A COMPARISON OF COOLING PERFORMANCES OF FARM BULK MILK TANKS[1] [2]

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Milk temperatures in 35 ice-bank and 23 direct-expansion (58 total) farm bulk milk tanks of atmospheric design were measured during the summers of 1958 and 1960. Additional information was obtained by a questionnaire.

Cooling requirements specified in 3-A Sanitary Standards were used as the basis for determining performance. Twenty-two percent of the DE tanks failed during the first milking to properly cool the milk to 40°F, and 26% failed during the second milking. IB tanks had 34% fail for the first milking and 17% for the second milking.

For the second milking 35% of the DE tanks permitted the milk to exceed a 50°F blend temperature. The average time above 50°F was 45 minutes. IB tanks had 23% fail to meet this requirement for an average time of 20 minutes. About 75% of the producers poured milk into the tanks in quantities of 3 to 5 gallons. Average milk temperature rise was 11°F for both types of tanks.

Maximum stratification temperatures for the DE tanks averaged 2.6°F and for the IB tank 3.2°F. The stratification temperature patterns were different for the two types of tanks.

Some of the faulty tanks were rechecked in 1960. Mechanical and refrigeration problems along with operator neglect were responsible for most of the tanks not cooling to 40°F in the specified time.

When loadings are heavy and air temperatures are high, second-milking blend temperatures will exceed 50°F in many farm tanks as they are now designed and operated. Faster rates of milking will also tend to cause high blend temperatures.

A systematic routine check of all tanks would reduce considerably the numbers not meeting 3-A Standards. An inspection system should involve the hauler, fieldman, sanitarian, tank dealer, and the producer.

Reports that some bulk milk tanks were not meeting recognized standards of cooling led to a study of the performances of bulk milk tanks on farms with representatives of the Iowa State Department of Health, U. S. Department of Agriculture, and Iowa State University cooperating. During the summers of 1958 and 1960, eight milk sanitarians located in seven different areas of Iowa with the assistance of milk plant fieldmen metered milk temperatures in 58 tanks of the atmospheric type. Some of the information obtained will be presented in this paper.

PROCEDURE AND INSTRUMENTATION

Temperatures were measured and recorded with 16-point recorders. Sensing elements were 24 AWG copper-constantan thermocouples housed in low-thermal conductivity rods.

The thermocouple junctions were located just below the surface of the rod. Fifteen 2-in spacings of junctions were used with the bottom junction one-eighth inch from the end of the rod. Components for one of the two instrumentation sets are shown in Figure 1.

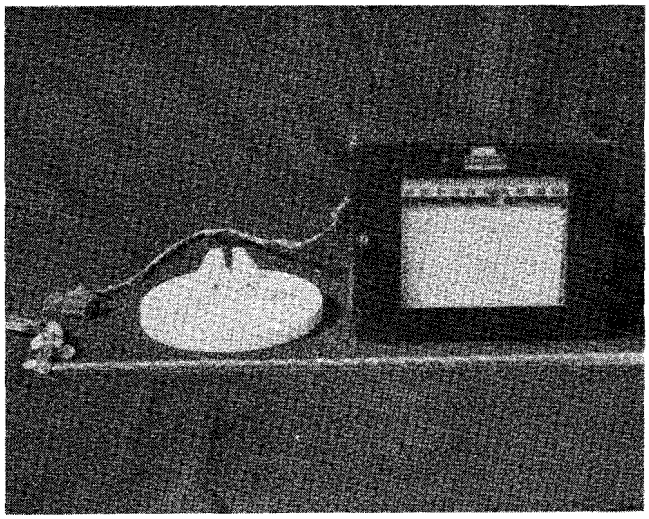

Figure 1. Thermocouple rod and rod clamp shown with recording instrument.

Milk temperatures in each tank were metered for 48-hour periods between May 15 and September 15, 1958, and August 1 and September 1, 1960. There were two exceptions in which the temperature was recorded through only three rather than four milkings. A tank with the temperature-measuring equipment in place is shown in Figure 2.

[1]Presented at the 47th Annual Meeting of the International Association of Milk and Food Sanitarians, Inc., Oct. 26-29, 1960 at Chicago, Illinois.

[2]Journal Paper J-3997, Iowa Agricultural and Home Economics

TABLE 1—DESCRIPTION AND OPERATING CHARACTERISTICS OF THE TANKS STUDIED-IOWA 1958

Brand	Number of tanks	Average tank capacity (gal)	Average capacity at pickup %	Average compressor motor size (hp)	Maximum quantity per milking EOD[a] (gal)	Hp. per 50 gal cooled per milking	Type of condenser cooling[b]
			DIRECT EXPANSION				
A	9	292	68	1.67	73	1.15	5-A 3-A & W 1-W
B	9	248	84	2.11	62	1.70	8-A 1-A & W
C	5	400	60	2.00	100	1.00	1-A & W 1-W
	23						
Average		298	73	1.91	75	1.27	
			ICE BANK				
D	16	312	80	1.03	78	0.66	16-A
E	10	335	75	1.25	84	0.74	4-A
F	5	355	57	1.20	89	0.67	10-A
G	4	345	75	1.06	86	0.62	4-A
	35						
Average		331	75	1.04	83	0.63	

[a]EOD=Every other day. [b]A=air; A & W=air and water; W=water

When installing the thermocouple rod in the tank cover, a fill opening was selected opposite to the end usually used by the farmer for pouring milk, or receiving milk from the pipelines. These cover openings were invariably located off the center line of the tank. Therefore, the thermocouple rod was never located over the lowest part of any tank. Permitting the rod to slope to the center line of the tank was inadvisable considering the locations of many agitators. The rod in its vertical position was permitted, however, to touch the bottom of the tank in all cases.

Thermocouple temperatures were recorded at the rate of one per 30 seconds. Any given thermocouple of the 16 had its temperature recorded once every 8 minutes. Therefore, the temperatures recorded are not necessarily the highest or lowest milk temperatures at the thermocouple locations.

Pouring of warm milk near the rod about the time the temperature of a thermocouple was being recorded could give a higher than normal temperature reading for that 8-minute period. Any temperature maintained at about the same level for several periods, however, was considered as a representative temperature.

To represent the cooling performances of the tanks with curves having a reasonable number of points, one location per tank was plotted at 32-minute intervals from the start of milking. As the lowest thermocouple, 1/8 inch from the bottom of the rod, was influenced by the evaporator temperatures on tanks, the next thermocouple, located 2 1/8 inches from the bottom, was selected as the one sensing the coldest milk temperatures.

DATA ON THE TANKS

Descriptions and operating characteristics of the seven different brands of tanks studied are shown in Table 1. Three of the brands were of the DE (direct expansion) and four of the IB (ice bank) types.

