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CASE HISTORY STUDIES OF ENERGY CONSERVATION
IMPROVEMENTS IN THE DAIRY INDUSTRY

June 1982

Work Performed Under Contract No. AC06-76RL01830

Pacific Northwest Laboratory
Richland, Washington

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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THE DAIRY INDUSTRY

June 1982

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Pacific Northwest Laboratory
Richland, Washington 99352

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- Cuba Cheese, Incorporated
- Vita-Milk Dairy, Incorporated
- Falls Dairy Company
- Carnation Company
- Foremost-McKesson, Incorporated
- Land O'Lakes, Incorporated

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INTRODUCTION

This report presents ten case histories about energy-efficient technologies implemented by the dairy industry. Basic information is provided about how the technologies work, the new equipment needed, and the plant modifications required to adopt the technology. Energy cost savings are reported, and the secondary benefits of the changeover, such as increased production capacity or improved product quality, are also described.

The technologies, some of which were developed with funding from the Department of Energy, include:

- Reverse Osmosis
- Evaporator Improvements
- Mechanical Vapor Recompression
- Boiler Optimization and Waste-Heat Recovery
- Refrigeration Optimization and Waste-Heat Recovery
- Waste-Heat Recovery
- Mechanical Dewatering by Centrifuge.

Because these technologies are generic in nature, they can be used to conserve energy in other industries as well.

Information for the case histories was gathered through extensive literature searches, a review of the Department of Energy projects and reports, and personal visits to the plant sites by the project team. The data collected for this report are presented in the following order for each case:

- Name and location of company, and its product line
- Energy consumption and costs at the plant before and after implementation of energy-conserving technology
- The factors that prompted the investment
- Product quality as a result of the new equipment.

The following table provides an overview of the amount of energy conserved by the various conservation measures.

Summary of Energy Savings and Capital Cost of
Ten Conservation Measures in the Dairy Industry

Conservation Measure	Company	Energy Savings Btu/yr x 10 ⁹	Investment \$Thousand
1. Refrigeration compressor replacement	Tillamook Cheese	7.1	150
2. Turbulators in boiler tubes	Vita-Milk Dairy	1.5	1
3. Reverse osmosis	Cuba Cheese	50.0	400
4. Stack exchangers on boiler	Vita-Milk Dairy	2.7	22
5. Six-effect evaporators	Falls Dairy	270	NA
6. Multi-effect evaporator with thermal recompression	Tillamook Cheese	68	4,500 ¹
7. Spray dryer heat recovery	Foremost-McKesson	8.4	83
8. Efficient compressor operations	Carnation Company	5.8	None
9. Mechanical vapor re-compression	Foremost-McKesson	140	1,500
10. Preheat spray	Land O'Lakes	5	30

(1) Includes capital cost for equipment in addition to compressor.

To obtain more information about these and other energy conservation measures for industry, please write or call the companies identified in this report or:

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1. CONSERVATION MEASURE: Refrigeration Compressor Replacement

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Plant Location: Tillamook, Oregon

INTRODUCTION/BACKGROUND

In recent years approximately 4 billion pounds of cheese were produced annually in the United States (Casper, 1977). While producing this cheese, the industry consumed approximately 22 trillion Btu of energy, or approximately 5,500 Btu of energy per pound of cheese produced. In recent years this energy was in the form of natural gas, fuel oils, purchased electricity, coal, and other miscellaneous types of fuel. The fraction of each fuel is shown in the following table.

Form of Energy Used by Cheese Manufacturers

(in percent)

Natural Gas	68
Fuel Oils	18
Purchased Electricity	8
Coal	3
Other	<u>3</u>
Total	100

An evaluation of these data by year also shows that the fraction of natural gas and electricity used by cheese makers is increasing. The majority (92%) of this energy is used as boiler fuel and for drying whey. The balance (8%) is in the form of electricity, which is used to drive process equipment and equipment for cleaning and lighting.

Compressors in refrigeration systems are large users of electricity, and it is the use of this energy that is the focus for this study. Refrigeration accounts for 20% of the electric energy consumed by a cheese producer. As the cost of electrical energy continues to escalate more rapidly than do other raw materials, ways to reduce the use of electricity (and refrigeration) becomes relatively more important.

Several ways exist for reducing the energy required for refrigeration (CENTEC, 1980). Some of these options are to: 1) reduce refrigeration load (through better insulation and caulking); 2) replace inefficient compressors; 3) replace compressor drivers with a new high-efficiency electric motors; 4) use a heat exchanger to subcool the ammonia liquid in the condenser receiver; and 5) adjust compressor operating conditions. All of these techniques will reduce the demand for electricity for refrigeration and should have a positive effect on production and product quality, as well.

Tillamook Cheese has continually upgraded and expanded its plant facilities since the founding of the Tillamook County Creamery Association in 1909. Cheese and whey powder are the principle products of the plant, which has a maximum capacity of 90,000 lb/day cheese production, and 60,000 lb/day dry whey powder production. The plant also produces relatively small amounts of bottled milk, ice cream, and butter. In recent years, with rapid increases in energy prices and further increases projected for the future, capital improvement projects at Tillamook Cheese have been increasingly concerned with energy conservation. Faced with the need to increase refrigeration capacity to meet expanded plant needs, Tillamook Cheese chose to replace an old, inefficient compressor system with a highly efficient system. The new compressor system greatly increased the efficiency of the refrigeration system, and resulted in large energy savings.

CONSERVATION MEASURE

Chilling requirements for processing and storing dairy products can make refrigeration a major energy cost for dairy plants. Improvements in the efficiency of the compressor system are often possible, particularly when the compressors are old or in poor condition. Older compressor systems were designed when energy costs were a very minor portion of total plant operating costs, so that

energy efficiency was given little, if any, design consideration. As a result, older units can often be replaced with compressors offering much higher efficiencies. If the old compressors are in poor condition, which is usually the case, efficiency will be even lower than it was when the units were originally installed, further increasing energy savings that could be obtained through replacement.

An important consideration in the design of any compressor system is the compression ratio, i.e., the ratio of the absolute pressure of the working fluid leaving the compressor to the absolute pressure of the fluid entering the compressor. Increasing the pressure ratio past an optimal range (which varies for different compressors) decreases the number of compressors needed to perform a given task, which lowers the capital cost for such equipment. Unfortunately, larger compression ratios also decrease the compressor's efficiency and increase its energy consumption. In the past, when energy was inexpensive, decreases in compressor efficiency could be seen as an agreeable trade-off for reduced capital cost.

PLANT PROCESS MODIFICATIONS

At Tillamook Cheese, an old compressor system was completely replaced with a new system of improved design and higher efficiency. In addition to saving energy, replacing the compressor system allowed Tillamook Cheese to expand capacity and gave the plant several operating advantages over the old system. Energy savings described in this case study are applicable to refrigeration systems throughout the dairy industry and in other industries as well.

At Tillamook Cheese, the freeze room must be maintained at a temperature of -10°F , while the product storage rooms, where the cheese is cured, must be kept at about 40°F . Achieving the -10°F temperature in the freeze room requires a refrigerant operating pressure of 7 psia; 35 psia is required for maintaining temperature in the cold room.

The old compressor plant used at Tillamook Cheese is shown in Figure 1.1. Eight reciprocating compressors of various sizes were used in parallel. Three of the compressors received refrigerant from the freeze room at a pressure of 7 psia and compressed it to a pressure of 195 psia. The other five compressors

FIGURE 1.1. Refrigeration Compressor System Prior to Modification

operated on refrigerant returning from cold storage, compressing it from a pressure of 35 psia to 195 psia, and discharging into a common outlet header with the other three compressors. The common discharge pressure of 195 psia for the compressors in the original design was chosen so that the same condensor could be used for both cold storage and for freezing requirements.

The old system was inefficient primarily because of the high pressure ratio of the three compressors that handle the refrigerant returning from the freeze room. The pressure ratio for the three freeze room compressors was 195:7, or 28, which is much higher than is recommended for modern designs, which are normally in the range of 4 to 8 or slightly higher (Perry, 1973). Increasing pressure ratios generally leads to a decrease in compressor efficiency, which can become pronounced at high pressure ratios.

The age of the compressors at Tillamook Cheese contributed to poor efficiency. The compressors were so old that operating reliability was poor, which suggests that internal wear may have further reduced the efficiency of the units. However, advances in compressor design would enable new units to have increased performance even if wear had not been a problem for the old compressors.

The 8 compressors in the old system ranged in size from 20 to 60 hp, and had a total combined power of 350 hp. The capacity of the old refrigeration system was 250 tons.

The efficiency of the refrigeration system increased dramatically when the old reciprocating compressor was replaced with a system having a different design layout and rotary screw compressors. The majority of the efficiency increase resulted from changing the compressor system layout, as shown in Figure 1.2. In the new system, refrigerant from the freezing room is compressed from 7 psia to 35 psia by two compressors operating in parallel, thereby eliminating the large pressure ratio required in the previous system. Refrigerant is discharged from these compressors to a receiver, where the 35-psia refrigerant returning from cold storage enters the system. Three compressors operating in series then compress the refrigerant from 35 psia to 195 psia. The redesigned compressor system operates with a maximum pressure ratio of under 6, which is much lower than the maximum pressure ratio of 28 for the old system.

FIGURE 1.2. Refrigeration Compressor System After Modification

Rotary screw compressors such as those installed by Tillamook Cheese have been used in chemical process industries since the early 1930's, but were not generally used in refrigeration applications until the late 1950's (ASHRAE, 1979). The use of internal compression, very small clearance volumes, and the lack of suction and discharge valves (with their associated losses) increase the adiabatic and volumetric efficiencies of rotary screw compressors, making them a good choice for the Tillamook Cheese application.

