

Energy Conservation in Agriculture

Well water precoolers

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The temperature of well water in Wisconsin ranges from 50–55°F year round (plus or minus a few degrees depending on the location), while milk harvested from the cow is around 95–98°F by the time it gets to the receiver jar.

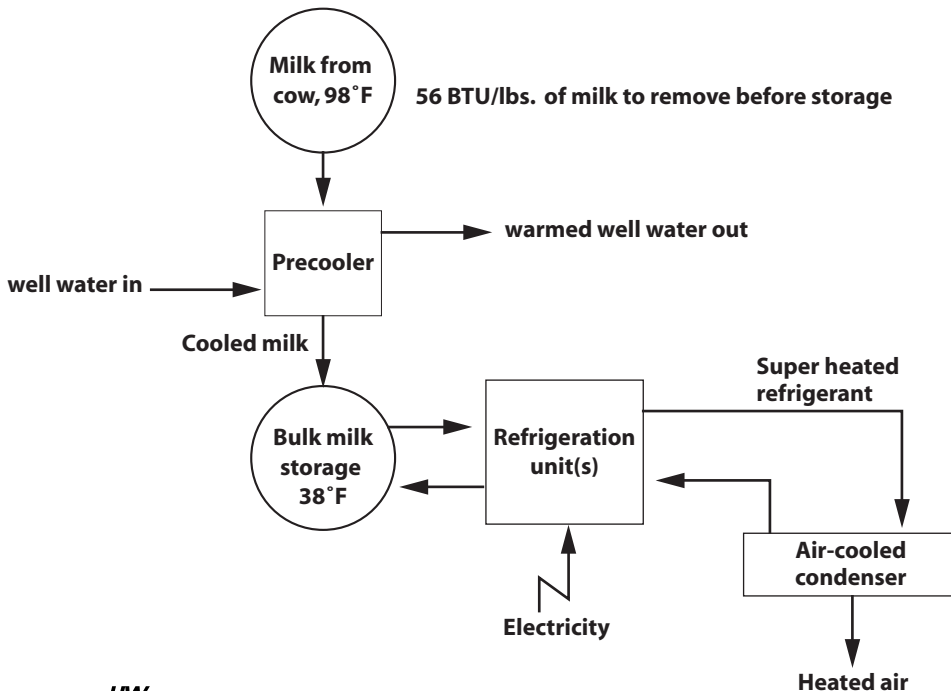
Since cows drink about three times more fluid (water) than they give as milk, it is logical to also use well water as a coolant to reduce the milk temperature and then supply the water to the cows for drinking. Milk temperature can be reduced up to 40°F with a properly sized and installed pre cooler, which will reduce refrigeration energy requirements by about 60%. This can reduce the overall farm electrical energy requirement by up to 15%.

How does it work?

A typical precooling system uses either a “shell and tube” or “plate type” heat exchanger with well water used as the coolant. The pre cooler is mounted in the milk discharge line between the receiver group and the bulk tank after the milk filter (see figure 1). The water and milk flow through the heat exchanger must be in opposite directions, called counter-flow, to get the greatest reduction in milk temperature.

As the water and milk pass each other in the heat exchanger, the heat is transferred from the milk to the water through the stainless steel wall of the heat exchanger. The flow rates of the milk and water, heat transfer area, milk residence time and water temperature affect the degrees of cooling that can be achieved. To achieve the maximum amount of cooling, the water-to-milk-flow ratio needs to be at least 1:1 with sufficient heat transfer area and residence time. It is possible to reduce the milk temperature to within 3–4°F of the well water temperature.

Figure 1. Milk cooling energy flows: refrigeration system with pre cooler



Types of heat exchangers

There are two main types of heat exchangers used for precooling: a “shell and tube” and a “plate type” (see figure 2). The simplest “shell and tube” heat exchanger is a single small tube inside of a larger tube, sometimes called a concentric tube heat exchanger, (see figure 3). To achieve greater surface area for heat transfer, multiple small tubes can be housed inside of a larger tube or shell (see figure 4).

