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NEW INDUSTRIAL HEAT PUMP APPLICATIONS TO CHEESE PRODUCTION

Phase I

Final Report

April 1990

Work Performed Under Contract No. FC07-88ID12790

For
U.S. Department of Energy
Office of Industrial Technologies
Washington, D.C.

By
Linnhoff March
Leesburg, Virginia

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Prepared for
U. S. Department of Energy
Idaho Operations Office, Idaho Falls, ID
Sponsored by the Office of the Assistant Secretary
for Conservation and Renewable Energy
Office of Industrial Technologies
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EXECUTIVE SUMMARY

An energy cost reduction study of the Sorrento Cheese Co. Inc. cheese/whey powder process (SIC code 2022) has been completed. Of Particular interest were the opportunities for utilizing heat pumps for energy cost reduction or other profit improving uses. Pinch Technology was used to identify heat recovery, heat pumping, process modification and cogeneration options. Pinch Technology provides a thermodynamically consistent base from which the relative merits of competing cost reduction options can be assessed.

The cheese/whey powder process consists of two stages, cheese production and whey powder production. Cheese is manufactured by adding an initiator to pasteurized milk. The resulting curd is then cooked, molded and packaged. The exact processing steps depend on the type of cheese being made. Whey which separates out during cheese making is concentrated in a TVR evaporator, crystallized and finally dried. The process studied is typical of those in the industry.

The study identified heat recovery opportunities which could save $198,0000/yr at an over all payback of 26 months. Individual project paybacks range from 18 to 36 months.

The use of heat pumps in the form of MVR and TVR evaporators is well established in the dairy industry. For this process, which already incorporates a TVR evaporator, no additional cost effective opportunities for utilizing heat pumps were identified. If, however, the plant was being expanded, a fan MVR whey pre-evaporator would be a very cost effective solution. The high stand alone efficiency of such a unit can be further improved by appropriate integration with the rest of the plant.

It is felt that the results obtained in this study are applicable to other cheese/whey powder manufacturing sites. This study, and others, indicate that reductions in thermal energy consumption of 10 - 15% can be expected. Also the use of MVR and TVR evaporators is appropriate.

1.0 INTRODUCTION

An energy cost reduction study of the Sorrento Cheese Co. Inc., Buffalo, NY cheese/whey powder process has been completed. This process is classified under SIC code 2022. The objective was to find cost effective energy cost reduction projects and to develop a coherent strategy for realizing the savings. There are many possible options for reducing energy cost. These are shown in Figure 1. To facilitate a fair comparison of the options Pinch Technology was used to identify appropriate heat recovery, heat pumping and cogeneration options.

Of particular interest were the opportunities for utilizing heat pumps, for energy cost reduction or other profit increasing uses. Therefore, where a heat pumping scheme was identified, its merits relative to other potential projects was carefully evaluated to ensure that the heat pump was technically and economically sound.

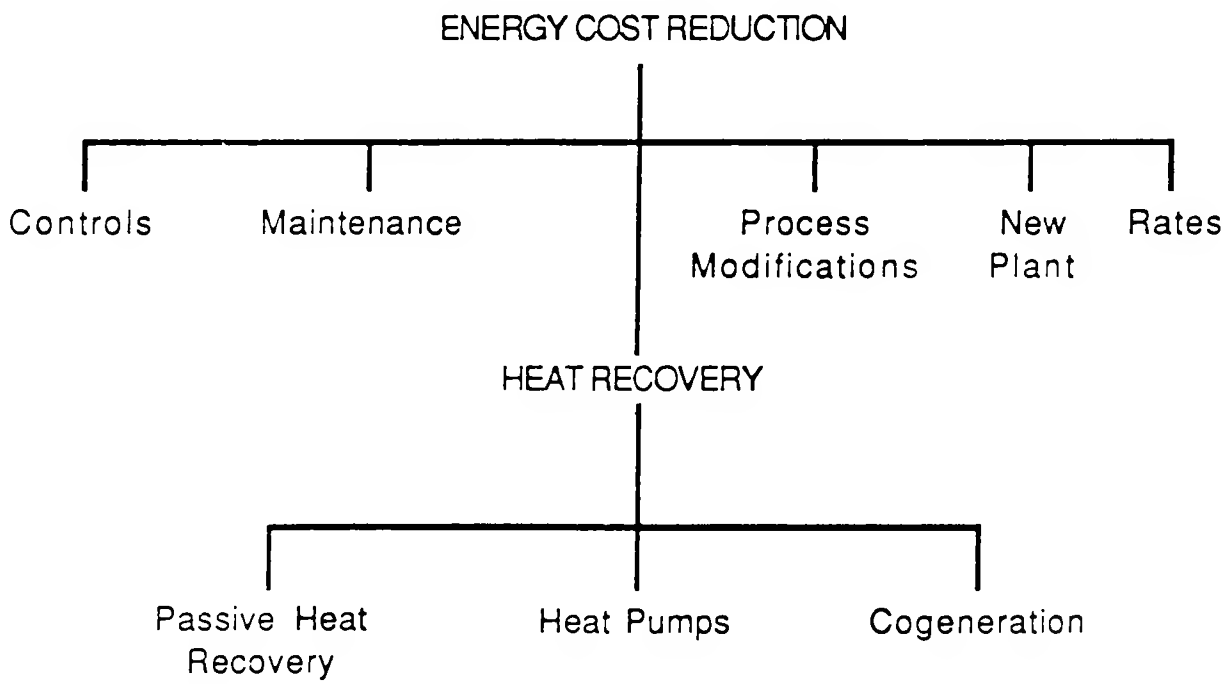


Figure 1 Energy cost reduction options

2.0 THE BUFFALO PLANT

The Buffalo site represents an average sized dairy, converting milk into Italian cheeses and whey powder. The plant operates for 20 hours/day with the down time being used for cleaning. The dairy operates for typically 340 days in a year so this site has a higher than average load factor for the industry; a more typical plant may only operate for 200-250 days, due to seasonal fluctuations in milk production.

The process uses steam for process heating resulting in an annual fuel cost of around $800,000/yr. In addition electricity costs add around $700,000/yr to the energy bill. All the significant processing operations were included in the study. The major items not included were building HVAC and the cold stores.

