# PROCESS ENERGY EFFICIENCY IMPROVEMENT IN WISCONSIN CHEESE PLANTS

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## ABSTRACT

Costs for the energy involved in cheese making has a major impact on profit. Although industrial cheese plants differ in size, production equipment, and the manner in which whey is processed, there are common elements in most plants. This paper evaluates several process integration opportunities at two representative cheese plants in Wisconsin. Pinch analysis is used to help assess the heat recovery potential for the major thermal processes in the plants. The potential of using packaged cheese as a thermal storage medium to allow electrical demand shifting in the cold storage warehouse is evaluated and shown to be feasible. Three major conservation measures are identified with a total cost savings of \$ 130,000 to \$ 160,000 annually.

## INTRODUCTION

Wisconsin provides about 30% of the national supply of cheese from the 153 cheese plants in the state. In 1994, 2.2 billion pounds of cheese were produced, and this consumed 87.7% of the milk produced in Wisconsin. The Wisconsin dairy industry provides about three billion dollars per year in gross income. National competition that narrows profit margins and threatens the industry has motivated this study.

The utility use of two representative cheese plants that produce approximately 45 and 65 million pounds of cheese per year, respectively, is examined in this study. These two plants are classified as "large" and together account for 5.5 % of the total state cheese production. Energy costs are about 11% of the total manufacturing cost of cheese, with the remainder due to milk and labor. The energy cost to produce cheese is \$ 0.01 to 0.02 per pound, which is a significant fraction of the profit. Energy use is one of the few variables that a plant manager can influence to improve plant profitability.

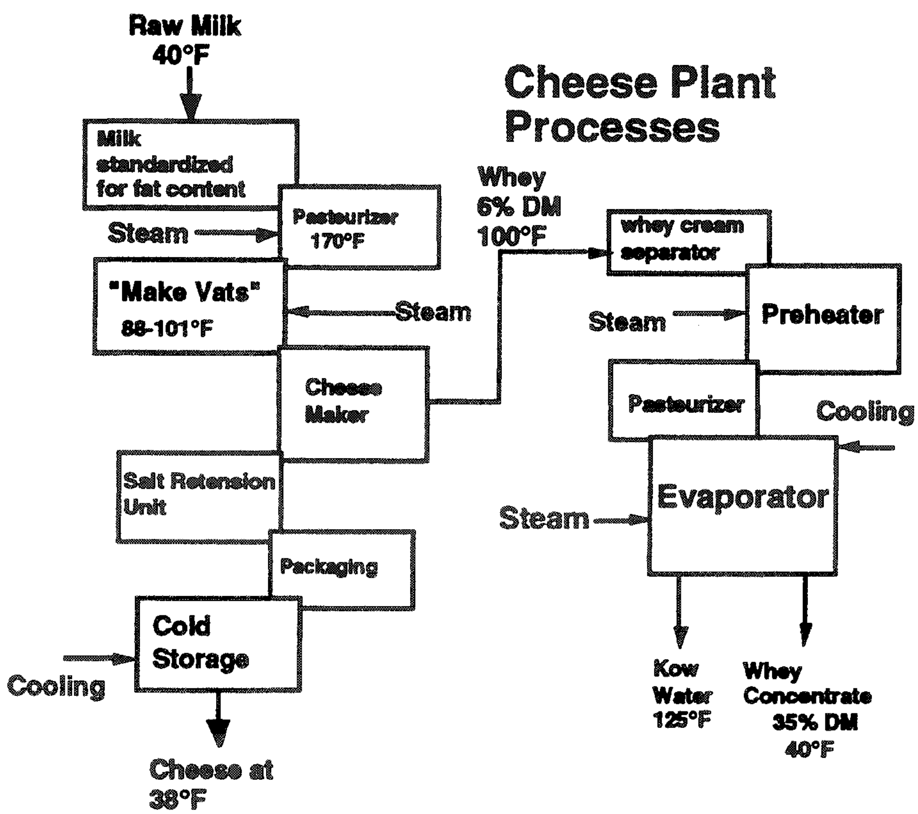
Eighty percent of the energy used at a typical plant is devoted to processing whey, a byproduct that has significant food value. Evaporation systems and spray dryers are commonly used to process or remove moisture from whey. Through the course of this research project, models for both evaporation and spray drying equipment were developed. Pinch analysis has been applied to investigate heat recovery options such as open cycle heat pumps and heat exchange units and to estimate the potential savings.

