AN ABSTRACT OF THE THESIS OF

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Date Thesis presented December 12, 1933

Title The Comparative Efficiency of Different Types of Dairy Farm Milk Coolers

[redacted]

Abstract Approved: [redacted]
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The object of this study was to compare the efficiency of a Hydro-Vac cooler with that of a 29 x 16½ inch tubular surface cooler, as well as with that of two other coolers (tub cooler and sprinkler cooler).

The cooling efficiency of a Hydro-Vac cooler was slightly lower than that of a 29 x 16½ inch tubular surface cooler. The cooling efficiency of a sprinkler cooler was found to be higher than that of a tub cooler, but the cooling efficiency of either one of these two coolers was considerably lower than that of a Hydro-Vac cooler. When a Hydro-Vac cooler and a tubular surface cooler were thoroughly cleaned and sterilized there was no difference of practical significance in the bacterial contamination of the milk by these two coolers.

The flavor and odor of milk cooled with a tubular surface cooler or with a Hydro-Vac cooler was on an average slightly superior to the flavor and odor of milk from the same lot which was cooled with a tub cooler or with a sprinkler cooler.

No difference was observed in the volume of cream forming on milk from the same lot when the milk was cooled with a tubular surface cooler or with a Hydro-Vac cooler or when it was not cooled. Cooling the same milk with a tub cooler produced a slightly greater cream volume than cooling with a tubular surface cooler or with a Hydro-Vac cooler.

T H E S I S

on

THE COMPARATIVE EFFICIENCY OF DIFFERENT TYPES OF DAIRY FARM MILK COOLERS

Submitted to the

OREGON STATE AGRICULTURAL COLLEGE

In partial fulfillment of
the requirements for the
Degree of

MASTER OF SCIENCE

by

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December 1933

7 May '39. G. Author. wt. 15^{00} +.90 bind.

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OK 2-8-34 GS
OK 3-1-34 GS

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I. INTRODUCTION

A high percentage of the milk and cream now received by Oregon cheese factories, condenseries, and creameries is often, especially during the warm summer months, of a quality which will prohibit the manufacture of a first class product. A general improvement in the quality of this milk and cream would undoubtedly be followed by an improvement in the quality of the products made. This would, in all probability, mean higher returns for the producer and an increase in the consumption of these products.

Milk must conform to four requirements if it is to be classed as high quality milk. It has to be of high food value, it must be healthful, it should be clean and free from unnatural flavors and odors, and it must possess a high keeping quality.

Even a substantial improvement in the keeping quality of milk and cream alone would mean a great progress. The problem of maintaining a satisfactory keeping quality is essentially a problem of restricting the development of bacteria. This may be done either by preventing the entrance of bacteria, by destroying them after they enter, or by holding the milk and cream under conditions which will prohibit the activity of the microorganisms after they enter.

Destruction of the bacteria after they enter the milk, by addition of preservatives, would probably be the simplest method of increasing its keeping quality. Such a procedure is, however, prohibited by the law, if the milk is intended for human consumption. Employing heat to kill the bacteria is also unlawful for all milk and cream which is intended for sale to a dairy products manufacturing plant.

Preventing the entrance of microorganisms into the milk and cream during the milking process is only partly possible. Thorough sterilization of the milking utensils is generally recognized as one of the most helpful means in the production of milk of a low bacterial content.

The cooling of milk and cream to temperatures which will retard bacterial activity is far more effective than preventing the entrance of the microorganisms for the simple reason that if milk is not cooled, no matter how few bacteria the milk may contain, these organisms will rapidly multiply and cause souring of the milk in a relatively short time. On the other hand, milk containing numerous bacteria may be kept sweet for a long time if these bacteria are rendered less active by low temperatures. This is the reason why cooling to temperatures between 32° and 40° F. is absolutely indispensible if a milk of highest quality must be produced.

The use of mechanical refrigeration and natural ice in milk cooling is far superior to any other method. Due to the fact that price conditions have not allowed the general introduction of mechanical refrigeration and natural ice for milk cooling purposes on the farm, only a small number of dairy farmers are employing them at the present time. Cooling to 60° or 50° F. is far better than not cooling the milk at all. Therefore, it would be a great help, in improving the keeping quality of milk and cream if a low priced cooler of high cooling efficiency, which offers a minimum chance for bacterial contamination and which uses tap- or well water for cooling medium, could be obtained on the market.

Several new types of coolers have made their appearance during the last few years, but whether they comply with the above requirements is a question yet to be answered. It would therefore be of benefit to the dairy farmer, as well as to the general cause of a quality improvement in milk and milk products, if the efficiency of these coolers were studied, and if it were compared with the efficiency of coolers which are now used for milk cooling purposes on the farm.

II. REVIEW OF LITERATURE

A. Influence of Temperature on the Keeping Quality of Milk

Cooling of milk is practiced with the view of creating temperature conditions which will retard bacterial activity in the milk. Long before the knowledge of micro-organisms dairymen have followed the method of keeping the milk in cool places because they had learned from experience that by doing so they were able to increase its keeping quality. With the beginning of this century, research workers became interested in improving the quality of the milk and they began to do investigational work along this line.

In 1903 Conn (13) made a series of tests to determine the influence of different temperatures on the keeping quality of milk which resulted in the following conclusions: "Variations in temperatures have a surprising influence upon the rate of multiplication of bacteria. At 50° F. these organisms may multiply only five-fold in 24 hours, while at 70° F. they may multiply 750-fold."

He further states that: "milk which is kept at 95° F. will curdle in 18 hours, while the same milk kept at 70° F. will not curdle for 48 hours and if kept at 50° F. may sometimes keep without curdling for two weeks or more."

Ayers and Johnson (5), in 1910, made an extensive investigation of the milk supply of several eastern cities. They found that the bacterial count of the pasteurized milk sold in a small city averaged 6,170,000 when fresh and 44,000,000 when 24 hours old if the milk was held at 50° F., while when holding the milk at temperatures ranging from 71.6° to 77.0° F. the number of bacteria per c.c. increased from 8,250,000 when fresh to 1,380,000,000 when 24 hours old.

Similar results were obtained when they examined the raw milk supply of Washington D. C.

In 1912 Frandsen (20) published results of an experiment which had been undertaken to determine the influence of different temperatures on the bacterial development in cream. He divided a can of cream into six parts and kept them at 32°, 50°, 60°, 70°, 80°, and 90° F. respectively for 10 to 11½ hours. The numbers of bacteria per c.c. at the end of the holding period were 3,300, 11,580, 15,120, 188,000, 2,630,000, and 4,426,000 respectively in the six lots of cream held at the temperatures mentioned above.

Hunziker, Mills, and Switzer (28) reported in 1916 that the cream received at the University of Purdue creamery from 20 patrons using cooling tanks to cool their cream contained 147,125 bacteria per c.c. The cream from 20 other patrons who did not employ cooling methods had a bacterial content of 226,750. The acidity of the cream was .38 percent and .52 percent respectively, and what was most important of all, the butter made from the cooled cream scored on an average two and one-half points higher than the butter made from the cream not cooled.

Gamble and Bowen (23) reported on a survey made in New England. The number of bacteria found per c.c. of the milk examined in this survey averaged 27,000,000 and the average temperature of the milk was 62° F. A campaign was then made among the producers of this milk with the purpose of showing them the necessity of cooling their milk. At the end of this campaign the average temperature of the milk had dropped to 54° F. and the average bacterial count had decreased to 750,000 per c.c.

The writers also pointed out that cooling is of little use if the milk is not kept continuously at a low temperature until it is delivered at the milk plant.

The relation of temperature to bacterial development in milk was also investigated by Rogers (3). On an average of 16 trials, he found the milk to contain 3,243 bacteria per c.c. when fresh. Holding this milk at 60° F. for 12, 24, and 48 hours increased the number of bacteria on an average to 4,056, 123,562, and 26,176,923 respectively; whereas, holding it at 70° F. raised the counts to 19,312, 10,006,875, and 2,014,692,307 respectively. He concluded that if milk of a low bacterial count is desired it must be cooled and held at 50° F. or lower on the farm.

That the storage temperature of milk and cream is of utmost importance upon bacterial development was also shown by an experiment made in 1930 by Marquardt and Dahlberg (32). They cooled milk in 10-gallon cans in a tank of cold water. With the water at 35° to 40° F. and with an original bacterial count of 11,700 per c.c. they found the milk to contain 12,700 bacteria per c.c. after a storage time of 12 hours. When the water temperature was 55° to 60° F. the bacterial count increased from 10,000 per c.c. to 86,400 in 12 hours. They concluded that 50° F. is approximately the critical temperature above which the bacterial count of milk increases markedly in 24 hours.

In 1930 Frayer (21) published the results of an investigation which he had undertaken in order to determine the influence of delayed cooling upon the quality of milk. He stated that milk which had been cooled immediately after milking and held at 50° F. for 48 hours showed a bacterial count of 410,000 per c.c. If the cooling of the same milk was delayed for four hours the count was 1,950,000 per c.c. or roughly five times as great as that of the milk cooled without delay. He concluded that the longer cooling is delayed the poorer the milk will be.

Price, Hurd, and Copson (38) stated that the bacterial content of milk did not increase during the first 12 hours when kept in 10-gallon cans in a tank of water at 35° to 40° F. However, if the water in the tank ranged from 55° to 65° F. the bacterial count of 46 samples increased from an average initial number of 1,930 per c.c. to an average of 5,570 per c.c. during 12 hours of storage.

Another illustration of how bacterial growth in milk is influenced by different temperatures is given by Kelly and Babcock (29). According to their data, milk held at 50° F. for 6, 12, and 24 hours contained 12, 15, and 41 bacteria per c.c. respectively when the initial count was 10 bacteria per c.c. When the milk was held at 68° F. instead of at 50° F. the number of bacteria per c.c. had increased after 6, 12, and 24 hours to a total of 17, 242, and 61,280 respectively.

An investigation undertaken by Tracy and Ruehe (40) brought out the fact that the milk having a temperature of below 70° F. upon arrival at a certain creamery was, on an average, of higher quality than the milk which had a temperature above 70° F. when received. Of all the milk with a temperature over 70° F. upon arrival, 39.4 percent scored grade A, 45.4 percent grade B, and 13.7 percent grade C; whereas, of the milk having a temperature below 70° F. 53.6 percent scored grade A, 43.5 percent grade B, and only 2.9 percent grade C. The grading was done by the methylene blue reduction test.

In May 1929 they made a similar check on the milk received at the University of Illinois creamery. They observed that the temperature of 81 percent of the milk having a bacterial count of less than 50,000 per c.c. was below 70° F. upon arrival. Of the milk with a bacterial count from 50,000 per c.c. to 200,000 per c.c. 62 percent had a temperature below 70° F.; of the milk with a count from 200,000 per c.c. to 500,000 per c.c. 41.4 percent had a temperature below 70° F.; and 37.5 percent of the milk with a bacterial count of over 500,000 per c.c. was below 70° F. when received.

Downs and Lewis (18) in 1932 made a series of experiments which furnished some interesting data on the influence of the holding temperature on bacterial growth in milk. They were able to hold relatively poor milk with an original bacterial count of 535,000 per c.c. at 40° and 50° F. for more than 15 hours without increasing the count above 1,000,000 bacteria per c.c. When the same milk was held at 60°, 70°, 80°, and 98° F. it still had a bacterial count of less than 1,000,000 bacteria per c.c. after nine, six, three, and two hours respectively. Milk with an initial count of 5,500 bacteria per c.c. was kept at 70° F. for over 15 hours before the bacterial count per c.c. reached 1,000,000.

In 1932 additional data on the influence of delayed cooling upon the quality of milk was published by Frayer

(22). In his conclusions he stated that "cooling milk immediately to 50° F. is a fairly satisfactory procedure, even when it is held over night." He also regarded the cooling of morning's milk immediately to 60° F. as a fairly satisfactory procedure. For best results in respect to its quality, both present and future, milk must be cooled immediately to and held at a temperature of 40° F. or below, according to his opinion.

B. Milk Coolers and Their Cooling Efficiency

Since it is of great importance that milk be cooled as quickly as possible, after milking, to a low temperature, the rate with which milk may be cooled by different methods has frequently been the subject of investigation.

Gamble (24) reported in 1918 on an experiment which was undertaken to demonstrate the proper use of ice in milk cooling. When a 10-gallon can of milk at an original temperature of 91° F. was placed in a wooden tank containing 120 gallons of water at 54° F. and when at the same time 100 pounds of ice were added to this water, the milk was cooled to 50° F. in nine hours.

Putting a partition in the tank and using only 42 gallons of water instead of 120 gallons and the same amount of ice resulted in a lowering of the temperature to 41° F. in nine hours. All conditions were identical for the two trials, with exception of the volume of cooling water.

One year later Gamble and Bowen (23) pointed out that the rate of cooling depends a great deal on the initial temperature of the cooling water. They cooled 10 gallons of milk in a tank of water containing 75 to 80 gallons of water. Three hundred pounds of ice were put in the tank at the same time as the can of milk was placed in it. With the initial water temperature at 70°, 60°, 55°, and 50° F. respectively the milk was cooled from 95° to 50° F. in 145, 105, 85, and 80 minutes respectively.

Agitating the cooling water in the case where tank cooling of the milk is practiced was shown by Knepp (30) to increase the rate of cooling markedly. In his experiments milk was cooled from 95° to 60° F. in 70 minutes when the water at 36° F. was not stirred; whereas, it required only 32 minutes when the water was agitated. Cooling to 50° F. was effected in 195 minutes with the water not agitated and in 75 minutes when the water was circulated.

Price, Hurd, and Copson (38) obtained similar results in their investigation. Holding the water temperature as low as possible, milk was cooled in 10-gallon cans from 95° to 59° F. in one hour when the cans were kept in still water (35° to 45° F.), and to 46° F. in one hour when the water was circulated around the cans by means of a propeller type water circulator. At two hours the milk in the still water was cooled to 56° F. while that in the agitated water was cooled to 42° F. With reference to the effect of stirring the milk, during cooling in a tank of refrigerated water, these investigators made the statement that "stirring milk in 10-gallon cans set in water at 35° to 40° F. does not materially increase the rate of cooling."

Ackerman (1) compared the cooling rates of milk precooled over a surface cooler before being placed in a tank of refrigerated water and milk not precooled. He observed that precooling by circulation of well water at 51° F. through a tubular aerator reduced the milk to a temperature as low as 52.5° F. This was accomplished at a cost of 25 cents for 100 quarts of milk, including storage for one day.

In order to avoid additional contamination with bacteria, Marquardt and Dahlberg (32) recommended disregarding of stirring the milk as well as of precooling it over a surface cooler, in spite of the fact that both procedures will increase the rate of cooling. They claimed that milk could be satisfactorily cooled by just placing it, immediately after the can is filled at milking time, in cold water at 40° F., provided the tank is of ample size, well insulated, and a large enough source of refrigeration is available.

Newlander (36) in 1931 made a comparison of the cooling rates of different methods of milk cooling. He found that it took five and one-half to six hours to cool a 10-gallon can of milk from 90° to 50° F. when held in a cold room (3° to 12° F.). It required 75 minutes to obtain the same cooling effect when the milk was placed in a tank of water at 32° F. When ice was added to the initial cooling water at 40° F., at the time the can was placed in the tank, the milk cooled to 50° F. in 75 minutes, when the milk was not stirred, and to 50° F. in 60 minutes when it was stirred. It required 105 minutes to cool 10 gallons of milk from 90° to 50° F. when the water containing ice was agitated and 165 minutes when it was not agitated.

