Dairy Farm Refrigeration

Compressors

The most common refrigeration compressor found on dairy farms today is the reciprocating. Reciprocating compressors can be either open type, hermetic or accessible hermetic. The open type has the drive unit external to the compressor. Power would generally be transmitted from the drive unit [motor] to the compressor by V-belts. The hermetic type has the compressor and motor in a common sealed housing. The seal is generally a weld. See Figure 2-2. The motor operates in a low- pressure atmosphere of the refrigerant.

Figure 2-2. Hermetically sealed reciprocating compressor (Copeland)

The accessible hermetic unit is similar except the housing is bolted together in a single unit rather than welded. The motor and compressor are accessible. See Figure 2-3. In some cases the low pressure - low temperature refrigerant passes over the motor.

Figure 2-3. Accessible reciprocating compressor (Copeland)

Condensers, Air- and Water-Cooled

The purpose of the condenser is to desuperheat and condense the refrigerant gas by removing the sensible superheat, the latent heat of condensation and sensible heat to subcool the liquid. There are two major types of condensers; air-cooled and water-cooled. If the condenser is an integral part with the compressor on a common platform, the unit is called a condensing unit. Condensers may also be mounted remote of the compressor.

The air-cooled units are similar to a car radiator. The refrigerant gas flows through finned tubing and air is moved over the fins perpendicular to the tubing to remove heat from the gas. The contact time between the air and the fins is short. The capacity of an air-cooled condenser is determined by the area of the fins, the velocity of the air across the fins, and a mean temperature difference between the air and refrigerant. Air-cooled condensers can be either an integral part with the compressor on a common platform or remove. An example of a remote air-cooled condenser is show in Figure 2-4 as installed on a dairy farm.

Figure 2-4. Example of a remote air-cooled condenser

A water-cooled condenser operates under the same principles as an air-cooled condenser except water is the coolant. Water-cooled condensers are generally smaller in size and offer a higher EER than air-cooled condensers. There are several reasons.

The heat transfer coefficient [Btu/ft^2, F, hr] between the metal surface of the exchanger and water is greater than that for air. This coefficient describes the heat transfer [Btu/hr] for each square foot of surface area and the mean temperature difference [F°] between the refrigerant gas and the cooling media. This means that for the same temperature difference, the surface area of a water-cooled condenser will be smaller than the air-cooled condenser. This generally means the size or footprint is less. This also means that the temperature difference can be smaller with the same surface area, which helps maintain a higher EER.

Water is a better carrier of heat than air. On an equal volume basis, water will absorb 3,500 times as much heat (Btu) for the same rise in temperature. This means that a much greater volume of air is required than water to remove the same amount of heat from the condensing refrigerant.

The airflow in an air-cooled condenser is perpendicular to the flow of refrigerant. This reduces the contact time between the air and the condenser surface thus requiring greater face area. This is not true in a water-cooled condenser.

Water-cooled shell and tube condensers are commonly used on dairy farms. A cross section of such a heat exchanger is shown in Figure 2-5 along with a complete unit. The unit shown has a removable core for cleaning. Generally the cooling water flows through the tubes and the condensing refrigerant gas is in the shell. The unit shown is a 2 tube passes with baffles in the shell to reduce short-circuiting and increase turbulence of the refrigerant. Condensed refrigerant collects in the bottom of the shell.

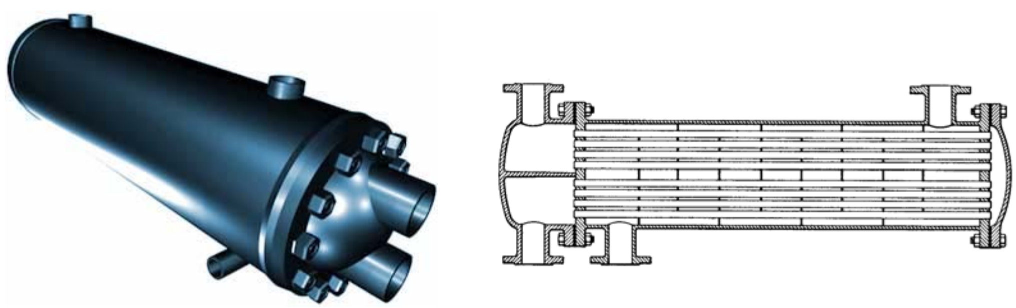

Figure 2-5. Example of a shell and tube water-cooled condenser (Standard Refrigeration)

There are two common milk cooling methods used on dairy farms: **direct expansion cooling** or **indirect (instant) cooling.** These differing methods are explained below.