After processing, the cheese is stored in a warehouse that is maintained at a low temperature by refrigeration equipment. Currently, the refrigeration system is operated as needed during the day. The possibility exists to shift electricity demand by sub-cooling the stored cheese during the off-peak period and turning the refrigeration system off during the demand period. This strategy was also evaluated.

## CHEESE PLANT DESCRIPTION.

A flow diagram for the processes, including the product and utility flows, in a typical cheddar cheese plant is shown in Figure 1. The processes are representative of those in most cheese plants, with newer plants having more energy conservation measures. The major components of the plant heating or cooling energy use are described in the following.

**Figure 1 Process flow diagram for a cheese plant**




**Pasteurization:** Before the cheese making process begins, the milk must be pasteurized. Generally, a method known as High Temperature Short Time (HTST) is used for this purpose. In a typical HTST operation, the 40°F milk is heated to 165°F using high pressure steam from a boiler. The milk is then cooled down to 88°F in a plate heat exchanger where the heat is transferred to cool raw milk. Due to the very high mass flow rate of milk, the heating and heat rejection requirements are significant. However, heat recovery opportunities from the 165°F milk are constrained since the milk is pasteurized and quality and health cannot be compromised.

**Cold Storage:** The finished pallets of cheese are cooled from a temperature of 97°F in a large storage warehouse that is maintained at about 38°F. It takes the incoming cheese approximately seven days to cool to the holding temperature of 40° F. The cheese is then maintained at this temperature for an average of two weeks until it is transported to the market. The refrigeration load to cool the product and to meet the building envelope, ventilation, and infiltration gains of the storage space are significant.

**Whey Processing:** Ten pounds of milk yield approximately one pound of cheese. The nine pounds of liquid that remain after the curd forms and is removed is called whey. Although it is rich in protein and lactose, whey has market value only if it is concentrated or powdered. Falling-film type evaporation systems are used to concentrate whey in the cheese industry. To fully dry the whey to a powder, condensed whey from an evaporator is fed to a spray dryer. Both of these processes are highly energy intensive due to the thermal energy required.

## PROCESS INTEGRATION AND PINCH ANALYSIS

As in many food production processes, a significant amount of heating and cooling are required. Process engineers seek to "integrate" these heating and cooling requirements wherever possible. For instance, if it is desired to cool a 160° F stream and to heat a 120° F stream, one can use the "hot" stream to add heat to the "cold" stream in an amount depending on the capacitance rates (mass flow rate x specific heat). Several techniques are available to determine the theoretical limit to which this integration can take place, as well as to define the optimal manner in which streams must be matched for heat exchange to achieve this theoretical limit. Once this theoretical limit to integration is known, the cost of the heat exchange or heat pumping equipment required to approach it must be balanced against the energy savings.

A method known as pinch analysis[5] has been utilized to investigate integration opportunities at the two cheese plants. With the pinch technique, the temperatures and capacitance rates of all "hot" streams (those that must reject heat) are combined into a single "hot composite" plot on Temperature - Total Enthalpy coordinates. Likewise, the temperatures and capacitance rates of all "cold" streams (those that require heat) are combined into a single "cold composite." These two plots can then be overlaid to accommodate a specified minimum temperature difference for heat exchange between the hot and cold streams. Once this has been done, the maximum possible heat recovery is able to be determined.