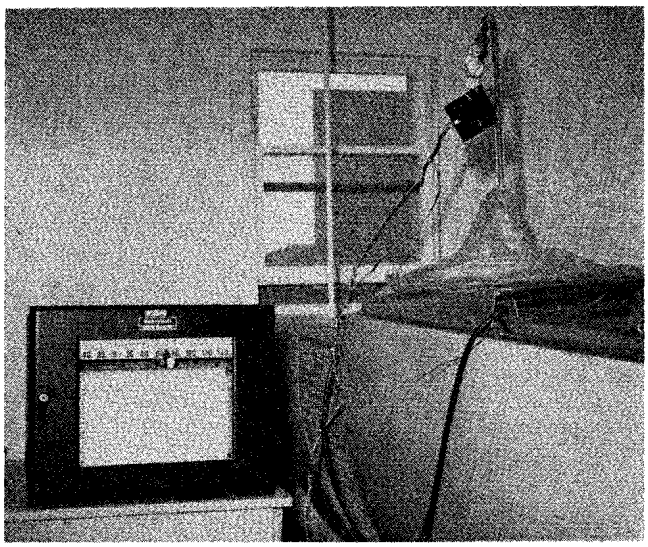

Figure 2. A bulk milk tank with instrumentation equipment in place.

The average DE tank had a capacity of 298 gallons, was filled to 73% capacity with four milkings, and had a compressor motor calculated to be 1.91 hp. Condensers on 13 of the 23 tanks were air-cooled, 8 were air-and-water-cooled, and 2 were water-cooled.

The average tank capacity of the IB group was 331 gallons. It was filled to 75% of its maximum capacity at the end of four milkings. The compressor motor size was 1.04 hp. All 34 tanks had air-cooled condensers.

COOLING PERFORMANCE—1958

The cooling performances for the first and second milkings of the seven brands studied are represented in Figures 3 through 9. The solid line of each figure represents the performance of the average tank. The broken lines show the extreme variations in performance and do not necessarily represent the cooling rate for a particular tank.

In the following discussions on cooling performance, references will be made to "3-A Sanitary Standards for Farm Milk Cooling and Holding Tanks" *(1)* (hereafter referred to as 3-A Sanitary Standards). Included in its functional standards for cooling performances are the following:

A tank designed for every-other-day pickup shall cool 25% of the rated volume of the tank containing raw milk from 90° to 50°F within 1 hour after the tank has been filled to 25% of its rated capacity, with cooling system in operation during the filling period. The cooling system shall then cool the above volume from 50°F to 40°F within the next hour.

Second or subsqeuent milkings: The cooling systems of tanks*** shall be capable of preventing the blend temperature of the milk in the tank from rising above 50°F. **** Before the addition of the second or subsequent***milkings, the*** milk in the tank shall be cooled to 37°F.

Brand A (DE)

Figure 3 represents the cooling performances of nine brand A tanks. Three of these tanks failed to cool both the first and second milkings to 40°F within the time allowed by the 3-A Sanitary Standards. It was evident that the cut-out settings of the thermostats on these three tanks were too high. Two of the three tanks also had blend temperatures above 50°F. Two other tanks with milk temperatures between 32 and 34°F at the start of the second milking also exceeded 50°F. One of these had a water-cooled condenser and was loaded to 93% of its capacity at pickup. The other was air cooled, operating in an ambient of 84° F and was 84% loaded.

The second-milking time for the four tanks exceeding a 50°F blend temperature averaged 1 hour 4