There are other variations where a coil of tubing is housed inside of a chamber to increase the heat transfer area. Regardless of the configuration, the milk flows through the smaller tube(s) while the well water flows through the shell. The more popular plate type heat exchanger consists of a series of ribbed plates placed side by side in a pack. Rubber gaskets port the plates such that there are two separate circuits. The milk flows between every other plate while the well water flows through the circuit on the opposite side of the plate from the milk. The plates are ribbed to promote turbulent flow to increase the heat transfer rate.

Plate type heat exchangers have the advantage of being compact as well as the ability to expand easily by adding additional plates to increase capacity. Shell and tube heat exchangers come in fixed units or lengths so expansion is not as flexible.

Heat exchanger design configurations

The simplest heat exchanger is a single pass or circuit, (figure 5), with the milk and water going through separate sets of plates or tubes and then exiting the heat exchanger. If the water and milk are flowing in opposite directions, the fluids are flowing in a “counter flow” direction. If the water and milk are flowing in the same direction, the fluids are flowing in a “concurrent flow” direction. Counter-flow is normally used because lower milk temperatures can be reached.

Figure 2. Plate-type precooler—single pass

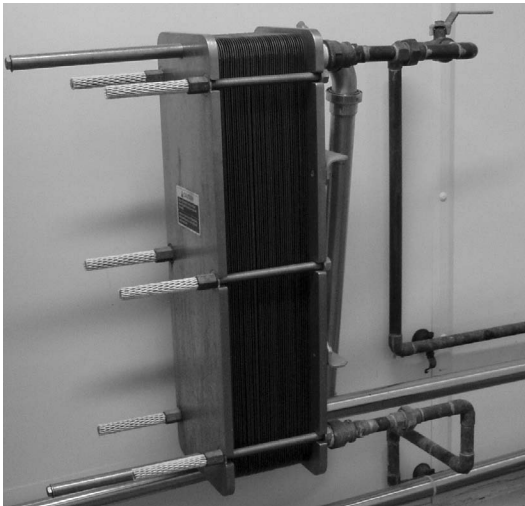


Figure 3. Concentric heat exchanger

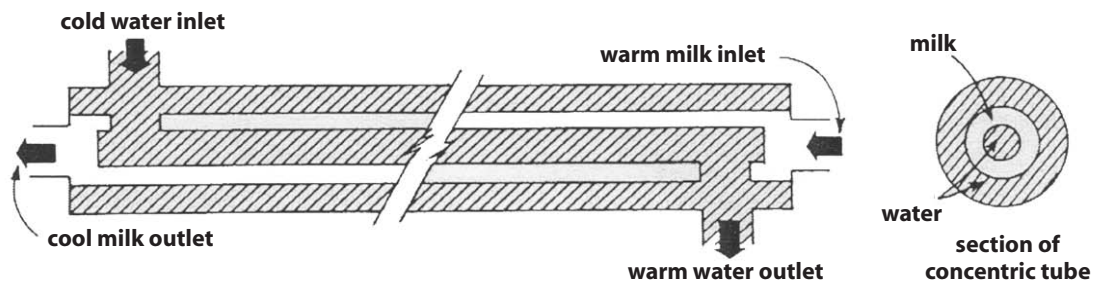
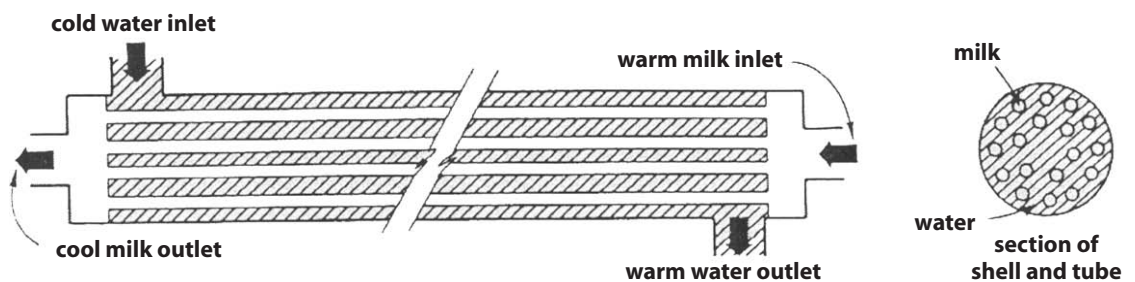


