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THE PRESENT STATUS OF THE PASTEURIZATION OF MILK

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MEANING OF THE TERM PASTEURIZATION

The term "pasteurization" originated in the experiments of Louis Pasteur in France. In the period 1860–1864, in experiments on the "diseases" of wine, he found that heating for a few moments at temperatures of 122° to 140° F. was sufficient to prevent abnormal fermentations and souring in wine. A little later he found that by similar heating beer could be prevented from souring. The application of the process gave rise to the term "pasteurization."

As applied under commercial conditions, pasteurization is the process of heating liquids for a short or a long period, as the different processes demand, at temperatures usually between 140° and 185° F. As applied to milk for direct consumption, pasteurization should mean a process of heating every particle of milk to a temperature not lower than 142° F. for not less than 30 minutes. The process is followed by rapid cooling.

PAST AND PRESENT THEORIES OF PASTEURIZATION

Pasteurization is at present favorably regarded by most medical men, sanitarians, dairymen, and consumers, but the use of the process has not been developed without opposition. Most of the objections to pasteurized milk have been based upon theory or upon experiments in which milk was heated at high temperatures.

[1] Mr. Ayers resigned from the department in 1923.

One of the early objections to pasteurized milk was that the heating destroyed the lactic-acid bacteria and that putrefactive organisms were left, which, when relieved from the restraining action of the acid-forming bacteria, would develop, forming toxins and putrefactive products. It was believed that the milk, because it was not sour, would be consumed in that condition. This objection was based on experiments in which milk was heated to temperatures near the boiling point and does not apply in the case of milk pasteurized at low temperatures. From the results of many years' work in the Bureau of Dairy Industry on commercial pasteurized milk, it has been found that such milk sours, but that the souring is delayed when compared with the rate of souring of the same grade of raw milk. Pasteurized milk sours in a manner similar to that of a high grade of raw milk, and there is no more reason to fear the overgrowth of putrefactive organisms in it than in any high-grade milk. Pasteurization for 30 minutes at a temperature not lower than 142° F., as is generally practiced in the United States, does not destroy all the lactic-acid organisms, and those which survive play an important part in the souring of commercially pasteurized milk.

Another objection to pasteurized milk has been that bacteria grow faster in it than in raw milk. In spite of several experiments which seem to prove this point, it has never been thoroughly established. It has been found that the rate of bacterial increase is approximately the same in raw milk and in pasteurized milk having about the same bacterial content.

It is often stated that pasteurization, even if it does kill bacteria, does not destroy poisonous products of their growth. This can hardly be considered a real objection, for if these products are present in raw milk they must be consumed with it, and if pasteurization does not destroy them the pasteurized milk would be no worse than raw milk containing the same products.

The question whether pasteurization destroys beneficial enzymes is still open. In the light of our present knowledge of the enzymes in milk and the part they play in the digestive process it is quite impossible to settle the question of their importance. It is evident, however, that the low temperatures now in use in pasteurization have little effect on the commonly recognized enzymes.

Objection to pasteurization has been raised on the ground of its direct influence on the milk producer. It has been asserted that pasteurization would lead to lax methods of production on the farm, because farmers knowing that the milk was to be pasteurized would therefore be careless in its production. However, only milk of high quality should be used for pasteurization, and there should be constant inspection of farms and bacteriological control of all milk that is to be pasteurized.

From a chemical standpoint serious objections have been raised against pasteurized milk, on the ground that the heating produces changes which render the milk less digestible, particularly by infants. However, Rupp (*50*)[2] found that milk pasteurized at a temperature as high as 145° F. for 30 minutes does not undergo any appreciable chemical change; he found that soluble phosphates do not become insoluble and that the albumin does not coagulate, but that when higher

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

temperatures are used chemical changes do occur. He also brought out the fact that 5 per cent of the albumin is rendered insoluble by heating the milk for 30 minutes at 150°, whereas 30.78 per cent of the albumin is coagulated at 160°. Further evidence that low-temperature pasteurization does not injure the digestibility and nutritive value of milk has been brought out in feeding experiments with babies. In experiments conducted by Weld (*61*) a number of babies were fed raw milk and pasteurized milk, and there was only a slight difference in the average net daily gain in weight during the feeding period. The slight difference was in favor of pasteurized milk. Hess (*35*), however, has found that milk pasteurized for 30 minutes at 145° may cause, in infants, a mild form of scurvy, which yields readily to so simple a remedy as orange juice.

The high-temperature heating of earlier days must not be confused with the low-temperature pasteurization of the present day. Many of the objections which have been raised to pasteurization have been founded on the observation of milk heated to high temperatures. However, the fallacy of the objections to pasteurization has been shown, through scientific research in the last few years, and as a result the value of the process has been firmly established.

VALUE OF PASTEURIZATION

From a sanitary standpoint, the value of pasteurization is of greatest importance when the general milk supply is under consideration. The pasteurization of milk, when the process is properly performed, affords protection from pathogenic organisms. Such disease-producing bacteria as *Eberthella typhi*, and the dysentery bacillus, and other organisms of the typhoid-paratyphoid-enteritis group, *Mycobacterium tuberculosis*, and *Cornyebacterium diptheriae*, when heated at 140° F. for 20 minutes or more, are destroyed, or at least lose their ability to cause disease.

Occasionally results are reported, such as those of Twiss (*60*) which again open the question of the destruction of certain pathogenic organisms by pasteurization. Using test organisms of the typhoid-paratyphoid group, she obtained results which indicated that not all these organisms were destroyed when they were heated in milk at 140° F., or even at 149°, for 30 minutes. Krumwiede and Noble (*43*), however, using some of the same test organisms of the typhoid-paratyphoid group used by Twiss, found that the organisms did not survive heating for 10 minutes at 140°. They further pointed out that the apparent heat resistance of the strains used by Twiss was due to the method of determining their thermal death point.

According to Mohler (*47*), pasteurization offers protection against foot-and-mouth disease. He makes the following statement:

> Milk which has been pasteurized for the elimination of tubercle and typhoid bacilli will not prove capable of transmitting the disease (foot-and-mouth) to persons or animals fed with it.

In view of the outbreak of foot-and-mouth disease in this country several years ago this statement is of importance.

The abortus-like bacteria in the udders of healthy cows which were demonstrated by Evans (*22*) should also be considered in a discussion of pasteurization. She (*23*) found that both the pathogenic and lipolytic varieties could be destroyed by heating to 125° F. for 30 minutes or to 145° for 30 seconds.

These pathogenic organisms are now considered to be of public-health significance since they may cause human disease. Evans (*24*) has also shown that the abortus group contains several different species and she later (*25*) reported on a number of cases of Malta fever due to *Brucella melitensis*. Whittaker and his committee (*64*) state that it has recently been recognized that undulant fever is caused by *B. abortus* (*B. melitensis*), which is responsible for infectious abortion in cattle and swine. This report further states that health authorities should recommend to American milk consumers that the general market milk supply be pasteurized before it is consumed. Arnold (*1*) found living Brucella after exposure to the temperature of commercial pasteurization. This was contrary to the findings of Boak and Carpenter (*14*), who concluded that an exposure of 15 minutes at 140° F. (60° C.) destroyed the human and bovine cultures of *B. abortus*. Gilbert and Coleman (*28*) report several cases of undulant fever and state that a consideration of the data available indicates three possible reasons why cases of undulant fever are not reported more frequently in districts where unpasteurized milk is used from herds in which contagious abortion is prevalent. Many of the severe infections of undulant fever have probably been diagnosed as cases of typhoid fever, influenza, or even tuberculosis or malaria; mild forms may have presented so few symptoms that physicians have not been consulted; and the blood from some cases of undulant fever may not have agglutinated cultures of *B. melitensis* or *B. abortus*. The laboratory data and epidemiological findings of Hardy and others (*33*) show that controlled pasteurization is effective against organisms of the Brucella group, and Hasseltine (*34*) states that pasteurization of the milk renders it safe and takes care not only of undulant fever but of all other communicable diseases transmitted by milk.

Scamman (*51*) reports that through 1928, 45 milk-borne outbreaks of septic sore throat have been recorded in the United States. In some of these epidemics it was found possible to destroy by pasteurization the streptococci isolated from throats of infected people and believed to be the infective agents. Pasteurization, properly performed, protects against epidemics of this kind.

The determination of the thermal death point of pathogenic streptococci by various investigators together with past experience with the use of properly pasteurized milk indicates very clearly that the thermal death point of these organisms is relatively low and that they are readily destroyed by proper pasteurization. Thus Hamburger (*29*) who studied the epidemic of septic sore throat in Baltimore in 1912, traced this epidemic to a certain milk supply. Advice to boil all milk was given, and the dairy to which the epidemic was traced, raised the temperature of its flash process to 160° F., and then changed to the holder process, by which the milk was heated to 145° and held for a period of 30 minutes. The cases of sore throat that followed were neither as severe nor as numerous and did not follow the milk supply, but appeared to have been transmitted from individual to individual. Hamburger (*30*) also found that a streptococcus, isolated from a patient having a case of sore throat, was killed by heating in milk at 145° for 30 minutes. Davis (*19*) found that streptococci isolated from cases of sore throat were readily killed by heating at 140° F. for 30 minutes. He also found that none of 24 strains of pathogenic hemolytic streptococci of human origin resisted heating at 140° for 30 minutes.

