POSSIBILITIES OF PRE-HEATING WATER WITH THE HEAT OBTAINED BY COOLING MILK IN A WET-TANK MILK COOLER

by

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INTRODUCTION

The problem of heating water to be used for washing, rinsing, and sterilization of milking utensils is a common one on dairy farms. An ample supply of hot water is necessary in the effective removal of fats and milk residues on which bacteria thrive.(17)* To meet this requirement, electric water heaters are in wide use, being especially desirable because of their cleanliness, low fire hazard, and convenience. The annual price paid in Virginia for electrical energy consumed in these heaters amounts to tens-of-thousands of dollars.

Cooling milk rapidly is another phase of the process for producing a healthful, quality product. Mechanical refrigeration equipped with an air condenser seems to offer the greatest satisfaction, resulting in an increasingly wide acceptance of this method. This means that the air in the milk house, passing through the condenser, indirectly absorbs the heat from the milk in the milk cooler. Removal of this heated air from the milk house is a problem in many sections during the warmer seasons.

With many mechanical milk coolers and electric water heaters being used, often in proximity to each other, a method of reducing the cost of operating the water heater, and in some cases eliminating unnecessary milk house temperature, suggests itself. A properly designed coil placed in an insulated pre-heat tank could replace the air condenser that is usually a part of a farm-size cooler. Tap water could then enter the

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*Refers to corresponding number in "Cited and Related Literature."

pre-heat tank to be preheated before entering the electric water heater. By this arrangement, an appreciable savings of electrical energy may be effected.

Theoretically, the heat loss through a four-can milk cooler and the heat given up by cooling four 10-gallon cans of milk from 90 F to 40 F amounts to approximately 22,000 BTU's per day. If this heat could be used to heat water, approximately 50 gallons of water could be raised in temperature from 60 F to 115 F every 24 hours. This water could then be heated to 150 F in the electric water heater. If electrical energy for heating water in Virginia sold for as low as one cent per kwhr, approximately 5,000 commercial producers of Grades A, B, and C milk could save approximately $125,000 annually on energy costs. The heat exchanger cost is a factor, however, that would require consideration.

OBJECTIVES

The purpose of this study is:

1. To develop a method of utilizing the heat obtained from cooling milk in a conventional wet-tank mechanical milk cooler to pre-heat water before it enters an electric water heater.
2. To determine the practicability of thus tempering water.

REVIEW OF LITERATURE

The heat pump has attracted the attention of scientists for a hundred years. Lord Kelvin suggested using a heat pump for changing the temperature of air in a given space in a paper presented at a meeting of the Glascow Philosophical Society in December, 1852. About 75 years later, Holdane performed some experiments in London with a heat pump using the Kelvin principle.(19)

There is no fundamental difference between a conventional refrigeration system and the "heat pump." Each employs a compressor, condenser, cooling coils, or evaporator, and an expansion valve, or constriction, to absorb heat at a low temperature level and reject it to a higher temperature level. The source of heat can be the atmosphere, earth, wells, lakes, streams, in manufacturing processes, or any other source of sufficient heat.

In 1934, the Pennsylvania Railroad installed and operated heat pumps in two of their passenger cars using the atmosphere as the heat source. In 1945, a Fruehauf refrigerator van was equipped with a heat pump to supply year round air conditioning. In addition to atmospheric air, waste heat from the engine was utilized to increase the efficiency of the system during the heating cycle.(19)

Nearly all the heat pumps built, tested, and discussed during the last ten years were used in conjunction with equipment to heat and cool commercial buildings and homes. Sporn and Ambrose report(23) on five test model heat pumps installed and operating in residential buildings. Three of the units are of the air-to-air type, one is a water and air-to-air type, and one is an earth and air-to air type. Water, earth, and air are used as the heat sources and air is used to supply the heating and cooling to the occupied space. Montagnon reports(14) on the heat pump installed to serve the Royal Festival Hall during Britain's recent celebration. Variations from these typical installations are the newspaper-reported Cleveland ice skating rink that uses heat from freezing ice to heat adjoining buildings, and the Chicago banana dealer who uses heat drawn from the 55 F storage room to heat the 75 F ripening room.

Although the heat pump has been largely used for year-round air conditioning for man's comfort, it is used for processing in industries which produce paper, artificial silk, salt, sugar, condensed milk, tobacco processing plants, and concentrated fruit juices.(19) These applications have overlooked many worthwhile ones, such as heating water for farm and domestic use.

Although the electric appliance industry as a whole has not shown a great interest in the heat pump water heater, it is possible to install a water tank in any high-temperature refrigerant gas line to heat water for general use. A heat pump unit designed especially for heating water is feasible and practical with any adequate heat source. Penrod(19) described a heat pump installed during the year 1934 to provide domestic hot water for use in the "Home of Tomorrow" of the Westinghouse Electric Corporation at Mansfield, Ohio. A commercial 1/2 hp compressor was used with a water coil of 3/8 in copper tubing soldered around the motor shell. A double tube condenser, one 3/8 in copper tube inside a 5/8 in copper tube, was helically wound and mounted concentrically over the motor shell and water coil. Water was circulated by a 1/20 hp centrifugal pump from the bottom of a 52 gal insulated storage tank. Air was used as a source of heat. Two or more kwhr of heat were added to the water for each kwhr of compressor energy consumption. Sporn and Ambrose reported(23) on a self-contained heat pump water heater with a forced air evaporator and a water-refrigerant heat exchanger located in a standard 80 gal electric water tank. However, the domestic heat pumps are in the experimental stage at the present time.

Theoretically, a heat pump could deliver eight times the heat energy supplied to the motor.(8) Performance ratios* in the neighborhood of four to five have been suggested as practical. The performance ratio is materially affected by water temperature, refrigerating compressor design, and motor efficiency. Since it seems desirable to provide domestic water at 150 F, and use standard refrigerating parts, such values are difficult to obtain. A performance ratio of 1.5 to 2.5 is about all that can be expected at this time because of mechanical losses, and present technical knowledge.(18,23) Fluctuating use of hot water will

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*The Coefficient of Performance (C.O.P.) is well understood, having been treated many times in refrigeration literature. It is the ratio of the heat capacity of the system to the heat equivalent of the energy supplied to the compressor. The Performance Ratio is the ratio of the heat delivered to the heat equivalent of the energy supplied the compressor. Stated as equations as used in this thesis:

$$\text{C.O.P.} = \frac{\text{Useful Refrigeration in BTU}}{\text{Electrical Energy Input to Milk Cooler in BTU}}$$

$$\text{P.R.} = \frac{\text{Useful Heat Output in BTU}}{\text{Electrical Energy Input to Milk Cooler in BTU}}$$

have a decided effect on the performance ratio of the heat pump unit. Large daily draw-offs cool the condensing water, thereby, allowing better performance of the refrigeration unit.

MATERIALS AND EQUIPMENT

A) Milk Cooler

The tests were started with a conventional "Unico" four can, spray type, milk cooler, using Freon-22 refrigerant. Tecumseh Products Company manufactured the hermetic refrigeration system compressor.

The cooler consists of: (a) the insulated cabinet, 2 in of fibreglass on the top and sides, and 3 in on the bottom; (b) a separate vertical tank about 3 ft high inside the cabinet holds water to the height of the overflow in the side of the tank; (c) distribution troughs located above the milk can area to receive water from the overflow in the vertical tank; (d) a circulating pump, similar in principle to a "sump pump," lifts the water from the bottom of the cabinet into the vertical tank (the lower 4 in section of the cabinet serves as a reservoir for water); (e) a pump time switch that controls the length of time that water is sprayed over the cans, and (f) a refrigeration system consisting of compressor, an air condenser, a copper tube evaporator, suspended in the vertical tank, and a thermostatic switch that controls the thickness of the ice bank on the evaporator. The manufacturer's specifications for the milk cooler are shown in Appendix D.

B) Water Heater

A conventional water heater, (See Figure 1), consisting of (a) a 52 gal galvanized iron tank; (b) three in of glass wool insulation; (c) an outer shell of enameled sheet metal, an upper heating unit of

1500 watts, thermostatically controlled; and (d) a lower heating unit of 1000 watts, thermostatically controlled, was used without modification throughout the tests.

C) Pressure Gauges and Recording Instruments

Gauges: A compound gauge, Frigidaire Type AMP 9567, with a range of 30 in vacuum to 60 psi was connected to the suction line near the compressor. A pressure gauge, Frigidaire Type 13163-1, with a range of 0-300 psi, was mounted near the capillary tube on the high pressure side. When the milk cooler system was modified, two of these pressure gauges were mounted on the milk cooler control panel and connected in the liquid line between the water condenser and the capillary tube. For this latter arrangement, a Bristol, Model 44, key-wind, 24-hr chart pressure recorder was connected to the multiple valve located in the liquid line (See Figure 2). This instrument had a range of 30 in vacuum to 50 psi.

Recording Potentiometer: A 16-point strip-chart recording potentiometer made by the Brown Instrument Company, Model 153 x 60P16-X1N, was used for the tests. This instrument, with a range of -50 F to 300 F, recorded at eight min intervals the temperatures indicated by each of the sixteen copper-constantan thermocouples (See Figure 3).

Recording Wattmeter: Two General Electric recording wattmeters, type CD 14, were used, one for the milk cooler, and one for the water heater.

To bring the one kw maximum range of the meters into the range of electric power used, General Electric Model No. 9JP1F4B2 current transformers were used, one with each wattmeter (See Figure 4).

Watthour Meter: Two Sangamo, type HC, watthour meters were used to determine separately the energy consumption of the milk cooler and water heater.

D) Miscellaneous

Solenoid Valve: A magnetic solenoid valve was connected to the outlet of the pre-heat tank as an overflow control. This valve was operated by a thermostatic switch located on the meter panel with the bulb of the switch attached to the side of the pre-heat tank.

Other pieces of equipment and materials used in assembling and constructing the test unit were a dehydrator, weigh-tanks, scales, water shut-off valves and galvanized water pipe. Three-eights in copper tubing and various fittings were used to inter-connect the refrigeration unit with the one-half in tubing used in the pre-heat tank coil.

Electric Power: The power supply used by the milk cooler compressor and pump motors was 115 volt alternating current, while that used by the water heater was 230 volts alternating current.

Water: Water used in the milk cans and water heater was taken from the Virginia Polytechnic Institute water supply.

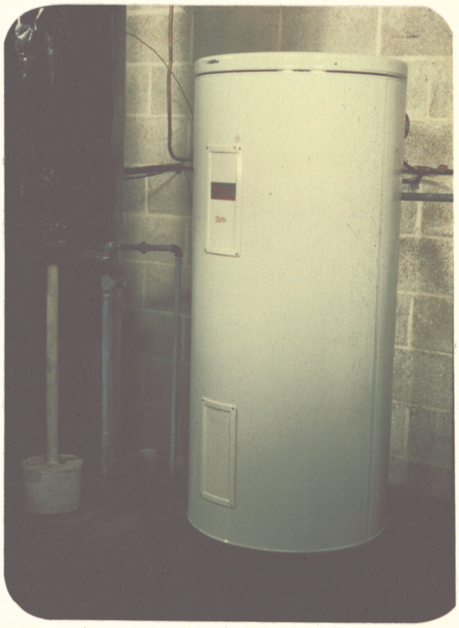


FIGURE 1

A 52 gal electric water heater was used in this study. Each of the heating units was controlled by an individual thermostat

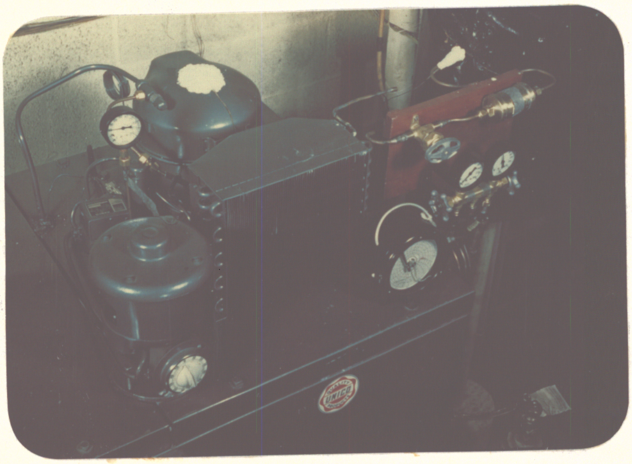
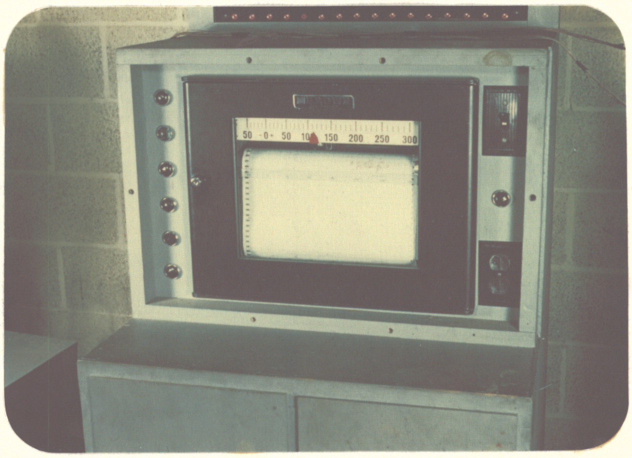


FIGURE 2

The pump motor, refrigeration unit, gauges, and some of the thermocouple locations are shown in this photograph. The white patch on the dome of the compressor covers a thermocouple.

FIGURE 3

This 16-point strip chart temperature recorder was used in making the temperature records.



