AIR AGITATION OF MILK

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This is to certify that the

thesis entitled

AIR AGITATION OF MILK

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Carl W. Hall

Major professor

Carl W. Hall

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AIR AGITATION OF MILK

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The agitation of milk by air is not completely new to the dairy industry, but the effect on the finished product by the method has had little serious consideration. The nature of milk is such that upon standing undisturbed for a period of time the butterfat rises to the surface, producing a non-homogeneous mixture. Once this occurs, some means is required to redistribute the fat. The early method was to take a ladle or paddle and simply stir the milk. With high production and large plants this means was entirely inadequate. A mechanically-driven agitator was developed which would produce the desired results of remixing the butterfat.

Mechanical agitators have been the most popular and most widely utilized method for years. However, the time element of mixing and the power requirements are factors which are unfavorable for an ideal means of agitating milk. Processors, in an attempt to gain efficiency, have attempted to use air as the means of agitation. One of the original problems with the use of air was that ordinary air compressors caused lubricating oil from the compressor to be carried into the milk during agitation. No satisfactory means was developed to overcome this problem until a carbon ring, self-lubricating compressor was developed which eliminated one of the major disadvantages of air agitation.

The determination of the effects of air agitation on the physical and chemical properties of milk is essential. Also some indication of the power requirements of this method is desired.

The aim of the research is to determine scientifically the effects of air agitation on milk, and to ascertain if air agitation is a feasible means of agitation on an industry-wide basis.

REVIEW OF LITERATURE

Agitation Theories

Neilson (1949) defined the word "mix", "to cause a promiscuous interpenetration of the parts of, as of two or more substances with each other, or of one substance with others; to unite or blend into one mass or compound, as by stirring together; hence to mingle; blend, as to mix flour and salt." Agitate is defined, "to move with a violent irregular action; to set or keep in motion; as to agitate water in a cup." Serner (1948) summarized these quite thoroughly, but briefly, by relating that mixing is the desired result, while agitation is the means for bringing it about. He noted that motion alone does not accomplish much mixing, but from the agitation created by motion, mixing does occur.

Peck (1955) related that the general direction of flow alone does not achieve satisfactory mixing. An intense zone of mixing must be created, and satisfactory direction and rate of flow of the material must be maintained. Serner (1948) adds that the first requirement of mixing is to set the liquid mass in motion.

Serner (1948) noted that "to accomplish mixing it is necessary to create shear planes between liquid layers." This may be brought about by:

(a) application of a device that produces multidirectional flow,

(b) use of irregular shaped vessels, or

(c) use of baffles, coils, etc., to obstruct normal flow.

Peck (1955) related that the intense mixing zone is the area where intense shearing is set up by differential velocity of the material due to motion of the containers or some other means which cause motion. He adds that to accomplish complete mixing the shape of the container must be considered in order for all of the material to pass through the shear zone.

Kaufman (1930) wrote that mixing by air agitation is largely caused by the expansion of air as it rises in the liquid and is dependent upon the speed with which the air rises.

Kaufman (1930) and Quillen (1954) both said that better agitation by air will be obtained from deep tanks because of some of the previous reasons.

Power Requirements

Several workers have presented ideas regarding the factors affecting power requirements for mixing and the quantity of air flow required to cause adequate mixing.

Serner (1948) noted that the power needed to produce and maintain continuous agitation of a confined liquid body is dependent mainly on three types of factors:

(a) The amount of initial acceleration imparted to the liquid,

(b) The amount of energy loss caused by surface friction, and

(c) The physical characteristics of the material.

Kaufman (1930) said the degree of agitation by air depends upon the quantity of air flowing, and also is dependent on the velocity with which the air leaves the holes.

Quillen (1954) adds that the degree of agitation depends upon the process and the liquid under consideration, as well as on the quantity of air flowing and the velocity of air leaving the orifice.

Storck (1951) showed a 1/2-hp compressor agitated a 4,000 gal tank of milk with air in 2 1/2 min where ordinary mechanical agitators ranging from 2 to 3 hp required 20 min for the desired results on the same tank.

Quillen (1954) noted air may be used as an aid for mechanical mixing to reduce power requirements. He adds that basically however, air agitation is inefficient; it does not compare favorably with electrically driven mixers. Further, air agitation has a very definite role in industry in the mixing of materials in shallow tanks.

Dunkley and Perry (1957) observed that the depth of milk to width of milk ratio was very important as associated with time required for complete fat redistribution. The greater the depth as compared to the width, the more rapid the mixing time.

Implications can be drawn from several articles that air agitation is very desirable in shallow vessels. The nature of the process makes it possible to agitate to within a few inches of the bottom of the tank.

Physical Changes

Several investigators have approached the problem of air incorporation or air contact, and its effect on some of the physical properties of milk.

Sharp <u>et al</u>. (1940) noted that the oxygen content of milk is associated with the ascorbic acid content. The oxygen content of milk is determined by adding an excess of ascorbic acid to milk and measuring the amount of ascorbic acid reduced by the oxygen. The amount of ascorbic acid utilized in the reduction is proportional to the original oxygen content of the milk.

Opposing views have been presented on the effect of air on the probability of oxidation of milk. Greenbank (1948) observed that the oxidized flavor could be inhibited by aeration. Greenbank (1936) found further that unless excessive copper was present, aeration and pasteurization would prevent the development of oxidized flavor. Thurston <u>et al</u>. (1936) showed that a form of aeration, prolonged agitation, inhibited the development of the flavor. They found that when milk was agitated for 2 1/2 hr the susceptibility of oxidation-susceptible milk to oxidized flavor was greatly reduced. However, when the milk was agitated for less than 45 min little effect on its susceptibility was shown.

Sharp <u>et al</u>. (1940) demonstrated that oxidized flavors could be largely prevented and the ascorbic acid content preserved by removing the oxygen from the milk.

Guthrie (1946) showed the flavor of deaerated milk was excellent when fresh and good at the end of 7 days whereas the flavor of un-deaerated milk was poor as a result of oxidized flavors after 7 days storage.

Brown et al. (1936) found that milk passed over a surface cooler and exposed to air showed no greater development of oxidized flavor than did milk passed through an internal cooler.

Storck (1951) related that milk agitated by air for 50 min, then held in a tank for 24 hr, and reagitated for 20 min, showed no evidence of oxidized flavor after holding the milk for 48 hr after the latter agitation.

Opposed to the above, Guthrie (1946) showed that one of the factors causing oxidation of milk is the presence of air in the milk. He stated that "One logical way to prevent the development of the oxidized flavor in dairy products is to eliminate the oxygen."

Dunkley and Perry (1957) observed that incidence of oxidized flavor was unrelated to the method of agitation whether it be air or mechanical. These workers also noted that ascorbic acid destruction was slightly greater at 61°F for samples agitated by air than for those mechanically agitated. At lower temperatures there was no difference in the ascorbic acid reduction even when the samples were held at 39°F for 48 hr.

Jokay (1956) determined the intensity of air intake affected the free fatty acid degree of milk in a pipeline installation and high free fatty acid degrees were effectively currected by reducing the air intake.

Thurston et al. (1936) noted that milk agitated for 150 min developed rancidity in all samples and some samples agitated for 120 min also developed the flavor.

Dunkley and Perry (1957) determined that samples treated at 39° to 50°F by air or mechanical agitation did not produce rancidity, but those samples exposed to air agitation when the samples were at 61°F produced rancidity frequently.

Little information pertaining to the effect of air agitation on the vitamin C content of milk could be found.

Herrington (1956) presented information which shows that foaming, not violent agitation, was associated with rancidity.

Tarassuk and Frankel (1955) observed that foaming appears to be the necessary condition for activation of lipolysis by "air agitation," with continuous mixing of milk and foam at temperatures that keep the butterfat in a liquid state.

The effect of air on the development of rancidity in milk is a problem that has received considerable attention in pipeline milkers. Pasteurization at accepted minimum temperatures inactivate the enzyme lipase which is the cause of rancid flavors.

Guthrie and Herrington (1956) noted that one of the factors concerning rancidity was activation of lipase caused by air. They further noted that air bubbling through raw milk, especially in a pipeline, would possibly tend to break the fat globules into smaller ones such as in homogenization, thus increasing the probability of rancidity development. It is known that the mixing of raw milk with homogenized milk greatly increases the action causing rancidity.

Storck (1951) presented work by Dr. R. F. Holland of Cornell University which showed, on limited tests, that the vitamin C content remained the same at 17 mg/liter when the milk was agitated for 50 min. The milk was held for 24 hr, re-agitated for 20 min, tested, and showed a drop of 4 mg/liter in the vitamin C content. According to the author this was a normal drop for milk held for this period of time.

Storck (1951) noted that this milk showed a drop of temperature from 41.5°F to 41°F for the original 50-min period of agitation. After the 24-hr holding period the temperature rose 1°F after 20 min of agitation.

Dunkley and Perry (1957) showed that the overall heat transfer coefficient for mechanically agitated milk was roughly 10 percent greater than for air at a rate of 4.6 cfm per 1500 gal of milk in a 4.7-ft x 8.3-ft oval milk tank.

Dunkley and Perry (1957) showed that the size of the air bubble formed at an orifice is a function of the velocity of the air passing through the orifice and not a function of the diameter of the orifice opening.

EQUIPMENT

Part A. Pilot Installation

The primary problem was to determine the cubic feet of air per minute required to give complete redistribution of the butterfat in a tank of raw whole milk which had been undisturbed for a time sufficient to allow the butterfat to separate, forming a cream layer. The effect of the volume of air flow on the flavor, vitamin C (ascorbic acid) content, and free fatty acid content were also of major importance.

A small laboratory model with an agitator suitable for use in a 10-gal milk can was developed to agitate small quantities of milk. A flexible 0.5-in. inside diameter, plastic tube was used as the air distributing section called the distributing ring. The length was such that when formed into a loop, the loop was in the center of the cross-sectional area of the can with half the volume of milk on the inside and half on the outside.

A molded 0.5-in. plastic pipe Tee was used as a means of joining the distributing ring in the form of a loop. The Tee was connected to a rigid, .5-in. clear plastic tube, called the lead line, which served as the means of getting the air to the distributing ring.

A rubber tube, with a U-tube manometer for measuring variation in static air pressure, connected the inlet line to a rotameter. Figure 1 shows a diagram of the laboratory apparatus.

A Brooks Rotameter model 1110 was used to measure the air flow from .05 to .75 cfm at 70°F and 14.7 psia.

The Michigan State University Dairy's compressed air supply was utilized in the research. To insure the air being delivered to the milk was free from foreign material, a moisture and oil separator, manufactured by the Beach Precision Parts Company of Boonton, New Jersey, was installed in the compressed air line.

To prevent complications due to materials which might cause oxidation of milk, all milk contact parts were made from inert plastics. The agitating equipment arrangement was simple to assemble and disassemble for cleaning and sanitation.

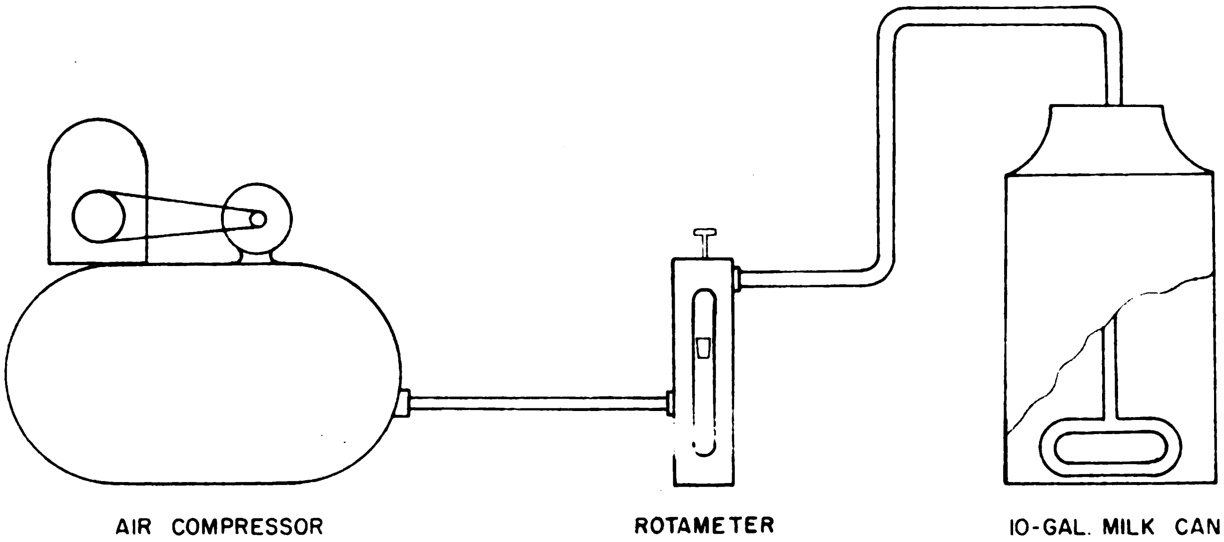

Figure 1. Pilot apparatus for air agitation - 5 gallons of milk.

Figure 2. Lead line and [illegible] pilot agitator.