Figure 2 shows a process flow diagram for the host site. There are two cheese plants. The Mozzarella/Provolone plant takes a continuous milk flow. After milk pasteurization and curd setting, a matted curd is developed, cooked and then mechanically molded into blocks. The cheese blocks are then salted by floating in a brine tank for a set period of time.

The other cheese plant makes a range of Whey and Ricotta type cheeses where the soft curd is set and cooked in open vats. The cheese is made in batches. The cheese from both plants is packaged before curing in refrigerated cool rooms. The extent of process heat integration in both production areas, is limited by processing constraints because the final product quality is the paramount manufacturing criteria.

A small quantity of cream is separated from the sweet whey, before it is transferred to the whey plant for processing to powder. The whey plant was built in the late 1970's as an add-on plant and is the most modern manufacturing facility on the site. The whey evaporator and dryer use a significant part of the process energy in removing the water from the sweet whey. The evaporator is a 6-stage multiple-effect evaporator (MEV) with

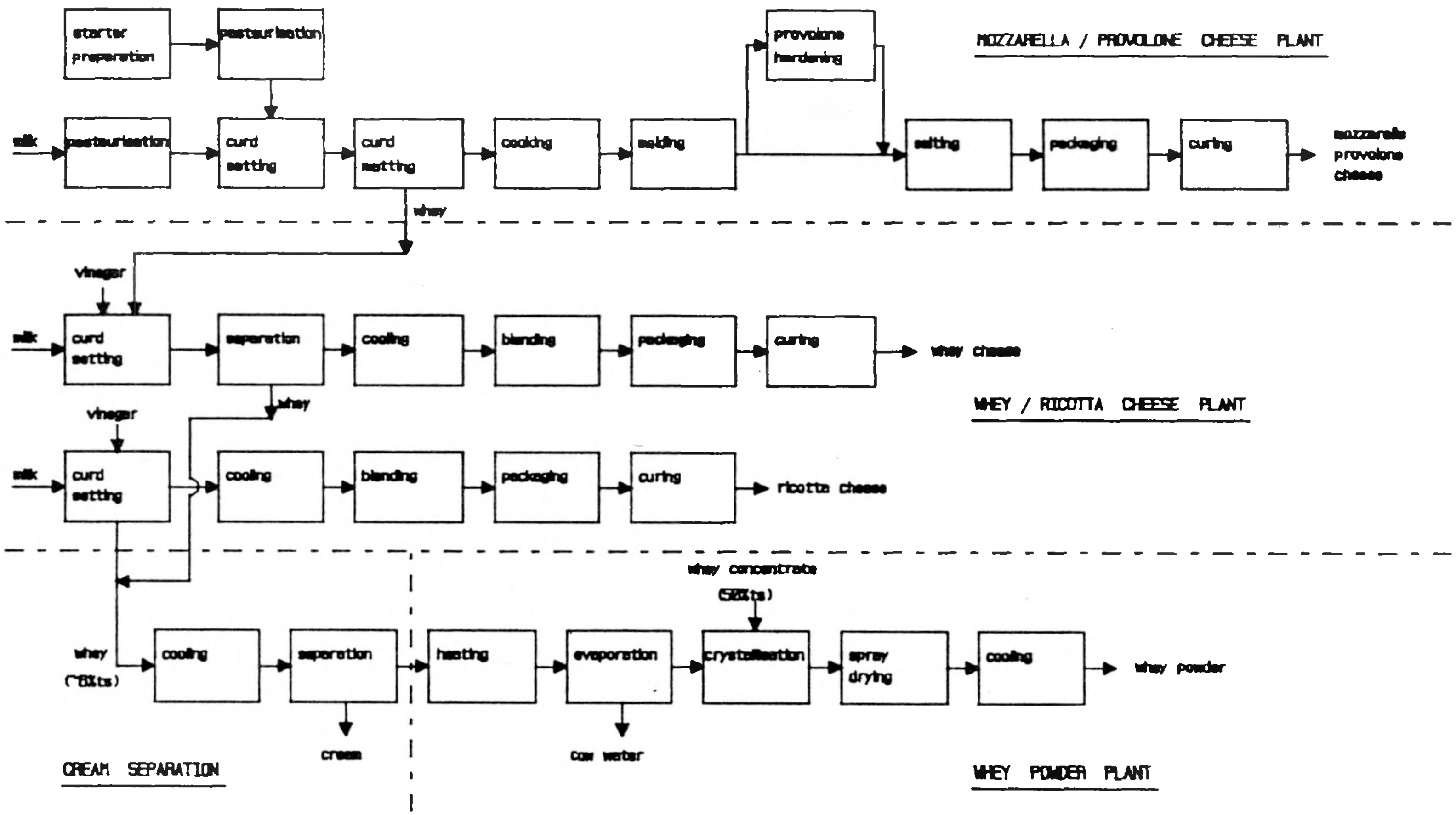


Figure 2 Process Schematic

thermal vapor recompression (TVR) across the first 2 stages so it demonstrates a high steam economy. The gas-fired spray dryer is presently the whey processing bottleneck and operates continuously, drying all the whey concentrate from the evaporator and from another company site.

Gas-fired boilers generate steam for all the process heating, apart from the primary air heating for the spray dryer which is brought up to temperature using a direct gas-fired burner. The boilers represent the utility bottleneck as they all have to be kept on-line to cover the peaks in the daily production pattern, which can occur in the early morning as the cheese plants are started-up and also during the day, depending on the manufacturing pattern in the Ricotta area. A common ammonia refrigeration system provides the process cooling below ambient temperatures. The largest load is for the cool rooms and the blast freezer, which rapidly cools the packaged Ricotta cheeses. Chilled water systems satisfy the brine cooling and the other cheese cooling duties. The cleaning-in-place (CIP) systems take appreciable quantities of hot water each day; currently it is all produced as needed by mixing steam and cold water.

The present extent of heat integration on the total site is limited. A hot water pump-around system recovers heat from hot whey and uses it to pre-heat incoming cold whey and milk in the Ricotta plant. Use is made of the condensate or cow water from the evaporator; some cow water is returned as boiler feed water (BFW) and the remainder is firstly recovered for cleaning of the evaporator and the excess provides make-up to the refrigeration system evaporative condensers. There is no other integration between the cheese manufacturing and whey processing plants.