Bowen (11) reported that a 10-gallon can of milk placed in a tank of water at an average temperature of 37° F. cooled in 60 minutes from 94° F. to 62°, 54°, 53°, and 45° F. respectively, when the milk was not stirred, stirred every 10 minutes, stirred every five minutes, and stirred continuously.

That the temperature to which the milk is cooled by a surface cooler is greatly influenced by the rate of milk-flow is mentioned by Downs and Lewis (18). They stated "observations of cooling methods on several dairies showed that in many instances where it was possible to cool to 40° F. the milk was going off the cooler at 48° to 50° F., and even as high as 58° F., due to the opening of the control valve and allowing the milk to flow too fast."

Bressler and Nicholas (12) recommended direct immersion cooling of the milk in all cases for small dairy farms, unless the milk is bottled on the farm. In their experiments they cooled milk by direct immersion to below 50° F. in 20 minutes if the cooling water was less than 36° F. and if the ratio of water to milk was greater than eight. The water in these tests was agitated but the milk was not stirred.

Trout (41) made a comparison of the cooling efficiency of several surface coolers of different types. He concluded that the efficiency of the surface milk cooler is dependent (1) upon the course of the cooling medium flowing through it, (2) upon the rate of milk-flow, and (3) upon the rapidity of the milk itself in passing over the cooling area. He also found that at least as much water is required in cooling milk by the surface cooler method as by the tank method.

C. Milk Coolers, a Source of Bacterial Contamination

It is obvious that surface coolers may be a source of bacterial contamination, if they are not properly sterilized.

Atwood and Giddings (4) found that a sterilized surface cooler contaminated two liters of sterile water run over the cooler with two bacteria per c.c. (average of five trials). When the cooler was not sterilized the contamination was 11,400 bacteria per c.c. (average six trials). The same cooler unsterilized contaminated 20 quarts of milk to an extent of 5,000 bacteria per c.c. (average of eight trials). Cooling 20 quarts of milk with the sterilized cooler, resulted three times in an increase and twice in a decrease of the number of bacteria in the cooled milk, as compared with the count of the uncooled milk. The average change in the bacterial count for the five trials was an increase of 10 bacteria per c.c.

D. Influence of Cooling on the Flavor and Odor of Milk

Marshall (33) found that odors and taints resulting from aromatic foods, physiological processes, and disease processes may be greatly reduced permanently by aeration. Odors and taints resulting from bacterial fermentations may also be greatly reduced by aeration, but they will return upon further development of bacteria.

Ernst (19) states that aeration of milk permitted the escape of carbonic acid, hydrogen, and sulphide of hydrogen and supplied the milk with air, so that in all probability the development of certain bacteria was checked, which otherwise, if the milk had been filled into containers in a warm and unaerated condition, would have imparted to the milk a sharp, disagreeable animal taste and odor.

In 1923 Babcock (6) conducted experiments on aerating milk which had an off flavor and odor due to feeding green alfalfa. He concluded that "proper aeration reduces strong off flavors and odors in milk caused by feeding green alfalfa, and slight off flavors and odors may be eliminated."

Gamble (25) made similar tests with milk possessing off flavors due to the feeding of silage. He observed that careful and prompt aeration of the warm milk permanently removed silage flavors and odors from slightly tainted milk and reduced the degree of more pronounced silage flavors and odors. He recommended aeration of milk in a milk room, in which the air is free from bad taints or dust, and which is well ventilated.

Babcock (7) in 1923 reported that milk with a strong feed flavor and odor resulting from feeding 15 pounds of turnips one hour before milking was greatly improved by aeration. The percentage of opinions rating the milk normal in flavor was increased by aeration from 30.7 to 51.0 percent, and the percentage rating the milk normal in odor was increased from 24.8 to 46.6 percent. Before aeration 13 percent of the opinions rated the milk off in flavor; this percentage was reduced to 10.4 percent by aeration. Likewise, the percentage of opinions rating the odor as "off" was reduced from 15.0 to 12.8 percent by aeration.

Still another example of improving the odor and flavor of milk by aeration is given by Babcock (8). In his experiments milk with a strong feed flavor and odor resulting from feeding cabbage to the cows was subjected to aeration with a surface cooler. This procedure increased the percentage of opinions rating the flavor of the milk normal from 15 percent to 34.7 percent and it increased the percentage of opinions rating the odor normal from 12.6 to 26.3 percent. Simultaneously the percentage of opinions rating the flavor and odor off decreased noticeably.

Marquardt and Dahlberg (32) state that according to their findings the flavor of milk was not injured when the milk was cooled without stirring by submerging it in 10-gallon cans in a tank of refrigerated water. It was not necessary to keep the cans uncovered until the milk was cooled. However, they observed that for milk with bad flavor, such as absorbed feed flavors, aeration may be desirable.

In 1931 Tracy and Ruehe (40) reported that the use of chlorine sterilizers on surface coolers (as well as other dairy utensils) should be confined to those of a non-corrosive nature. In no case should the disinfectant be added directly to the milk, and all utensils treated with chlorine sterilizers should be rinsed with uncontaminated water before adding the milk, otherwise, puckery, unclean, or medicinal flavors may result.

They also pointed out that exposing milk to sunlight during cooling with a surface cooler (at or any other time) may be the cause of the occurrence of two kinds of flavor defects, one a tallowiness and the other a burnt flavor.

In an article published in "The Milk Dealer" Washburn (44) made the following statement: "All milk is made better by some aeration. If the milk is to be used as raw milk, it by all means needs to be aerated before it is bottled. If it is to go to the city to be pasteurized and bottled, it still needs to be aerated while it is still warm and while being cooled in order to remove the odor before the flavors become fixed in the milk." He also was of the opinion that while aeration of milk is not imperative, if the milk is to be used for evaporated, condensed or powdered milk purposes and for cheese, it certainly is highly desirable.

Bennett (10) found that certain weed flavors, such as garlic flavor, may be reduced in intensity by aerating the milk, preferably at high temperatures. Furthermore, he found that aerating milk flavored with bitterweed had no appreciable effect in removing this flavor from the milk. Flavors in milk due to absorption from the air of strong odors given off by other food stuffs, or chemicals and odors as found in poorly ventilated stables, may be partially, but not completely, removed by aeration of the milk.

E. Influence of Cooling on the Creaming Ability of Milk

It has been known for a long time that the temperature at which milk is held after it is drawn from the cow is greatly influencing the amount of visible cream rising on it.

In 1916 Hammer (26) reported that setting milk in ice water for creaming increased the depth of the cream layer 114 percent (average of 29 trials) as compared with creaming at room temperature. In ice water a deep cream layer formed in a short time, which decreased on further holding in the ice water. Holding over night in ice water and then taking a sample for creaming usually decreased the cream layer. He further noticed that agitating the milk either at room temperature or at low temperatures did not decrease its creaming ability enough as to be of any significance. The cream layer decreased markedly when milk creamed in ice water for 24 hours was kept at room temperature thereafter.

Harding (27) made the statement that "the amount of cream which will develop on raw milk depends quite largely upon the agitation to which it has been subjected while cold." However, when milk is moderately heated (to 140° F. momentarily) it has, in his opinion, a fairly comparable creaming power, regardless of the agitation to which it has been exposed while cold.

Agitating hot milk in the pasteurizer was found to be a "neglectible factor" in decreasing the creaming ability of milk by Martin and Combs (34). But they observed that cooling the milk in the vat, following pasteurization, resulted in a decisive impairment of its creaming power.

Trout (42) found that a greater creaming efficiency resulted when milk, raw, pasteurized, or pumped, was creamed in ice water than when creamed at higher temperatures in air. Pumping raw milk at 60° F. and preheating to 85° or 90° F. decreased the creaming ability of milk about nine percent.

Whittaker, Archibald, Shere, and Clement (45) concluded from their experiments that allowing milk to stand or to be agitated for 15 minutes or more at temperatures between 60° and 110° F. had generally a detrimental effect on the cream volume. Furthermore, they found that pumping raw milk with four different types of pumps had practically no effect on the cream volume.

Recreaming of raw milk decreased the cream volume, but after one recreaming, the age of the milk was of more importance than the number of times it was recreamed.

Dahlberg and Marquardt (14) observed that creaming at lower temperatures produced higher cream volumes. Quick cooling and holding at 40° F. for 18 hours resulted in smaller cream layer volumes than in normal fresh milk. In order to find out whether agitation had any influence on the creaming ability of milk they hauled milk in partly filled cans over a rough road, but no impairment of the creaming power of the milk thus treated was detected. More violent agitation at 60° F. resulted in an increase, and at 40° F. in a slight decrease of the creaming ability.

In a later publication Dahlberg and Marquardt (15) stated that milk cooled to and held at 60° F. gave a short cream layer volume, but upon resetting at 40° F. the cream layer volume was increased as compared with normal fresh milk. This increase in the volume of cream was caused by a decreased percentage of fat in the cream.

Tests made with pasteurized milk by Dahlberg and Marquardt (16) showed that agitation when heating, holding, and cooling the milk was of minor importance. However, agitation after cold storage for some time, reduced the cream volume to some extent. They recommended rapid cooling, immediately after pasteurization, if good creaming is to be insured.

Following are the results obtained by Mertens (35). Like other investigators, he pointed out the value of quick cooling, the decrease of the creaming ability upon aging of the milk at low temperatures, and the small influence of agitation on the cream volume. In addition, he stated that freezing reduced the creaming ability markedly; however, normal creaming was restored by heating the milk for five minutes to 58° F.

Many investigators have worked on the problem of how the cream layer is formed on milk. Several theories have been advanced as a result of it. However, so far none of these theories have been entirely satisfactory in explaining all the phenomena involved in creaming. Based on their extensive research work, Dahlberg and Marquardt (17) developed the theory given below. They associated the clumping of the fat globules with the calcium ions in solution, and assumed, although they could not prove, that the fat globules possess a negative charge which keeps them apart. The positively charged calcium ions would cause the fat globules to cluster by offsetting part of their weak, negative charges. Furthermore, they were of the opinion that the Brownian movement of the fat globules is hindering the formation of clusters, and that an increase in the creaming ability upon cooling of the milk is the result of stopping the Brownian movement by the lowering of the temperature. Heating the milk to higher temperatures is precipitating part of the calcium in solution, which in return would permanently impair the creaming power.

Bell (9), Magee, and Harvey (31) have proved that heating milk to higher temperatures caused a permanent precipitation of a fraction of its calcium in solution. This substantiates the theory of Dahlberg and Marquardt.

Rahn (39) claims that the size of the fat globules have little influence on the creaming ability of milk, since the fat globules rise in clumps and not as single globules. He explained the formation of the clumps by the sticking together of the globules, due to the presence of a sticky, proteinaceous substance on their surface.

Palmer and Anderson (37) were of the opinion that the volume of cream rising on raw milk of uniform fat content was determined largely by the content of solids not fat in the plasma. They also considered the viscosity of raw milk as a good index of its creaming ability, since they found that an increase in the viscosity of milk was almost invariably followed by an increase in the cream volume forming on it.

Contrary to this, Troy and Sharp (43) concluded from their experiments that fat clumping, and not viscosity, controls the fat content of the cream forming on milk.

III. STATEMENT OF THE PROBLEM

It is well known that a high percentage of the milk and cream intended for purposes other than retail marketing is not of the high quality that is essential for the manufacturing of first class dairy products. This is mainly due to the fact that the producers of this class of milk and cream pay too little attention to the proper cooling of their products. The cooling methods employed by them, if such are used at all, either have the disadvantage of offering too great a possibility for bacterial contamination of the milk during the cooling process, or they are of low cooling efficiency.

The need for a low priced cooler which possesses high cooling efficiency combined with a minimum chance for bacterial contamination has been felt for some time. As a result of this a number of new types of milk coolers have been put on the market during the last few years. The manufacturers of these coolers are claiming for them highest efficiency in securing rapid and low cooling, minimum contamination of the milk with bacteria during the cooling process, and some of them also guarantee proper aeration of the milk. The farmer who wishes to purchase a cooler is more or less at a loss when trying to select the one most suitable for his specific needs. He has to rely almost entirely upon the recommendation of the manufacturers, since very little comparable data on the merits of these new-type coolers is available at the present time.

The main purpose of the investigation reported on in this paper was to study and compare the efficiency of one of these new coolers, called "Hydro-Vac" cooler, with that of a tubular surface cooler, as well as with that of two other types of coolers.

The following points are considered in this report:

(a) Cooling efficiency

(1) Influence of different temperatures of the cooling water on the cooling efficiency of a 29 x 16½ inch tubular surface cooler.

(2) Influence of different temperatures of the cooling water on the cooling efficiency of a Hydro-Vac cooler.

(3) Influence of different rates of water-flow on the cooling efficiency of a 29 x 16½ inch tubular surface cooler.

(4) Influence of the rate of milk-flow on the cooling efficiency of a 29 x 16½ inch tubular surface cooler.

(5) Influence of the length of cooling time on the cooling efficiency of a Hydro-Vac cooler.

(6) Comparative cooling efficiency of a $29 \times 16\frac{1}{2}$ inch tubular surface cooler and a Hydro-Vac cooler.

(7) Comparative cooling efficiency of a Hydro-Vac cooler, sprinkler cooler, and tub cooler.

(b) Bacterial contamination of milk by different types of milk coolers.

(c) Influence of different methods of cooling on the flavor and odor of milk.

(d) Influence of different methods of cooling on the creaming ability of milk.

IV. EXPERIMENTAL

A. Methods Used

The cooling methods studied in this investigation were (1) cooling of the milk with a tubular surface cooler, (2) cooling with a Hydro-Vac cooler, (3) cooling with a sprinkler cooler, and (4) cooling with a tub cooler.

The surface cooler employed in the experiments was the cooler which was used daily at the college dairy barn to cool the milk produced by the college dairy herd. This cooler had a length of 29 inches and a height of $16\frac{1}{2}$ inches. It consisted of nine horizontal tubes, situated above each other. A metal strip was soldered between each pair of tubes in such a way that a continuous cooling surface was created from top to bottom. Above the cooler proper there was a receiving tank for the milk. From this tank the milk flowed through a stop-cock into a small trough, which contained a row of holes along the entire length of the bottom. This trough was situated above the top tube of the cooler so that the milk running through its holes was evenly divided over the whole length of the top tube. A second trough was located below the bottom tube to collect the milk flowing off the cooler. From there the milk ran through an opening in the middle of the trough into the milk can placed underneath.

The cooler was connected with the city water line by means of a hose. The water entered the cooler at the bottom and left it at the top, which means that the counter flow principle was employed with this cooler.