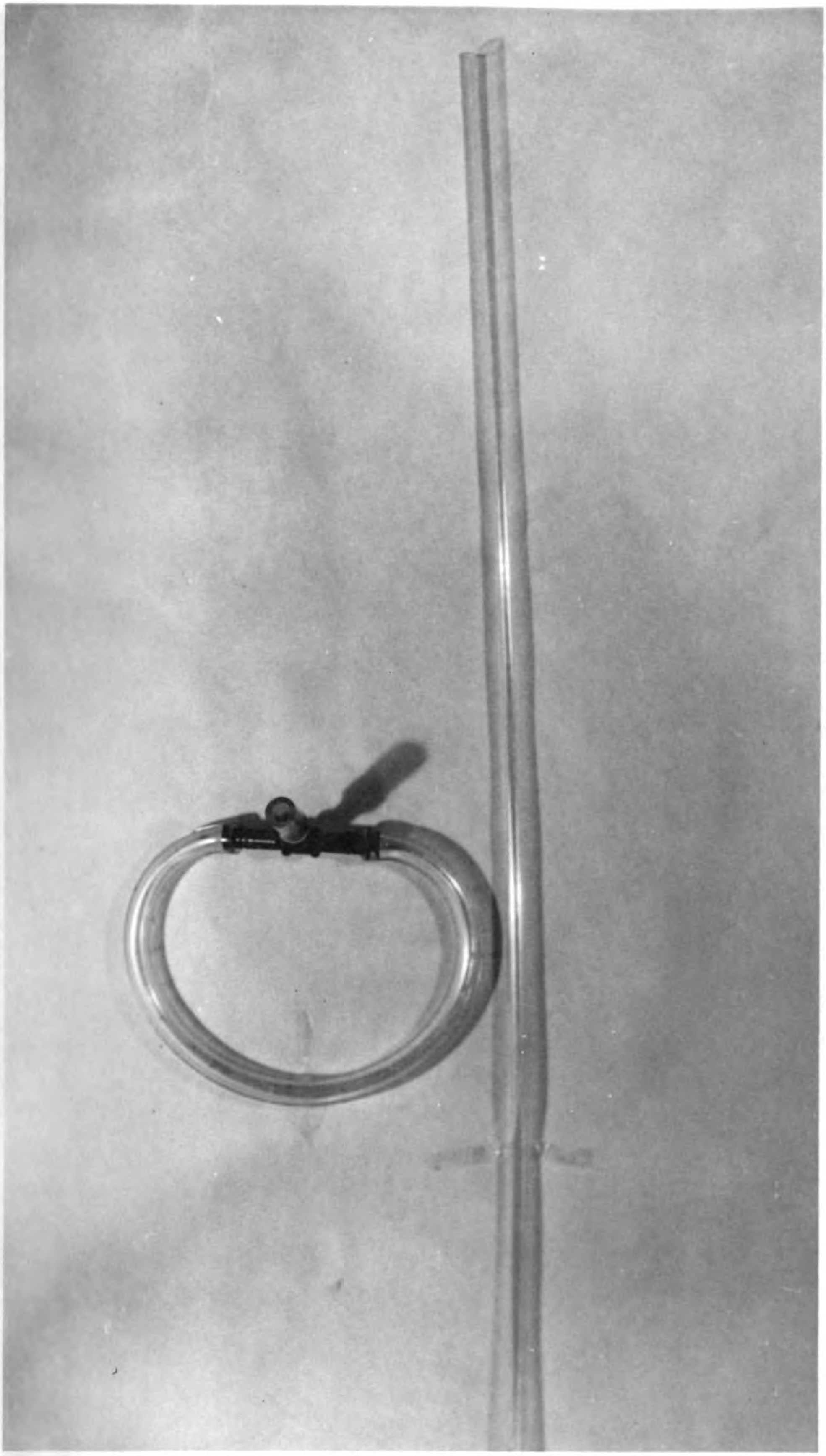

Figure 2. Lead line and distributing ring for 5-gallon pilot agitator.

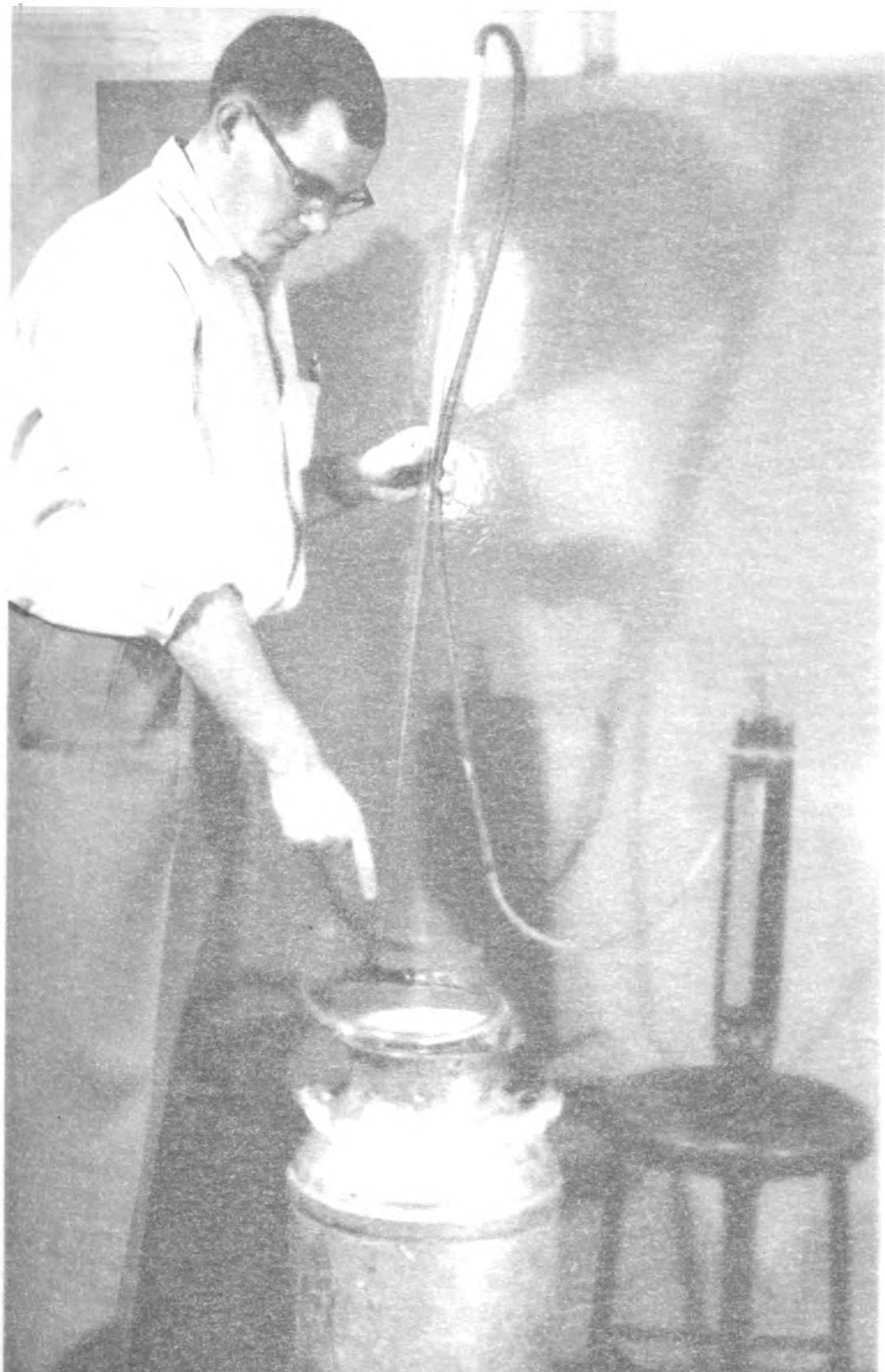

Figure 3. Equipment for agit. of milk.

Figure 3. Equipment for agitating 5-gallon samples of milk.

Part B. Plant Installation

To substantiate the results obtained on a pilot installation, a 2,000-gal rectangular milk storage tank was equipped with air agitation devices. The equipment was installed in the receiving room of the Michigan State University Dairy.

The assumption was made that the results obtained in the pilot installation could be directly projected to the larger installation. The volume of air per gallon of milk was found to be a constant quantity. Results of the pilot installation showed that an air flow rate of .03 cfm/gal of milk gave satisfactory butterfat redistribution in raw whole milk held for 24 hr before agitation, with no apparent harmful effects on the physical or chemical properties of the milk. As a result, 60 cfm of air for a 2000-gal tank of milk was assumed to be adequate.

However, the initial tests conducted in the 2000-gal storage tank proved this assumption to be invalid. An air flow rate above 20 cfm per 2000-gal of milk agitated the milk so violently and the resulting foaming was so great that the assumption of .03 cfm of air per gal of milk was discarded.

Equipment

Stainless steel tubing, 1 1/2-in. diameter with 1/8-in. holes on 12-in. centers, was used as the air distributing device. The tube was installed 4 in. from the storage tank floor with the holes on the underside. The lead line, also of 1 1/2-in. stainless steel tubing, connected the horizontal distributing line through an observation port, with a rotameter placed on the observation platform of the storage tank.

Two Brooks rotameters with ranges of .05 to .75 cfm and 1 to 15 cfm, were used as the air measuring device and a dial type pressure gage was installed in the air line between the rotameter and the lead line.

The air source was the same for this phase of the experiment as that described in the pilot apparatus section.

The equipment was installed in a 2000-gal rectangular storage tank. The tank was equipped with a mechanical agitator which was not operated when the air agitation equipment was in use. Figures 4 through 9 show the air agitation set-up for a 2000-gal tank.

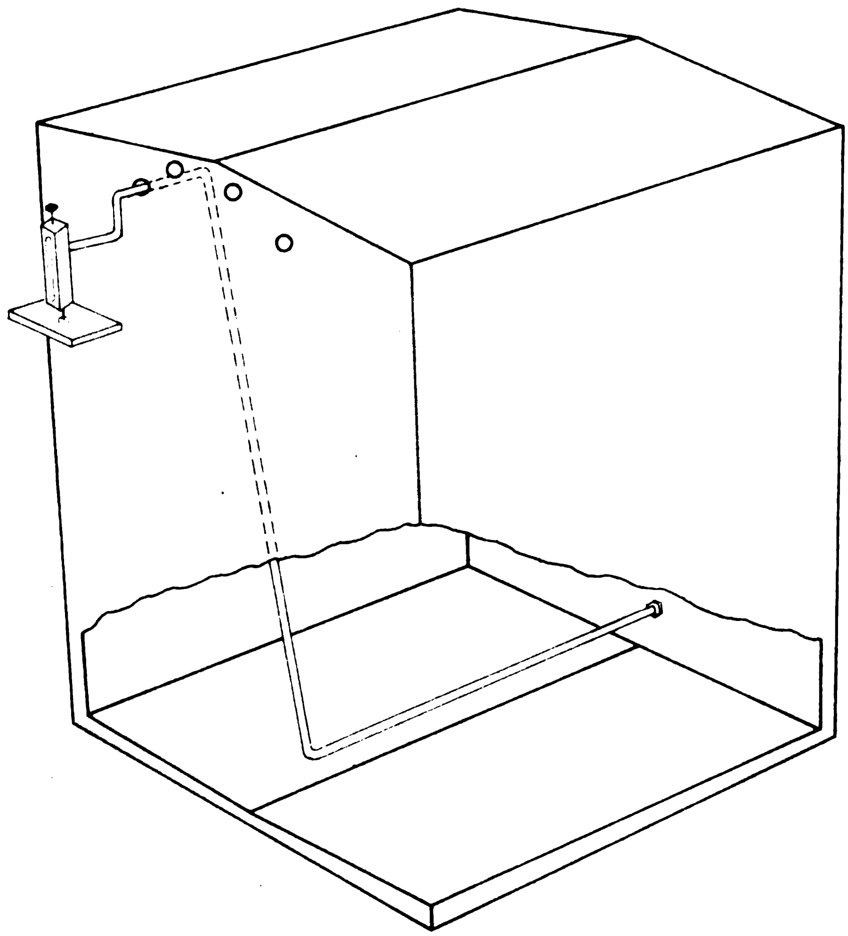

Figure 4. Cut-away view of 2000-gallon storage tank with air flow lead and distribution lines and air measuring device.

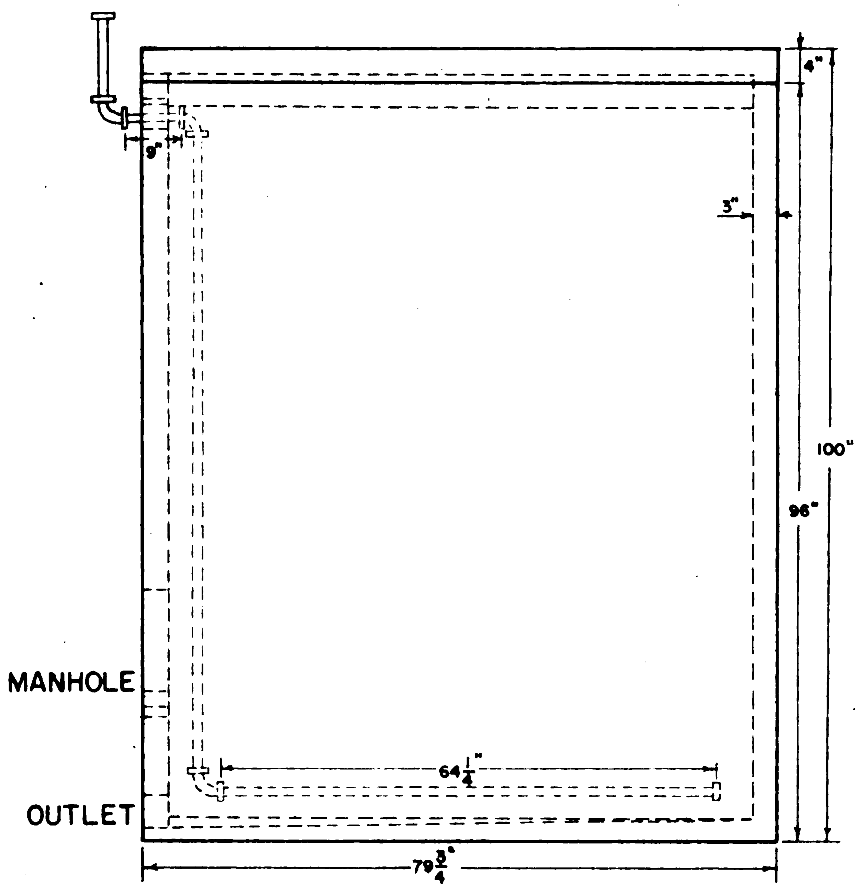

Figure 5. 2000 - gallon storage tank with air flow lead and distribution lines. (Side view)