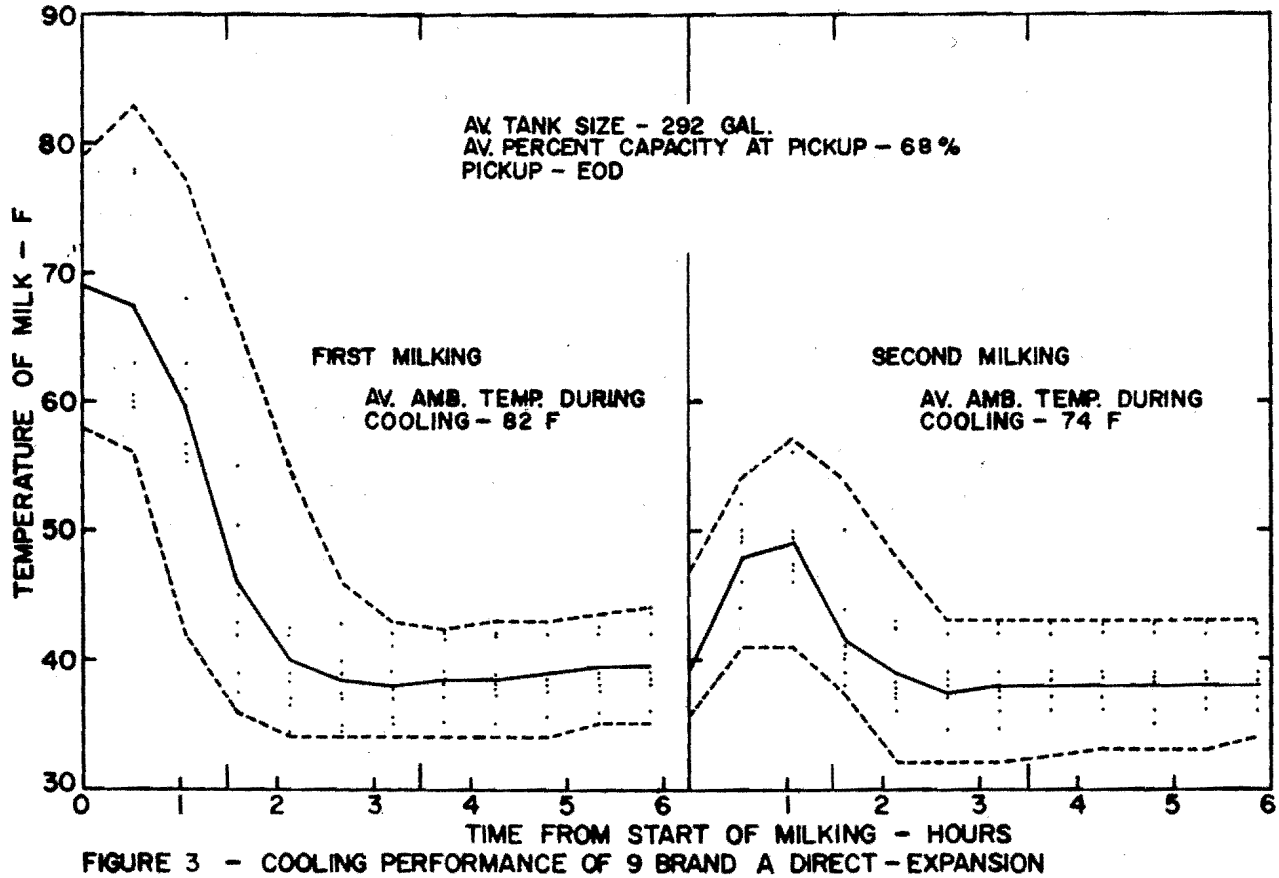

FIGURE 3 - COOLING PERFORMANCE OF 9 BRAND A DIRECT-EXPANSION BULK MILK TANKS - IOWA 1958

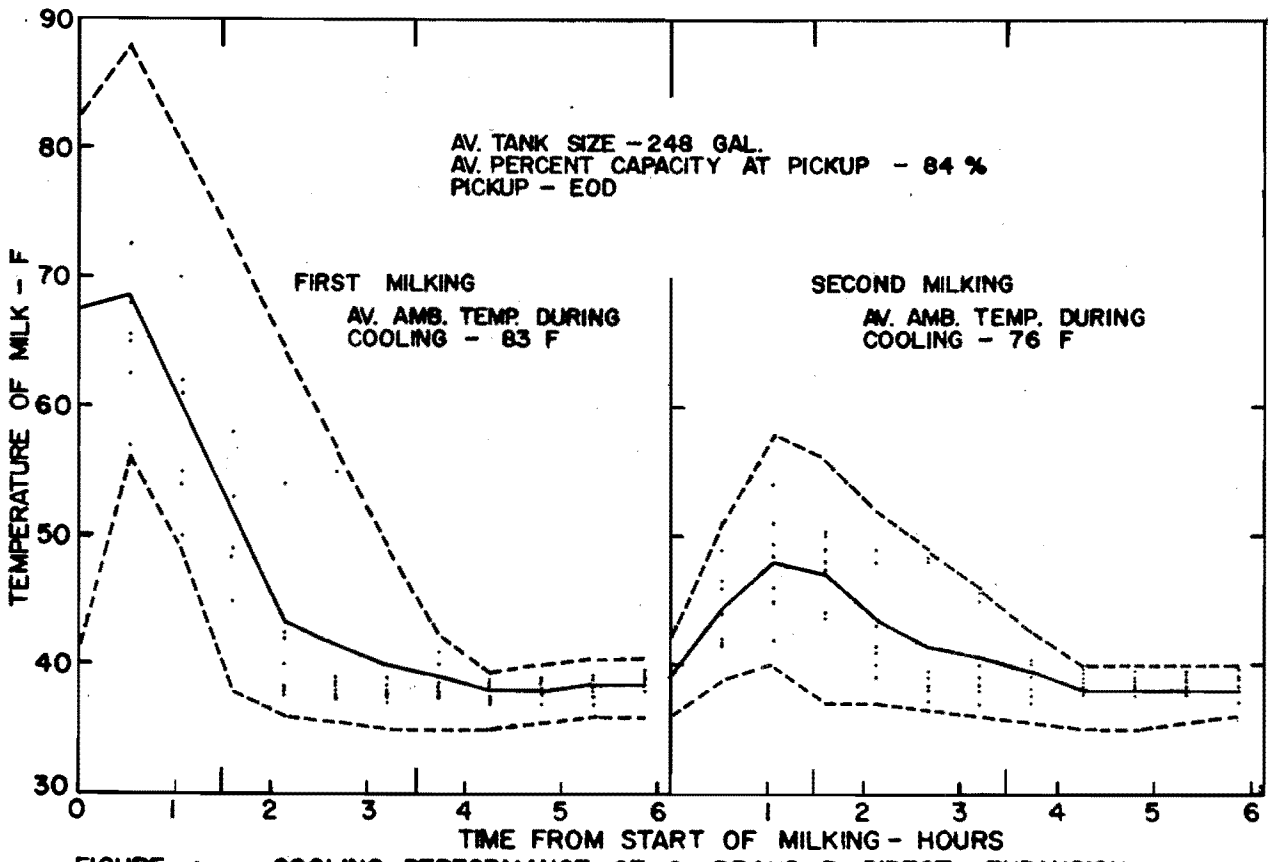

FIGURE 4 – COOLING PERFORMANCE OF 9 BRAND B DIRECT-EXPANSION BULK MILK TANKS – IOWA 1958

minutes. The average milking time for the five tanks of Brand A which did not exceed the 50°F blend temperature was 1 hour. Loadings in these latter tanks, however, averaged only 56% of capacity.

Brand B (DE)

Temperatures in nine brand B tanks are represented in the curves of Figure 4. Average second-milking time was 1 hour 15 minutes.

Two of these tanks were unable to meet 3-A Standards for cooling to 40°F for the first and second milkings and a third tank failed to meet requirements during the second milking. The shapes of the curves indicate that thermostat settings were low enough to be nonrestrictive to the cooling process. One of these tanks utilized only 64% of the tank capacity and operated during the second milking in an average ambient temperature of 75°F. The other two tanks were 80% and 93% loaded and operated in average ambients of 85°F and 80°F, respectively, for the second milkings.

Four tanks with air-cooled condensers failed to meet the 3-A Standards blend temperature requirement of 50°F. One of these was the 93% loaded tank referred to in the group that failed to meet 3-A Standards cooling time. The other three tanks were loaded to 95, 86, and 69% and were operated during the second milking in average ambient temperatures less than 70°F.

Brand C (DE)

Figure 5 represents five brand C tanks with condensers cooled as follows: three air and water; one water; and one air. Data show that three tanks had milk temperatures of 32°F and lower during both the first and second-milking periods. The reader is reminded that the location of the thermocouple from which these temperatures were taken was 2 1/8 inches from the bottom of the rod. Such low temperatures indicate that some icing of the milk occurred in these tanks.

All five tanks cooled the milk within the time periods specified by 3-A Standards. The average second-milking period was 1 hour 18 minutes. One tank operating in an average ambient temperature of 76°F permitted the blend temperature during the second milking to exceed 50°F. This 600-gallon tank with a 3-hp air-cooled condensing unit was loaded to 74% of its rated capacity.

Brand D (IB)

Figure 6 represents the cooling performances of 16 brand D tanks. Average time for the second milking was 1 hour 18 minutes.