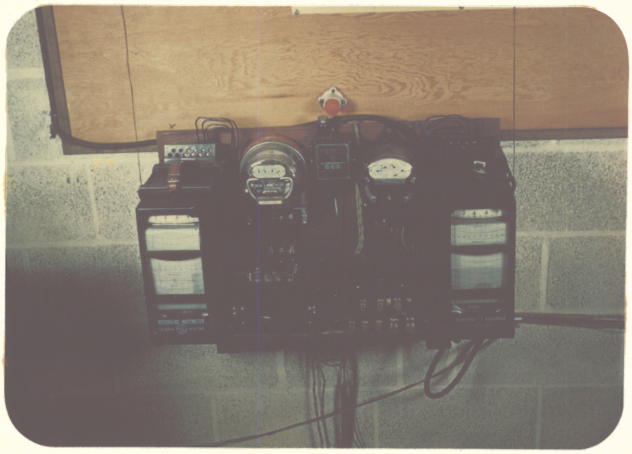


FIGURE 4

Mounted on the meter panel pictured were the kwhr meters, watt meters, transformers, and thermostatic switch with indicator light.

PROCEDURE

A. Test Procedure

The milk cooler and electric water heater were first operated as separate units as they are normally operated on a dairy farm. Then the air condenser of the milk cooler refrigeration unit was replaced by a specially designed copper condensing coil placed in a pre-heat tank. (See Figure 5 and 6). Tap water was then preheated in this tank before entering the electric water heater.

Electrical energy consumption and cycles of operation of the milk cooler and water heater were recorded for all tests. Temperatures determined by using copper-constantan thermocouples were recorded at the following places: (a) water at the top of the electric water heater; (b) five points on the pre-heat tank; (c) five points in one of the milk cans placed in the milk cooler; (d) inlet and outlet lines of the air condenser; (e) inlet and outlet lines of the condenser coil of the pre-heat tank, and (f) ambient.

In all tests involving the milk cooler, water was used in the milk cans. Although an average specific heat for milk is 0.93, the average weight is approximately 8.6 pounds per gallon, which gives about the same heat content as water in the temperature range of 90 to 40 F.(2)

The average temperature of milk placed in a milk cooler is approximately 90 F. To simulate this condition, water from the hot and cold water taps was mixed in each milk can to a temperature of 90 F. After very little practice, and a lot of stirring with a wooden paddle, a temperature of 90 F as measured with a mercury thermometer, was readily obtained (See Figure 7).

SCHEMATIC DIAGRAM OF MAJOR TEST EQUIPMENT

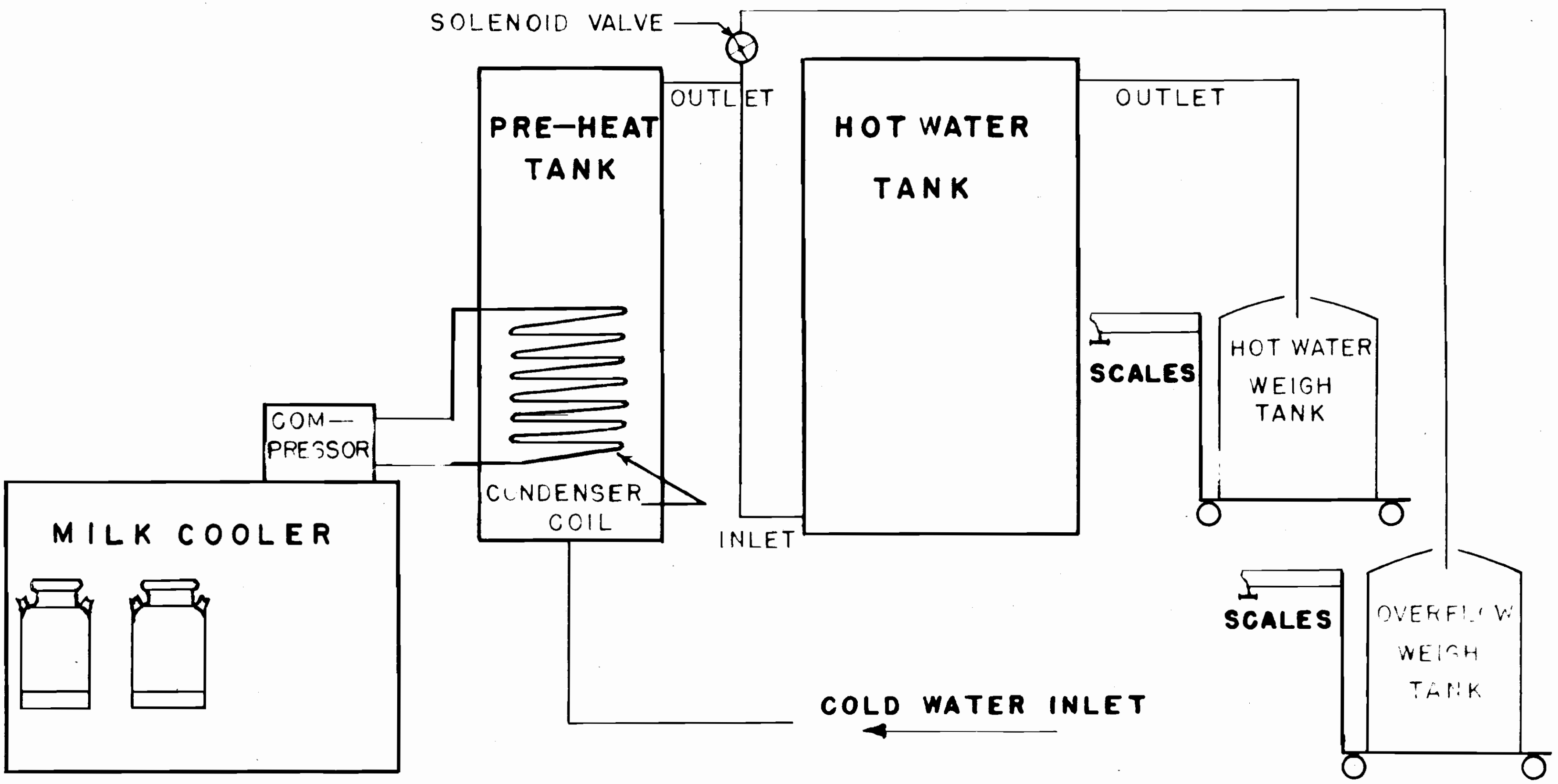


FIGURE 5

FIGURE 6

The major equipment used in the study is shown in this picture. The 16-point temperature recorder on the left is adjacent to the milk cooler. The instrument panel was mounted above the milk cooler. The pre-heat tank, electric water heater, and weigh tank are shown to the right of the cooler.

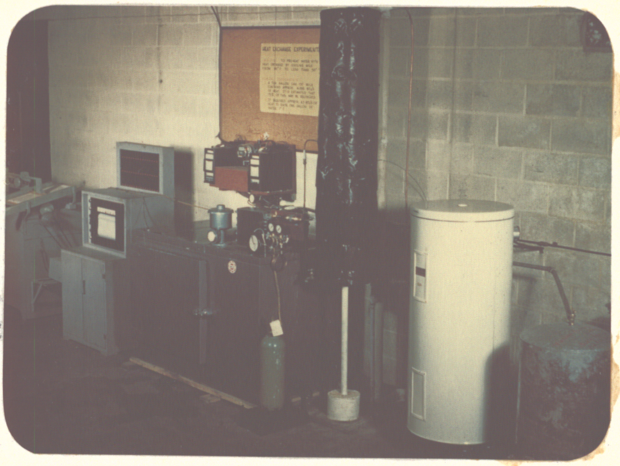


FIGURE 7

Before each test, hot and cold water was mixed in the milk cans until a temperature of 90 F was obtained.

In cooperation with the Dairy Department of the Virginia Polytechnic Institute, it was estimated that a dairy farm producing four 10-gallon cans of milk per day would use 68 gal of approximately 150 F water for washing, rinsing, and sterilization of equipment.(3) Much of the 34 gal drawn off for each of the two milking periods normally would be mixed with colder water until it becomes comfortable for the hands while washing the utensils. Some of this water would be used at intervals throughout the milking period with the largest portion being used at the end for washing and rinsing equipment. To provide what appeared to be a reasonable rate of water consumption, the following procedure was used:

At 8:00 p.m., four gal of approximately 150 F water were drawn from the water heater into a weigh-tank (See Figure 8). Four gal were again drawn for the next three consecutive 15-minute periods, making a total of 16 gal. Fifteen minutes later, or one hour after the start of the test, 18 gal of water were drawn, making a total of 34 gal for the assumed milking period.

At 8:30 p.m., one-half hour after the start of the test, the first can of water was placed in the milk cooler, and the spray pump operated for 30 minutes (See Figure 9). The second can was placed in the cooler at 9:00 p.m., and the spray motor time clock set to operate for one hour. The five thermocouples were placed in this second can (See Figure 10).

At 8:00 a.m., twelve hours after the start of the test, the procedure for drawing water from the water heater was repeated, resulting in the withdrawal of a total of 68 gal per day. A third can of 90 F water was

FIGURE 8

The scales and tank used to measure the amount of hot water drawn from the electric water heater are pictured at the right.

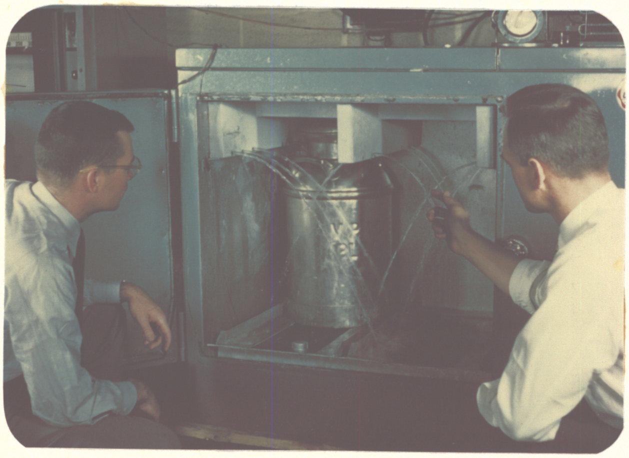


FIGURE 9

Cooling of the milk cans was accomplished by a spray of chilled water as shown here.

placed into the cooler at 8:30 a.m., and the spray pump operated until the fourth and last can was placed in the cooler at 9:00 a.m. At this time, the thermocouples were placed in the fourth can. It was assumed that the dairy farm was so located on the route of the pick-up truck that the two cans of milk produced in the morning would remain in the milk cooler for an hour along with the two cans produced the previous night. Therefore, at 10:00 a.m. all four cans were removed from the cooler. The milk cooler was then empty for the remainder of the day, as it would normally be on a dairy farm. The procedure heretofore outlined was followed for the 12 runs before the pre-heat tank was installed as well as for the 13 runs after it was installed.

In order to be sure that the compressor would not be operating against dangerously high condensing pressures during the tests with the pre-heat tank, a thermostatically controlled solenoid valve was placed at the outlet of this tank (See Figures 1 and 11). This valve released small quantities of water to a weigh-tank when the water surrounding the condensing coil, at approximately one-half its length from the inlet, attained a temperature of approximately 110 F. The water released by this valve was weighed and the results are tabulated in Table 5. Should the refrigeration unit fail to cut off at the end of the cooling period, this valve would also serve as a safety device, admitting colder water into the pre-heat tank.

Individual recording wattmeters and kwhr meters were used for the milk cooler and water heater (See Figure 4). Readings of the kwhr meter, associated with a piece of equipment, were recorded at the beginning and end of each 24 hr test period. The recording wattmeters gave a continuous record of the electrical demands of each unit. The milk cooler

FIGURE 10

Temperatures in the milk cans were determined by copper constantan thermocouples mounted on a rod. The rod was in turn attached to the lid of the can. The can with the thermocouples in place in shown here.

FIGURE 11

A thermostatically controlled solenoid valve pictured at the left was mounted near the outlet of the pre-heat tank.

kwhr meter was calibrated to read in tenths, while the one for the water heater was calibrated in hundredths.

Obviously, the use of a refrigerating system of a different design might result in an entirely different water temperature in the pre-heat tank. To approximate the electrical energy consumption of the electric water heater when other water temperatures prevailed in the pre-heat tank, water of 95 F to 135 F in steps of approximately 5 degrees was admitted to the water heater. Complete records were kept of the energy requirements and operating time of the electric water heater. The procedure mentioned earlier for drawing 68 gal of approximately 150 F water from the water heater in 24 hr was followed.

B. Design and Construction Procedure

Most of the equipment required for these tests was available before the study was undertaken. However, it was necessary to design and construct the condensing coil for the pre-heat tank and modify the tank itself. Preliminary estimates indicated that a 30 gal pre-heat tank would be suitable for the purpose of the study, and one of this size was obtained.

Tank: The tank was a 30-gal galvanized iron water tank, such as was commonly used some years past in conjunction with a kitchen range heating coil (See Figure 12). A 2 3/4 in section of 8 in wrought iron pipe coupling was first welded to the top of the tank. Then, the end of the tank inside the pipe was burned out with an acetylene burning torch. To close this opening, a plug was constructed from a short section of threaded 8 in wrought iron pipe, to which a cap plate was welded (See Figure 13). To this cap, one 3/4 in and one 1/2 in pipe couplings were welded (See Figure 16). To provide openings from the couplings to water in the tank, the cap metal inside the couplings was then removed with a drill. The 3/4 in coupling was connected to the inlet pipe of the electric water heater. A thermocouple wire was inserted through the 1/2 in coupling and satisfactorily sealed. Tap water was connected to the 3/4 in pipe connection at the center of the bottom of the pre-heat tank.

Condensing Coil: The quantity of heat conducted through a substance per unit of time is proportional to the area through which the heat flows and to the temperature difference. Stated as a formula: $Q = UA\Delta t$.

FIGURE 12

A 30 gal galvanized iron water tank was used for the pre-heat tank. The tank as seen above was before modification.

FIGURE 13

To provide an opening for placing the condensing coil inside the tank, a section of an eight inch coupling was welded to the top of the tank. The cap made from a plate welded to a section of pipe coupling is also shown in this view.