Figure 4. Shell & tube heat exchanger



A heat exchanger can be designed so the milk goes through multiple circuits and the water goes through a single circuit or pass (figure 6), or both the milk and water flow can be routed through multiple circuits (figure 7). A single pass heat exchanger has the advantage of low pressure drop, while multiple pass heat exchangers have the disadvantage of higher head pressures but more efficient heat transfer between the milk and water because of longer residence times.

On large farms that are milking long hours, it is typical to use a multiple pass heat exchanger design for two coolants. In this design, well water would be used for the primary coolant and chilled water or a glycol solution would be used for the second coolant. When milking for long hours, the milk has to be cooled as fast as it is harvested. The combination of well water and a chiller can cool the milk in one trip through the heat exchanger.

Plumbing

The water flow rate through a pre-cooler directly affects the pre-cooler's effectiveness, so it is important to have a well-designed plumbing system. A typical 1 HP milk pump can pump about 35 gallons per minute (gpm), so to get a 1:1 water-to-milk-flow ratio, the water system needs to be designed to provide a minimum of 35 gpm. Table 1 is a guideline for the water flow rate that can be expected through piping of different sizes.

Table 1. Water flow rate in copper and plastic pipes @ 40 psi water pressure

Pipe diameter	Equivalent pipe length 50 ft	Equivalent pipe length 100 ft
1/2"	9 gpm	6.1 gpm
3/4"	27	18.6
1"	55	39.2
1 1/4"	105	71.1

If we use a 1 HP milk pump and want a 1:1 water-to-milk ratio, the water supply plumbing would need to have at least 1" piping to supply 35 gpm of water, according to table 1. A 50-ft equivalent length of pipe might be typical of new construction while an old facility could be 100 ft or more equivalent length of pipe. The water supply system (well, water pump and piping) must have the capacity to keep up with the existing farm 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 minimize the volume of water used for precooling, a solenoid valve can be installed on the water supply line to the pre-cooler and be actuated only when the milk pump runs. A bypass line around the solenoid valve or a time delay relay can also be used to provide additional cooling of the residual milk in the pre-cooler between pumping cycles. A water hammer

Figure 5. Single pass plate heat exchanger

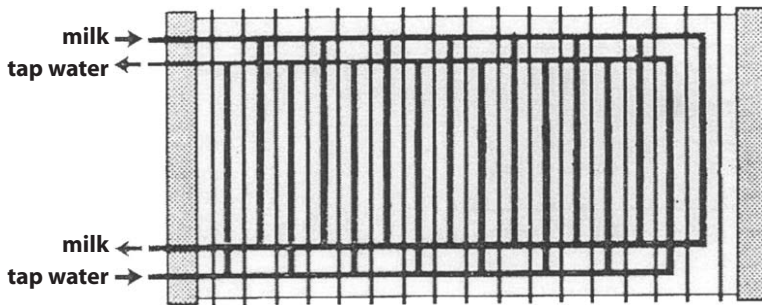


Figure 6. Multi-pass Milk/Single Pass Coolant Precooler

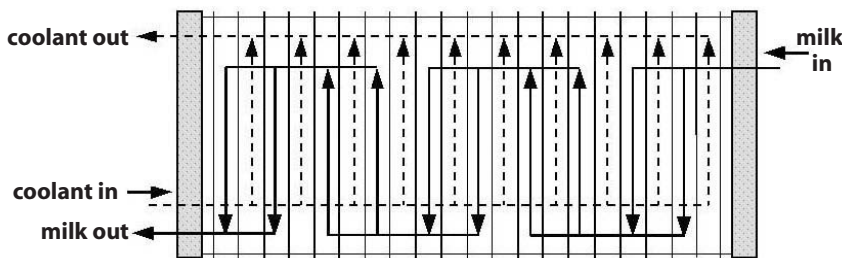
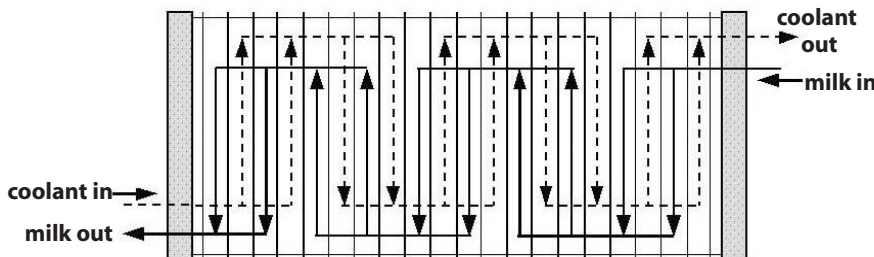


