Assessment of a Wort-style Heat Exchanger as a Geothermal Milk Chiller

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Abstract: Rising energy cost are beginning to affect dairy farms, especially since up to 30% of all cost goes into cooling the milk. The study performed looked at using a wort-style heat exchanger to more efficiently cool milk. The milk will be pumped through the wort-chillers and will be surrounded by a groundwater bath. If the cooling process of the milk can be made more efficient, this would result in lower production cost, and result in lower consumer cost for products containing milk.
**Introduction:** With rising energy costs, dairy farms are looking for new, more efficient ways to cool milk. Currently, a large refrigeration tank is used, but some dairy farms are switching to heat exchangers. These heat exchangers are supposedly more efficient and could become popular in the push to become greener. New Hampshire dairy farm regulations state that the milk must be cooled to 7.2 degrees Celsius or cooler within two hours after the completion of milking, resulting in a temperature change of 20 degrees Celsius. The main farm in focus for this project will be the Organic Dairy Farm at the University of New Hampshire.

Large dairy farms use a plate heat exchanger to cool the milk. In these heat exchangers, the milk and water are going in opposite directions. There are three main kinds of plate exchangers currently being used, a single pass, dual pass, and a two-stage heat exchanger (Figure 1.). In the single pass the fluids make a single pass across the plates. In the dual pass, the fluids make two passes across the plates, increasing the cooling of the milk. The two-stage heat exchanger is like two single pass heat exchangers joined together. One section is used to precool the milk and the other section is used for the final cooling of the milk. In all of these, the milk and the water flow in opposite directions, in order to increase the efficiency of cooling (Ludington *et al.* 2004).
B.)

Dual Pass

C.)

Two Stage

Figure 1. The three main kinds of plate heat exchangers. A.) The single pass exchanger; B.) The dual pass exchanger; C.) The two stage exchanger. (Figures courtesy of California Dairy Farm Energy Management Guide)
The main problem being addressed is how the cooling of milk can be made more efficient. Of particular focus will be comparing the current refrigeration tank in use to the proposed method discussed here. For this project, a stainless-steel wort chiller, usually used in the production of beer, will be run through a large room temperature water bath. The cold water, simulating the milk, will be pumped through the wort chillers at varying flow rates to see how efficient this method will be in warming. A revised budget for the heat exchanger will be developed and the return on investment (ROI) will be calculated. The more efficient this method is, the higher the ROI will be. The budget will include capital cost for materials and also the operating cost. This will be compared to the current cost to see if the method described here is more efficient or not.
**IMPORTANT:** For experimental purposes, cold water was run through the wort-chillers and was surrounded by room temperature water. Cold water was easier to keep at a more constant temperature than hot water. For actual use, it will be the hot milk running through the chiller surrounded by a cold-water bath.

**Method:** The wort chiller was placed in the room temperature water bath and will be surrounded by warm water. Cold water of around 0 degrees Celsius, to simulate the milk, will be pumped through the wort chiller at a measured flow rate. The temperature will be measured for the cold water before it goes through the wort chiller, the warm water in the room temperature water bath, and the water after it has gone through the wort chiller. This will be done several times at different flow rates in order to maximize the cooling process and efficiency.

![Diagram](image)

Figure 3. The set-up used for this experiment, flow direction being to the right through the chillers with the water returning to the ice-water bath.

Data was gathered using a Campbell Scientific CR200 data logger. Thermistors were placed at three locations on the wort-chillers; at the entry point of the cold water, the water exiting the first chiller, and at the exit point of the second chiller. The
thermistors were wrapped in piping insulation to ensure the most accurate temperature recording possible. They were connected to the data logger were a calibration was inputted in order to get an output of proper units in degrees Celsius. A thermometer was placed in the room temperature water bath and this was also hooked up to the data logger. The data logger was hooked up to a computer and the program PC200 was used to collect the data. Afterwards, the data was stored in excel for easy analysis. Using this data, a number of different values were calculated, including the Reynolds number, head loss, heat flow, and coefficients of performance (COPs). Based on the data gathered from the organic dairy farm, the amount of energy that will be used in cooling the milk can be estimated.