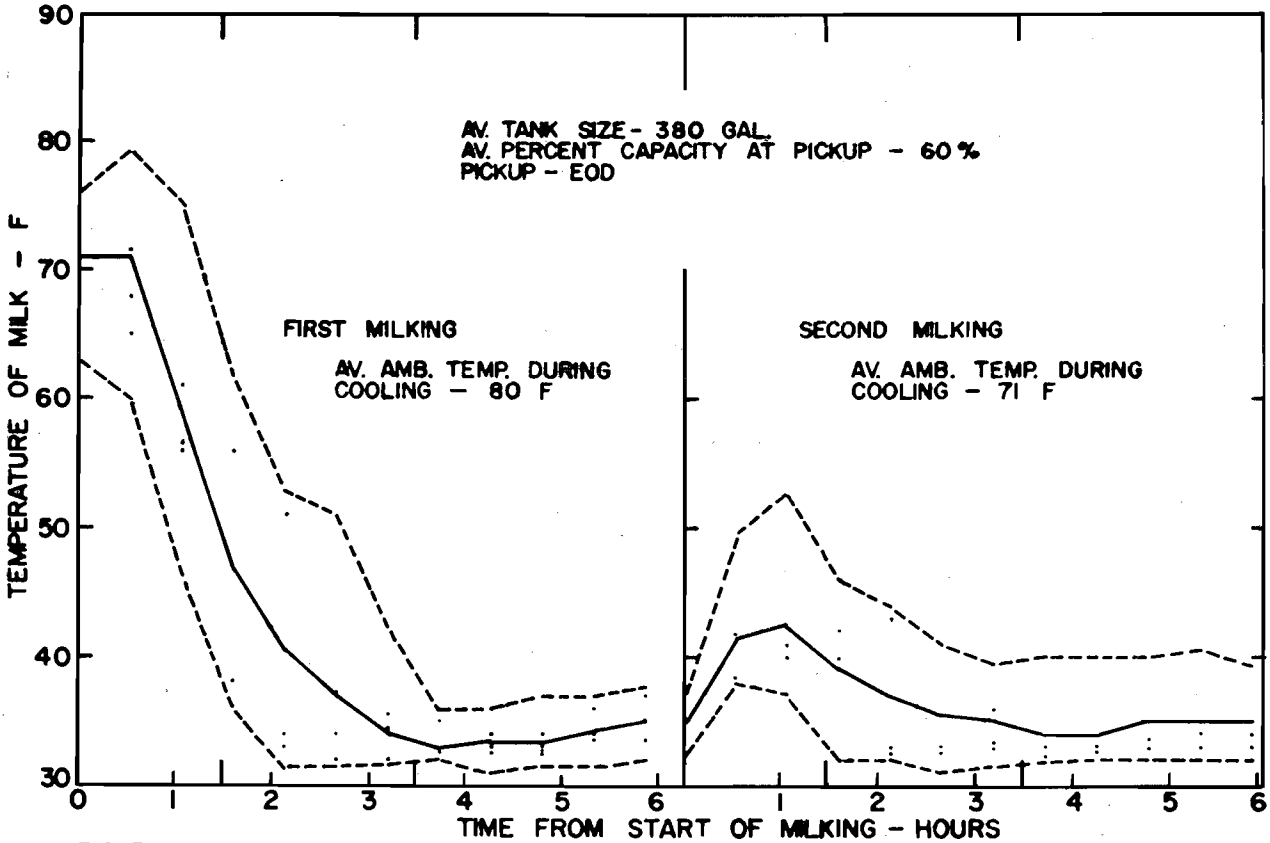

FIGURE 5 - COOLING PERFORMANCE OF 5 BRAND C DIRECT - EXPANSION BULK MILK TANKS - IOWA 1958

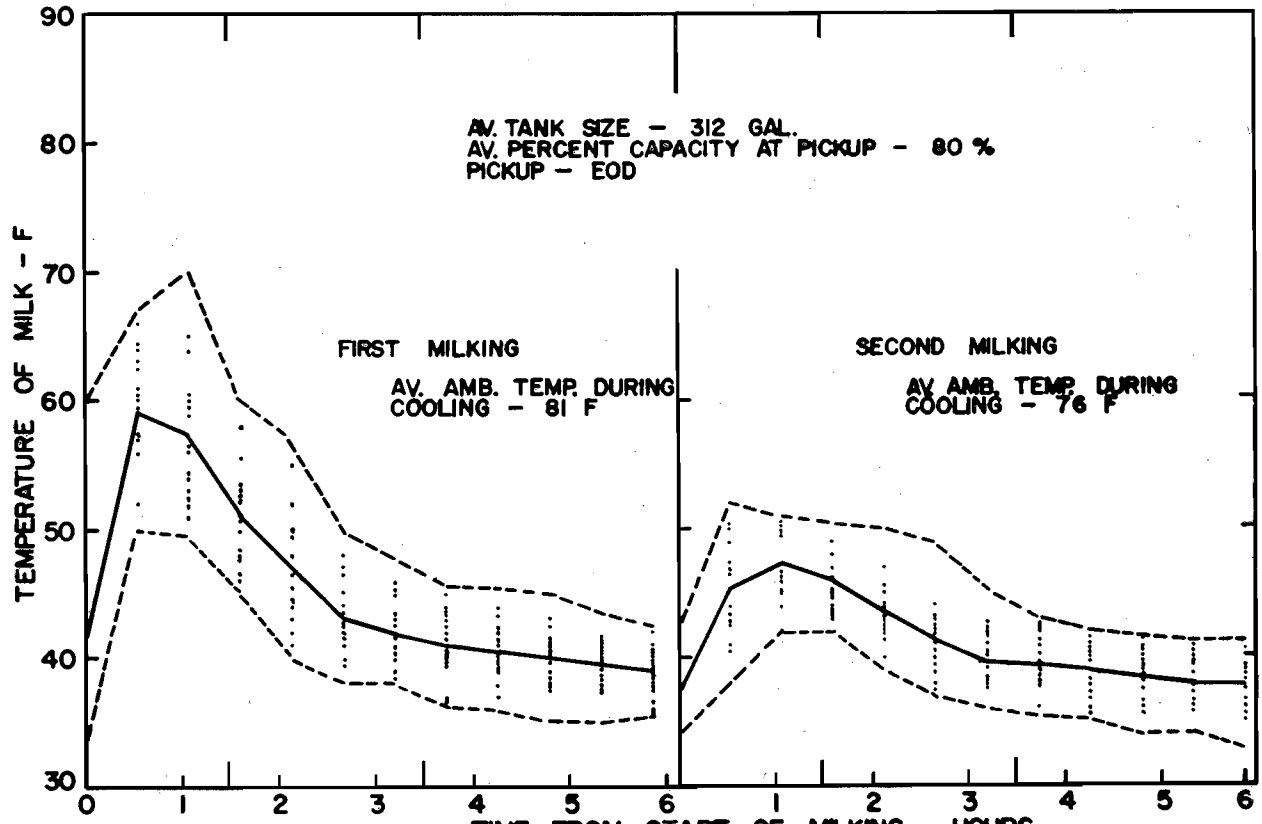

FIGURE 6 - COOLING PERFORMANCE OF 16 BRAND D ICE-BANK BULK MILK TANKS - IOWA 1958

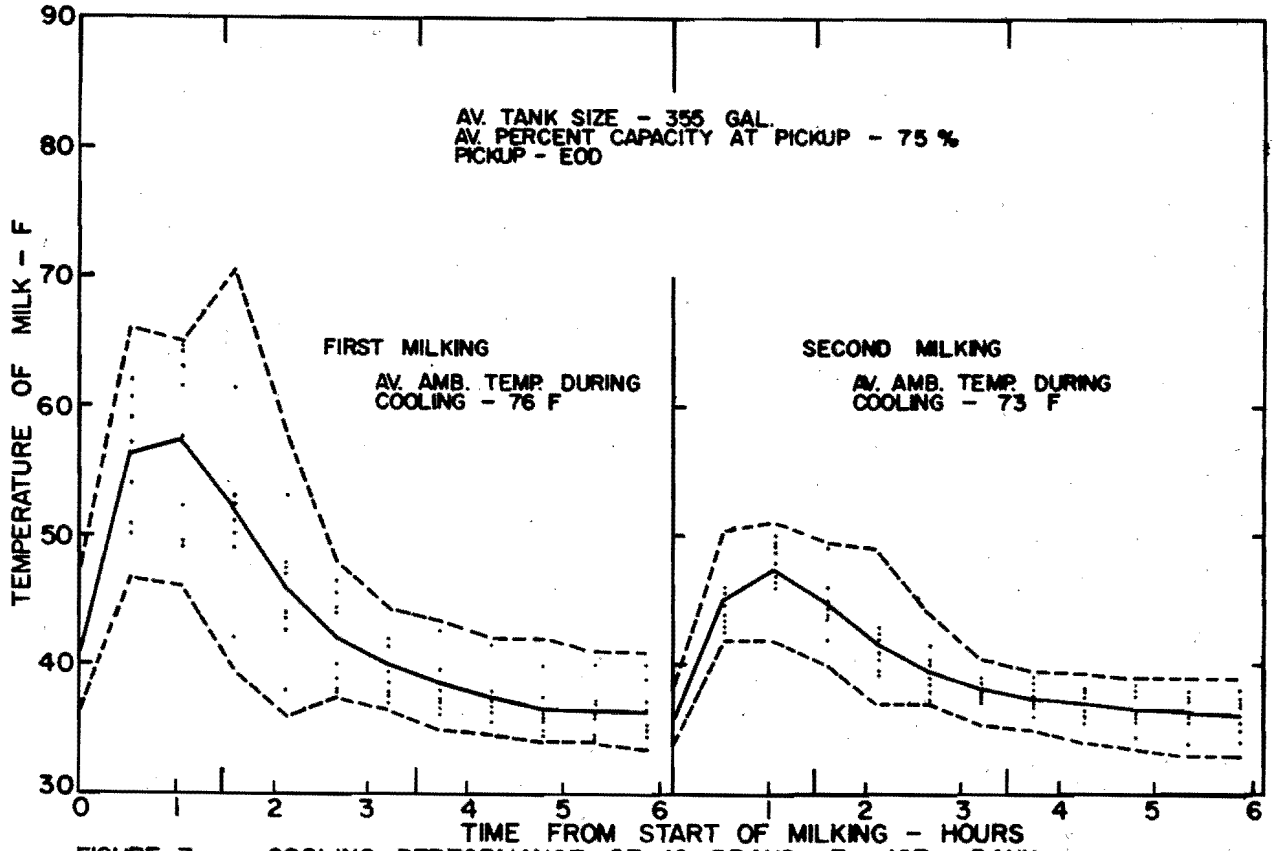

FIGURE 7 - COOLING PERFORMANCE OF 10 BRAND E ICE - BANK BULK MILK TANKS - IOWA 1958

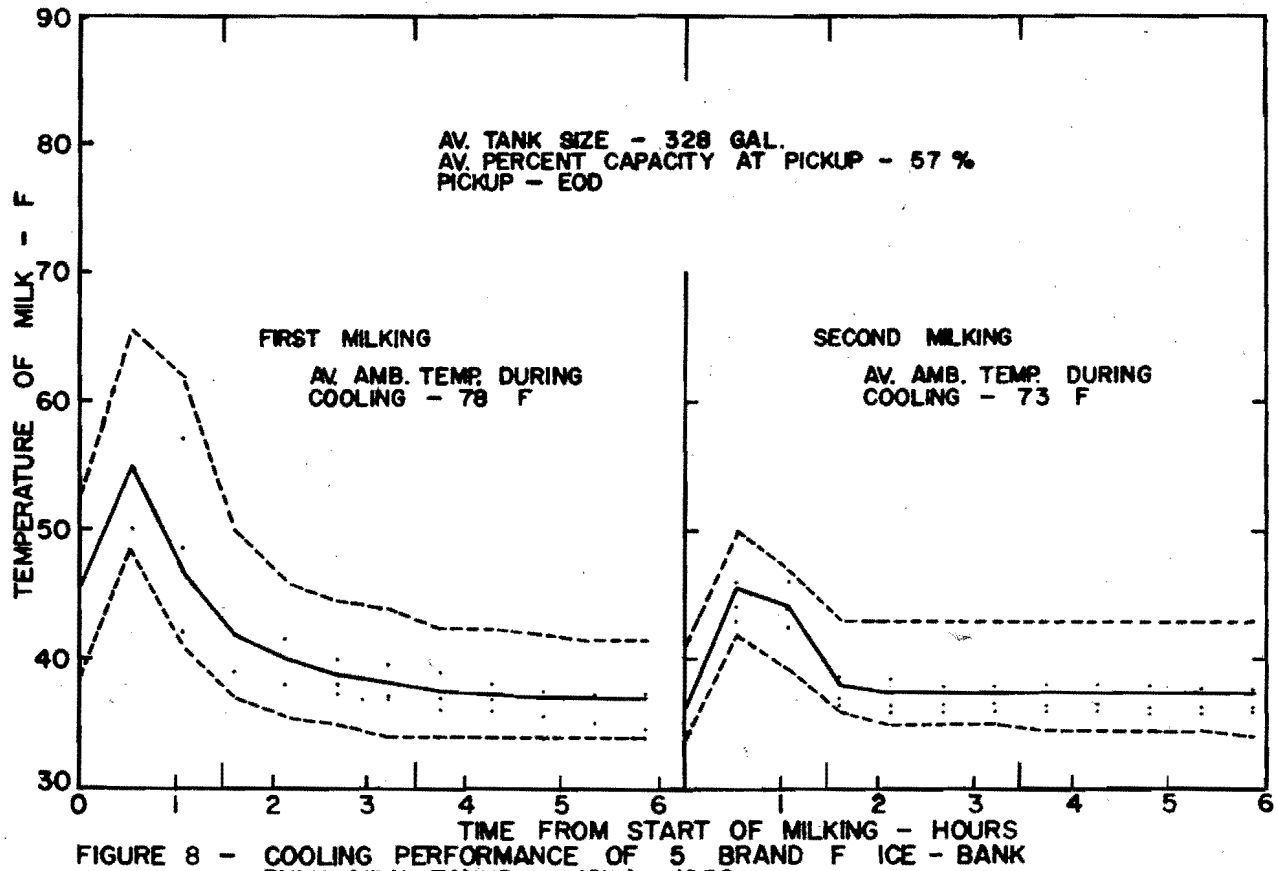

FIGURE 8 - COOLING PERFORMANCE OF 5 BRAND F ICE - BANK BULK MILK TANKS - IOWA 1958

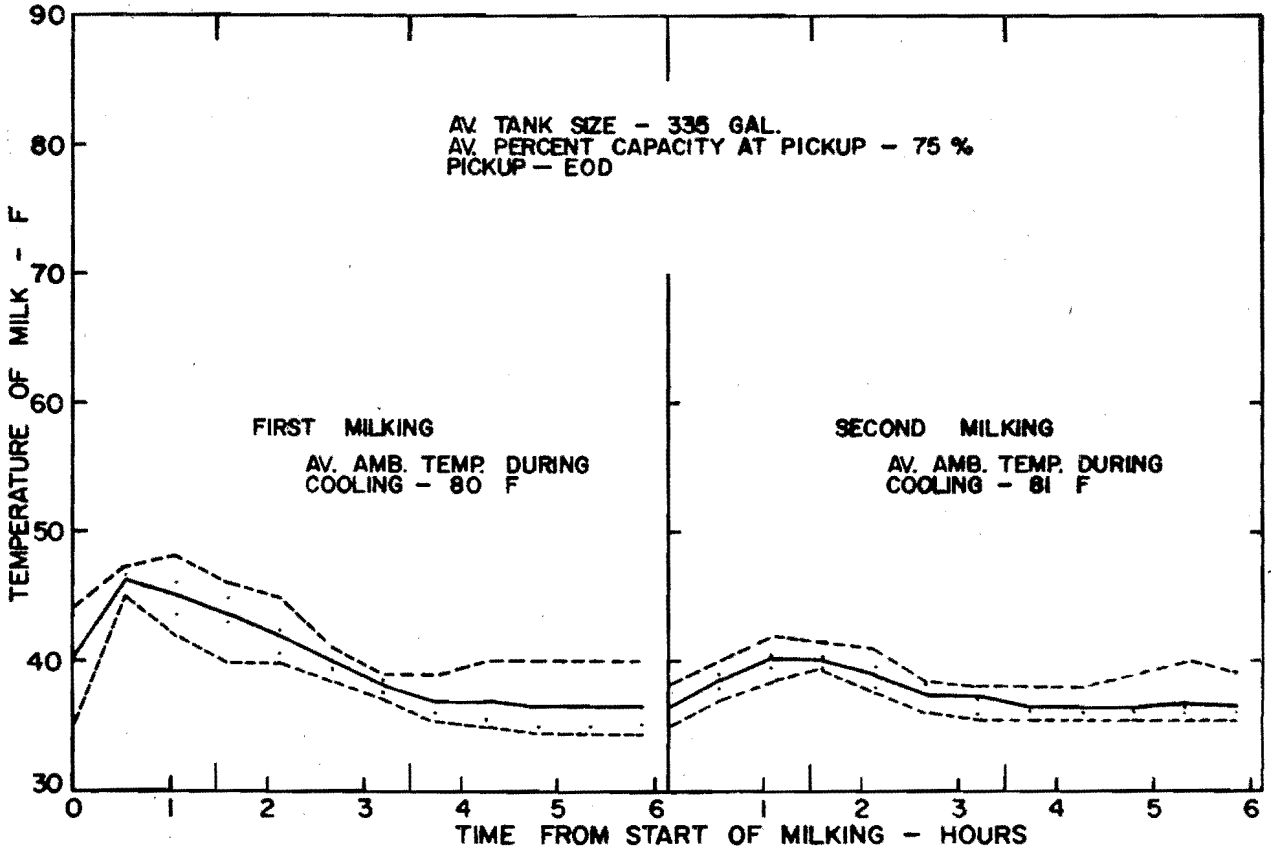

FIGURE 9 - COOLING PERFORMANCE OF 4 BRAND G ICE - BANK BULK MILK TANKS - IOWA 1958

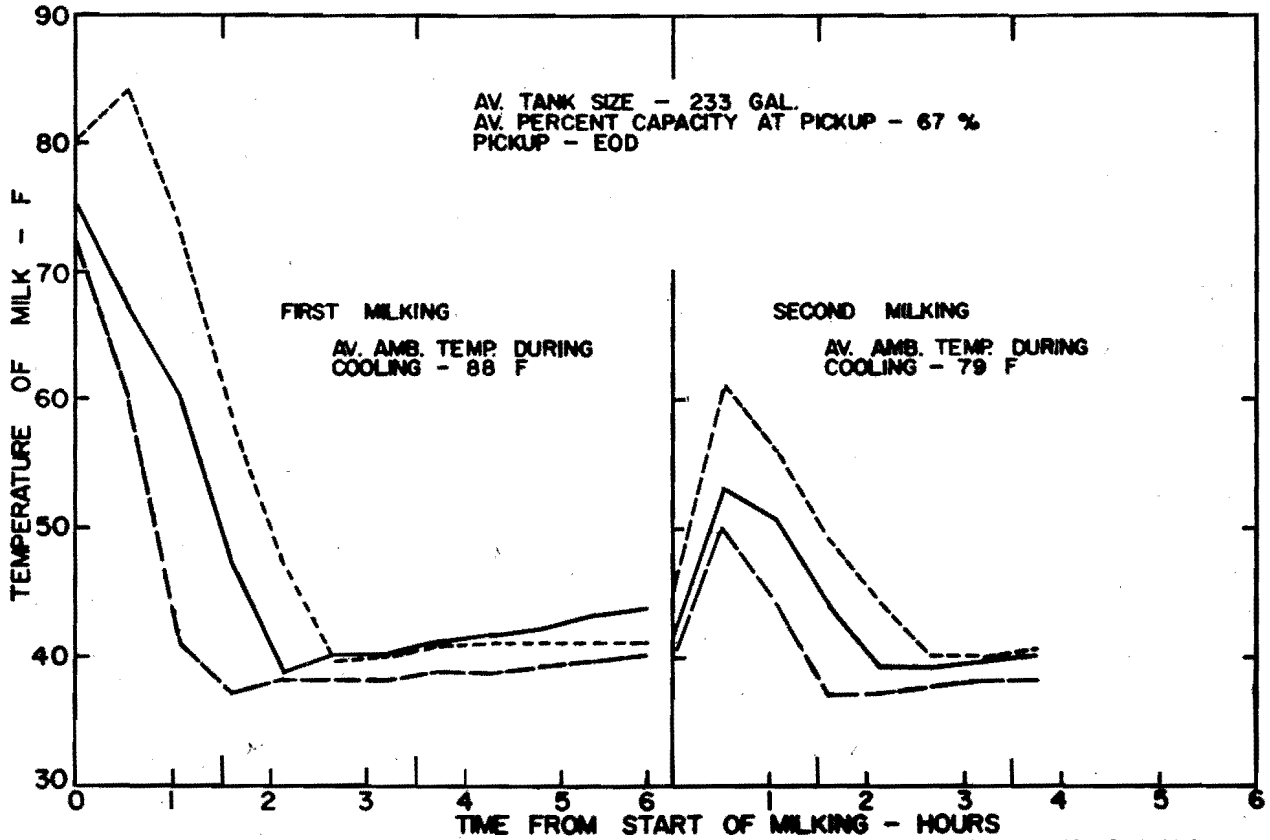

FIGURE 10 - RECHECKED PERFORMANCE OF 3 DIRECT - EXPANSION TANKS WHICH PERFORMED UNSATISFACTORILY IN INITIAL STUDY - IOWA 1960

TABLE 2—SECOND-MILKING BLEND TEMPERATURES IN BULK MILK TANKS—IOWA 1958

