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Dairy Refrigeration on Rural Electric Lines

By
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Dairy Refrigeration on Rural Electric Lines

THIS circular reports the results of studies made as a part of the experimental work on rural electrification conducted in cooperation with the Alabama Power Company and with dairymen in different sections of the State. The work was based upon studies of the requirements for proper refrigeration of dairy products, as determined by bacteriologists and public health officials. Its objects were to study: (1) small dairy refrigeration units and results obtained from their use; (2) the adaptability of electrically operated equipment to the refrigeration needs of the dairies.

REASONS FOR PROPER REFRIGERATION OF DAIRY PRODUCTS

The Standard Milk Ordinance for Alabama Municipalities, adopted by the Alabama State Board of Health in 1924, reads as follows:

"Grade 'A' milk must be cooled within one hour after milking to 50°F. or less and maintained at or below that temperature until delivery, unless it is delivered to a milk plant for pasteurization within two hours of the time of production.

"Grade 'B' raw milk must be cooled the same as Grade 'A' milk, except that the cooling temperature shall be changed to 70°F."

Market milk contains bacteria, even though it is produced under most sanitary conditions. The growth and multiplication of bacteria are very materially affected by temperature. The effect of temperature upon the growth of bacteria in milk is shown by the following experiment conducted by the State Board of Health. Two pint bottles of milk were taken, immediately after milking, from the same pail at one of the best dairies in the Mobile district. One of these samples was chilled immediately below 50°F., and the other left unchilled. At the end of a three-hour period (the average time for delivery) both samples were placed in the refrigerator of the Health Department Laboratory, which varied in temperature from 50° to 60°F. in order to imitate conditions in the household after delivery. The uncooled milk soured 80 hours before the chilled milk. Table 1 shows the marked effect of the chilling on the bacterial count.

TABLE 1.—Bacterial Counts on Cooled and Uncooled Milk.

	Number of bacteria per cubic centimeter	
	Cooled milk	Uncooled milk
Plate count when milked—3 p. m.	5,000	5,000
Plate count 10 a. m. next day	3,000	40,000
Plate count 2 p. m. next day	6,000	85,000
Plate count 10 a. m. second day	45,000	1,000,000
Plate count 2 p. m. second day	170,000	14,000,000

AMOUNT OF HEAT WHICH MUST BE REMOVED BY REFRIGERATION

Milk when drawn from the udder is at a temperature of approximately 95°F. It should be cooled to 40°F. within one hour. This means that the temperature should be lowered about 55°F. One gallon of 4 per cent milk weighs approximately 8.6 pounds and its specific-heat[1] is 0.93. Therefore, eight ($8.6 \times 0.93 = 7.998$) units of heat must be removed from a gallon of milk for each degree that the temperature is lowered. Then to cool one gallon of milk 55°F. (55×8) 440 units of heat (B.T.U.)[2] must be removed.

To determine the amount of heat to be removed in cooling a quantity of milk the following formula may be used:

Heat to be removed (B.T.U.) = gallons of milk $\times$ 8 $\times$ (T_1—T_2)

T_1 = temperature of milk before cooling

T_2 = temperature of milk after cooling

For example—to cool 100 gallons of milk from 95°F. to 40°F.:

Heat to be removed (B.T.U.) = $100 \times 8 \times 55 = 44{,}000$ B.T.U.

However, it should be remembered that this represents only the heat to be removed from the milk and not the total amount of refrigeration needed at a dairy. In addition to cooling the milk, it must be maintained at a low temperature in cold storage until time for delivery; the milk bottles must be cooled; drink-

[1] **Specific-heat.**—The specific-heat of a substance may be defined as the ability of that substance to absorb heat compared to that of water. Water being one of the hardest substances to heat, its specific-heat is taken as unity. Therefore, the specific heat of other substances is usually less than one. The specific-heat of milk varies with its composition and temperature, but for practical purposes may be considered as 0.93.

[2] **British Thermal Unit (B.T.U.).**—The quantity of heat required to raise one pound of pure water one degree Fahrenheit, at or near its minimum density, 39.1°F. For practical purposes it may be considered the heat required to raise the temperature of one pound of water one degree Fahrenheit.

ing water must be provided for the dairymen, and in many cases ice must be made to crack over the crated milk bottles en route to market. Then, many unavoidable refrigeration losses occur.

REFRIGERATION NEEDED AT RETAIL DAIRIES

Studies conducted at 12 retail dairies extending over a period of twelve months show that refrigeration was needed for the following purposes:

1.—To cool all of the milk immediately after milking.