Again, Capps and Miller (*17*), who studied the Chicago epidemic of septic sore throat, traced it to a dairy where the milk was heated by the flash process at 160° F. On certain dates they found that there was a pronounced failure to heat the milk properly and that following these dates there were outbreaks of septic sore throat. These facts, together with the fact that no outbreak occurred among the children of the Michael Reese Hospital, where efficient pasteurization was practiced, led these investigators to believe that final responsibility for the epidemic rested on inadequate and unreliable pasteurization.

Bray (*16*), who studied an epidemic of tonsillitis among tuberculosis patients, traced the epidemic to a milk supply from one farm. Forty cases of tonsillitis resulted among 400 people. As soon as the epidemic broke out the milk was pasteurized, and after that only one case appeared.

Knowlton (*42*) reported in 1926 that Connecticut had suffered one milk-borne septic sore throat outbreak per year for the last three years. Such infections ceased when the distribution of raw milk was stopped, either by stopping the sale of milk or by pasteurizing. In 1928, two outbreaks of septic sore throat were reported in Massachusetts (*13, 38, 44, 49, 62*). The source of the Lee outbreak was traced to an infected cow, and the Charlton outbreak was traced to a dairyman and his family. It was concluded that the best way to prevent such outbreaks is to pasteurize all milk. McKay and Hardman (*45*) also report a severe epidemic of septic sore throat in Ontario which was spread through the use of raw milk. Bigelow and Forsbeck (*12*) conclude that the eventual obliteration of milk-borne disease depends more on pasteurization than on any other single factor.

Further evidence that pathogenic streptococci are killed by pasteurization was presented by the results obtained by Ayers, Johnson, and Davis (*8*), who found in their work that 27 strains of these organisms were always killed by being heated at 140° F. for 30 minutes.

Epidemics of scarlet fever have been traced to milk supplies, and in such cases pasteurization has been resorted to, with apparently satisfactory results, as a means of safeguarding the public health.

Pasteurization is of value from a commercial standpoint, in that it increases the keeping quality of the milk and assists in preventing financial losses caused by souring. This is a collateral advantage, but pasteurization should not be relied upon to take the place of efforts to produce high-quality milk. At the present time, pasteurization is the best process for killing pathogenic bacteria in milk on a commercial scale.

The need of safeguarding the general milk supply is amply proved by the numerous epidemics traced to milk. Trask (*58*) reported 179 epidemics of typhoid fever from 1881 to 1907, of which 107 were in the United States; 51 epidemics of scarlet fever, 25 of which were in this country; and 23 epidemics of diphtheria from 1879 to 1907, of which 15 occurred in the United States. Table 1, compiled by the United States Public Health Service [3] shows the number of milk-borne epidemics reported in the United States for the years 1924 to 1930.

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[3] FRANK L. C. THE PUBLIC HEALTH SERVICE MILK SANITATION PROGRAM. U. S. Pub. Health Serv., p. 3. 1932. [Mimeographed.]

TABLE 1.—*Milk-borne outbreaks reported by State and city health officers of the United States for the years 1924 to 1930, inclusive*

Disease	1924	1925	1926	1927	1928	1929	1930	Total
Typhoid	34	31	49	23	25	28	27	217
Paratyphoid A	0	1	2	0	0	0	0	3
Paratyphoid B	1	1	0	2	0	1	0	5
Diphtheria	1	1	2	2	2	0	0	8
Septic sore throat	1	6	6	0	3	8	9	33
Scarlet fever	5	4	5	5	8	11	2	40
Miscellaneous	2	0	4	4	3	2	6	21
Total	44	44	68	36	41	50	44	327

During this 7-year period, the average number of milk-borne outbreaks reported per year is approximately 47.

EXTENT OF PASTEURIZATION IN THE UNITED STATES

The application of Pasteur's discovery to the milk industry was slow. The heating of milk was first done secretively and for the sole purpose of preserving the milk, thereby saving losses to milk dealers. Jacobi, a noted American health authority, is believed to have been the first public-health expert to recommend the heating of milk; this was in 1889. The adoption of pasteurization by the cities came some years later. Pasteurization of milk was begun in Cincinnati in 1897; in New York, 1898; in Philadelphia, 1899; in St. Louis, 1900; in Boston and Chicago, 1908. Some firms would pasteurize but dared not admit it to the public. In 1906, New York City passed an ordinance prohibiting clandestine pasteurization, and in 1910 began to regulate the time and temperature of pasteurization. The increase in pasteurization was slow. Although in 1892 the heating of milk in tenement homes was widely practiced, Jordan (*41*) states that only about 5 per cent of the milk supply of New York City was pasteurized by the milk dealer in 1903. Other sources of information show that by 1910, 25 per cent of New York's supply was so treated, and in the next two years the percentage increased to 40. Beginning in 1912, the amount pasteurized increased rapidly for a number of years. The Boston market was somewhat slower in starting; so little was pasteurized in 1902 that it was not reported. However, by 1910, 50 per cent was being processed; and by 1915, 80 per cent. These rapid increases were due to the fact that as the practice became more general much scientific study was given to the subject. These studies brought out the facts that pasteurization, when properly done, was not detrimental to the chemical and physical properties of the milk, and that it safeguarded the consumer by killing pathogenic organisms.

Table 2 is compiled from three questionnaires sent to health officials. In 1915 the figures were based upon 344 replies, in 1924 upon 328, and in 1930 upon 344. The 1930 figures represent reports from 46 States.

TABLE 2.—*Comparison of extent of pasteurization of milk in cities in the United States in 1915, 1924, and 1930*

Population of cities	Cities reporting			Cities with no pasteurized milk		Cities having some raw milk	Milk pasteurized	
	1915	1924	1930	1924	1930	1930	1924	1930
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Per cent*	*Per cent*
500,000 and over	9	9	11	0	0	11	98.1	97.1
100,000 to 500,000	40	37	56	0	0	55	81.7	84.9
75,000 to 100,000	19	19	13	0	0	13	66.6	81.5
50,000 to 75,000	30	25	37	0	0	37	66.6	72.2
25,000 to 50,000	78	60	56	2	0	53	67.0	73.1
10,000 to 25,000	168	105	92	21	6	90	42.5	52.1
Under 10,000	------	73	79	20	[1] 44	73	33.6	27.1

Population of cities	Percentage of cities in which the percentage of pasteurized milk was—										
	90 to 100 per cent		50 to 100 per cent			10 to 50 per cent			0 to 10 per cent		
	1924	1930	1915	1924	1930	1915	1924	1930	1915	1924	1930
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
500,000 and over	100.0	90.9	77.8	100.0	100.0	22.2	0.0	0.0	0.0	0.0	0.0
100,000 to 500,000	56.8	53.6	30.0	91.9	96.4	50.0	8.1	3.6	15.0	0.0	0.0
75,000 to 100,000	26.3	50.0	26.3	73.6	84.6	42.1	15.8	15.4	21.0	10.6	0.0
50,000 to 75,000	20.0	40.5	12.3	80.0	77.8	50.0	12.0	22.2	20.0	8.0	0.0
25,000 to 50,000	20.0	30.4	16.7	80.0	80.4	39.7	13.3	17.8	15.4	5.0	1.8
10,000 to 25,000	12.4	17.4	6.0	45.7	55.4	23.8	31.4	33.7	10.7	2.9	10.9
Under 10,000	5.5	11.4	------	41.1	25.0	------	27.4	12.0	------	2.7	63.0

[1] 38 of these towns and cities were reported by a State board of health.

The tendency in this country is to pasteurize practically all milk sold for direct consumption. The 1930 survey shows that 14 cities and towns in eight States required pasteurization of all milk. In 16 cities and towns, certified milk or milk of equal grade is the only raw milk allowed to be distributed. Since 1924 the percentage of cities having more than 50 per cent of their milk pasteurized has increased. The cities of 50,000 to 75,000 population having from 50 to 100 per cent of their milk pasteurized apparently have not increased, although Table 2 shows that more cities of this size are pasteurizing from 90 to 100 per cent and from 10 to 50 per cent of their supply.

The larger cities were the first to adopt pasteurization. However, a study of the figures show that the trend of the smaller cities is toward its adoption. In Table 2, by deducting the number of cities having some raw milk from the cities reporting, it is to be noted that 11 of the 12 cities having no raw milk in 1930 are within the groups under 10,000, 10,000 to 25,000, and 25,000 to 50,000, and only two groups, the under 10,000 and 10,000 to 25,000, report cities with no pasteurized milk. In the 10,000 to 25,000 group there are only 30 per cent as many cities reporting no pasteurized milk in 1930 as in 1924.