<u>Direct Expansion</u>

This system cools the milk directly in the milk storage tank. The lower section of the tank is the evaporator. There is a chance that the milk can be frozen at the evaporator if the evaporator temperature is too low and there is insufficient mixing of the milk that allows the milk to remain in contact with the evaporator too long. Direct Expansion milk cooling systems are most common on small and medium size dairy farms.

Indirect or Instant Cooling

Here an intermediary fluid, such as water or a water-glycol solution, is employed to transport heat from the milk to the evaporator. The chiller generally works in conjunction with a dual stage plate cooler. Well water is used in the first stage of the plate cooler to reduce milk temperature to within 5°F of input water temperature. The chiller provides 28-34° F water – propylene glycol solution to the second stage of the plate cooler. When milk enters the second stage of the plate cooler, chilled solution from the chiller "instantly" cools the milk to 38° F. The milk enters the bulk tank completely cooled.

Generally, instant chilled water/glycol cooling systems are slightly less efficient than direct expansion systems. The reason for the lower efficiency is the lower suction pressure to achieve lower evaporator temperatures inherent to instant cooling systems and the pumping energy required to move the water/glycol thru the heat exchanger. The lower temperatures and short heat transfer period along with pumping energy cause the instant cooling system to use more energy per hundredweight than a direct expansion system.

Instant cooling systems are most often used on large dairy farms where large quantities of milk are harvested quickly, and fast cooling is necessary to maintain milk quality.

Milk Cooling Heat Exchangers or Plate Coolers

The heat exchangers used for cooling milk are made of stainless steel and are designed to be opened for cleaning. A well-water-cooled heat exchanger that partially cools the milk prior to entering a direct expansion cooling system or an instant cooler has been available for over 20 years. Today this energy conservation measure [ECM] is standard equipment on larger farms. For instant milk cooling systems this precooler is the first section of a larger plate heat exchanger with final cooling occurring in the second section.

Well Water Partial Cooling

The use of a well water-cooled plate or shell & tube heat exchanger to precool milk prior to the milk entering a refrigerated milk tank or a final plate heat exchanger is common. Earlier, shell & tube or double tube heat exchangers were commonly used. More recently plate type heat exchangers have become dominant.

There are three major configurations of a plate heat exchanger. The configuration shown in Figure 2-15 is a single pass unit. Here the two fluids are in contact [on either side of a plate] as the fluids make one pass between the plates.

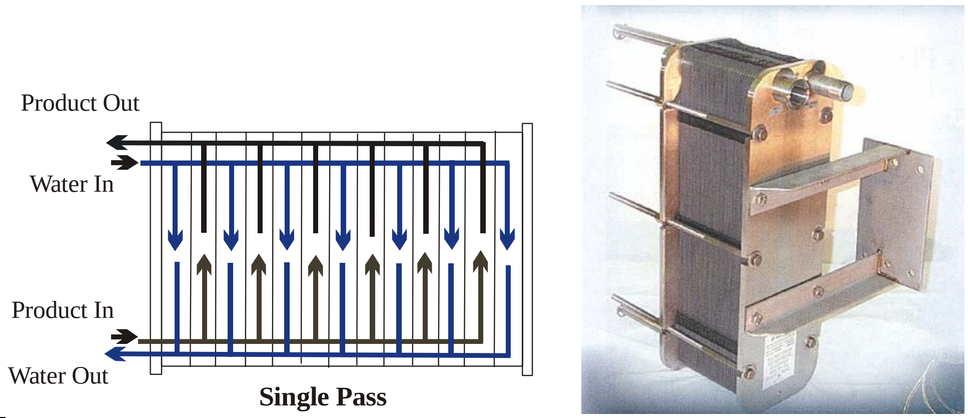

Figure 2-15. Single Pass plate heat exchanger

The flow pattern in Figure 2-15 is a counterflow configuration, the coolant and milk flow in opposite directions, the cold water input is next to the cool milk out. All heat plate exchanger should be installed with counterflow. This flow pattern has a higher mean temperature difference and a greater effectiveness than parallel flow.

A dual or double pass heat exchanger is more effective than a single pass unit. Here the product makes two passes so that the product is in contact with the coolant twice as long, assuming all other factors are equal. See Figure 2-16.

