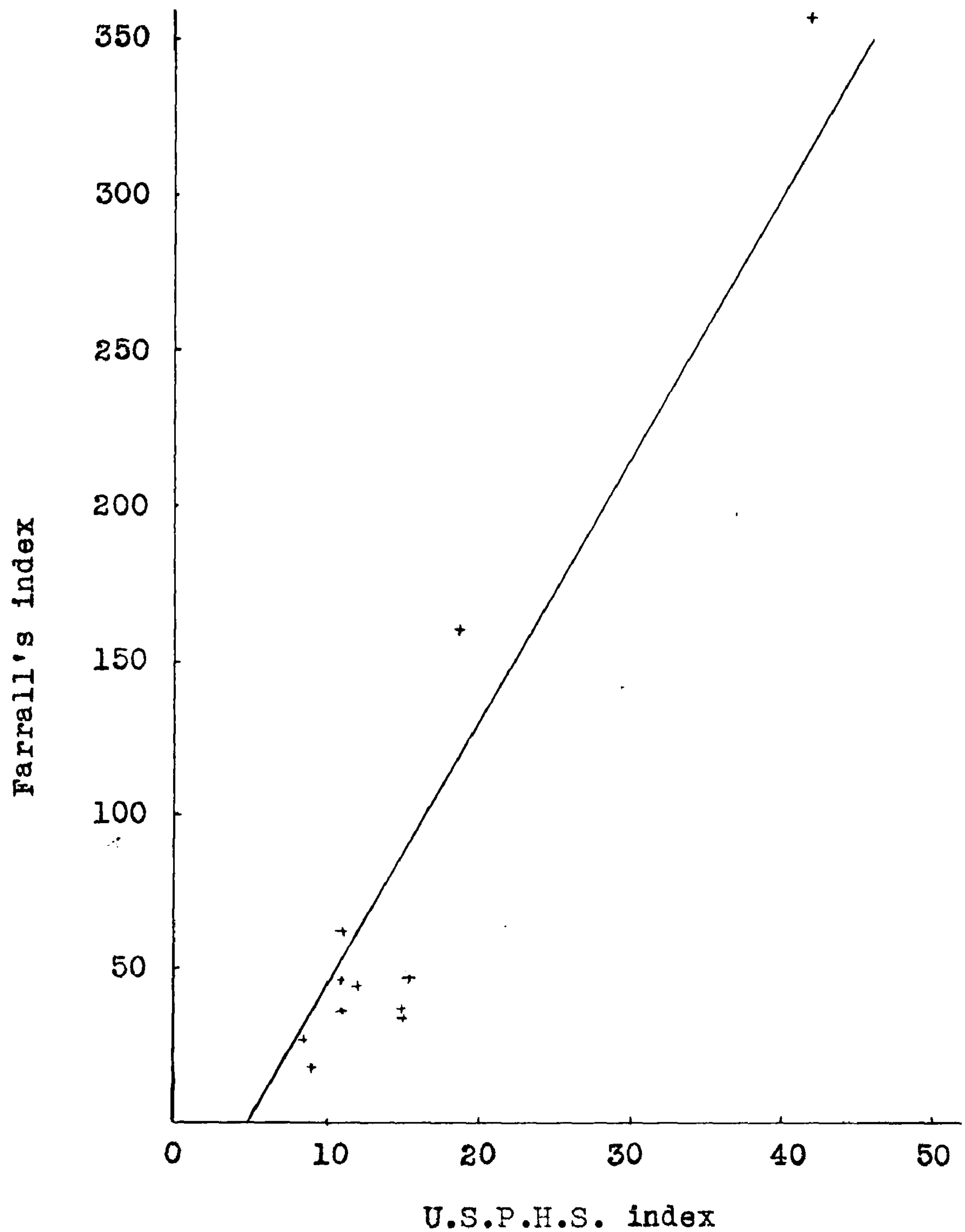


Figure A12 Farrall's index versus U.S.P.H.S. index of the degrees of homogenization of eleven samples of milk.

