BUSINESS PROGRAMS

Refrigeration Systems Design, Operation and Maintenance

TECHNICAL DATA SHEET

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Refrigeration systems play a critical role on every dairy farm. They ensure that milk quality is maintained and that it meets food safety standards. A basic refrigeration system includes three components: a refrigerated bulk tank or insulated holding tank and chiller, refrigeration compressor units and air or water-cooled condensing units. The entire system consumes energy and must be maintained properly to ensure it operates as energy efficiently as possible.

Milk typically leaves a cow's body at 95°F to 100°F. It must then be cooled to storage temperature, typically about 38°F, to preserve its quality. The cooling process involves removing 56 Btu (the equivalent of the amount of energy needed to melt a third of a pound of ice) of energy from each pound of milk.

SET YOUR PRIORITIES

For most farms, the best way to improve the energy efficiency of refrigeration systems is to install energy saving measures in a logical, step-by-step manner. If you are planning a major expansion, it may make sense to install multiple energy saving measures. These measures, in order of priority, include:

1. Refrigeration Heat Recovery (RHR) Units
2. Scroll Compressors
3. Plate/Pre-coolers
4. Variable Speed Milk Pumps

These measures can reduce refrigeration-related energy costs substantially and maintain, or even improve, milk quality. They reduce refrigeration requirements and/or capture waste heat and use this excess heat energy to pre-heat water.

However, before installing one or more of these measures, you should consult with farm refrigeration experts, including Focus on Energy, UW Extension agents or your dairy supply company. The reason? You may inadvertently increase your energy usage. For example, installing an RHR unit and a pre-cooler may cause an increase in energy consumption if all factors are not considered when designing the new system. Experts can also help you avoid damage to equipment or equipment failures. This factor is of greatest concern for farms with 120 cows or fewer, but all farms can benefit from expert advice before proceeding.

REFRIGERATION OPTIONS

Refrigeration Heat Recovery Units

Refrigeration heat recovery (RHR) units can capture 20 percent to 60 percent of the heat energy from milk and use this excess heat to pre-heat water before it enters the water heater. An RHR unit captures rejected heat from the refrigerant that would normally be discharged to the air and uses the heat to pre-heat well water before it enters a water heater. Figure 1 illustrates a typical RHR unit.

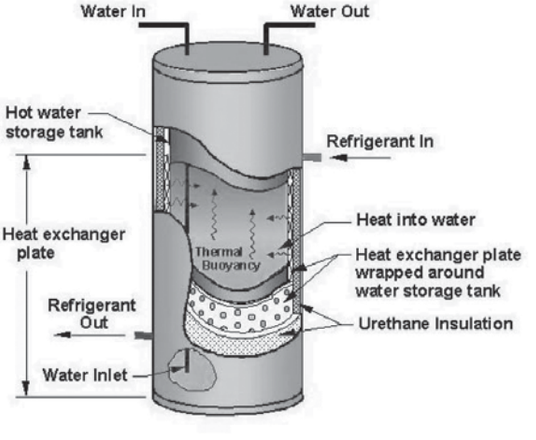

Figure 1. Refrigeration Heat Recovery Unit

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The RHR unit is comprised of a water storage tank and a heat exchanger. Different manufacturers use different configurations for heat exchangers. In one of the most common systems, the heat exchanger is wrapped as a jacket to the outside of a water storage tank and is covered with insulation and a protective shell. Hot refrigerant gas from the compressor unit is piped through the RHR heat exchanger and its heat is then transferred to the water. During this process, the refrigerant cools and the water heats up.

Sizing RHR units

A properly sized RHR unit can heat a farm's water to an upper range of 120°F, sometimes higher. Before you install a unit, work with an expert to ensure you are selecting a unit that is correctly sized for your operation. For example, if you have a small farm, an oversized tank will decrease the energy savings benefit. A larger tank requires more heat to increase the temperature and translates into greater energy use. Smaller farms may want to consider installing an 80 gallon unit. One hundred and twenty gallon units work well for farms with more than one milk cooling compressor. Large farms may benefit by having two or more RHR storage tanks. It is possible to install an insulated storage tank next to the RHR unit and plumb the tank drains together and the tank outlets at the top together. Thermal buoyancy will move warm water into the storage tank as it is heated. To increase the efficiency further, you can install a small circulator pump so that water is continuously being circulated whenever the refrigeration system's compressors are running.

