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USDA DMRY FORAGE RESEARCH CENTER MILKING SYSTEM IMPROVEMENTS

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Summary:
The effects of different *milking* equipment and its configuration on energy use and system performance of a medium-sized milking parlor are examined. A prototype ambient milk cooling system that uses cold winter air for cooling is evaluated.

Keywords:
Energy use. Cleaning and sanitation, milking systems, cooling, milking equipment

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Background

The USDA Dairy Forage Research Center (USDFRC) in Prairie du Sac, Wisconsin, is an operating dairy farm and research facility. Milking system design improvements were made at the USDA Dairy Forage Research Center to improve system function and reduce energy use. Research was conducted with support of the USDFRC, University of Wisconsin Biological Systems Engineering Department, the Wisconsin Farm Electric Council, and BouMatic Dairy Equipment Company. Equipment was installed to monitor energy use of key components in the milking center, including the refrigeration unit, prototype ambient chiller and vacuum pump.

Original Milking System:

Approximately 300 cows are milked twice daily in a double-8 milking parlor. Before milking center design changes were made, two 7.5 hp oil vane pumps with a maximum air capacity of about 4700 *L/min (165* cfm) produced vacuum for the milking and cleaning system. A concentric tube well water precooler was used to reduce milk temperature to 27^{0}C (81^{0}F) prior to final cooling in the *15,160-liter* (4000-gallon) direct expansion bulk tank. Two air injectors, one on the milkline and one on the washline, were used to produce slug flow during cleaning. The air injectors opened simultaneously to create slug flow in the milk and wash lines (Reinemann et. al. 1994.)

The vacuum pump capacity was excessive according to previous 3-A accepted practices of 170 *L/min* (6 cfm) per milking unit and twice the capacity recommended by the new ASAE Standard (ASAE *S518)* of 1000 L/min plus *85 L/min* (35 cfm plus 3 cfm) per milking unit. Oversizing vacuum pumps is a typical practice in milking parlors in the United States.

Despite the original excessive vacuum pump capacity of about 280 l/min per milking unit (10 cfm per milking unit), the cleaning system was not functioning properly and a residue was accumulating in the milk meters.

System Changes

Milk Cooling

An existing concentric tube well water precooler was upgraded to a more efficient two-stage plate heat exchanger with a variable speed milk pump. At first, this heat exchanger was operated using well water in both stages. A chiller with ambient cooling capabilities was then installed to cool a glycol solution for the second stage of the plate cooler. ~ The two-stage system well water circulates through the first stage to reduce milk temperature to approximately 23^{0}C (74^{0}F). The chilled glycol solution is circulated in stage two to further reduce milk temperature to about 7^{0}C (46^{0}F) before storage and final cooling in the bulk tank. A variable speed milk pump optimizes milk flow through the plate heat exchanger to regulate water-to-milk flow ratio and enhance milk precooler performance.

When ambient temperature was below 0^{0}C (32^{0}F), the glycol solution is cooled using outdoor air (ambient cooling mode). Above 0^{0}C. a compressor is used to cool the glycol solution (chiller mode.) To avoid freezing of the glycol solution, the ambient cooling loop does not run when outdoor air temperatures fall below minus 29^{0}C (-20^{0}F.)

Effective Reserve and Milk Cleaning System Improvements

UW-NIRIL researchers reconfigured the system to improve regulation efficiency, increase effective reserve, and reduce vacuum pump size. With an effective reserve of over 90%, the airflow requirements of the system were reduced to 83 cfm (ASAE, 1996) and one of the vacuum pumps was no longer needed during milking. However, the second pump was still used during cleaning.

To enhance cleaning system performance, researchers sequenced the two air injectors so that the two never opened simultaneously (Peebles et al, 1995.) After introducing sequenced air injection, only one vacuum pump was needed during cleaning.