TABLE AXX

REGRESSION OF THE U.S.P.H.S. INDEX ON FARRALL'S INDEX OF HOMOGENIZATION

Sample No.	U.S.P.H.S. Index x	Farrall's Index y	Product of indices xy	Squares of U.S.P.H.S. Index x^2	Regression Farrall's Index y'	Deviation from Regression $y-y'$	Square $(y-y')^2$	Deviation from Mean $y-\bar{y}$	Square $(y-\bar{y})^2$
1	41.3	362	14950	1705.7	318.25	44	1936	229	52441
2	18.1	161	2914	327.6	114.9	46	2116	26	676
3	11.0	47	517	121	52.7	-6	36	-37	1369
4	11.0	62.3	685	121	52.7	9	81	-37	1369
5	11.0	37.1	408	121	52.7	-16	256	-37	1369
6	12.0	43.1	517	144	61.5	-18	324	-28	784
7	8.47	28.2	239	71.7	30.5	-2	4	-59	3481
8	14.8	34.8	515	219.04	86	-52	2704	-3	9
9	8.86	18.8	167	78.5	33.9	-15	225	-55	3025
10	14.6	38.8	566	213.16	84.3	-46	2116	-5	25
11	15.6	47.0	733	243.36	93.0	-46	2116	4	16
Sum	166.73	980.1	22211	3366.07			18914		64564

From the results shown in Table AXIX the mathematical relationship between the two methods of measuring the degree of homogenization may be derived by applying the least square method as follows.

Let the least square line be $y' = a + m(x - \bar{x})$,

x = observed U.S.P.H.S. index,

y = observed Farrall's index, and

n = number of samples.

$$a = \bar{y} = \Sigma y/n = 980.1/11 = 89.1$$

$$\bar{x} = \Sigma x/n = 166.73/11 = 15.16$$

$$m = (n\Sigma xy - \Sigma x\Sigma y)/[n\Sigma x^2 - (\Sigma x)^2]$$

$$= (11 \times 22211 - 166.7 \times 980.1)/(11 \times 3366.07 - 166.73^2)$$

$$= 8.764$$

Hence, the lease square line is

$$y' = 89.1 + 8.764(x - 15.16)$$

or

$$y' = 8.76x - 43.7$$

This equation is the experimentally derived relation between Farrall's index and the U.S.P.H.S. index of degree of homogenization. From this equation the value of Farrall's index corresponding to a U.S.P.H.S. index of 10, which is the common upper limit of homogenized milk, was calculated to be 44.

Doan, Josephson and Adams (9) found that a Farrall's index of 20 corresponds to a U.S.P.H.S. index of 5. Later Doan, and Mykleby (10) recommended a Farrall's index of 12 as satisfactory limit of homogenized milk. In the same year Doan (8) found that a Farrall's index ranging from 5 to 7 corresponded to a U.S.P.H.S. index ranging from 2 to 7.

The variation in the findings was more likely due to the unstandardized method of performing the U.S.P.H.S. method of determining the homogenization efficiency. Various methods of separating the top 100 ml. of milk after 48 hours of standing at a certain temperature can be found in the literature. Those methods may yield very different results.

Farrall's method should serve as a quick and convenient way of determining the degree of homogenization. However, the method may show variable results because

1. There may be variation in the thickness of the milk films on the slides.
2. There may be variation in the abilities of the operators to differentiate globules of neighboring size classes.
3. There may be variation introduced in the calculation of the index by neglecting the variation in fat content of the milk samples. A richer milk would have more fat globules than a less rich milk if the globules are of the same size distribution.

APPENDIX XII

Statistical Analysis of the Results of Homogenizing Milk with Air Injection Using the Knife-edged Valve

TABLE AXXI

EFFECT OF ADDING AIR TO MILK ON HOMOGENIZATION EFFICIENCY

(U.S.P.H.S. indices of milk homogenized by the knife-edged valve at a homogenizer pump pressure of 800 psi, second-stage pressure of 50 psi, and four different air saturation pressures, temperature of milk at 140° F.)

	Air Saturation Press., psi				Sum	Mean
	25	20	10	0		
Run 1	14.1	12.5	7.8	11.8	46.2	11.5
Run 2	11.9	12.3	11.5	10.2	45.9	11.5
Run 3	9.8	11.9	10.9	11.4	44.0	11.0
Sum	35.8	36.7	30.2	33.4	136.1	
Mean	11.9	12.2	10.1	11.1		11.3

Correction term = $136.1^2/12 = 1543.6008$

Total sum of squares = $14.1^2 + \ldots\ldots + 11.4^2$ - C.T. = 27.1492

Treatment sum of squares = $(35.8^2 + \ldots\ldots + 33.4^2)/3$ - C.T.

= 8.4425

Run sum of squares = $(46.2^2 + 45.9^2 + 44.0^2)/4$ - C.T.

= 0.7117

TABLE AXXII

ANALYSIS OF VARIANCE OF THE EFFECT OF ADDING AIR TO MILK ON HOMOGENIZATION EFFICIENCY

Source	Degree of Freedom	Sum of Squares	Mean Square	F ratio
Total	11	27.1492		
Treatments	3	8.4425	2.8141	0.938
Runs	2	0.7117		
Discrepance	6	17.9950	2.9991	

The small value of F ratio for treatments indicates that no significant effect on the efficiency of homogenization was produced by the particular air saturation pressures used.