The facts presented in Table 2 are accentuated in Table 3. Reports from the same 125 cities of over 10,000 population were available for both 1924 and 1930, and have been placed in Table 3 in the population groups as in Table 2. Each group shows as many or more cities pasteurizing from 50 to 100 per cent of their milk, and a gain in the average percentage pasteurized over the 1924 figures. Every city but one reports pasteurized milk in 1930. Of these 125 cities, 32.8 per cent reported from 90 to 100 per cent pasteurized milk in 1924 and 46.4 per cent were in the same group in 1930.

TABLE 3.—*Comparison of extent of pastuerization of milk in the same cities in 1924 and in 1930*

Population of cities	Cities reporting		Cities with no pasteurized milk		Milk pasteurized		Percentage of cities in which the percentage of pasteurized milk was—							
							90 to 100 per cent		50 to 100 per cent		10 to 50 per cent		0 to 10 per cent	
	1924	1930	1924	1930	1924	1930	1924	1930	1924	1930	1924	1930	1924	1930
	Number	*Number*	*Number*	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
500,000 and over	6	6	0	0	97.8	98.7	100.0	100.0	100.0	100.0	0	0	0	0
100,000 to 500,000	37	37	0	0	75.9	84.7	43.2	56.8	89.2	91.9	10.8	8.1	0	0
75,000 to 100,000	10	10	0	0	78.0	84.5	50.0	50.0	80.0	90.0	20.0	10.0	0	0
50,000 to 75,000	14	14	0	0	64.5	76.5	21.4	42.9	85.7	85.7	14.3	14.3	0	0
25,000 to 50,000	24	24	0	0	68.1	78.7	29.2	37.5	79.2	87.5	20.8	12.5	0	0
10,000 to 25,000	34	34	8	1	37.5	61.6	11.8	32.3	41.2	64.7	29.4	32.3	29.4	3

Table 4 gives the percentage of milk reported pasteurized in 302 cities for the years 1924 and 1930. The cities are listed in order of their population according to the 1930 census. It is interesting to compare the 1924 figures with the 1930 figures and to note the increase in the percentage of milk pasteurized in cities of less than 50,000 population.

TABLE 4.—*Approximate percentage of milk pasteurized in 302 cities in 1930 and in 1924*

City	Population (1930 census)	Milk pasteurized in—		City	Population (1930 census)	Milk pasteurized in—	
		1930	1924 [1]			1930	1924 [1]
		P. ct.	*P. ct.*			*P. ct.*	*P. ct.*
New York, N. Y	6,981,927	98.0	98.0	Providence, R. I	251,029	88.5	63.3
Chicago, Ill	3,375,235	99.7	99.0	Syracuse, N. Y	207,007	97.2	92.4
Philadelphia, Pa	1,964,430	99.0	------	Dayton, Ohio	200,225	98.0	95.0
Los Angeles, Calif	1,231,730	82.2	------	Worcester, Mass	196,837	96.8	85.0
Cleveland, Ohio	900,430	98.7	98.0	Youngstown, Ohio	170,004	98.1	96.0
Baltimore, Md	801,741	98.4	98.2	Grand Rapids, Mich	168,650	92.7	90.0
Boston, Mass	787,271	99.3	97.0	Hartford, Conn	163,818	86.2	------
Pittsburgh, Pa	669,742	95.0	------	New Haven, Conn	162,650	90.5	90.0
San Francisco, Calif	637,212	98.1	97.0	Fort Worth, Tex	160,892	92.0	------
Buffalo, N. Y	573,070	99.7	------	Flint, Mich	156,422	99.5	85.0
Milwaukee, Wis	572,557	99.5	------	Nashville, Tenn	153,153	66.3	------
Washington, D. C	486,869	97.0	95.0	Springfield, Mass	149,861	97.1	87.7
Minneapolis, Minn	464,753	96.3	95.9	San Diego, Calif	147,897	79.1	------
New Orleans, La	455,792	64.3	20.0	Bridgeport, Conn	147,206	90.5	90.0
Cincinnati, Ohio	449,331	100.0	98.0	Scranton, Pa	143,428	99.4	90.0
Newark, N. J	442,842	98.0	90.0	Des Moines, Iowa	142,469	84.7	75.0
Kansas City, Mo	392,761	49.8	50.0	Long Beach, Calif	141,390	79.3	79.5
Rochester, N. Y	325,019	97.4	95.0	Tulsa, Okla	141,281	75.3	50.0
Jersey City, N. J	315,642	89.0	------	Salt Lake City, Utah	140,184	95.0	------
Louisville, Ky	307,808	98.0	------	Paterson, N. J	138,267	75.7	------
Columbus, Ohio	289,056	94.0	90.0	Jacksonville, Fla	129,682	43.7	50.0
Denver, Colo	287,644	95.3	80.0	Kansas City, Kans	122,327	60.0	25.0
St. Paul, Minn	271,418	80.7	------	Chattanooga, Tenn	119,539	84.0	65.0
Atlanta, Ga	266,559	57.7	------	Camden, N. J	117,172	99.0	------
Birmingham, Ala	257,657	48.0	65.0	Spokane, Wash	116,010	80.0	80.0
Akron, Ohio	253,653	98.0	------	Fall River, Mass	115,301	100.0	55.0

[1] Leaders signify no report.

TABLE 4.—*Approximate percentage of milk pasteurized in 302 cities in 1930 and in 1924*—Continued