Reconfiguring the milking and cleaning system reduced air flow needs and brought the USDFRC vacuum pump capacity into agreement with ASAE standard 5518, annex A, Guidelines for Vacuum Pump Sizing (ASAE, 1996.) According to the guidelines, the minimum vacuum pump capacity is:

35 cfm + 3 cfm * (number of milking units)

Using this formula, the capacity of the vacuum pump at the double-8 parlor at the USDFRC should be 83 cfm, approximately equal to the capacity of one of the 7.5-hp vacuum pumps.

Variable Frequency Drive for Vacuum Pump

The 7.5 hp oil vane vacuum pump has been replaced by a 10-hp blower-type pump equipped with a variable frequency drive (VFD.) The VFD eliminates the need for traditional vacuum regulators. Instead, the capacity of the vacuum pump rises and falls according to the need for air removal to maintain a set vacuum level. The VED was installed to save energy and reduce emissions of oil in the exhaust of the old pump. The new pump has a variable capacity of between 560 and 4000 *l/min* (20 cfm and 140 cfm.)

Results

Milk Cooling

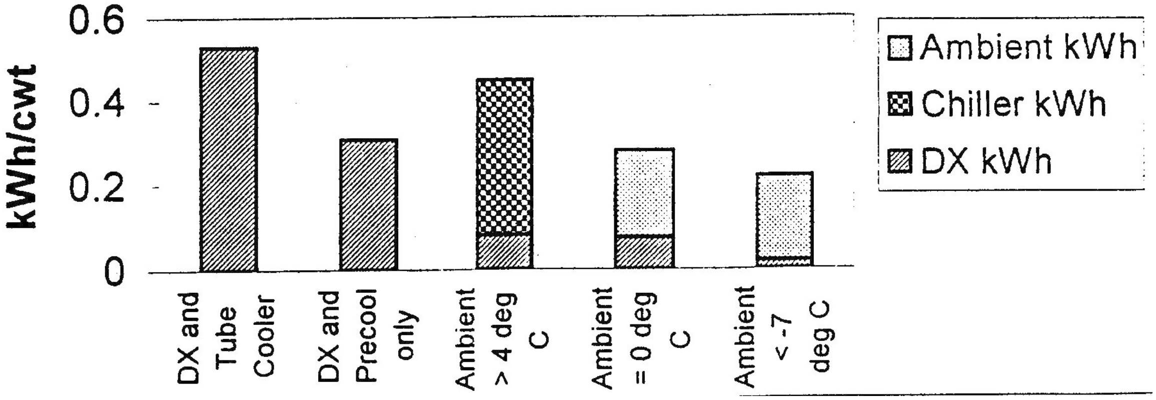
Table 1 lists average energy use and average unit energy use for each milk cooling scenario analyzed. Figure 1 shows unit energy use for the four milk cooling scenarios.

The original milk cooling system at USDFRC used 99 kWh (11.66 kWh/tonne or 0.53 kWh/cwt) of DX compressor energy daily to cool about 8000 liters (180 cwt) of milk. Using the more efficient plate cooler with the variable speed milk pump and no chiller unit. DX compressor energy use was reduced by 42% to 57 ~ per day or 6.82 kWh/ tonne (0.31 kWh/cwt). With the chiller unit in operation but no ambient cooling, daily milk cooling energy use averaged 83 kWh (9.9 kWh/tonne or 0.45 kWh/cwt.) At ambient temperatures of about 0^{0}C (32^{0}F), milk cooling energy use dropped to 51 kWh per day (6.2 kWh/tonne or 0.28 kWh/cwt.) When outside air temperature was -7^{0}C (20^{0}F) or lower, milk cooling energy was 40 kWh/day (4.84 kWh/tonne or 0.22 kWh/cwt.)

Table 1. Average and Unit energy use for various milk cooling scenarios.