The over-all heat transfer coefficient, U, of a condensing refrigerant can be separated into four components. These are (a) the refrigerant vapor film, (b) the refrigerant condensate film, (c) the tube wall, and (d) the cooling water film.* The first two components may be combined by assuming that the total thermal resistance lies in the film of condensate, through which the latent heat of condensation is conducted, neglecting the cooling of the condensate.(10) These three resistances are combined in determining the over-all heat transfer coefficient by using the following formula:

$$U = \frac{1}{\frac{1}{h_f} + \frac{1}{h_c} + \frac{1}{h_w}}$$

Twenty-five ft of 1/2 in copper tubing was used for the condensing coil. To arrive at this value, calculations were made for the heat load that would have to be removed in a 24 hr period (See Appendix B). The heat transfer losses through the milk cooler cabinet walls, ceiling and floor based on 80 F ambient and 40 F milk cooler temperature were calculated to be 5,877 BTU per 24 hrs.

Published data pertaining to air changes(1) are for larger refrigeration units. Because of the limited number of times the door would be opened each day, five air changes would be reasonable for this type of

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* An old tube might have an additional resistance due to scale deposit. This scale may be outside the tube as a result of impure cooling water, or may be inside the tube as a result of oil in the refrigerant. For this experiment, a new, clean tube was used, which eliminated this additional component.

box and the methods of loading. This resulted in a calculated infiltration load of 349 BTU per 24 hrs.

The calculated product load, including 330 pounds of water and 106 pounds of galvanized iron cans, based on cooling from 90 F to 44 F, was 15,814 BTU per 24 hrs. Therefore, the total calculated heat load for the milk cooler cabinet for a 24 hr period was 22,040 BTU. In addition, considerable heat could be expected to be imparted to the refrigerant from the sealed-in motor and compressor. It was calculated that this would amount to 22,128 BTU per 24 hrs of operation. Combining these values, the total amount of heat estimated to be available for preheating water was 44,168 BTU per 24 hrs of operation.

On the basis of the refrigeration unit of the milk cooler operating 16 hrs per day, the theoretical amount of heat to be removed each hr averaged 2,302 BTU. A temperature difference of 40 F was assumed between the refrigerant condensate and the condensing water. From these two values and the over-all coefficient of heat transfer, a tube area of 1.78 sq ft was calculated, using the formula: $A = Q/U\Delta t$. The high pressure lines from the compressor to the pre-heat tank coil were necessarily longer than the original ones to the 3/8 in O.D. tubing air condenser. To eliminate any additional back pressure on the compressor, as a result of increased length of tubing, 1/2 in copper tubing was selected for the coil. With this size, a tube length of 15.1 ft was required, based on the formula: $L = A/D$. This length was increased to 25 ft for the reasons stated in Appendix A. A six-in mean diameter turn was the largest that could be conveniently fitted into the tank (See Figure 14). This resulted in a coil of 16 turns (See Figure 15).

Insulation: After the condensing coil had been secured inside the pre-heat tank and the plug fitted into the top of the tank, 2 in, blanket type, rock wool insulation was wrapped around the tank (See Figure 16). Two in of insulation was thought to be adequate for the study, considering that commercial water heaters of comparable size, and operating at considerably higher water temperatures than anticipated in the pre-heat tank, have approximately three in of insulation with coefficient of heat transfer values close to that of rock wool. Cord, and then four-ply bituminous treated building paper wrapped with wire, held the insulation in place (See Figures 17 and 18). To decrease the heat loss from the 3/4 in pipe, connecting the outlet of the pre-heat tank to the inlet of the water heater, 85 per cent magnesium insulation was used.

Temperature Measurements: Copper-constantan thermocouples were used for all tests. Exclusive of those within the milk cooler, thermocouples were immersed in the water in the following locations: (a) top of the pre-heat tank; (b) the inlet line of the pre-heat tank; (c) the inlet line of the water heater; and (d) the outlet line of the water heater. The thermocouple wires passed through 1/2 in pipe nipples and a suitable pipe fitting for the particular location, and the openings were sealed to prevent leaks (See Figure 19). Thermocouples that would have been exposed directly to the room air were held in place with rubber tape, then covered with asbestos insulations (See Figure 2).

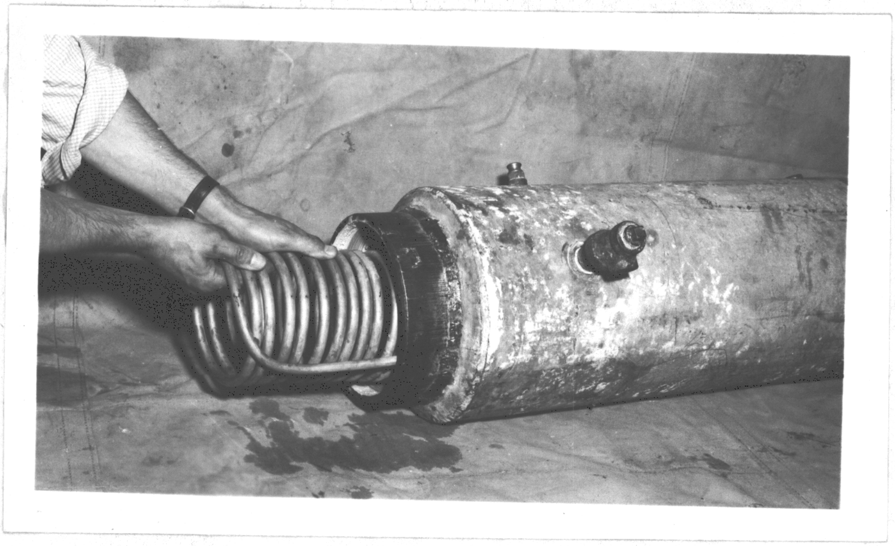

FIGURE 14

A coil of 6 in mean diameter was about the largest that would conveniently pass through the tank opening. The coil is shown above as it was being placed into the tank.

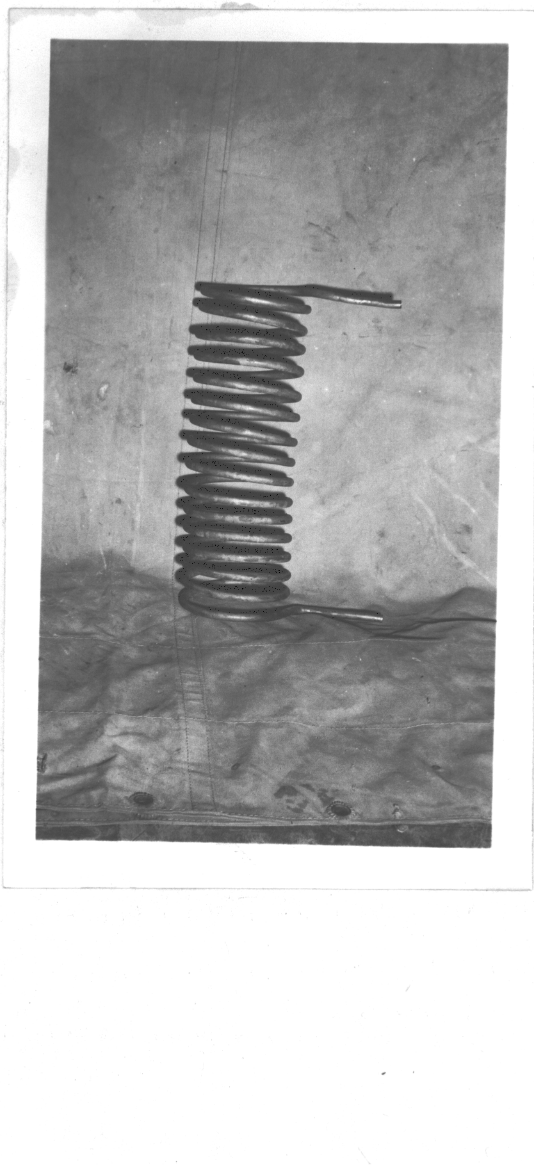

FIGURE 15

The condensing coil for the preheat tank is pictured at the left. It had 16 turns of one-half in copper tubing.

FIGURE 16

Two inch blanket type rock wool insulation was wrapped around the pre-heat tank and secured in place with cord. Pipe couplings were welded to the top of the eight inch plug for the water outlet and a thermocouple.

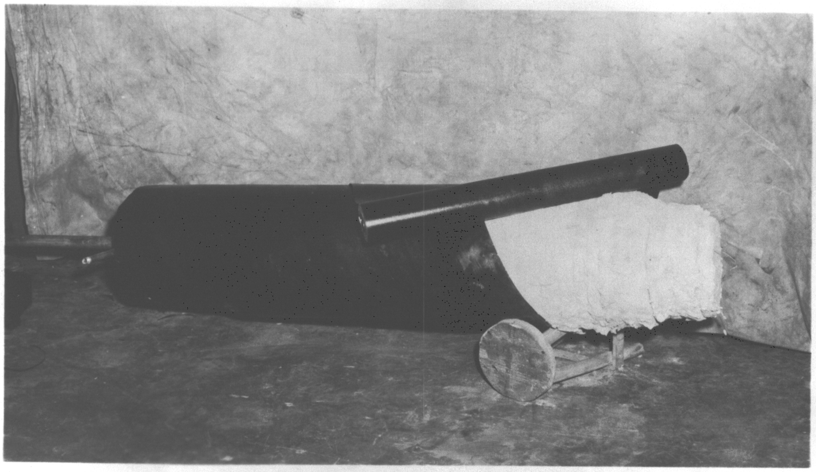

FIGURE 17

As an additional support for the insulation, building paper was used as shown above. The paper was held in place with wire.

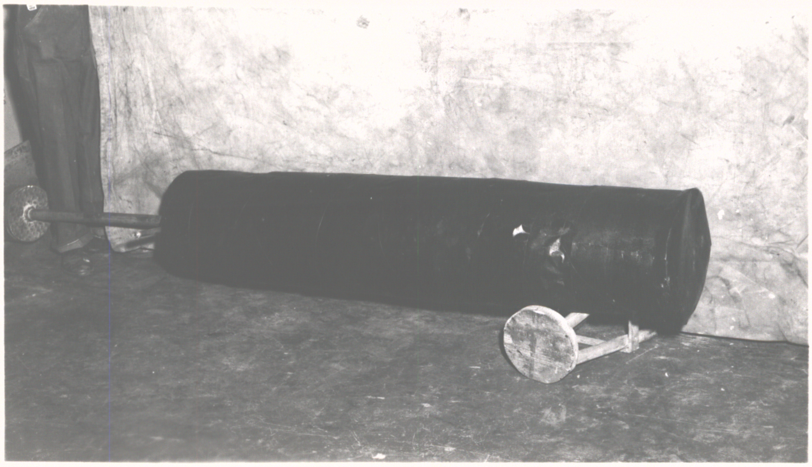

FIGURE 18

The completely insulated pre-heat tank is shown above. The 1 1/4 in supporting pipe and base can be seen.

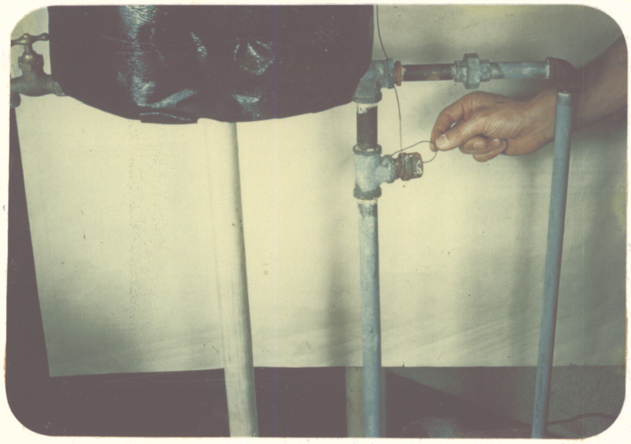

FIGURE 19

To seal the opening through which the copper-constantan thermocouple wires passed, a solid rubber stopper, such as used in a chemistry laboratory was sliced axially to the center to receive the two thermocouple wires. The rubber stopper was compressed with a 1/2 in pipe cap drilled at the end to admit the wires, as shown at the left.

Those located on the side of the pre-heat tank were secured in place with scotch tape and then covered with rock wool insulation to the same 2 in thickness as the rest of the tank.

Five thermocouples were spaced on a wooden rod and supported by the can lid, as shown in Figure 20, for measuring temperatures in the milk can. With this arrangement, the top thermocouple was one and three-quarters in below the surface of the water, the lowest thermocouple, one and three-quarters in from the can bottom, with the three remaining thermocouples spaced four in on center between the other two.

Temperatures of the milk cooler water was observed by a thermocouple located in the center and one in below the surface of the water in the bottom of the storage compartment.

Thermocouple locations for all tests are shown in Tables 1 and 2.

FIGURE 20

The thermocouple device for measuring temperatures in the milk can is shown above.

TABLE 1

Milk Cooler and Water Heater in Conventional Arrangement

Thermocouple Number	Location
1	Milk Can
2	Milk Can
3	Milk Can
4	Milk Can
5	Milk Can
6	Water in Bottom of Milk Cooler
7	Top of Air Condenser
8	Inlet of Air Condenser
9	Outlet of Air Condenser
10	Tap Water
11	Top of Water Heater
12, 13, 14, 15, 16	Ambient--3 ft Above Floor

TABLE 2

Milk Cooler and Water Heater With Pre-Heat Tank

Thermocouple Number	Location
1	Milk Can
2	Milk Can
3	Ambient--3 ft Above Floor
4	Milk Can
5	Milk Can
6	Water in Bottom of Milk Cooler
7	Thermostatic Switch Bulb Location on Side of Pre-heat Tank
8	Top of Compressor
9	Two in From Bottom of Pre-heat Tank
10	Tap Water
11	Top of Water Heater
12	Outlet of Pre-heat Tank Coil
13	Top of Pre-heat Tank
14	1/4 Distance From Bottom On Side of Pre-Heat Tank
15	1/2 Distance From Bottom On Side of Pre-Heat Tank
16	Inlet of Pre-Heat Tank Coil

RESULTS

The results obtained from this experiment, including observed readings are shown in Tables 3 through 7 and Figures 24 to 29, inclusive. All of the curves in Figures 24 through 29 were plotted from the temperature recordings of the strip-chart recorder, with a machine designed for work of this type (See Figure 21).