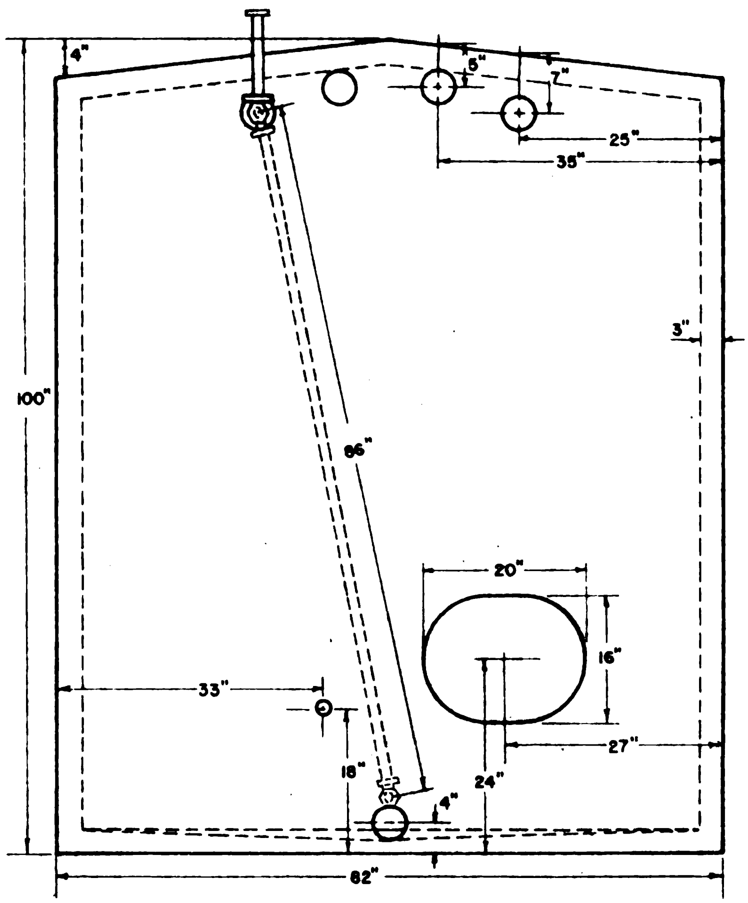

Figure 6. 2000 - gallon storage tank with air flow lead and distribution lines. (Front view)

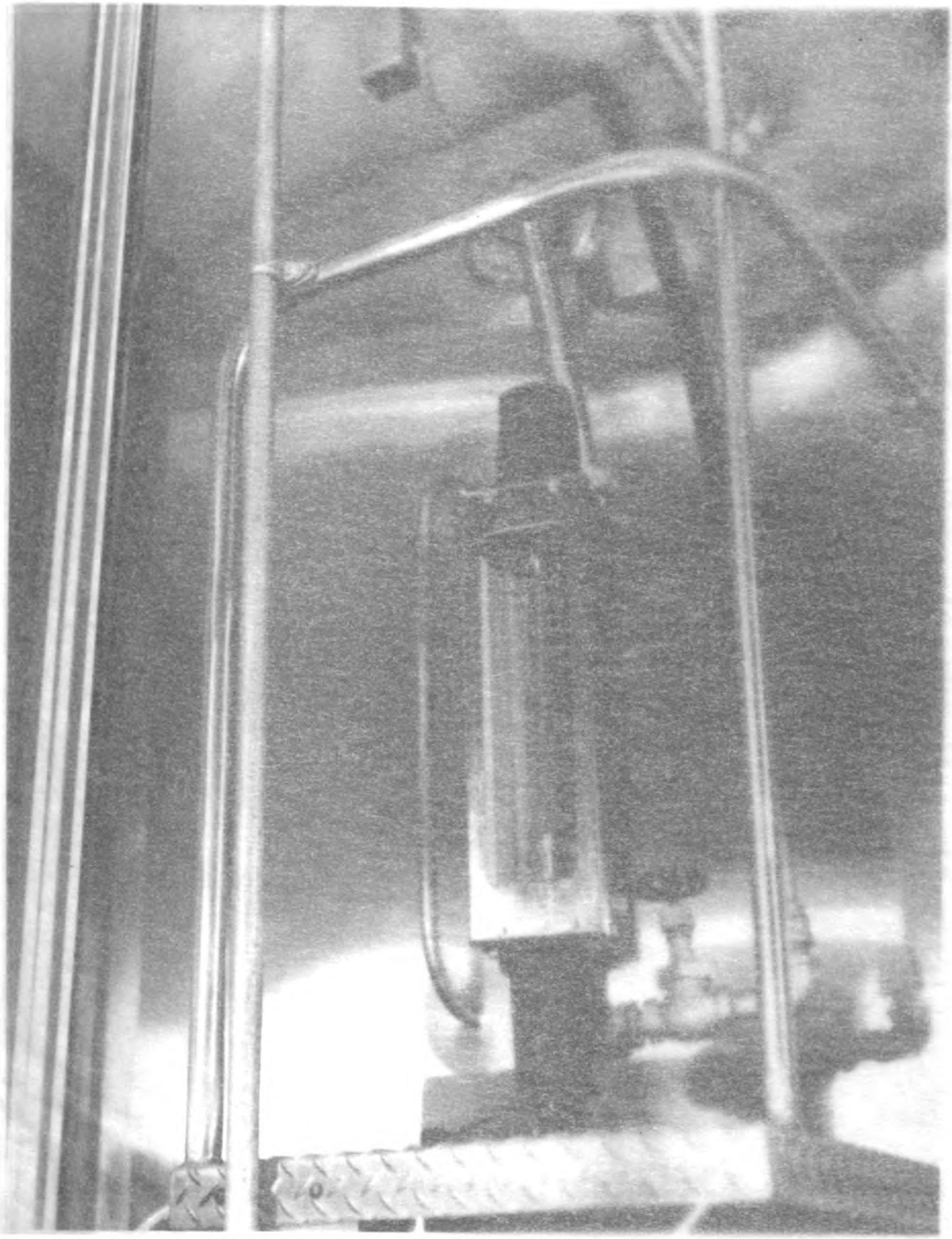

Figure 7. Air measuring device [illegible] tank.

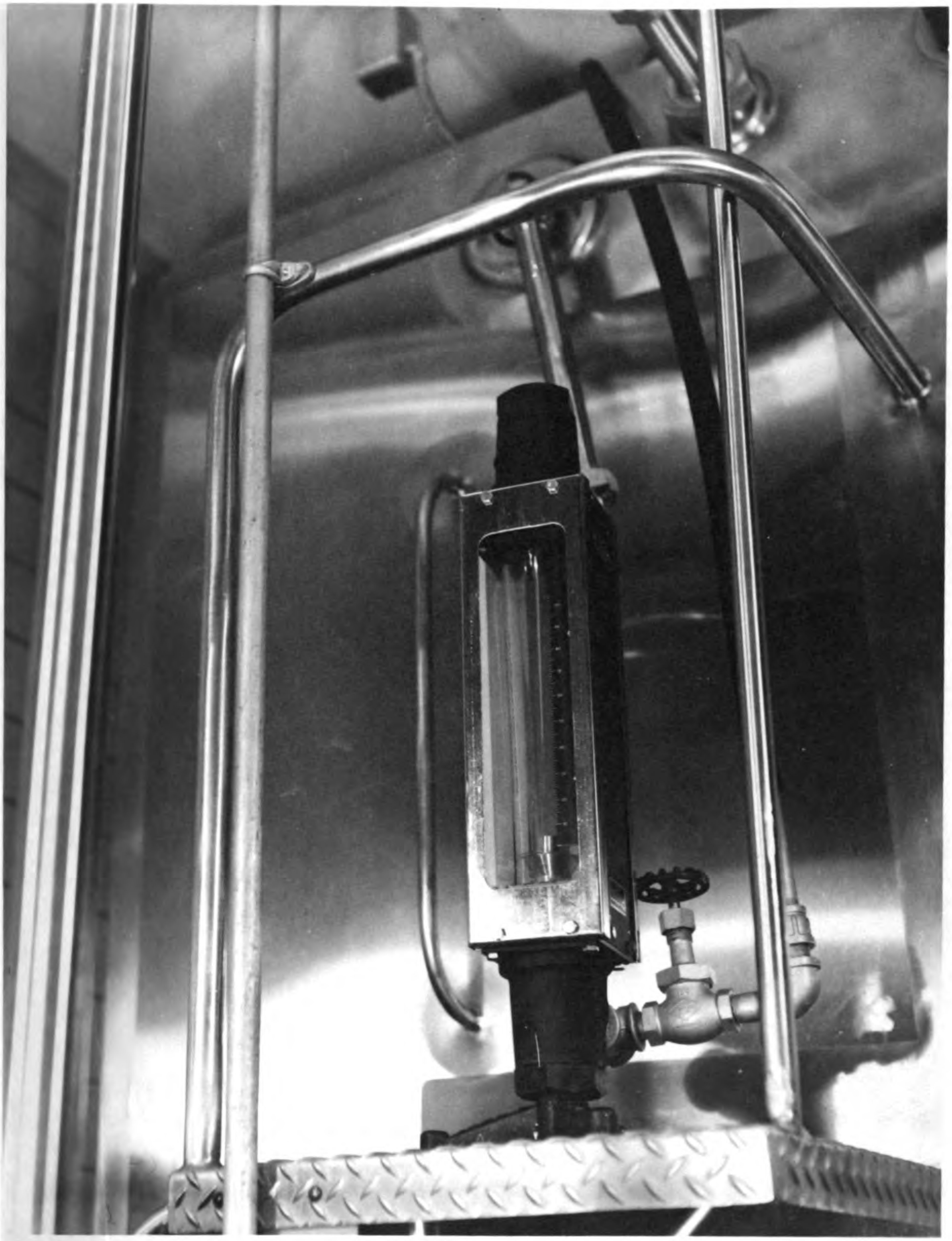

Figure 7. Air measuring device installed on 2000-gallon storage tank.