In the new compressor system, the two compressors operating on the 7 psia refrigerant are both rated at 15 hp. The other three compressors are rated at 150 hp each, giving a total combined power for the system of 480 hp. The new compressor increased the capacity of the refrigeration system from 250 tons to 570 tons.

ENERGY SAVINGS

Energy savings have been calculated for the new operating capacity of 570 tons of refrigeration. Energy consumption for the old compressor system (rated at 250 tons capacity) was about 2,286,000 kWh/year. Assuming a constant efficiency, comparative energy consumption for the old compressor system at 570 tons capacity is estimated by the ratio of new to old capacity times the energy consumption of the old system or by $570/250 \times (2,286,000 \text{ kWh/yr}) = 5,212,000 \text{ kWh/year}$. Based on information provided by Tillamook Cheese, the new system's energy consumption at a capacity of 570 tons has been estimated to be only 3,136,000 kWh/year, resulting in a net savings in electric consumption of 2,076,000 kWh/year. Overall, the improvement in process efficiency resulting from installation of the new compressor system can be calculated as follows:

$$\text{Old Efficiency (coefficient of performance)} = \frac{3,000,000 \text{ Btu}}{\text{hr}} \bigg| \frac{\text{hr}}{890,750 \text{ Btu}} = 3.368$$

$$\text{New Efficiency (coefficient of performance)} = \frac{6,840,000 \text{ Btu}}{\text{hr}} \bigg| \frac{\text{hr}}{1,221,600 \text{ Btu}} = 5.999$$

$$\text{Percentage Increase in Efficiency} = \frac{5.999 - 3.368}{3.368} \times 100 = 66\%$$

The new refrigeration compressor system was installed for a total capital cost of \$150,000. Tillamook Cheese purchases electric power at a cost of \$0.012/kWh. At this price, the 2,076,000 kWh/year saved by the compressor system translates to a \$25,000/year energy savings. Because of its location in the Pacific Northwest, where electric rates are lower than the U.S. national average, Tillamook Cheese currently has relatively low electricity costs. Higher electric rates would, of course, increase savings in energy cost proportionately. Also, significant rate increases for electricity in the Pacific Northwest are likely to occur in the future, making annual savings greater than \$25,000.

In areas of the United States that must pay much higher electric rates, the potential energy savings could justify installing similar energy-efficient refrigeration compressors. For example, in Boston or San Francisco where industrial customers paid \$0.0795 and \$0.0553 per kWh, respectively (Energy User News, 11/30/81), the annual savings for a similar system would be:

Boston: $2,076,000 \text{ kWh/yr} \times \$0.0795 = \$165,000 \text{ per year}$

San Francisco: $2,076,000 \text{ kWh/yr} \times \$0.0553 = \$114,800 \text{ per year}$

Using only these annual savings (\$165,000 and \$114,800) and disregarding tax credits, the payback period for this project would be approximately 11 months for a firm in the Boston area and approximately 16 months for a firm in the San Francisco area, assuming installation costs were \$150,000 in all areas. These are attractive payback periods even in times of high interest rates. Actual payback periods will, of course, vary among different plants.

Overall, the new compressor system has proved to be more reliable than the old system and has resulted in greatly reduced maintenance costs.

DECISION PROCESS

The need to increase refrigeration capacity was the motivating force behind the decision to replace the old compressor system. Plans for expanding the output at Tillamook Cheese required modifications to many of the plant facilities, including the refrigeration system.

Realizing that energy costs will continue to increase for the foreseeable future, Tillamook Cheese put a high priority on energy efficiency in selecting

the new compressor system. The system that was installed had an efficiency 66% higher than the system it replaced.

An additional benefit achieved by the new compressors is an improvement in product quality. The increased capacity of the refrigeration system has decreased temperature fluctuations in the freezing room and cold storage room, allowing production of a higher-quality product.

Installation of the compressors was carried out over a period of roughly 3 years. Most of the installation was handled by plant personnel. Staggering the installation allowed the plant to stay on line throughout the period and helped smooth out fluctuations in capital expenditures.

REFERENCES

ASHRAE Handbook and Product Directory 1979 Equipment, 1979. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. New York, New York.

Casper, M. E., ed. 1977. Energy Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey. 1977.

Energy User News, November 30, 1981.

Energy Conservation and Cost Benefits in the Dairy Processing Industry. 1980. CENTEC Corp.

Perry, R. H. and C. H. Chilton. 1973. Chemical Engineers Handbook. 5th ed. McGraw Hill Book Company, New York, New York.

2. CONSERVATION MEASURE: Turbulators in Boiler Tubes

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INTRODUCTION/BACKGROUND

In 1978, approximately 56 billion pounds of whole, skim, and low-fat milk were produced by the fluid milk industry (U.S.D.A., 1980). Even though the production of fluid milk has remained fairly constant over the last few years, the number of plants in the United States has been decreasing, with an even faster rate of decline observed among the small plants (<20 employees). Nearly 600 Btu's per pound, or 33.5 trillion Btu's, were required to achieve this production figure, making the fluid milk industry one of the major consumers of energy in the food industry (U.S. Department of Commerce, 1981). This energy can be divided into the intermediate uses shown in the following table (Casper, 1977).

Intermediate Uses of Energy in Fluid Milk Industry

(in percent)

Boiler Use	69
Electrical Inputs	25
Direct Use	<u>6</u>
Total	100

The table shows that boiler use is by far the largest energy drain. Natural gas and fuel oil are the main sources of energy for boiler use, and the trend

is toward using more natural gas and less fuel oil. The following table shows the end-use patterns of boiler energy in the fluid milk industry (Casper, 1977).

Energy End-Use Activity for Boiler Fuel

(in percent)

Boiler Stack Losses	30
Hot Water for Cleaning	24
Condensing Milk and Whey	13
Pasteurization	10
Line and Trap Losses	9
Other Boiler Losses	8
Space Heating	3
Other	<u>3</u>
Total	100

Since boiler stack losses are so significant (30%), efforts are being made to recover some of this heat. At present, the three major methods of recovering the heat lost through boiler stack gases are (CENTEC Corporation, 1980):

1. replacement with more efficient boiler
2. economizers
3. turbulators.

This case study focuses on the installation of turbulators by Vita-Milk Dairy. Vita-Milk is a privately owned, medium-sized dairy that produces mostly fluid milk and some ice cream (10% of total gallonage). At Vita-Milk, a fire-tube boiler is used to handle the heating load, while the cooling load is handled by an ammonia refrigeration system.

CONSERVATION MEASURE

The two main types of boilers used in industry today are the fire-tube boiler and the water-tube boiler. Fire-tube boilers are usually of small or medium capacity and are designed to generate steam at moderate pressure. In this type of boiler, the fire passes through the tubes. Fire-tube boilers have a low first cost, and are often portable. In comparison, water-tube boilers have the water in the tubes with the fire on the outside. This type of boiler is used

for larger steam-capacity requirements and pressures above 150 psi. In addition, water-tube boilers usually generate steam more quickly and efficiently. They are almost always stationary and have a much greater first cost than fire-tube boilers. At Vita-Milk, steam is generated with a 100 hp, fire-tube boiler.

In fire-tube boilers, a core of hot gases tends to form down the center of the tube. This lowers the temperature of the gases near the tube wall, decreasing the heat transfer through the tube walls and making the boiler less efficient. Turbulators can be placed in the boiler tubes to break up this "core" effect and improve boiler efficiency. Turbulators are made of 14-gauge flat metal strips that are twisted into opposing 30° , 45° , or 60° cross-deflecting planes. The device drives hot gases to the tube wall, thereby increasing the amount of heat transferred through the wall to the water on the other side. Turbulators are smaller than the tube's inside diameter and are held in place by a spring-like action. This action is created by extending the last couple inches of the turbulator beyond what would be the tube wall, and by bending this section down so that it is pinned against the inside tube wall. The tension created is more than enough to keep the turbulator in place and to minimize any vibration of the turbulator within the tube (see Figure 2.1). Because there is only point contact between the turbulator and the wall, soot buildup is kept to a minimum. Point contact is a necessary part of the design; were it not, extensive soot might accumulate in the tube and lead to the formation of carbonic acid, which in turn could eat a hole in the tube wall. The formation of acid has not been a problem with properly designed turbulators.

Another problem that turbulators remedy in fire-tube boilers is the tendency of combustion gases to rise and go mainly through the top tubes. This limited use of the lower tubes greatly reduces boiler efficiency. Placing longer turbulators at the top of the boiler reduces this problem because the longer turbulators, which are usually about 70% of the tube's total length, increase the resistance to flow through the upper tubes. Since the lower tubes now offer relatively less resistance to flow, the gases seek the path of least resistance and flow through these neglected lower tubes (see Figure 2.2). The resistance to flow in each tube can be controlled by varying the width and deflection

FIGURE 2.1. Turbulator held in place by "spring-like" action of end piece

FIGURE 2.2. Boiler with Turbulators Installed

angles of the turbulator. These design variables are determined by the desired operating parameters of the boiler, and are incorporated into the turbulator design by the product engineer. Because turbulators increase heat transfer at the wall of each tube and more efficiently use the lower boiler tubes, more heat is captured from the hot gases, and less heat lost out the stack.

Turbulators are not only applicable to fire-tube boilers, but can be used in any fire-tube technology that transfers heat (recuperators, economizers, and so forth). In other words, any process that has the hot air on the tube side is a candidate for turbulator use. (Only in fire-tube boilers where the flame is very close to the end of the tubes can turbulators not be used. The turbulators are deformed due to the extreme heat of the flame in this case.) Turbulators are guaranteed by the manufacturer to last five years, but they often last longer.

PLANT PROCESS MODIFICATION

A standard 100-hp, fire-tube boiler is used at Vita-Milk for steam generation. This steam is used primarily in the pasteurization process and for cleanup purposes. The burner in the boiler uses natural gas as the fuel source, with No. 2 diesel as the back-up. Before modification, the flue gases from the boiler were discharged to the atmosphere and no attempt was made to recover heat. These flue gases were usually around 650°F, which indicates how extensive heat loss from the stack was.