City	Population (1930 census)	Milk pasteurized in— 1930	Milk pasteurized in— 1924
		P. ct.	*P. ct.*
Fort Wayne, Ind	115,121	97.0	95.0
Elizabeth, N. J	114,557	87.0	87.0
Cambridge, Mass	113,650	98.6	95.0
New Bedford, Mass	112,836	99.0	98.0
Miami, Fla	110,510	65.2	------
Knoxville, Tenn	105,797	61.0	33.0
South Bend, Ind	104,066	100.0	------
Evansville, Ind	103,151	93.8	------
Utica, N. Y	102,633	82.8	50.0
Lynn, Mass	102,327	99.0	------
Duluth, Minn	101,417	53.3	87.0
Waterbury, Conn	101,025	59.3	40.0
Tampa, Fla	100,910	70.0	------
Lowell, Mass	100,300	76.5	------
Schenectady, N. Y	95,652	95.7	95.0
Allentown, Pa	92,052	98.5	98.0
Savannah, Ga	87,714	40.0	1.0
Rockford, Ill	84,957	98.5	97.9
Berkeley, Calif	81,543	93.6	89.0
Altoona, Pa	81,503	98.9	97.0
Saginaw, Mich	80,350	75.0	45.0
Lansing, Mich	78,420	86.2	85.0
Manchester, N. H	76,886	84.0	96.0
Shreveport, La	76,659	49.7	------
Lincoln, Neb	75,919	75.0	76.0
Huntington, W. Va	75,575	66.7	------
Niagara Falls, N. Y	75,398	98.3	------
Troy, N. Y	72,350	37.5	------
Quincy, Mass	71,965	93.1	66.6
Roanoke, Va	69,096	97.2	------
Springfield, Ohio	68,406	93.5	90.0
New Britain, Conn	68,095	68.4	70.0
Racine, Wis	67,515	99.5	------
Pueblo, Colo	66,032	61.0	------
Montgomery, Ala	65,801	21.0	14.3
Newton, Mass	65,295	94.9	------
Pontiac, Mich	64,897	96.0	50.0
Hammond, Ind	64,523	99.7	------
Topeka, Kans	64,005	33.3	5.0
Oak Park, Ill	63,819	90.0	------
Brockton, Mass	63,695	80.0	------
Passaic, N. J	63,108	86.9	------
Evanston, Ill	61,766	98.2	------
Wheeling, W. Va	61,752	76.0	72.0
Mount Vernon, N. Y	60,869	98.2	100.0
Davenport, Iowa	60,728	75.0	55.0
Lancaster, Pa	60,596	65.3	80.0
Charlestown, W. Va	60,411	74.2	75.0
Augusta, Ga	60,204	18.7	------
Malden, Mass	58,143	99.8	------
Madison, Wis	57,815	94.9	75.0
Springfield, Mo	57,507	42.1	------
Cedar Rapids, Iowa	56,078	85.0	60.0
York, Pa	55,237	97.0	90.0
Jackson, Mich	54,870	58.0	------
Kalamazoo, Mich	54,388	91.9	------
Galveston, Tex	53,427	68.2	------
Greensboro, N. C	53,422	38.9	------
Austin, Tex	53,118	32.7	------
Waco, Tex	52,824	55.5	------
Port Arthur, Tex	50,067	18.4	------
Kenosha, Wis	49,844	99.5	95.0
Pittsfield, Mass	49,675	59.8	33.3
Aurora, Ill	49,522	100.0	98.5
Haverhill, Mass	48,687	85.0	30.0
Everett, Mass	48,298	98.0	80.0
Stockton, Calif	47,951	84.3	------
Brookline, Mass	47,437	94.7	85.0
Williamsport, Pa	45,695	74.5	60.0
Portsmouth, Va	45,353	62.5	51.0
Chelsea, Mass	44,827	100.0	------
Perth Amboy, N. J	44,007	96.6	85.0
Chicopee, Mass	43,981	94.3	70.0
Wichita Falls, Tex	43,614	91.2	------
Salem, Mass	43,287	99.3	------
Amarillo, Tex	43,107	80.0	30.0
Lima, Ohio	42,217	72.1	100.0
Lynchburg, Va	40,559	100.0	------
Sheboygan, Wis	39,249	82.8	------
La Crosse, Wis	38,687	42.4	------
Santa Monica, Calif	36,993	78.5	------
Auburn, N. Y	36,736	80.0	90.0
Superior, Wis	36,100	48.6	65.0
Arlington, Mass	36,089	98.8	80.0
Elgin, Ill	35,806	80.0	66.7
Steubenville, Ohio	35,418	82.0	------
Plainfield, N. J	34,405	78.3	------
Alameda, Calif	34,367	97.0	------
Newport News, Va	34,285	40.0	33.3
New Brunswick, N. J	34,280	89.0	------
Paducah, Ky	33,541	77.8	------
Colorado Springs, Colo	33,241	82.0	------
Meridian, Miss	32,527	0	------
Rome, N. Y	32,496	47.3	------
Tucson, Ariz	32,198	89.9	------
Watertown, N. Y	32,088	84.8	------
Baton Rouge, La	31,465	50.0	------
Newburgh, N. Y	31,243	79.1	50.0
Nashua, N. H	31,091	50.4	50.0
Bloomington, Ill	30,915	88.3	90.0
Riverside, Calif	30,654	20.0	------
Bellingham, Wash	30,602	84.4	75.0
Parkersburg, W. Va	29,605	63.0	------
Galesburg, Ill	28,702	54.4	------
Fargo, N. Dak	28,609	100.0	------
Mishawaka, Ind	28,628	100.0	------
Bristol, Conn	28,402	76.8	------
Ottumwa, Iowa	28,074	56.0	------
New London, Conn	27,827	42.9	------
Newport, R. I	27,430	97.0	94.3
Ann Arbor, Mich	26,872	95.0	90.0
Albuquerque, N. Mex	26,526	22.8	------
Fond du Lac, Wis	26,362	28.6	------
Monroe, La	26,002	51.3	------
Elyria, Ohio	25,606	100.0	------
San Angelo, Tex	25,304	50.0	------
Concord, N. H	25,162	30.0	33.3
Johnson City, Tenn	25,073	48.2	------
Beverly, Mass	24,985	96.8	60.0
Burlington, Vt	24,720	39.7	------
Hackensack, N. J	24,506	99.0	75.0
Northampton, Mass	24,350	34.0	------
Washington, Pa	24,239	54.1	------
Alexandria, Va	24,185	62.8	25.0
East Liverpool, Ohio	23,197	75.0	70.0
Fairmont, W. Va	23,139	40.0	20.0
Alexandria, La	23,010	15.0	0
Norwich, Conn	22,776	45.0	------
Hannibal, Mo	22,760	52.0	------
Danville, Va	22,236	26.6	------
Oil City, Pa	22,048	49.1	------
Freeport, Ill	22,026	85.0	75.0
Fort Dodge, Iowa	21,860	78.4	75.0
Aberdeen, Wash	21,718	72.6	------
North Adams, Mass	21,627	37.5	0
Janesville, Wis	21,507	90.0	90.0
Olean, N. Y	21,350	37.5	33.3
Middletown, N. Y	21,298	43.7	------
Winona, Minn	20,852	100.0	100.0
Pomona, Calif	20,695	43.0	------
Rochester, Minn	20,626	91.6	50.0
Tuscaloosa, Ala	20,610	73.0	40.0
Hot Springs, Ark	20,115	13.0	------
Westfield, Mass	19,772	88.2	------
Asbury Park, N. J	19,500	97.5	97.0
Findlay, Ohio	19,327	55.7	------
North Tonawanda, N. Y	19,020	100.0	80.0
Bradford, Pa	18,875	28.6	------

TABLE 4.—*Approximate percentage of milk pasteurized in 302 cities in 1930 and in 1924*—Continued

City	Population (1930 census)	Milk pasteurized in—		City	Population (1930 census)	Milk pasteurized in—	
		1930	1924			1930	1924
		P. ct.	*P. ct.*			*P. ct.*	*P. ct.*
Auburn, Me	18, 567	21. 9	------	Santa Fe, N. Mex	10, 884	42. 8	------
Glens Falls, N. Y	18, 527	50. 7	------	Medford, Oreg	10, 847	79. 2	------
Salem, Oreg	18, 299	82. 5	------	Johnstown, N. Y	10, 794	39. 8	20. 0
Athens, Ga	18, 189	23. 5	1. 0	Griffin, Ga	10, 321	41. 2	------
Pittsburg, Kans	18, 051	75. 0	------	Ames, Iowa	10, 261	80. 0	------
Englewood, N. J	17, 819	95. 7	------	Manhattan, Kans	10, 101	12. 1	10. 0
Dunkirk, N. Y	17, 756	71. 2	------	Stoneham, Mass	10, 058	98. 7	------
Batavia, N. Y	17, 448	89. 5	------	Dover, N. J	10, 031	0	0
Winthrop, Mass	16, 968	96. 3	------	Carthage, Mo	9, 686	0	------
Kewanee, Ill	16, 916	93. 9	95. 0	Palmer, Mass	9, 575	47. 7	------
Aberdeen, S. Dak	16, 338	84. 1	------	Cadillac, Mich	9, 571	89. 5	------
Hornell, N. Y	16, 166	52. 1	25. 0	Bellefontaine, Ohio	9, 535	80. 0	------
Geneva, N. Y	16, 050	94. 7	66. 0	Windber, Pa	9, 290	42. 8	------
Rahway, N. J	15, 973	85. 1	------	Sidney, Ohio	9, 289	100. 0	------
Watervliet, N. Y	15, 781	52. 9	------	Cleveland, Tenn	9, 131	20. 0	------
Vancouver, Wash	15, 759	23. 1	------	Peru, Ill	9, 121	100. 0	------
Lake Charles, La	15, 753	17. 4	0	De Kalb, Ill	8, 536	90. 4	------
Ardmore, Okla	15, 741	16. 7	------	Washington Court House, Ohio	8, 415	65. 0	66. 7
Walla Walla, Wash	15, 725	64. 8	50. 0	New Iberia, La	8, 093	0	------
Corning, N. Y	15, 648	66. 7	10. 0	Wellesville, Ohio	7, 925	61. 7	------
La Porte, Ind	15, 639	95. 1	------	Breckenridge, Tex	7, 558	53. 5	------
Waycross, Ga	15, 507	100. 0	0	Fayetteville, Ala	7, 387	13. 0	------
Dothan, Ala	15, 471	18. 0	0	Wellington, Kans	7, 402	33. 3	------
Decatur, Ala	15, 447	53. 0	------	Junction City, Kans	7, 308	0	0
Newburyport, Mass	15, 059	69. 5	------	Gallipolis, Ohio	7, 102	50. 0	------
Greenville, Miss	14, 795	12. 8	------	Franklin, Mass	7, 028	38. 8	0
Florence, S. C	14, 655	0	------	Bozeman, Mont	6, 818	40. 0	------
Lafayette, La	14, 622	9. 8	------	Houma, La	6, 534	0	------
Missoula, Mont	14, 616	21. 7	1. 0	Hudson Falls, N. Y	6, 448	100. 0	------
Santa Cruz, Calif	14, 389	52. 2	------	Brookfield, Mo	6, 365	23. 1	------
Southbridge, Mass	14, 262	16. 6	------	Ridgway, Pa	6, 298	0	------
Ironwood, Mich	14, 254	50. 0	20. 0	Opelousas, La	6, 279	0	------
Marietta, Ohio	14, 244	61. 1	------	Morgan City, La	5, 985	0	------
Anderson, S. C	14, 130	0	------	Fredonia, N. Y	5, 772	60. 0	------
Bogalusa, La	14, 036	0	------	Marysville, Calif	5, 760	50. 0	------
Chambersburg, Pa	13, 813	99. 0	25. 0	Minden, La	5, 622	0	------
Palo Alto, Calif	13, 635	76. 2	55. 0	Nelsonville, Ohio	5, 229	90. 0	------
Stevens Point, Wis	13, 622	10. 0	------	Bastrop, La	5, 078	0	------
Bedford, Ind	13, 140	90. 0	------	Moscow, Idaho	4, 415	100. 0	------
La Salle, Ill	13, 084	100. 0	------	Ruston, La	4, 392	0	------
Webster, Mass	12, 992	79. 5	------	Greenfield, Ind	4, 171	99. 0	------
Plymouth, Mass	12, 968	54. 5	------	Jackson, La	3, 966	0	------
Fostoria, Ohio	12, 745	75. 0	------	Mansfield, La	3, 836	0	------
Claremont, N. H	12, 343	5. 7	------	Eunice, La	3, 597	0	------
Laconia, N. H	12, 314	0	------	Stafford Springs, Conn	3, 485	0	------
Lawton, Okla	12, 115	63. 3	------	Franklin, La	3, 271	0	------
Virginia, Minn	11, 957	65. 4	------	Auburn, Ala	2, 803	0	------
New Bern, N. C	11, 922	20. 0	0	Chapel Hill, N. C	2, 697	63. 0	------
Florence, Ala	11, 773	65. 0	0	Merryville, La	2, 633	0	------
San Leandro, Calif	11, 315	93. 0	------	Ferriday, La	2, 502	0	------
Rock Hill, S. C	11, 244	0	------	Bunkie, La	2, 464	0	------
Salisbury, Md	10, 981	33. 6	------				