The Hydro-Vac cooler was furnished by the Hydro-Vac Company of Chicago, Illinois for the purpose of being used in this investigation. This cooler was an apparatus which could be placed on the shipping can containing the milk to be cooled, in the same manner as a lid. By means of a hose the cooler was connected with the water pipe. The water was used for three different purposes: (1) on entering the cooler, it first ran through a water jet vacuum pump creating a suction of 0.379 pounds per square inch at a water-flow of four gallons per minute. This may eliminate odors from the milk. The suction pressure was determined by connecting the vacuum pump with a suction gage. (2) From the vacuum pump the water was conducted to a small water wheel located in the top part of the cooler. The shaft of the water wheel, which was in a vertical position, had a downward extension on the lower end of which a small propeller was mounted. This propeller served the purpose of stirring the milk during the cooling process. It could be readily disconnected for washing and sterilizing. (3) The overflow from the water wheel was used as cooling medium. The water was conducted onto the shoulder of the milk can in such a way that it formed a continuous film all around the can when flowing down the sides.

The "sprinkler cooler" was a device which employed the same principle for the cooling of the milk as was used by the Hydro-Vac cooler. The only difference between the two coolers was that the sprinkler cooler possessed neither stirring- nor aerating mechanism.

The cooler itself consisted of a piece of $\frac{1}{2}$ inch copper tubing, bent to form a circle of an inside diameter of nine inches. The tubing was sealed on one end and fitted with a hose connection on the other end. A row of small holes were drilled in the tubing in such a manner that they were facing inside and downward when the tubing was placed on the shoulder of the milk can containing the milk to be cooled. When the cooler was in operation the water ran down the sides of the can in the form of a continuous film. During the entire cooling process the lid was kept on the can. The milk was not stirred in order to avoid possible contamination with bacteria.

The tub cooler used in the investigation was a tank-type immersion cooler. Instead of having a low milk to water ratio, as is usually the case with tank coolers, this cooler had a milk to water ratio of 1:1.4. This was, however, offset by a continuous renewal of the cooling water.

The cooler consisted of a wooden ice cream tub, with a tripod in it, on which the can containing the milk to be cooled was set. The tripod was of such height that the milk can was submerged up to its neck when the tub was filled with water. A hose was introduced at the bottom of the tub and a continuous flow of water was maintained during the cooling process. Thus a current of cold water was caused, moving from the bottom of the tub upwards, along the sides of the can. In order that bacterial contamination of the milk could be completely eliminated the milk was not stirred during the entire cooling process.

The water of the city of Corvallis was used as the only cooling medium throughout the investigation. The temperature of this water varied considerably with the season of the year. The extreme temperatures of the water used as cooling medium in this work were 42.5° F. and 57.0° F.

The milk for the experiments was furnished by the cows of the college dairy herd. It consisted of approximately two-thirds of Holstein- and one-third of Jersey milk. Each cow's milk was brought separately to the milk house, where it was strained while warm into a 10-gallon can. As soon as the can was filled the temperature of the milk in it was adjusted to 90° F. except in a few cases where it was adjusted to 94° F. This was done in order to facilitate the comparison of the results of cooling. The temperature adjustment was made by running hot or cold water from a hose over the outside of the can, depending on the initial temperature of the milk being below or above the one desired. Simultaneously the milk in the can was stirred with a sterile hand stirrer to accelerate the temperature change. With the finishing of the temperature adjustment the milk was then ready for the cooling experiment.

All bacterial counts were made in accordance with the "Standard Methods of Milk Analysis" of the American Public Health Association (2). The sample bottles, sampling pipettes, and dilution blanks were sterilized in an autoclave for 30 minutes at 15 pounds pressure. The rest of the bacteriological equipment was sterilized in a hot air sterilizer for two hours at 320° F. "Dehydrated Bacto Nutrient Agar" was used for the preparation of the culture medium. Most of the samples were plated in 1:50 dilution. Duplicate plates were made of every sample. The colonies were counted with the aid of a "Buck" colony counter and the arithmetic average of the counts of the two plates was recorded.

The acidity determinations were made by titrating 17.5 c.c. of the milk with one-tenth normal solution of sodium hydroxide using phenolphthalein as indicator.

The creaming ability of the milk was determined in the following way. One hundred c.c. of milk were placed in a 100 c.c. graduated cylinder. The cylinder was then set in a tank containing ice water, for creaming. The depth of the cream layer was measured at the end of six and 24 hours of creaming with the aid of a pair of dividers. The cylinder was graduated to one c.c. and the readings were made to one-fourth c.c. by approximation.

The butterfat determinations were made by the "Babcock" method and the fat column was read to one-tenth of one percent. The tests were made in duplicate and the arithmetic average of the two findings was recorded.

B. Results Obtained

1. The Cooling Efficiency of Different Types of Milk Coolers

a. Influence of different temperatures of the cooling water on the cooling efficiency of a 29 x 16½ inch tubular surface cooler. A total of eight tests was made to determine the influence of different temperatures of cooling water on the cooling efficiency of a 29 x 16½ inch tubular surface cooler. The amount of milk cooled in each trial was 80 pounds. The temperature of the milk before cooling was in each test adjusted to 90° F. The cooling water was flowing through the cooler at a rate of four gallons per minute and the milk-flow was so regulated that it required 10 minutes to cool 80 pounds of milk. The milk to water ratio was 1:4.17 or in other words for each gallon of milk cooled, 4.17 gallons of cooling water were used. The room temperature varied from 57.0° F. in the first trial to 77.0° F. in the last trial and it averaged 66.8° F. The range of the temperature of the cooling water was from 47.0° to 57.0° F. and the average temperature of the cooling water was 51.4° F.

Table 1.

Influence of Different Temperatures of Cooling Water on the Cooling Efficiency of a 29 x 16 1/2 Tubular Surface Cooler.

Amount of milk cooled in each trial: 80 pounds
Rate of flow of milk over cooler: 8 pounds per min. (10 minutes for 80 pounds of milk.)
Rate of flow of water through cooler: 4 gal. per min.
Ratio of milk to water: 1:4.17

Number of Trial	Temperature					Temp. Reduction of Milk	Temp. Diff. between Milk after Cooling & of In-going Water
	Room	Cooling Water		Milk			
		In-going	Out-going	Before Cooling	After Cooling		
	Deg.F	Deg.F	Deg.F	Deg.F.	Deg.F.	Deg.F.	Deg.F.
1	57.0	47.0	55.0	90.0	51.5	38.5	4.5
2	64.0	47.0	56.0	90.0	52.0	38.0	5.0
3	58.0	48.0	56.0	90.0	54.0	36.0	6.0
4	69.0	51.0	60.0	90.0	56.0	34.0	5.0
5	69.0	52.0	60.0	90.0	57.0	33.0	5.0
6	64.0	53.0	60.0	90.0	57.5	32.5	4.5
7	76.0	56.0	64.0	90.0	61.0	29.0	5.0
8	77.0	57.0	65.0	90.0	61.5	28.5	4.5
Ave.	66.8	51.4	59.5	90.0	56.3	33.7	4.9

As shown in Table 1, the milk was cooled to 51.5° F. with the cooling water at 47.0° F. In other words it was cooled to 4.5° above the temperature of the cooling water. With increasing temperature of the cooling water the temperature to which the milk was cooled increased also and consequently the temperature reduction of the milk decreased by the same amount. With the cooling water ranging from 47.0° to 57.0° F. the temperature extremes of the cooled milk were 51.5° and 61.5° F. and the extremes of the temperature reduction of the milk were 38.5° and 28.5° F. The temperature difference between the milk after cooling and the water entering the cooler ranged from 4.5° to 6.0°. The average of the temperature of the cooled milk was 56.3° F., that of the temperature reduction of the milk was 33.7° F., and that of the temperature difference between the cooled milk and the cooling medium was 4.9°. Table 1 shows also the temperature of the cooling water at the time it left the cooler. It ranged from 55.0° to 65.0° F. and averaged 59.5° F.

It is of interest to note that with increasing temperature of the cooling water the rate of increase of the final temperature of the milk was practically identical with the rate of the temperature increase of the cooling water. This in return was the reason that the temperature difference between the cooled milk and the water entering the cooler remained almost constant with increasing temperature of the cooling water.

A tendency for a small decrease in the temperature difference between the cooled milk and the cooling water was noticeable for the higher temperatures of cooling water, however, it was not pronounced enough to allow to draw the conclusion that such a relation was actually existing for the given temperature range of the cooling water.

b. Influence of different temperatures of the cooling water on the cooling efficiency of a Hydro-Vac cooler. In order to find out how the temperature to which milk is cooled by a Hydro-Vac cooler was influenced by different temperatures of the cooling water, nine tests were made. The results which were obtained are recorded in Table 2. Eighty pounds of milk were cooled in each trial. The temperature of the milk before cooling was adjusted to 90° F. in all but three trials. In two trials it was 89.5° F. and in one trial it was 91.0° F. The average for all the nine tests was exactly 90.0° F. The water was flowing through the cooler at a rate of four gallons per minute. The cooling process was interrupted after 5, 10, and 15 minutes and each time the temperature of the milk was determined and recorded. The milk to water ratio for 5, 10, and 15 minutes of cooling was 1:2.09, 1:4.17, and 1:6.26 respectively. The room temperature varied from 52.5° to 85.0° F. and it averaged 62.4° F. The temperature of the cooling water ranged from 42.5° to 56.0° F. and its average was 48.4° F.

An increase of the temperature to which the milk was cooled with increasing temperature of the cooling water, similar to that found for the surface cooler, was also observed for the Hydro-Vac cooler. The temperature to which the milk was cooled in 5, 10, and 15 minutes respectively ranged from 62.5° to 70.0°, from 51.5° to 62.0°, and from 47.0° to 59.0° F. The average temperature to which the milk was cooled in 5, 10, and 15 minutes respectively was 66.1°, 56.5°, and 52.4° F. The temperature reduction of the milk ranged for five minutes of cooling from 20.0 to 27.0°. The average was 23.9°. For 10 minutes of cooling the range of the temperature reduction was from 28.0° to 38.0° F., with an average of 33.5° F. For 15 minutes of cooling the temperature reduction varied from 31.0° to 42.5° F. The average was 37.6° F.

Comparing the temperature reductions for five minutes of cooling with the corresponding temperature reductions for 10 and 15 minutes of cooling brought out the fact that the rate of cooling during the first five minutes was on an average almost two and one-half times as high as for the second five minutes of cooling, and nearly six times as high as for the third five minutes of cooling. This means that the longer cooling was continued the slower became the rate of cooling.

Table 2.

Influence of Different Temperatures of the Cooling Water on the Cooling Efficiency of a Hydro-Vac Cooler

Amount of milk cooled in each trial: 80 pounds
Rate of flow of water through cooler: 4 gal. per min.
Ratio of milk to water for 5 min. of cooling: milk to water 1:2.09
10 " " " : " " " 1:4.17
15 " " " : " " " 1:6.26

Number of trial	Temperature						Temperature Reduction of Milk in 5, 10, 15 min. of cooling			Temp. Diff. between Milk after 5,10,15 min. of cooling & cooling water.		
	Room	Cooling Water	Milk									
			Before Cooling	After 5, 10, 15 min. of cooling								
				5 min.	10 min	15 min	5 min.	10 min	15 min	5 min.	10 min	15 min
	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.
1	53.0	42.5	89.5	62.5	51.5	47.0	27.0	38.0	42.5	20.0	9.0	4.5
2	53.5	43.5	89.5	63.0	52.0	48.0	26.5	37.5	41.5	19.5	8.5	4.5
3	52.5	44.5	90.0	63.5	53.5	48.5	26.5	36.5	41.5	19.0	9.0	4.0
4	53.0	44.5	91.0	65.5	54.5	50.0	25.5	36.5	41.0	21.0	10.0	5.5
5	53.5	45.0	90.0	64.0	54.0	49.5	26.0	36.0	40.5	19.0	9.0	4.5
6	69.0	52.0	90.0	68.0	59.5	55.5	22.0	30.5	34.5	16.0	7.5	3.5
7	66.0	53.0	90.0	68.5	60.0	56.0	21.5	30.0	34.0	15.5	7.0	3.0
8	76.0	54.5	90.0	69.5	61.5	58.0	20.5	28.5	32.0	15.0	7.0	3.5
9	85.0	56.0	90.0	70.0	62.0	59.0	20.0	28.0	31.0	14.0	6.0	3.0
Ave.	62.4	48.4	90.0	66.1	56.5	52.4	23.9	33.5	37.6	17.7	8.1	4.0

The temperature difference between the milk after cooling and the cooling water ranged from 14.0° to 21.0°, from 6.0° to 10.0°, and from 3.0° to 5.5° respectively, for 5, 10, and 15 minutes of cooling. It can be readily seen that this temperature difference was not nearly as constant as it was found to be for the surface cooler. On the contrary, a pronounced tendency was observed to exist for a decrease of this temperature difference, with increasing temperature of the cooling water. This was found to be true for 15 minutes, for 10 minutes, and especially for 5 minutes of cooling.

It was seen that 80 pounds of milk were cooled with the Hydro-Vac cooler in 10 minutes on an average to a temperature 8.0° above the temperature of the cooling water while under similar conditions the milk cooled with the surface cooler showed an average temperature of 4.9° above that of the cooling water. An interpretation of these facts might result in the conclusion that the surface cooler had a higher cooling efficiency than the Hydro-Vac cooler. It must, however, be borne in mind that the range of the temperature of the cooling water in the test with the Hydro-Vac and of that in the test with the surface cooler were not identical. Therefore, the above-mentioned data should not be used for direct comparison, nor should any definite conclusion be drawn from them as to the comparative cooling efficiency of the two coolers. It may be said that the above obtained data give an indication of a slight superiority of the surface cooler over the Hydro-Vac cooler so far as the cooling efficiency was concerned. The actual existence of such a superiority was proven in another test to be discussed later on.

c. Influence of different rates of water-flow on the cooling efficiency of a 29 x $16\frac{1}{2}$ inch tubular surface cooler. It is evident that the temperature to which milk is cooled by a surface cooler is influenced to a certain degree by the rate of water flowing through the cooler. A series of eight tests was made to study the relation between the temperature of the cooled milk and the rate of water-flow. The data obtained are shown in Table 3. The amount of milk cooled in each test was 80 pounds. The rate of milk-flow was eight pounds per minute, or in other words, 10 minutes were required to cool the 80 pounds of milk. The temperature of the cooling water was 48° F. and that of the milk before cooling was 90° F. for all trials. The room temperature ranged from 52° to 64° F. In the first test the water-flow was so regulated that three gallons of water were flowing through the cooler. In each successive test the amount of water was increased by one gallon a minute until a water-flow of 10 gallons per minute was reached. The milk to water ratio decreased from 1:3.13 for a water-flow of three gallons per minute to 1:10.43 for 10 gallons of water flowing through the cooler a minute.

Table 3.

Influence of Different Rates of Water-Flow on the Cooling Efficiency of a 29 x 16½ Tubular Surface Cooler

Amount of milk cooled in each trial: 80 lbs.
Rate of milk flow over cooler: 8 lbs. per min. (10 min. for 80 lbs.)
Temperature of cooling water: 48° F.
Temperature of milk before cooling: 90° F.