The milk cooler consumed an average of 7.45 kwhr of electric energy in an average operating time of 14 hrs-30 min out of the 24 hr with the air condenser in the refrigeration system (See Table 3). Energy consumption ranged from 7.1 to 7.6 kwhr for the eleven complete tests. Eight of these results were within two percent of the average. Operating time ranged from 14 hrs-15 min to 14 hrs-35 min, with six of those results within one percent of the average.

After substituting the coil in the pre-heat tank for the air condenser, the milk cooler consumed an average of 7.26 kwhr of electric energy in an average operating time of 15 hrs-13 min out of the 24 hrs (See Table 4). Energy consumption ranged from 7.2 to 7.3 kwhr for the ten complete tests. All test results were within one percent of the average. Operating time ranged from 14 hrs-59 min to 15 hrs-33 min, with five of the results within one percent of the average.

Figures 24 and 25 indicate that the rates of cooling of the water in the milk cans were not significantly different for the milk cooler in conventional arrangement and for the milk cooler in combination with the pre-heat tank. The maximum temperature reached by the thermocouples in the milk cans was 83 F for the first situation while the maximum temperature reached in the second situation was 82 F. Variation in temperature of the water in the bottom of the milk cooler during the first hour of cooling was a result of shutting-off of the spray system water pump at the time of placing another can into the milk cooler. Temperatures within the cabinet were influenced by ambient temperatures as shown between the hours of 8 to 13 on Figure 25 and between the hours of 14 to 20 on Figure 24.

In the conventional arrangement, the water heater consumed an average of 17.12 kwhr of electric energy in an average operating time of 15 hrs-5 min when 68 gal of 150 F water were withdrawn in 24 hrs (See Table 5). Energy consumption ranged from 17.06 to 17.26 kwhr for the six complete tests. All six results were within one percent of the average. Operating time ranged from 15 hrs-00 min to 15 hrs-10 min with all results within 0.6 percent of the average.

With the pre-heat tank arrangement, the water heater used an average of 11.92 kwhr of electric energy in an average operating time of 10 hrs-28 min, when 69 gal of 150 F water were withdrawn in 24 hrs (See Table 6). Energy consumption ranged from 11.58 to 12.06 kwhr for the nine complete tests. Six of these results were within one percent of the average. Operating time ranged from 10 hrs-16 min to 10 hrs-37 min, with five of the results within one percent of the average. Under these conditions, 30.2 percent of the water heater electric energy consumption was saved by placing the refrigeration condenser in the pre-heat tank.

In addition to the 249 pounds of 95.9 F water in the pre-heat tank at the time the refrigeration unit stopped operating for each 12 hr milking period (See Appendix C), there was an average of 167 pounds of 115.8 F water passed through the solenoid valve to the overflow tank. The quantity of water in the overflow tank ranged from 148 to 185 pounds, while the temperatures ranged from 115 F to 116 F (See Table 5).

As shown in Table 7, an average Performance Ratio of 1.41, with a range of 1.34 to 1.47 was attained with the heat pump. The average Coefficient of Performance was 1.27, with a range of 1.25 to 1.33.

As shown on Figure 26, the maximum temperature at the inlet of the air condenser was 153 F. At this time, the outlet temperature was 105 F. Ambient temperature was approximately 80 F. Water temperature in the bottom of the cabinet reached a low of 35 F when two cans of water were being cooled, and a low of 38 F when the milk cooler had a capacity load of four cans. The characteristic temperature rise of the water in the bottom of the cooler due to the interruption of the spray system can also be seen in this chart.

Figure 27 shows maximum temperature of 189 F at the inlet to the pre-heat tank coil. At this time, the top of the shell of the sealed refrigeration unit reached a maximum temperature of 185 F. Temperatures at the outlet of the pre-heat tank coil reached a maximum of 116 F. The 8:00 a.m. to 8:00 p.m. period showed six ripples in these curves, while the 8:00 p.m. to 8:00 a.m. period showed five ripples. This corresponds in time to the openings of the solenoid valve to discharge water to the overflow tank, as shown in Figure 22. Under the maximum cabinet load of four cans more heat was released to the condensing water. Greater variations in temperatures were noted at the coil outlet, which, of course, was nearest to the tap water inlet.

Figure 28 shows temperatures which existed at various points in and on the pre-heat tank. The maximum temperature at the top of the tank was 122 F. Temperatures midway of the tank, at the same level as the coil inlet, followed very closely temperatures at the top for most of the test period. These midpoint temperature values decreased earlier and more rapidly at the time of withdrawals of large quantities of water from the water heater.

Water temperature in the upper half of the tank did not vary noticeably with solenoid valve operation. Temperatures 43 in and 53 in from the top of the tank, the latter being in line with the coil outlet, indicate very definitely each time water was released to the overflow weigh -tank (See Curves 3 and 5 of Figure 28). The greatest variation of these two positions was in the one farthest from the tap water inlet at the center of the bottom of the tank. Water temperatures 64 in from the top or two in from the bottom of the tank varied little during a test (See Curve 6, Figure 28). Maximum temperature of 75 F reached at this point was recorded during the two periods when large quantities of water were withdrawn, resulting in maximum circulation of water within the tank. Curves 5 and 6, Figure 28, representing temperatures from the lowest coil turn to the bottom of the tank indicate that water temperature in the lower part of the tank was raised on an average of approximately 10 F above that of entering water.

Figure 29 shows typical water temperatures obtained at the top of the water heater, top of the pre-heat tank, and for tap water. The variation at the water heater was slight compared to that at the pre-heat tank. This was expected, as the thermostatically controlled heating element of the water heater responded quickly to water temperature change. Also, the entire 52 gal of water was approximately 150 F at the beginning of each 12 hr milking period. With 34 gal of water withdrawn over an hour period, temperatures at the top of the tank did not change very much.

Figure 22 shows a representative chart of suction pressures for a 24 hr period. For approximately 45 min after the beginning of a milking period, pressures were considerably below those for the remainder of the cycle. These low pressures occurred at the time water was withdrawn from the water heater, and cool tap water entered the pre-heat tank.

At no time during any of the test runs was the 1500 watts, upper unit of the water heater required to operate. The lower 1000 watt unit provided sufficient heat to maintain a water temperature of approximately 150 F under the conditions of the test.

A series of tests were run to determine the electrical energy required for the water heater when water ranging from 95 F to 135 F was admitted to the water heater. Results are shown in Table 6 and Figure 23. The curve in Figure 23 was plotted from the data of Table 6. Comparison was made to the 17.12 kwhr consumed by the water heater when approximately 62 F tap water replaced that withdrawn from

FIGURE 21

A specially developed machine for making continuous graphs from recordings of the Strip-Chart Recorder is shown at the right.

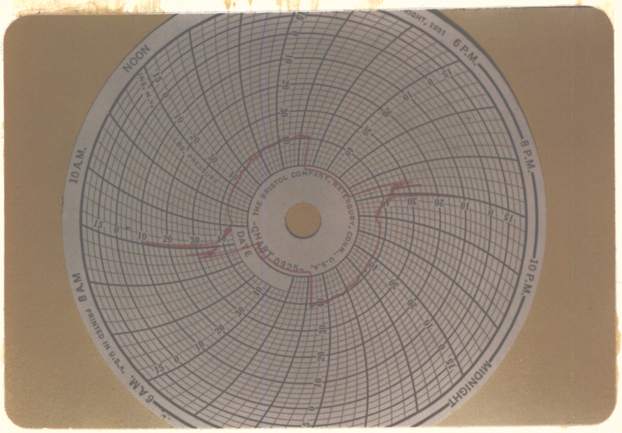

FIGURE 22

The suction pressure chart pictured here is typical of those obtained while the pre-heat tank was in the circuit.

the heater. When 110 F water entered the water heater, the savings on energy for the water heater were 45 percent. Similarly, for 120 F water, the energy savings were 56 percent.

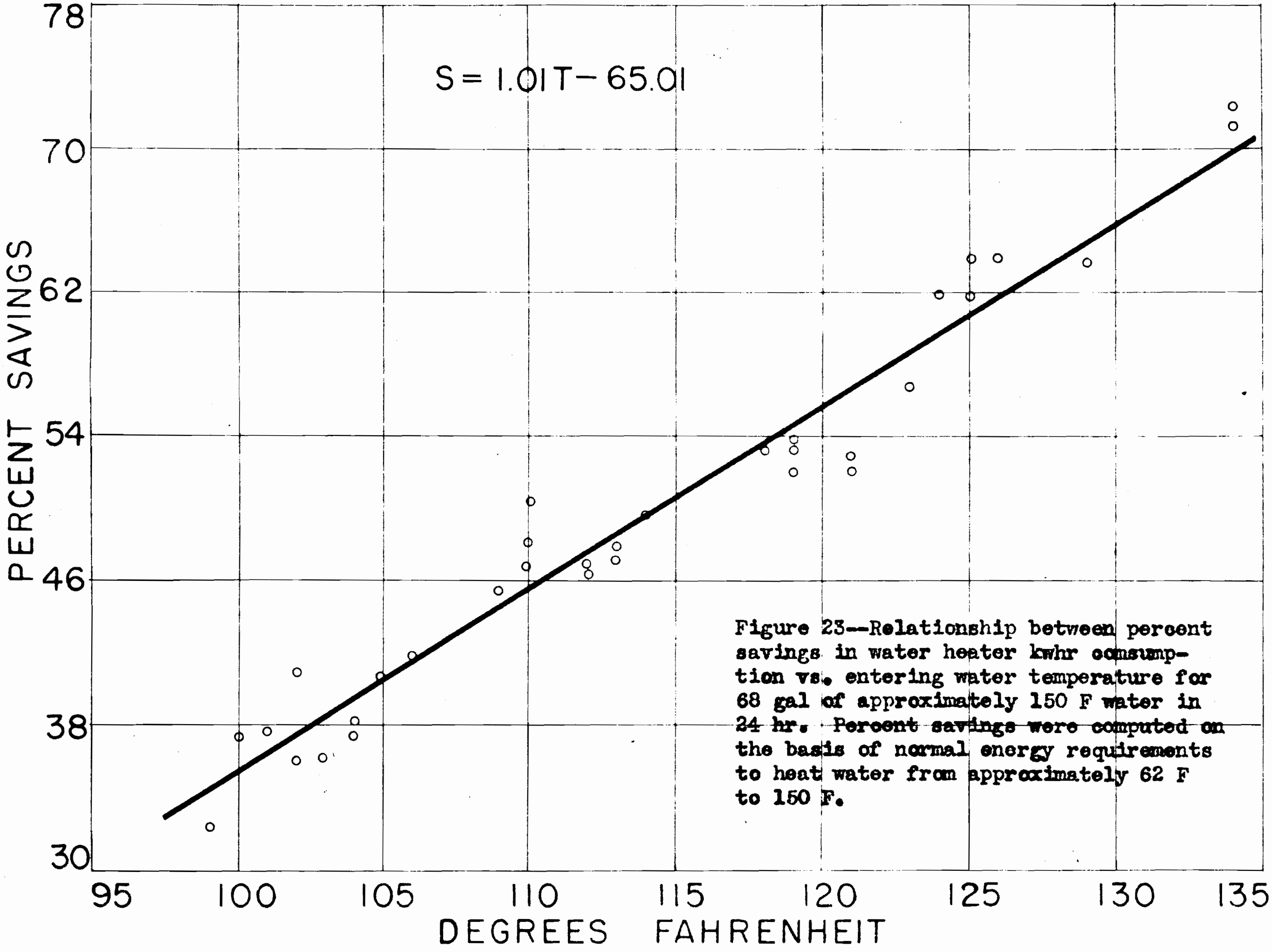

Figure 23--Relationship between percent savings in water heater kwhr consumption vs. entering water temperature for 68 gal of approximately 150 F water in 24 hr. Percent savings were computed on the basis of normal energy requirements to heat water from approximately 62 F to 150 F.

TABLE 3

ELECTRICAL ENERGY CONSUMPTION
AND
TIME OF OPERATION FOR MILK COOLER
IN
CONVENTIONAL ARRANGEMENT

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption in kwhr for 12 hrs	Energy Consumption in kwhr for 24 hrs	Hours Operation in 24 Hours	
					Hrs	Min
1	8 a.m.	702.5				
			3.5			
	8 p.m.	706.0		7.1	*	*
			3.6			
2	8 a.m.	709.6				
			3.7			
	8 p.m.	713.3		7.3	14	15
			3.6			
3	8 a.m.	716.9				
			3.7			
	8 p.m.	720.6		7.5	14	21
			3.8			
4	8 a.m.	724.4				
			3.7			
	8 p.m.	728.1		7.5	14	22
			3.8			
5	8 a.m.	731.9				
			3.8			
	8 p.m.	735.7		7.6	14	35
			3.8			
6	8 a.m.	739.5				
			3.9			
	8 p.m.	743.4		7.1	13	36
			3.2			

(continued)

TABLE 3 (continued)

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption in kwhr for 12 hrs	Energy Consumption in kwhr for 24 hrs	Hrs Operation in 24 Hours	
					Hrs	Mins
7	8 a.m.	746.6				
	8 p.m.	*	*	*	*	*
8	8 a.m.	*	*			
	8 p.m.	758.0	3.8	7.6	14	35
9	8 a.m.	761.8	3.8			
	8 p.m.	765.6	3.8	7.6	14	39
10	8 a.m.	769.4	3.8			
	8 p.m.	773.1	3.7	7.6	14	34
11	8 a.m.	777.0	3.9			
	8 p.m.	780.7	3.7	7.6	14	35
12	8 a.m.	784.6	3.9			
	8 p.m.	TC				
			Ave =	7.45	14 hr	30 min

* Incomplete Tests
TC Tests Completed

TABLE 4

ELECTRICAL ENERGY CONSUMPTION AND TIME OF OPERATION FOR MILK COOLER AFTER MODIFICATION WITH PRE-HEAT TANK

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption In kwhr for 12 hrs	Energy Consumption In kwhr for 24 hrs	Hours Operation in 24 Hours Hrs	Min
1	8 a.m.	892.6				
			4.2			
	8 p.m.	896.8		7.2	15	00
			3.0			
2	8 a.m.	899.8				
			*			
	8 p.m.	**		**	*	*
			*			
3	8 a.m.	907.5				
			3.6			
	8 p.m.	911.1		7.3	15	30
			3.7			
4	8 a.m.	914.8				
			3.7			
	8 p.m.	918.5		7.3	15	05
			3.6			
5	8 a.m.	922.1				
			3.7			
	8 p.m.	925.8		7.3	15	25
			3.6			
6	8 a.m.	929.4				
			*			
	8 p.m.	**		**	*	*
			*			
7	8 a.m.	936.9				
			3.7			
	8 p.m.	930.6		7.2	15	33

(continued)

TABLE 4 (continued)

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption in kwhr for 12 hrs	Energy Consumption in kwhr for 24 hrs	Hours Operation in 24 Hours	
					Hrs	Min
7	8 p.m.	930.6			***(repeated)	
			3.5			
8	8 a.m.	944.1				
			3.7			
	8 p.m.	947.8		7.3	15	15
			3.7			
9	8 a.m.	951.4				
			3.7			
	8 p.m.	955.1		7.2	14	59
			3.5			
10	8 a.m.	958.6				
			3.7			
	8 p.m.	952.3		7.3	15	08
			3.6			
11	8 a.m.	965.9				
			3.6			
	8 p.m.	969.5		7.3	15	12
			3.7			
12	8 a.m.	973.2				
			3.5			
	8 p.m.	976.7		7.2	15	06
			3.7			
13	8 a.m.	980.4				
	8 p.m.	TC				
			Avg =	7.26	15 hrs	13 min

* Incomplete Tests
TC Tests Completed
*** This data repeated from previous page for clearness of table.