In mid-1978, Vita-Milk installed turbulators in its boiler tubes (see Figure 2.2). As shown in the figure, the longest turbulators were placed in the top tubes, and progressively shorter turbulators were installed in the bottom tubes. This modification did not change the production level of fluid milk and had no effect on product quality. Significant amounts of heat were recovered, as is indicated by a drop of flue gas exhaust temperatures from 650°F to 450°F and by the reduction in boiler gas consumption.

ENERGY SAVINGS

The energy savings from installing turbulators in the boiler tubes are shown below.

Energy Savings with Turbulators

	Gas Use (10 ⁹ Btu/year)
Before Installation	15.0
After Installation	<u>13.5</u>
Savings	1.5

Gas consumption by the boiler was reduced from 15 billion to 13.5 billion Btu/year for a savings of 10%, while electrical power usage was unaffected.

Vita-Milk was paying \$2.50 per million Btu's for natural gas when the turbulators were installed in mid-1978. This meant a savings of:

$$\frac{1.5 \times 10^9 \text{ Btu saved}}{\text{year}} \left| \frac{\$2.50}{10^6 \text{ Btu}} \right| = \$3750 \text{ saved/year.}$$

Currently, Vita-Milk pays approximately \$4.50 per million Btu's for natural gas. This mean a savings today of:

$$\frac{1.5 \times 10^9 \text{ Btu saved}}{\text{year}} \left| \frac{\$4.50}{10^6 \text{ Btu}} \right| = \$6750 \text{ saved/year.}$$

DECISION PROCESS

The turbulators were installed in the boiler tubes in mid-1978 at a total capital cost of \$1000. With a savings in energy of \$3750/year at that time, the payback period was:

$$\frac{\$1000}{\$3750} \left| \frac{\text{year}}{12 \text{ months}} \right| = 3.2 \text{ months.}$$

Assuming that the turbulators could be installed today for \$1500, and that a savings of \$6750/year is realized, the payback period would be:

$$\frac{\$1500}{\$6750} \left| \frac{\text{year}}{12 \text{ months}} \right| = 2.7 \text{ months}$$

The low first cost and the associated short payback period from energy savings were at the heart of Vita-Milk's decision to install the turbulators. Gas prices were rising dramatically at that time, and the company realized that it could save money with the turbulators.

Energy savings was the dominant reason for installing the turbulators, but other reasons also entered the decision process. For one, maintenance costs for cleaning the boiler tubes would be less because turbulators leave fewer residuals. For another, because the turbulators could be installed in less than one day, no significant process downtime was required.

REFERENCES

Casper, M. E. ed. 1977. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.

CENTEC Corporation. Energy Conservation and Cost Benefits in the Dairy Industry. Fort Lauderdale, Florida. (Draft Report)

U.S. Department of Agriculture. 1980. Agricultural Statistics 1980. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce. 1981. "Fuels and Electric Energy Consumed." 1978 Annual Survey of Manufacturers. M78(AS)-4.1, Bureau of Census, Washington, D.C.

3. CONSERVATION MEASURE: Stack Exchanger on Boiler

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Plant Location: Seattle, Washington

CONSERVATION MEASURE

Pleased with the energy savings after turbulators were installed in 1978, Vita-Milk Dairy installed an economizer in 1980 to further recover waste heat from the plant's boiler stack.

"Economizers" or heat exchangers are usually installed in boiler stacks to expose the unit to the greatest temperatures and flue gas flows. Economizers are placed as close to the boiler as possible, since a slight temperature drop occurs as the gas moves up the stack, and because the equipment is easier to monitor at the boiler level. Vita-milk's exchange unit is a tube and plate model, with water on the tube side. In essence, it works like a radiator operating backward. The tube-side stream is usually heated city water that joins the steam condensate return line, together making up the boiler feed water. Because water losses occur along the way, the condensate is not sufficient feed for the boiler, so city water must be added. No effort is made to control the temperature of the hot water out of the tubes and, as the volume or temperature of the boiler flue gases varies, so does the temperature out.

Placing a heat exchanger inside the boiler stack increases the resistance to flue-gas flow up the stack. This is compensated for by installing an electrically powered, induced-draft fan that helps move the gases upward. The fan

turns at a constant rate, but a damper placed just upstream is used to control the flow. An extra stack (usually smaller in diameter) is installed so that the gases can be routed through it when the exchanger needs cleaning or servicing. The entire stack exchanger is made of corrosion-resistant materials and is quite compact, which makes retrofitting simple.

Economizers are available for fire-tube, water-tube, or cast-iron industrial boilers as long as the boiler is in the 100-to 1200-hp range. Certain boilers outside of this range can be fitted with stack exchangers, but they require special construction and are more costly. Economizers have been used in industry for nearly ten years without a single unit wearing out, which is a true indication of their reliability. In highly corrosive environments, the economizer parts are made of stainless steel. Although economizers are air-liquid exchangers used, basically, to preheat boiler make-up water or to generate hot water for clean-up, the heat from boiler flue gases could also be used to preheat the air used for combustion by the burner. These air preheaters are feasible technically, but are usually much more expensive.

Conservative estimates of the boiler fuel savings made possible with these stack exchangers are 4% to 15%. These savings are possible whether the burner is fired by natural gas, fuel oil, or a combination of the two. This fuel savings means that a boiler operating at the same capacity would use less fuel, or that for the same amount of fuel, the boiler capacity could be increased. The latter is important when a plant wants to increase production slightly without having to purchase a larger boiler. As a rough guideline, the following three items must be satisfied for the economizer to be economically feasible (Peabody Gordon-Piatt Corporation, 1977):

1. 3000 hours of boiler operation/year
2. stack gas temperature of 350°F or more
3. a continuous sink for the recovered heat.

Many parameters will affect the amount of savings, but once the unit is installed, the savings are generally a function of flue gas temperature, feed water temperature, and excess air. The boiler fuel savings for 30% excess air are shown in Figure 3.1. Most boiler burners operate with 20% to 30% excess air for best combustion results with natural gas. To date, many economizers

FIGURE 3.1. Boiler Fuel Savings with 30% Excess Air

have been installed at industrial plants to conserve energy, and the number should continue to grow noticeably in the future.

PLANT PROCESS MODIFICATION

A standard 100-hp, fire-tube boiler is used at Vita-Milk for steam generation. This steam is used primarily in the pasteurization process and for clean-up purposes. The burner for the boiler operates on natural gas; No. 2 diesel is the back-up fuel. Turbulators were installed in mid-1978, and significant savings in boiler fuel resulted. The stack gas temperature dropped from 650°F to 450°F with the installation of turbulators, but much heat was still being lost with stack gas exhaust temperatures at 450°F. The original system is shown in Figure 3.2.

In early 1980, Vita-Milk installed a stack exchanger on its fire-tube boiler (Figure 3.3). Before the exchanger was installed, Vita-Milk had a batch water feed process. In other words, the boiler was filled with water and, when most of the water had turned to steam, the boiler was filled with water again. This was changed to a modulated, continuous water-feed system so that the heat recovered by the exchanger would always have a place to go. After this change, the stack exchanger and an additional stack were mounted on gratings above the existing boiler. This tube and plate exchanger, using recovered waste heat, warmed a city water stream, which then joined the returned condensate stream to form the boiler feed water.

After installing the stack exchanger, Vita-Milk observed a marked savings in boiler gas consumption, as flue-gas exhaust temperatures dropped from 450°F to 250°F. This modification did not affect the amount of fluid milk produced and had no effect on product quality.

ENERGY SAVINGS

Energy savings resulting from the installation of a stack exchanger on the boiler are shown in the following table.

FIGURE 3.2. System Before Boiler Stack Exchanger

FIGURE 3.3. System After Boiler Stack Exchanger

Energy Savings with Boiler Stack Exchanger

	<u>Gas Use (10⁹ Btu/year)</u>
Before Installation	13.5
After Installation	<u>10.8</u>
Savings	2.7

Data from Vita-Milk indicate that gas consumption by the boiler was reduced from 13.5 billion to 10.8 billion Btu/year for a savings of approximately 20%, whereas electrical consumption rose very slightly. This increase resulted because a small motor was needed to run the fan and damper in the stack. Nevertheless, the increase in electrical consumption was negligible compared to the amount of boiler fuel savings.

Vita-Milk was paying \$3.70 per million Btu's for natural gas when the stack exchanger was installed in early 1980. This meant a savings of:

$$\frac{2.7 \times 10^9 \text{ Btu saved}}{\text{year}} \bigg| \frac{\$3.70}{10^6 \text{ Btu}} = \$9990 \text{ saved/year.}$$

Currently, Vita-Milk pays approximately \$4.50 per million Btu's for natural gas. This would mean a savings today of:

$$\frac{2.7 \times 10^9 \text{ Btu saved}}{\text{year}} \bigg| \frac{\$4.50}{10^6 \text{ Btu}} = \$12,150 \text{ saved/year.}$$

DECISION PROCESS

The stack exchanger and associated instrumentation were acquired in early 1980 at a cost of \$11,000. Another \$11,000 was required for installation, making a total capital cost of \$22,000. With an energy savings of \$9990/year at that time, the payback period was:

$$\frac{\$22,000}{\$9990 \text{ / year}} = 2.20 \text{ years}$$

Assuming the boiler stack exchanger could be installed in 1982 for \$25,000, and that a savings of \$12,150/year is realized, the payback period would be:

$$\frac{\$25,000}{\$12,150 \text{ year}} = 2.06 \text{ years}$$

These payback periods are based on the price that Vita-Milk was paying for natural gas in the Seattle area. As the price of natural gas varies in different parts of the United States, so does the economic attractiveness.