ELECTRICAL AND ULTRA-VIOLET-RAY TREATMENT OF MILK

Many attempts to kill bacteria in milk by means of electricity have been made, but no such process has been devised which has come into extensive commercial use.

Alternating currents have been worked with most extensively, because direct currents were found to produce undesirable chemical changes in milk. Although the proper application of suitable alternating currents has resulted in bacterial reductions similar to those produced by pasteurization, it appears to be an open question whether the bactericidal action is due to the heat generated or to the direct action of electricity on the bacterial cells.

Thornton (*57*), who studied this question in England, came to the conclusion that the killing of bacteria must be regarded as due largely to thermal rather than to electrical changes, but thought his results indicated some electrical action on the molecular structure of the bacteria. Beattie (*9, 10*), also working in England on the same problem, came to the conclusion that heat was not the principal factor in killing bacteria by electricity, but found that to obtain satisfactory results the temperature should not be below 145° F. In the United States an electric process was investigated about 1918 by Anderson and Finkelstein (*2, p. 405*). Their conclusion was:

> The destruction of bacteria in the Electro-pure process is apparently due to the heat produced by the electric current rather than to the electric current itself. The Electro-pure process furnishes a method for producing a very sudden high temperature for a brief period of time.

Gelpi and Devereux (*27*) concluded that in laboratory tests for spore destruction the electro pure process at 71° C. (159.8° F.) with momentary holding was superior to pasteurization at 62.8° C. (145° F.) for 30 minutes.

It seems evident from a review of the literature that in the use of electricity, as it has been applied, sufficient heat is generated by electricity, or by a combination of steam and electricity, to raise the milk to a high temperature. Since the temperatures reached are in themselves destructive to most bacteria, the problem of determining whether the effect of electricity is due to heat or to electric action is difficult.

The use of ultra-violet rays for the destruction of bacteria in milk has not proved to be of commercial value. Experiments with these rays carried on by Ayers and Johnson (*6*) showed that, while the rays cause great destruction of bacteria in milk when exposed under suitable conditions, the process in its then state of development could not replace pasteurization. It was difficult to obtain the proper exposure of milk to the rays on a scale sufficient to permit of practical operation, and it was impracticable to secure suitable bacterial reductions without seriously injuring the flavor of the milk.

METHODS OF HEATING MILK

At present three processes of heating milk are practiced in the United States. The first is known as the flash process, the second as the holder or holding process, and the third as pasteurization in the bottle.

The flash process consists in heating the milk rapidly, then cooling it quickly. In this process the milk is heated for 30 seconds to 1 minute only, usually at a temperature of 160° F. or above. This method does not comply with the usual time and temperature definition of "pasteurization." Most cities prohibit its use in the pasteurization of milk.

By the holder process the milk is heated to temperatures of from 142° to 145° F. and held for approximately 30 minutes, after which it is cooled rapidly. Sometimes the milk, instead of being held at a certain temperature in one tank for 30 minutes, is merely retarded in its passage through several tanks, or other retarding device, so that the theoretical length of time required for the milk to pass through is about 30 minutes. In such cases, however, there is not always assurance that all the milk is held for the desired time.

A study of 404 municipal ordinances, made in 1928 (Table 5), shows that cities in the population groups from 50,000 up to and including 500,000 and over are very uniform in their requirements for pasteurization. The temperature requirements range from 140° to 145° F., with the majority of the cities using 142°. The lengths of time for which the milk is required to be held at these temperatures are even more uniform, with 97 of the 99 cities studied requiring 30 minutes. The cities in the groups 10,000 and less, 10,000 to 25,000, and 25,000 to 50,000 show more variation in temperature and length of time required. However, disregarding the cities in these groups that have no requirements, nearly half of the others require a temperature of 142° and the greater number require 30 minutes as the time of holding.

Results of studies made upon continuous-flow holders, both under actual commercial conditions and in the laboratory, indicate that careful qualitative bacteriological analysis should be made of the milk pasteurized by this method. It must be remembered that a low-count milk is not always a safe milk. If an apparatus is used which produces a low-count milk but which does not hold every particle of milk at pasteurization temperature for at least 30 minutes, such apparatus should be viewed with distrust, for the safety factor is not assured. In many instances the actual flow through the machine does not coincide with the theoretical flow. The holder process has almost entirely replaced the flash process, and is the one most used in the United States.

Pasteurization in the bottle was developed several years ago, but has not come into general use. Under this system the bottles of milk, usually in the cases, are placed in a compartment where the milk is heated to the required temperature, and then held and cooled. By some types of bottle pasteurization the bottles of milk are removed from the cases and then conveyed slowly through the machine, being heated at the beginning and cooled at the end of the process. The heating is usually accomplished by passing sprays of hot water over the bottles or by immersing them in tanks filled with water of temperature high enough to heat the contents to the pasteurization temperature. Either a special water-tight cap is used or the bottles are covered with a specially constructed pan in which there are small holes through which the hot water passes and forms a thin film around the bottles. The advantage of this process lies in the fact that the milk, after being heated, is not exposed until it reaches the consumer, and any danger of contamination through handling is therefore eliminated. However, the cost of pasteurizing under this system is greater than that of bulk pasteurization, for steam and refrigeration are required to heat and cool the bottles and cases as well as the milk. Furthermore, extra space and more handling are necessary.

TABLE 5.—*Municipal pasteurization requirements for market milk in cities in various population groups*

Number and population of cities, and time required for pasteurization	Temperature (°F.)																Cities having no requirements
	140°	142°	143°	144°	145°	148°	150°	152°	155°	157°	158°	160°	165°	170°	175°	176°	
11 cities of 500,000 and over:																	*Number*
Requirements ... number	3	7			1												
Average ... minutes	30	30			30												
Maximum ... do	30	30			30												
Minimum ... do	30	30			30												
43 cities of 100,000 to 500,000:																	
Requirements ... number	4	26	2		9												2
Average ... minutes	30	30	30		30												
Maximum ... do	30	30	30		30												
Minimum ... do	30	30	30		30												
14 cities of 75,000 to 100,000:																	
Requirements ... number	2	6	1		3												2
Average ... minutes	25	30	30		30												
Maximum ... do	30	30	30		30												
Minimum ... do	20	30	30		30												
31 cities of 50,000 to 75,000:																	
Requirements ... number	4	14		1	9									1			3
Average ... minutes	27.5	30		30	28.8									[1]			
Maximum ... do	30	30		30	30									[1]			
Minimum ... do	20	30		30	20									[1]			
74 cities of 25,000 to 50,000:																	
Requirements ... number	10	38	1	1	15		1		1	1		1	2		1		10
Average ... minutes	28.5	30	30	30	28.6		15		5	20		5	.75		[1]		
Maximum ... do	30	30	30	30	30		15		5	20		5	1		[1]		
Minimum ... do	20	30	30	30	20		15		5	20		5	.5		[1]		
128 cities of 10,000 to 25,000:																	
Requirements ... number	19	36	4	1	26	1	2	1	2		1	1	1			1	42
Average ... minutes	27.89	30	30	30	29.42	15	20	10	10		3	10	.5			[1]	
Maximum ... do	30	30	30	30	30	15	20	10	15		3	10	.5			[1]	
Minimum ... do	20	30	30	30	20	15	20	10	5		3	10	.5			[1]	
104 cities of 10,000 and less:																	
Requirements ... number	9	22	1	2	25								1				45
Average ... minutes	30	30	30	30	29.2								.5				
Maximum ... do	30	30	30	30	30								.5				
Minimum ... do	30	30	30	30	20								.5				

NOTE.—Several cities have 2 or more optional requirements.

[1] Flash.