TABLE 5

ELECTRICAL ENERGY CONSUMPTION AND TIME OF OPERATION FOR WATER HEATER IN CONVENTIONAL ARRANGEMENT

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption In kwhr For a 12 hr period	Energy Consumption In kwhr For a 24 hr period	Hours Operation in 24 Hours	
					Hrs	Min
1	8 a.m.	087.33				
			8.52			
	8 p.m.	095.85		17.06	15	06
			8.54			
2	8 a.m.	104.70				
			8.46			
	8 p.m.	113.16		17.07	15	04
			8.61			
3	8 a.m.	121.77				
			8.72			
	8 p.m.	130.49		17.09	15	03
			8.37			
4	8 a.m.	138.86				
			8.59			
	8 p.m.	147.55		17.15	15	10
			8.46			
5	8 a.m.	156.01				
			8.48			
	8 p.m.	164.49		17.09	15	00
			8.61			

(continued)

TABLE 5 (continued)

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption In kwhr For a 12 hr period	Energy Consumption In kwhr For a 24 hr period	Hours Operation in 24 Hours Hrs	Min
6	8 a.m.	173.10				
			8.71			
	8 p.m.	181.81		17.26	15	05
			8.55			
7	8 a.m.	190.36				
			8.73			
	8 p.m.	199.09		T.C.	T.C.	
			Avg. =	17.12	15 hr05 min	

T.C. Tests Complete

TABLE 6

ELECTRICAL ENERGY CONSUMPTION AND TIME OF OPERATION OF WATER HEATER WHEN USED IN CONJUNCTION WITH PRE-HEAT TANK

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption in kwhr for 12 hrs	Energy Consumption in kwhr for 24 hrs (X)	Hours Operation in 24 Hours	
					Hrs	Min
1	8 a.m.	383.44				
	8 p.m.	389.99	6.05	12.06	10	37
2	8 a.m.	396.00	6.01			
	8 p.m.	401.94	5.94	11.92	10	33
3	8 a.m.	407.92	5.98			
	8 p.m.	413.92	6.00	11.58	10	16
4	8 a.m.	419.50	5.58			
	8 p.m.	*	*	*	*	*
5	8 a.m.	432.87	*			
	8 p.m.	438.96	6.09	12.00	10	31
6	8 a.m.	444.87	5.91			
	8 p.m.	450.86	5.99	11.94	10	33
			5.95			

(continued)

TABLE 6 (continued)

Test Number	Time	Watt-Hour Meter Reading	Energy Consumption in kwhr for 12 hrs	Energy Consumption in kwhr for 24 hrs (X)	Hours Operation in 24 Hours	
					Hrs	Min
7	8 a.m.	456.81				
	8 p.m.	462.82	6.01	11.97	10	37
8	8 a.m.	468.78	5.96			
	8 p.m.	474.75	5.97	11.94	10	32
9	8 a.m.	480.72	5.97			
	8 p.m.	486.67	5.95	11.84	10	27
10	8 a.m.	492.56	5.89			
	8 p.m.	498.59	6.03	12.02	10	35
11	8 a.m.	504.58	5.99			
	8 p.m.	TC				
			Ave =	11.92	10 hr	28 min

* Incomplete Tests

TC Tests Completed

X This is not a true indication of possibilities for system as much hot water was released from pre-heat tank to weigh-tank (see table).

TABLE 7

PERFORMANCE FACTOR AND COEFFICIENT OF PERFORMANCE OF MILK COOLER WITH PRE-HEAT TANK

*Water in Pre-Heat Tank = 249 pounds

Test Number	Time	Pounds Water In Over-flow Tank	Avg. Temperature Rise of Water In Overflow Tank, F	Avg. Temperature Rise of Water In Pre-Heat Tank, F	Approximate Tap Water Temperature, F	BTU's Required for Water in Overflow Tank Plus Pre-Heat Tank *	BTU's Input to Milk Cooler	Performance Factor	Coefficient of Performance
3	8 a.m.	176	52.0	31.0	63	16,870	12,250	1.38	1.29
	8 p.m.	175	52.0	31.5	63	16,950	12,600	1.34	1.25
4	8 a.m.	185	53.6	33.3	62	18,200	12,600	1.44	1.25
	8 p.m.	170	53.2	33.0	62	17,270	12,250	1.41	1.29
5	8 a.m.	179	54.5	33.5	61	18,100	12,600	1.44	1.25
	8 p.m.	173	53.5	33.3	62	17,550	12,250	1.43	1.29
7	8 a.m.	***	***	33.8	61	***	***	***	***
	8 p.m.	148	53.4	33.5	63	17,650	12,600	1.40	1.25
8	8 a.m.	176	55.0	35.5	61	18,520	12,600	1.47	1.25
	8 p.m.	***	***	33.0	63	***	***	***	***
9	8 a.m.	167	54.6	34.6	61	17,720	12,600	1.41	1.25
	8 p.m.	148	54.0	33.4	62	16,320	11,900	1.37	1.33
10	8 a.m.	174	54.2	33.4	62	17,720	12,600	1.41	1.25
	8 p.m.	149	53.6	33.0	62	17,820	12,250	1.45	1.29
11	8 a.m.	153	54.9	33.7	62	16,790	12,250	1.37	1.29
	8 p.m.	172	53.5	33.7	63	17,590	12,600	1.40	1.25
12	8 a.m.	148	53.8	33.7	62	16,360	11,900	1.37	1.33
	8 p.m.	170	53.9	34.0	63	17,630	12,600	1.40	1.25
		Avg. 167	Avg. 53.8	Avg. 33.9	Avg. 62	Avg. 17,441	Avg. 12,403	Avg. 1.41	Avg. 1.27

TABLE 8

ELECTRICAL ENERGY CONSUMPTION AND TIME OF OPERATION OF WATER HEATER FOR ENTERING WATER TEMPERATURES IN THE RANGE OF APPROXIMATELY 95 F - 135 F

Test Number	Time	Temperature of Entering Water, F	Energy Consumption in kwhr for 12 hrs	Operating Time In 24 hrs		Average Ambient Temperature 3 ft Above Floor, F
				Hrs	Min	
1	8 a.m.	101	4.30	4	58	88
	8 p.m.	106	5.34	5	12	89
2	8 a.m.	100	4.98	4	34	86
	8 p.m.	102	5.36	5	11	86
3	8 a.m.	109	5.45	4	2	79
	8 p.m.	98	4.68	4	31	76
4	8 a.m.	102	5.79	4	39	79
	8 p.m.	103	5.07	4	47	82
5	8 a.m.	104	5.40	4	57	79
	8 p.m.	112	5.33	4	52	80
6	8 a.m.	110	4.55	4	8	82
	8 p.m.	119	4.43	4	9	83
7	8 a.m.	110	3.94	3	45	81
	8 p.m.	119	4.54	4	4	81
8	8 a.m.	121	3.90	3	29	81
	8 p.m.	126	3.58	3	21	80
9	8 a.m.	125	3.11	2	45	83
	8 p.m.	134	3.12	2	50	80
10	8 a.m.	125	2.45	2	30	71
	8 p.m.	124	3.13	2	54	79
11	8 a.m.	112	**	3	45	81
	8 p.m.	113	4.54	3	57	82
12	8 a.m.	119	4.44	3	30	81
	8 p.m.	118	4.10	3	18	81
13	8 a.m.	114	4.01	3	18	81
	8 p.m.	100	5.27	5	27	81

(continued)

TABLE 8 (continued)

Test Number	Time	Temperature of Entering Water, F	Energy Consumption in kwhr for 12 hrs	Operating Time In 24 hrs		Average Ambient Temperature 3 ft Above Floor, F
				Hrs	Min	
14	8 a.m.	119	**	*	*	81
	8 p.m.	123	4.25	4	7	83
15	8 a.m.	121	3.70	3	19	86
	8 p.m.	113	4.52	4	16	85
16	8 a.m.	115	4.11	3	42	85
	8 p.m.	113	5.07	4	16	86
17	8 a.m.	115	4.51	4	5	85
	8 p.m.	129	3.28	3	7	75
18	8 a.m.	134	3.12	2	47	88
	8 p.m.	**	**	2	20	88