Figure 7. Multi-pass milk and coolant



arrester must be installed with any solenoid valve to prevent damage to the plumbing system from the sudden closure of the valve. The amount of water used per hour by a pre-cooler with a solenoid valve (no bypass) can be estimated by the following formula:

$$\text{Water used per hour} = \frac{\text{Lbs. milk harvested per hour}}{8.6} \times \frac{\text{Water flow rate (gpm)}}{\text{milk flow rate (gpm)}}$$

A storage tank will be necessary for “used” cooling water storage until it is re-used for watering cows, cleanup or another purpose on most farms. If the water is to be used for potable water uses, it must be handled according to state and local plumbing and sanitary codes. On farms with more than 500 cows there may be sufficient water flow rate to the cow waterers in the barns such that the well water can be run through the pre-cooler on its way to the cow waterers, avoiding the need for water storage and re-pressurizing the water. A variable speed milk pump will be necessary to reduce the milk flow rate to maintain a sufficient water-to-milk ratio for this to work. The average daily water flow rate would be expected to be 1.9 gpm per 100 milking cows but can vary during the day by plus 100% or minus 50%. If water is not reused, the cost of pumping and water disposal must be considered in the economic analysis. The water source for use in a pre-cooler must meet state and local potable water standards. Water sources such as streams and ponds are not usable as coolants for pre-coolers.

Sizing

The milk flow rate through the pre-cooler must be calculated, taking into account the frictional line losses in the piping from the milk pump to the pre-cooler inlet and from the pre-cooler outlet to the bulk tank, the pressure

drop through the pre-cooler, pressure drop through the milk filter and the elevation difference between the milk pump and the highest point of the milk line.

If bottom fill is used on the bulk tank, the static head pressure of the milk in the bulk tank must be included in the calculation. The flow rate required during washing can be considerably higher and, if not considered during equipment selection, can cause the wash water to back up in the receiver and eventually flood the vacuum trap, causing the milking system to not be properly washed. If return piping from the bulk tank is used for the milking pipeline wash system, the head loss calculations also need to be done on the system as it would be used during washing to see if adequate flow rates of wash solution can be achieved.

A bypass around the pre-cooler for washing should *never* be necessary if the pre-cooler is sized correctly. Table 2 provides an estimate of the typical flow rates from various milk pump sizes without pre-coolers.

Table 2. Typical milk pump flow rates w/o pre-coolers

Horsepower	Gallons per minute
—	25
—	30
1	35
2	45
3	60

To cool milk to a specific temperature, the flow rate of well water needs to be sufficient, as does the heat transfer area and residence time. The amount of water per gallon of milk flowing through the pre-cooler at a given instant has a direct effect on the amount of cooling that takes place.

Many manufacturers advertise water to milk flow ratios of 1:1 up to 3:1. However, in practice, ratios of 1/2 :1 are very common because of the milk pump’s high flow rates compared to the plumbing system’s ability to supply high flow rates of water. If you refer to tables 1 and 2, you will see the typical 3/4 or 1 HP milk pump, which is common on many farms in Wisconsin, would require a 1” water supply line to achieve a ratio greater than 1:1. A second issue on many of the smaller and older facilities is that the water systems aren’t capable of supplying water flow rates of 30+ gpm. This should be taken into account when purchasing a pre-cooler.