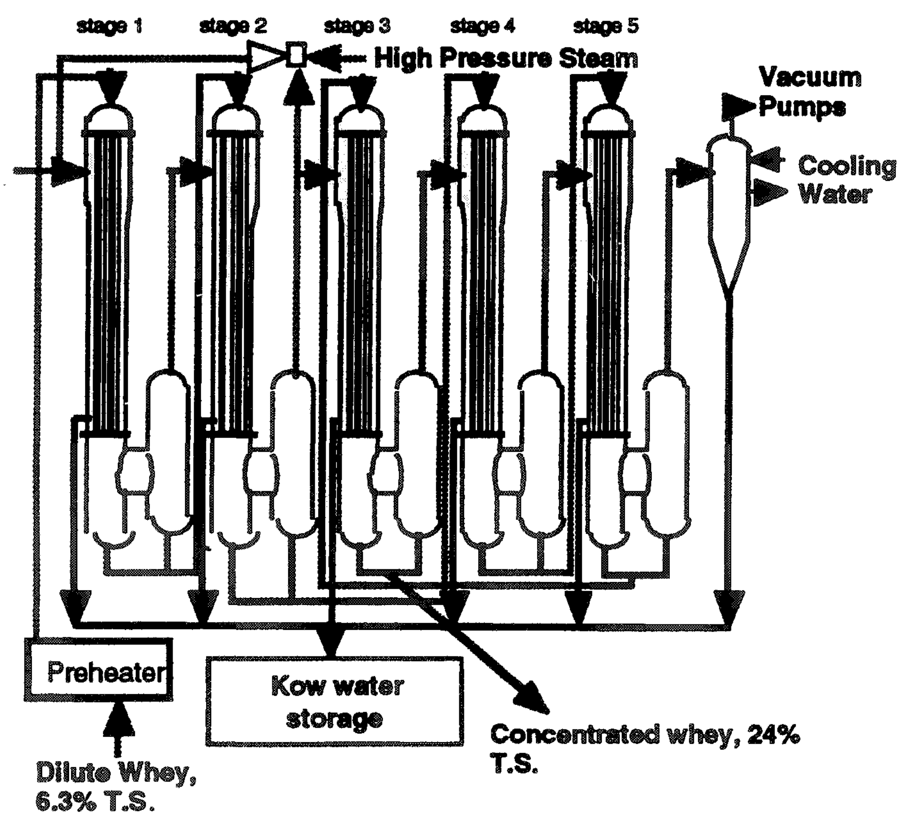
The temperature at the point where the hot and cold composites differ by the minimum temperature difference is called the pinch temperature. Heat should be transferred only between streams above or below this temperature in order to obtain the minimum heating or cooling requirements.

## PINCH STUDY OF A STEAM DRIVEN EVAPORATION SYSTEM

Although many of the streams within the whey evaporation system possess appreciable energy, altering those energy flows would affect the operating point of the entire evaporation system. For this reason, only the streams leading into or flowing out of the evaporator are considered in this study.

At the first plant, a five-effect falling-film evaporation system is used to concentrate the whey before shipping. A schematic diagram of this system is presented in Figure 2. This system requires large amounts of steam for preheating the whey, for producing boiling in the first effect, and for flash cooling the concentrated whey. A cooling tower is used to reject heat from the condenser that condenses the vapor produced in the fifth effect. Due to the low temperature of this vapor, it is not useful for preheating the whey or to drive the flash cooler. However, there is a low temperature heating requirement elsewhere in the plant. To pasteurize the milk that is to be used to make cheese, it must be heated from 40 to 165°F. The potential exists to accomplish some of this heating with waste heat from the evaporator.

**Figure 2 Evaporation system for processing whey (T.S. denotes total solids)**




The set of five process streams that were considered in the pinch analysis are:

1. Heating 79,500 lb/hr of dilute whey from 92° to 176° F.

   (Preheating whey to boiling temperature in the first evaporator stage.)

2. Heating 45,300 lb/hr of supply water from 55° to 96°F.
   (Water to be stored and later used for cleaning purposes.)
3. Heating 87,222 lb/hr of raw milk from 40° to 96° F.
   (Preheating milk before pasteurization.)
4. Cooling 20,408 lb/hr of concentrated whey from 140° to 42° F prior to storage.
5. Condensing 4,810 lb/hr of 106° F vapor raised in the fifth effect.

The pinch diagram is presented in Figure 3 for a minimum temperature difference of 10 F, which represents a practical temperature difference for a heat exchanger. The resulting pinch temperature is 96° F. The situation represents the maximum possible heat transfer, and the cooling requirement is reduced to almost zero. If it is possible to capture fully this integration potential using heat transfer equipment, the cooling tower would be eliminated. In addition to eliminating the purchased energy to heat the milk, about one-half of the energy required to heat the cleaning water would be supplied by heat recovery.