2.—To store overnight the milk produced at the evening milking, and

3.—For ice to crack over the crated bottles when the milk must be hauled for considerable distances in hot weather.

The amount of refrigeration found to be needed per gallon of milk is shown in the following table.

TABLE 2.—Refrigeration Needed Per Day at Retail Dairies per Gallon of Mlik

To cool one gallon of milk from 95°F. to 40°F.	3.5 pounds of refrigeration[3]
To cool bottles or cans for one gallon of milk from 85°F. to 40°F.	1.5 pounds of refrigeration
Two pounds of ice to crack over milk en route to market.	3.2 pounds of refrigeration
To provide cold storage and allow for losses, drinking water, etc.	2.0 pounds of refrigeration
Total refrigeration needed per gallon of milk	10.2 pounds of refrigeration

[3] One pound of refrigeration is equivalent to the "cold produced" by the melting of one pound of ice.

Capacities of Refrigerating Machines.—Refrigerating machines are rated in tons of refrigeration per twenty-four hours of operation, in pounds of "ice melting capacity" per day, or in British Thermal Units (B.T.U.) output per hour.

For proper refrigeration it is very essential to install a machine with ample capacity to take care of the refrigeration without operating more than eighteen hours per day when the atmospheric temperature is 95°F.

The table below gives the minimum capacity machine for complete refrigeration at different size retail dairies as determined by

the above mentioned studies. These capacities are based upon 18 hours operation per day in hot weather.

TABLE 3.—Minimum Capacity Refrigerating Machine for Retail Dairies.

Gallons of milk per day	Minimum capacity of refrigerating machine		
	In tons per day	In pounds refrigeration per day	In B. T. U. output per hour
15	⅛	250	1,500
30	¼	500	3,000
45	⅜	750	4,500
60	½	1,000	6,000
90	¾	1,500	9,000
120	1	2,000	12,000
150	1¼	2,500	15,000
180	1½	3,000	18,000
210	1¾	3,500	21,000
240	2	4,000	24,000
300	2½	5,000	27,000
360	3	6,000	36,000

At all of the dairies studied aerators or tubular coolers were used for cooling milk. In some instances double section tubular coolers were used. In these, water from the well or spring was circulated through the upper section and the temperature of the milk lowered about 25°F. Thus, the required capacity of the plant for complete refrigeration at these dairies was reduced about 16 per cent. This was found to be an advantage not only by permitting the use of a smaller refrigerating machine, but also in the reduction of operating costs. An ample supply of running water is, of course, necessary for this system.

To avoid the installation of a machine without sufficient capacity to provide proper refrigeration, the dairymen must be careful to give the refrigerating engineer a complete description of the operation of the dairy, including the amount of milk produced or expected to be produced, how the milk is delivered, the location of storage room or refrigeration box, and the amount of such products as butter and buttermilk that may have to be cooled. There is a decided tendency to underestimate the amount of refrigeration required at the retail dairy. This results in overloading machines and decreasing their operating efficiences in addition to increasing the cost of maintenance.

At retail dairies producing 100 gallons or more of milk per day the most satisfactory equipment was found to consist of:

1.—Refrigerating machine complete with compressor, expansion coil, water cooling tower with circulating pump, and power units.
2.—Brine tank.
3.—Cold storage room.

4.—Aerator or pre-cooler, with circulating pump and power unit for circulating the cold brine from the brine tank through the aerator and back into the brine tank.

In dairies producing less than 100 gallons of milk per day the equipment found to be most satisfactory was the same as that listed above except that the brine tanks are placed in the cold storage boxes or rooms and the smaller refrigerating machines used did not require the water cooling towers.

The Operation of Refrigerating Equipment at Retail Dairies.—The refrigerating machine forces the refrigerant through expansion coils in the brine tank and in the cold storage room, thus cooling the coils and brine in the brine tank and the air in the cold storage room. The degree of cooling may be controlled automatically or by hand. An automatic installation is simple and convenient to operate, requiring practically no care other than oiling of moving parts and protection of water pipes and jacket against freezing in cold weather. This type was found to be most satisfactory in that it did not require constant attention to maintain a proper temperature.