ADVANTAGES OF LOW-TEMPERATURE PASTEURIZATION

In general, the trend of pasteurization has been toward the holder process, and with this tendency the use of lower temperature has become more common. As a general rule, when the holder process is used the milk is heated to not less than 142° F. for 30 minutes. From bacteriological, chemical, and economic standpoints, the present consensus is that pasteurization can be satisfactorily accomplished with a temperature as low as 142°.

From a bacteriological standpoint, pasteurization at 142° F. for 30 minutes is believed to kill all nonspore-forming disease-producing bacteria, and at the same time leave in the pasteurized milk the maximum percentage of the bacteria that cause milk to sour (lactic-acid bacteria) and only a small percentage of those that cause it to decompose (peptonizers). When higher temperatures are used the total number of all kinds of bacteria is reduced, but the percentage of lactic-acid bacteria becomes less and less and the peptonizing group increases until at 180° or above, the lactic-acid bacteria are practically all destroyed and most of the bacteria left belong to the peptonizing group. The heat-resistant lactic-acid bacteria which survive pasteurization at 142° for 30 minutes play an important rôle in the souring of commercially pasteurized milk.

From a chemical standpoint, the advantage of the lower temperature is that milk pasteurized at 142° F. for 30 minutes does not undergo any appreciable change affecting its nutritive value or digestibility. According to Rupp (*50*) the soluble phosphates of lime and magnesia do not become insoluble and the albumin does not coagulate. At 150° about 5 per cent of the albumin is rendered insoluble, and the percentage increases with higher temperatures up to 160°, when about 30 per cent of the albumin is coagulated. The heating period in Rupp's experiments was 30 minutes.

From an economic standpoint the advantage of pasteurization at low temperatures is the saving in the cost of heating and cooling the milk. Bowen (*15*) has shown that the flash process requires approximately 17 per cent more heat than the holder process. Also there is a correspondingly wider range through which the milk must be cooled, which also adds to the cost. This is because of the fact that in the holder process milk may be heated to 142° F. and held for 30 minutes, whereas to obtain the same bacteriological reduction with the flash process, with 1-minute heating, the milk would have to be heated to 165°, and even then it is doubtful whether all the disease-producing bacteria would be killed.

TEMPERATURES AND METHODS MOST SUITABLE FOR PASTEURIZING

It has been found that heating milk at 140° for 30 minutes will kill pathogenic bacteria, provided all the milk is heated to that point and held for the full length of time. But it has been shown by Schorer and Rosenau (*52, p. 157*) that it is difficult to do this under commercial conditions. These investigators inoculated milk with *Bacillus diphtheriae*, *B. typhi*, and *B. tuberculosis* and pasteurized it in 100-gallon lots under commercial conditions. They found that sometimes not all of the organisms were killed, and in this connection state:

> Nothing in our experiments throws doubt upon the thermal death points of the microörganisms tested. We are sure that if the milk reaches 140° F. and is held

there for twenty minutes it will kill tubercle, typhoid, and diphtheria bacilli. Our experiments show that milk pasteurized at this temperature for the specific time may not always, in practice, reach these minimum requirements. It is therefore evident that a liberal factor of safety is necessary in the operation of this type of pasteurizer under commercial conditions.

The United States Department of Agriculture advises the use of a temperature not lower than 142° F. for a period of not less than 30 minutes, for the pasteurization of milk. Besides insuring an ample margin of safety, a temperature of 142° causes a greater destruction of bacteria in milk than does 140°, when the milk is held for the same period of 30 minutes.

There is a tendency in milk plants to pasteurize as near the minimum temperature required as possible, so as not to injure the cream line. Whittaker, Clement, and others (*63*) have studied the effect of temperature on the cream line in a number of different plants throughout the country, and have come to the following conclusion:

In the case of milk heated to 143° F. for 30 minutes there was practically no decrease in cream volume, and in some cases an increase resulted. Heating at 145° to 146° for 30 minutes reduced the cream volume an average of approximately 8 per cent, with considerable variations above and below. Heating at approximately 148° for 30 minutes caused a decrease in cream volume of 18.5 to 41.7 per cent, with an average decrease of approximately 31 per cent.

The method of pasteurization, whether it is the holder or in-the-bottle process, is not so important, provided the process is such that the milk is heated to a temperature not lower than 142° and that all of it is held for not less than 30 minutes at that temperature.

Marcussen (*46, p. 62–63*) also presents the following conclusions:

1. The temperature of pasteurization exerts an influence on the quantity of cream present on pasteurized milk.
2. The quantity of cream present on milk pasteurized at 145 degrees F. is always less than the quantity of cream present on the same milk when pasteurized at 142 degrees F.
3. The average volume of cream on milk pasteurized at 145 degrees F. was 13.325 per cent less than the average volume of cream on the same milk pasteurized at 142 degrees F.

Erb (*21*) states that agitation of either raw or pasteurized milk at temperatures between 42° and 100° or 105° reduced the cream layer from 2 to 3 per cent of the volume of the milk, while agitation at temperatures from 100° or 105° to 144° had no effect on the cream layer.

Trout (*59*) reports that heating milk at 145° for 30 minutes decreased the creaming ability of milk from 9 to 16 per cent, depending upon the temperature of creaming.

Dahlberg and Marquardt (*18*) state that there is no known method of restoring the creaming properties of milk which has been heated above 145° for 30 minutes or momentarily to temperatures in excess of 165°.

SUPERVISION OF THE PROCESS

Supervision of the pasteurizing process is absolutely necessary, but it can not be fully effective unless the supervisor has a thorough knowledge of the primary object of pasteurization and the bacteriological principles involved.

The primary object is to kill any disease-producing bacteria which may be in the milk, and to handle the pasteurized milk in such manner that it will not be infected before bottling. Pasteurization at a temperature not lower than 142° F. maintained for a period of 30 minutes kills a large percentage of the bacteria in the milk and the keeping quality of the milk is greatly improved. The milk after being heated should be immediately cooled, bottled, mechanically capped, and placed in a refrigerator the temperature of which should never exceed 50°. All coolers, bottlers, bottles, and other milk-contact surfaces must be thoroughly cleaned and treated to kill bacteria.

This process seems relatively simple, yet problems that may defeat the primary object are encountered at every step.

First of all, bacteria are distributed in the air of the milk plant, upon the equipment with which milk comes in contact, and upon the hands of employees. Also, flies carry millions of bacteria.

When milk comes to the plant to be pasteurized the logical thing to do is to permit it to come in contact only with apparatus which has been thoroughly cleaned and thoroughly steamed or treated to kill bacteria. As bacteria can not be seen with the naked eye, a tank or pipe that is apparently clean may contain many millions. As many of the bacteria as possible must be killed. To do this steam is usually employed, for heat at 200° F. or above, applied for a period of 5 minutes, will kill disease-producing bacteria and all but the spores of the harmless types. Equipment must be visibly clean before treating to kill bacteria if the results are to be satisfactory.

The United States Department of Agriculture recommends that the following points in the pasteurizing process be carefully looked after: (1) Heat all milk to a temperature not lower than 142° F., and hold at this temperature for not less than 30 minutes. (2) Watch for leaking valves. (3) Avoid exposed outlet pipes, valves, and pipe lines which hold milk below the pasteurization temperature. (4) Use accurate recording thermometers, with the chart spaced in single degrees throughout the pasteurization range. Check these frequently against a standard thermometer of unquestionable accuracy. (5) Take temperatures near the bottom of the pasteurizer. (6) Watch for foam on the milk, and do not let foam remain in the vat.

It is of the greatest importance that the hands of milk handlers do not touch the pasteurized milk, the apparatus, the bottles or the caps, after these have been treated to kill bacteria. The hands are perhaps the most dangerous source of reinfection in the plant, for through such means milk may be contaminated by persons who are carriers of disease. In order to guard against such possibilities, all employees who handle apparatus or milk in the plant or during delivery should undergo frequent medical examination, and any diseased persons or carriers of disease should be prevented from working where they are even in indirect contact with milk or milk equipment, either in the plant or on the delivery route.

It is perhaps unnecessary to say that flies are also a very serious menace to the milk supply. They must be kept out of milk plants, for it is impossible to tell when they may infect the milk. Such infection can occur directly through flies getting into the milk, or indirectly through contamination of equipment or containers.

HANDLING OF MILK AFTER PASTEURIZATION

Although pasteurization kills all pathogenic bacteria some harmless organisms remain. On account of this fact pasteurized milk is still a perishable product, and must be handled with the same care as raw milk. This is a point for both the consumer and the milkman to remember.

After pasteurization milk should be cooled to from 33° to 40° F. and kept at that temperature until delivery. In warm weather it should be iced on the delivery wagons. From a sanitary standpoint all milk, whether raw or pasteurized, should be delivered without delay, in order that the consumer may get it in the best condition. In milk held at about 40° there is only a slight bacterial increase during the first 24 hours. Pasteurization and delivery can be so arranged that the consumer gets the milk before any appreciable change has taken place in the bacterial content.