Brand	Number of tanks	Number exceeding 50°F, 2nd milking	Average time above 50°F (min)	Average rise during 2nd milking (°F)	Range of rise during 2nd milking (°F)
		DIRECT EXPANSION			
A	9	4	48	11	6 to 20
B	9	4	45	12	3 to 21
C	5	1	34	9	3 to 13
	23	9			
		Av.	45	11	
		ICE BANK			
D	16	6	23	12	9 to 14
E	10	2	11	13	10 to 17
F	5	0	0	11	10 to 16
G	4	0	0	4	3 to 6
	35	8			
		Av.	20	11	

The agitator on each of these tanks was operated with a timer, which means that the operation of the agitator depended upon the tank operator. More recent models of brand D have the agitator electrically connected to operate with the water pump. This inter-connection is necessary to insure fast cooling. These newer models were not available for this study.

Ten of the 16 tanks did not meet 3-A Standards of cooling to 40°F for the first milking and five failed for the second milking. Thermostats on four tanks were not set low enough to permit cooling of the milk to 40°F.

Six tanks exceeded a 50°F blend temperature during the second milking when the average milking time was 1 hour 25 minutes and the ambient temperature was under 75°F. The continuous but slow rate of cooling of some of these tanks indicates that agitation of the milk was not maintained throughout the cooling period.

Brand E (IB)

Ten tanks of brand E are represented in the curves of Figure 7. Average second-milking time was 1 hour 19 minutes.

Two tanks during the first milking did not meet 3-A Standards time of cooling to 40°F. During the second milking all tanks cooled the milk within the allotted time.

Two of the 10 tanks exceeded 50°F blend temperature during the second milking. Both of these two tanks were 70% loaded and the milking times for the second milkings were 55 minutes and 1 hour 50 minutes, respectively. Average ambient temperatures during the milking and cooling periods were less than 75°F. The operator of one tank reported that the condensing unit ran continuously which suggests that the unit was low on refrigerant.

Brand F (IB)

Figure 8 represents the cooling performances of five brand F tanks. Milking time averaged 1 hour for the second milking.

One tank failed to cool both the first and second milkings to 40°F within the time allowed by the 3-A Standards. During the second milking it was evident that the cut-out setting of the thermostat controlling the water pump and agitator was too high.

Blend temperatures in all five tanks were within the limit of 50°F set by 3-A Standards. Average loading was 57%.

TABLE 3—MAXIMUM TEMPERATURE STRATIFICATION OF MILK IN BULK TANKS—IOWA 1958

Brand	Average temperature (°F)	Temperature range (°F)	Average ambient temperature (°F)	Average capacity at pickup %
		DIRECT EXPANSION		
A	2.3	2 to 4	68	74
B	2.8	1 to 4	84	76
C	2.9	1 to 4	60	73
Average	2.6		73	75
		ICE BANK		
D	3.6	1 to 5	80	78
E	3.4	1 to 5	75	79
F	2.0	1 to 2	57	75
G	2.7	1 to 4	75	81
Average	3.2		75	79