Vita-Milk's first project to conserve energy was the installation of turbulators in the boiler tubes. This was a very successful operation, and the company's investment was quickly recovered through energy savings. Vita-Milk's second project examined the possibility of placing a stack exchanger on the boiler. The company believed that the stack exchanger could save enough energy to make it economically worthwhile, and began the installation in early 1980. Based on Vita-Milk's energy savings of \$9990 for the first year of operation, the stack exchanger payback period was only 2.2 years. With the price of natural gas continually rising, the dollar savings in fuel will rise, which in turn will reduce this payback period.

Once the stack exchanger was installed, there were some initial operation and maintenance costs. These unforeseen costs were incurred trying to get the "bugs" out of the system. Since the problems were minor, they were quickly resolved. As expected, no effect was observed in either the product quantity or quality. An important benefit was that the stack exchanger, associated instrumentation, and necessary piping were installed in less than one week, with only four hours of boiler downtime.

With the use of turbulators and a stack exchanger, Vita-Milk has essentially conquered boiler and stack heat losses. This success in heat recovery has prompted the company to research ways to recover heat from the existing ammonia refrigeration system.

REFERENCES

Casper, M. E. ed. 1977. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.

CENTEC Corporation. Energy Conservation and Cost Benefits in the Dairy Industry. Fort Lauderdale, Florida. (Draft Report)

Peabody Gordon-Piatt Corporation. 1977. Heatmizer-Boiler Heat Reclaimer for Fuel and Cost Savings. Winfield, Kansas.

U.S. Department of Agriculture. 1980. Agriculture Statistics 1980. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce. 1981. "Fuels and Electric Energy Consumed," 1978 Annual Survey of Manufacturers. M78(AS)-4.1, Bureau of Census, Washington, D.C.

4. CONSERVATION MEASURE: Reverse Osmosis

GENERAL INFORMATION:

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General Manager, Manufacturing

Plant Location: Cuba, New York

INTRODUCTION/BACKGROUND

Whey is a byproduct of cheese and cheese products made from pasteurized milk. Whey is composed of lactose, proteins, various mineral salts, and large volumes of water. Currently, in the United States, there are more than a dozen large installations that can process up to 1.5 million pounds of raw whey per day, in addition to many smaller-capacity installations (CENTEC Corporation, 1980).

Environmental legislation prohibits dumping whey directly into waterways without some form of treatment. Energy-efficient methods that concentrate solids and reduce water content provide economic incentive for recovering whey solids that are marketable as human foodstuffs and animal feed. Conventional equipment used for dewatering and drying whey include evaporators and spray dryers. Both of these processes rely on heating the large volumes of liquid whey to drive off water vapor, which is then either condensed for heat recovery and discharged into water streams or vented directly into the atmosphere.

Whey drying is an energy-intensive process. It has been estimated that nearly 27 percent of the total direct energy requirements for cheese manufacturing can be charged to whey drying. At an energy input of 5,620 Btu/lb (Casper, 1977) for all dairy products produced in the cheese industry, and at a projected 1980 cheese production of 4.0 billion pounds, the energy expended for drying whey in 1980 was:

$$\frac{0.27}{1 \text{ lb cheese}} \times \frac{5620 \text{ Btu}}{1 \text{ lb cheese}} \times \frac{4.0 \times 10^9 \text{ lb cheese}}{\text{year}} = 6.1 \times 10^{12} \text{ Btu/yr}$$

Based on these data, approximately 6 trillion Btu's were required to dry whey in 1980. Obviously, methods that might reduce energy requirements for whey drying could result in significant overall energy savings in the manufacturing of cheese and cheese products. Cuba Cheese is one plant where reverse osmosis (RO) has been successfully implemented as an energy conservation method.

Cuba Cheese produced over 25 million pounds of cheese and 15 million pounds of powered whey in 1981. By using RO, Cuba Cheese has reduced energy costs, expanded production capacity, and improved process versatility with a minimum of capital expenditure.

CONSERVATION MEASURE

Reverse osmosis (RO) is an energy conservation measure that can be used to concentrate whey and produce whey powder. Reverse osmosis is a separation process that uses hydraulic pressure to force process-stream liquid through a semipermeable membrane. Solids contained in the stream cannot pass through the membrane and are concentrated upstream of the membrane. Salts and dissolved solids are also concentrated in solution upstream and on one side of the membrane as the relatively pure water passes freely to the other side of the membrane.

Reverse osmosis systems typically operate at pressures ranging from 500 to 800 psi. In general, RO membranes retain dissolved ions and molecules whose molecular weights are greater than 100, although this depends on the actual membrane being used. However, reverse osmosis membranes are often characterized by their ability to retain more than 90% of the sodium chloride in solution, (sodium chloride's molecular weight is roughly 58.). Other typical operating characteristics for RO applications to whey concentration are provided in Table 4.1.

Reverse osmosis is most useful for dewatering up to 24% solids concentrations (it is not effective for concentrating beyond the 24% solids range, however because of viscosity effects). For instance, concentrating from 6% solids to 12% solids is equivalent to removing half of the water contained in the liquid whey. Since energy consumption is considerably lower for RO compared to thermal processes such as evaporation, significant energy savings are realized if RO is used before evaporation and spray drying.

TABLE 4.1. Typical System Characteristics for Reverse Osmosis Concentration of Whey (Centec Corporation, 1980)

Membrane	
- type	- cellulose acetate
- configuration	- plate and frame or tubular
- area	- 800-1,800 ft ² /10,000 lb/hr permeate
System	
- configuration	- membrane modules arranged in series or parallel
- space requirement	- 100-200 ft ² /10,000 lb/hr permeate
- floor loading	- 100-200 lb/ft ²
- pump horsepower	- 20-35 hp/10,000 lb permeate
Operation	
- mode	- batch or continuous
- pressure	- 500-750 psi
- temperature	- 50-110°F
- pH	- 3-8
- molecular weight cutoff	- 500
- power consumption	- 15-25 kWh/10,000 lb permeate
- run length	- up to 20 hr/day
Performance	
- permeate flux	- 4-16 lb/ft ² /hr
- solids concentration	- 6-12% total solids (to as high as 24% TS)
- volumetric concentration	- 2:1 (to as high as 4:1)
- membrane life	- 6-18 months
Maintenance	
- method	- clean-in-place (CIP) 2-4 hours daily using various cleaners, sanitizers, and clean water rinses
- cleaners	- detergents, enzymes, citric acid, and other proprietary formulations
- sanitizers	- hydrogen peroxide

Actual equipment designs for dairy industry applications can be based on various membrane configurations including (CENTEC Corporation, 1980):

- plate and frame
- tubular
- hollow fiber
- spiral wound.

In general, several individual membrane elements or cartridges are housed within a pressure vessel and constitute what is known as a module. Modules are connected in series or parallel, depending on a number of factors including equipment type, operation mode (batch, continuous, or continuous with recirculation), process flow conditions, allowable pressures and pressure drops, and products handled. Other system components include feed and pressurization pumps, control valves and instrumentation.

Recent advances in membrane technology during the last decade have resulted in more versatile and durable RO membranes. As a result, overall use of RO is gaining widespread acceptance as a workable method for saving vast quantities of energy in the concentration of whey. For further energy savings within the dairy industry, RO also can be applied to skim milk drying.

PLANT PROCESS MODIFICATIONS

Before the RO system was installed, Cuba Cheese operated a three-stage evaporator with no pretreatment, which was followed by a two-stage dryer. Liquid whey entered the evaporator at approximately 6% solids and was concentrated to 50% solids; the 50% concentrate then entered the two-stage dryer, where thermal drying reduced moisture content from 50% to 4% (96% solids). Boiler efficiency was 82% and overall evaporator efficiency was 2.5 lb H₂O evaporated/lb steam. The dryer's efficiency was 1 lb H₂O evaporated/2 lb steam. Figure 4.1 shows the process before modification. The evaporator removed 750,000 lb H₂O/day based on an 18-hr/day schedule and used 300,000 lbs of steam/day. In addition to being energy inefficient, the evaporator at Cuba Cheese limited expansion since it was already operating at maximum capacity.

After investigating various options, the management of Cuba Cheese decided to install an RO unit directly preceding and in series with the evaporator. In the modified system (Figure 4.2), whey at 6% solids enters the RO unit, which

1. THREE-STAGE EVAPORATOR
2. TWO-STAGE DRYER

—— PRODUCT STREAM
 - - - - WATER VAPOR

FIGURE 4.1. Whey Processing Components Prior to Installation of Reverse Osmosis

1. THREE-STAGE EVAPORATOR
2. TWO-STAGE DRYER
3. REVERSE OSMOSIS UNIT

————— PRODUCT STREAM
 - - - - - WATER VAPOR
 WATER

FIGURE 4.2. Whey Processing with Reverse Osmosis

is of tube and shell design. Influent pressure is supplied at 800 psig by a 55-hp electric motor, and effluent pressure is 450 psig. Forty percent of the total water previously removed by evaporation is now removed by RO, and the concentrate stream emerging from the RO unit is maintained at 10% solids. Whey now enters the evaporator at 10% solids (rather than 6%), and is further concentrated to 50%. This concentrated stream then flows to the dryer where most of the remaining water is removed.

The RO unit at Cuba Cheese is extremely flexible because flow rates can be accommodated by adding or rearranging existing RO tubes in typical module fashion.

ENERGY SAVINGS

Before modification, a significant portion of energy was consumed in thermally concentrating the whey from 6% solids to 50% solids through evaporation alone. Now the evaporator concentrates the whey from 10% solids to 50% solids. Actual energy consumption comparisons are estimated below.