Costs/Benefits

RHR units reduce water heating costs. Therefore, you should examine the costs and benefits of installing this technology. For example, if the water is heated from 55°F to 100°F using an RHR unit, and the water heater provides the remaining heat energy to reach 160°F, the estimated water heating cost savings will be 43 percent. Actual savings will vary depending on farm conditions but 50 percent savings on water heating is possible.

PRE-COOLER AND RHR INTERACTIONS

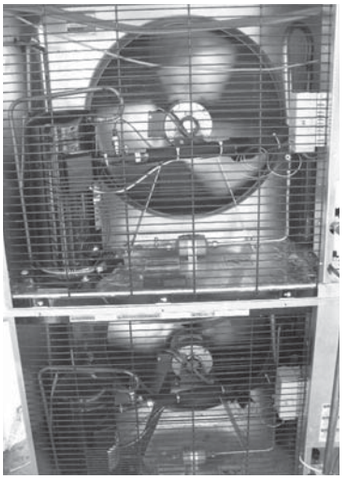
Please work with an expert if you are considering the use of both a pre-cooler and RHR unit. These systems can interact and "compete" with each other if their interaction is not carefully designed. This interaction can cost you money.

Depending on a dairy's hot water usage, only a portion, or all of the available energy may be useable for pre-heating water. If all the energy captured by the RHR unit can be used for preheating water, then installing a pre-cooler will increase overall energy costs because some of the heat energy will be transferred to well water, as opposed to preheating water for the water heater.

COMPRESSOR MAINTENANCE CHECKLIST	
	Clean condensing unit with an approved degreaser twice a year.
	Check that all condensing unit fans are operating properly.
	Have refrigeration service contractor check the refrigerant level annually.
	Straighten fins with a fin comb if fins are dented or pressed against one another.

SCROLL REFRIGERATION COMPRESSORS

Most compressors greater than ten years old are likely reciprocating compressors; these units work much like a car engine. The newest refrigeration technology is called a scroll compressor. It was invented in 1905 but was not commercially available until the mid-1980s. The dairy industry adopted it in the mid-1990s and the technology now comes standard on most new refrigeration systems.



The scroll compressor is a pump that uses two nested scrolls; one is held fixed while the second rotates in an orbital motion. There are many advantages of a scroll compressor, including a smaller number of moving parts, no valves and it is a completely balanced unit. Scroll compressors are about 15 percent to 20 percent more energy efficient than traditional reciprocating compressors and can be used in all applications where reciprocating compressors are used.

If your current compressor fails and must be replaced, you should install a scroll compressor. The units are only slightly more expensive than reciprocating compressors, but they offer substantial energy savings over the life of the unit. Scroll compressors can be adapted to existing condenser units if the unit is sized within five percent of the Btu/hr capacity of the existing compressor.

Costs/Benefits

If replacing a compressor, you should inspect the condensing unit to ensure it is in good condition. Condensing unit air exchangers that have signs of corrosion on the aluminum fins should be replaced. Corrosion is a sign that the contact surface between the aluminum fins and the copper tubing that carries the refrigerant has deteriorated. This corrosion will reduce the heat transfer from the refrigerant. If you have an old compressor in poor condition, you could save more than 20 percent in refrigeration energy costs by upgrading to scroll compressors.

WELL WATER PRE-COOLERS

Well water pre-coolers use well water as a coolant to cool milk before it reaches the refrigeration system for chilling to storage temperature. This system consists of a simple heat exchanger.

A typical pre-cooling system uses either a “shell and tube” or "plate type" heat exchanger. The pre-cooler is mounted in the milk discharge line between the receiver group and the bulk tank, after the milk filter. Milk is cooled when its heat is transferred to the well water as the milk and water flow through the pre-cooler. The milk and water should flow through the heat exchanger in opposite directions – called counter-flow – to achieve the greatest reduction in milk temperature.

Well water, which typically measures about 55°F in Wisconsin, is pumped through the plate cooler in one direction and warm milk flows in the other direction. The well water removes heat from the milk and cools it. A plate cooler can drop the milk's temperature 20°F to 40°F before it reaches the bulk tank. Pre-cooling reduces refrigeration compressor operation, which saves electricity. The flow rates of the milk and water, heat transfer area, milk residence time and water temperature all affect the achievable maximum cooling with a pre-cooler. Properly sized and installed well water pre-coolers can reduce refrigeration energy requirements by as much as 60 percent; this amount represents approximately 15 percent of total dairy farm electrical energy costs.