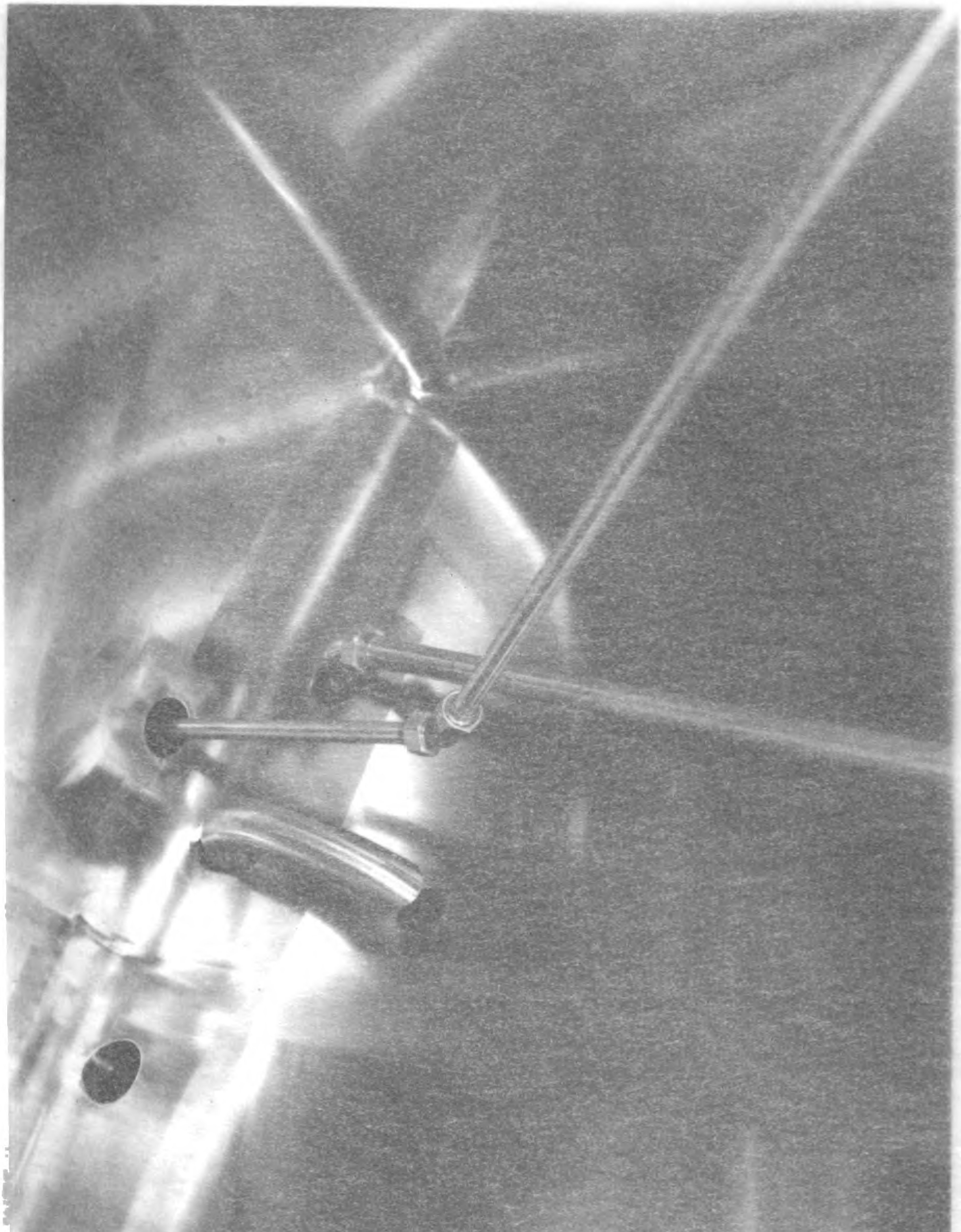

Figure 8. Air flow lead line

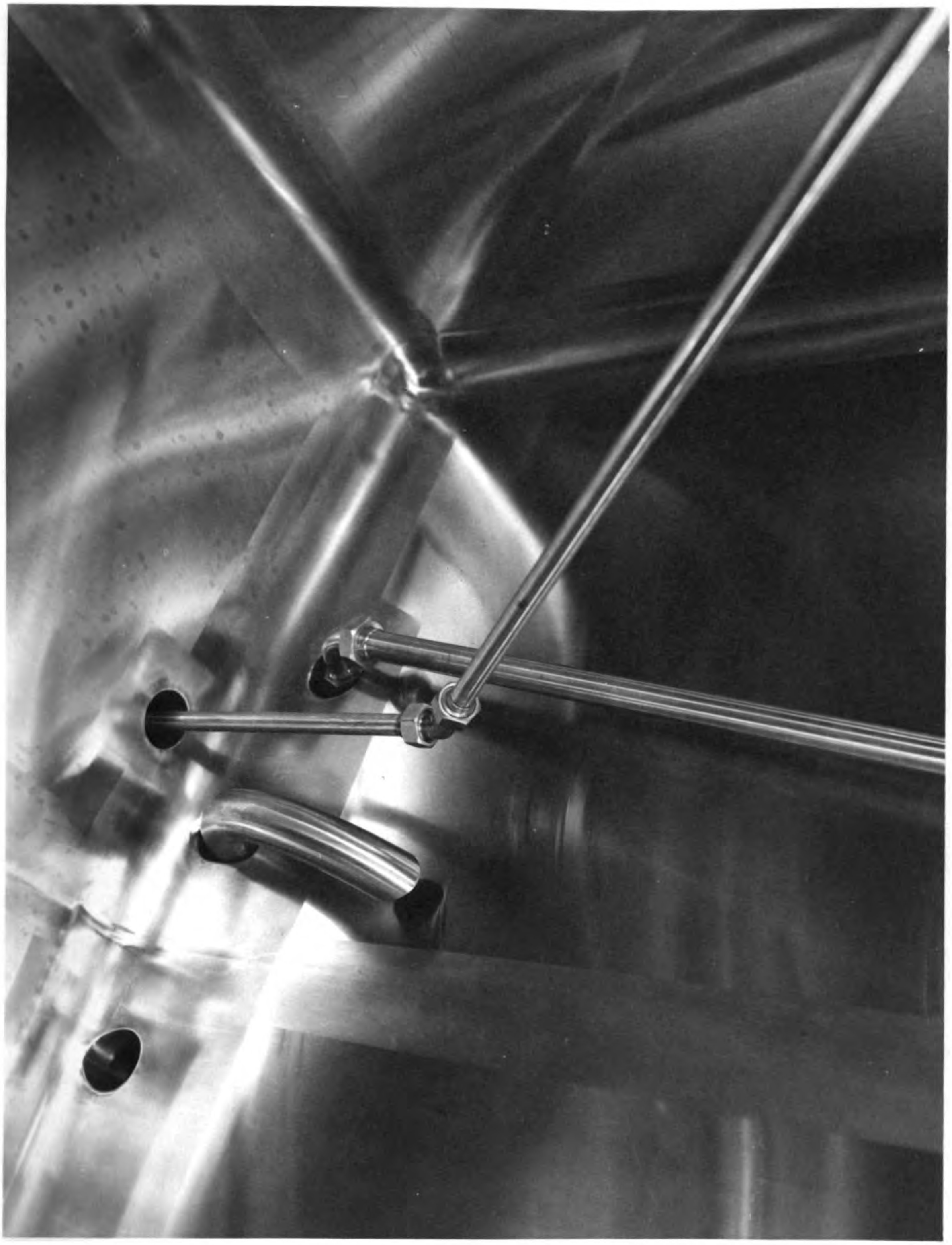

Figure 8. Air flow lead line viewed from tank interior.

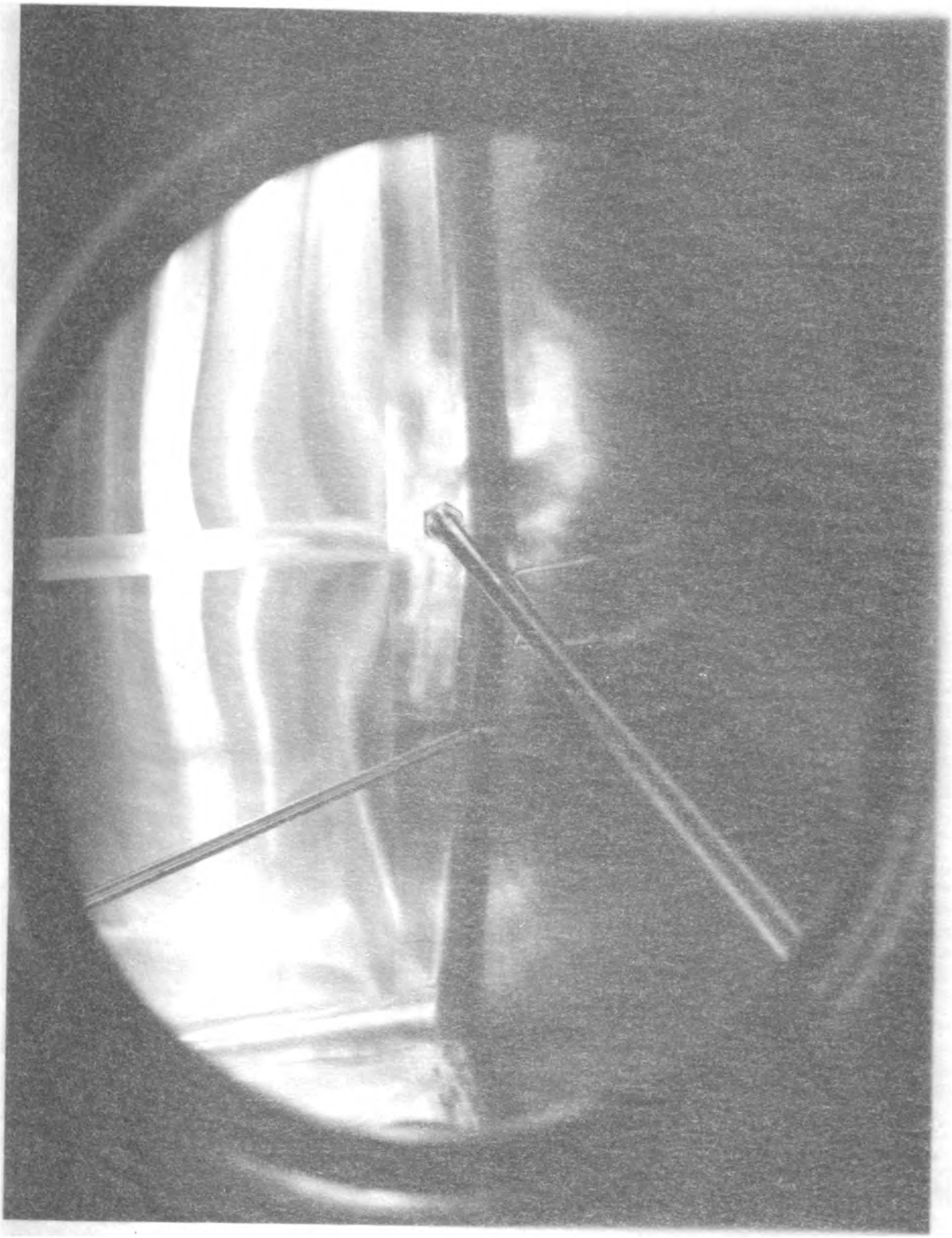

Figure 9. Air flow dist[illegible]
manhole of 2[illegible]

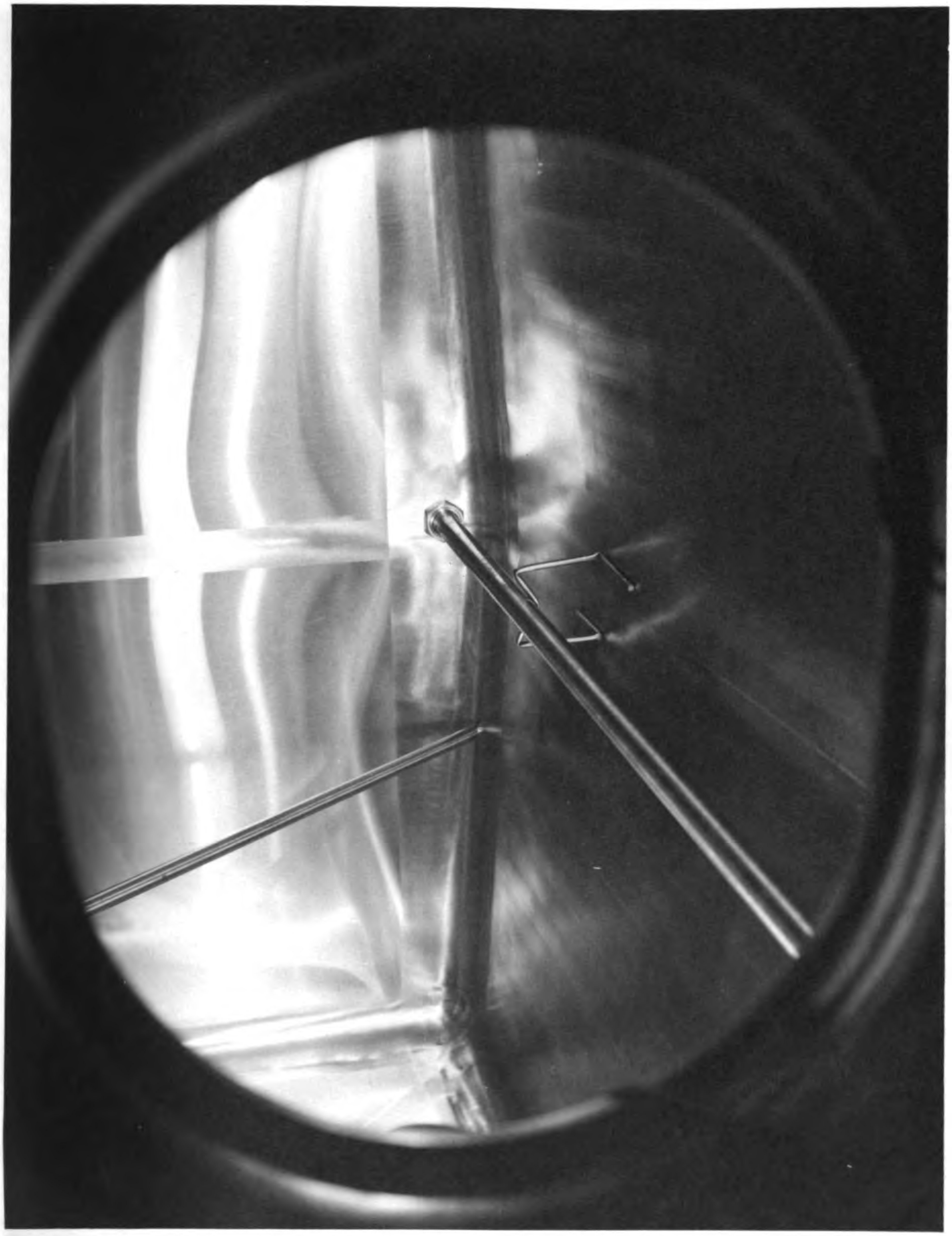

Figure 9. Air flow distribution line viewed through manhole of 2000-gallon storage tank.

Part C. Foam Formation Study

A foaming problem was encountered when milk was agitated with air so tests were conducted to determine the effects of various air flow rates on the type and volume of foam.

A 9-ft length of 1 1/2-in. glass pipe was placed in a vertical position with an adapter on the bottom to allow air to be put into the tube through various sized orifices. The orifice was connected to a compressed air supply through a rotameter for air measuring purposes. A tape measure was fastened to the side of the glass pipe to give a simple means for determining the amount of foam on a specific height of fluid for a given air flow. Figure 10 shows this apparatus.

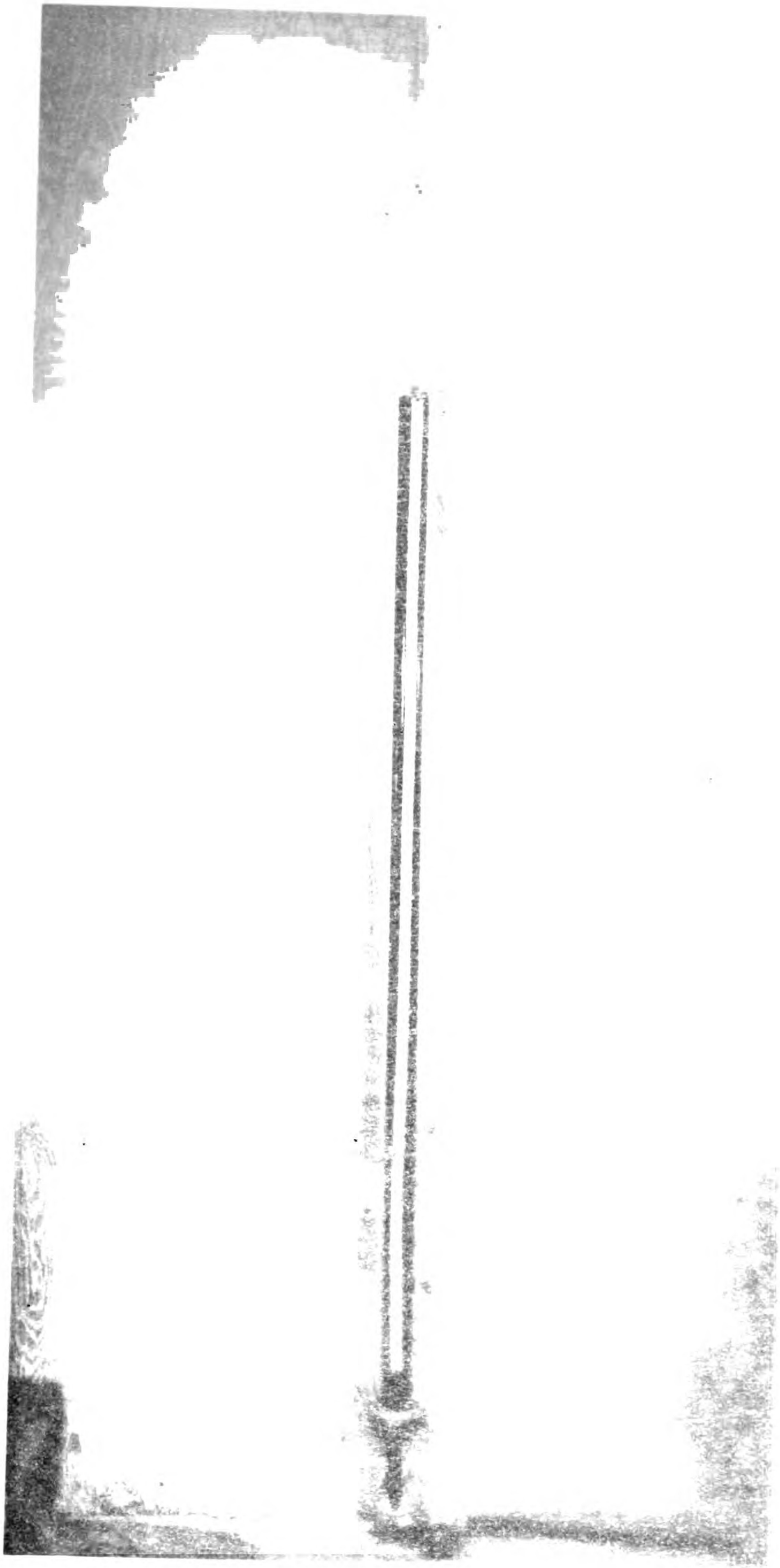

Figure 10. Equipment us[illegible]
foaming eff[illegible]

Figure 10. Equipment used in studying the foaming effect of milk.