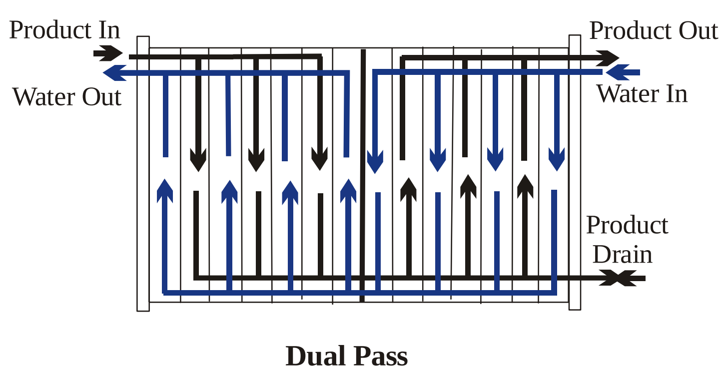

Figure 2-16. Dual pass plate heat exchanger

The comparison between single and dual pass plate heat exchangers is shown in Figure 2-17. The graph shows the relationship between the number of plates and the expected temperature drop in the milk with single and dual pass plate heat exchangers. The ratio of low rate between the milk and cooling water was 1:1. There are three data points for the single pass unit. A linear projection of those three data points was made to estimate the temperature drop for a single pass exchanger unit with more plates. Two data points are plotted for a dual pass unit. If both types had 32 plates, the expected drop in temperature for the single pass unit would be 25 F° and slightly over number of plates and temperature drop 28 F° for a dual pass unit. For the same number of plates, a dual pass is more effective that a single pass.

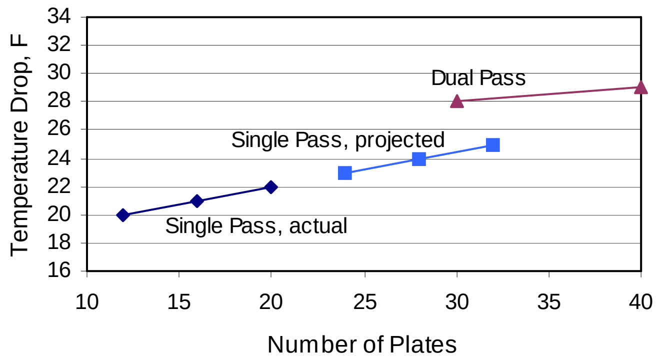

Figure 2-17. Relationship between number of plates and temperature drop

The third configuration for a plate heat exchanger is the two-stage. Figure 2-18 shows the flow configuration for this unit. This unit is equivalent to two single pass units jointed together. One section is used for precooling with well water and the second section is for final cooling with chilled water or glycol-water solution. This unit is common on California dairy farms.

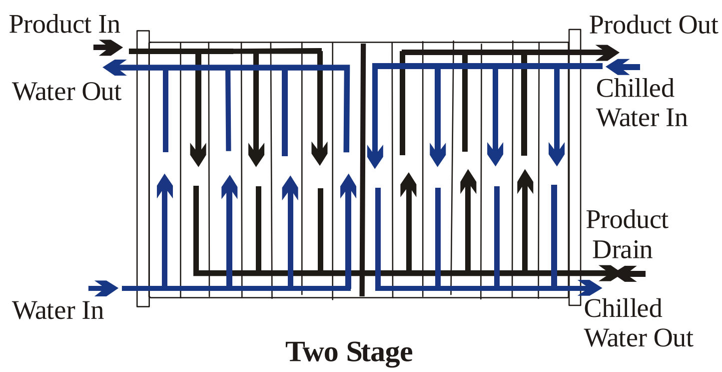

Figure 2-18. Two stage; well water precooler and chilled water or water-glycol final cooling)

The effectiveness of a heat exchanger is also dependent on the ratio of flow [gpm] between the product and the cooling media. A higher coolant flow rate provides a greater mean temperature difference between the milk and coolant and a higher coolant velocity between the plates that increases the heat transfer coefficient. Most manufacturers recommend at least a ratio of 2, water flow twice the milk flow.

The data for the graphs shown in Figure 2-19 were taken from manufacturer's literature to demonstrate the impact of coolant flow on the exit milk temperature. The milk flow from the milk pump on a receiver is intermittent. When the level of milk in the receiver reaches the upper probe, the pump starts. The milk flow could be at least 25 gpm for a few seconds and then stop for perhaps a minute.

Tests on two conventional receiver pumps in a double parlor showed that the average milk flow rate during milking was about 12 gpm. Both receiver pumps operated 26 percent of the time, meaning that the average flow rate of milk when a pump was operating was 44 gpm. To achieve a recommended flow ratio of 2, the chilled coolant flow rate while the milk pump was operating must be 88 gpm which difficult to achieve on a dairy farm.