The whey evaporator dominates the use of process energy and the site already makes use of heat pumping in the form of thermal vapor recompression (TVR) to obtain a good steam economy with the multiple-effect evaporator.

The dairy industry in the United States is large and growing. Total milk production, partially due to the effect of the Government Price Support

Program, has increased from 115.6 billion lb/year in 1975 to 135.7 billion lb/year in 1984. About 15 billion pounds of the increase has gone into cheese production. Some new plant construction and expansion has occurred, and existing plants are generally operating at full capacity. Industry expenditures on energy amounted to $114 million in 1981, a 15% increase over 1980.

The U.S. Government's Price Support Program effectively sets a floor on the price of butter, skim milk powder, and American cheese. Whey powder, the major by-product of cheese manufacturing, is not protected by the Price Support Program. It is traded on the free, open market. One of the results of the high current cheese production is a glut of whey powder on the market. The price has, therefore, been driven down. As the cheese plants' profit margin has been reduced at these low prices, low processing costs are very important.

A number of MVR (Mechanical Vapor Recompression) evaporator systems have been installed in cheese plants in recent years. These employ electric heat pumps to markedly reduce energy use. Hence, they have contributed significantly to reduced production costs in these installations.

3.0 IMPROVED HEAT RECOVERY

Process information for each of the four main plant areas; mozzarella/provolone cheese, whey/ricotta cheese/cream, whey powder and services was used to develop the basis for the Pinch analysis. A Grand Composite Curve for the total site is shown in Figure 3.

The energy target is 735 units. It is easily seen that the whey evaporator is the dominant heat load, and that the existing TVR evaporator is appropriately placed in taking 247 units from below to above the pinch. The remaining utility target is 418 units. Compared to an existing utility consumption of 1000 units this suggests that energy usage can be decreased by over 50%. However, in constructing the curve in Figure 3 it has been assumed that all of the streams in the process are suitable for heat recovery. For practical reasons, certain heating duties must be done by direct steam injection (i.e. heating of cheese) and certain cooling duties must be done by brine rather than cooling water. These practical constraints alter the quantity of heat recovery possible and must be accounted for. Also, it was decided that only the whey evaporator first effect and condenser duties plus the feed and condensate streams should be considered in the analysis because

1) the evaporator is already efficient, and

2) the arrangement of the effects is complex and changes would be difficult.

Figure 4 shows the revised grand composite curve which takes into account the constraints described above. The hot utility target has actually increased from 486 units 680 to units. This reflects the loss of scope for heat recovery caused by the constraints. However, the utility targets generated in this fashion are more realistic and Figure 4 will be used as the baseline grand composite curve. Table 1 compares the target with the existing plant consumption.

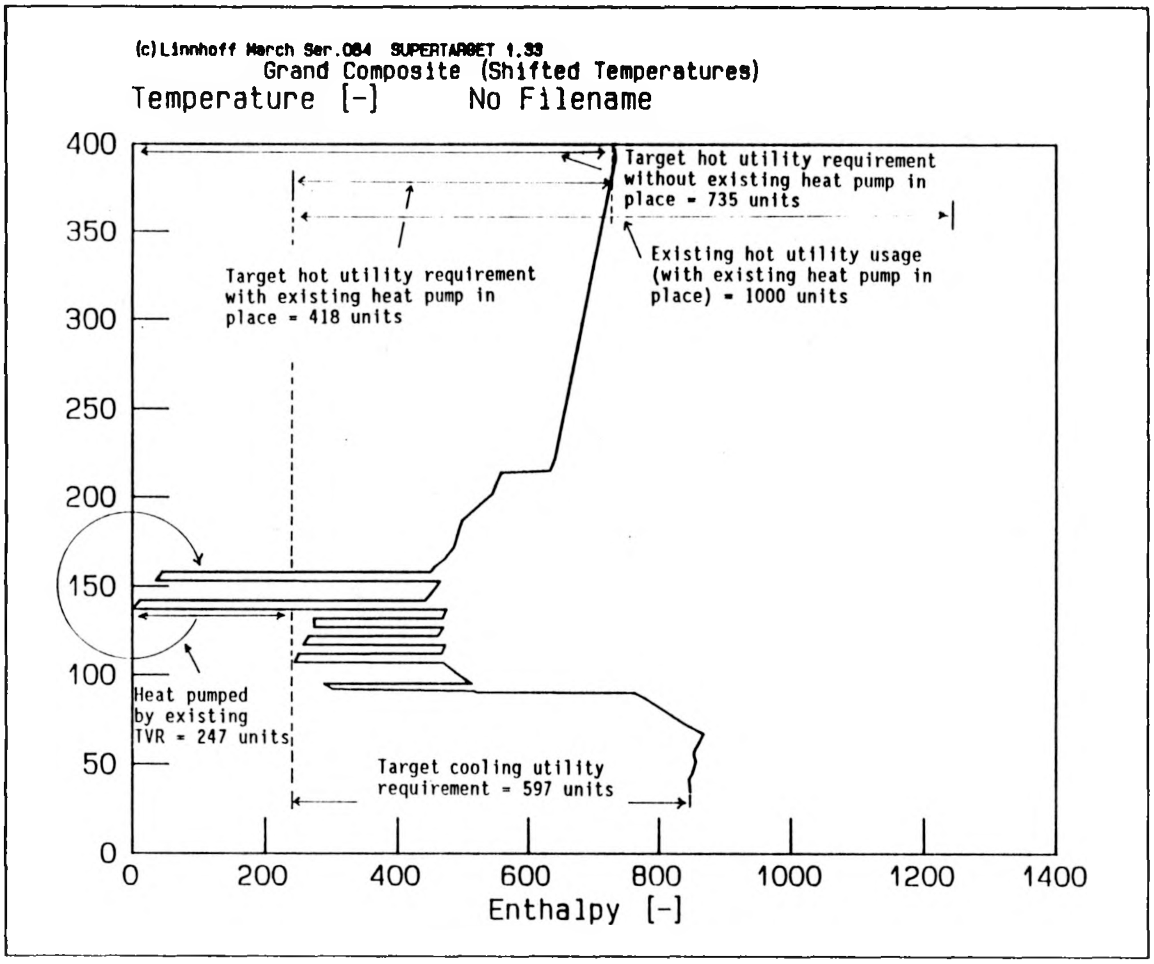


Figure 3 Grand composite curve for entire process (without constraints)