**Figure 3 Pinch plot of temperature as a function of enthalpy**

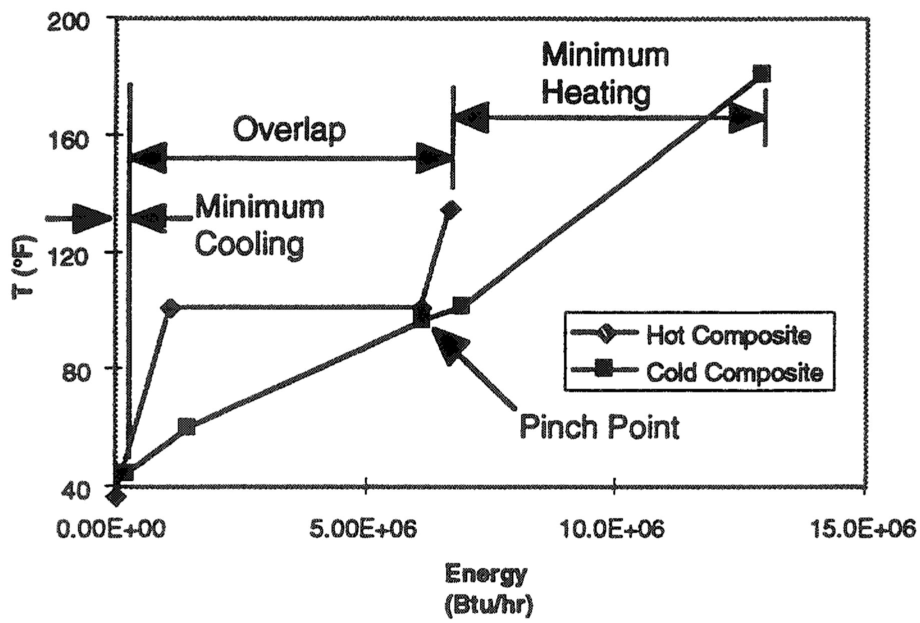



Table 1 compares the theoretically possible minimum use as indicated by pinch analysis to the current usage at the plant. The cooling energy is essentially eliminated and the heating energy reduced to one-half.

**Table 1 Comparison of Minimum and Actual Energy Use**

| | Cooling (Btu/hr) | Heating (Btu/hr) |
|---|---|---|
| Current Use | $6.64 \times 10^6$ | $12.7 \times 10^6$ |
| Minimum Use | $0.20 \times 10^6$ | $6.64 \times 10^6$ |

After determining the minimum usage, the next step is to design a heat exchange configuration to accomplish the integration suggested by the pinch plot. One scenario involves splitting the 106°F vapor from fifth effect, represented as the horizontal line in Figure 3, into flows to two shell and tube heat exchangers. In the first, raw milk could be heated from 40° to 96°F (assuming a minimum temperature difference of 10° F) just prior to pasteurization. This preheating of raw milk accomplishes 88% of the heat rejection from the low temperature vapor that is now being handled by the cooling tower. In the second heat exchanger, city water from the mains would be heated from 55°F to 96°F to be used for off-production cleaning. A control strategy would be needed to vary the flow rate of city water to maintain this temperature rise. This is necessary since the flow rate of vapor is not constant over the entire operating period. In this way, the remainder of the heat rejection from the low temperature vapor is achieved and the cooling tower eliminated.

The savings derived from these heat exchange opportunities includes both the reduction in boiler fuel as well as the avoided cost of operating the cooling tower. The plant operates 18 hours per day, 290 days per year. There is a reduction of $4.98 \times 10^6$ Btu/hr of heating, and over the course of a year this amounts to $26.0 \times 10^9$ Btu. At the local utility energy cost of $0.28 per therm ($10^5$ Btu) of natural gas, this represents an annual savings of $72,800.

The cooling tower is equipped with a 60 hp motor that operates under partial load. Energy savings accrued from eliminating the cooling tower were estimated assuming a 50% load factor for the 18 hours each day that the evaporation system is in operation. This represents $1.17 \times 10^5$ kWh per year. At the local electrical energy cost of $ 0.027 per kWh, this amounts to $ 3,150 per year. For plants served by utilities with demand charges there would be increased savings due to reduced demand. The total utility savings are approximately $76,000 per year, and would need to be balanced against the cost of equipment to determine whether they are cost effective. A survey of cheese plants has been conducted, and showed that this level of integration is not employed.