EXPERIMENTAL PROCEDURE

The milk used in the research was raw whole milk received at the Michigan State University Dairy. The milk was from bulk tank pick-up and the milk received may have been from a few hours to over 48 hr old before being subjected to research study.

Part A. Pilot Installation

Flavor Tests

The first tests were conducted to determine the effect of air flow on the flavor of milk. Five gallon samples of raw milk at approximately 40°F were exposed to air flow rates ranging from .01 to .30 cfm/gal of milk. Samples were taken before exposure to air agitation and after 20 min, 1 hr, and 2 hr of air agitation. Samples also were taken for creaming ability test. The temperature of the milk was taken at the time of sampling. The flavor of the milk was determined by organoleptic examination.

Creaming Ability Test

Tests were run to determine if air agitation affected the creaming ability of raw milk. The test consisted of placing 100 ml of milk, agitated for the various times of 20 min, 1 hr, and 2 hr, and a control sample, in 100-ml graduated cylinders and holding undisturbed, under refrigeration for 24 hr. After 24 hr the cream volume was read directly in percentage of cream per volume of milk.

The milk used had been exposed to mechanical agitation in farm bulk tanks and in the receiving room tank before samples were taken.

Fat Redistribution Time

The next phase was to determine the volume of air flowing through the milk required to give complete mixing. An agitation period to give complete redistribution of the butterfat was the objective. The equipment used in the previous portion of the experimental procedure was utilized. Five-gallon samples of raw unclarified milk from the storage tanks at the Michigan State University Dairy were obtained and held undisturbed under refrigeration at approximately 42°F for 24 hr and then exposed to various air flows from .01 to .10 cfm/gal of milk. Duplicate control samples were taken at 2-min intervals. The samples taken at approximately the same location in the can each time, were obtained by dipping with a beaker a portion of milk from the surface. These samples were then tested for butterfat content using the Babcock test. From these data the time required to obtain a consistent butterfat test indicating redistribution of the fat was obtained. After a minimum number of tests, airflow rates of .01, .02, and .03 cfm/gal were found to give results which approached an agitation time of 3 min, so the bulk of the tests were run at these values.

Vitamin C (Ascorbic Acid) Test

After an airflow rate which would give complete redistribution of the butterfat in approximately 3 min was obtained, the relation of the airflow volume and the vitamin C content was determined. The vitamin C content of dairy products is determined as the total of the ascorbic acid content.

The test used to determine the ascorbic acid content is a method developed by Shapr (1938) and is outlined in the Appendix.

Five gallon samples of raw milk from the Michigan State University Dairy bulk pick-up were used for these tests. The milk was agitated using the air agitator described earlier at an air flow rate of .03 cfm/gal of milk which was determined to be the flow rate adequate for proper mixing of 5 gal of milk. Control samples of the milk were taken before agitation and the milk was agitated for periods of 20 min and 1 hr. After each period of agitation, samples were taken and tested immediately for the ascorbic acid content, as were the control samples. The control samples, 20-min samples, and 1-hr samples also were held 24 hr under refrigeration in dark brown bottles and again tested for the ascorbic acid content to determine if there was a time lag involved with the effects of air agitation on the ascorbic acid destruction.

The milk which had been agitated for 1 hr was held under refrigeration for 24 hr and again air agitated for 20 min at a flow rate of .03 cfm/gal of milk. Samples were taken and tested immediately for ascorbic acid content.

Rancidity Tests

After an airflow rate which would give complete redistribution of the butterfat in approximately 3 min was obtained, the relation of the airflow volume and the free fatty acid was determined.

Five gallon samples of raw milk from the Michigan State University Dairy bulk pick-up were used for the tests. The milk was agitated using the air agitator at an airflow rate of .03 cfm/gal of milk for periods of 20 min, 1 hr and 2 hr. Samples of milk from the same supply, held under the same condition with no air agitation, were taken at the same time intervals and used as controls.

The samples were shipped to Dr. W. S. Harper of the Ohio State University Dairy Technology Department where the free fatty acid degree was determined by the chemical procedure of Harper *et al.* (1954) and Thomas *et al.* (1954).

Part B. Plant Installation

The procedure followed in conducting this phase of the research was to agitate volumes of raw, whole milk which had been held undisturbed overnight in the 2000-gal storage tank. Samples were taken before air agitation and every minute thereafter through 11 min. The butterfat contents of these samples were then determined with the Babcock test. Tests were conducted at various air flow rates until flow rates were obtained which gave complete fat redistribution in approximately 3 min. The bulk of the tests were then conducted at these air flow rates.

The effect of air agitation on the foaming and churning of the milk was also observed and recorded.

Part C. Foam Formation Study

Brief tests were conducted on this set-up using orifices of 1/16-in. and 1/8-in. diameter holes. There was no apparent difference in the bubble sizes from either method, substantiating the work cited by Dunkley and Perry (1957). The opening sizes studied were assumed to be the sizes most likely used in a plant installation.

Raw whole milk at a temperature of 50°F was placed in the tube to a height of 48 in. above the orifice, requiring roughly one quart. The milk was exposed to an air flow rate of .05 cfm and the amount of foam and the time required to develop the maximum amount of foam was measured. The actual effects of the foam such as bubble size, how foam is formed, and life of the foam were also observed.

The procedure was repeated using .10 cfm, .15 cfm, .20 cfm, and .25 cfm of air.

RESULTS

Part A. Plant Installation

Flavor

The flavor tests which were conducted as described in the procedure section indicate that at a flow rate of .03 cfm/gal of milk or lower, which is adequate to give satisfactory redistribution of butterfat, there is no effect on the organoleptic quality of raw whole milk. At low air flow rates, of .01 to .10 cfm/gal of milk, there was no change in the flavor of samples agitated for 20 min, 1 hr or 2 hr, when compared to samples of the same milk which had not been exposed to air agitation. At high flow rates, above .10 cfm/gal of milk, the samples agitated for 2 hr had rancidity development.

Creaming Ability

The results of the creaming ability tests indicate that air agitation over a wide range of air flows has no effect on the creaming ability of raw whole milk, even when the samples have been exposed to .3 cfm of air/gal of milk for 2 hr. The results are below the quantity of cream normally expected on the raw milk, but the previous treatment of the milk is such that the creaming ability has probably been affected. The milk has been agitated both in the farm bulk tanks and the milk storage tank in the dairy before samples were drawn for study. This previous agitation would have a tendency to reduce subsequent creaming. (Table 2)

TABLE 1

EFFECT OF AIRFLOW RATE ON DEVELOPMENT OF OFF-FLAVOR IN 5-GALLON SAMPLES OF RAW MILK AGITATED FOR PERIODS INDICATED. SAMPLES HELD UNDER REFRIGERATION 24 HOURS BEFORE BEING CHECKED ORGANOLEPTICALLY

Test Number	Airflow Rate cfm/gal	Agitation Time hr	Off-flavors
2	.3*	4	rancid
3	.3*	4	rancid
4	.3*	2	rancid
5	.3*	2	none
6	.03	2	none
7	.03	2	none
8	.03	2	none
9	.03	2	none
10	.03	2	none
11	.03	2	none
12	.03	2	none
13	.03	2	none
14	.03	2	none
15	.03	2	none
16	.03	2	none

*The air flows are considerably above the rate required for fat redistribution.

TABLE 2

PERCENTAGE OF CREAM ON SURFACE OF MILK AFTER AIR AGITATION, FOR PERIODS INDICATED, AT .03 CFM/GAL. SAMPLES HELD UNDISTURBED UNDER REFRIGERATION FOR 24 HOURS AFTER AGITATION

Test Number	Temp.	Agitation Time			
		Control	20 min	1 hr	2 hr
	°F	Percent	Percent	Percent	Percent
6	52	9.0	9.0	9.0	9.0
7	50	9.0	9.0	9.0	9.0
8	42	10.0	10.0	10.0	10.0
9	44	10.0	10.0	10.0	10.0
10	44	10.0	10.0	10.0	10.0
11	44	5.5	6.0	6.0	6.0
12	44	5.0	5.0	5.0	5.0
13	43	10.5	10.5	10.5	10.5
14	43	10.5	10.5	10.5	10.5
15	43	10.5	10.5	10.5	10.5
16	44	10.0	10.0	10.0	10.0
*2		11.0	11.0	11.0	11.0
*3		11.0	11.0	11.0	11.0
*4	41.5	10.0	10.0	10.0	10.0
*5	43	9.0	9.0	9.0	9.0

*Airflow rate .30 cfm/gal

Low values of cream percentages are probably due to previous agitation of milk in farm bulk tanks and dairy plant storage tank.

Fat Redistribution Time

Preliminary tests indicated that air flow rates of .01, .02, and .03 cfm/gal of raw whole milk would give complete fat redistribution in approximately 3 min, so the bulk of the laboratory tests were run at these flow levels. After approximately ten sets of data for each of the air flow rates were obtained, a statistical analysis was applied to the results. The calculations and data are shown in Tables A-1 through A-4. These results indicate a flow rate of .03 cfm/gal would produce complete fat redistribution in raw whole milk which had been held undisturbed for 24 hr before agitation. Figures 11 and 12 show these results.

Vitamin C (Ascorbic Acid) Content

The results of the tests conducted in reference to vitamin C content appear in Table 3. These tests show that air agitation has no significant effect on the vitamin C content of raw whole milk. The milligrams of ascorbic acid per liter of milk is below the value normally present in milk, but the previous history of the milk must be the cause of the low values.

Rancidity Test

The results obtained from a private laboratory showed that raw whole milk exposed to .03 cfm/gal of milk had no greater free fatty acid content than did milk kept under similar conditions with the exception that the control milk was not exposed to air agitation. These results appear in Table 4.

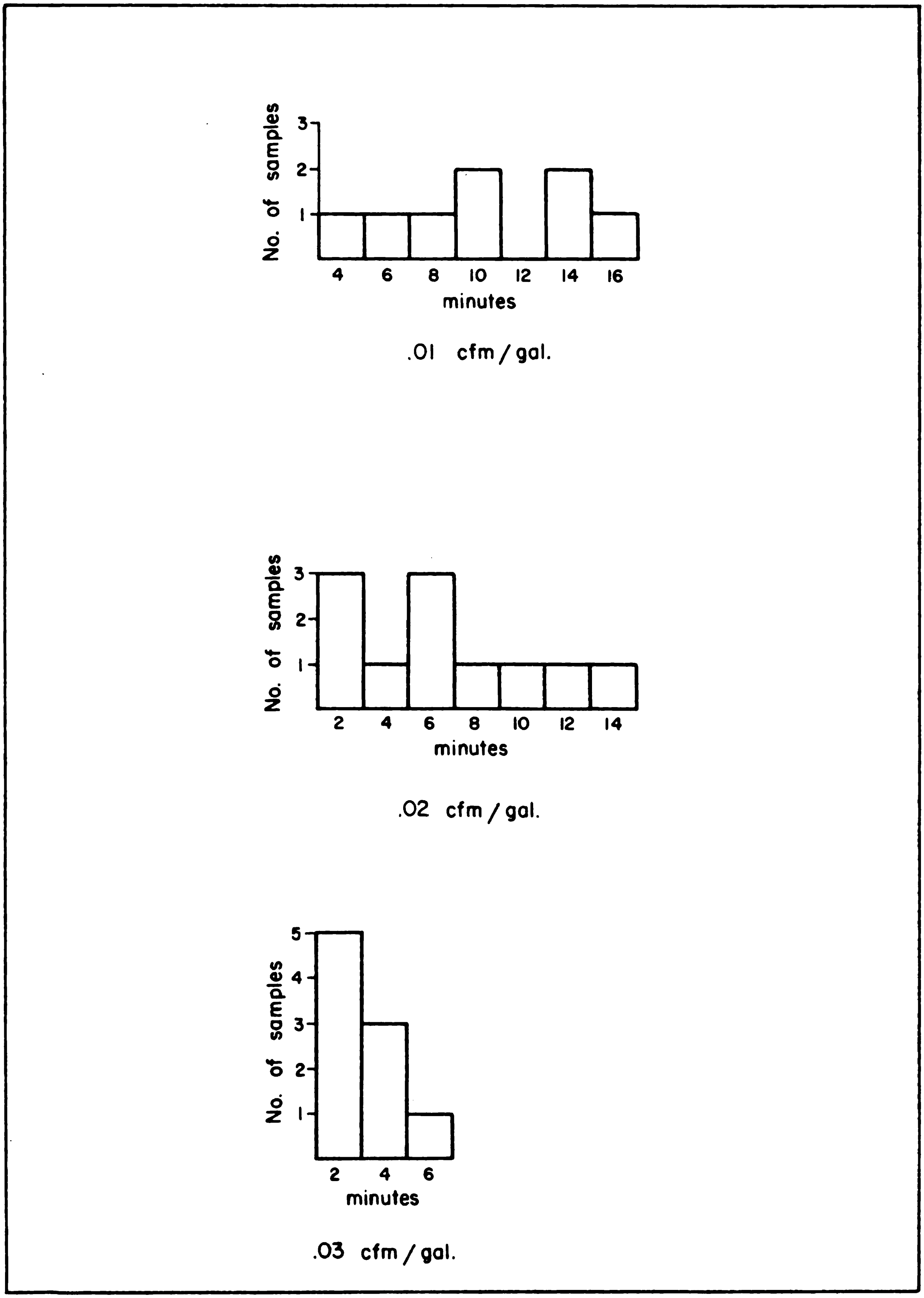

Figure 11. Bar graph (Number of samples to reach constant fat test at various times and various air flow rates.)