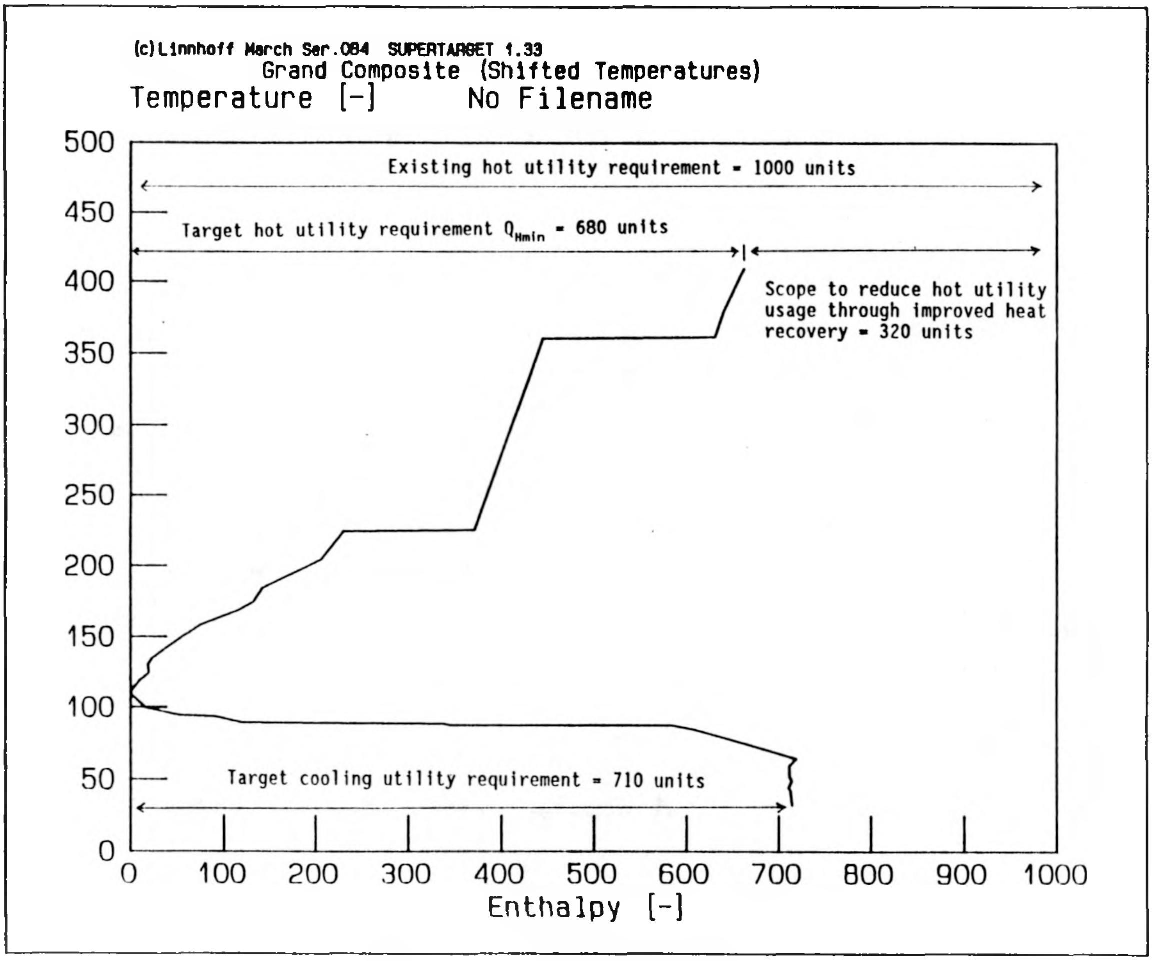


Figure 4 Grand composite curve for process, taking process constraints into account

Table 1 - Actual vs Target Energy Consumption

Existing Usage	Target	Potential Savings
1000	680	32%

Following his initial targeting phase, the projects required to get from the existing energy consumption to the target consumption were identified. This process took into account process constraints and Sorrento Cheese Co. Inc. preferences.

A package of four mutually compatible projects was identified (Project 1). These projects save 90% of the targeted amount and are worth $140,000/yr. The overall package has a payback of 22 months, with individual project paybacks being in the range of 18 to 30 months. Table 2 summarizes the projects. In addition, a hot water loop (Project 2) could be installed as a new hot utility, picking up and distributing heat from /to a variety of sources and uses around the site. The heat savings include utility related streams such as condensing boiler flue gases and ammonia desuperheating. This project could save an additional $58,000/yr at a payback of around 36 months.

Table 2 - Heat Recovery Projects

1. Improved milk preheating
2. Improved heat recovery from hot whey
3. Increased preheat of whey to the evaporator
4. Boiler feed water and wash water heating

4.0 HEAT PUMPING OPPORTUNITIES

The Grand Composite Curve for the total site including the whey evaporator demonstrates that the existing Thermal Vapor Recompressor (TVR) system is appropriately placed and operating effectively. Two possible additional heat pumping opportunities exist. These are:

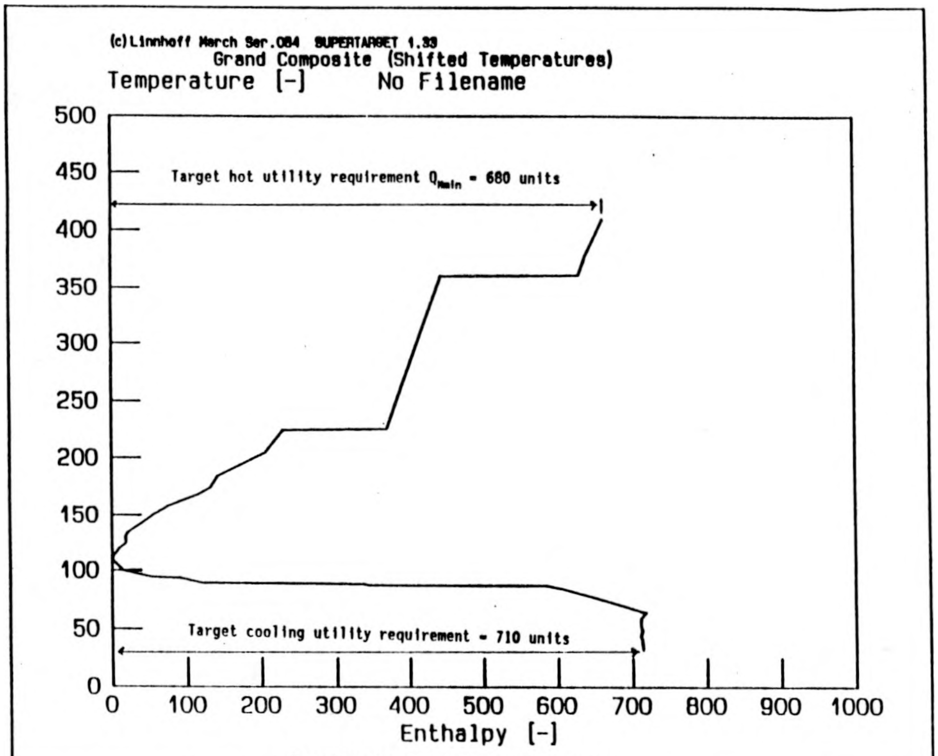
1. Convert the existing TVR to an MVR
2. Given that the existing TVR cannot be changed, install a closed cycle heat pump to operate around the 'simplified process pinch.