## INTEGRATION OF A GAS FIRED SPRAY DRYER

In the second plant studied the condensed whey is further processed in a spray drier/ bed dryer combination to remove the remaining moisture from the whey. The vertical spray dryer is supplied with 55,750 cfm of outdoor air that has been heated by a direct fire gas burner to 240°F. The condensed whey is sprayed under very high pressure from nozzles around the top perimeter of the chamber. Given the high temperature of the air and the large exposed surface area of the whey droplets, drying proceeds at a rapid rate. Whey powder settles to the bottom of the chamber and is moved by conveyer to the vibrating bed dryer. The moisture laden exhaust air is drawn off near the bottom of the drying chamber at approximately 156°F. The air is then passed through a series of cyclone separators to rid it of fine whey particulates before being exhausted to the atmosphere.

A potential exists to integrate the supply air and the exhaust air flows from both the spray drier and the bed drier. An indirect heat recovery heat exchanger loop was modeled[4] and used to predict the energy savings from installing heat exchangers in both of these stream pairs. The performance depends on the ambient temperature, and TMY data for a nearby location (Madison, Wisconsin) was used to represent the weather. Annual simulations were run using a wide range of heat exchanger effectiveness. Savings of $50,000 to $75,000 per year are possible using the local gas price of $0.28/therm.

## DEMAND SAVINGS FOR A CHEESE STORAGE WAREHOUSE

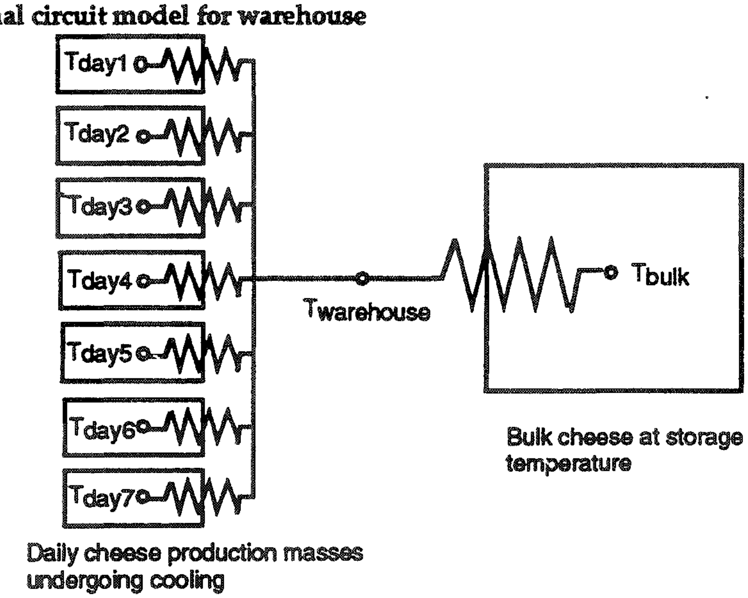
Each cheese plant has a cold storage space in which the cheese is cooled and stored at low temperature. The ventilation and cooling equipment required to condition the air in this space accounts for a significant demand for electricity 24 hours a day, 365 days a year. The cooling load is fixed but the opportunity exists to reduce the cost to meet this load by taking advantage of utility rate structures. The feasibility of using the cheese as a thermal storage medium was evaluated.

A model for the stored cheese was developed that involves seven individual terms each representing a single day's production of cheese. These are coupled to form a finite difference model for the cooling of cheese in the warehouse. A diagram of the thermal circuit modeled is shown in Figure 4. The energy balance includes the envelope, ventilation lighting, and equipment loads. The final energy balance becomes:

$$Q_{refrigeration} = \sum_{i=1}^{7} m_{prod,daily}\, c_{p,cheese} \frac{\left(T^{+}_{cheese,i} - T_{cheese,i}\right)}{\Delta t} \frac{(1 - SHR)}{SHR}$$

$$+ m_{bulk}\, c_{p,cheese} \frac{\left(T^{+}_{bulk,i} - T_{bulk,i}\right)}{\Delta t} - Q_{ventilation} - Q_{lighting} - Q_{motors} - Q_{envelope}$$

Figure 4 Thermal circuit model for warehouse



where Q is a heat flow, ma the mass of cheese, $c_p$ is the specific heat, and T is temperature. The sensible heat ratio (SHR) term accounts for the latent load. The $\Delta t$ term represents a one-hour interval. This model is then solved for hourly intervals over a 24 hour period under design conditions.

The thermal capacitances are treated as lumped, which means that the cheese blocks are assumed to be at uniform temperature at each time step. This greatly facilitates the evaluation of the temperatures. The error inherent in making this assumption has been examined and has been found to be acceptable for the purpose of evaluating the energy use.