Number of Trial	Rate of Water-Flow in Gal. per min.	Ratio of Milk to Water	Temperature: Room	Temperature: Water out-going	Temperature: Milk after Cooling	Temp. Reduct. of Milk	Temp. Diff. between Milk after being cooled & In-going water
			Deg.F	Deg.F	Deg.F	Deg.F	Deg.F
1	3	1:3.13	58.0	58.0	55.0	35.0	7.0
2	4	1:4.17	58.0	56.0	54.0	36.0	6.0
3	5	1:5.21	64.0	53.5	52.0	38.0	4.0
4	6	1:6.26	52.0	53.0	50.0	40.0	2.0
5	7	1:7.30	52.0	53.0	50.0	40.0	2.0
6	8	1:8.34	52.0	52.0	49.5	40.5	1.5
7	9	1:9.38	61.0	52.0	50.0	40.0	2.0
8	10	1:10.43	61.0	51.5	49.5	40.5	1.5

The temperature to which the milk was cooled ranged from 55.0° to 49.5° F. Increasing the water-flow resulted in a lowering of the final temperature of the milk. This decline was readily noticeable up to a water-flow of six gallons per minute. A further increase of the water-flow seemed to be of little value since it produced only a very small additional decrease of the final temperature of the milk. With the water-flow ranging from 3 to 10 gallons per minute a temperature reduction of the milk varying from 35.0° to 40.0° was obtained. The extreme of the temperature difference between the milk after cooling and the water entering the cooler were 1.5° and 7.0°. With an increasing water-flow this temperature difference declined continuously, however, at a rate which was steadily falling off. Eventually this temperature difference reached a value which remained more or less constant with increasing water-flow.

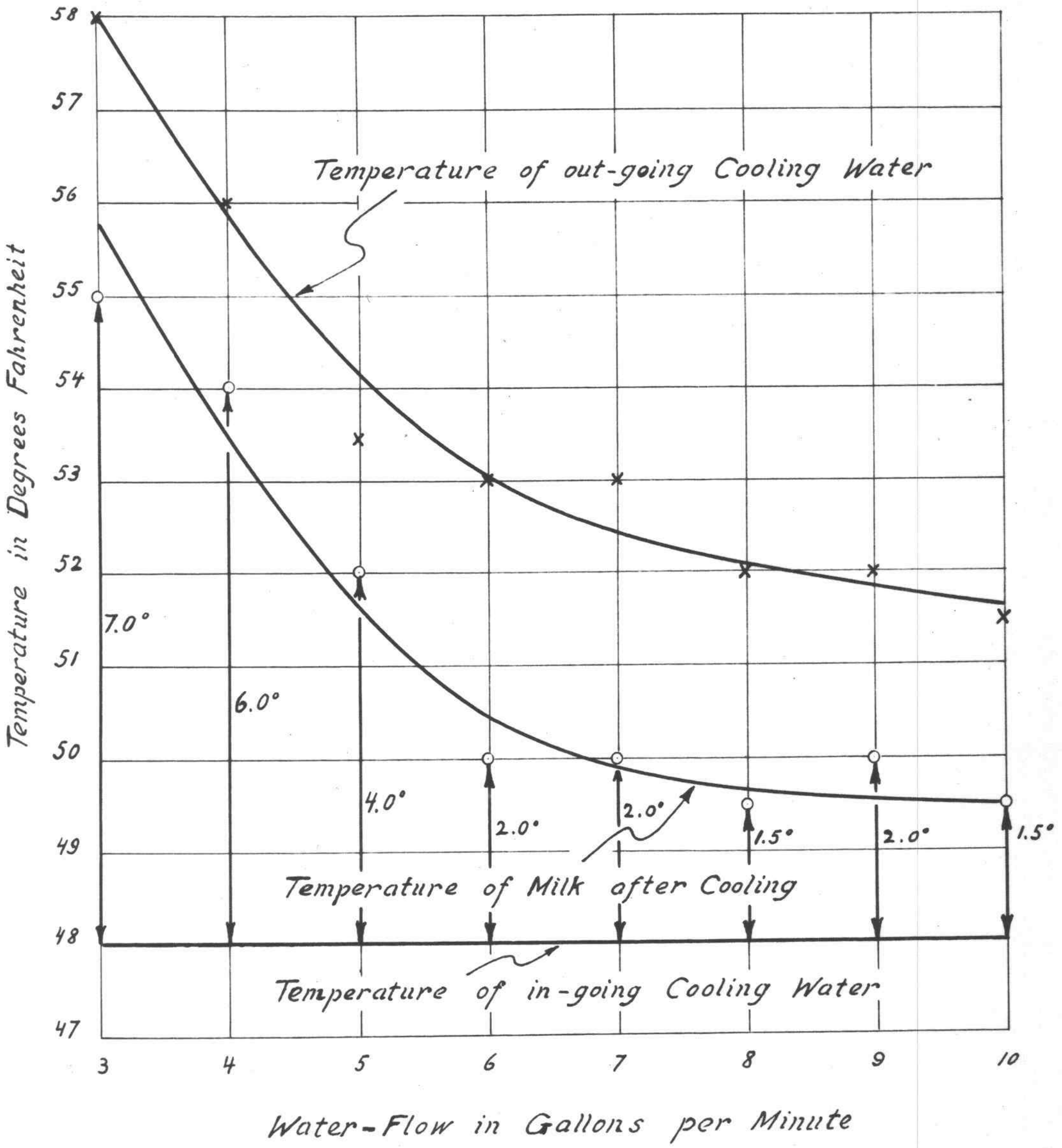
For practical milk cooling this would mean that there is an upper limit for the rate of water-flow which should not be increased if the cooler is to be operated economically. The effect of different rates of water-flow on the final temperature of the milk is also shown in Figure 1.

A similar experiment with the Hydro-Vac cooler was not reported on in this paper for the reason that the rate of water-flow for this cooler must be kept within narrow

Figure 1

— INFLUENCE OF DIFFERENT RATES OF WATER-FLOW ON THE COOLING EFFICIENCY OF A 29 × 16½ INCH TUBULAR SURFACE COOLER —

Amount of Milk Cooled in each Trial: 80 lbs.
Rate of Flow of Milk over Cooler: 8 lbs. per min.
Temperature of Cooling Water: 48° F.
Temperature of Milk before Cooling: 90° F.



limits. These limits were approximately three and four gallons of water per minute. A water-flow of less than three gallons per minute caused the water to drop on the floor instead of flowing onto the shoulder of the can, whereas, a water-flow above four gallons per minute brought about an increased speed of the stirrer which is undesirable for the reason that foaming or even churning may occur.

d. Influence of the rate of milk-flow on the cooling efficiency of a 29 x $16\frac{1}{2}$ inch tubular surface cooler. The temperature to which milk is cooled is not only depending on the rate of water-flow but also on the amount of milk flowing over the cooler per unit of time. Five tests were made to determine the influence of the rate of milk-flow on the temperature of the cooled milk. Eighty pounds of milk were cooled in each test. The rate of water-flow was five gallons per minute and the temperature of the cooling water was 46° F. The room temperature was 58° F. for all trials. The temperature of the milk was throughout the series adjusted to 90° F. prior to cooling. Table 4 and Figure 2 show the data obtained in these tests.

Table 4.

Influence of the Rate of Milk-Flow on the Cooling Efficiency of a 29 x 16½ inch Tubular Surface Cooler.

Amount of milk cooled in each trial: 80 lbs.
Rate of water-flow: 5 gal. per min.
Temperature of milk before cooling: 90° F.
Temperature of cooling water: 46° F.
Room temperature: 58° F.

Number of Trial	Cooling Time min.	Milk Flow per Min. lbs.	Milk to Water Ratio	Temp. Water out-going Deg.F	Temp. Milk after Cooling Deg.F	Temp. Reduct. of Milk Deg.F	Temp. Diff. between Milk after cooling and in-going Water Deg.F.
1	8	10.0	1:4.17	55.0	54.0	36.0	8.0
2	9	8.9	1:4.69	54.5	52.0	38.0	6.0
3	10	8.0	1:5.21	53.5	51.0	39.0	5.0
4	12	6.7	1:6.26	53.0	50.0	40.0	4.0
5	15	5.3	1:7.82	51.5	49.0	41.0	3.0

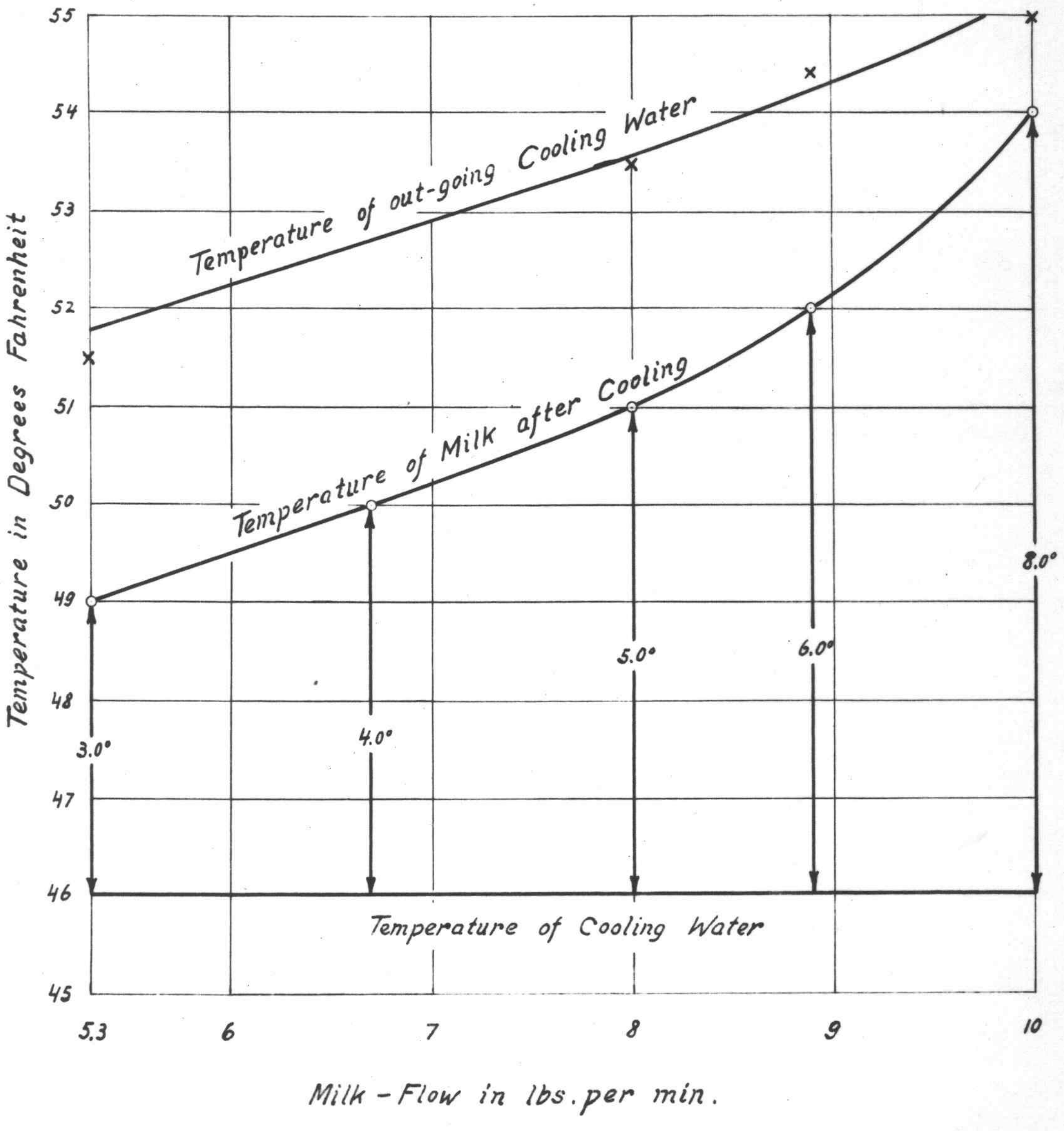
The time required to cool the 80 pounds of milk varied from 8 to 15 minutes. The milk-flow per minute was calculated by dividing the cooling time into the amount of milk cooled. It ranged from 5.3 pounds per minute to 10.0 pounds per minute and the corresponding milk to water ratio varied from 1:7.82 to 1:4.17.

Decreasing the milk-flow from 10.0 pounds per minute to 8.9, 8.0, 6.7, and 5.3 pounds respectively resulted in

Figure 2

INFLUENCE OF THE RATE OF MILK-FLOW ON THE COOLING EFFICIENCY OF A 29×16½ INCH TUBULAR SURFACE COOLER

Amount of Milk cooled in each Trial: 80 lbs.
Rate of Water-Flow: 5 gal. per min.
Temperature of Cooling Water: 46.0 °F.
Temperature of Milk before Cooling: 90 °F.



drop of the temperature to which the milk was cooled from 54° F. to 52°, 51°, 50°, and 49° F. As a result of this the temperature reduction of the milk was increasing steadily with a decreasing milk-flow, whereas, the temperature difference between the cooled milk and the ingoing cooling water was steadily diminishing. Both these changes proceeded at a rate which was continuously falling off for a constant rate of decrease of the milk-flow. The extremes of the temperature reduction were 36° and 41° and those of the temperature difference between the cooled milk and the cooling water were 3° and 8°.

It can be readily seen that the additional lowering of the temperature of the cooled milk was obtained at the expense of the cooling time and the amount of cooling water used. In practical milk cooling the lowering of the milk-flow should, therefore, not be carried on below a certain rate in order to prevent uneconomical operation of the cooler.

e. <u>Influence of the length of cooling time on the cooling efficiency of a Hydro-Vac cooler</u>. It was not possible to make a study of the relationship between the milk-flow and the temperature to which the milk was cooled with a Hydro-Vac cooler, since a whole can of milk is cooled simultaneously (milk not flowing) with this type of cooler. It was seen that for a surface cooler the milk-flow was inversely proportional to the time required for the cooling of a given amount of milk. Therefore, instead of studying the influence of the milk-flow on the cooling efficiency of a Hydro-Vac cooler, the relation between the length of cooling time and the final temperature of the cooled milk was determined.

In this experiment the temperature of 80 pounds of milk was adjusted to 90° F. The milk was then cooled with the cooling water at 49° F., the room temperature at 70° F. and with the water flowing through the cooler at a rate of four gallons per minute. Cooling was interrupted every two minutes in order to make a temperature reading. Table 5 and Figure 3 show the data obtained.

Table 5.