Type of Cooling System	Average Daily Energy Use	Avg. Unit Energy Use
Tube cooler and DX (original system)	99 kWh	11.66 kWh/tonne 0.53 kWh/cwt
Plate cooler and variable speed milk pump, DX only	57.1 kWh	6.82 kWh/tonne (0.31 kWh/cwt)
Chiller mode: Plate cooler, chiller, and variable speed milk pump. Ambient temperature > 0°C	83 kWh	9.9 kWh/tonne (0.45 kWh/cwt)
Ambient cooling mode: Plate cooler, chiller, and variable speed milk pump. Ambient temperature = 0°C	51 kWh	6.2 kWh/tonne (0.28 kWh/cwt)
Ambient cooling mode: Plate cooler, chiller, and variable speed milk pump. Ambient temperature < -7°C	40 kWh	4.84 kWh/tonne (0.22 kWh/cwt)

Figure 1. USDFRC Milk Cooling Average Unit Energy Use



Because of the high energy use of the chiller unit when outdoor air *is* not available *for* free cooling, a control system for optimal energy use could be used in which the chiller unit is bypassed when ambient cooling is not available. However, if the chiller unit is installed for the purpose of instant cooling, this control scheme would not be acceptable. The USDFRC system was later modified to use the glycol loop only when ambient cooling is available because the chiller unit is no longer functional

Milk Cleaning System
The introduction of sequenced air injection improved cleaning system performance and solved-the problem of milk residue accumulation in the milk meters. In addition, one vacuum pump instead of two was needed during cleaning.

Vacuum Pump Energy Use
Both energy (kWh) and demand (kW) were cut *in* half during milking and cleaning after researcher made design changes to improve effective reserve and sequence air injectors. The elimination of one vacuum pump reduced demand by half, from 12 kW to 6 kW, and cut energy use in half, from 160 kWh daily to

80 kWh daily. Consequently, vacuum pump energy cost was cut from $2500 per year to $1250 per year, with minimal investment cost.

Variable Frequency Drive on Vacuum Pump Savings
The addition of a variable frequency drive led to energy savings of about 50%, from 80 kWh per day to 40 kWh per day and peak demand savings of about *25%,* from 6 kW to 4.5 kW and operating cost savings of about 40%. Noteworthy is the noise reduction that results from the elimination of traditional vacuum regulators.

Table 2 shows an economic analysis of the VFD system. Electric rates for are determined as the lesser of:

a. $0.092 per kWh or, the sum of:
b. $5.75 per kW monthly demand
+ $1.00 per kW customer demand (highest kW in past 12 months)
+ $0.02702 per kWh

Table 2. Economic Analysis of VFD installation

Vacuum Pump Energy cost with VFD
4.5 kW x *6.75* $/kW + 40 kWh/day*360 days*0.02702 *$kWh = $*750 per year

Energy cost without VFD
6 kW * 6.75 *$/kW* + 80 kWh/day*360 days*$0.02702 = $1250 per year

Annual Savings at USDFRC
$500

Cost of installed VFD system for a 10 hp motor
$4200 (estimated)

Simple payback period
8.4 \years

The simple payback period for a VFD system at the USDFRC is rather long. However a typical farm that is charged a flat rate of $0.06 per kW would experience a simple payback period of 4.8 years. At 9.2 cents per kWh the payback period shortens to about 3 years.

Conclusions

Milking system design changes at the US Dairy Forage Research Center resulted in enhanced system performance and energy savings. A 2-stage plate cooler with variable speed milk pump replaced a concentric tube precooler and reduced milk cooling energy use by 42%. Addition of a chiller/ambient cooling unit resulted in increased energy use when operating in chiller mode and reduced energy use when operating in ambient cooling mode. Energy use was increased in chiller mode by 45% over the plate cooler-DX cooling scenario. When operating in the ambient cooling mode, energy use was cut by 30% compared to the plate cooler-DX cooling scenario.

Vacuum pump energy use was reduced by *50%* by bringing the system into compliance with ASAE 5518 and sequencing the air injectors for cleaning. Replacing traditional vacuum regulation with a variable frequency drive further reduced vacuum pump energy use by *50%* and demand by 25%.

References

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