Heat transfer rate equations are needed to couple the temperature of the cheese blocks to that of the warehouse air. The heat flows to or from each cheese mass are given in terms of an effective convection coefficient, effective surface area, and the temperature difference between air and the cheese.

$$Q = h_{effective} \, A_{exposed} \left(T_{air} - T_{cheese}\right)$$

The exposed area is estimated based on a geometric analysis of the stacking method in which the cheese boxes are placed on palettes. A value of 0.071 $ft^2$ of exposed area per pound of cheese was determined. The effective heat transfer coefficient was estimated based on the temperature decay for a lumped capacitance[3]:

$$\frac{T_t - T_\infty}{T_{initial} - T_\infty} = \exp\left[-\frac{h\,A\,t}{m\,c_p}\right]$$

For a 42.7 lb block cheese with a seven day cooling period, a value of $h_{effective} = 0.127$ Btu/hr $ft^2$ °F was found. This value represents both the surface heat transfer resistance and the internal resistance of the cheese.

The outputs of interest are the temperature response of the air in the warehouse and the bulk cheese in storage. This latter is the cheese that has already completed the seven day cooling period and is awaiting shipment. Current regulations are that the cheese be maintained between freezing and 40°F. The temperature swing that occurs during a 24 hour period depends on the cooling strategy and the amount of cheese already in storage, which varies between 0.5 to 3.5 million pounds.

In a full storage control strategy the refrigeration system is off during the on-peak period, which is typically 12 hours during the daytime. Figure 5 depicts the temperature variations for a 24 hour period with a daily flow of 156,000 pounds of cheese into a warehouse containing 2.8 million pounds (the average amount of cheese in storage at the plant) and an outdoor temperature of 92°F. The air temperature increases rapidly from 30 F to 55 F when the refrigeration system is turned off, and drops rapidly when the system is turned on again. In contrast, the cheese bulk temperature rises and falls slowly over a 3 F range.

**Figure 5 Temperature variation in warehouse**

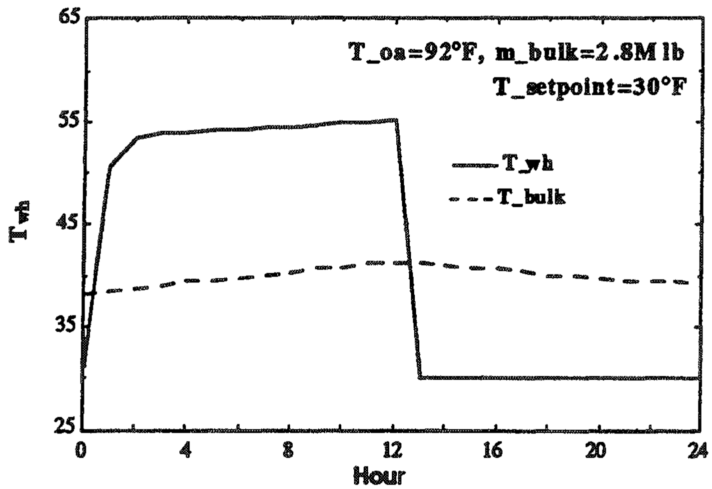
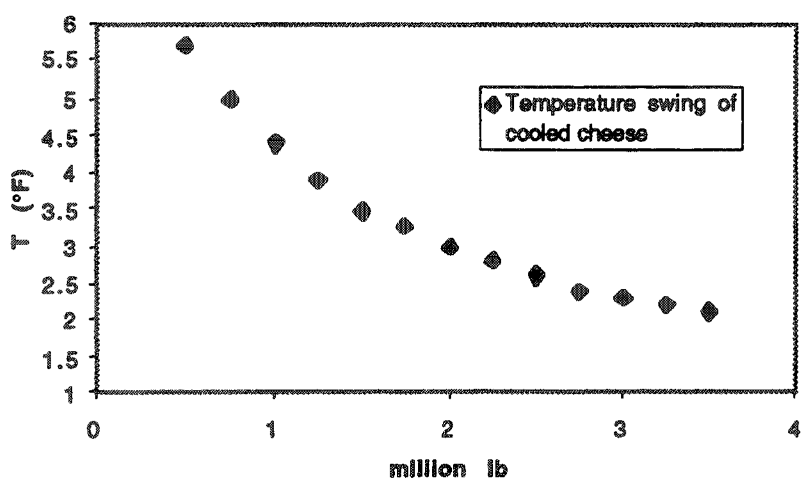