Options for low capacity water systems

If your water supply will not be able to keep up with the short-term demands of a pre-cooler, there are a few options. The milk pump typically runs only for short periods of time, depending on the harvest rate of the milk, with longer periods between pump cycles. The solution may involve increasing the size of the water system pressure tank or adding an additional pressure tank. This will increase short-term water flow rate availability.

If the water system cannot keep up with the necessary water flow rate during milking, it may be necessary to install a water reservoir (tank) that is filled and then used during peak water demand periods. The water reservoir and plumbing will need to meet all potable water regulations. The water reservoir could be used exclusively for the precooler or used to meet peak demands for the entire water system.

The use of a variable speed milk pump will reduce the milk flow rate which increases the water to milk flow ratio and therefore increases milk cooling on low capacity water systems. Water use will increase with the use of a variable speed milk pump. Refer to figure 8 for system diagram of a pre-cooler with water reservoirs.

Precooler and refrigeration heat recovery unit interactions

Precoolers and refrigeration heat recovery units are competing technologies, so an energy analysis needs to be conducted to ensure that if both technologies are implemented, it will not actually increase energy costs. Figure 9 is a schematic of a typical milk cooling system with a precooler and refrigeration heat recovery unit (RHR). An RHR unit can recover 20–60% of the 56 BTU that must be removed from the milk to cool it to storage temperature. Depending on the hot water usage on the dairy, only a portion or all of the available energy may be usable for preheating water. If all of the energy captured by the RHR can be used for preheating water, then the installation of a precooler will increase overall energy costs because some of the heat in the milk will be transferred to well water versus being used for preheating water. If an RHR unit is not being used and is not economical, then maximum cooling of the milk (within 3°F of the

Figure 8. Well water pre-cooler system

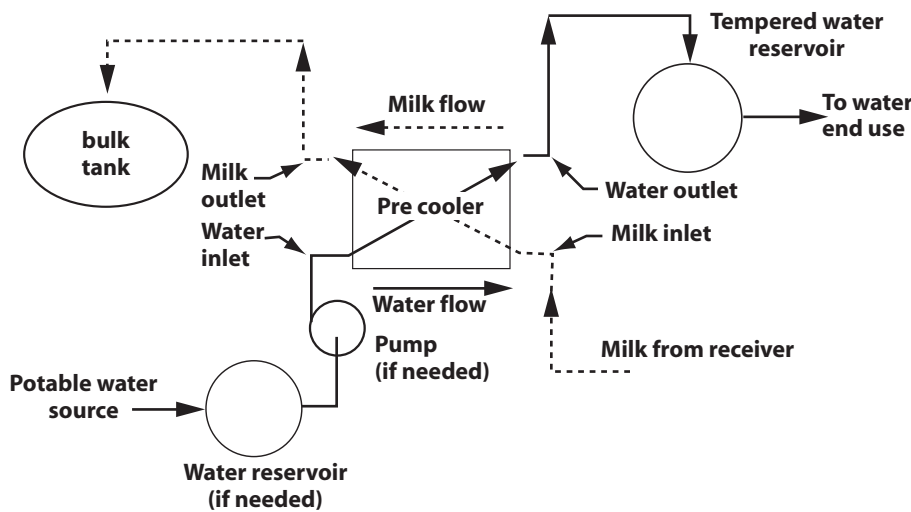
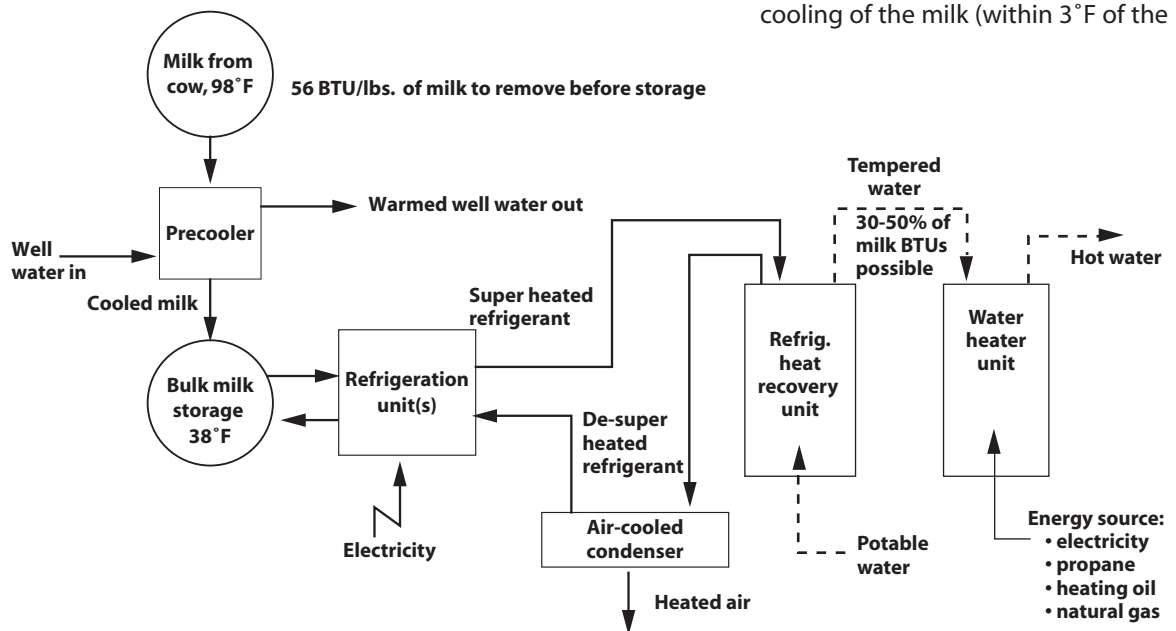