Retrofits of multieffect evaporates to MVR evaporators have been carried out in the dairy industry. Figure 5 shows the Grand Composite Curve for the process incorporating a single effect MVR. The effect of this change is to increase the energy target from 680 units to 2050 units. However, the power required by a steam compressor operating around the resulting "nose" is low. About 1650 units can be supplied by a heat pump with a COP of around 30. In this instance, though, such a retrofit is not attractive because the cost of running the MVR would exceed that of the existing TVR. This is due to the high efficiency of the existing unit and the relatively higher cost of power compared to fuel. While this project is not attractive as a retrofit, the use of MVR evaporators in new installations is very common.

Figure 6 shows the opportunity for a closed cycle heat pump. Such a unit would need to pump 150 units through a lift of about 90 or 100°F. The COP of this heat pump would be around 4 which is not economically attractive. This system would have practical drawbacks including the need to collect heat from a variety of sources and deliver it to a variety of sinks.

4.1 Plant Capacity Increase

The major opportunity for a heat pump appears if an increase in plant capacity is required. It is now common practice to use an MVR evaporator for whey preconcentration, followed by a finishing stage. In many instances the usual single stage centrifugal steam compressor used in MVR applications is being



Base Case Process Grand Composite Curve

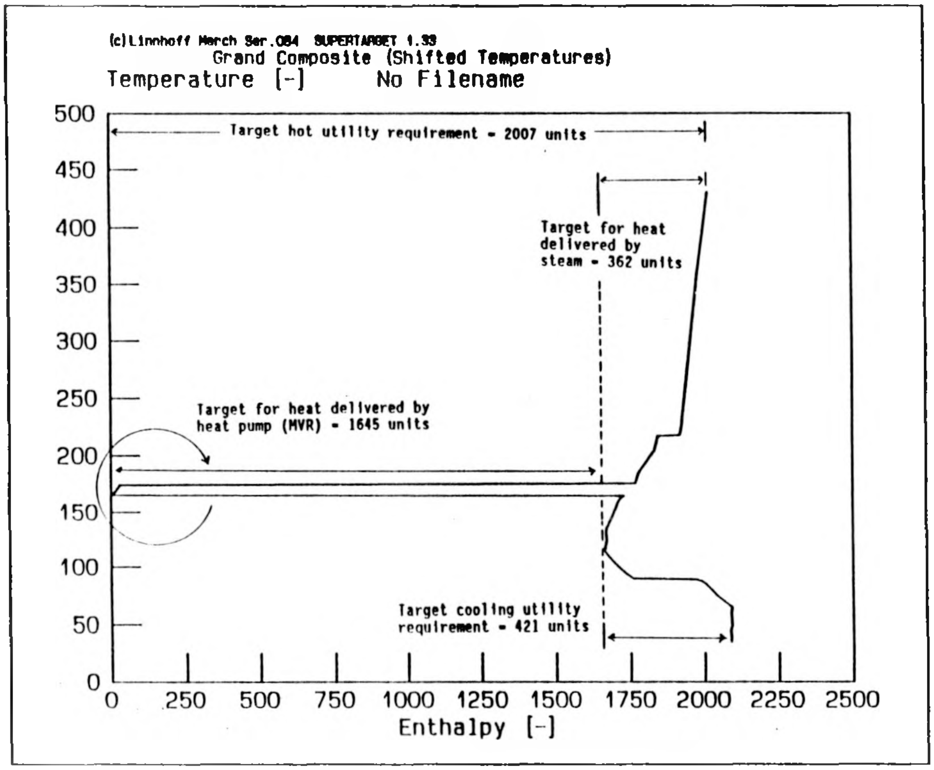


Figure 5 Grand composite curve showing heat pumping (MVR) opportunity

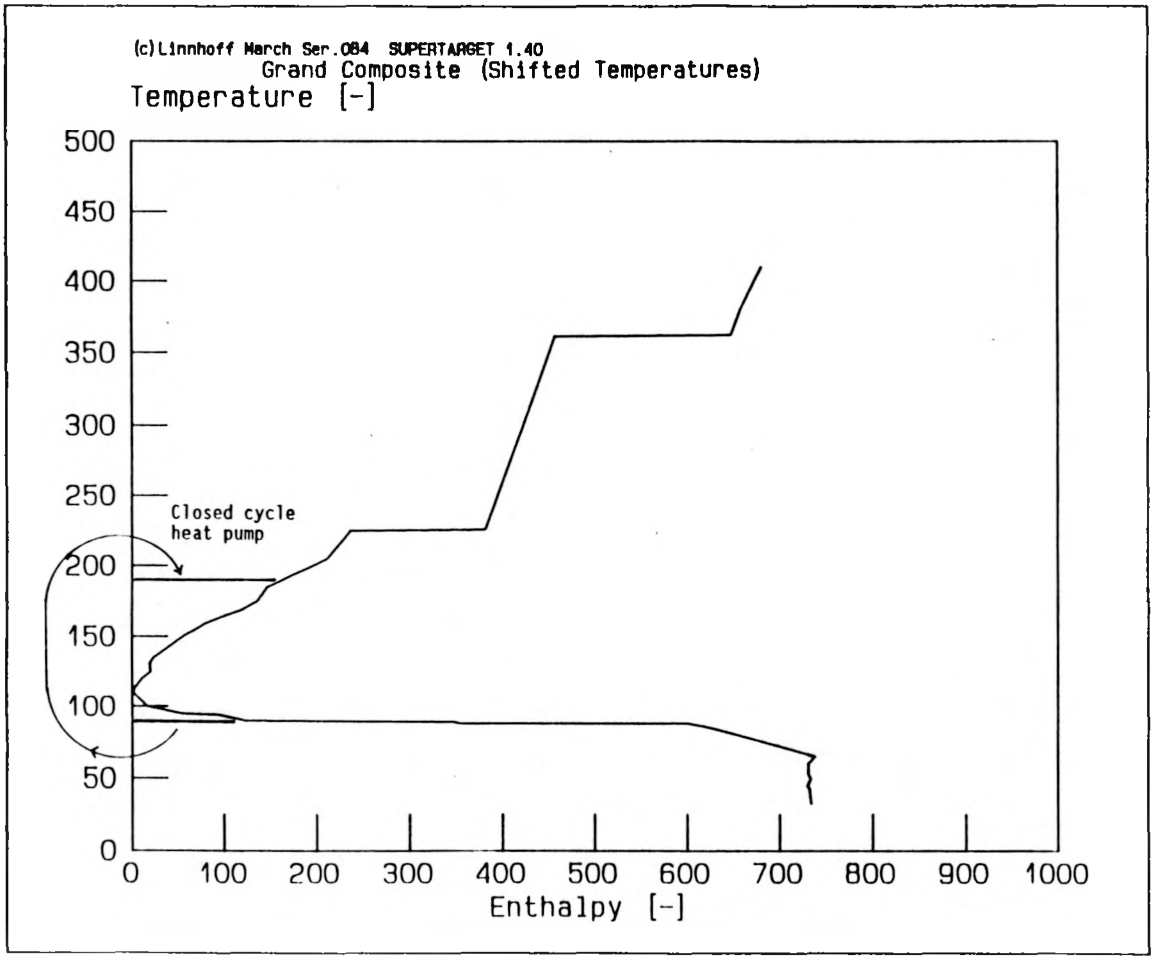


Figure 6 Grand composite curve showing closed cycle heat pump opportunity