Basic energy use before modification is calculated as follows: in concentrating whey from 6% to 50% solids, 750,000 lb of water was removed each day through evaporation. Steam requirements were:

$$\frac{750,000 \text{ lb H}_2\text{O evaporated}}{\text{day}} \left| \frac{1 \text{ lb steam supplied}}{2.5 \text{ lb H}_2\text{O evaporated}} \right| = 300,000 \text{ lb steam supplied/day}$$

At a boiler efficiency of 82% and assuming that it takes 1000 Btu to generate 1 lb of steam, the original system's energy requirements were:

$$\frac{300,000 \text{ lb steam supplied}}{\text{day}} \left| \frac{1}{0.82 \text{ efficiency}} \right| \left| \frac{1000 \text{ Btu}}{1 \text{ lb steam}} \right| = 366 \times 10^6 \text{ Btu/day}$$

Basic energy use after modification for RO concentrating the whey to 10% solids is as follows. The evaporator is now only responsible for concentrating the whey from 10% solids to 50% solids.

Electrical energy requirements for RO concentration are estimated to be:

$$\frac{55 \text{ hp pump}}{\text{hp-hr}} \left| \frac{2545 \text{ Btu}}{\text{hp-hr}} \right| \frac{20 \text{ hrs}}{\text{day}} \frac{1}{0.67 \text{ efficiency}} = 4.2 \times 10^6 \text{ Btu/day}$$

The reduced evaporator energy requirements are estimated in the following manner. A simple mass balance demonstrates that roughly 300,000 lb/day H₂O is removed by RO and the remainder, 450,000 lb H₂O/day (750,000 minus 300,000 lb H₂O/day), is removed in the evaporator. The new energy requirements for evaporation correspond to:

$$\frac{450,000 \text{ lb H}_2\text{O evaporated}}{\text{day}} \left| \frac{1 \text{ lb steam supplied}}{2.5 \text{ lb H}_2\text{O evaporated}} \right| = 180,000 \text{ lb steam supplied/day}$$

The modified energy requirements for evaporation, assuming a boiler efficiency of 82% and assuming it takes 1000 Btu to generate 1 lb of steam, are:

$$\frac{180,000 \text{ lb steam supplied}}{\text{day}} \left| \frac{1}{0.82 \text{ efficiency}} \right| \left| \frac{1000 \text{ Btu}}{1 \text{ lb steam}} \right| = 220 \times 10^6 \text{ Btu/day}$$

Total modified system (RO + evaporator) energy consumption is:

	Energy Consumption (Btu/day)
RO	4×10^6
Evaporator	220×10^6
Total	224×10^6

The net energy savings attributable to RO are then calculated as the difference in energy consumption for the original and modified systems:

$$\text{Net energy savings} = 366 \times 10^6 \text{ Btu/day} - 224 \times 10^6 \text{ Btu/day} = 142 \times 10^6 \text{ Btu/day}$$

A summary of these energy use/savings data are contained in Table 4.2.

Energy cost savings resulting from installation of RO are calculated below. Pre-modification energy costs were estimated as follows for the evaporator section:

$$\frac{366 \times 10^6 \text{ Btu}}{\text{day}} \left| \frac{1 \text{ scf}^{(1)} \text{ natural gas}}{1075 \text{ Btu}} \right| \left| \frac{\$0.0037}{\text{scf}} \right| = \$1260/\text{day}$$

(1) scf = standard cubic foot

Energy costs to achieve the same 50% solids concentration using RO followed by evaporation are estimated below:

$$\text{Electricity costs} = \frac{4.0 \times 10^6 \text{ Btu}}{\text{day}} \left| \frac{2.93 \times 10^{-4} \text{ kWh}}{\text{Btu}} \right| \frac{\$0.055}{\text{kWh}} = \$64/\text{day}$$

$$\text{Evaporator steam costs} = \frac{220 \times 10^6 \text{ Btu}}{\text{day}} \left| \frac{1 \text{ scf natural gas}}{1075 \text{ Btu}} \right| \frac{\$0.0037}{\text{scf}} = \$757/\text{day}$$

TABLE 4.2. Energy Savings

	Before	After	Difference
Steam Energy Consumption (Btu/day) ^(a)	366 x 10 ⁶	220 x 10 ⁶	146 x 10 ⁶
Additional Electricity Consumption (Btu/day) ^(b)		4 x 10 ⁶	-4 x 10 ⁶
Total Energy Savings			142 x 10 ⁶ Btu/day or 49.7 x 10 ⁹ Btu/yr ^(c)

(a) At 82% boiler efficiency and 1000 Btu/lb steam

(b) Excess beyond pre-installation demand due to RO pumping requirements

(c) Assuming 350 day/year operating schedule

$$\text{Total modified system energy costs} = \frac{\$757}{\text{day}} + \frac{\$64}{\text{day}} = \$821/\text{day}$$

$$\begin{aligned} \text{Energy cost savings} &= \text{cost before modification} - \text{cost after modification} \\ &= \$1260 - 821 = \$439/\text{day}. \end{aligned}$$

Energy cost savings are estimated to be \$439/day, or \$154,000 per year based on a schedule of 350 operating days per year.

DECISION PROCESS

As already discussed, whey drying can consume 27% of the direct energy used in cheese manufacturing processes. Cuba Cheese faced increasing energy costs for drying whey if it continued to use its old, energy-inefficient evaporator.

Based on energy cost savings alone, a simple pre-tax payback period for RO is estimated to be 2.5 years for the \$400,000 RO system purchased in April 1979. The payback estimate is based on a 350-day/year operating schedule and an energy cost savings of \$439/day (or an annual savings of \$154,000).

Although these cost savings and the payback period provided real stimulus for investing in RO, other considerations were also important in the decision process. Capital cost and process expansion potential were two of these important considerations.

Cuba Cheese wanted to keep equipment costs to a minimum. The relatively low cost of RO, compared to newer and more efficient evaporators now on the market, was a determining factor in the selection of RO as the most favorable option. Moreover, capacity can be expanded as the need arises by adding more RO modules to the existing system. Thus, capital need not be invested until production demand warrants further expansion. Cuba Cheese recognized that RO could expand capacity and reduce energy costs for an appreciably smaller capital investment than other alternatives.

Cuba Cheese was initially concerned about the reliability of reverse osmosis systems. When the equipment manufacturer extended the written guarantee, Cuba Cheese decided, finally, to purchase the unit. Cuba Cheese reports that, after 2.5 years of RO operation, the RO has performed beyond expectations. Maintenance is minimal and no additional personnel are required to operate the system. Also, RO requires relatively little space and is easily adapted to existing process lines.

REFERENCES

Casper, M. E. 1977. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.

CENTEC Corporation. Energy Conservation and Cost Benefits in the Dairy Processing Industry. Fort Lauderdale, Florida. (Draft Report).

5. CONSERVATION MEASURE: Six-Effect Evaporator

GENERAL INFORMATION

Company Name and Address: Falls Dairy Company
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President and General Manager

Plant Location: Jim Falls, Wisconsin

INTRODUCTION/BACKGROUND

In recent years, about 5.4 billion pounds of dairy products (SIC 2022), excluding processed milk, have been produced every year in the United States. Dairies consume about 5500 Btu per pound of produce, or 30 trillion Btu per year. The bulk of this energy is used to generate steam to dry whey. According to Development Planning and Research Associates, Inc. approximately 27% of the energy used in the dairy industry (SIC 2022) goes for drying whey (Casper, 1977).

Energy is expended to concentrate and eventually dry whey because whey has food value and, under law, cannot be disposed of in an untreated form. Drying operations use considerable energy per pound of product produced, but several energy-efficient techniques can be used to remove water (concentrate solids) and limit energy use. The major technologies involve:

- multiple-effect evaporators
- ultrafiltration
- reverse osmosis
- thermal or mechanical recompression.

These processes, all of which are in use, require capital investments. The economic attractiveness of each technology improves as the cost of energy escalates. In Europe, where energy costs are greater than the United States, these technologies are used more frequently.

The Falls Dairy Company produces more than 60 million pounds of cheddar cheese and 40 million pounds of dry whey and whey-specialty products each year. Drying the whey to powder is an energy-intensive process because of the large quantities of water that must be removed before a dry product is obtained. Before

September 1977, Falls Dairy Company used old, relatively energy-inefficient evaporators to produce dry whey.

After careful evaluation of available options for concentrating whey (e.g., multiple-effect evaporators, ultrafiltration, reverse osmosis, and mechanical recompression), the management at Falls Dairy selected a six-effect evaporator. For the first time in the United States, a six-effect evaporator would be used to process whey.

CONSERVATION MEASURE

Evaporation concentrates solutions consisting of a nonvolatile solute and a volatile solvent (usually water). Evaporation differs from drying in that evaporation leaves a thick liquid. Drying results in a solid product, although some moisture might be present.

Both single- and multiple-effect evaporators are available for use in industry. When a single evaporator is used, vapor from the boiling liquid is usually condensed and discarded. Single-effect evaporators are simple but inefficient. Often, evaporation of 1 lb of water requires expenditures of 1 to 1.3 lb of steam or the equivalent of 1000 to 1200 Btu's energy input (Energy Research and Development Administration, 1977). If the vapor from one evaporator is used to supply the necessary thermal energy to a second evaporator, the operation is termed a double- or two-effect evaporator. Efficiency approximately doubles in a cascading energy effect, as unused thermal energy is given an opportunity to interact again with liquid in a subsequent evaporator to drive off additional vapors. However, since the cascading energy is of lower quality (i.e., the vapors are at lower temperature), subsequent effects are typically drawn under greater and greater vacuum to enhance evaporation. Using a series of evaporators between the steam supply and the condenser is called multiple-effect evaporation.

Because of the high capital cost of additional effects, an economic balance is generally struck between the cost of these additional effects and the corresponding energy cost savings. Escalations in energy prices over the last decade have swung the balance in favor of multiple-effect evaporation.