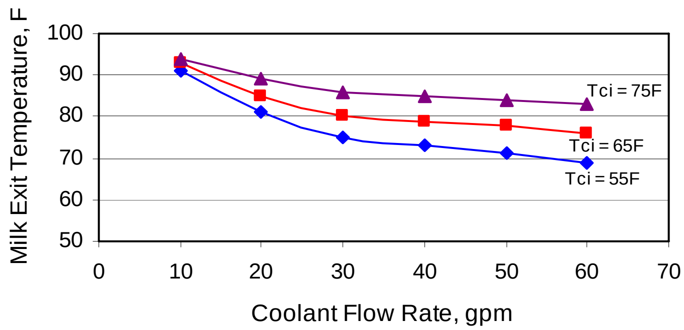

Figure 2-19. Impact of coolant flow rate on exit milk temperature for three coolant temperatures (Tci), inlet milk temperature = 98°F, intermittent milk flow = 35 gpm, coolant flow while milk pump is operating, low flow between cycles.

Milk cooling system	EUI, kWh/cwt cooled
Conventional	1.2 – 0.8
Well water precooler	0.9 – 0.6
Well water precooler with VFD on receiver pump	0.7 – 0.4

Milk Cooling Energy Utilization Indices (EUIs)

The EUI for milk cooling with a well maintained cooling system and no energy conservation measures (ECMs) averages between 0.8 and 1.2 kWh/cwt [hundred weight] of milk cooled. There are two ECMs that can be employed. They will be described in the next section. As ECMs are added, the EUI will decrease. Partial cooling the milk with a well water “precooler” will save 0.2 to 0.3 kWh per cwt milk cooled. Installing a variable frequency drive will lower the EUI an additional 0.2 kWh per cwt milk cooled. The actual reduction in energy use will be dependent on well water temperature, water flow and the effectiveness of the VFD to reduce the milk flow through the heat exchanger.

Milk Cooling Energy Conservation Measures (ECMs)

There are several measures that can be implemented that will reduce the energy consumed to cool milk. Some of these were mentioned above.

Precoolers

Well water-cooled heat exchangers partially cool milk prior to the milk entering the refrigerated storage tank or a second heat exchanger for instant cooling. This practice was discussed earlier because the practice has been widely accepted and in many
areas has achieved 100 percent market penetration.

Variable Frequency Drives [VFD] For Milk Pumps

As stated earlier, under conventional practice, the flow rate (gpm) of milk from a receiver is not uniform. The flow of milk during milking from the milk pump will vary from zero to 25 - 50 gpm. In a milking parlor with two milk pumps, the pumps may operate 10 to 25 percent of the time while the cows on one side of a parlor are being milked. This means that there is no milk flowing through the heat exchanger 75 to 90 percent of the time and the flow during the other 10 to 20 percent of the time will be high. This is not an efficient way to operate a heat exchanger. On the well water or chilled water-glycol side of the heat exchanger the flow needs to be 50 to 100 gpm for that 10 to 20 percent of the time. This to is difficult.

To help alleviate this problem, a variable frequency drive can be applied to the milk pump. The concept here is to slow down the flow of milk from the receiver so that the milk pump operates a higher percentage of the time. This means the flow of milk through the heat exchanger will be lower and more continuous. Both factors improve the effectiveness of the heat exchanger.

Control for the variable frequency drive is generally a series of magnetic reed switches mounted inside a hollow stainless steel pipe [probe] mounted vertically near the center of the receiver through the Plexiglas cover. Depending on the length of the probe, two to four reed switches are positioned along the probe at appropriate locations. Stainless steel floats that hold a magnet fit around the probe and are held positioned along the probe at the same location as the reed switches. The floats are held in place by clips on either side of the float. When the float with a magnet floats up to the reed switch the switch either closes or opens depending on the logic being used. When the float leaves the switch the switch returns to its initial position.

Using a binary code, the frequency output from the VFD and thus the speed [rpm] of the receiver pump can be controlled by which reed switches are closed [one] and which ones are open [zero]. The VFD can be programmed to provide different speeds depending on the position of the floats. When the top reed switch is activated the VFD generally goes to 60 Hz for full speed of the milk pump. When the lowest switch is activated as the milk rises in the receiver, the pump will start at the lowest preset speed giving the lowest milk flow. The goal is to have the pump operate at the lowest speed for the greatest percentage of the time.