replaced by a fan which operates over a lower pressure ratio and hence requires less power than a compressor. If such a unit were to be utilized in an expansion, it would normally be considered as a stand alone unit with the existing TVR being used at the finisher. Assuming that an increase of 50% in evaporation capacity is required and that is satisfied by a new MVR fan evaporator, the fan power input would be 9 units assuming a COP of around 60. However, appropriate integration of the new unit can lead to an even greater efficiency.

There are two possible ways of integrating a new MVR (1) at an evaporation temperature in the preconcentrator above the existing process pinch and (2) at an evaporation temperature below the existing process pinch. Both are discussed below.

(1) Integration at a boiling temperature at 170°F (Project 5)

The fan MVR preconcentrator would boil the whey at 170°F, directly after pasteurization. Figure 7 shows the grand composite curve for this scheme, while Figure 8 shows the corresponding flowsheet. Part of the separated steam evaporated in the preconcentrator is raised in pressure to a saturation temperature of 177°F (compression ratio 1.2) in the fan and part would supply the #1 effect of the existing evaporator. The existing TVR heat pump would make-up the steam requirements to the preconcentrator. A new nozzle to accommodate the increased compression ratio would be required. The main advantage of this scheme would be the reduced size and brake horsepower requirements for the fan. Compared to a stand alone MVR fan evaporator there is potential to reduce the fan size and power consumption by almost 40%. The disadvantage of this scheme is the higher boiling temperature which could cause product denaturisation.

(2) Integration at a boiling temperature at 135°F (Project 6)

This process integration is far more complex as it involves placing the MVR preconcentrator in between #2 and #3 effects of the existing evaporator. The preconcentrator will be driven by both the MVR fan and the steam from #2