APPENDIX XIII

Statistical Analysis of the Results of Homogenizing Ice Cream Mix with Air Injection Using the Knife-edged Valve

TABLE AXXIII

EFFECT OF ADDING AIR TO ICE CREAM MIX ON HOMOGENIZATION EFFICIENCY

(Farrall's indices of ice cream mix homogenized by the knife-edged valve at 150° F.)

Homo. Pump Press. psi	Air Sat. Press. psi	2nd.-stage Press. psi	Run 1	Run 2	Run 3	Total	Mean
800	0	100	239.2	191.7	153.2	584.1	194.7
800	0	200	277.1	118.3	138.9	534.3	178.1
800	50	100	212.1	88.2	168.1	468.4	156.1
800	50	200	241.0	97.4	84.0	422.4	140.8
800	75	100	97.1	56.8	80.9	234.8	78.3
800	75	200	147.5	55.2	95.8	298.5	99.5
Total			1214.0	607.6	720.9	2542.5	
Mean			202.33	101.2	120.1		141.25
1000	0	100	212.6	31.1	52.0	295.7	98.5
1000	0	200	173.1	36.5	90.6	300.2	100.1
1000	50	100	62.5	25.4	236.9	324.8	108.3
1000	50	200	57.5	20.0	56.2	133.7	44.6
1000	75	100	60.6	5.7	35.2	101.5	33.8
1000	75	200	33.3	24.1	66.9	124.3	41.4
Total			599.6	142.8	537.8	1280.2	
Mean			99.9	23.8	89.6		71.12
Total			1813.6	750.4	1258.7	3822.7	

TABLE AXXIV

THREE TWO-WAY TABLES OF THE EFFECT OF ADDING AIR TO ICE CREAM MIX ON HOMOGENIZATION EFFICIENCY

	Air Sat. Press.	Second-stage pressure 100	Second-stage pressure 200	Total	Mean
A	0	879.8	834.5	1714.3	142.8
	50	793.2	556.1	1349.3	112.4
	75	336.3	422.8	759.1	63.2
	Total	2009.3	1813.4	3822.7	
	Second-stage Press.	**First-stage Pressure 800**	**First-stage Pressure 1000**	**Total**	**Mean**
B	100	1287.3	722.0	2009.3	111.5
	200	1255.2	558.2	1813.4	100.7
	Total	2542.5	1280.2	3822.7	
	Air Sat. Press.	**First-stage Pressure 800**	**First-stage Pressure 1000**	**Total**	**Mean**
C	0	1118.4	595.9	1714.3	143.0
	50	890.8	458.5	1349.3	112.3
	75	533.3	225.8	759.1	63.2
	Total	2542.5	1280.2	3822.7	

Correction term = 405,917.64694

Total sum of squares = $239.2^2 + \ldots + 124.3^2$ - C.T.

= 197,439.1431

Run sum of squares $= (1813.6^2 + \dots + 1258.7^2)/12 - C.T.$

$= 47,129.9206$

Air saturation pressure sum of squares

$= (1714.3^2 + \dots + 759.1^2)/12 - C.T.$

$= 38,721.3356$

First-stage pressure sum of squares

$= (2542.5^2 + 1280.2^2)/18 - C.T.$

$= 44,261.1470$

Second-stage pressure sum of squares

$= (2009.3^2 + 1813.4^2)/18 - C.T.$

$= 1,066.0225$

Total sum of squares of table A

$= (879.8^2 + \dots + 422.8^2)/6 - C.T.$

$= 44,200.5648$

Air saturation pressure and second-stage pressure interaction sum of squares $= 44,200.5648 - 38,721.3356 - 1,066.0225$

$= 4,413.2067$

Total sum of squares of table C

$= (1118.4^2 + \dots + 225.8^2)/6 - C.T.$

$= 84,925.1514$

Air saturation pressure and first-stage pressure interaction sum of squares $= 84,925.1514 - 38,721.3356 - 44,261.1470$

$= 1,942.2688$

Total sum of squares of table B

$= (1287.3^2 + \dots + 558.2^2)/9 - C.T.$

$= 45,808.9719$

First-stage pressure and second-stage pressure interaction

sum of squares $= 45,808.9719 - 44,261.1470 - 1,066.0225$

$= 481.8024$

Sum of squares of pressure combination

$= (584.1^2 + 534.3^2 + ... + 124.3^2)/3 - C.T.$

$= 92,543.9898$

Air saturation pressure, second-stage pressure and first-stage pressure interaction sum of squares