PLANT PROCESS MODIFICATIONS

Falls Dairy previously used two three-effect evaporators, one double-effect evaporator, and one finishing evaporator to concentrate whey solids. Whey from the cheese room arrived at 6.3% solids, and after passing through the series of evaporators, was concentrated to approximately 50% solids. The overall efficiency of the original evaporation system was 2.2 lb H₂O evaporated per lb of steam. Moreover, plant capacity was limited by evaporator throughput capacity. Operation of these evaporators was both labor- and energy-intensive.

In September of 1977, Falls Dairy installed the first six-effect evaporator in the U.S. for whey processing. The evaporator, housed in its own building, stands almost three stories tall and is nearly half a block long. The new six-effect evaporator is not a simple straight-through system. Instead, the unique design incorporates a split-system effect, which maintains smaller temperature differentials and results in increased efficiency. Simply stated, the process flow proceeds through the evaporator effects in the order 1 2 4 5 6 3.

Whey entering the evaporator at 6.3% solids is currently processed at the rate of 105,000 lb/hr. Evaporation concentrates the whey to approximately 53% solids. An overall evaporator efficiency of 6.3 lb H₂O/lb of steam from preheating to concentrating (compared to 2.2 lb H₂O/lb of steam for the previous system) leads to impressive energy savings (LeMair, 1978).

The evaporator also provides other benefits. Falls Dairy has further reduced its steam consumption by using the hot condensate (120°F) from the evaporator instead of well water (60°F) to feed the plant's hot-water (140°F) washing system. Hot condensate is stored in large holding tanks until needed at the end of each operating shift; this saves many gallons of hot water each day. The six-effect evaporator has also expanded the plant's capacity for processing whey.

ENERGY SAVINGS

Falls' management has estimated that the plant has reduced fuel consumption by 40% per unit of product since the six-effect evaporator was installed. The fuel in this case is highly volatile bituminous coal, which fires the plant boiler. Energy savings calculations are provided below.

Before installation of the six-effect evaporator, the Falls Dairy boilers consumed 70 tons/day of highly volatile bituminous coal with a heating value of about 13,500 Btu/lb. Before modification, the energy equivalent of this coal consumed was:

$$\frac{70 \text{ tons}}{\text{day}} \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \frac{13,500 \text{ Btu}}{\text{lb}} = 1890 \times 10^6 \text{ Btu/day}$$

Because of the modification, coal consumption was reduced by 40% to 42 tons/day while the heating value of the coal consumed remained the same. Current energy consumption is:

$$\frac{42 \text{ tons}}{\text{day}} \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \frac{13,500 \text{ Btu}}{\text{lb}} = 1130 \times 10^6 \text{ Btu/day}$$

The calculated yearly energy savings based on a 350-day/year operating schedule is:

$$\frac{(1890 \times 10^6 - 1130 \times 10^6) \text{ Btu}}{\text{day}} \left| \frac{350 \text{ day}}{\text{year}} \right| = 2.66 \times 10^{11} \text{ Btu/year}$$

The cost savings from reduced coal consumption are based on 1981 prices of \$70/ton for highly volatile, washed, and delivered bituminous coal. Since actual coal reduction equaled 28 tons/day (a 40% savings), yearly cost savings are estimated as follows:

$$\frac{28 \text{ tons}}{\text{day}} \left| \frac{350 \text{ days}}{\text{year}} \right| \frac{\$70}{\text{ton}} = \$686,000/\text{year}$$

DECISION PROCESS

Whey drying is an energy-intensive and costly process. Multi-effect evaporation is one of several methods for saving energy in this area. Several factors entered into the dairy's decision to install a six-effect evaporator--a first for the industry--in its plant, namely increasing energy costs and limiting production capacity.

After an energy audit by a private consulting firm, the Falls Dairy management evaluated its option. Armed with economic data on energy waste estimates and payback periods for different energy conservation options, Falls Dairy mapped

out strategies to make the best use of its capital expenditures. The most significant potential savings would result from installing the six-effect evaporator.

Although evaporator systems are probably more expensive than any other single piece of process equipment in a dairy, Falls Dairy found that this particular six-effect evaporator was available at low cost. Actual cost information was not released, but the management has indicated that a 3-year payback period is a reasonable estimate, based on energy and operation and maintenance cost savings.

The new system requires fewer employees than the old system, is more reliable in dewatering and has performed beyond original expectations. Control of the system is considerably easier than originally anticipated. These changes have resulted in decreases in operation and maintenance costs, and costs associated with downtime. This factor also played heavily in the decision to replace the original evaporators.

Before the modification, cold city water was used as make-up water for the hot-water cleaning system. Now, warm condensate from the six-effect evaporator is used instead, and less energy is expended for heating and pumping. Furthermore, the amount of water released into the sewage system and the corresponding utility bill have declined.

Installation of an evaporator of this size is a major undertaking. The three-story-tall, half-a-block-long evaporator system is housed in a separate building. Because of good engineering and proper planning by Falls Dairy management, very little downtime was required when the system was brought on-line.

Although other energy conservation measures are being considered to cut overall plant energy consumption by another 10% to 12%, no future improvements to the evaporator have been suggested.

REFERENCES

Casper, M. E. 1977. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.

Energy Research and Development Administration. 1977. Upgrading Existing Evaporators to Reduce Energy Consumption. C00/21870-2, Technical Information Center, Washington, D.C.

LeMaire, W. H. February 1978. "A First! Six-Effect Evaporator at Wisconsin Dairy." Food Engineering, G7-70.

6. CONSERVATION MEASURE: Multi-Effect Evaporator with Thermal Vapor
Recompressor

GENERAL INFORMATION

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INTRODUCTION/BACKGROUND

Approximately 4 billion pounds of cheese is produced annually in the United States (Casper 1977; U.S. Department of Agriculture, 1980). Cheese production consumes approximately 22 trillion Btu of energy, or approximately 5,500 Btu of energy per pound of cheese produced. In recent years, this energy was in the form of natural gas, fuel oils, purchased electricity, coal and other types of fuel. Fuel consumption by category is shown in the following table.

Form of Energy Used by Cheese Manufacturers

(in percent)

Natural Gas	68%
Fuel Oils	18
Purchased Electricity	8
Coal	3
Other	<u>3</u>
Total	100%

Whey, a by-product of cheesemaking, accounts for nearly 90% of the volume of milk used in cheese production. Liquid whey typically consists of about 94.3% water, 0.8% protein, 4.3% lactose, 0.5% ash, and 0.1% fat (Spindler, Yates and Havighoist, 1981). Whey may be disposed of if no market exists for it locally but more and more, it is being sold as a dry product for use in food products.

The production of dried whey has grown steadily since 1974, reaching 733 million pounds in 1979 (U.S. Department of Agriculture, 1980). Concentration of the whey is required even in instances where it is not sold, because the diluted product cannot be economically disposed of.

Producing dry whey is a highly energy-intensive process because of the large quantities of water (16.8 H₂O/pound of dry whey powder produced) that must be removed. If none of the heat of evaporation were recovered, production of dry whey would require about 16,800 Btu/lb of dry whey produced.

This case study focuses on the use of energy-efficient evaporation to reduce the energy requirements of whey production. Two principal types of energy-efficient evaporators are available to the dairy industry: multi-effect evaporators (4 or more effects) with thermal vapor recompression or with mechanical vapor recompression. The choice between these options depends on a number of factors, such as the price of electricity relative to fuels. As such, no one evaporator is best for all types of plants. This chapter discusses the benefits of a multi-effect evaporator featuring thermal vapor recompression that was installed at the Tillamook Cheese plant in Tillamook, Oregon.

Cheese and whey powder are the principal products of Tillamook Cheese, which has a maximum capacity of 90,000 lb/day cheese production, and 60,000 lb/day dry whey powder production. The plant also produces relatively small amounts of bottled milk, ice cream, and butter. In 1979, Tillamook Cheese began a project to expand capacity and improve the efficiency of its 25-year-old whey processing facility. Faced with rapid increases in energy prices and additional increases projected for the future, Tillamook Cheese decided to replace an old, inefficient evaporator system with a modern, four-effect evaporator featuring thermal vapor recompression.

CONSERVATION MEASURE

In the past, energy costs were low, and evaporators were typically designed with an emphasis on low capital cost rather than efficient energy use. Many existing evaporators in industry are older units that are energy inefficient compared to modern designs. Replacing an old evaporator with a modern, efficient unit can result in large energy savings.

The key to the efficiency of today's evaporators is their recovery of the heat contained in the evaporator. Heat can be recovered in two methods, which may be used independently or together. One method is to inject the steam in an evaporator chamber, which is at a lower pressure than the injected steam. This is the basic principle of multi-effect evaporators. Another way is to recompress the steam, increasing its pressure and temperature, and then to reinject it into the evaporator. If the recompression is done by a steam jet, the evaporator is termed thermal vapor recompression (TVR). When recompression is done by a mechanical compressor, the evaporator is termed mechanical vapor recompression (MVR).

Multi-effect evaporators achieve greater design efficiencies as more effects are added. (Effects are separate evaporation chambers.) Evaporation takes place under a vacuum, with pressure decreasing from one effect to the next. As pressure decreases, the boiling temperature of the product also decreases, so that the operating temperature decreases from the first effect to the last. Because of the temperature decrease from one effect to the next, the vapor removed from an effect is at a higher temperature than the boiling product in the next effect. Therefore, the vapor from the first effect can be used to supply part of the heat required in the second effect, and vapors from the second effect supply part of the heat required in the third effect. One pound of process steam can evaporate more than one pound of water as a result of this cascading energy approach.

The energy efficiency of a multi-effect evaporator increases with the number of evaporator effects, but the progression is not linear. A two-effect evaporator typically has an efficiency of 2 lb steam/lb water; a three-effect evaporator has an efficiency of 3 lb water/lb steam; and so forth. Because the net gain in efficiency is less for each subsequent evaporator effect, the total evaporator effects that are optimal for a given application are a function of the cost of energy. In the past, when energy costs were of little concern, evaporators typically had few effects.