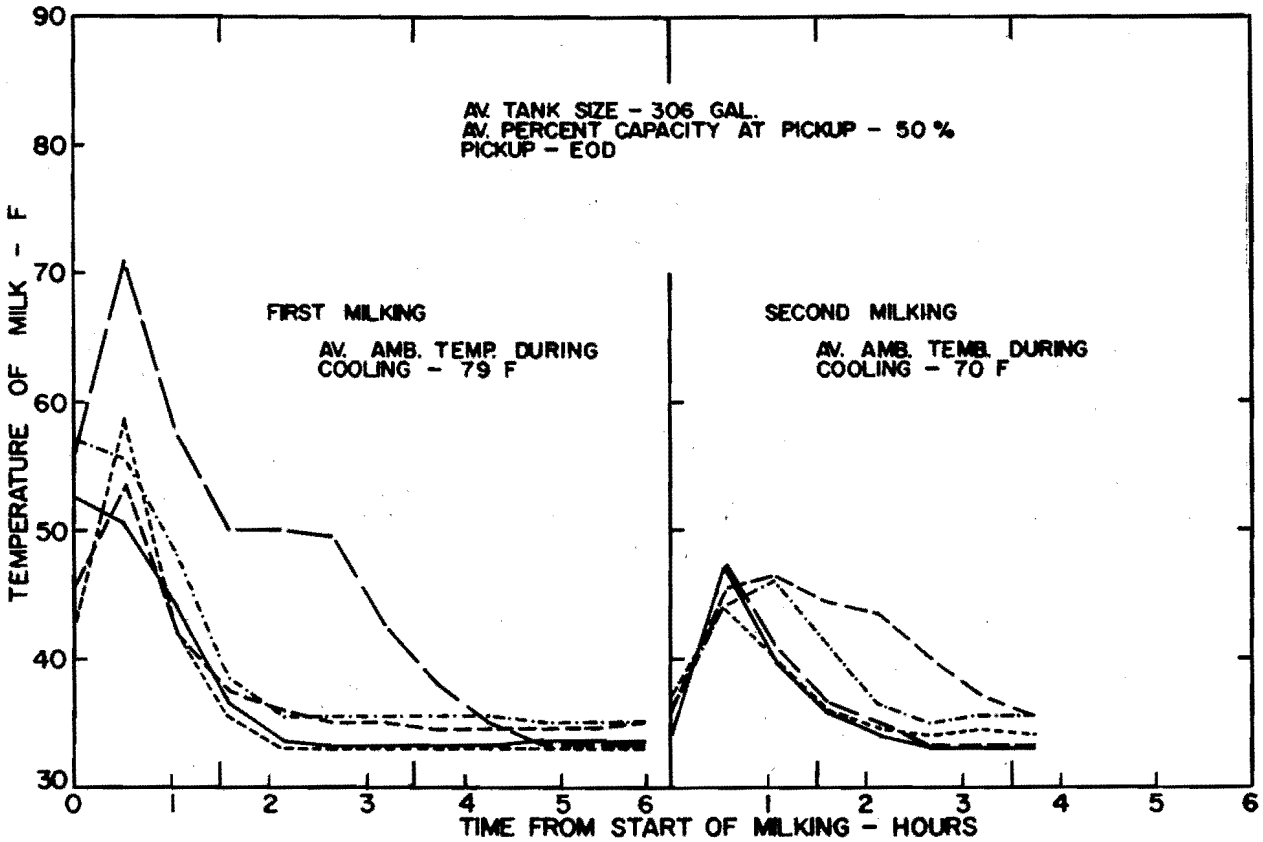

FIGURE 11 - RECHECKED PERFORMANCE OF 5 ICE-BANK TANKS WHICH PERFORMED UNSATISFACTORILY IN INITIAL STUDY - IOWA 1960

Brand G (IB)

The cooling performances of four brand G tanks are represented in Figure 9.

The average tank of 335 gallons was 75% loaded. A different feature of this brand was that milk being added to the tank was distributed over a refrigerated wall. The trough for distributing the milk was attached to the tank sidewall.

These four tanks met 3-A Standards of cooling and easily kept the blend temperature below 50°F. The average milking time during the second milking was 1 hour 23 minutes.

BLEND TEMPERATURES

Second-milking blend temperatures are good indicators of how well a tank is performing. As shown in Table 2, nine of the 23 DE and eight of the 35 IB tanks permitted the milk to rise above 50°F during the second milking. The average temperature rise for both types of tanks was 11°F. Brand G had a considerably lower average rise than the other tanks, but the small number of tanks did not affect greatly the average temperature rise of the IB tanks. For those tanks failing to meet blend temperature requirements, the time that the milk was above 50°F averaged 45 minutes for the nine direct-expansion tanks and 20 minutes for the eight ice bank tanks.

Compressor horsepowers for the air-cooled condenser DE tanks averaged 1.47 hp. for each 50 gallons of milk that could be cooled per milking. This ratio is very close to the minimum value of 1.5 hp. recommended by Turner *(2)*.

As shown in Table 1, the average horsepower for all types of condenser cooling on the basis of 50 gallons of milk cooled per milking was 1.27 hp. This ratio again is in the range recommended.

Ice bank tanks averaged 0.63 hp. per 50-gallon unit of milk cooled per milking as shown in Table 1. This is almost twice the minimum value recommended by Turner *(2)*. However, the capacity of the condensing units for these tanks has relatively little influence on the rate of cooling the milk. Cooling is primarily dependent upon the ice bank and water-circulating features.

Fifty-five of the 58 producers in the study responded to a question concerning whether pails or a pipeline was used in getting the milk into the tank. Forty-two of the 55 producers used pails. The type of tank had no influence on whether pails or pipelines were used.

Thirty-three of the 42 producers estimated that milk quantities in the range of 3 to 5 gallons were

poured at one time into the tanks. Six producers reported quantities of 8 gallons, and three producers stated that 10-gallon cans were used.

STRATIFICATION TEMPERATURES

Temperature stratification refers to the temperature difference that occurs when the milk is not agitated. As milk often is picked up shortly after the fourth milking, maximum temperature stratification is likely to occur either during the period after milk from the third milking is cooled, or during this period for the second milking if this is a morning milking.

Values of temperature in Table 3 are averages of those recorded for the second or third milkings, depending upon which were the highest. Maximum stratification in the DE tanks averaged 2.6°F, with the average tank filled to 73% of capacity and the average milkhouse air temperature at 75°F. These corresponding values for the IB tanks were 3.2°F, 75% and 79°F.

During stratification, the DE tanks had a different characteristic temperature profile than most of the IB tanks. Temperatures in the former were higher in the bottom and top layers of milk than in the center. This accounts for the lower stratification temperatures of this type of tank.

Ice bank tanks with the exception of brand G showed a progressive temperature rise from bottom to top. Part of the bottom surfaces of brand G are like DE tanks in that heat losses from the milk go directly to the outside. The pattern of profile temperatures in brand G was similar to that of the DE tanks but less pronounced.

COOLING PERFORMANCE—1960

Figures 10 and 11 represent the cooling performances of three DE and five IB tanks that were rechecked during the summer of 1960. All of these tanks had failed to meet the 3-A Standards rate of cooling to 40°F during the initial study. Yet, in this later study, all tanks met this rate of cooling.

A partial and perhaps in some cases a complete explanation of these improved performances was the service given to the eight tanks in the period between the two studies. The kinds of work and adjustments required as reported by the farmers concerned were as follows:

ITEM	NUMBER OF TANKS
Compressor repairs	2
Refrigerant added	5
Thermostats adjusted	5
Condenser fan repairs	2
Agitator wired to pump	4
Agitator repairs	1
Condenser cleaned	2

The broad curve shown in Figure 11 for one tank was partly the result of the milking period extending over 2 hours 30 minutes.

REFERENCES

1. 3-A Sanitary Standards For Farm Milk Cooling and Holding Tanks—Revised, J. of Milk and Food Technol., **23**: 172-178. 1960.

2. Turner, C. N., 1955 Progress Report, New York Farm Electrification Council, Cornell University, Department of Agricultural Engineering, Ithaca, N. Y. April 1960.