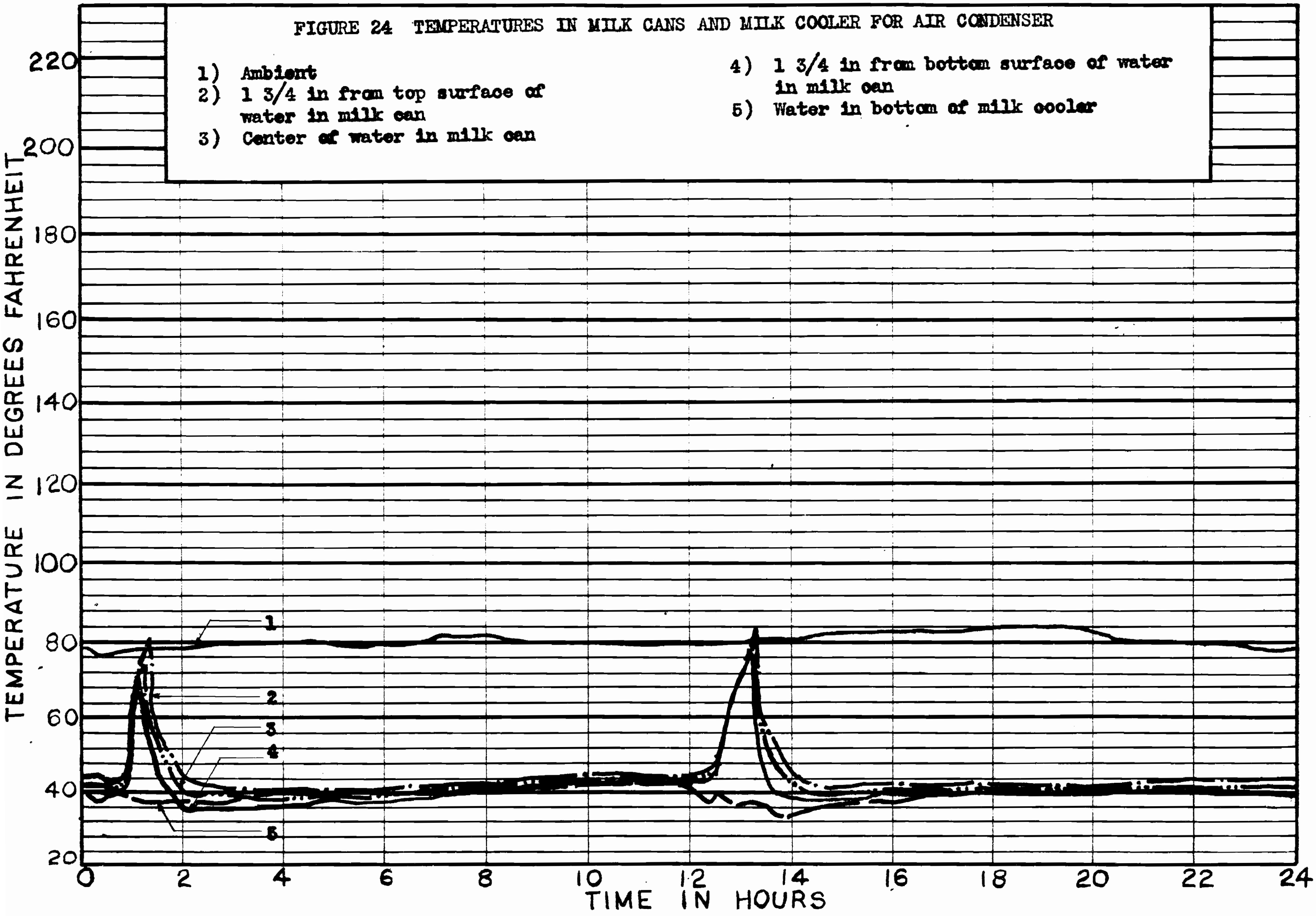

FIGURE 24 TEMPERATURES IN MILK CANS AND MILK COOLER FOR AIR CONDENSER

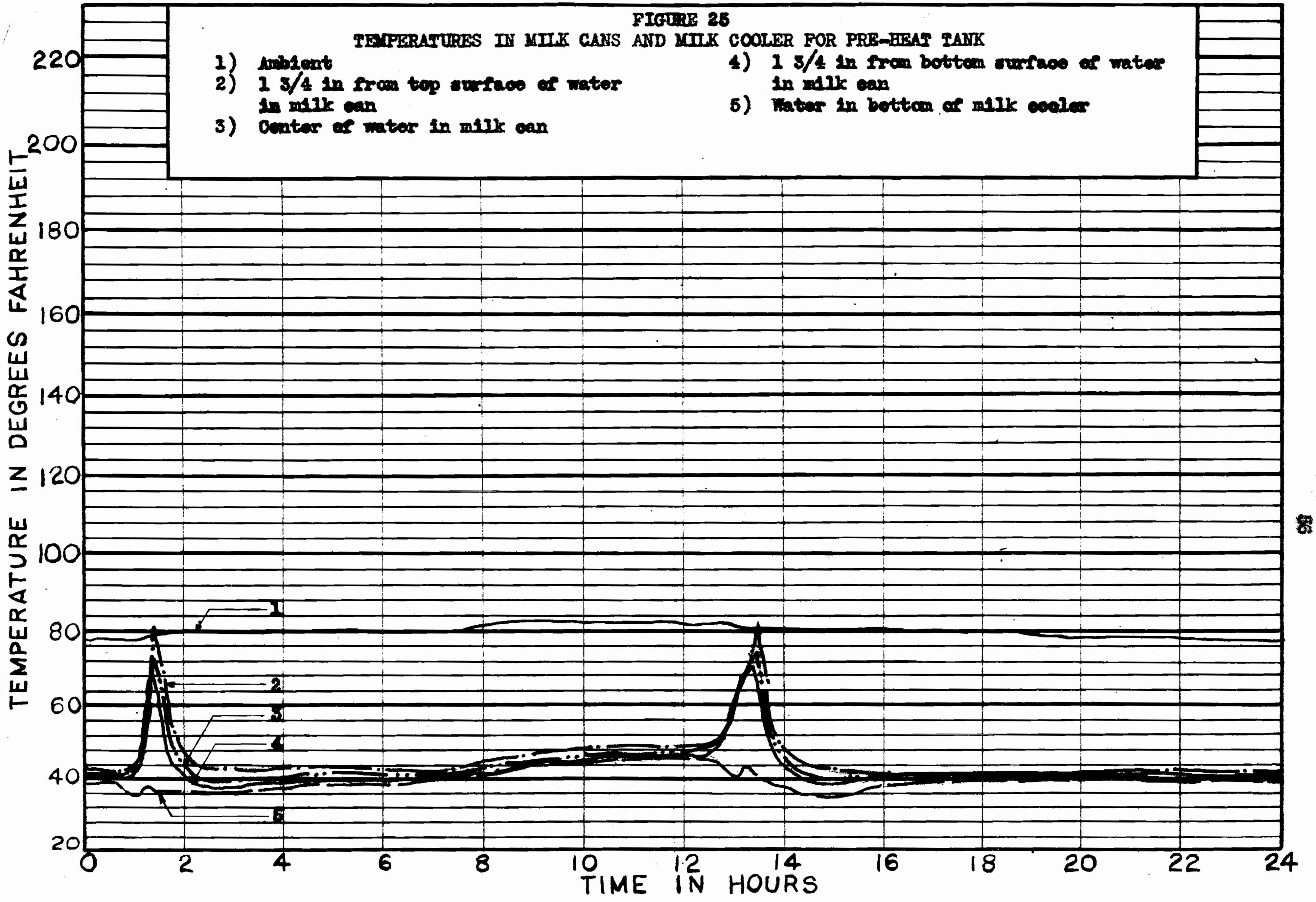

FIGURE 25

TEMPERATURES IN MILK CANS AND MILK COOLER FOR PRE-HEAT TANK

1) Ambient
2) 1 3/4 in from top surface of water in milk can
3) Center of water in milk can
4) 1 3/4 in from bottom surface of water in milk can
5) Water in bottom of milk cooler