The general procedure at most dairies was found to be as follows: At milking time the cold brine was circulated through a pre-cooler over which the milk was poured. With plenty of brine at a low temperature—usually about 15°F.—this process cooled the milk immediately to about 35°F. The evening milk was bottled immediately after cooling, crated, and set in cold storage where the temperature was about 40°F. The morning milk was cooled in the same way and immediately loaded on the delivery truck with the evening milk taken from the storage room. Ice was taken from the brine tank and cracked over the bottles to maintain a low temperature until the milk was delivered to the customer's door.

Electricity Required to Operate Refrigerating Machinery at Retail Dairies.—To determine the amount of electricity required for complete refrigeration at retail dairies, monthly kilowatt-hour consumption records were kept at the eleven retail dairies for a full year. The refrigeration of:

1.—Cooling the evening milk to about 40°F. immediately after milking.

2.—The storage of evening milk overnight at a temperature of about 40°F.

3.—Cooling the morning milk about 40°F. immediately after milking, and

4.—Making ice to crack over the milk. This averaged two pounds of ice per day for each gallon of milk produced.

TABLE 4.—Monthly Kilowatt-Hour Consumption for Complete Refrigeration at Retail Dairies.

Month	Kilowatt-hours per month for each gallon of milk per day	Kilowatt-hours per per 100 gallons of milk cooled
January	5.0	16.7
February	5.4	18.0
March	5.3	17.7
April	8.3	27.6
May	7.9	26.4
June	8.9	29.6
July	10.8	36.0
August	9.8	32.6
September	10.0	33.3
October	7.8	26.0
November	7.3	24.4
December	5.9	19.6
Average	7.6	25.3

The average kilowatt-hours per month for each gallon of milk produced per day varied at the different dairies from 4.6 KWH to 12.3 KWH. Many factors entered into the efficiency of operation at the different dairies which affected the amount of electricity used. Records of the different plants in operation indicated that the most important factors causing the variation in efficiency were: (1) the amount of insulation used in the installation of the plant, (2) the amount of care taken in preventing the loss of refrigeration, (3) and the amount of ice made to crack over the crated bottles.

The Cost of Electricity for Operating Refrigerating Plants at Retail Dairies.—Inasmuch as the rates for electricity vary in different localities and with the amount of electricity used, it is practically impossible to include an item of cost that would apply to different individual conditions. However, at 4¢ per KWH, the average cost of electricity for operating the refrigerating equipment at the eleven dairies would amount to 30¢ per month for each gallon of milk produced per day, or about 1¢ per gallon of milk cooled.

REFRIGERATION REQUIREMENTS FOR WHOLESALE DAIRIES

The refrigeration requirements at three wholesale dairies were studied. These dairies delivered all of their milk to a central plant immediately after the morning milking. This practice required refrigeration for cooling all of the milk and overnight storage for the evening's milking. The amount of refrigeration per gallon of milk was as follows:

For cooling milk (from 95°F. to 40°F.)	3.5	pounds of refrigeration
For cooling cans	1.0	pound of refrigeration
For cold storage losses, drinking water, etc.	1.5	pounds of refrigeration
Total per gallon milk	6.0	pounds of refrigeration

These amounts, of course, varied with different installations, but were found to be sufficient for ample refrigeration at these wholesale dairies during the summer months. The refrigeration capacities for various sized wholesale dairies as calculated from these studies is shown in the following table. This is based upon eighteen hours operation per day.

TABLE 5.—Capacity Refrigeration Plants Needed at Wholesale Dairies.

Gallons of milk produced per day	Minimum capacity of refrigerating machine		
	In tons per day	In pounds refrigeration per day	In B.T.U. output per hour
15	-----	150	900
30	-----	300	1,800
50	¼	500	3,000
75	⅜	750	4,500
100	½	1,000	6,000
150	¾	1,500	9,000
200	1	2,000	12,000
300	1½	3,000	18,000

Installation and Operation of Refrigerating Equipment at Wholesale Dairies.—While the required capacity of refrigerating equipment for wholesale dairies is less than that for retail dairies, it is equally important to have a plant of sufficient capacity properly installed for efficient operation and complete refrigeration.

The installations at the wholesale dairies studied consisted of one wet- and two dry-storage boxes. In the case of the wet-storage installation, the expansion or cooling coils were installed in a box in which there was water. The operation of the machine cooled the water and the milk was cooled by circulating the cooled water through an aerator over which the milk was poured. After cooling, the cans of milk were set in the water for storage. This installation was not entirely satisfactory as partly filled cans floated in the water and were easily upset, and again in removing cans from the box it was almost impossible to prevent the wetting of one's clothes.