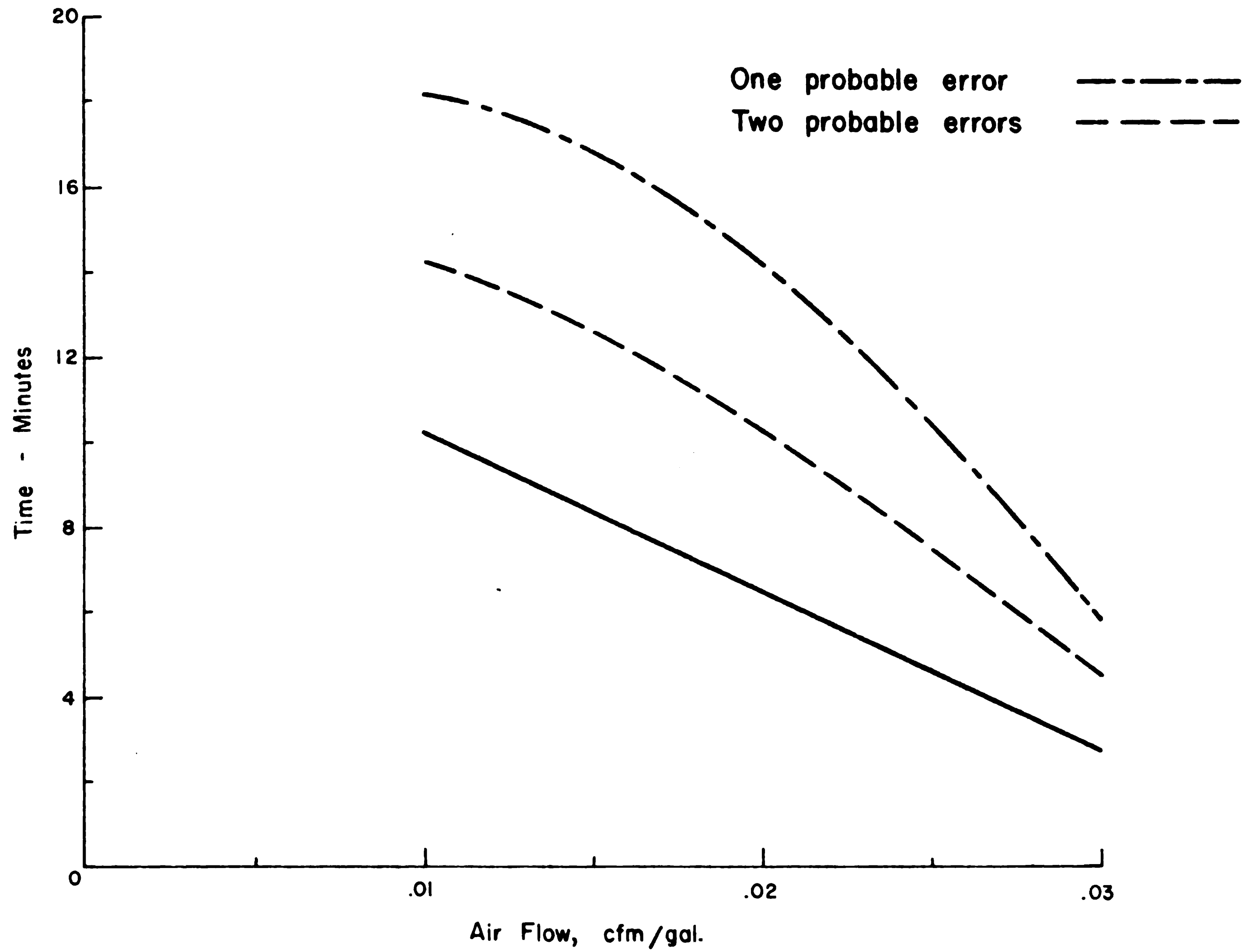

Figure 12. Relationship of airflow rate with time required for butterfat content of milk to reach equilibrium.

TABLE 3

AVERAGE ASCORBIC ACID CONTENT OF THREE SETS OF SAMPLES OF RAW WHOLE MILK EXPOSED TO .03 CFM OF AIR PER GALLON OF MILK

Time of Testing	Control	Agitation	
	0 min	20 min	1 hr
	mg ascorbic acid per liter milk		
Immediately after agitation	11.4	11.5	11.3
24 hr after air agitation	7.3	7.3	7.3
Milk agitated 1 hr, held 24 hr, reagitated for 20 min and then tested immediately	7.4	7.3	--

Low value of ascorbic acid content is a result of previous history of the milk.

TABLE 4

FREE FATTY ACID CONTENT OF RAW WHOLE MILK
AGITATED AT AN AIRFLOW RATE
OF .03 CFM/GAL OF MILK

No.	Agitation Time	Fat	Temperature	Titration Value	A°
		percent	°F	ml	
1	control	4.1	36	0.65	1.585
2*	control	9.1	35	1.05	1.155
3	20 min	3.7	37	0.55	1.489
4*	20 min	3.6	37	0.55	1.530
5	1 hr	3.65	40	0.45	1.234
6*	1 hr	3.65	40	0.50	1.369
7	2 hr	3.65	45	0.45	1.234
8*	2 hr	4.0	46	0.55	1.375

*Samples were from same milk supply, held under same conditions as others with the exception they were not exposed to air agitation.

Note: /1 ml $^{n}/100$ base - ml $^{n}/100$ base for blank test

/2 $A^{o} = \frac{\text{Titration value}}{\text{g fat in sample}}$

Part B. Plant Installation

The results of this part of the work, which are shown in Table 5, show that .50 cfm of air will redistribute butterfat in a 2000-gal tank of milk in 2 min. When this flow rate was used, about 20 percent of the surface of the milk in the tank was covered with foam to a depth of 2 in. The foam was very light and caused no apparent effects on subsequent operations performed on the milk such as standardization with a standardizing clarifier.

A higher flow rate of 1 cfm of air per tank gave butterfat redistribution in 2 min, but the foaming was considerably more than the amount produced by .5 cfm of air. When the milk agitated with 1 cfm of air was passed through a standardizing clarifier, considerable difficulty was encountered in adjusting the machine. The reason for the trouble was not fully understood, but the history of the milk used may have had some effect on the foaming characteristics of this milk.

When an air flow rate of 1 cfm was used, there was a slight amount of churning as determined by small butter flakes clinging to the walls of the storage tank when the tank was emptied. No evidence of churning was observed at .5 cfm per tank of milk. No evidence of air incorporation was found in samples of milk agitated at 1 cfm of air.

When .25 cfm of air per 2000 gal of milk was used the air volume was insufficient to cause air to leave all of the openings in the distributing line. The result was determined by observing the surface of the milk in the tank. Above each hole through which air was passing there was a slight fountaining effect and air bubbles were formed at the milk surface. At a flow rate of .25 cfm, only the holes in approximately the front half of the distributing line had air flowing through them. When the flow rate was increased to .5 cfm all openings had air passing through them.

Computation of the horsepower requirements is shown and is a purely theoretical approach. The head loss in the pipe, friction loss due to air passing through holes and other factors are omitted. These values are extremely small and would have little significance on the final horsepower. A .25-hp motor is used on the mechanical agitator on a tank identical to the 2000-gal tank used in the air agitation study.

$$\text{hp} = \frac{\text{lb/min of air x feet head}}{33{,}000}$$

$$\text{hp} = \frac{.05 \quad \text{x} \quad 7}{33{,}000} = .00001$$

TABLE 5

BUTTERFAT CONTENT, DETERMINED BY BABCOCK TEST, OF SAMPLES RUN AT 1-MIN INTERVALS FROM 2000-GAL STORAGE TANK HELD UNDISTURBED ENOUGH TO ALLOW CREAM LAYER TO FORM BEFORE EXPOSING TO AIR AGITATION. RESULTS ARE AVERAGE OF DUPLICATE TESTS

Test Number	1	2	3	4	5	6	7	8	9	10
Gal of Milk	1120	1900	1875	1875	1910	1600	1600	1850	1500	1500
Temp °F	41	41	41	40	40	40	41	40	41	41
Airflow Rate	1 cfm	1 cfm	1 cfm	1 cfm	1 cfm	.5 cfm	.5 cfm	.5 cfm	.25 cfm	.5 cfm
Time samples taken after air flow was started	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.
0 min	2.7	2.95	2.45	2.4	2.55	2.8	2.8	2.65	2.4	2.6
1 "	3.6	4.0	3.8	3.85	3.65	3.1	3.3	3.05	3.3	3.1
2 "	3.9	4.1	3.95	3.9	3.8	3.8	3.9	3.5	3.8	3.75
3 "	3.9	4.1	3.9	3.85	3.8	3.8	3.9	3.7	3.6	3.7
4 "	3.9	4.1	3.95	3.9	3.85	3.8	3.8	3.7	3.5	3.7
5 "	3.95	4.05	3.95	3.85	3.8	3.8	3.9	3.7	3.75	3.7
6 "	3.9	4.05	3.95	3.9	3.8			3.7	3.6	3.7
7 "	3.9	4.1	4.0	3.85	3.8			3.7	3.55	3.7
8 "	3.95	4.1	4.0	3.9	3.85			3.7	3.6	3.7
9 "	3.8	4.05	4.0	3.85	3.75			3.7	3.7	3.75
10 "	3.9	4.1	4.0	3.9	3.8					
11 "	3.9	4.05	4.0	3.9	3.8					

Part C. Foam Formation Study

The results show that at airflow rates from .05 to .15 cfm per 48 in. of milk (1 qt) in a 1.5-in. glass tube, milk at a temperature of 50°F developed a 9-in. column of foam as shown in Table 6.

At flow rates above .15 cfm in the same apparatus the foam rate was greatly accelerated and the height of foam rose to 42 in. before foaming out the end of the column.

When a foam column of 42 in. was formed by an airflow rate above .20 cfm it took several minutes for the foam column to return to the 9-in. length when the airflow rate was cut back to .05, .10 or .15 cfm.

When air bubbles left the orifice they tended to join with other bubbles, until near the top of the milk column the bubbles were about 4 in. in length and nearly filled the cross-section of the column. As the bubbles neared the surface of the milk they collapsed allowing the milk carried above them to run down the tube causing turbulent motion at or near the surface of the main body of milk. The foam formed at this point was of a rather permanent type and constituted the majority of foam in the column. These bubbles were about 1/32-in. in diameter at the milk surface and increased in size to about 1/8-in. diameter at the top of the foam column.

The air bubbles leaving the orifice either joined with other bubbles in the movement through the liquid, eventually

collapsing as it neared the surface or remained as single bubbles which rose to the milk surface and became a part of the foam column.

At flow rates slow enough so little or no bubble joining took place in the movement through the liquid there was very little or no turbulent motion at the milk surface and the foam was original bubbles leaving the orifice. The foam column, in this case, was about 1 1/2 in. in height and was very light.

TABLE 6

TIME REQUIRED TO FORM 9 IN. OF FOAM ON A 48-IN. COLUMN OF MILK CONTAINED IN A VERTICAL 1.5-IN. DIAMETER GLASS PIPE AT VARIOUS AIRFLOW RATES. AIR INTRODUCED THROUGH .125-IN. ORIFICE AT BOTTOM OF PIPE

Airflow Rate	Time to Form 9 In. Foam
.05 cfm	30 sec
.10 cfm	30 sec
.15 cfm	30 sec
.20 cfm	*
.25 cfm	*

*Impossible to measure because column including milk and foam mixture flowed out open end of pipe.

DISCUSSION

Air agitation in a liquid causes bubbles, issuing from holes in a distributing line, to rise in a stream to the surface. These bubbles form an air lift which lightens the surrounding milk and causes it to rise. As the bubbles move upward, they move aside the milk above and impart velocity to the milk. The milk rises to the surface where the air bubbles leave and the retained velocity carries the milk to a lower region in the tank.

Repetition of this motion sets up a pattern of movement that insures complete mixing.

Figure 13 shows the motion of liquid and air in a tank. The velocity of the air and milk in a deep tank will be greater at the surface as a result of increased buoyancy of the air causing more rapid mixing than in a more shallow tank. The greater the width of tank, the slower will be the mixing time because more milk in a lateral direction must be moved by the air stream.

At a flow rate of .10 cfm/gal of milk, a rancid flavor is produced. However, two things must be noted. First, the temperature increase in the milk was such that a natural inducement or speed up of rancidity development was possible, and second, the flow rate which produced rancidity in the milk was extremely high. The agitation of the milk was so violent and the foaming so excessive that such a high airflow rate is impractical. If the air agitating equipment is operated properly no rancidity or other off-flavors will be developed.