Vapors cannot be returned to the same effect from which they were extracted. Heat transfer is not possible, because they are at the same temperature as the evaporating product in that effect from which they came. This constraint can

be avoided by recompressing the vapors, which raises their temperature and pressure and allows them to be reinjected for heating the same stage from which they were extracted. A TVR scheme recompresses a fraction of the vapors drawn off an effect, but a MVR unit is able to recompress all of the vapors leaving an effect.

Generally, TVR evaporators are not as efficient as MVR evaporators, but TVR units have some inherent advantages that may make them the preferred choice. Namely, they cost less and don't use high-grade energy sources, such as electricity, to produce steam.

PLANT PROCESS MODIFICATION

Before installing the new multi-effect TVR evaporator, Tillamook Cheese concentrated whey using three evaporators in series. These evaporators were single-effect, rising film evaporators that were old, inefficient, and generally worn-out. They had been designed at a time when energy costs were low enough so that energy consumption was not a critical concern. Except for the first evaporator, vapors from the evaporators were removed and not used for product heating.

Preheated feed entered the first evaporator and passed through three stages. Stages are different from evaporator effects in that only the liquid product passes between stages and each stage is at the same pressure. The vapors from this evaporator were drawn off and compressed in a 300-hp compressor, raising the vapor pressure and temperature. The vapors were then reinjected into the evaporator to provide operating heat. Of the three evaporators in the old system, the first evaporator had the most efficient design because of its reuse of the vapors exiting each stage. Even though the first evaporator incorporated mechanical vapor recompression, its efficiency was lower than for the modern MVR evaporators because of its age.

The second evaporator in series was also a three-stage evaporator, but of completely different design. In this evaporator, steam was injected into each stage to provide the required heat. The vapors drawn off from each stage were exhausted to the atmosphere. A complete lack of heat recovery from the vapors made this a very energy-inefficient design.

The third and final evaporator in series was a single-stage evaporator. Process steam provided the heat for evaporation. Vapors from this evaporator were condensed in a surface condensor without heat recovery. The lack of any heat recovery made this evaporator, like the second evaporator, energy inefficient. The product left the evaporator at 45% total solids and was transferred to crystallizers.

As part of its plant expansion program, Tillamook Cheese completely replaced the old evaporator system with a modern (Figure 6.1) multi-effect evaporator featuring thermal vapor recompression. The new evaporator uses four effects with TVR and a high concentrator, and has a rated efficiency of 6 lb water/lb steam.

The first effect of the new evaporator operates at 160°F, the second effect at 148°F, the third effect at 140°F, and the fourth effect at 129°F. Pre-heated feed enters the first evaporator effect, then flows through to the second effect, which is a two-pass effect. The whey then flows from the second effect to the fourth effect, which is also a two-pass effect. From the fourth effect the whey goes through a heat exchanger to increase its temperature, and then enters the third evaporator effect, which is a three-pass effect with two bodies. The whey leaves the third evaporator effect at a concentration of 48% total solids, and is further evaporated in a high concentrator, finally reaching 60% total solids before being transferred to the crystallizers.

In addition to the inherent efficiency of a multi-effect evaporator, the new evaporators also use dual thermocompressors to increase the efficiency. The thermocompressors compress and heat a fraction of the vapors leaving the second effect. These vapors, and the steam used to compress them, provide the heat for the first evaporator effect. The efficiency of the evaporator is further enhanced by recovering heat from evaporator condensate in a heat recovery tank.

ENERGY SAVINGS

Table 6.1 compares energy consumption for the old evaporator system and the multi-effect evaporator for a common operating rate. Tillamook Cheese generates roughly half its process steam in electric boilers, and half by burning fuel oil. Before the evaporator was replaced, the plant also used a substantial amount of propane in operating the whey drier. When the evaporator was

FIGURE 6.1. Tillamook Cheese Four-Effect Evaporator with TVR

TABLE 6.1. Energy Savings Using Multi-Effect Evaporator

System	Energy Use by Type		
	Fuel Oil 10^6 Btu/year	Propane 10^6 Btu/year	Electricity 10^3 kWh/year
Old evaporator System ⁽¹⁾	69,000	15,100	39,300
Multi-Effect Evaporator	41,000	0	32,000
Savings	28,000	15,100	7,300

(1) Energy use scaled to same evaporator capacity as multi-effect evaporator assuming a constant efficiency.

replaced, the whey dryer was switched from propane to electric fired, so that propane savings are not directly due to evaporator replacement. Assuming that the whey drier operates at the same efficiency on either propane or electricity, then the propane savings can be converted to a savings in electricity of 4.4 million kWh/year in addition to the electricity savings listed in Table 6.1.

The new evaporator system was installed in 1979 and 1980 as part of an overall modification to the whey-powder plant. The entire changeover cost \$4.5 million.

Tillamook Cheese currently pays \$0.012/kWh for electricity and \$0.74/gallon for #6 fuel oil. Current propane prices at the plant are not available, since Tillamook Cheese no longer uses propane. Although the price would depend on the quantity ordered, a propane dealer indicated that \$0.71/gallon is a reasonable assumption. Based on these prices, and on assumed heating values of 150,000 Btu/gallon for #6 fuel oil and 92,400 Btu/gallon for propane, the annual energy savings from the new evaporator are calculated as follows:

$$\text{Electricity Savings} = \frac{7,300,000 \text{ kWh}}{\text{year}} \left| \frac{\$0.012}{\text{kWh}} \right| = \$87,600/\text{year}$$

$$\text{Fuel Oil Savings} = \frac{28.0 \times 10^9 \text{ Btu}}{\text{year}} \left| \frac{\text{gal.}}{150,000 \text{ Btu}} \right| \left| \frac{\$0.74}{\text{gallon}} \right| = \$138,000/\text{year}$$

$$\text{Propane Savings} = \frac{15.1 \times 10^9 \text{ Btu}}{\text{year}} \left| \frac{\text{gal.}}{92,400 \text{ Btu}} \right| \left| \frac{\$0.71}{\text{gal.}} \right| = \$116,000/\text{year}$$

$$\text{Total Savings} = \$341,700/\text{year}$$

OTHER CONSIDERATIONS

Installation of the new evaporator has had several important benefits in addition to the savings in energy costs. The new evaporator is easier to operate than the evaporators it replaced because the new system has better instruments and controls. Also, the capacity of the whey-powder line increased and at the same time, the quality of the powdered whey improved, which increased the price the whey-powder brings in the marketplace. Operation of the whey dryer has significantly improved, since the whey concentrate now enters the dryer at 60% total solids, compared to 45% total solids on the old system. The system also requires much less water during operation, since water requirements for condensing vapors have been eliminated.

DECISION PROCESS

The old evaporator had to be replaced to facilitate expansion of the whey processing plant. Energy efficiency in the face of rising costs was one of the most important factors in selecting the evaporator. The primary options considered were the four-effect evaporator with TVR (this was eventually chosen), a five-effect evaporator with TVR, and a MVR evaporator. Low capital costs and inherent design simplicity lead to the decision to use a TVR evaporator rather than a MVR evaporator. For this application, the increased efficiency of a MVR unit was not thought to be sufficient to justify its increased costs and complexity over a TVR evaporator. Engineering analysis of the life-cycle cost showed that the increased efficiency of the five-effect TVR unit was not sufficient for this application to justify its additional cost over the four-effect TVR unit.

REFERENCES

- Casper, M. E. (ed.), Energy-Saving Techniques for the Food Industry, Noyes Data Corporation, 1977.
- Spindler, J. E., Yates, E. C., Havighoist, C. R. "Continuous Cheese-Whey Processing", Food Engineering, September 1981, page 73, Chilton Company.
- U.S. Department of Agriculture. 1980. Agricultural Statistics 1980. U.S. Government Printing Office, Washington, D.C.

7. CONSERVATION MEASURE: Spray Dryer Heat Recovery

GENERAL INFORMATION

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INTRODUCTION/BACKGROUND

The production of dried dairy products consumes a significant portion of energy in the dairy industry. Roughly 1.8 billion pounds of dried dairy products were produced during 1979 (USDA, 1980). These products included dry buttermilk, dry whole and nonfat milk, dry skim milk, dry cream, dry whey, dry lactose, and others. Energy consumption in the condensed and dried milk industry alone amounted to 23 trillion Btu in 1972 (Casper, 1977).

Drying is typically done in spray dryers, which are not only large users of energy, but are usually fired by high-grade fossil fuels. Energy used in spray dryers can be recovered by using heat exchangers to capture heat from the exit stream of the dryer which would otherwise be lost to the atmosphere. One of the best uses for recovered waste heat is to preheat the air entering the dryer. This results in a direct displacement of the fuel required for the dryer, thus increasing dryer efficiency and decreasing energy use.

This case study discusses a waste-heat recovery system added to an anhydrous spray dryer at Foremost-McKesson's Rothschild, Wisconsin, plant. The primary products of the Rothschild plant are dried lactose and dried whey. Foremost-McKesson installed the waste-heat recovery system on the dried lactose line, which has a capacity of over 2,800 lb/hr of dried product.

CONSERVATION MEASURE

The concentration and drying of dairy products are inherently energy-intensive processes because of the latent heat required to evaporate water from the

product. Production of dried products generally occurs in two steps. In the first step the product is concentrated, usually in an evaporator, which removes a large percentage of the water. In the second step, the product is dried by the circulation of large quantities of heated air through a spray dryer. Normally, after the dried product is separated from the moist hot air, the air is exhausted to the atmosphere.

Waste-heat recovery systems offer a simple way of using spray dryers more efficiently. By passing the exhaust air, which is typically at a temperature of about 200°F, through a heat exchanger, a significant amount of energy can be recovered which would otherwise be lost to the atmosphere.