One needs to be careful when setting this lowest speed. Nearly all receiver milk pumps are centrifugal [variable delivery, delivery varies with total head and rpm] as opposed to positive displacement pumps where delivery is nearly linear with speed and within reason unaffected by discharge pressure. Centrifugal pumps experience shut-off head. At a certain combination of total head [pressure] and pump rpm, the flow from the pump stops. The total head is the sum of the suction head, between 12 and 15 inches of Hg, and discharge head that includes the vertical height to the discharge point or height of milk in a silo, the pressure loss in the filter, the friction of the heat exchanger and piping.

The curves shown in Figure 2-20 illustrate the performance of a 4-blade impeller milk receiver pump driven at different speed with a VFD. A vacuum of 13 inch Hg was maintained in the receiver. The pump had considerably different characteristics during speeding up and slowing down. With 13 inch of vacuum the shut off head occurred at 42 Hz, or 2,400 rpm for a motor rated at 3,450 rpm.

The first seven data points in Figure 2-20 are plotted on the graph in Figure 2-21. The sensitivity of the pumping rate to pump speed is significant. When speeding up, a change in pump speed of 10 Hz or about 600 rpm made little difference in flow rate. However, when the pump was being slowed down by the VFD, the flow rate decreased from 14 to 0.6 gpm for the same change of 600 rpm. Setting the preset speeds on a VFD for any milk pump must be done with care.

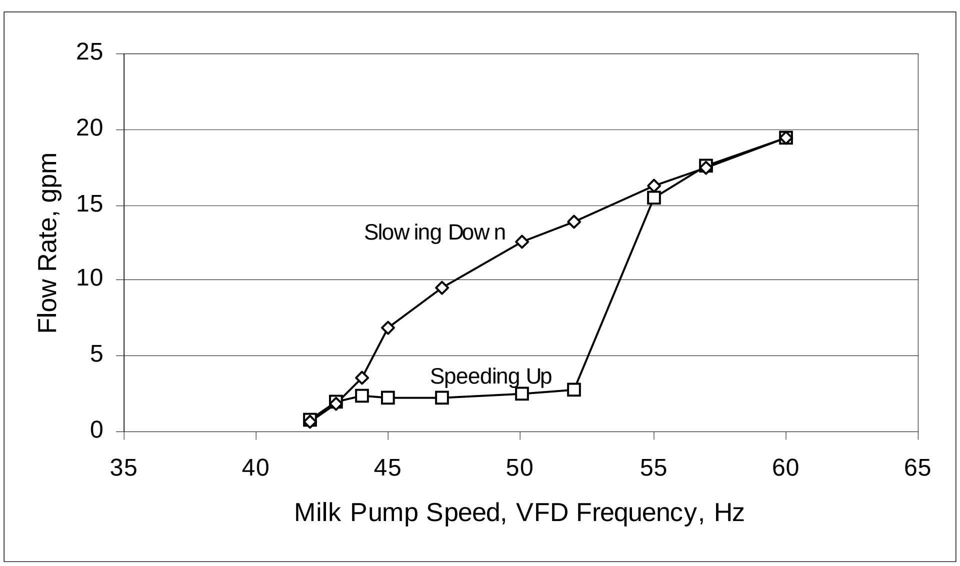

Figure 2-20 Characteristics of a 4 Blade Impeller Milk Pump with a VFD

Another issue that should be considered is the agitation of the milk inside the milk pump at lower speeds. When the pump is operating at full speed (the impeller was turning at 3,450 rpm) the delivery rate was about 20 gpm. For every gallon of milk delivered the impeller turned 172 times. At low speed the delivery was less than 4 gpm but the speed was 2,400 rpm. Now the impeller turned 600 times per gallon or more that three times the agitation. The impact of this additional agitation has never been studied.

Scroll Compressors

Two new classes of compressors, the scroll and discus are now being introduced for milk cooling on dairy farms. These new compressors are both more efficient. The scroll compressor utilizes two identical scrolls, one fixed and the second rotating within the fixed scroll. Because the scroll compressors operate in a circular motion, have fewer moving parts and no intake or discharge valves, there is less vibration and less noise.

Figure 2-22. Scroll Compressor (Copeland)

A study comparing a scroll compressor with a reciprocating hermetically sealed compressor on a direct expansion cooling system showed a 20 percent reduction in energy use. The reduction in energy use was caused primarily by a reduction in the electrical demand. These units are quieter and operate with less vibration.