COST OF PASTEURIZING MILK

The cost of pasteurization in 1922 was estimated by Bowen from the cost given in his earlier paper (*15*). He obtained information in five establishments which were considered to represent the average city milk plant. The pasteurizing equipment in each plant consisted of a heater, a holding tank, a regenerator, and a cooler. The cost of operation was based on the pasteurizing cycle, starting with the initial temperature of the raw milk and raising it to the pasteurizing temperature, then cooling to the initial temperature of the raw milk. Bowen based the costs on interest at 6 per cent per annum on capital invested in all equipment used in the pasteurizing process. He allowed 25 per cent per annum for depreciation and repairs on the pasteurizing equipment proper, and 10 per cent on other mechanical equipment, such as engines, boilers, etc. Other costs figured were labor; coal, estimated at $8.16 a ton; cooling water, estimated at $0.75 per 1,000 cubic feet; and refrigeration, estimated at $2 a ton. With later estimates substituted for his older figures, Bowen calculated that the average cost of pasteurizing 1 gallon of milk was approximately $0.0049, or a little less than one-half cent.

BACTERIA THAT SURVIVE PASTEURIZATION

About 1 per cent of the bacteria in the milk remain alive after pasteurization, and the kinds left depend entirely on the temperature to which the milk was heated and the number of heat-resistant bacteria in the milk. From studies of the bacteria which survive pasteurization, it is possible to show graphically the hypothetical relations of the bacterial groups in raw milk and in milk pasteurized by the holder process at various temperatures under laboratory conditions (*3*, *4*).

The bacterial flora of the various kinds of milk is represented in Figure 1 by columns of equal length divided into sections, which, in a general way, show the relative proportions of the bacterial groups.

From the illustration it may seen that raw milk contains four principal groups of bacteria—the acid, inert, alkali, and peptonizing. The acid group is divided into two types—the acid-coagulating, which produces sufficient acid to curdle the milk in 14 days; and a type which produces acid more slowly and does not curdle the milk in 14 days. In raw milk the inert group is the larger.

In milk heated at 145° F. the great increase in the proportion of the acid-coagulating and acid groups, in comparison with that of

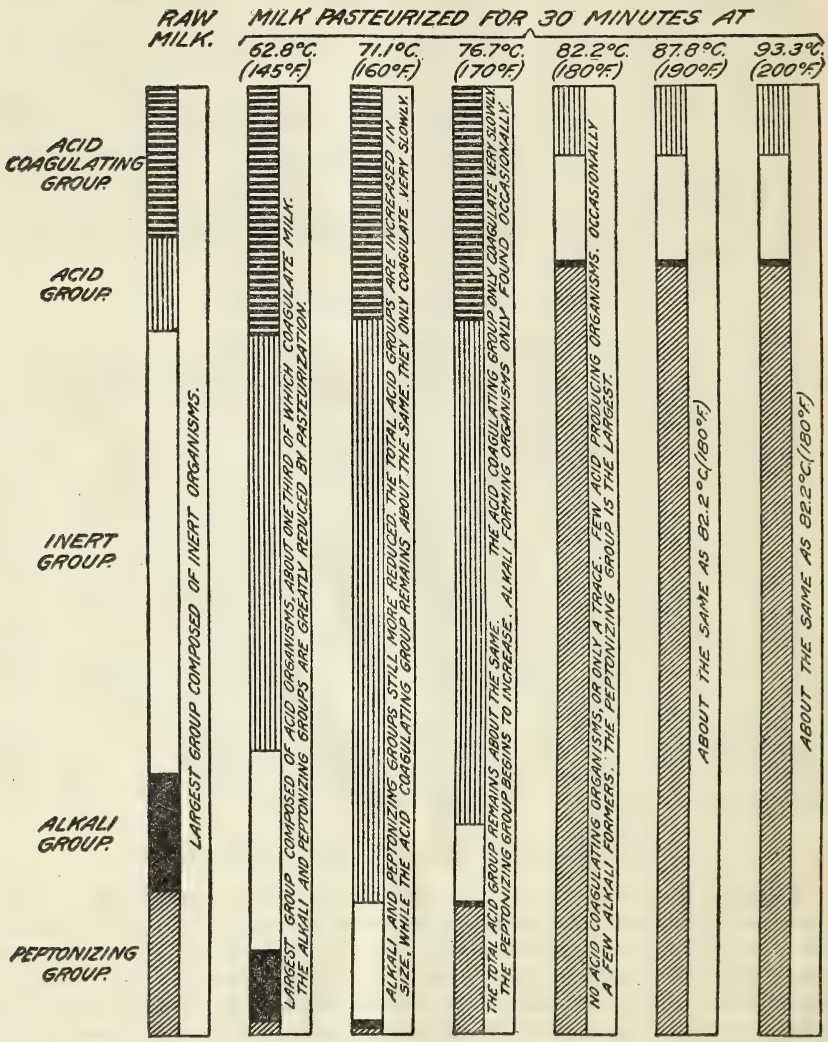

FIGURE 1.—The hypothetical relationship between the various groups of bacteria in raw milk and in milk pasteurized at different temperatures

the same organisms in raw milk, is plainly shown; and the proportion of the alkali and peptonizing groups is reduced.

At 160° the total acid group is still the largest, but the acid-coagulating group is made up of bacteria which cause coagulation very slowly. At this temperature the alkali group is greatly reduced, and the peptonizing group is reduced to a minimum.

At 170° F. the total acid group remains about the same, but the organisms produce acid and coagulate the milk very slowly. The alkali group is practically destroyed, although occasionally a sample may show a fairly high percentage. The most important change is in the peptonizing group. At this temperature the ratio of this group to the total number of bacteria begins to increase.

The increase when milk is heated at 180° F. is even more striking. At this temperature more than 75 per cent of the bacteria which survive are peptonizers. No organisms of the acid-coagulating group are found, and only a small percentage of the acid group. Occasionally a few of the alkali group may be found.

At 190° and 200° F. the bacterial groups which survive are about the same in their relative sizes as at 180°.

It is very evident that when the bacterial flora of pasteurized milk is under discussion the temperature of the process is of fundamental importance. In Figure 1 the proportions of the bacterial groups left in milk heated at different temperatures may be seen at a glance. It must be borne in mind, however, that the relations of the bacterial groups represent only average conditions and that the bacterial flora of every sample of milk must not be expected to conform exactly to these averages. Variations in methods and conditions in the production of milk may influence considerably the bacterial group relations of an individual sample.

The results in Figure 1 may perhaps be better explained in popular terms. When milk is pasteurized at 142° F. for 30 minutes, most of the bacteria (lactic-acid) left alive in it are of the kind which cause it to sour, and there are present only a few bacteria (peptonizing) which cause it to decompose. As the milk stands, the acid formers grow and cause the milk to sour instead of decompose. However, when milk is heated at 180° for 30 minutes, the bacteria (lactic-acid) which cause the souring of milk are practically all killed, and those which are alive (peptonizing) continue to grow and cause the milk to decompose.

Not only do certain types of lactic-acid bacteria survive pasteurization, but some also grow at or near the pasteurizing temperature. These are known as thermophilic bacteria and according to Robertson (*48*) grow best between 55° and 75° C. (131° and 167° F.). Sometimes upon long-continued heating at 140° to 145° F. for several hours, milk sours in the holding tanks because of the growth of these organisms. The ordinary period of holding does not provide sufficient time for their development, so this type of souring is not encountered in milk plants except when there is an interruption in the pasteurizing process caused by some abnormal condition.

Pasteurizing plants, however, frequently experience considerable trouble with thermophiles or bacteria causing "pin-point colonies" in the pasteurized milk. Yale and Breed (*65, p. 1198*) came to the following conclusion:

> Faulty plant operations proved to be more important factors in the development of thermophilic bacteria than the type of pasteurizing equipment.

Hammer and Trout (*32, p. 23*) state:

> On plates poured with dairy products, especially those that had been subjected to heat, there were often yellow colonies of cocci. In general these organisms resisted the usual pasteurization exposures for market milk * * *.

SURVIVAL OF STREPTOCOCCI

The general groups of bacteria that survive pasteurization have been discussed. A more specific group will now be considered. It has been the custom of some authorities to consider the presence of streptococci in pasteurized milk to be an indication of ineffectiveness in the process. As already pointed out, pathogenic streptococci are readily destroyed by proper pasteurization. In a study of the subject (*5*) it was found that certain strains of streptococci are able to survive pasteurizing temperatures.

The thermal death points of 139 cultures of streptococci isolated from cow feces, from the udder and mouth, and from milk and cream, showed a wide variation when the milk was heated for 30 minutes under conditions similar to pasteurization. At 140° F., 89 cultures, or 64.03 per cent, survived; at 145°, 46, or 33.07 per cent, survived; and at 160°, 3 cultures, or 2.16 per cent, survived; and all these were killed at 165°. The streptococci from the udder were, on the whole, less resistant and those from milk and cream more resistant to heat than those from the mouths and feces of the cows.