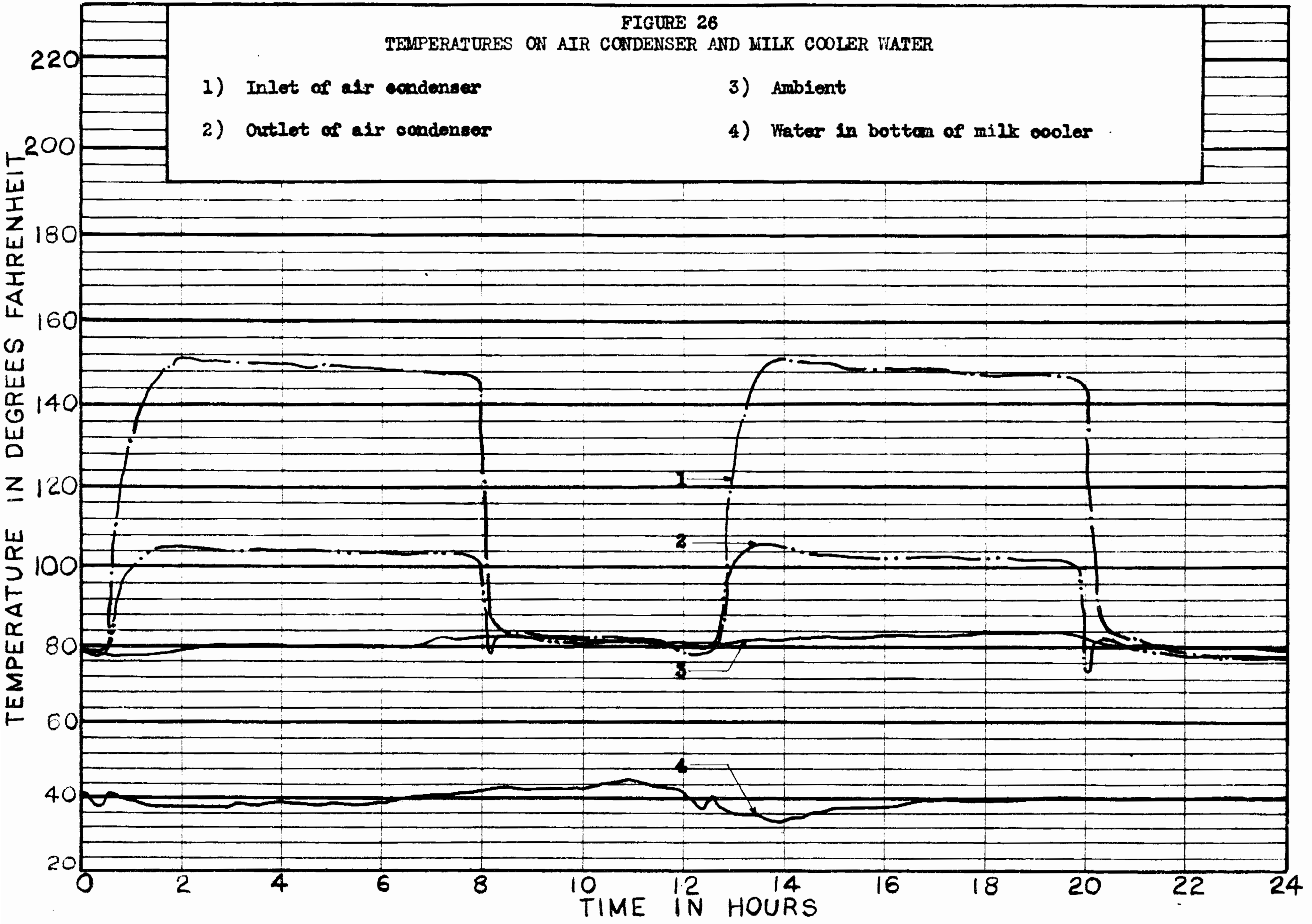

FIGURE 26
TEMPERATURES ON AIR CONDENSER AND MILK COOLER WATER

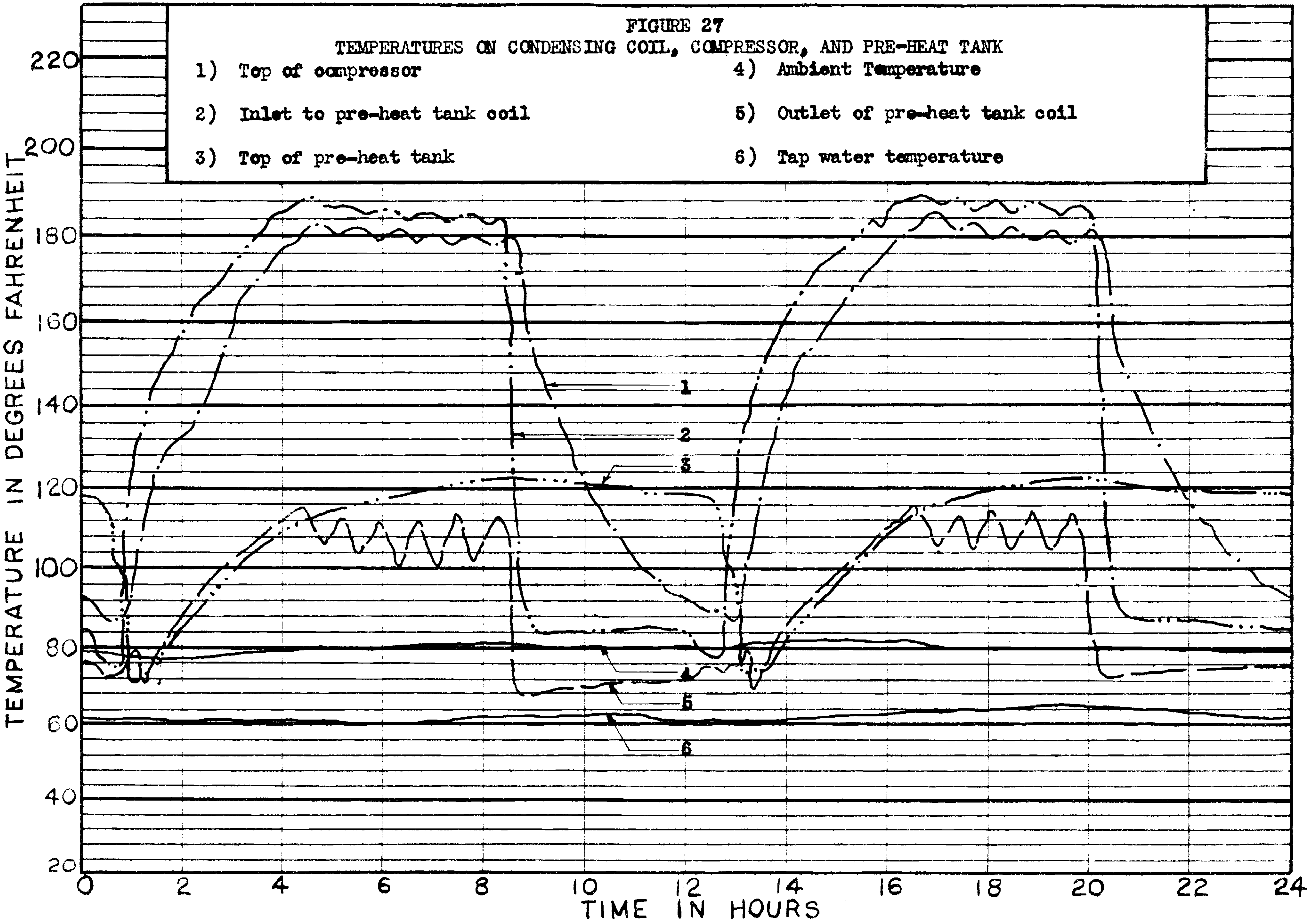

FIGURE 27

TEMPERATURES ON CONDENSING COIL, COMPRESSOR, AND PRE-HEAT TANK

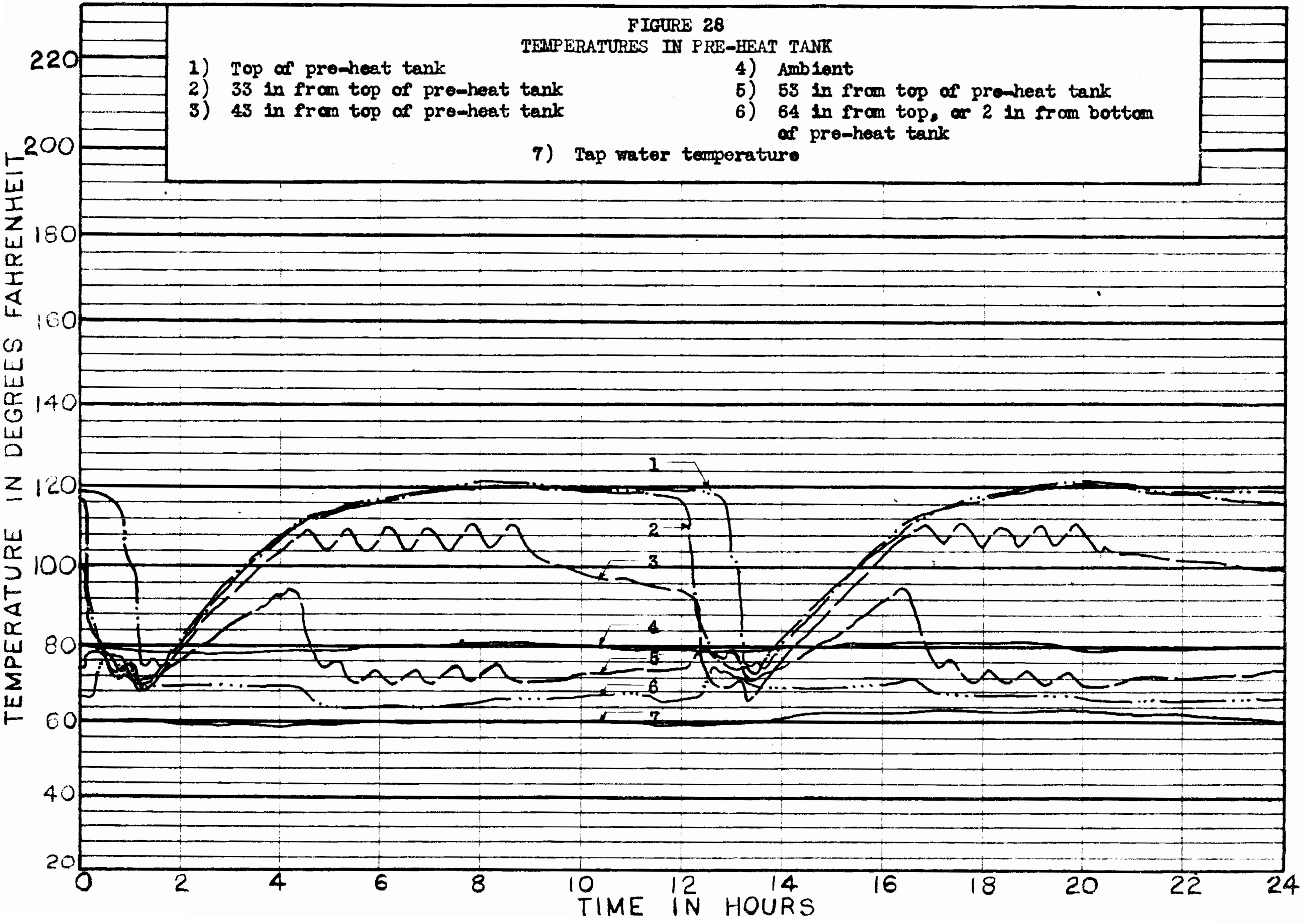

FIGURE 28
TEMPERATURES IN PRE-HEAT TANK

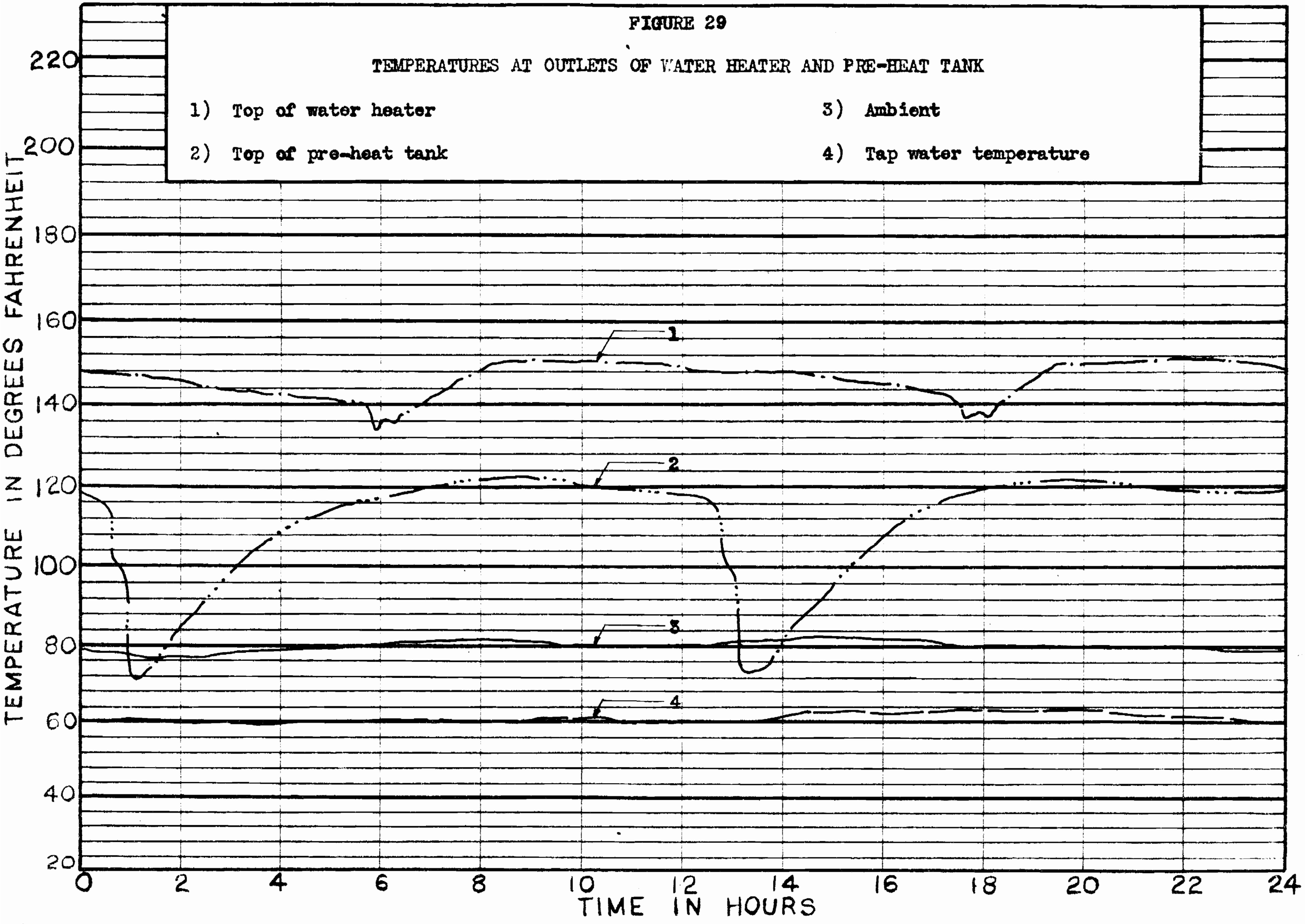

FIGURE 29

TEMPERATURES AT OUTLETS OF WATER HEATER AND PRE-HEAT TANK

DISCUSSION

From discussions with several dairy specialists of the Virginia Polytechnic Institute, it was estimated that the average dairy farm in the Roanoke area, producing commercial grade milk, has approximately 25 cows producing 20 pounds of milk per day per cow. With milk weighing approximately 8.6 pounds per gal, the average farm in this area would produce 5.61, ten gal cans of milk per 24 hr. A four-can milk cooler would be adequate to cool this milk, if the pick-up truck schedule was such that two cans of milk from the previous evening were left outside the milk cooler for not more than an hour.(2) Otherwise, a six-can cooler would be required.

A six-can milk cooler would probably be more representative of the capacity used on the average commercial milk producing farm of Virginia, since the production for the Richmond and Washington areas is about twice that of the Roanoke area. However, a four-can size was used for this experiment, primarily because of its availability in the Agricultural Engineering Laboratory. Therefore, results obtained from this experiment may not represent average conditions for the State of Virginia, but are indicative of what might be expected. Although a four-can milk cooler could handle eight cans of milk in 24 hrs under the right pick-up schedule, four cans per day were used in this experiment. It was determined that this number would provide sufficient heat for the size of pre-heat tank used in the study.

The 52 gal electric water heater used in the tests is a size often used on farms.

There appeared to be no significant differences in the rates of cooling of the water in the milk cans for any of the tests. Representative temperature curves in Figures 24 and 25 show the temperature relationship in the cans when the air condenser was used and also when the pre-heat tank was used. These curves show that essentially all of the temperature reduction occurred during the first hour. It is apparent that more heat was removed from a can of water in the first hour than in the following 11 hr.(14) These results were anticipated, because of the principle of operation of this particular milk cooler, which, according to the manufacturer, builds up an evaporator ice bank of approximately 125 pounds. This ice bank, combined with the spray system, was largely responsible for the rapid cooling of the water during the first hr.

The refrigeration unit operated until the ice bank on the evaporator coils encircled the bulb of the hydraulic type thermostatic switch controlling the compressor motor. At times, the switch was opened just as the bulb became completely imbedded in the ice, while at other times ice formed up to approximately three-eights of an inch over the bulb before the system shut off. This variable performance of the switch could in part account for the variation in Performance Ratio and Coefficient of Performance, (See Table 7), and was probably a contributor to the greater variation of energy consumption and time of operation within a series of milk cooler tests than between them, (See Tables 3 and 4). Although a slightly lower average energy consumption, and longer operating time of the milk cooler resulted with the pre-heat tank arrangement, these differences did not appear to be significant.

The amount of heat accounted for in the 249 pounds of water of the pre-heat tank, immediately after the final opening of the solenoid valve to discharge water to the overflow tank, was approximately 10.525 BTU. This value was based on temperatures of the pre-heat tank water, which were continuously recorded at five points (See Table 2). To raise the average value of 167 pounds of water (See Table 7) that passed through the solenoid valve from 62 F to 115.8 F required approximately 8,980 BTU. For a 24 hr period, or two milking periods, the sum of the heat added to these two sources, as calculated, was 39,010 BTU. In addition to this heat, stand-by losses from the pre-heat tank, as calculated and shown in Appendix C, was estimated to be approximately 1,000 BTU per 24 hr. During the first hr of each milking period, there was some heat delivered from the refrigeration unit to the water that was drawn from the pre-heat tank to the electric water heater. This heat was calculated to be 5,575 BTU for each milking period, making a total of 11,150 BTU per day. This value was thought to be high, as manufacturers' ratings for 1/3 hp compressor units are in the vicinity of 2,500 BTU per hr, or as used in this test, 5,000 BTU per day. Using this smaller value of heat for a 24 hr period and adding it to the heat as calculated in the other three sources gives a total of approximately 46,000 BTU per 24 hr.

Of the 46,000 BTU to be accounted for, approximately 22,000 BTU could have been provided from the milk cooler with load (See Appendix B). Considering the utilization of all the heat from this source, then 24,000 BTU must have been provided by the compressor and compressor motor. A 1/3 hp motor is approximately 63 percent efficient. From this source, assuming full load conditions, for the approximately 15 hr of operation, a maximum of 7,480 BTU could be expected. The compressor might have had a mechanical efficiency as low as 50 percent, giving 6,375 BTU, assuming full load operating conditions. These combined figures total to 13,855 BTU, or 10,145 BTU less than the unaccounted for 24,000 BTU. Compressor shell, high-pressure refrigerant lines, water lines connecting the pre-heat tank to the water heater, and other stand-by losses have not been taken into consideration thus far. Although these losses were not measured, it would appear that they were substantial. The high temperatures represented by Curves 1 and 2 in Figure 27 lend considerable support for this conclusion. Unquestionably, the theoretical heat of the milk cooler, compressor and compressor motor would not be completely utilized as useful heat.

Power requirements for the milk cooler, shown in Tables 3 and 4, seem to be excessively high for all of the tests. Manufacturer's estimates and tests conducted by Purdue University Agricultural Engineering Department(22) indicate that for comparable milk coolers the energy consumption per 10 gal of milk cooled should be in the vicinity of one kwhr, whereas, for these tests the average was 1.83 kwhr per can cooled. On the basis of the hours of operation, energy consumption of the milk cooler, and the approximately 10,000 BTU of unaccounted for heat, it is, therefore, concluded that:

1) Cabinet losses were higher than anticipated. This may have been due to undetermined insulation conditions, giving rise to a higher thermal conductivity coefficient. Apparently, there were some joints of the outer shell of the metal cabinet that were not tight, which would offer some support to this conclusion.

2) If the average temperature of the water in the pre-heat tank immediately after the refrigeration unit had stopped operating for a 12 hr period had been a few degrees lower than that calculated, the quantity of heat in the water would have been appreciably lower. Therefore, the quantity of heat unaccounted for would have been lower. This condition may have existed as temperatures in the upper half of the tank, which was 66 in long, were recorded by two thermocouples, while temperatures in the lower half of the tank were recorded by three thermocouples.

3) A quantity of heat was evidently added to the water of the milk cooler by the water pump. A 1/3 hp electric motor operated the pump. Assuming that the pump was fully loaded, approximately 3,412 BTU would be added during the three hr of operation of the pump for a 24 hr test period.

Possibly the constant high ambient temperatures for the air condenser and the high condensing temperatures in the pre-heat tank for the second series of tests, accounted for some of the high energy requirements. Certainly, temperatures in the vicinity of 185 F on the sealed in compressor unit, as indicated by Curve 2, Figure 27, would appear to be excessive for the design of the unit. Temperatures within the electric motor may have been much higher.

As previously mentioned, the temperature on the shell of the compressor was quite high. By immersing a specially designed refrigeration unit in the pre-heat tank with the condenser, it is thought that the heat from the compressor, including the I^2R loss and other losses from the motor, and heat of compression, could be utilized. With a thermostatically controlled booster heating element of the resistance type located in the top of the tank, the conventional water heater might be eliminated completely. The thermostat controlling the heating element could be set for the minimum acceptable water temperature.

An average of 167 pounds of 116 F water passed to the over-flow tank each milking period. This amounted to 40 gal per day, a large part of the higher temperature water. If a larger pre-heat tank had been used, a larger quantity of water near the temperature of 120 F would have been supplied to the water heater. This is quite definitely indicated by Curve 1 of Figure 28. Had this been done, the energy savings in operation of the water heater may have been greatly increased over the 30.2 percent recorded. The water entering the pre-heat tank was approximately 62 F for most of the tests and the average ambient temperature was a little more than 80 F as indicated by Curves 4 and 7 of Figure 28. During the cooler months, lower tap water temperature could be expected from many farm water systems, which would raise the average Performance Ratio. Also the average ambient temperature would probably be lower most of the time thereby decreasing the cabinet loss and slightly increasing the Performance Ratio.

There is a marked variation in rock wool coefficient of heat transfer values for temperature changes in the range of 60 F to 120 F.(21) For the pre-heat tank stand-by loss calculations in Appendix C, a value of 0.27 BTU/$(ft^2)(hr)(^{\circ}F)$ was considered representative.(8) However, observed condensation on the walls of the pre-heat tank, at the time 18 gal of heated water was withdrawn and replaced with 62 F tap water, leads the author to believe that thermal conductivity of the insulation was greater than assumed, which would have led to greater stand-by losses than indicated, and a larger amount of unaccounted for heat.