Figure 9. Refrigeration system with pre-cooler and refrigeration heat recovery unit



well water temperature) with a pre-cooler should be considered. If an RHR unit is being used and it is economical to use a pre-cooler, the degrees of milk cooling by the pre-cooler may be only a portion of the possible 40°F to keep from increasing energy usage.

Precooler maintenance

A milk filter must be used upstream of the pre-cooler at all times. This aids in keeping large debris from getting lodged between the plates or within the tubes of a heat exchanger. Well water to the pre-cooler must be turned off and preferably drained from the pre-cooler before washing. If the water is left on, the well water will cool the wash water, which could lead to incomplete washing, milk solids build-up on the milk lines and eventually, high plate counts. If the pre-cooler gets dirty and can't be cleaned by normal CIP methods, a plate heat exchange can be opened by loosening the threaded rods that hold the plates together and cleaned as necessary.

To inspect and clean a shell and tube heat exchange, the fittings must be removed from both ends and a light shown through the tube for inspection. A special tube brush is needed if cleaning is necessary. To reduce the possible need to open a heat exchanger to clean out debris, it can be reverse-washed. This involves pumping the wash solution through the heat exchanger in the opposite direction that the milk is pumped

through to dislodge or flush out any debris that might have passed the milk filter.

When re-assembling a plate heat exchanger, care must be given to tighten the pack up evenly and not to over tighten. The manufacturer should provide a tightening specification per plate or an overall length.

Buying a precooler

1. Contact an energy consultant or your extension agent for an energy audit to determine if a pre-cooler would be economical.
2. If you are also using a refrigeration heat recovery unit, determine the desired amount of milk cooling that can be done without increasing water heating costs.
3. Determine the water flow rate (gallons per minute) that can be supplied from your water system.
4. Determine the cold water temperature.
5. Determine the friction losses and milk flow rate from the milk pump as if the pre-cooler was installed (friction loss analysis—your dairy equipment dealer can help with this).
6. Determine the wash water flow rate as if the pre-cooler was installed (friction loss analysis—your dairy equipment dealer can help with this).

7. Ask the dealer to guarantee the degrees of milk cooling based on the inputs (milk flow rate, water flow rate, water temperature). If the amount of cooling cannot be guaranteed, then your return on investment is questionable.

For more information

Information on different technologies and energy conservation opportunities are contained in the *Energy Conservation in Agriculture* publication series, available from Cooperative Extension Publications at <http://cecommerce.uwex.edu>.

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