In the dry-storage installations, storage compartments were provided on one or both sides of a brine tank in one combined box. The operation of these installations was the same as wet storage, except that the cans were set in dry storage. The dry-storage type plants were only slightly more expensive to install, and were more satisfactory to the dairymen and no more expensive to operate.

The amount of electricity used during the year for refrigeration at the three dairies that were cooling all of the milk to about 40°F. and storing the night's milk, was an average of 4.6 KWH per month for each gallon of milk cooled per day, or an average of 15.3 kilowatt-hours for each 100 gallons of milk cooled. The amount of electricity used per month for each gallon of milk cooled per

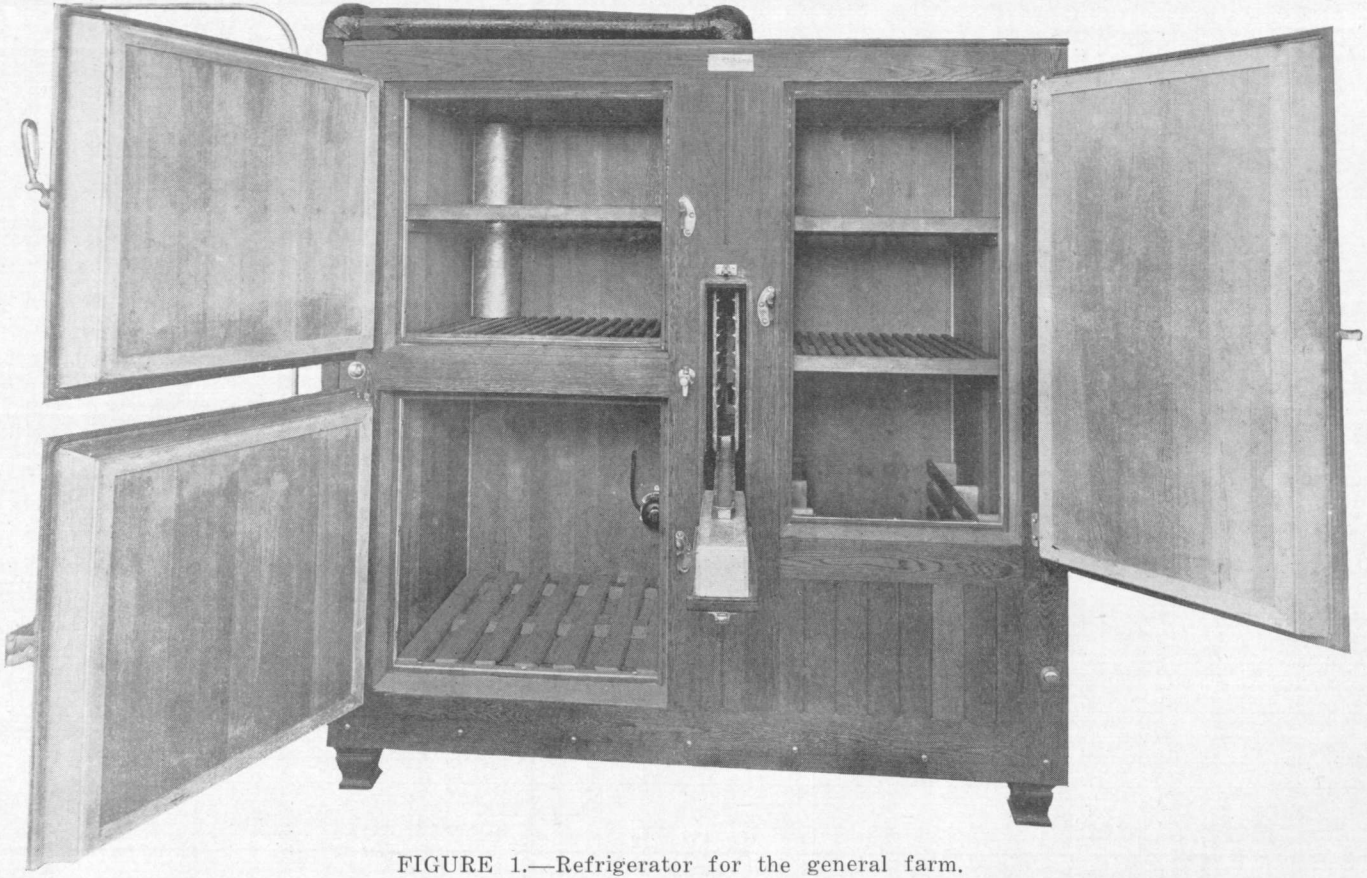

FIGURE 1.—Refrigerator for the general farm.

day varied from 2.1 kilowatt-hours in January to 7.8 kilowatt-hours in August.