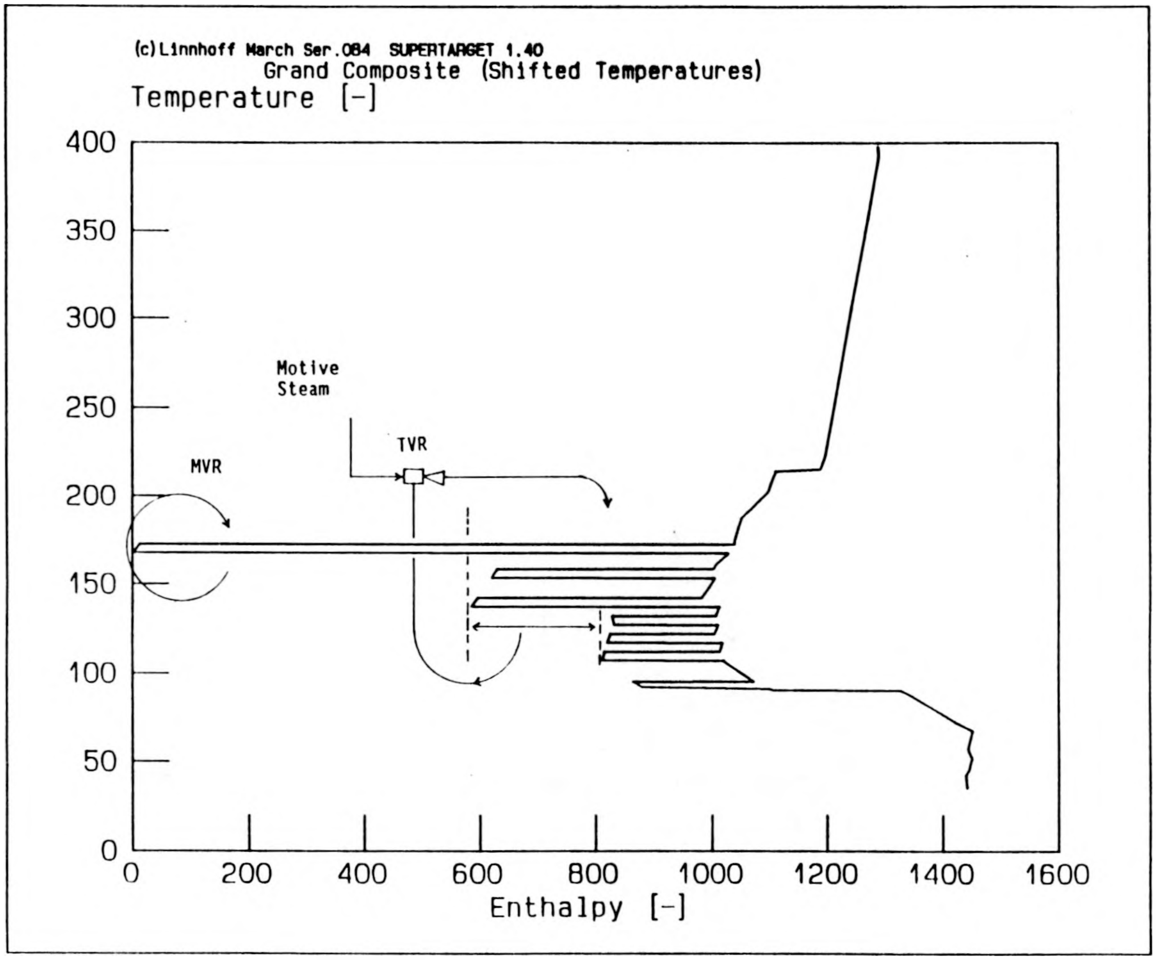


Figure 7 Grand composite of process reflecting increased evaporation load by integration of a pre-evaporator at 170 °F

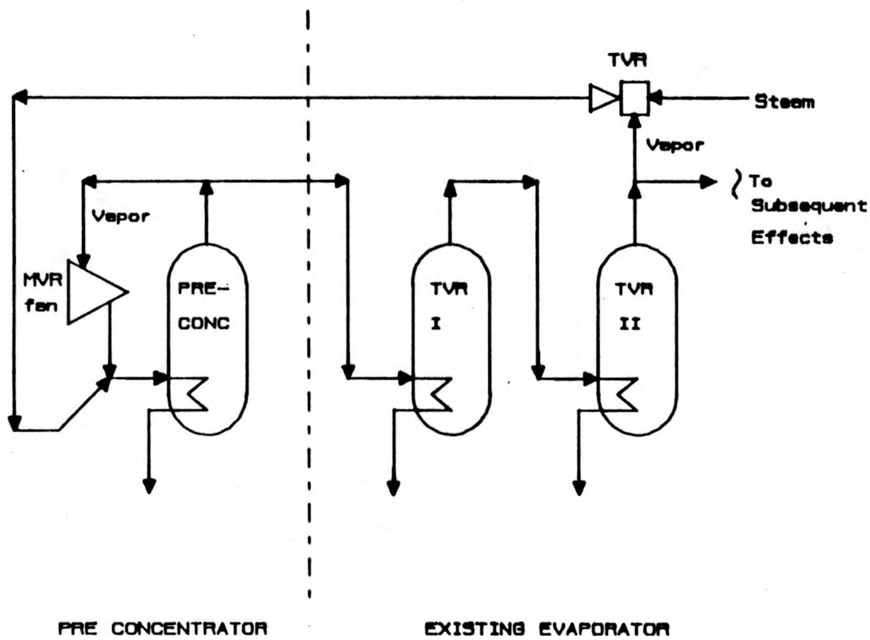


Figure 8 Equipment Configuration Suggested by Figure 7

effect. Figures 9 and 10 show the Grand Composite Curve and corresponding flowsheet. Part of the separated steam from the preconcentrator is recompressed by the fan and the remainder is recompressed by a compressor for the #1 effect, with part being used to supply the #3 effect. A compressor has to be used in this case because the compression ratio is 2.5 and far less motive steam for a TVR is available. This integration does allow the fan size and power consumption to be reduced by 50% compared to the stand alone MVR, and the steam requirement is reduced. But on the negative side, a multi-stage centrifugal compressor or blower will be required for the second MVR unit.

Such multiple MVR systems are used for evaporation duties but the complexity and possible control difficulties make this scheme unattractive at first glance.