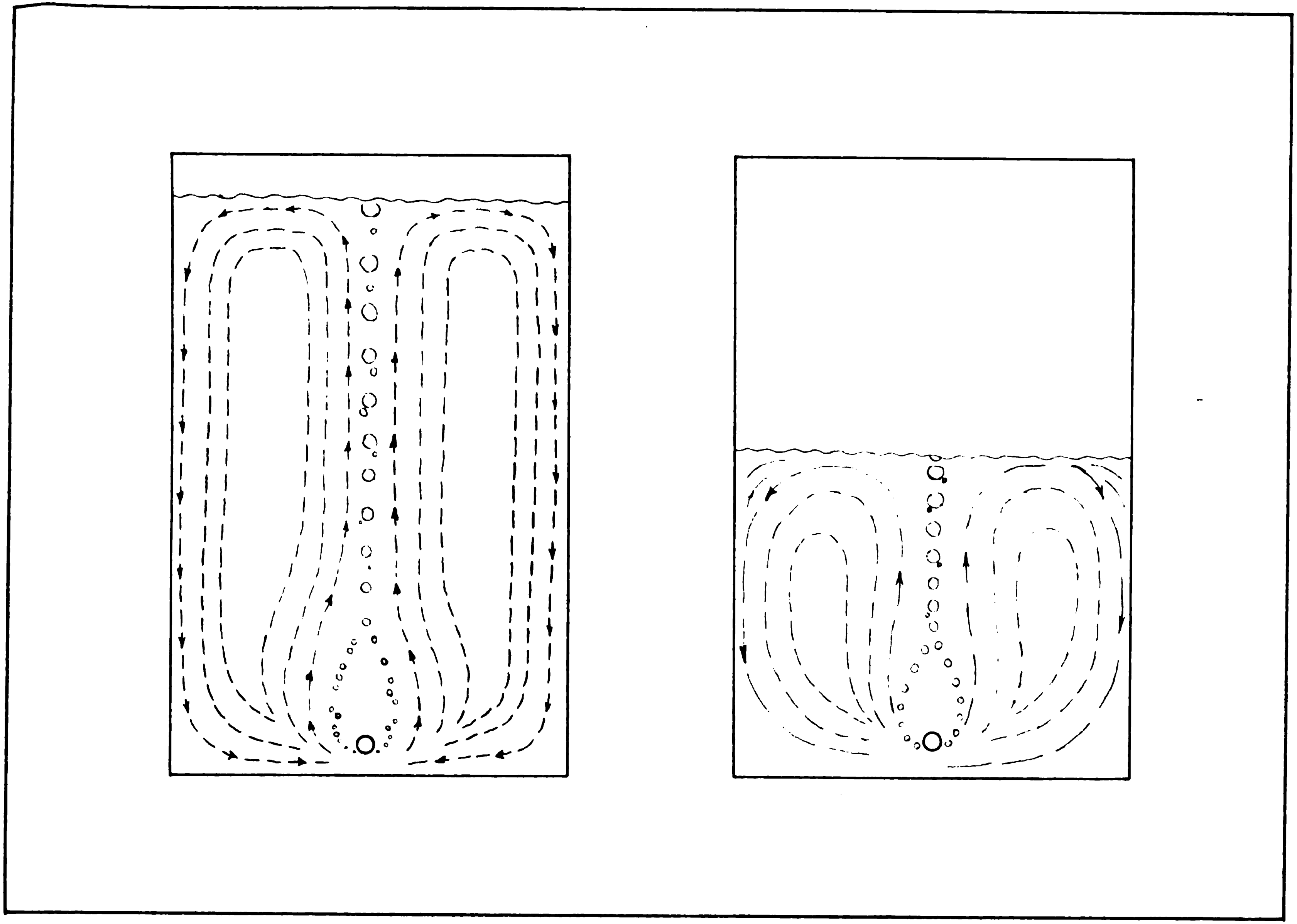

Figure 13. Action of air in milk at two levels.

The values for the volume of cream on raw milk reported herein are much lower than the expected value of 1/6 to 1/5 of the total volume of milk represented as cream. The low values probably are due to previous agitation of the milk. The milk was from farm bulk tanks which had possibly been agitated a minimum of two times before delivery to the dairy. This milk again may have been subjected to agitation in the dairy storage tank. Frequent mixing of milk when the butterfat is in a solid state will cause the subsequent creaming ability to be reduced.

The vitamin C content of the milk was not affected by air agitation at air flows suitable for fat redistribution which agreed with work cited by Storck (1951).

The assumption that the ratio of air volume to gallons of milk required for fat redistribution is a constant, was proven to be invalid when projected from a pilot installation to a plant installation.

The relatively high value required for the pilot installation is most likely the result of the low static pressure due to milk above the openings in the distribution line. The low head, causing a low density bubble, and the short path of the bubble are factors which discourage high velocity of bubble rise. Since air agitation is a function of bubble size and bubble velocity, the conditions in the pilot apparatus were unfavorable for air agitation and thus for projection to larger and deeper quantities of milk. The results which showed faster agitation and more mixing occur when deep volumes of milk are used agree with work noted by Kaufman (1930) and Quillen (1954).

The effect of air agitation on the physical and chemical properties of milk should be more closely associated with the air to milk ratio. The redistribution of butterfat is a function of the movement created by air and not by the quantity of air as such. However the physical and chemical properties will be affected more by the quantity of air. As a result the assumption may be made that the larger airflow per gallon of milk required in a pilot installation would have a greater influence on the properties of the milk. Because the flow rate suitable for air agitation in the pilot installation had no harmful effects on the milk it is logical to presume that the lower air volume per gallon of milk in the plant installation would produce no unfavorable results.

When milk has remained undisturbed in a storage tank for a long period of time the cream layer has a tendency to become quite rubbery. A satisfactory method for breaking the cream layer would be to impress a high airflow rate into the air agitating equipment for a few seconds merely to break the layer and then reduce the airflow rate to a smaller value to complete the agitation. When less than .5 cfm per 2000-gal tank was used, the air flow was insufficient to cause air to leave all holes in the distributing line. However, when a higher flow rate (.5 cfm or above) was used to break the cream layer and start motion, all holes had air leaving them when the flow rate was reduced to less than .5 cfm.

The airflow rate required for fat redistribution was a function of the length of the tank being agitated for a particular tank cross-section. The milk path in a tank being agitated was mainly perpendicular to the axis of the distributing line and each air stream caused motion half-way to the adjacent air streams.

With air agitation the work required is only the work required to free the air in the milk. The air moving through the milk due to its buoyancy does the work in putting the milk in motion.

Work on the foam formation study apparatus shows that the size of bubbles leaving an orifice is not a function of the orifice diameter. This is in agreement with work presented by Dunkley and Perry (1957).

From observations made in the foam formation study, higher airflow rates cause considerable bubble clustering, thus creating greater fluid movement and faster mixing.

Results of this work indicate that air agitation is a highly satisfactory means of mixing raw milk. The general skepticism of dairy men to purposely put air in contact with milk appears to be unfounded. The air used in air agitation is only passed through the milk to create motion and does not become a part of the milk volume.

The installation of air agitation equipment should be approached with several points kept in mind. The distribution line, 3 to 4 in. from the floor, should run the length of the tank with orifices along the entire length. The holes should be 1/8-in. diameter on 12-in. centers. Another recommendation is that each tank should have individual controls at the tank for regulating the airflow rate. Run tests to determine relationship of airflow rate which will redistribute the butterfat in the desired period of time. The air flow should not be allowed to continue for excessive periods of time.

SUMMARY

The flavor of raw whole milk was not affected by air agitation at an airflow rate of .03 cfm per gallon of milk for 2 hr in the the 5-gal pilot apparatus. At an air flow of .3 cfm/gal for 2 hr, rancid flavor was developed. The creaming ability of raw whole milk was not affected by airflow rates up to .3 cfm/gal for 4 hr in the laboratory installation. The laboratory results showed that .03 cfm of air per gallon of milk gave fat redistribution in a mean time of 3.1 min. In the laboratory installation it was found that the ascorbic acid content and free fatty acid content which represent vitamin C content and rancidity development, respectively, are not affected by .03 cfm/gal of milk when exposed to this air flow for 2 hr.

In the plant installation, .5 cfm per 2000-gal tank was sufficient to redistribute the butterfat in 2 min. At higher flow rates (1 cfm and above) excessive foaming of the milk and slight churning of the butterfat occurred.

An airflow rate of .25 cfm was not sufficient to cause air to leave all of the holes in the distributing line and as a result very poor agitation resulted.

An airflow rate of 1 cfm per 2000-gal tank caused no evidence of air incorporation in milk.

The results of the foam formation study indicate that .05 to .15 cfm of air through a 4-ft depth of milk (1 qt) will form a specific volume of foam, but above these flow rates, the foam formation is greatly accelerated. The foam is composed, only in a small part, of the original bubbles leaving an orifice, but is composed mainly of foam resulting from splashing and turbulent action at the upper milk surface.

No apparent relationship exists between milk to cubic feet of air per minute ratio for pilot apparatus and plant installation when determining time required for complete butterfat redistribution.

The depth of milk above the air distributing appears to be the important factor in air agitation.

CONCLUSIONS

1. The ascorbic acid content of milk is not affected by air agitation for 1 hr in a pilot installation at an airflow rate of .03 cfm/gal of milk.

2. Development of rancidity in milk as measured by the free fatty acid content is not affected by air agitation for 1 hr in a pilot installation at an airflow rate of .03 cfm/gal of milk.

3. The butterfat redistribution time for 5 gal of milk in a pilot installation was approximately 3 min when the milk was exposed to .03 cfm of air per gallon of milk.

4. No correlations exist between the airflow rate to milk volume ratio between a 5-gal pilot installation and a 2000-gal storage tank.

5. The creaming ability of milk is not affected by air flow rates up to .03 cfm/gal of milk for a total agitation time of 2 hr.

6. The flavor of milk is not affected by an airflow rate of .03 cfm/gal of milk for 2 hr in a pilot installation. At an air flow rate of .3 cfm/gal, rancid flavor was produced on samples agitated for 2 hrs.

7. The cream layer in a 2000-gal storage tank, unagitated for 20 hr, will be redistributed in 2 min by .5 cfm of air.

8. The pressure in the air lines after the rotameter in the pilot installation is not great enough to register on a dial type pressure gage.

9. The results of air agitation on the physical and chemical properties of milk in a pilot installation can be projected to a large scale plant installation.

RECOMMENDATIONS FOR FUTURE STUDY

1. Develop a milk foam theory using a transparent liquid with milk characteristics.

2. Compare efficiency of operation of mechanical and air agitation.

3. Determine foaming relationship to churning.

4. Evaluate heat transfer rates of air and mechanically agitated liquids.

5. Determine air agitation requirements for various sizes and shapes of milk storage tanks.

6. Conduct economical comparison of air and mechanical agitation.

7. Develop air measuring and timing device suitable for commercial use on milk storage tanks.

8. Determine the effect of air agitation on dairy products after processing.

9. Study the possibility of using one-way air valves at orifice point in air distributing line.

10. Evaluate CIP cleaning of tanks equipped with air agitation.

11. Determine minimum airflow rates for preventing separation of butterfat.

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APPENDIX

The procedure outlined below is from work presented by Sharp (1938).

Vitamin C (Ascorbic Acid) Titration

Reagents:

A. The dye (2-6 dichlorophenol-indophenol)

B. Sulfuric acid (concentrated)

C. Ascorbic acid

Equipment:

A. Mortar and pestle

B. One liter volumetric flask

C. 500-ml volumetric flask

D. 200-ml beakers

E. Burrette 10 ml calibrated in 0.05-ml divisions

F. 100-ml graduated cylinder

G. 50-ml graduated cylinder.

The Dye

Place 0.2 grams of 2-6 dichlorophenol indophenol in a mortar and pestle. Grind thoroughly and add 55 ml of hot distilled water. Grind further and decant through a filter (paper) into a one liter volumetric flask. Add more hot water to the mortar, grind, and decant, continue this process until the blue color has passed through the filter. Adjust to room temperature and make up to one liter with distilled water.

The Sulfuric Acid

Prepare a stock solution of 10 normal C. P. H_2SO_4 by diluting 285 ml of concentrated acid to one liter. For use, dilute 10 ml of this stock solution to one liter. This is approximately N/10, and is used for acidifying and diluting the milk for titration. Approximately 25 ml of this is added to exactly 10 ml of milk.

Stardardizing the Dye Solution

A. Weigh accurately approximately 50 ml of ascorbic acid; transfer to a 500-ml volumetric flask and dilute to volume with distilled water. It should be used within one to 4 min after preparation.

B. Transfer 5 ml of the standard ascorbic acid solution into a 200-ml beaker, add approximately 15 ml of the dilute sulfuric acid and 15 ml of distilled water. Titrate with the dye solution to a light pink color permanent for at least 30 sec; record value.

C. Determine titration of an acid-water blank brought to the same end-point. A blank of approximately 0.3 ml is usually obtained. Subtract this from the value of (B).

D. Calculations. The amount of ascorbic acid in the 5-ml sample divided by the number of milliliter of dye solution needed, gives the milligrams of ascorbic acid corresponding to 1 ml of the dye solution. This value times 100 gives, in terms of milligrams per liter, the amount of ascorbic acid corresponding to each milliliter of dye solution required for the titration. The strength of the dye solution should be such that this factors in the limits of 5 to 8.

E. 1. Restandardize dye at 2 to 4-day intervals.

2. Discard dye solutions over two weeks old.

Titration of the Milk

A. Pipette 10 ml of milk into a 200-ml beaker. Add 25 ml of the dilute acid and titrate at once with the dye solution.

B. On titration, the milk will assume a pink color upon the addition of a small amount of the dye. However, upon standing a few seconds this color will fade. More dye may then be added. The procedure is continued until the pink color persists for at least 30 sec. This is the end-point of the titration.

C. A blank determination should be conducted and this blank value represents the residual titration of the milk and is obtained by allowing milk to stand until the ascorbic acid disappears and until constant value is secured. The blank may be determined on milk which has been stored in the cold for several days, or on milk which has been treated with about 1 mg of copper sulfate or exposed to sunlight.

D. Calculate and express results on the basis of milligrams of ascorbic acid per liter of milk.

E. Precautions. 1. Addition of acid to milk accelerates the destruction of the ascorbic acid, so that the milk should be titrated as soon as the acid is added.

2. The exposure of the milk to light should be reduced to the minimum required for the titration procedure. Light markedly accelerates ascorbic acid destruction.