Influence of Length of Cooling Time on the Cooling Efficiency of a Hydro-Vac Cooler

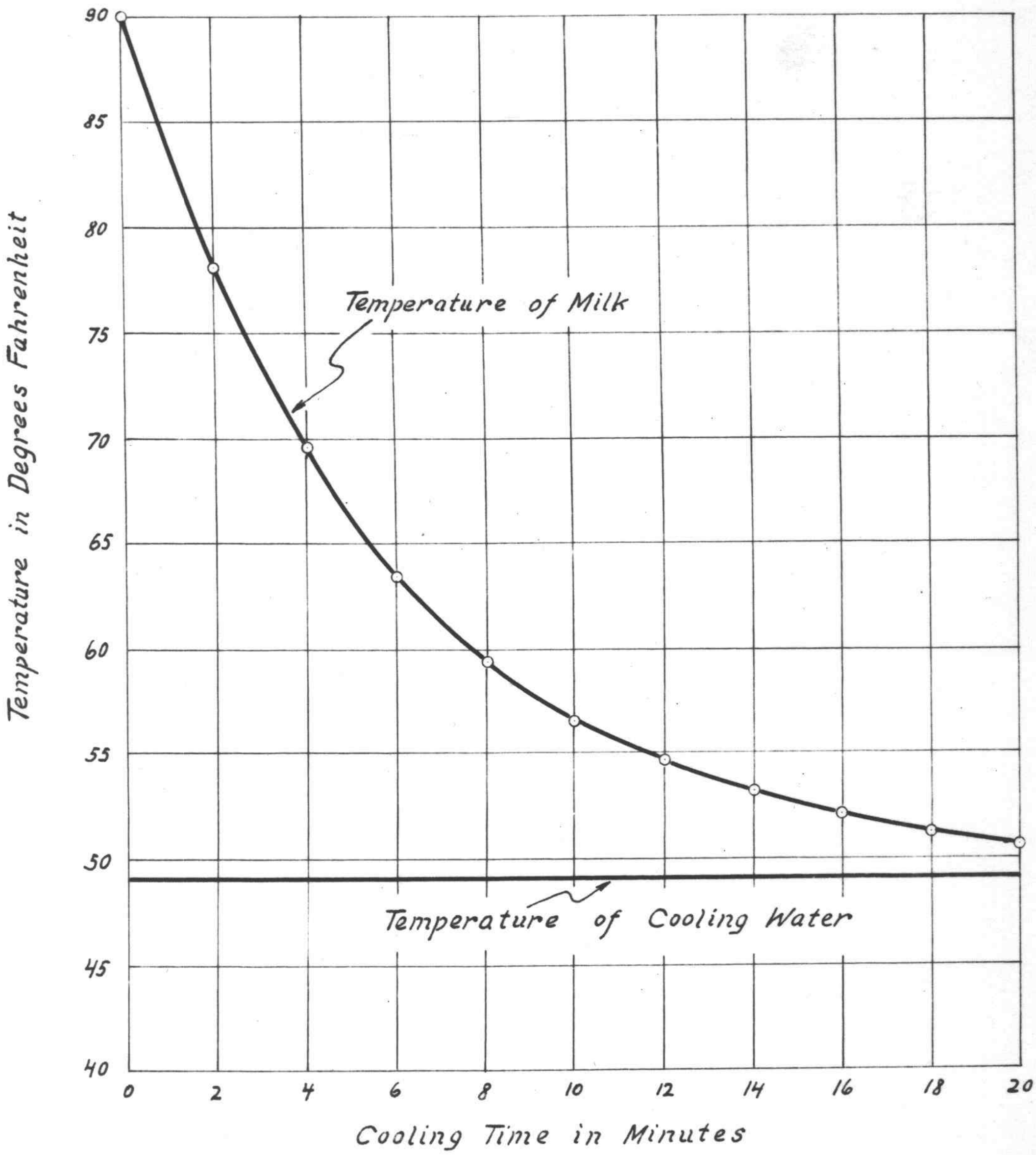
Amount of milk cooled: 80 lbs.
Room temperature: 70° F.
Temperature of cooling water: 49° F.
Rate of flow of cooling water: 4 gal. per min.
Temperature of milk before cooling: 90° F.

Cooling Time	Milk to Water Ratio	Temp. of Cooled Milk	Temp. Reduct. of Milk	Temp. Diff. between Cooled Milk & Cooling Water
min.		Deg. F	Deg. F.	Deg. F
2	1:0.83	78.0	12.0	29.0
4	1:1.67	69.5	20.5	20.5
6	1:2.50	63.3	26.7	14.3
8	1:3.34	59.5	30.5	10.5
10	1:4.17	56.7	33.3	7.7
12	1:5.01	54.7	35.3	5.7
14	1:5.84	53.3	36.7	4.3
16	1:6.68	52.0	38.0	3.0
18	1:7.51	51.3	38.7	2.3
20	1:8.34	50.7	39.3	1.7

Figure 3

INFLUENCE OF LENGTH OF COOLING TIME ON THE COOLING EFFICIENCY OF A HYDRO-VAC COOLER

Amount of Milk cooled: 80 lbs.
Temperature of Milk before cooling: 90°F.
Water-Flow: 4 gal. per min.
Temperature of Cooling Water: 49°F.



After the first two minutes of cooling the temperature of the milk had decreased from 90° to 78° F., after 10 minutes of cooling the temperature of the milk had dropped to 56.7° F., and after 20 minutes of cooling it had declined to 50.7° F. The temperature reduction of the milk was 12.0°, 33.3°, and 39.3° F. respectively for 2, 10, and 20 minutes of cooling. The corresponding temperature differences between the cooled milk and the cooling water were 29.0°, 7.7°, and 1.7° F. With the length of cooling time increasing at a constant rate the temperature of the milk was found to drop at a steadily decreasing rate. During the first two minutes of cooling the temperature drop amounted to 12°; whereas, from the sixteenth minute on the temperature reduction for any two minutes interval was less than one degree.

This would mean that under normal conditions little would be gained if 10 gallons of milk were cooled with a Hydro-Vac cooler for a time exceeding 15 minutes.

f. <u>Comparative cooling efficiency of a 29 x 16½ inch tubular surface cooler and a Hydro-Vac cooler.</u> In order to obtain some data on which an accurate comparison between the cooling efficiency of a Hydro-Vac and a 29 x 16½ inch tubular surface cooler could be based, five trials were made, in each of which the two coolers were operated under identical conditions. The amount of milk cooled in each trial was 80 pounds, the rate of water flow was four gallons per minute, the cooling time was 10 minutes, and the milk to water ratio was 1:4.17. Table 6 shows the results that were obtained in the five tests.

Table 6.

Comparative Cooling Efficiency of a 29 x 16½ Tubular Surface Cooler and a Hydro-Vac Cooler

Amount of milk cooled in each trial: 80 lbs.
Rate of water-flow through cooler: 4 gal. per min.
Cooling time: 10 min.
Ratio of milk to water: 1:4.17

Number of Trial	Temperature: Room	Temperature: Cooling Water	Temperature: Milk: Before Cooling	Temperature: Milk: After Cooling: S	Temperature: Milk: After Cooling: H	Temperature Reduction of Milk: S	Temperature Reduction of Milk: H	Temp. Diff. between Milk after Cooling & Cooling W.: S	Temp. Diff. between Milk after Cooling & Cooling W.: H
	Deg.F	Deg.F	Deg.F	Deg.F	Deg.F	Deg.F	Deg.F	Deg.F	Deg.F
1	57.0	47.0	90.0	51.5	55.0	38.5	35.0	4.5	8.0
2	69.0	51.0	90.0	56.0	58.5	34.0	31.5	5.0	7.5
3	69.0	52.0	90.0	57.0	59.5	33.0	30.5	5.0	7.5
4	64.0	53.0	90.0	57.5	61.0	32.5	29.0	4.5	8.0
5	77.0	57.0	92.0	61.5	63.5	30.5	28.5	4.5	6.5
Ave.	67.2	52.0	90.4	56.7	59.5	33.7	30.9	4.7	7.5

W= Water

H = Hydro-Vac cooler

S = Tubular surface cooler

The room temperature ranged from 57^{o} to 77^{o} F. and it averaged 67.2^{o} F. The extremes for the temperature of the cooling water were 47.0^{o} and 57.0^{o} F. The average was 52.0^{o} F. In the first four trials the milk temperature was adjusted to 90.0^{o} F. before cooling and in the fifth trial it was adjusted to 92.0^{o} F. The average for all five tests was 90.4^{o} F. With the surface cooler the milk was cooled to 51.5^{o}, 56.0^{o}, 57.0^{o}, 57.5^{o}, and 61.5^{o} F. respectively in the five trials made; whereas, the corresponding temperatures for the Hydro-Vac were 55.0^{o}, 58.5^{o}, 59.5^{o}, 61.0^{o}, and 63.5^{o} F. The average temperature of the milk cooled with the surface cooler was 56.7^{o} F. and that of the milk cooled with the Hydro-Vac was 59.5^{o} F. The temperature reduction of the milk varied from 30.5^{o} to 38.5^{o} for the surface cooler and from 28.5^{o} to 35.0^{o} for the Hydro-Vac. The averages of the temperature reductions for the two coolers were 30.9^{o} and 33.7^{o} respectively. Cooling with the surface cooler lowered the temperature to within 4.5^{o} to 5.0^{o} and on an average to within 4.7^{o} of the temperature of the cooling water. The corresponding figures for the Hydro-Vac cooler were 6.5^{o} to 8.0^{o} and 7.5^{o}.

Under the above described conditions the milk was in no case cooled as low with the Hydro-Vac as it was with the surface cooler. The temperature difference between the milk cooled with the two coolers varied from 2.0^{o} to

3.5° and it averaged 2.8°. Judging by the temperature reduction of the milk which took place between the tenth and fourteenth minute of cooling, as shown in Table 5, the milk cooled with the Hydro-Vac would have had to be cooled for an additional four minutes in order that a total temperature reduction would have been obtained equal to that obtained with the surface cooler in 10 minutes of cooling. This would mean that, on an average, approximately 14 minutes of cooling with the Hydro-Vac would produce a temperature lowering in 80 pounds of milk at 90° F. equal to that obtained in 10 minutes of cooling with the surface cooler, provided the amount of milk cooled, the temperature of the milk before cooling, the rate of water-flow, the temperature of the cooling water, and the time required to cool a given amount of milk were identical in each trial for both coolers.

g. <u>Comparative cooling efficiency of a Hydro-Vac cooler, sprinkler cooler, and tub cooler.</u> In another series of tests a Hydro-Vac cooler, a sprinkler cooler, and a tub cooler were compared as to their cooling efficiency. All three coolers were operated under the same conditions; namely, the amount of milk cooled in each trial was 80 pounds, the rate of water-flow was four gallons per minute and the temperature of the cooling water was 54° F. The results of this comparison are shown in Table 7 and in Figure 4.

Table 7.

Comparative Cooling Efficiency of a Hydro-Vac Cooler, Sprinkler Cooler and Tub Cooler

Amount of milk cooled in each trial: 80 lbs.
Rate of flow of cooling water: 4 gal. per min.
Temperature of cooling water: 54° F.
Temperature of milk before cooling: 90° F.

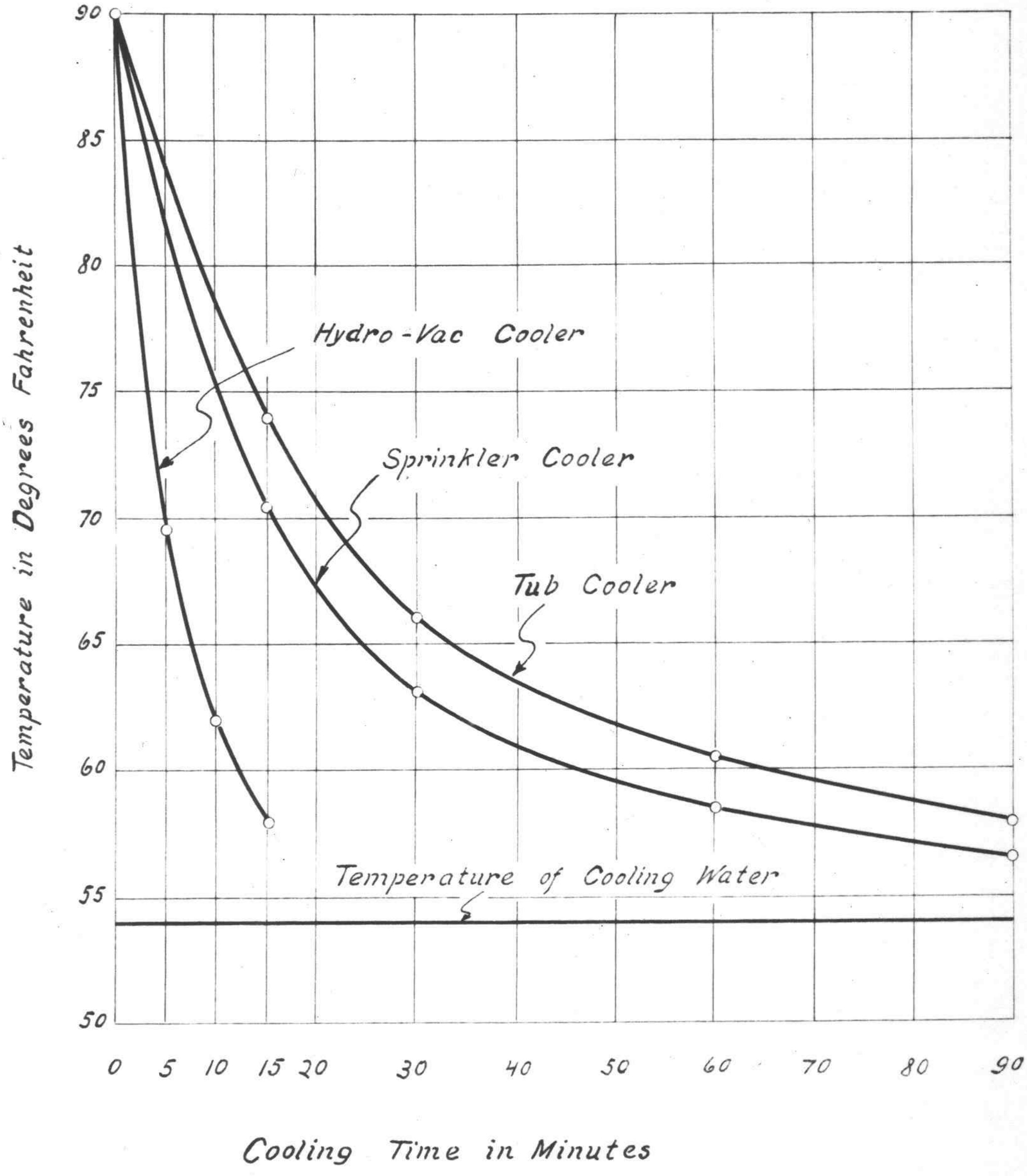
Cooling Time	Milk to: Water Ratio	Temperature			
		Cooling: Water	Milk		
			Hydro-Vac	Sprinkler	Tub
min.	Deg.F.	Deg.F.	Deg.F.	Deg.F.	Deg.F.
5	1: 2.09	54	69.5	-	-
10	1: 4.17	54	62.0	-	-
15	1: 6.26	54	58.0	70.5	74.0
30	1:12.51	54	-	63.0	66.0
60	1:25.02	54	-	58.5	60.5
90	1:37.53	54	-	56.5	58.0

The milk at 90° F. was cooled with the Hydro-Vac cooler to 69.5°, 62.0°, and 58.0° F. respectively in 5, 10, and 15 minutes. During the first 15 minutes of cooling with the sprinkler cooler the temperature of the milk was lowered to 70.5° F.; whereas, the tub cooler decreased the temperature to 74.0°.F. The temperature reduction of the milk for the first 15 minutes of cooling amounted to 32.0°, 19.5°, and 16.0° respectively for the Hydro-Vac-, for the sprinkler-, and for the tub cooler. The temperature differences between the cooled milk and the cooling water after 15 minutes of cooling were 4.0°, 16.5°, and

Figure 4

COMPARATIVE COOLING EFFICIENCY OF A HYDRO-VAC COOLER, SPRINKLER COOLER AND TUB COOLER

Amount of Milk Cooled in each Trial: 80 lbs.
Rate of Flow of Cooling Water: 4 Gallons per Minute
Temperature of Cooling Water: 54° F.
Temperature of Milk before Cooling: 90° F.