Two classes of streptococci seem to survive pasteurization: (1) Streptococci which have a low majority thermal death point (the temperature at which a majority of the bacteria are killed), but among which a few cells are able to survive the pasteurizing temperature. This ability of a few bacteria to survive may be due to certain resistance peculiar to them or it may be due to some protective influence in the milk. (2) Streptococci which have a high majority thermal death point, and which, when such is the case, survive because this point is above the temperature of pasteurization. This ability to resist destruction by heating is a permanent characteristic of certain strains of streptococci.

These streptococci which have a high thermal death point above the pasteurizing temperature undoubtedly play an important part in the occasional high counts found in pasteurized milk. Such counts are sometimes observed when the count of the raw milk runs the same as usual. As the proportion of these heat-resistant types varies in milk, their numbers may at times reach such figures that their survival through the pasteurizing process gives an abnormally high-count product. The presence and variation of their numbers in milk, therefore, are matters which must be considered in connection with bacterial standards for pasteurized milk.

It is evident that certain varieties of streptococci are able to survive pasteurization, while others probably are always killed. It has been found that the streptococci causing septic sore throat are killed by pasteurization at 142° F. for 30 minutes.

These results, together with the protection which proper pasteurization affords against epidemics of that disease due to milk supplies, indicate that the varieties of streptococci associated with or responsible for septic sore throat are among the varieties which have a low thermal death point.

THE COLON TEST FOR EFFECTIVENESS OF PASTEURIZATION

In a study (*7*) of the ability of colon bacilli to survive pasteurization it was found that certain strains could survive heating at 145° F. for 30 minutes. On examining 174 cultures of colon bacilli it was found that at 140°, the lowest temperature used, 95 cultures survived; at 145°, 12 survived. In each case the heating period was 30 minutes.

De Jong and De Graff (*40*) also describe seven strains of *Escherichia coli* which survived 149° to 152.6° F. for 30 minutes in milk. They concluded from their results that the presence of *E. coli* in pasteurized milk could not be taken as indicating improper pasteurization. Gage and Stoughton (*26*) showed that the majority of thermal death points of *E. coli* were from 132° to 140°. The temperature at absolute death point showed the presence of heat-resistant organisms in this group. Zelenski (*66*) also found a strain of *E. coli* which survived unusually high temperatures, while Tanner (*56*) states that in view of the results he obtained, it seems fair to assume that *E. coli* in concentrations in which it occurs in milk, would be destroyed by exposure to 62.8° C. for 30 minutes, yet there is the possibility of encountering resistant strains or cultures containing some resistant cells.

Beavens (*11, p. 100*) states:

> Reviewing the experimental evidence and the possible biological factors present in pasteurization, the statement can be made that organisms of the Escherichia-Aerobacter group may survive in milk that has been properly pasteurized. Therefore, the coli test can not be used as a true index of proper pasteurization.

This statement opposes the findings of Swenarton (*55*) and Jenkins (*39*) but confirms those of De Jong and De Graff (*40*), Ayers and Johnson (*7*), Shippen (*53*), and Hammer (*31*).

The colon test as an index of the effectiveness of the process of pasteurization is therefore complicated by the ability of certain strains to survive a temperature as high as 142° F. for 30 minutes and to develop rapidly when the pastuerized milk is held under certain temperature conditions met during storage and delivery. Consequently the presence of a few colon bacilli in pasteurized milk under ordinary market conditions does not necessarily indicate that the milk was not properly heated. The presence of a large number of colon bacilli immediately after the heating process indicates that the milk has not been heated to 142° for 30 minutes, and the colon test, properly applied, should be valuable in control work. Fermentation tubes can be used for making the test, but when gas formation is noted the presence of colon bacilli should be demonstrated by further tests. Often anaerobic spore formers that survive pasteurization and give the typical fermentation-tube test are encountered.

PASTEURIZATION AND VITAMINS

The discovery of vitamins within recent years has shown how impossible it is to estimate nutritive requirements solely in terms of digestible protein, carbohydrates, fat, and inorganic salts. Little is known of the real chemical nature of vitamins, but they are necessary for normal growth and health.

Six vitamins are now recognized (*54*). They are known as vitamin A (soluble in fat); vitamin B or B_1 (soluble in water), often called the antineuritic vitamin; vitamin G or B_2 (soluble in water), the antipellagric vitamin; vitamin C (soluble in water), the antiscorbutic; vitamin D (soluble in fat), the antirachitic; and vitamin E (soluble in fat), the antisterility vitamin. Vitamins A and G are abundant in milk, while vitamin B and vitamin C are present in small quantities only. Vitamins D and E do not occur in milk in sufficient quantities to make it an important source of these vitamins.

Fat-soluble vitamin A, and vitamin G have been found to be quite resistant to heat, and pasteurization has little or no effect upon them. The antiscorbutic vitamin C, and vitamin B, are sensitive to heat. Although the destruction of these vitamins depends upon the temperature and length and condition of heating, as well as upon the reaction of the material in which they exist, there seems little doubt that pasteurization of milk at a temperature of 142° F. for 30 minutes destroys some of these vitamins.

Hess and Fish (*37*), studying scurvy in children in 1914, found that some cases of scurvy developed when milk which had been pasteurized at 145° F. for 30 minutes was used.

After further studies on this subject Hess (*36*) made the following statement:

> Although pasteurized milk is to be recommended on account of the security which it affords against infection, we should realize that it is an incomplete food. Unless antiscorbutics, such as orange juice, the juice of an orange peel, or potato water is added, infants will develop scurvy on this diet.

PASTEURIZED MILK FOR INFANTS

A rational view of the use of pasteurized milk must be taken. Shall the protection against infection afforded by the pasteurization of general milk supplies be discarded because pasteurized milk is deficient in antiscorbutic and antineuritic properties, or shall the protection be accepted and the deficiency in vitamins C and B be made up by feeding orange juice and other foods?

As Eddy (*20*) says, there are two points to be kept in mind in infant nutrition. The first is that the vitamin content of cow or human milk depends primarily upon the vitamin content of the food eaten by the producer of the milk. He further states that cereals are poor in vitamins and green grasses are rich in them, and that this brings up the question of winter feeding, if the milk supply is used for infants. He suggests further that the variability of the vitamins A and B content in milk may at times make it necessary to supplement the diet.

The second point brought out by Eddy expresses what appears to be the most reasonable attitude toward the use of pasteurized milk for infant feeding according to our present knowledge of vitamins, and it is therefore quoted:

> The second point in regard to milk lies in the effect of pasteurization. This measure is now well-nigh universal and in America at least has played a tremendous part in the reduction of infant mortality, especially in the summer months. At present, however, we know that this treatment, while removing dangerous germs, may also eliminate the antiscorbutic factor. The sensible attitude then is to recognize this fact and if a clean whole milk is not available, retain the pasteurization and meet the vitamin deficiency by other agents. Such agents are orange juice and tomato juice, and experience has already shown that these juices can be well tolerated by infants much earlier than used to be thought possible.

It seems, therefore, that the only serious effect of pasteurization on the vitamins is on the antiscorbutic vitamin C and the antineuritic vitamin B, and it is evident that the feeding of orange and tomato juice, or other foods rich in these vitamins, readily makes up for the deficiency of these vitamins in pasteurized milk.

THE NECESSITY FOR PASTEURIZATION

As stated under Value of Pasteurization, there have been reported in the United States numerous epidemics of septic sore throat, typhoid fever, scarlet fever, and diphtheria, traceable to milk. Investigators have shown that the thermal death point of pathogenic bacteria is relatively low, and that where epidemics have been due to milk, efficient pasteurization was effective in controlling the spread of the epidemic through the agency of milk.

The problem of pasteurization is not simply the question of which is preferable, raw or pasteurized milk, but rather, what is the most economical and practical way of producing and safeguarding a city's milk supply.

In connection with the possibility of transmission of disease through the agency of milk, the following fundamental facts must be recognized:

(1) Certain diseases transmitted to man, such as tuberculosis and undulant fever, may come from diseased animals. The danger from this source can be minimized by the elimination of infected cattle from producing herds on the basis of tests devised for the purpose.

(2) Freeing herds from infected cattle offers no protection against other diseases, such as typhoid fever, diphtheria, and septic sore throat, because the pathogenic organisms causing these diseases may come from infected water supplies or from human carriers of disease.

It is manifestly impossible to examine medically all persons engaged in producing and handling milk. Yet such examinations at frequent intervals would be necessary, together with tests for the health of cattle, and the assurance of unpolluted water supplies on every farm in order to safeguard the general milk supply of the Nation to the same extent that is now possible through proper pasteurization. The appreciation of the need for pasteurization is distinctly shown by the marked increase in the use of pasteurization in the United States.

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