Figure 6 presents the relationship between the magnitude of the temperature swing of the bulk cheese and the amount of cheese in storage. A temperature swing of a large magnitude does not necessarily mean that the control strategy is not practical. It simply means that the off-peak setpoint must be reduced to maintain the cheese within the desired temperature range. Operating the equipment at a cooler setpoint does, however, slightly reduce the performance of the cooling system. Figure 6 shows that the bulk cheese temperature swing will be less than 4°F under this control strategy if there is one million pounds or more in storage. A setpoint of 28°F or lower may be required to safely allow shutdown of the cooling system during on-peak hours in order to prevent the temperature of the bulk stored cheese from increasing above 40°F. An experimental study on the effect of temperature swings on the quality of the cheese is currently underway.

**Figure 6 Temperature swing in warehouse as a function of the amount of cheese in storage**



The savings derived from the thermal storage strategy have been estimated based on estimates of the cooling load and system performance. Table 2 presents the estimated annual operating energy costs of the cooling system under present operating conditions along with the estimated annual energy costs under a full storage control strategy. The average daily load and the COP of the refrigeration system are also given.

**Table 2 Costs for System Operation with and without Storage**

| Month | Daily Load (Btu/day) | Refrigeration COP | Oper. cost conventional ($) | Oper. Cost with storage ($) | Savings ($) |
|---|---|---|---|---|---|
| Jan | $7.9 \times 10^6$ | 8.0 | 1,397 | 190 | 1,207 |
| Feb | $8.0 \times 10^6$ | 8.0 | 1,379 | 174 | 1,205 |
| Mar | $8.6 \times 10^6$ | 8.0 | 1,417 | 207 | 1,210 |
| April | $9.4 \times 10^6$ | 5.7 | 1,531 | 308 | 1,223 |
| May | $10.0 \times 10^6$ | 4.2 | 1,703 | 460 | 1,243 |
| June | $11.0 \times 10^6$ | 3.2 | 1,872 | 619 | 1,253 |
| July | $11.0 \times 10^6$ | 3.0 | 1,957 | 696 | 1,261 |
| Aug | $11.0 \times 10^6$ | 3.1 | 1,925 | 667 | 1,258 |
| Sept | $10.0 \times 10^6$ | 3.8 | 1,741 | 502 | 1,239 |
| Oct | $9.7 \times 10^6$ | 4.9 | 1,615 | 382 | 1,233 |
| Nov | $8.9 \times 10^6$ | 7.8 | 1,423 | 213 | 1,210 |
| Dec | $8.1 \times 10^6$ | 8.0 | 1,403 | 195 | 1,208 |
| Total | $113.6 \times 10^6$ | | 19,363 | 4,613 | 14,750 |

A summary of the predicted savings from each of the opportunities evaluated is presented in Table 3, listed in order of decreasing energy savings potential. These annual savings need to be balanced against the costs of necessary modifications in order to determine whether they are cost effective. The results of this study have been discussed with the plant managers and the measures appear to be feasible for cheese plants. A project is currently underway to experimentally demonstrate one of these measures in a Wisconsin cheese plant.

**Table 3 Summary of Major Energy Savings**

| Description | Expected Annual Savings |
|---|---|
| Evaporator Integration Strategy | $76,000 |
| Spray Dryer Integration Strategy | $42,000 - $69,000 |
| Thermal Storage Warehouse Control | $14,750 |

## SUMMARY

Pinch analysis has been used to identify conservation measures for thermal energy savings at a cheese plant. The evaporation system studied currently uses a cooling tower to reject heat into the environment during operation. The potential exists to heat the 40°F raw milk prior to pasteurization and to preheat city water for cleaning purposes. This would provide two simultaneous economic benefits in that the cooling tower could be eliminated and the heating requirement of the pasteurizer could be reduced significantly. Spray dryers draw in a large volume flow of outside air, heat it by a direct fired burner, and exhaust it to the outside. A heat exchange system would recover exhaust energy and produce significant savings.

Peak load reduction savings using stored cheese as a thermal storage medium was investigated using finite difference techniques. A full storage control strategy would significantly reduce the cost of operating the cooling equipment during the peak rate period.

## ACKNOWLEDGMENTS

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