20.0° for the three coolers in the same order as mentioned above. Cooling with the sprinkler cooler for 30 minutes reduced the temperature of the milk to 63.0° F., whereas, cooling for the same length of time with the tub cooler lowered the temperature of the milk to 66.0° F. During 60 minutes of cooling the temperature of the milk dropped to 58.5° and to 60.5° F. respectively for the sprinkler- and for the tub cooler, while the corresponding temperatures for 90 minutes of cooling were 56.5° and 58.0° F.

This would mean that under above conditions it required approximately four times as long for the sprinkler cooler and six times as long for the tub cooler, as was necessary for the Hydro-Vac cooler, to lower the temperature of 80 pounds of milk from 90.0° F. to a temperature four degrees above that of the cooling water.

It is thus seen that the cooling efficiency of the Hydro-Vac cooler was about four times as high as that of the sprinkler cooler and six times as high as that of the tub cooler.

2. Bacterial Contamination of Milk by Different Types of Milk Coolers

It is evident that there are at least two sources of possible bacterial contamination of the milk during its cooling with a tubular surface cooler. These are (1) the surfaces of the cooler, and (2) the air with which the milk comes in contact during the cooling process. Both the surfaces of the cooler and the air may carry microorganisms, some of which may pass over into the milk when it is flowing over the cooler. A Hydro-Vac cooler offers a much smaller possibility for bacterial contamination than a surface cooler because the small stirrer is the only part that comes in contact with the milk during cooling.

In order to find out to what extent the milk was actually contaminated with bacteria during cooling with the above mentioned two coolers the following experiment was conducted.

On 18 different days a bacterial count was made on 10 gallons of milk immediately before and after cooling with a 29 x 16½ inch tubular surface cooler. All samples were taken with sterile 50 c.c. pipettes from 10-gallon cans of milk and were placed without delay in ice water, where they were kept until plating. The cooler was always thoroughly sterilized. Sterilization consisted of exposing the cooler to flowing steam at atmospheric pressure for approximately three hours in a concrete sterilizing tank. After sterilization the cooler was kept in the closed sterilizer until immediately before being used. Table 8 shows the number of bacteria per c.c. of the milk before and after cooling as well as the change in the number of bacteria which took place during cooling.

The bacterial count of the milk before cooling ranged from 400 bacteria per c.c. to 12,200 bacteria per c.c.; whereas, the number of bacteria per c.c. of the cooled milk varied from 350 to 13,150. In 11 trials the number of bacteria per c.c. had increased during cooling and in seven trials it had decreased. The increases ranged from 50 bacteria per c.c. to 1,750 bacteria per c.c. and the extremes of the decreases were 50 bacteria per c.c. and 2,900 bacteria per c.c.

A similar test was made with the Hydro-Vac cooler, the results of which are given in Table 9.

The sampling and the plating were done in the same way as in the corresponding experiment with the surface cooler. The stirrer of the Hydro-Vac cooler was sterilized in the same manner as was the surface cooler.

Table 8.

Bacterial Contamination of 80 lbs. Milk by a 29 x $16\frac{1}{2}$ inch Tubular Surface Cooler

Cooler sterilized in a steam sterilizer

Number of Trial	No. of Bacteria per c.c. Before Cooling	After Cooling	Change in Bacterial Count Increase	Decrease
1	6,300	7,200	900	
2	4,000	3,750		250
3	7,800	8,300	500	
4	4,300	3,900		400
5	12,200	9,300		2,900
6	6,200	6,850	850	
7	10,100	10,200	100	
8	5,300	5,700	400	
9	2,300	4,050	1,750	
10	8,550	8,150		400
11	11,700	13,150	1,450	
12	1,900	1,500		400
13	1,650	1,400		250
14	4,100	4,150	50	
15	5,750	6,150	400	
16	6,550	6,600	50	
17	1,750	1,950	200	
18	400	350		50

Table 9.

Bacterial Contamination of 80 lbs. of Milk by the Hydro-Vac Cooler.

Stirrer of Cooler Sterilized

Number of Trial	No. of Bacteria per c.c. Before Cooling	After Cooling	Change in Bacterial Count Increase	Decrease
1	6,900	8,450	1,550	
2	16,850	18,500	1,650	
3	20,450	8,050		12,400
4	18,700	17,100		1,600
5	11,150	13,450	2,300	
6	4,750	5,400	650	
7	7,000	7,700	700	
8	10,800	11,200	400	
9	1,850	2,600	750	
10	3,300	3,500	200	
11	2,600	2,800	200	
12	6,650	6,350		200
13	11,150	12,300	1,150	
14	17,100	16,250		850
15	4,700	5,400	700	
16	5,450	6,550	1,100	
17	3,900	4,650	750	
18	5,850	5,500		350
19	7,150	7,100		50
20	5,450	6,000	550	

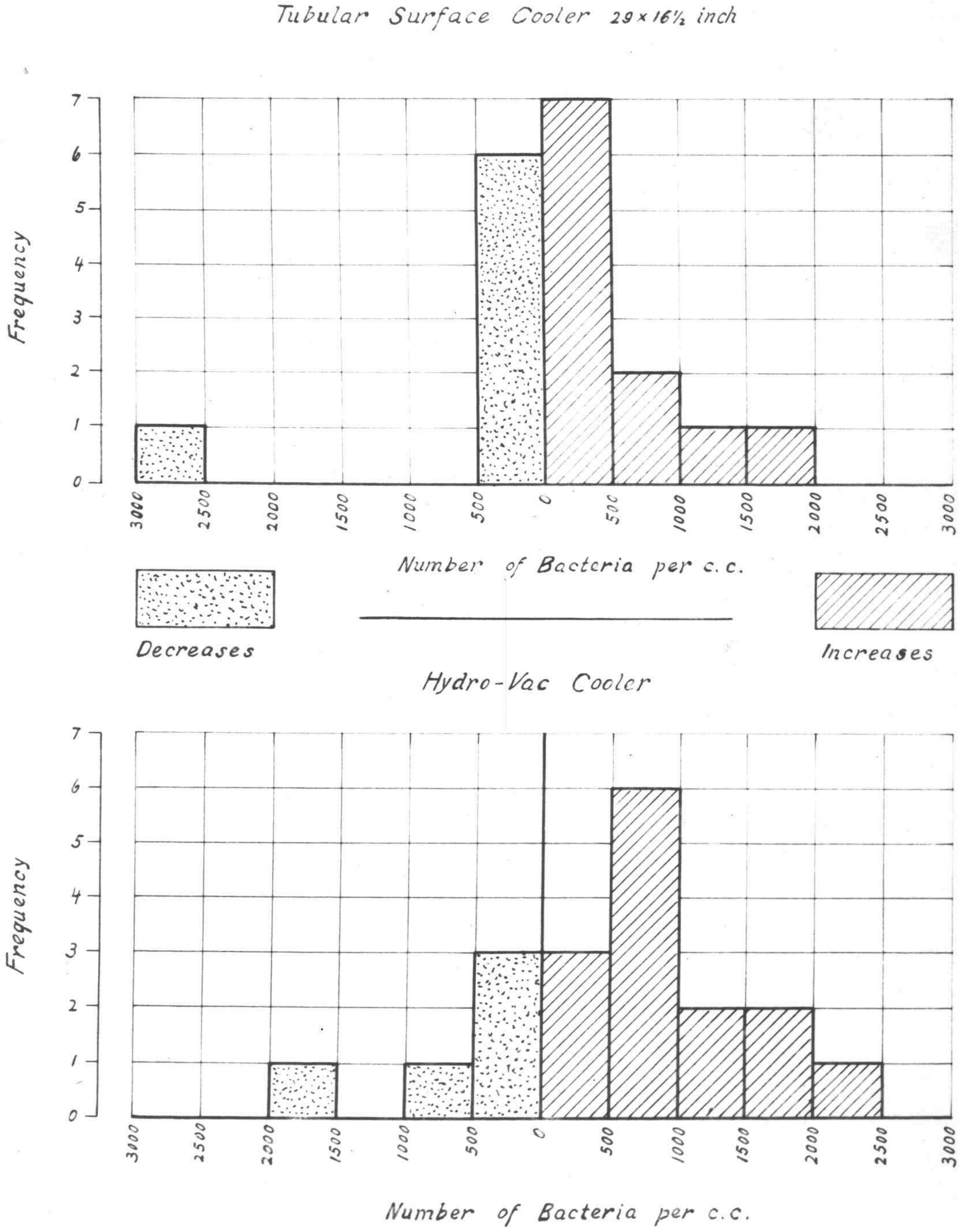
The number of bacteria per c.c. of the uncooled milk ranged from 1,850 to 20,450 and that of the cooled milk from 2,600 to 18,500. The bacterial count of the cooled milk in 14 trials showed an increase and in six trials a decrease as compared with the count of the milk before cooling. The increases ranged from 200 bacteria per c.c. to 2,300 bacteria per c.c.; whereas, the range of the decreases was from 50 bacteria per c.c. to 12,400 bacteria per c.c. Instead of calculating the average increase (or decrease) in the number of bacteria per c.c. which took place during the cooling of milk with the two coolers frequency distributions of the increases and decreases have been made. They are shown in Figure 5.

It is obvious that the increases in the number of bacteria, as shown in Tables 8 and 9, cannot be regarded as increases due to contamination during cooling of the milk. If this were done, it would have been rather difficult to explain the occurrence of the relatively numerous decreases in the number of bacteria during cooling. It is possible that such decreases might have been caused by the breaking up of clumps and chains of bacteria in the samples of milk taken before cooling. It is well known that the number of bacteria which is determined by the standard plate count on different samples of milk taken at the same time from the same can of milk will show some variation. This variation is the greater, the higher the number of bacteria is, in that can of milk. The variation is due to the fact that the actual numbers of bacteria per c.c. of the different samples taken are not identical and that the standard plate count method is not 100 percent accurate.

A fairly accurate determination of the contamination of milk during cooling could, therefore, be made by means of the difference in the bacterial counts of the milk before and after cooling only, if the contamination were

Figure 5

FREQUENCY DISTRIBUTION OF INCREASES AND DECREASES IN BACTERIAL COUNTS OCCURRING DURING COOLING OF 10 GALLONS OF MILK



greater than the variation as discussed above. In this case all bacterial counts of the cooled milk would be higher than the corresponding counts on the not cooled milk.

The fact that the increases and decreases as shown in Tables 8 and 9 were of approximately the same magnitude was, therefore, an indication that bacterial contamination of the milk during cooling with either cooler was, in all probability, low.

In order to obtain more information on this subject, the following two experiments were made. In the first experiment a 29 x 16½ inch tubular surface cooler was subjected, in a steam sterilizer, for approximately three hours, to flowing steam at atmospheric pressure. About seven hours later it was placed in the same position as for the cooling of milk. It was then rinsed with 1,000 c.c. of sterile water, whereupon the number of bacteria in this water was determined. Table 10 gives the results of this experiment.

The total number of bacteria rinsed off the cooler was 22,000 in trial 1, 16,000 in trial 2, and 33,000 in trial 3. The average for the three trials was 23,300 bacteria. When the cooler was not sterilized the average total number of bacteria washed off in three trials was 1,641,700.

Table 10

Contamination of Milk by 29 x $16\frac{1}{2}$ inch

Tubular Surface Cooler Sterilized and Unsterilized

	Number of Trial	Cooler Sterilized	Cooler not Sterilized
Number of bacteria rinsed off cooler with 1000 c.c. of sterile water	1	22,000	455,000
	2	16,000	2,480,000
	3	33,000	1,990,000
	Average	23,300	1,641,700
Contamination per c.c. of 10 gallons of milk	1	0.58	12.02
	2	0.42	65.52
	3	0.87	52.57
	Average	0.62	43.37

10 gallons = 37,854 c.c.

Assuming that a similar number of bacteria were washed off the same cooler treated in the same way as above, by 10 gallons of milk during cooling, the contamination of the milk would have amounted to $\frac{23,000}{37,854} = 0.62$ bacteria per c.c. in the case of the sterilized cooler and to $\frac{1,641,700}{37,854} = 43.37$ bacteria per c.c. when the cooler was not sterilized.

The second experiment was planned in such a way as to furnish some information about the bacterial contamination of the milk due to its contact with the air during the cooling process.

On different days sterile agar plates were exposed to the air in the milk house for a duration of 10 minutes. This was approximately the same length of time as was, on an average, required to cool 10 gallons of milk with a 29 x 16½ inch surface cooler. After the exposure the plates were incubated for 48 hours at 37° C. whereupon the number of colonies which had developed was determined. A total of 10 plates was exposed to the air. The number of colonies on these plates ranged from 3 to 35 and averaged 12. The area of milk exposed to the air during the cooling of milk with a 29 x 16½ inch surface cooler measured about 1,650 square inches and the average surface of an agar plate was found to be approximately 10 square inches. The area of exposed milk was, therefore, 165 times as large as the surface of an agar plate. By multiplying the average number of bacteria found on the plates exposed to the air by 165, the probable contamination of 10 gallons of milk with bacteria from the air, which took place during cooling, was obtained. The determined total contamination with bacteria from the air amounted to 1,980 bacteria, which was equal to 0.05 bacteria per c.c. of the milk. Both these experiments showed that contamination of milk during the cooling with the surface cooler was, under the conditions of this experiment, so small as to be negligible.

Milk containing a large number of bacteria will usually sour quicker than milk containing a small number of bacteria, if both are kept under identical conditions. When milk of the same original bacterial content is cooled with two different coolers, it would be expected that the milk which was contaminated during cooling to a lesser degree, would possess the best keeping quality. Since the keeping quality of milk may be influenced in various ways by different types of microorganisms, no definite conclusions can be made regarding it, based on the number of bacteria which the milk contains. Nevertheless, two comparisons of the keeping quality of milk cooled with different coolers was undertaken during the course of this investigation. Table 11 shows the data collected in the two tests.

One-half of a five-gallon can of milk was cooled with a surface cooler to within four degrees of the temperature of the cooling water, while the remainder of the milk was cooled to the same temperature with a Hydro-Vac cooler. In trial 1 both coolers were sterilized in a steam sterilizer as described above. In trial 2 they were, in addition to the steam sterilization, rinsed with a chlorine solution containing 200 p.p.m. of available chlorine. The chlorine solution adhering to the coolers was washed off with sterile water to make sure that none of it got into the milk. Samples of the same size were taken from each of the two lots of cooled milk and these were kept at a temperature which ranged from 70° to 80° F. The acidity and the number of bacteria per c.c. were determined in both samples after 0, 15, 27, 39, and 51 hours of holding.

In trial 1 the acidity of the milk cooled with the Hydro-Vac cooler increased from 0.17 to 0.43 percent during 51 hours of holding of the milk, while the acidity of the milk cooled with the surface cooler increased from 0.17 to 0.62 percent during the same interval. The number of bacteria per c.c. of the uncooled milk was 460. It increased to 2,500 bacteria per c.c. in the milk cooled with the Hydro-Vac, and to 420,000 bacteria per c.c. in the milk cooled with the surface cooler, during the first 15 hours of holding. After 27 hours of holding the number of bacteria per c.c. had increased to 5,650,000 in the milk cooled with the Hydro-Vac compared with 34,100,000 bacteria per c.c. in the milk cooled with the surface cooler. The corresponding figures for 39 hours of holding were 430,000,000 for the milk cooled with the Hydro-Vac cooler and 520,000,000 for the milk cooled with the surface cooler.