$= 92,543.9898 - 38,721.3356 - 44,261.1470$

$- 1,066.0225$

$= 8,495.4847$

TABLE AXXV

ANALYSIS OF VARIANCE OF THE EFFECT OF ADDING AIR TO ICE CREAM MIX ON HOMOGENIZATION EFFICIENCY

Source	Degree of Freedom	Sum of Squares	Mean Square	F ratio
Total	35	197,439.1431		
Run	2	47,129.9206	23,564.96	10.36**
Air saturation pressure	2	38,721.3356	19,360.67	8.37**
First-stage pressure	1	44,261.1470	44,261.15	19.25**
Second-stage pressure	1	1,066.0225	1,066.02	
Air x 1st.-stage press.	2	1,942.668	971.33	
Air x 2nd.-stage press.	2	4,413.2067	2,206.60	
1st.-stage press. x 2nd.-stage press.	1	481.8024	481.80	
1st.-stage press. x 2nd.-stage press. x air saturation press.	2	8,495.4847	4,247.74	
Discrepance	22	50,927.5548	2,314.88	

**Significance level equal to 1%.

Standard deviation = $\sqrt{2314.888} = 48.2$

$t_{.05}$ for 24 degrees of freedom = 2.064

$t_{.01}$ for 24 degrees of freedom = 2.797

Least significant difference between treatment means at 5% level

$$= \sqrt{\frac{2314.88 \times 2}{12}} \times 2.064$$

$$= 40.7$$

Least significant difference between treatment means at 1% level

$$= \sqrt{\frac{2314.88 \times 2}{12}} \times 2.797$$

$$= 55$$

The test of significance indicates that the use of 75 psi air saturation pressure produced results different from using no air at a significance level of 1% and from using 50 psi air saturation pressure at a significance level of 5%. The use of 50 psi air saturation pressure was insignificantly different from using no air. There was no significant difference between the two second-stage pressures.

APPENDIX XIV

Statistical Analysis of the Results of Homogenizing Concentrated Milk with Air Injection Using the Knife-edged Valve

TABLE AXXVI

EFFECT OF ADDING AIR TO CONCENTRATED MILK ON HOMOGENIZATION EFFICIENCY

(Farrall's indices of concentrated milk homogenized by the knife-edged valve at a homogenizer pump pressure of 900 psi and second-stage pressure of 100 psi at a temperature of 140° F.)

	Deaerated Sample	Air Saturation Pressure						Sum	Mean
		Atmospheric	10	20	25	50	75		
Run 1	188.0 166.8 354.8	127.8 114.4 242.2	63.1 66.3 129.4	43.1 53.9 97.0	64.0 40.6 104.6	99.6 92.6 192.2	79.6 64.4 144.0	1264.2	90.3
Run 2	213.0 172.2 385.2	91.4 102.7 194.1	125.3 124.0 249.3	117.9 85.9 203.8	133.5 117.0 250.5	93.5 91.0 184.5	65.0 65.5 130.5	1597.9	114.1
Sum	740.0	436.3	378.7	300.8	355.1	376.7	274.5	2862.1	
Mean	185.0	109.1	94.7	75.2	88.8	94.2	68.6		102.2

Correction term = $2862.1^2/28$ = 292,557.7289

Total sum of squares = $188.0^2 + 166.8^2 + \ldots + 65.5^2$ - C.T.

= 51,219.7811

Run sum of squares = $(1246.2^2 + 1597.9^2)/14$ - C.T.

= 3,976.9890

Treatment sum of squares = $(740.0^2 + \ldots + 274.5^2)/4$ - C.T.

= 36,242.5636

TABLE AXXVII

ANALYSIS OF VARIANCE OF THE EFFECT OF ADDING AIR TO CONCENTRATED MILK ON HOMOGENIZATION EFFICIENCY

Source	Degree of Freedom	Sum of Squares	Mean Square	F ratio
Total	27	51,219.781		
Runs	1	3,976.989	3,976.989	7.23*
Treatments	6	36,242.564	6,040.427	10.98**
Discrepance	20	11,000.228	550.114	

* Significance level equal to 5%.
**Significance level equal to 1%.

$t_{.05}$ for 20 degrees of freedom = 2.086

$t_{.01}$ for 20 degrees of freedom = 2.845

Least significant difference between treatment means at 5% level

$$= \sqrt{\frac{2 \times 550.114}{4}} \times 2.086$$

$$= 34.60$$

Least significant difference between treatment means at 1% level

$$= \sqrt{\frac{2 \times 550.114}{4}} \times 2.845$$

$$= 47.18$$

Hence there was significant difference at 1% level between the deaerated and all the other samples in favor of the latters. And there were significant differences between atmospheric and 20 psi air saturation pressures and between atmospheric and 75 psi air saturation pressures, the atmospheric sample being less homogenized.

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