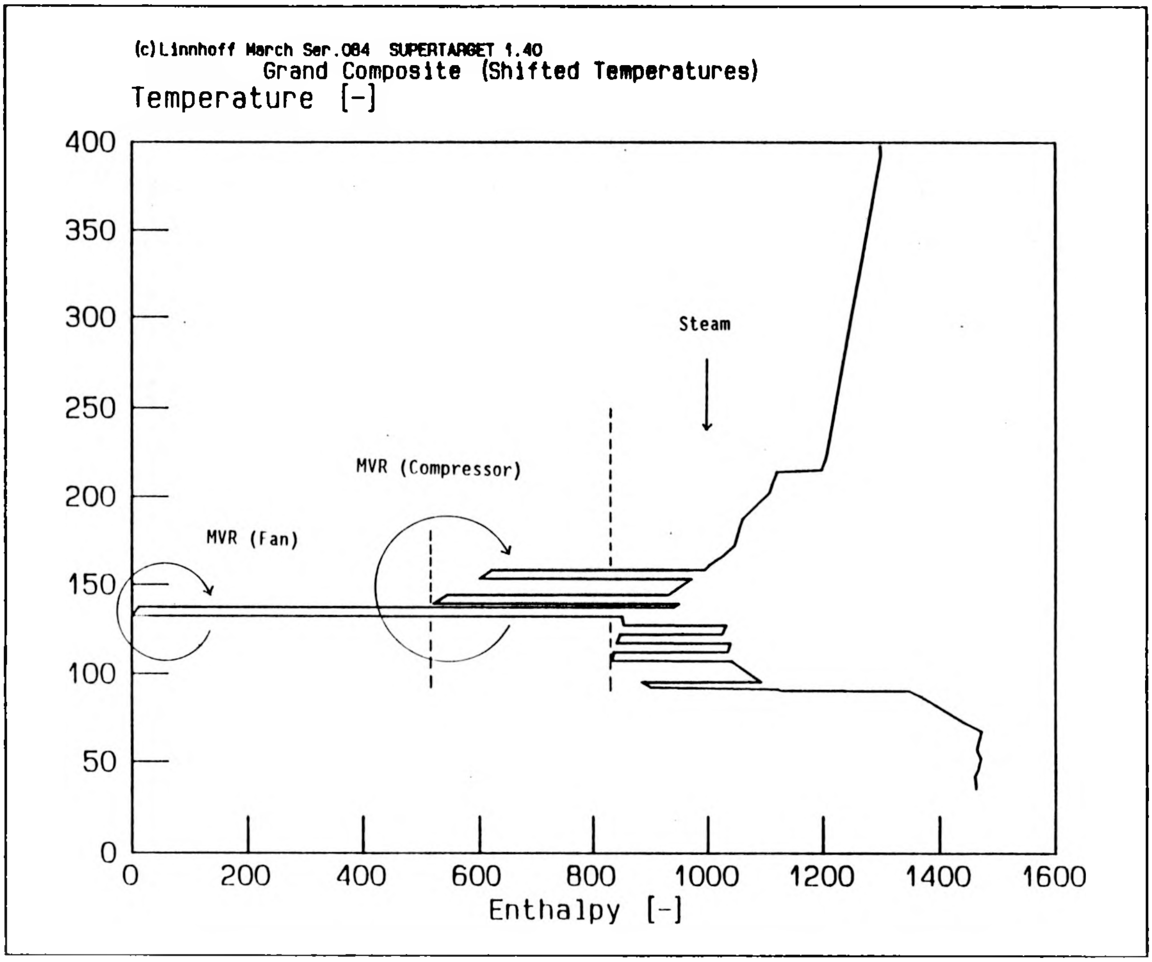


Figure 9 Grand composite of process reflecting increased evaporation load by integration of a pre-evaporator at 130 °F

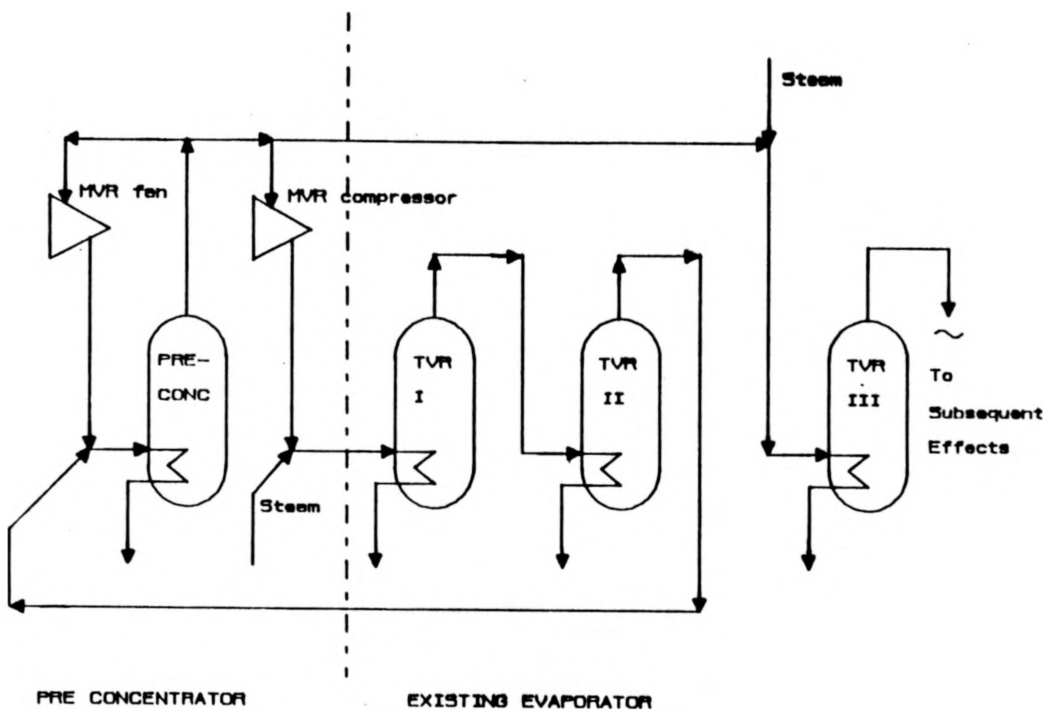


Figure 10 Equipment Configuration Suggested by Figure 9

5.0 UTILITY SYSTEMS

The majority of process heating load can be satisfied by a low temperature utility such as low pressure steam or even hot water. This suggests that a cogeneration system could be matched to the process in order to exploit the low temperature heat sink.

Possibilities include gas and steam turbines and gas fueled reciprocating engines. This site is, however, not very well suited to a cogeneration facility because the heat sink is relatively small and heat demands are very time dependent. No economic cogeneration schemes were identified.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Table 6.1 summarizes the energy cost reduction projects identified in this study.

Additional heat recovery offers the most attractive energy cost reduction strategy for the cheese/whey powder process. Savings of around $198,000/yr can be achieved at an overall payback of 26 months.

The process studied already makes use of heat pumping in the form of a TVR evaporator. This evaporator is correctly integrated with the process. The main opportunity for additional heat pumping is integration of a fan MVR whey preconcentrator. This is most attractive when a plant expansion is being considered. The high stand alone efficiency of this MVR system can be improved upon by appropriate integration of the new evaporator with the existing unit. Such integration could reduce the fan power requirements by up to 40%.

It is recommended that the heat recovery projects be implemented first. If expansion is planned, the options for integrating an MVR fan evaporator should be investigated further.

It is felt that the results of this study will be applicable to other cheese plants and similar dairy facilities. The results of this study are in line with previous experience indicating that thermal energy savings of 10-20% can be achieved through improved heat recovery.

Table 6-1 Project Summary

Project Category	Project #	Utility Reductions Steam/ Fuel units/h	Utility Reductions CW units/h	Heat Pump Power Input (1) units/h	Saving $000's/yr	Capital Cost $000	Pay Back years
Additional heat recovery between process streams	1	302	30	N/A	140	257	1.8
	2	73	23	N/A	58	174	3
Heat pumping projects for existing plant	3	330	317	79	0	-	-
	4	200	150	38	-	-	-
Heat pumping projects for expanded plant	5	N/A	N/A	-40%	-	-	-
	6	N/A	N/A	-50%	-	-	-

NOTE: (1) Power input converted to heat units and related to existing site heat demand of 1000 units

Existing site power demand on this basis = 795 units