In trial 2 practically no difference was found in the development of the acidity in the milk cooled with the two different coolers. The increases in the number of bacteria per c.c. of the two lots of milk were very much

Table 11.

Comparison of Keeping Quality of Milk Cooled with Different Coolers

Trial 1. Coolers sterilized in steam sterilizer
Trial 2. Coolers sterilized in steam sterilizer followed by rinsing with chlorine sterilizing solution

Time Milk held at Room Temperature Hours	Hydro-Vac		Surface Cooler	
	Acidity: percent	No. of Bact. per c.c.	Acidity: percent	No. of Bact. per c.c.
Trial 1				
0 (before cooling)	0.17	460	0.17	460
15	0.17	2,500	0.17	420,000
27	0.175	5,650,000	0.18	34,100,000
39	0.275	430,000,000	0.39	520,000,000
51	0.43		0.60	
Trial 2.				
0 (before cooling)	0.16	260	0.16	260
0 (after cooling)	0.16	320	0.16	240
15	0.16	17,900	0.16	14,100
27	0.17	16,300,000	0.17	14,300,000
39	0.21	163,000,000	0.22	75,000,000
51	milk curdled		milk curdled	

alike up to the time when the milk curdled.

It has already been mentioned that no conclusions could be drawn from these findings as to the contamination of the milk during cooling. However, trial 2 showed that two portions of milk originating from the same lot may, under certain conditions, possess equal keeping quality after having been cooled with a surface cooler and a Hydro-Vac cooler respectively.

It is obvious that so far as bacterial contamination is concerned the tub cooler and the sprinkler cooler rated higher than the surface cooler and the Hydro-Vac cooler, since bacterial contamination with the first mentioned two coolers was completely eliminated.

3. The Influence of Different Methods of Cooling on the Flavor and Odor of the Milk.

While certain authorities in the field of dairying are advocating the aeration of milk, there are others who believe that milk of good, clean flavor and odor can be produced without aerating. Because of the difference of opinion which exists in regard to aeration, it was deemed advisable to make a comparison of the flavor and odor of milk cooled and aerated simultaneously, with the flavor and odor of milk which had been cooled but not aerated. The results obtained in the experiment are shown in Table 12 and in Figure 6.

Table 12.

Influence of Different Methods of Cooling on the Flavor and Odor of the Milk

Each sample was judged by three judges (samples of trial No. 12, two judges only).

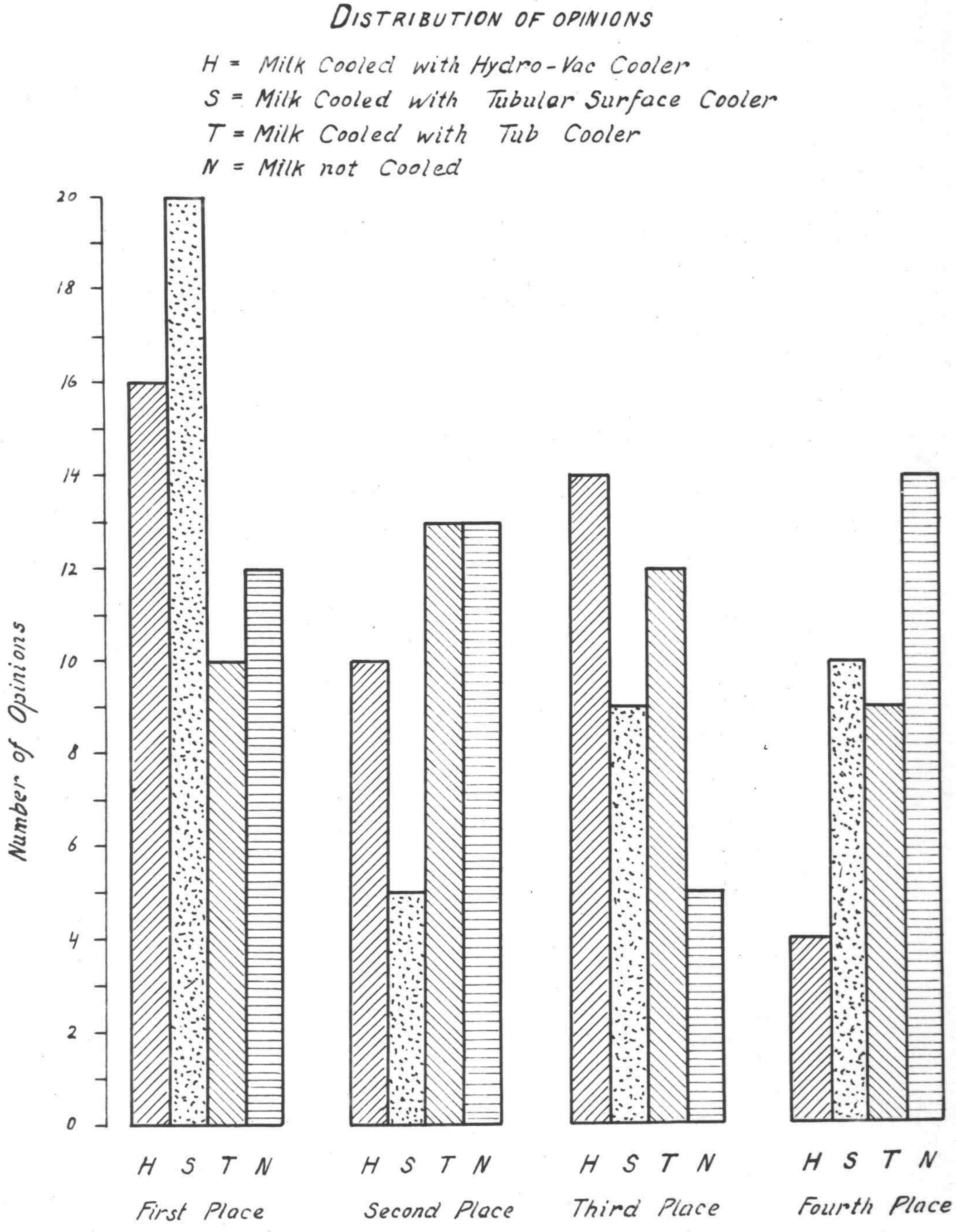
H - Milk cooled with Hydro-Vac cooler
S - " " " surface cooler
T - " " " tub cooler
N - " not cooled

Number of Trial	Distribution of Opinions															
	First Place				Second Place				Third Place				Fourth Place			
	H	S	T	N	H	S	T	N	H	S	T	N	H	S	T	N
1	2		1					3	1	2				1	2	
2		3						3	2		1		1		2	
3			1	2	1		1	1	1	1	1		1	2		
4		2		1	1	1		1	2		1				2	1
5	3					2		1			2	1		1	1	1
6	2	1		2	1	1	2			1					1	1
7		3			1		2		2		1					3
8	1	1	2	2					2	2	1	1				
9	1	2			2			1			3			1		2
10	1	1	1		2	1	2	1		1						2
11		1	2	1	1		1		2			1		2		1
12				2	1		1			2	1		1			
13	2	1		1			2	2			1		1	2		
14	1	2	1				2		2			1		1		2
15	3	3	2	1								1			1	1
Total	16	20	10	12	10	5	13	13	14	9	12	5	4	10	9	14

-65-

Figure 6

INFLUENCE OF DIFFERENT METHODS OF COOLING ON THE FLAVOR AND ODOR OF MILK



In each of 15 different trials, 20 gallons of milk were divided into four parts. One part was cooled with a Hydro-Vac cooler, a second part with a surface cooler, and a third part with a tub cooler, while a fourth part was not cooled. A sample was then taken from each of the four parts of milk to be used for the flavor and odor comparison. The samples from the Hydro-Vac cooler and surface cooler were usually taken during the afternoon milking and they were then kept in flowing tap water until next morning. A small stream of water was maintained in the tub cooler during the night and a sample was taken the following morning. The sample from the milk that was not cooled was taken at milking time in the afternoon and it was kept at room temperature until the next morning. Some time during the forenoon following the cooling of the milk, the four samples were warmed up to approximately 95° F. and they were then judged, compared, and placed first, second, third, and fourth, according to their flavor and odor, by three competent judges.

In the case of a tie, all samples involved were given the highest placing possible; for example, if samples 3 and 4 were placed first and fourth respectively, and if there was no difference in the flavor and odor of the samples 1 and 2, both of these samples were given second place.

Table 12 shows that the opinions on the milk cooled with the three different coolers, and on the milk not cooled, were fairly well divided between first, second, third, and fourth places. Of the 44 opinions on the milk cooled with the Hydro-Vac cooler, 16 were for first place, 10 for second place, 14 for third place, and 4 for fourth place. The opinions on the milk cooled with the surface cooler were divided in the following way: 20 opinions for first place, 5 for second place, 9 for third place, and 10 for fourth place. The opinions on the milk cooled in the tub showed the following distribution: 10 opinions for first place, 13 for second place, 12 for third place, and 9 for fourth place. Of the 44 opinions on the milk not cooled, 12 were for first place, 13 for second place, 5 for third place, and 14 for fourth place.

It was observed that in many trials no uniformity existed in the placing of the four samples by the three judges. For instance, in trial 1, one judge placed the milk cooled in the tub first, while the other two judges placed it last. In a few instances two of the judges placed the samples in the same order, but not once did all three judges agree upon the placing.

During the first eight trials the cows were on winter feed, which consisted of mixed hay, corn silage, and grain. The silage was fed about $1\frac{1}{2}$ hours before milking. The result of this was that the milk had a distinct silage flavor and odor. Aeration with the surface cooler or Hydro-Vac cooler seemed to have no pronounced effect in diminishing this off flavor and odor. This was made clear by the fact that in the trials 1, 3, and 5 the milk cooled with the surface cooler received not one opinion for first place, and only two opinions for second place. In the trials 2, 3, 4, and 7 the milk cooled with the Hydro-Vac cooler was given no opinion for first place and but three opinions for second place. In some other trials aeration with the surface cooler seemed to exert a certain influence in lowering the intensity of the silage flavor and odor. This was, for instance, the case in the trials 2 and 7, where all three judges placed the milk cooled with the surface cooler first, and in trial 4 two judges placed it first and one gave it second place.

Similar conditions were found in trials 9 to 15. At this time the cows were on pasture. During this period the cows received no silage. The milk in these trials was criticized for grass-, weed-, or feed-flavor and odor. Aeration seemed to have no uniform influence throughout the tests in removing these flavors and odors from the milk or in minimizing them.

In order to facilitate the comparison of the results obtained the following procedure was adopted. Four points were allowed on each opinion for first place, three points on each opinion for second place, two points on each opinion for third place, and one point on each opinion for fourth place. The total number of points received by the milk cooled with the surface cooler, Hydro-Vac cooler, tub cooler, and by the milk which was not cooled, was then determined. On the basis of the above procedure the milk cooled with the Hydro-Vac cooler received 126 points, that cooled with the surface cooler received 123 points, and the milk cooled with the tub cooler was credited with 112 points. The milk which was not cooled received 111 points.

The total number of points received by the milk cooled with the surface cooler and by the milk cooled with the Hydro-Vac cooler were only three points apart, while the difference in the total number of points received by the tub cooled milk and the milk not cooled was one point only. The important fact is the existence of a noticeable difference between the total number of points received by the milk cooled with the first two mentioned coolers, on the one hand, and the total number of points received by the milk cooled in the tub and the not cooled milk on the other hand. This difference may have been due to the aeration to which the milk was subjected during the cooling with the surface cooler, and the aeration which possibly took place when milk was cooled with the Hydro-Vac cooler. Attention should also be given to the fact that in the 15 trials practically no difference was found to exist between the average placing of the milk cooled with a surface cooler and the placing of the milk cooled with a Hydro-Vac cooler.

4. The Influence of Different Methods of Cooling on the Creaming Ability of Milk.

A series of eight trials was made to determine whether different methods of cooling would influence the amount of cream that would form on the milk. The experiment was arranged in the following way. A lot of milk was divided into four parts. One part was cooled with a surface cooler, another with a Hydro-Vac cooler, a third with a tub cooler, and a fourth part was not cooled at all. A sample of 100 c.c. was then taken from each part and placed in 100 c.c. graduate cylinders. The milk in these cylinders was then surrounded by ice water for creaming and the cream volumes were read 6 and 24 hours after setting. Table 13 shows the cream volumes per one percent fat in the milk at the end of 6 and 24 hours of creaming.

The percentage of fat in the milk varied from 3.35 to 3.85 percent and averaged 3.68 percent for the eight trials. When the milk was not cooled and when it was cooled with a Hydro-Vac cooler and with a surface cooler, the cream volume per one percent fat in the milk, which formed during the first six hours of creaming, ranged from 4.59 to 5.22 percent of the total milk volume.

Table 13.

Influence of Different Methods of Cooling on the Creaming Ability of Milk

N - Milk not cooled before setting in ice water
H - Milk cooled with Hydro-Vac cooler
S - Milk cooled with surface cooler
T - Milk cooled in tub for 3 - $3\frac{1}{2}$ hours

Number of Trial	Fat Content of Milk	Cream Volume per one Percent Fat in Milk: 6 Hours of Creaming N	H	S	T	24 Hours of Creaming N	H	S	T
	%	%	%	%	%	%	%	%	%
1	3.8	5.00	4.87	5.00	5.13	4.34	4.21	4.34	4.47
2	3.6	5.00	5.00	5.00	5.07	4.44	4.44	4.44	4.44
3	3.8	4.74	4.74	4.74	5.13	4.21	4.21	4.21	4.47
4	3.7	4.59	4.59	4.59	5.00	4.12	4.05	4.12	4.46
5	3.85	4.68	4.61	4.61	5.19	4.16	4.16	4.16	4.55
6	3.35	5.22	5.22	5.22	5.22	4.93	4.93	4.93	4.93
7	3.75	4.93	4.93	4.93	5.73	4.27	4.27	4.27	4.80
8	3.6	5.21	5.21	5.21	5.56	4.31	4.31	4.31	4.58
Ave.	3.68	4.92	4.90	4.91	5.25	4.35	4.32	4.35	4.59

The cream volume per one percent fat of the milk cooled in the tub varied from 5.00 to 5.73 percent for six hours of creaming. The averages of the cream volumes were 4.92 percent for the milk which had not been cooled, 4.90 percent for the milk which had been cooled with a Hydro-Vac cooler, 4.91 percent for the milk which had been cooled with a surface cooler, and 5.25 percent for the milk which had been cooled with a tub cooler.

At the end of 24 hours of cooling, the average cream volumes per one percent fat in the milk amounted to 4.35, 4.32, 4.35, and 4.59 percent, given in the same order as above. The cream volume of the not cooled milk and that of the milk cooled with the surface cooler ranged from 4.12 to 4.93 percent, while that of the milk cooled with the Hydro-Vac cooler varied from 4.05 to 4.93 percent. The extremes of the cream volume of the milk cooled in the tub were 4.44 and 4.93 percent.