It was observed, as shown in Figure 28, that considerable stratification of water took place in the pre-heat tank. Natural convection currents were not of sufficient magnitude to appreciably affect water temperatures below the lowest turn of the condensing coil. It, therefore, seems reasonable to conclude that the capacity of the tank might have been used to better advantage by placing the outlet of the condensing coil closer to the bottom. This position probably would cause all of the water to be heated at a more uniform rate, and slightly increase the Performance Ratio.

The average Performance Ratio of 1.41 is not impressive. However, Sporn and Ambrose(20) state that, with present day refrigeration equipment, heat pump Performance Ratios of 1.5 to 2.5 are about the best that can be expected. On this basis, the averages for these tests do not appear to be excessively low.

Since the Performance Ratio is indicative of heat supplied by a heat pump per unit of power consumption, it is advantageous from the view point of operating costs, for a heat pump only, to use minimum condensing temperatures and maximum evaporating temperatures. In this particular situation, however, the primary function is to supply refrigeration for milk. This in itself requires low evaporator temperatures. The function of heating water is a secondary one, and therefore, it may be necessary, with equipment of this type, to sacrifice higher Performance Ratios in order to increase the temperature of the condensing water and at the same time maintain a sufficiently low evaporating temperature in the milk cooler.(9)

CONCLUSIONS

The following conclusions appear to have merit:

1) The heat obtained from cooling milk in a mechanical farm milk cooler may be used for pre-heating a quantity of water.

2) The amount of water heated and the temperature to which it is heated are functions of the heat obtainable from the milk cooler and refrigeration equipment.

3) The percentage of available heat from the condenser that is available in the water passed to the electric water heater is a function of: (a) the design of the condenser-to-water heat transfer system, (b) the size and shape of the storage tank, and (c) the losses from the storage tank.

4) The savings in cost of electric energy for operation of the electric water heater are appreciable when heat extracted from cooling milk is used to pre-heat water. In this study, the savings amounted to slightly more than 30 percent. However, a large quantity of heated water passed to the overflow tank. A savings of 54 percent could be realized when the water drawn from the pre-heat tank into the water heater was raised from 62 F - 120 F in the pre-heat tank.

5) Without the assistance of a competent refrigeration mechanic, the technical problems involved make it inadvisable for the individual farmer to attempt a conversion of current milk cooling equipment for the additional function of heating water.

6) This study indicates that greater savings may be effected with a refrigeration unit and condensing unit specifically designed for

heating water, using the basic principles outlined in this study.

SUGGESTIONS FOR FUTURE STUDY

1. Tests may be conducted using a larger pre-heat tank with the condensing coil outlet placed as close as practical to the bottom of the tank. In this manner, better utilization of the extracted heat and the tank capacity and more uniform heating of the water may be effected.

2. It is recommended that tests be conducted with a refrigeration unit immersed in a hot water tank. A refrigeration unit designed for operation in a condensing temperature of 150 F - 160 F would be desirable. With this arrangement a larger water tank could be used, and a thermostatically operated booster heating unit, of the resistance type, placed near the top. In this manner, the electric water heater might be eliminated completely.

ACKNOWLEDGMENTS

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The writer is indebted to the Southern States Cooperative for the use of a milk cooler.

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VITA

The author was born in Lincoln, New Hampshire. He was graduated from Manchester Central High School, Manchester, New Hampshire, and attended the University of New Hampshire where he was graduated in February, 1941. Approximately a year was spent in teaching Vocational Agriculture in Winchester, New Hampshire, and NYA courses in Nashua and Manchester, New Hampshire.

After a short period as submarine electrician at Portsmouth, New Hampshire, he enlisted in the Army of the United States, where he served from May 4, 1942 to March 20, 1946. Approximately twenty-two months of this service was spent in the ETO as Communications Officer for the United States Army Air Force. Upon separation from military service, he spent a year in house construction employment, after which time he entered the University of Utah for a year's study in electrical engineering. In September, 1948, graduate work in Agricultural Engineering was undertaken. Graduate teaching was a part of this program until January, 1950, at which time a full-time teaching program in Agricultural Engineering was accepted.

Leon J. Charity

APPENDIX A

DESIGN OF CONDENSING COIL FOR PRE-HEAT TANK

APPENDIX A

DESIGN OF CONDENSING COIL FOR PRE-HEAT TANK

The following equations were used in designing the condensing coil.

$$A = \frac{Q}{U\Delta t}$$

where: Q = Quantity of heat transmitted--BTU/hr

A = Outside surface area of coil--sq ft

Δt = Temperature difference causing heat to flow in degrees F

U = Overall heat transfer coefficient--BTU/(ft^2)(hr)($^\circ$F)

$$U = \frac{1}{\frac{1}{h_f} + \frac{1}{h_c} + \frac{1}{h_w}}$$

where: h_f = Refrigerant condensate coefficient

h_c = Thermal conductance of the tube metal

h_w = Water film coefficient

For the design of the coil, the temperature difference between the refrigerant vapor and condensing water was assumed to be 40 F.(1) This value was divided as follows: 10 F through the water film, and the remaining 30 F through the refrigerant condensate. An assumption of this division was necessary in order to use design information available. The added length of 3/8 in tubing to reach from the compressor to the pre-heat tank will offer more resistance to the refrigerant vapor than the 3/8 in tubing which connected the compressor to the same size tubing of the air condenser. Therefore, 1/2 in copper tubing was selected for the design, in order to somewhat compensate for the extra length required.

The refrigerant condensate film coefficient h_f was obtained from the theoretical equation recommended by McAdams for film-type condensation of a pure saturated vapor outside of horizontal tubes.(2)

$$(1) \quad h_f = 0.725 \left(\frac{k_f^3 \rho_f g \lambda}{N D_o \mu_f \Delta t} \right)^{\frac{1}{4}}$$

h_f = Refrigerant condensate coefficient--BTU/(ft^2)(hr)($^\circ$F)

k_f = Thermal conductivity of condensate at temperature of condensate film--BTU/(ft^2)(hr)($^\circ$F)(3)

ρ_f = Density of condensate film at temperature of condensate film--lbs/ft^3(4)

g = Acceleration due to gravity--ft/hr-hr

λ = Enthalpy change, latent heat of condensation, at saturation temperature, BTU/lb(4)

N = Number of horizontal rows in a vertical tier

D_o = Outside diameter of tube in ft

μ_f = Absolute viscosity of condensate at temperature of condensate film--lbs/hr-ft

Δt = Temperature difference across film--F

$$h_f = 0.725 \left(\frac{.053^3 \text{ x } 75^2 \text{ x } 4.17 \text{ x } 10^8 \text{ x } 60}{16 \text{ x } \frac{.5}{12} \text{ x } 20.7 \text{ x } 2.42 \text{ x } 30} \right)^{\frac{1}{4}}$$

$$h_f = 155$$

The water film coefficient, h_w, was taken as 92 from a nomograph in the text, Heat Transmission, by McAdams.(13) In order to use this alignment chart for the estimation of natural convection coefficients several assumptions had to be made. Mean temperature of the water film (T_f) was assumed to be 90 F, which lies between the expected maximum condensing water temperature of 115 F and tap water temperature of 60 F. The temperature difference across the film (t) was assumed to be 10 F as previously mentioned.

The coefficient of heat transfer, h_c, of the ½ in OD copper tube was 52,400. This value was obtained from the equation, $h_c = k/L$, where k was the thermal conductivity of the tube in BTU/(ft^2)(hr)(^{o}F)(ft)^5, and L was the thickness of the tube in ft.$^{(13)}$

A value of 32 was obtained for the overall heat transfer coefficient, U, using the calculated values of h_f, h_w, and h_c in the previously described basic equation for this coefficient.

The amount of heat, Q, to be removed in the condenser, based on 16 hr operation of the compressor$^{(3)}$ was 2,297 BTU per hr. The anticipated heat for a 24 hr period is shown in Appendix B.

From the equation, $A = \frac{Q}{U \Delta t}$, the surface area required for the condenser coil was calculated to be 1.78 sq ft. A coil length of 15.1 ft was determined from the equation $L = \frac{A}{\pi D}$, where L is the length of the tube in ft, A is the area in sq ft, and D is the diameter of the tube in ft. For this design, the arithmetic mean diameter was used.$^{(5)}$ Following are the solutions for the values of area and length obtained.

$$A = \frac{2297}{32 \times 40} = 1.78 \text{ sq ft}$$

$$L = \frac{1.78}{x \ \frac{0.45}{12}} = 15.1 \text{ ft}$$

To subcool the refrigerant is desirable from the standpoint of better efficiency of the evaporator. For this reason and because the theorêtical equations used to calculate the over-all coefficient of heat transfer may be in considerable error for correct balance of the existing refrigeration unit, a condensing coil of 25 ft of 1/2 in copper tubing was used, providing a safety factor of approximately 30 percent.

By placing as much of the condenser coil as practical in the lower part of the pre-heat tank, lower condensing water temperatures might be utilized. Therefore, coil turns of the largest practical diameter would be the most desirable. However, the largest turn that would fit conveniently through the tank opening was a coil turn of 6 in mean diameter. This resulted in a coil of 16 turns.

APPENDIX B

HEAT LOAD CALCULATIONS FOR MILK COOLER

APPENDIX B

HEAT LOAD CALCULATIONS FOR MILK COOLER

Basic Conditions

1. Average Daily Ambient temperature		80 F
2. Average Milk Cooler air and water temperature		40 F
3. Product load		
a. 4 sheet iron cans. . each		26.5 lbs
b. water . . each can		82.5 lbs
4. Air changes		5 per 24 hrs
5. Dimensions used for Milk Cooler		
a. Outside		
Depth (less door)	30 in	
Width	58 in	
Height	43 in	
b. Inside		
Depth (less door)	26 in	
Width	54 in	
Height	38 in	
c. Milk Cooler Door		
Depth	2 in	
Width	35 in	
Height	30 in	
d. Milk Cooler Volume	Approximately 32 cu ft	

6. Surface Areas and Conductivities

	Area sq ft	Heat Transfer Coefficient U
Bottom	11.5	0.0839
Side Walls (including door)	33.2	0.1160
Top	11.5	0.1160

Conducted heat load for 80 F Ambient temperature and 40 F cabinet temperature.

$$Q = UA\Delta T$$

where: Q = quanity of heat transmitted

U = overall coefficient of heat transfer BTU/$(ft^2)(hr)(^\circ F)$

A = area through which heat passes

ΔT = temperature difference causing the heat to flow

$$U = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{X_1}{K_1} + \frac{X_2}{K_2}}$$

where: f_1 = conductance of inside film

f_o = conductance of outside film

K = thermal conductivity of a material

X = thickness of the material

By applying the equation $Q = UA\Delta T$ to find the conducted heat load for the milk cooler, the following results were obtained:

Q (Bottom) = 0.0839 x 11.5 x 40 x 24 = 927 BTU per 24 hrs

Q (Side Walls) = 0.1160 x 33.2 x 40 x 24 = 3670 BTU per 24 hrs

Q (Top) = 0.1160 x 11.5 x 40 x 24 = 1280 BTU per 24 hrs

Total conducted load = 5877 BTU per 24 hrs

Infiltration Heat Load for Milk Cooler for 80 F Entering Air

Losses = Volume x Air Changes x BTU per cu ft

Q_L = 32 x 5 x 2.18 = 349 BTU per 24 hrs

Product Load for 24 hrs in Cooling from 90 F to 44 F

Q_p (330 pounds water) = 330 x 46 = 15,180 BTU per 24 hrs

Q_p (106 pound cans) = 53 x 0.13 x 46 = 634 BTU per 24 hrs

Total Product Load = 15,814 BTU per 24 hrs

Total Milk Cooler Load for 24 hr Period

Conducted	5,877 BTU
Infiltration	349 BTU
Product Load	15,814 BTU
Total =	22,040 BTU per 24 hrs

In addition to the calculated total milk cooler load, it was expected that the sealed-in compressor and motor would contribute considerable heat to the refrigerant vapor. A 1/3 hp electric motor operating under full load is about 63 percent efficient. This would make available as heat approximately 498 BTU per hr of operation, or 11,952 BTU per 24 hrs of operation. Assuming that 50 percent of the energy of the 1/3 hp compressor is available as heat energy from compression of the gas, 424 BTU hr, or 10,176 BTU per 24 hrs of operation would be added to the refrigerant.

Total theoretical heat released to the condenser

Total cabinet load	=	22,040 BTU/24 hrs
Electric motor	=	11,952 BTU/24 hrs
Compressor	=	10,176 BTU/24 hrs

APPENDIX C

STAND-BY HEAT LOSS CALCULATIONS FOR PRE-HEAT TANK

APPENDIX C

STAND-BY HEAT LOSS CALCULATIONS FOR PRE HEAT-TANK FOR A 24 HR PERIOD

Basic Conditions

1. Average Daily Ambient temperature	80 F
2. Average Water temperature in top half of pre-heat tank	105 F*
3. Average Water temperature in lower half of pre-heat tank	87 F*
4. Area tank(includes average of 2 in insulation)	22.38 sq ft
5. Overall coefficient of heat transfer	0.115 BTU/hr-ft^2-F

Conducted Heat Loss From Tank

$$Q = UA\Delta T$$

Q (upper half of tank) = $0.115 \times 11.19 \times 25 \times 24$ = 775 BTU per 24 hrs

Q (lower half of tank) = $0.115 \times 11.19 \times 7 \times 24$ = <u>231</u> BTU per 24 hrs

Total = 1,006 BTU per 24 hrs

---

*Represents the arithmetic average of each eight min temperature recording of each of the five thermocouples located on and in the tank for a 24 hr test period

APPENDIX D

MILK COOLER SPECIFICATIONS

APPENDIX D

MILK COOLER SPECIFICATIONS

Manufacturer's specifications for milk cooler:

Capacity in 10 gal cans	4
Cooling--cans per day (24 hrs)	8
Size Unit	1.3 H.P.
Depth (less door)	30 in
Width	58 in
Height (Cabinet)	43 in
Height (Overall)	58 in
Water capacity (approximate)	80 gal
Nominal Ice Bank (approximate) Weight	125 pounds