**Results:** From the raw data gathered, several values were calculated and a number of graphs made. They are presented below.
Figure 4. Raw data from Run 5, which consisted of two wort-chillers and a flow rate of 0.6 GPM. The top, light blue line represents the temperature of the water bath; the second line down, the yellow one, represents the temperature of the water coming out of the second chiller; the third, gray, line down represents the temperature of the water coming out of the first chiller; the bottom dark blue line represents the incoming temperature of the water. Notice the gradual decrease in the water bath temperature and temperature of water coming out of both the first and second chillers.
Figure 5. Notice how the BTUs/hr consumed by the water bath decrease as it gets colder, therefore becoming less efficient the colder it gets. Run 4.5 represents after the water has gone through just one-chiller, the same for 5.5. In order to calculate the BTUs/hr the equation $900 \times \Delta T \times Q$; where $Q$=the flow rate in GPM; $\Delta T$=the change in temperature; and 900 is a conversion factor.
Figure 6. The BTUs/hr consumed by the water bath decreases as the difference between the water bath temperature and the average temperature running through the worts decreases. The average temperature in the worts was calculated by taking the max temperature and the minimum temperature, adding them, and then dividing by two. This number was then subtracted by the water bath temperature to acquire the difference value.

Figure 7. As the GPM through two chillers decreases, the BTUs/hr consumed by the water bath increases.
**Discussion:** The water bath can consume a great deal of the heat, and the more chillers there are, the more heat that will be exchanged between the milk and the water bath. Based on this and information from the farm, the following set up is being proposed (Figure 8.):

![Diagram](image)

Figure 8. The proposed design for use at the University of New Hampshire Dairy Farm. This design consists of four-series of two chillers. The total flow rate is 2 GPM with a flow rate of 0.5 GPM through each chiller pair in order to maximize cooling.

The design in figure 8 would result in about 36,000 BTUs being consumed per hour with a temperature change of about 20 degrees Celsius. This was calculated using figure 7 and multiplying by four for the flow rate of 0.5 GPM. Using this set up, the milk would be cooled within about 75 minutes, meeting New Hampshire dairy regulations. This is based on there being 150 gallons of milk per milking and it all being pumped continuously. While continuing to increase the number of series would result in more BTUs consumed by the water bath, four was chosen mainly due to practicality. More worts would take up more space and there is not much space currently at the dairy farm.

Figure 9 shows the cost for cooling 150 gallons of milk at the UNH Organic Dairy Farm. The farthest right point is the cost to cool the milk without the wort-chillers,
just with the refrigeration tank, about $1.50 per day. As series of wort-chillers are added, the cost decreases. This is assuming that the cost for the pumping is negligible, and it comes out to <$0.01 per day. This decrease in cost is due to heat being removed by the cold water bath, resulting in less heat needed to be removed by the refrigeration tank. Using the proposed set-up above, this would result in a daily cost of around $0.50 per day. Though a savings of just $1.00 per day does not seem too significant, it will add up and if energy cost continue to rise, then there will be even more savings.

Figure 9. As numbers of series are added, the cost to cool the milk using the refrigeration tank decreases.

In order to better understand how well this set up would work, there are future test that need to be conducted. One very important aspect is the cold water bath. For experimental purposes, the water bath was left stationary, with neither an in-flow or out-flow. For actual use and to maximize efficiency, water would need to be flowed through the water bath in order to keep it at a fairly constant temperature. This would add an extra pump, but like the pump for the milk, the cost for this would be very negligible. Also of consideration is using the wort-chillers in a more traditional way, pumping the cold water
through the chillers and placing them in baths of hot milk. This idea could work for a smaller farm, such as the one in focus here, but may not be ideal for a larger farm, since there would need to be a lot of baths for the milk.

Other future studies could be done looking at more variation in flow rates. Variations ranging from less than 1 GPM to over 20 GPM would be good to look at and see how they affect the cooling of the milk. Another would be to experiment with different diameters of wort-chillers. One other very important area to look at would be using this set up for a larger farm. It would be important to know how a larger volume of milk could be cooled and if this set up would be as efficient on a larger farm as on a smaller farm.

**Conclusion:** The initial findings for this set up prove to have the potential to be very beneficial to dairy farmers and to society. Using wort-chillers to pre-cool the milk can save around a dollar per day at the University of New Hampshire dairy farm. There is more testing that needs to be done in order to better understand how this set-up would work on a larger dairy farm. Pumping milk through the wort-chillers, which are surrounded by a cool, groundwater bath, looks as though it can be more efficient than the current refrigeration tank in use at the University of New Hampshire organic dairy farm.

**References:**