These installations were not as well insulated as those of the retail dairies studied which increased the amount of electricity used in proportion to the amount of refrigeration actually obtained. At one of these wholesale dairies where the box was well insulated the average electrical energy consumption per month for each gallon of milk produced per day was 3.5 kilowatt-hours.

REFRIGERATION OF MILK ON THE GENERAL FARM

The proper refrigeration of milk products on the general farm is even more important in providing good and palatable milk than at the specialized dairy, due to the fact that the specialized dairy is better equipped with facilities essential to the production of clean milk.

On general farms there are, in addition to milk, certain other products that require refrigeration. Appreciating this fact and with the realization that the purchase of a separate milk refrigeration box is out of the question, studies were made of the refrigerating needs of the general farm.

Based on these studies a box (Figure 1) was designed and tested to meet these needs. This included space for chilling and curing meat and for storage of such farm products as milk, eggs, and vegetables. Figure 1 shows one commercial box built on the basis of this design. Plans and specifications for home-made farm boxes that can be used with commercial refrigeration machines are also available[4].

INSTALLATION OF REFRIGERATING EQUIPMENT

In these studies and in observations of other dairies throughout the State it was found that most dairy refrigeration boxes were poorly insulated. Regardless of whether ice or mechanical refrigerating equipment is used, the storage box or room should be well made and insulated with not less than four inches of sheet-cork or its equivalent. The value of insulation is shown by the following example:

> A concrete box six inches thick, six feet long, four feet wide and four feet high, without any insulation, will require about 750 pounds of ice per twenty-four-hour day to maintain a temperature of 40°F. inside the box when the outside temperature is 80°F.
>
> The same box insulated with four inches of sheet-cork on sides and bottom and a wooden lid insulated with two inches of cork will require only 80 pounds of ice per twenty-four-hour day to maintain a temperature of 40°F. inside the box when the outside temperature is 80°F.

From the observations of many dairies and installations of refrigeration equipment it is recommended that:

[4] These plans may be obtained free by residents of the state by writing the Department of Agricultural Engineering, Auburn, Ala.

1.—The installation of refrigerating equipment at the dairy should be carefully planned by a competent refrigerating engineer, taking into consideration not only the convenience of handling the milk in cooling but also of storing, and loading on trucks for delivery. Excess capacity should be provided to allow for future expansion of the dairy.

2.—In planning the installation, the public health department should be consulted to make sure that the installation will meet all sanitary regulations.

3.—The equipment should be installed under the direct supervision of a refrigerating engineer, and the company selling the equipment should be responsible in its contract for correct installation and the delivery of refrigeration up to rated capacity.

CONCLUSIONS

1.—Electrically-operated refrigerating equipment was found to meet the requirements for satisfactory dairy refrigeration when machines of sufficient capacities were properly installed.

2.—Sufficient capacity of refrigerating equipment was found to be very important for complete refrigeration and efficient operation.

Retail dairies, for complete refrigeration, should have a plant with a minimum capacity of 15 pounds "ice melting capacity" per twenty-four-hours operation for each gallon of milk produced per day.

Wholesale dairies, for complete refrigeration, should have a plant with a minimum capacity of 10 pounds "ice melting capacity" per twenty-four-hours operation for each gallon of milk produced per day.

By circulating fresh water through the upper sections of the tubular cooler, the minimum capacity of refrigerating equipment for retail dairies can be reduced to 12½ pounds "ice melting capacity" per twenty-four hours operation for each gallon of milk produced per day; and for wholesale dairies the minimum capacity can be reduced to 7.5 pounds "ice melting capacity" for each gallon of milk produced per day.

3.—The refrigerating equipment must have sufficient capacity for complete refrigeration without operating more than eighteen hours per day.

4.—The most important single factor affecting both the efficiency and cost of proper refrigeration at the dairy was found to be that of insulation. Poor or inadequate insulation results in incomplete refrigeration at increased cost.

5.—To operate refrigerating equipment for complete refrigeration at retail dairies required an average of approximately 7.6 kilowatt-hours of electricity per month for each gallon of milk cooled per day. At wholesale dairies the average electrical energy consumption for complete refrigeration was approximately 4.6 kilowatt-hours per month for each gallon of milk cooled per day.