Dairy farmers benefit in additional ways by installing a pre-cooler. Once the well water flows through the unit and absorbs the milk's heat, this warm water can be used to water the cows or for cleaning the parlor after milking. Research shows that milk production is affected by cows' water intake – the more they drink, the more they produce. Cows will often drink more water if it is relatively warm. Even during the warmer months, cows will show preference for the warm water versus groundwater.

DESIGN CONFIGURATIONS

Farmers should consider a number of system design configurations when installing a well water pre-cooler. These include water flow rates, water system capacity and how to re-use or dispose of the water exiting the precooler. First, the water flow rate will directly affect the pre-cooler's effectiveness. The system should provide a minimum 1:1 water-to-milk flow ratio; a 2:1 ratio is required for maximum cooling for most pre-coolers. A typical one horsepower milk pump can produce about 35 gallons per minute, so to reach the 1:1 ratio, the water system should provide a minimum of 35 gallons per minute. Table 1 illustrates expected water flow rates of common pipe diameters.

TABLE 1. WATER FLOW RATES IN COPPER AND PLASTIC PIPES @ 40 PSI WATER PRESSURE

PIPE DIAMETER	EQUIVALENT PIPE LENGTH	
	50 ft	100 ft
1/2”	9 gpm	6.1 gpm
3/4”	27	18.6
1”	55	39.2
1 1/4”	105	71.1

The water supply system (well water pump and piping) must have the capacity to meet the farm's existing water demands and additional demands of a pre-cooler. If the water supply flow rate is inadequate, a storage tank with a booster pump or a variable speed milk pump may be required to achieve maximum energy savings.

If a farm's water supply cannot keep up with the short-term demands of a pre-cooler, a few options exist to address this challenge. It may be possible to increase the size of the water system pressure tank or add an additional pressure tank. This option will aid in meeting short-term high water flow rates. Adding an electrically activated water valve that opens when the milk pump is operating will reduce water consumption.

Costs/Benefits

A well water pre-cooler reduces the milk temperature entering the bulk tank, lowers the refrigeration load and saves energy. The percent savings can be estimated if the milk temperature entering the bulk tank is known. For example, if the milk is entering the bulk tank at 70°F with a pre-cooler and was entering at 95°F without the pre-cooler and the milk is cooled to 38°F for storage then the estimated savings is 26 percent.

VARIABLE SPEED MILK PUMPS

Variable speed (VS) milk pumps slow the flow rate of the milk passing through the pre-cooler, increasing the water-to-milk ratio and cooling the milk more effectively. A typical VS milk pump installation can cool milk by an additional 10°F to 15°F, but this amount will vary by installation.

VS milk pumps are useful on farms where water flow rates cannot be increased to an acceptable cooling level because of high capacity milk pumps or on farms with low capacity water system flow rates. A pre-cooler on a typical Wisconsin farm without a VS milk pump will only have a 0.5:1 water-to-milk flow ratio. A VS milk pump with the same pre-cooler could change the water-to-milk ratio to 1.0 to 1.5:1 or higher.

A typical VS milk pump consists of a:

- Variable frequency drive
- Probe assembly that senses the level of milk or wash solution in the receiver, and
- Milk pump with a 3-phase motor (the control system can convert single phase power to three phase power).

A VS milk pump adjusts the motor speed between a minimum and maximum speed while trying to maintain the milk level in the receiver jar between high and low level probes, or floats. The VS controller replaces the conventional on/off liquid level controller.

Costs/Benefits

A VS pump is a very useful tool, but it can have a high initial cost. Be sure to weigh several other options before deciding to install one:

- Upgrading the water supply plumbing.
- Installing a water reservoir and pump.
- Purchasing a larger capacity cooler.

FOCUS ON ENERGY CAN HELP

Focus on Energy's agricultural energy advisors can help Wisconsin farmers learn more about operational benefits of refrigeration systems. Call 800.762.7077 for information or assistance, or visit our Web site at focusonenergy.com.

For further information refer to one of the following University of Wisconsin-Extension publications at http://learningstore.uwex.edu/Energy-Conservation-C29.aspx

A3784-04 – Energy Conservation in Agriculture: Refrigeration Systems

A3784-03 – Energy Conservation in Agriculture: Well Water Pre-coolers

A3784-07 – Energy Conservation in Agriculture: Variable Speed Milk Pumps

A3784-02 – Energy Conservation in Agriculture: Heating Water on Dairy Farms