According to these data there was practically no difference between the cream volume of the milk not cooled, the milk cooled with the Hydro-Vac cooler, and the milk cooled with the surface cooler. Cooling the milk in the tub resulted in a slightly greater cream volume than with the other methods. An injury to the creaming ability due to the stirring action of the Hydro-Vac cooler had apparently not occurred.

Before starting this investigation the question had been raised as to whether any churning would take place when milk was cooled with a Hydro-Vac cooler. In regard to this it must be stated that in no case the slightest trace of churning was observed, so long as the cooling was done immediately after the milk had been obtained from the cow.

In one instance, however, where 80 pounds of milk were kept in a cool room at approximately 40° F. for several hours before being used in a cooling experiment, minute butter granules were observed floating on the milk after 15 minutes of cooling with a Hydro-Vac cooler. Previous to the cooling with the Hydro-Vac cooler the milk had been warmed up to 90° F.

V. DISCUSSION OF RESULTS

A study of the influence of different temperatures of the cooling water on the cooling efficiency of a 29 x $16\frac{1}{2}$ inch tubular surface cooler showed that with increasing temperature of the cooling water, the temperature to which the milk was cooled increased simultaneously. A certain increase in the temperature of the cooling water invariably caused an increase of approximately the same extent in the temperature of the cooled milk. Such a relation may not hold true for a very wide range of the temperature of the cooling water, but it was found to exist for the range of 47.0° to 57.0° F., which seemed to be about a normal range of the water temperature for the local conditions. With the above mentioned surface cooler it was possible to cool 80 pounds of milk in 10 minutes to a temperature, on an average, 4.9 degrees above that of the cooling water when four gallons of water were flowing through the cooler per minute.

Similar conditions were found to exist when milk was cooled with a Hydro-Vac cooler. An increase in the temperature of the cooling water was always followed by an increase of the temperature of the cooled milk. Contrary to the practically constant temperature difference between the cooled milk and the cooling water as observed for the surface cooler, this temperature difference was found to show a distinct tendency for a decrease with an increasing water temperature when the milk was cooled with the Hydro-Vac cooler. Such a relation existed for 15 minutes of cooling, but it was more pronounced for 10 minutes of cooling, and still more pronounced for 5 minutes of cooling. It was possible to cool 80 pounds of milk with a Hydro-Vac cooler in 10 minutes to a temperature, on an average, 8.1° F. above that of the cooling water when a water-flow of 4 gallons per minute was maintained.

A series of tests was conducted in order to obtain some information on the relation of different rates of water-flow for a 29 x 16½ inch surface cooler to the temperature to which the milk was cooled with this cooler. The fact was brought out that increasing the water-flow caused a decrease in the temperature to which the milk was cooled. The temperature difference between the cooled milk and the in-going cooling water decreased at a rate which was continuously slowing up with a constant rate of increase in the flow of cooling water. With a steadily increasing rate of water-flow, eventually a rate was reached above which no additional appreciable decrease in the temperature of the cooled milk was observed. Due attention should be paid to this fact in practical milk cooling.

No tests were conducted to show the influence of different rates of water-flow on the final temperature of the milk for the Hydro-Vac cooler, since the water-flow for this cooler had to be kept between narrow limits, due to the construction of this piece of equipment.

A study of the relationship between the milk-flow and the temperature to which the milk was cooled by a 29 x 16½ inch tubular surface cooler showed that decreasing the rate of milk-flow caused a decrease in the temperature of the cooled milk. When a constant rate of decrease in the milk-flow was maintained, the final temperature of the cooled milk was lowered at a steadily decreasing rate. Due to the fact that the time required to cool a given amount of milk was inversely proportional to the rate of milk-flow, the temperature to which 80 pounds of milk were cooled decreased at a steadily declining rate with an increasing length of cooling time, provided this increase proceeded at a constant rate. For practical milk cooling this would mean that extending the cooling time for a given amount of milk beyond a certain number of minutes would be uneconomical, since little additional decrease in the final temperature of the milk was obtained beyond a certain length of cooling time.

A test with a Hydro-Vac cooler showed that the length of cooling time influenced the final temperature of the cooled milk in a similar way, as it did for the surface cooler. With the cooling time increasing at a constant rate, the temperature of a given amount of milk was found to decline at a steadily decreasing rate. It was noticed that on an average of nine trials the temperature lowering of the milk which took place during the first five minutes of cooling was nearly two and one-half times as high as for the second five minutes of cooling and it was approximately six times as high as for the third five minutes of cooling. According to this experiment 12 to 15 minutes were found to be an average normal cooling time, for 80 pounds of milk when cooled with a Hydro-Vac cooler.

In a comparison of the cooling efficiency of a 29 x 16½ inch tubular surface cooler with that of a Hydro-Vac cooler the fact was brought out that the surface cooler was slightly superior to the Hydro-Vac cooler. Both coolers were operated under identical conditions during this comparison; that is, the amount of milk cooled, the rate of flow and temperature of the cooling water, the cooling time, the temperature of the room, as well as the temperature of the milk before cooling were the same for the Hydro-Vac cooler and for the surface cooler, for each trial conducted. On an average of five tests 80 pounds of milk were cooled with the surface cooler, in 10 minutes, to a temperature which was 2.8° lower than that to which the milk was cooled with the Hydro-Vac cooler. According to a calculation based on the data obtained in the experiment which showed the relation of cooling time to the temperature of the milk cooled with the Hydro-Vac cooler, it would have required approximately four additional minutes of cooling in order to secure a total temperature reduction in the milk equal to that obtained with the surface cooler.

A similar comparison was made between the cooling efficiency of a Hydro-Vac cooler, a sprinkler cooler, and a tub cooler. It was found that the Hydro-Vac cooler was far superior to the sprinkler cooler and to the tub cooler. The cooling efficiency of the sprinkler cooler proved to be slightly higher than that of the tub cooler. It required approximately four times as long for the sprinkler cooler and six times as long for the tub cooler as for the Hydro-Vac cooler to reduce the temperature of 80 pounds of milk to a temperature four degrees above that of the cooling water.

Efforts were made to determine the extent of the bacterial contamination taking place when milk was cooled with a Hydro-Vac cooler and with a surface cooler. Both coolers were thoroughly sterilized. In approximately two-thirds of the trials the number of bacteria per c.c. of the cooled milk exceeded the number of bacteria per c.c. of the uncooled milk; in one-third of the trials the situation was reversed. The changes in the number of bacteria as shown by the difference between the counts before and after cooling of the milk were believed to be due, to a far greater extent, to the error of the method used to determine the number of bacteria, than to contamination of the milk during the cooling process. No definite conclusions could be drawn from the data obtained. There was, however, a certain indication that with either cooler contamination during the cooling of the milk was probably very low.

Rinsing of a sterilized surface cooler with sterile water and subsequent calculating of the probable contamination per c.c. of 10 gallons of milk, based on the number of bacteria found in the rinse water, was found to be an additional indication that contamination of milk during cooling with a well sterilized surface cooler was probably very small.

The average number of colonies which developed on sterile agar plates which had been exposed for 10 minutes to the air of the milk house was determined. The probable contamination of milk with bacteria from the air during 10 minutes of cooling with a 29 x 16½ inch surface cooler would have been 165 times as high as this average number of colonies, since the area of milk exposed to the air during the cooling process was 165 times as large as the area of an agar plate. The calculated contamination of 10 gallons of milk with bacteria from the air amounted to a total of 1,980, or to 0.05 per c.c.

In another experiment a can of milk was divided into two parts which were then cooled with a surface cooler and with a Hydro-Vac cooler respectively. Samples were taken from the two lots of cooled milk and a comparison was made of their keeping quality while being held at room temperature. It was found that under certain circumstances milk may be cooled by the two different methods without the appearance of a difference in the keeping quality of the two lots of cooled milk.

Cooling and aerating milk with a surface cooler or with a Hydro-Vac cooler did not consistently cause an improvement in the flavor and odor of this milk, as shown by a comparison with milk from the same lot which had been cooled with a tub cooler without aeration and with milk from the same lot which had not been cooled. In 15 trials, the milk cooled with a surface cooler and with a Hydro-Vac cooler generally placed higher than the milk from the same lot cooled with a tub cooler, or milk of the same origin which had not been cooled.

A comparison of the creaming ability of milk cooled with a surface cooler, with a Hydro-Vac cooler, with a sprinkler cooler, and of milk which had not been cooled showed that the method of cooling had no influence on the amount of cream rising on the milk, except when the milk had been cooled with a tub cooler. For this milk a distinct increase in the cream volume was observed over the cream volumes on the milk cooled with a Hydro-Vac cooler and on the milk cooled with a surface cooler, as well as over the cream volume on the milk which had not been cooled.

VI. CONCLUSIONS

A. Cooling experiments with a surface cooler

(1) With four gallons of water per minute flowing through a 29 x 16½ inch tubular surface cooler and with the water temperature gradually increasing from 47.0° F. to 57.0° F., 80 pounds of milk were cooled in 10 minutes from 90° F. to a temperature which ranged from 51.5° F. to 61.5° F., depending on the temperature of the cooling water.

The temperature of the cooled milk was from 4.5° to 6.0° F. above the temperature of the cooling water.

(2) Increasing the rate of flow of 48° F. cooling water with a 29 x 16½ inch tubular surface cooler, from three gallons per minute to 10 gallons per minute, resulted in a lowering in the temperature of the milk, amounting to 5.5° F., when 80 pounds of milk at 90° F. were cooled in 10 minutes. Increasing the rate of water-flow to more than six gallons per minute did not result in any appreciable further drop in the temperature of the milk.

(3) With five gallons of cooling water per minute flowing through a 29 x 16½ inch tubular surface cooler, and with the temperature of the water at 46.0° F., a gradual decrease in the milk-flow resulted in a decrease in the temperature to which milk at 90° F. was cooled.

The temperature of the cooled milk ranged from 54.0° F. with a milk-flow of 10 pounds per minute to 49.0° F. with a milk-flow of 5.3 pounds per minute.

B. Cooling experiments with a Hydro-Vac cooler.

(4) When cooling 80 pounds of milk in 10 minutes with a Hydro-Vac cooler, through which were flowing four gallons of water per minute, an increase in the temperature of the cooling water used was accompanied by an increase in the temperature to which the milk was cooled.

The temperature of the cooled milk ranged from 51.5° to 62.0° F. with the water temperature increasing from 42.5° to 56.0° F.

(5) Increasing the length of cooling time at a constant rate, when cooling 80 pounds of milk with a Hydro-Vac cooler, through which were flowing four gallons of water per minute, was found to lower the temperature of the milk at a steadily decreasing rate.

With the water temperature at 49° F. the average temperature decrease in the milk amounted to 3.3° F. per minute for the first 10 minutes of cooling.

Above a cooling time of 13 minutes, the temperature reduction in the milk was less than one degree F. for any one minute period of cooling.

C. Comparative cooling efficiency of different coolers

(6) On an average of five tests, 80 pounds of milk at 90.4° F. were cooled in 10 minutes to 56.7° F. when a 29 x 16½ inch tubular surface cooler, through which were flowing four gallons of cooling water at 52.0° F. per minute, was used. With a Hydro-Vac cooler, the same amount of milk was cooled in 10 minutes to 59.5° F., when the initial temperature of the milk, the temperature of the cooling water and the rate of water-flow were the same as with the surface cooler.

The temperature reduction in the milk cooled with the surface cooler exceeded the temperature reduction in the milk cooled with the Hydro-Vac cooler by 2.8° F.

This showed that under the conditions of this experiment the surface cooler possessed a cooling efficiency slightly higher than that of the Hydro-Vac cooler.

(7) With the temperature of the cooling water at 54° F. and with a rate of water-flow of four gallons per minute, it was found that it required 15 minutes with a Hydro-Vac cooler, 60 minutes with a sprinkler cooler, and 90 minutes with a tub cooler to cool 80 pounds of milk from 90° F. to 58° F. The rate of water-flow was four gallons per minute and the temperature of the cooling water was 54.0° F.

D. Bacterial contamination by different coolers

(8) Bacterial counts were made on 10 gallons of milk before and after cooling with a sterilized 29 x 16$\frac{1}{2}$ inch tubular surface cooler and with a sterilized Hydro-Vac cooler, in order to study the bacterial contamination of the milk by the cooler.

In approximately two-thirds of the tests the bacterial count had increased during cooling, and in the remaining tests it had decreased.

The increases ranged from 50 to 2,300 bacteria per c.c., while the decreases varied from 50 to 2,900 per c.c. (one decrease of 12,400 was observed).

These changes were believed to be due mainly to the possible error of the standard plate count method rather than to contamination during cooling, since the increases and the decreases were of practically the same magnitude.

The contamination by either of the two coolers was probably very small.

(9) Rinsing a 29 x 16$\frac{1}{2}$ inch tubular surface cooler, which had been sterilized in a steam sterilizer for three hours with flowing steam under atmospheric pressure, with 1,000 c.c. of sterile water contaminated the rinse water in three trials with an average of 23,300 bacteria. On this basis 10 gallons of milk would have been contaminated

with $\frac{23,300}{37,854} = 0.62$ bacteria per c.c. during the cooling with the cooler. (10 gallons = 37,854 c.c.)

(10) The number of colonies which developed on a sterile agar plate which was exposed to the air in the milk house for 10 minutes averaged 12 in 10 trials. Using this data as basis for calculating, 10 gallons of milk would have been contaminated during 10 minutes of cooling with a 29 x $16\frac{1}{2}$ inch tubular surface cooler to the extent of $\frac{12 \times 165}{37,854} = 0.05$ bacteria per c.c. as a result of the contact with the air, since the surface of milk exposed to the air during the cooling process was found to be 165 times as large as that of an agar plate.

E. Odor and flavor of milk cooled with different coolers

(11) Milk from the same lot was cooled with a surface cooler, with a Hydro-Vac cooler, and with a tub cooler. A sample was then taken from each of the three portions of cooled milk and also one from the milk not cooled. The four samples were then classified by three judges. When 4, 3, 2, and 1 points were allowed respectively for first, second, third, and fourth place, the total number of points received by the milk cooled with the Hydro-Vac cooler was 126; the milk cooled with the surface cooler received 123 points; while the milk cooled with the tub cooler and that not cooled were given 112 and 111 points

respectively.

F. Creaming ability of milk cooled with different coolers

(12) Portions of milk from the same lot were cooled with a Hydro-Vac cooler, with a surface cooler and with a tub cooler, respectively. A sample was then taken from each of the three batches of cooled milk and a fourth sample was obtained from the milk not cooled. All four samples were then set in ice water for creaming. At the end of 24 hours of creaming the cream volume per one percent fat in the milk was found to be 4.35 percent of the total milk volume for the milk which had not been cooled and for the milk cooled with the surface cooler, 4.32 percent of the total milk volume for the milk cooled with the Hydro-Vac cooler, and 4.59 percent of the total milk volume for the milk cooled with the tub cooler.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to Dr. G. H. Wilster and to Mr. F. E. Price for their assistance in planning and carrying out this work and for their helpful criticism in the preparation of this thesis. The writer feels also indebted to the Hydro-Vac Company of Chicago, Illinois for furnishing the Hydro-Vac cooler which was used in this investigation.

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