TABLE A.1

BUTTERFAT CONTENT DETERMINED BY BABCOCK TEST OF SAMPLES TAKEN AT 2-MIN INTERVALS FROM 5 GAL OF RAW MILK HELD UNDISTURBED FOR 24 HR BEFORE EXPOSING TO AIRFLOW RATE OF .01 CFM/GAL OF MILK

Time Sample Taken	Text #1 % B.F.	Test #5 % B.F.	Test #9 % B.F.	Test #17 % B.F.	Test #18 % B.F.	Test #22 % B.F.	Test #26 % B.F.	Test #29 % B.F.	Test #30 % B.F.	Test #35 % B.F.
0 min	15.00	4.82	10.50	15.00	15.00	15.50	13.70	15.50	14.00	11.50
2 "	3.95	4.70	4.4	13.00	12.00	15.50	8.35	12.50	7.90	11.00
4 "	4.30	3.85	3.75	10.00	11.00	9.40	6.75	7.60	5.70	6.30
6 "	3.95	3.95	3.70	5.55	6.70	8.60	6.35	5.65	5.20	5.40
8 "	3.85	3.90	3.90	5.25	5.70	6.75	3.80	9.00	6.15	5.50
10 "	3.90	3.80	3.80	3.60	4.40	4.20	3.70	9.80	6.00	3.70
12 "	3.90	3.85	3.70	3.60	3.70	4.15	3.90	5.95	5.25	3.30
14 "	3.80	3.85	3.75	3.65	3.60	4.60	3.80	5.20	6.85	3.60
16 "	3.85	3.90	3.70	3.65	3.60	4.60	3.80	5.85	7.05	3.60
18 "	3.85	3.85	3.70	3.60	3.50	3.25	3.70	5.60	5.85	3.60
20 "	3.90	3.90	3.70	3.70	3.50	3.25	3.75	6.05	3.75	3.70
Time Required for complete mixing	6 min	4 min	10 min	10 min	14 min	16 min	8 min	?	?	14 min

Average time of all tests - 10.25 min

TABLE A.2

BUTTERFAT CONTENT DETERMINED BY BABCOCK TEST OF SAMPLES TAKEN AT 2-MIN INTERVALS FROM 5 GAL OF RAW MILK HELD UNDISTURBED AT 44°F FOR 24 HR BEFORE EXPOSING TO AIRFLOW RATE OF .02 CFM/GAL OF MILK RESULTS ARE AVERAGE OF DUPLICATE SAMPLES

Time Sample Taken	Test 7	Test 12	Test 13	Test 16	Test 19	Test 20	Test 24	Test 28	Test 32	Test 33	Test 34
	% B.F	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.
0 min	7.25	15.00	13.00	14.00	13.00	9.50	24.50	22.20	17.10	14.10	13.50
2 "	5.50	3.70	3.70	8.80	3.60	12.00	7.20	11.50	5.70	6.10	5.10
4 "	5.30	3.75	3.80	5.50	3.60	5.90	4.35	9.30	5.70	4.40	3.75
6 "	6.00	3.75	3.80	4.65	3.60	3.50	3.50	6.10	4.00	3.90	3.70
8 "	4.55	3.70	3.60	3.60	3.60	3.50	3.60	5.70	6.00	4.00	3.75
10 "	4.30	3.75	3.70	3.65	3.10	3.50	3.65	3.50	4.00	3.95	3.75
12 "	4.15	3.75	3.70	3.60	3.60	3.40	3.60	3.25	3.90	3.95	3.75
14 "	3.80	3.75	3.75	3.65	3.60	3.40	3.65	3.30	3.95	3.90	3.75
16 "	3.85	3.75	3.80	3.60	3.60	3.50	3.60	3.35	3.90	3.90	3.75
18 "	3.80	3.70	3.70	3.60	3.60	3.40	3.60	3.35	3.90	3.90	3.75
20 "	3.85	3.70	3.75	3.65	3.60	3.40	3.60	3.35	3.95	3.90	3.70
Time required for complete mixing	14 min	2 min	2 min	8 min	2 min	6 min	6 min	12 min	10 min	6 min	4 min

Average time for all tests - 6.55 min

TABLE A.3

BUTTERFAT CONTENT DETERMINED BY BABCOCK TEST OF SAMPLES TAKEN AT 2-MIN INTERVALS FROM 5 GAL OF RAW WHOLE MILK HELD UNDISTURBED AT 44°F FOR 24 HR BEFORE EXPOSING TO AIRFLOW RATE OF .03 CFM/GAL OF MILK. RESULTS ARE AVERAGES OF DUPLICATE SAMPLES.

Time Sample Taken	Test 2	Test 6	Test 10	Test 11	Test 14	Test 21	Test 25	Test 31	Test 40	Test 42
	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.	% B.F.
0 min	7.35	6.60	6.90	11.00	15.00	13.00	21.40	14.00	11.40	8.65
2 "	3.85	3.90	3.80	3.80	3.90	10.00	5.85	5.00	3.60	3.70
4 "	3.85	3.90	3.85	3.80	3.75	3.75	3.95	3.85	3.60	3.70
6 "	3.85	3.90	3.90	3.80	3.70	3.65	3.75	3.85	3.60	3.70
8 "	3.90	3.85	3.90	3.80	3.60	3.60	3.70	3.85	3.60	3.70
10 "	3.85	3.90	3.90	3.80	3.65	3.60	3.75	3.90	3.60	3.70
12 "	3.90	3.85	3.90	3.75	3.65	3.60	3.75	3.90	3.60	3.70
14 "	3.90	3.90	3.90	3.80	3.65	3.55	3.75	3.87	3.60	3.70
16 "	3.90	3.90	3.90	3.75	3.65	3.55	3.70	3.90	3.60	3.70
18 "	3.90	3.85	3.90	3.80	3.65	3.60	3.70	3.90	3.60	3.70
20 "	3.90	4.65	3.90	3.75	3.60	3.60	3.75	3.90	3.60	3.70
Time required for complete mixing	2 min		2 min	2 min	4 min	4 min	6 min	4 min	2 min	2 min

Average time for all tests - 3.10 min

TABLE A.4

STATISTICAL ANALYSIS OF RESULTS APPEARING IN TABLES A.1, A.2 AND A.3

.01 cfm/gal

x	f	d	fd	fd^2
4	1	-6	-6	36
6	1	-4	-4	16
8	1	-2	-2	4
10	2	0	0	
14	2	+4	+8	32
16	1	+6	+6	36
			+2 = Σfd	124 = Σfd^2

Assumed average = 10

$$\frac{\Sigma fd}{f} = \frac{+2}{8} = +.25$$

arithmetic mean = 10.00 + .25 = 10.25

$$\sigma = \sqrt{\frac{\Sigma fd^2}{f} - \frac{\Sigma fd}{f}^{\ 2}}$$

$$= \sqrt{\frac{124}{8} - \frac{4}{64}}$$

$$= \sqrt{15.5 - .06} = \sqrt{15.44}$$

σ_1 = $\pm$ 3.93 one probable error

σ_2 = $\pm$ 7.86 two probable errors

.02 cfm/gal

x	f	d	fd	fd^2
2	3	-4.00	-12	48
4	1	-2.00	-2	4
6	3	0	0	0
8	1	+2.00	+2	4
10	1	+4.00	+4	16
12	1	+6.00	+6	36
14	1	+8.00	+8	64
			+6 $= \Sigma fd$	162 $= \Sigma fd^2$

Assumed average = 6.00

$$\frac{\Sigma fd}{f} = \frac{+6.00}{11.0} = +.55$$

arithmetic mean = 6.00 + .55 = 6.55

$$\sigma = \sqrt{\frac{\Sigma fd^2}{f} - \left(\frac{\Sigma fd}{f}\right)^2}$$

$$= \sqrt{\frac{162}{11} - \frac{36}{121}}$$

$$= \sqrt{14.7 - .30} = \sqrt{14.4}$$

$\sigma_1 = \pm 3.80$ one probable error

$\sigma_2 = \pm 7.60$ two probable errors

.03 cfm/gal

x	f	d	fd	fd^2
2	5	-1.00	-5.00	5
4	3	+1.00	+3.00	3
6	1	+3.00	+3.00	9
			+1.00 $=\Sigma fd$	18 $=\Sigma fd^2$

Assumed arithmetic mean = 3.00

$$\frac{\Sigma fd}{f} = \frac{+1.00}{9} + +.11$$

arithmetic mean = 3.00 + .11 = 3.11

$$\sigma = \sqrt{\frac{\Sigma fd^2}{f} - \left(\frac{\Sigma fd}{f}\right)^2}$$

$$= \sqrt{\frac{18}{9} - \frac{1}{81}}$$

$$= \sqrt{2 - .012} = \sqrt{1.988}$$

σ_1 = $\pm$ 1.42 one probable error

σ_2 = $\pm$ 2.84 two probable errors

ANALYSIS OF VARIANCE

.01 cfm (x_i)	$(x_i)^2$	.02 cfm (y_i)		.03 cfm (z_i)	
6 min	36	14 min	196	2 min	4
4 "	16	2	4	2	4
10	100	2	4	2	4
10	100	8	64	4	16
14	196	2	4	4	16
16	256	6	36	6	36
8	64	6	36	4	16
14	196	12	144	2	4
$82 = \sum x_i$	$964 = \sum (x_i)^2$	10	100	2	4
		6	36	$28 = \sum z_i$	$104 = \sum (z_i)^2$
nx = 8		4	16	nz = 9	
		$72 = \sum y_i$	$640 = \sum (y_i)^2$		
		ny = 11			

Total sum of squares

$$\sum x_i^2 + \sum y_i^2 + \sum z_i^2 - \frac{(\sum x_i + \sum y_i + \sum z_i)^2}{nx + ny + nz}$$

$$964 + 640 + 104 - \frac{(82 + 72 + 28)^2}{8 + 11 + 9}$$

$$964 + 640 + 10.1 - \frac{33,124}{28}$$

$$1704 - 1182 = 426 = I$$

Between sum of squares.

$$\frac{(\Sigma x_i)^2}{nx} + \frac{(\Sigma y_i)^2}{ny} + \frac{(\Sigma z_i)^2}{nz} - \frac{(\Sigma x_i + \Sigma y_i + \Sigma z_i)^2}{nx + ny + nz}$$

$$\frac{(82)^2}{8} + \frac{(72)^2}{11} + \frac{(28)^2}{9} - \frac{(82 + 72 + 28)^2}{8 + 11 + 9}$$

$$\frac{6724}{8} + \frac{5184}{11} + \frac{784}{9} - \frac{33,124}{28}$$

$$840 + 471 + 87 - 1182 = 216 \qquad II$$

	Degrees of Freedom	Sum Square	Mean Square	F
Total nx + ny + nz -1				
8 + 11 + 9 - 1 =	27	420		
Between	2	216	108	$\frac{108}{8.2} = 13.2$
Within	25	204	8.2	

$F_{exp} = 13.2 \qquad F_{.99} = 7.77$

Since $F_{exp} > F_{.99}$ we then can conclude that there is a difference of population with a risk of 1/100 of being wrong.

"t" test

x_i y_i z_i

$t_{.95\,(25)} = 2.06$

$t_{.99\,(25)} = 2.79$

$$\sigma(x - z) = \sqrt{\text{mean sum of squares for within}} \left(\frac{1}{nx} + \frac{1}{ny}\right)^{\frac{1}{2}}$$

$$= \sqrt{8.2 \times (1/8 + 1/[illegible])}$$

$$= \sqrt{156/88} = \sqrt{1.78} = 1.34$$

$$\Delta \frac{M_{exp}}{x \;\; y} = 10.25 - 6.50 = 3.75$$

$$\Delta m_{.95} = t_{.95} \times \sigma_{x-y} = 2.06 \times 1.34 = 2.76$$

2.76 < 3.75 then x and y are different with a risk of 1/20 of being the same.

$$\sigma\; y - z = \sqrt{8.2 \times (1/9 + 1/11)} = \sqrt{164/99} + \sqrt{1.66} = 1.29$$

$$\Delta m_{exp} = 6.50 - 3.10 = 3.40$$

$$\Delta m_{.95} = 2.06 \times 1.29 = 2.66$$

2.66 < 3.40, therefore y and z are different with a risk of 1/20 of being the same.

TABLE A.5

BUTTERFAT CONTENT DETERMINED BY BABCOCK TEST ON SAMPLE TAKEN AT 2-MIN INTERVALS FROM 5 GAL OF RAW MILK HELD UNDISTURBED AT 36°F FOR 24 HR BEFORE EXPOSING TO AIRFLOW RATE OF .03 CFM/GAL OF MILK. RESULTS ARE AVERAGE OF DUPLICATE TESTS

Agitation Time	Test 50 % B.F.	Test 51 % B.F.	Test 52 % B.F.	Test 53 % B.F.
Control	13.0	13.40	13.65	13.40
2 min	4.0	3.95	4.0	4.0
4 "	4.0	3.95	4.0	4.0
6 "	4.0	3.95	4.0	4.0
8 "	4.0	3.95	4.0	4.0
10 "	4.0	3.95	4.0	4.0

TABLE A.6

BUTTERFAT CONTENT DETERMINED BY BABCOCK TEST ON SAMPLE TAKEN AT 2-MIN INTERVALS FROM 5-GAL RAW WHOLE MILK HELD UNDISTURBED AT 44°F FOR 24 HR BEFORE EXPOSING TO AIRFLOW RATES OF .04 CFM/GAL RESULTS ARE AVERAGE OF DUPLICATE TESTS

Time Sample Taken	Test 8 % B.F.	Test 23 % B.F.	Test 27 % B.F.	Test 41 % B.F.	Test 43 % B.F.
0 min	10.00	13.00	20.60	7.10	13.20
2 "	4.15	8.50	6.15	3.75	3.60
4 "	3.95	3.50	3.80	3.70	3.60
6 "	3.85	3.50	3.65	3.70	3.60
8 "	3.90	3.55	3.70	3.70	3.60
10 "	3.90	3.50	3.65	3.70	3.60
12 "	3.90	3.55	3.65	3.70	3.60
14 "	3.85	3.50	3.70	3.70	3.60
16 "	3.85	3.35	3.70	3.70	3.60
18 "	3.85	3.50	3.70	3.70	3.60
20 "	3.90	3.55	3.70	3.70	3.60
Time required for complete mixing	4 min	4 min	4 min	2 min	2 min

TABLE A.7

POUNDS OF AIR PER FEET OF HEAD FOR 1 CUBIC FOOT OF AIR AT 30 PERCENT RELATIVE HUMIDITY

Ft. of Head	Lb. of air/cfm
0	.0858
1	.0884
2	.0910
3	.0934
4	.0959
5	.0985
6	.1009
7	.1035
8	.1060
9	.1086
10	.1110

Date Due