Waste-heat recovery has not been used extensively for spray dryers in the past for two reasons: the low cost of energy and the potential for fouling problems. When energy costs were low, installing equipment to recover spray-dryer waste heat did not provide a sufficient return on the initial investment. Rising energy prices and expectations of future increases have altered this concern, so that now waste heat recovery systems are economical for many spray dryer applications.

Fouling can occur in any heat exchanger where dirt, impurities, and corrosion become deposited on heat exchanger surfaces. These deposits increase the resistance to heat transfer, reduce heat transfer coefficients, and reduce the efficiency of the heat exchanger. Extensive fouling may require frequent cleaning of the heat exchanger and result in high maintenance costs. Fouling is especially likely in heat exchangers used after spray dryers, because small quantities of dried product are carried over in the exhaust stream, where they impinge and stick to the heat transfer surfaces. The detrimental effects of fouling can be avoided by proper design of the waste-heat recovery equipment.

PLANT PROCESS MODIFICATION

The Rothschild, Wisconsin, plant uses an anhydrous spray dryer to produce lactose. A generalized process flow diagram of the spray dryer before the addition of the waste-heat recovery system is shown in Figure 7.1. The lactose concentrate was introduced into the top of the drier and dispersed into fine droplets. Air, heated by the combustion of natural gas, entered the top of the

FIGURE 7.1. General Spray Dryer Configuration Prior to Modifications

spray dryer. As the lactose concentrate fell through the dryer in contact with the hot air, water evaporated from the lactose, producing a dried product that collected on the bottom of the dryer. Air exited from the dryer and was passed through cyclones to remove any entrained lactose. From the cyclones, the air (still at a temperature of 190°F or more) was exhausted to the atmosphere.

The rising cost of natural gas led Foremost-McKesson to investigate ways to recover waste heat from the lactose dryer. A heat recovery unit was added to recover heat from exhaust air behind the cyclone separators, as shown in Figure 7.2. In this process, exhaust air enters the heat exchanger at roughly 190°F. Without contacting the exhaust air, inlet air to the natural gas heater is preheated in a separate loop in the heat exchanger. During tests conducted at mild ambient temperatures in March 1981, Foremost-McKesson found that when air passed through the heat recovery unit, it had been heated from ambient temperatures to over 160°F. After passing through a length of ductwork, the air arrived at the dryer burner at a temperature of roughly 140°F. This temperature decrease is due to heat loss through the uninsulated duct, which is located outside the building.

The heat recovery equipment chosen for this installation is known as the Z-Duct energy-recovery unit and is manufactured by DesChamps Laboratories, Inc. The Z-Duct manufacturer claims several advantages which are worth noting, because they illustrate some potential problem areas with this application. One advantage in the equipment design is that condensation removal does not create a problem with the heat exchanger; in fact, condensation is claimed to improve the performance of the unit and to help keep heat exchange surfaces clean. The ability to handle condensation is important, because air from the dryer exhaust is at a high humidity and will lose moisture through condensation as it passes through the heat exchanger. Another advantage claimed by Z-Duct is easy inspection and cleaning. This advantage could be important in this application because of the possibility that entrained lactose can become deposited on the heat exchange surfaces and reduce the efficiency of the unit.

ENERGY SAVINGS

Before the spray-dryer heat-recovery system was installed, a six-month running average of the spray dryer's natural-gas consumption was 1,880 Btu/lb of dry

FIGURE 7.2. Spray Dryer Configuration with Waste Heat Recovery Unit

product. Following installation and initial adjustment of the heat recovery system, Foremost-McKesson made a series of one-day test runs. As shown by the results in Table 7.1, the dryer used only about 998 Btu/lb of dry product.

The actual expected energy savings from the system are expected to be lower than the test results indicate, since energy consumption varies with ambient temperature and humidity. Overall, test results and engineering studies by Foremost-McKesson have indicated that the heat recovery unit has reduced the annual natural-gas requirements for the lactose spray dryer by 42%.

Before modification, the annual energy requirements for the spray dryer were about 20 billion Btu/yr. The 42% reduction in natural gas consumption due to the heat recovery equipment therefore results in a savings of roughly 8.4 billion Btu/yr. These energy requirements are approximate, since the actual energy consumption is strongly affected by weather variations.

The waste-heat recovery system was installed in 1981 at a total capital cost of \$83,000. The price for natural gas at the Rothchild plant at the time the system was installed was about \$3.92/million Btu. Based on this energy cost and a savings of 8.4 billion Btu/yr, the first year's savings from the waste heat recovery system are \$33,000.

TABLE 7.1. Experimental Results for Spray-Dryer Heat Recovery

<u>Trial</u>	<u>Dryer Natural-Gas Use, Btu/lb Product</u>
1	890
2	1,040
3	1,110
4	1,030
5	920
	Average = 998

A simple payback period for the unit can be calculated as:

$$\text{Payback period} = \frac{\$83,000}{\$33,000 \text{ year}} = 2.5 \text{ years}$$

The simple payback period shown above does not consider future cost increases that may take place, which could significantly reduce the actual payback period.

As mentioned in the description of the waste-heat recovery system, the temperature of the recovered heat drops from 160°F at the heat exchanger to 140°F at the dryer due to heat losses in the ductwork. To reduce this heat loss, Foremost-McKesson plans to insulate the ductwork. The company estimates that the duct insulation should raise the temperature of the air entering the dryer by 12° to 15°F, and should raise the overall savings of the system from 42% to 44 to 45%. For a 45% improvement in efficiency, the first year's annual energy cost would be approximately \$35,000/year.

DECISION PROCESS

The waste-heat recovery system was installed because of its large savings in natural gas and favorable payback period. At present prices, the simple payback period for this installation is roughly 2.5 years, but future price increases could shorten this figure. Concern over future increases in the price of energy and the general availability of natural gas were additional factors in the decision to install the waste-heat recovery system.

REFERENCES

- Casper, M. E. (ed.). 1981. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.
- U.S. Department of Agriculture. 1980. Agricultural Statistics 1980. U.S. Government Printing Office, Washington, D.C.

8. CONSERVATION MEASURE: Efficient Compressor Operations

GENERAL INFORMATION

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INTRODUCTION/BACKGROUND

In 1979, 811 million gallons of ice cream were manufactured in the United States (U.S.D.A., 1980). Ice cream production made it necessary to purchase 8.3 trillion Btu's of energy at a cost of nearly \$49 million (U.S. Department of Commerce, 1981). The following shows energy usage by type:

Energy Usage in Ice Cream Production

in percent of total cost (\$48.6 million)

Electricity	77.0
Natural Gas	10.6
Fuel Oils	5.5
Other	<u>6.9</u>
Total	100.0

The total amount of energy purchased that is electricity has remained constant over the last few years at approximately 40% of the total amount consumed in terms of Btu equivalents. The above figures suggest that conserving electricity can be quite cost-effective as the cost per Btu is much higher than for other energy forms.

The following table details the end-use patterns of electricity consumption in ice cream manufacturing plants (Casper, 1977).

Energy End-Use Activity for Electricity in Ice Cream Production

(in percent)

Refrigeration	54
Process Equipment	18
Offices	12
Lighting	5
Air Compressors	4
AC and Ventilation	4
Miscellaneous	<u>3</u>
Total	100

Carnation Company's largest dairy plant is in Los Angeles and uses approximately two million dollars of energy per year. Electricity accounts for two-thirds to three-fourths of this cost or about \$1.5 million/year. Energy conservation techniques are available that could reduce the energy consumed especially in the refrigeration operation.

Carnation Company is one of the largest manufacturers and sellers of dairy products in the United States. Some of the products produced by Carnation are evaporated milk, fluid milk, ice cream, yogurt, dry milk, cottage cheese, cream, and diet products. Carnation also sells animal feed, canned tomato goods, cereals, and tinplate and aluminum cans. In 1980, the dairy-based segment of Carnation Company had net sales of \$1.5 billion, which was 46% of the total sales, and an operating profit of \$110 million, which was 39% of the total operating profit (Moody's, 1981). Carnation Company processes dairy products at a number of locations throughout the United States because of their perishable quality. The Los Angeles plant is one of the largest and oldest of these dairy plants. It processes 200,000 gallons of fluid milk per day and 12 million gallons of ice cream per year which requires a large quantity of energy. Energy conservation techniques could save a fraction of this energy. For example, three major categories for conservation of refrigeration energy are:

1. reduction of refrigeration demand (load)
2. increased refrigeration cycle efficiency
3. waste heat recovery from the refrigeration cycle.

The reduction in refrigeration demand, method 1, saves energy by decreasing the amount of work performed by the compressor. This case involves reducing demand by maintaining the highest practical refrigerated space temperature. Minimizing the amount of product to be cooled and stored, insulation, weather stripping, air curtains, minimal defrosting, and reducing lighting levels are other methods being used to reduce demand.

CONSERVATION MEASURE

The conservation measure used at Carnation's Los Angeles plant was an operational rather than an equipment change. Operational changes are usually less costly than equipment changes, but because historical patterns of behavior must be altered, they are sometimes difficult to implement. The changes instituted at the Los Angeles plant required operating the high-stage compressor at an increased suction pressure. This results in operating the refrigeration cycle at a higher temperature but still cool enough to produce a good product. The end result of this change in operating conditions was a savings in energy while maintaining product quality. Similar energy savings are available to other industries that use refrigeration in their production process. An overview of a refrigeration cycle is provided to illustrate the effect of changes associated with this change in operating conditions.

Figure 8.1 shows a simplified diagram of the basic vapor compression system used at Carnation's Los Angeles plant. The principle for this system is basic to refrigeration and is very similar to the single-stage compression cycle (ASHRAE, 1981). Figure 8.1 shows the two compressors (low- and high-stage), condenser, liquid receiver, expansion valve, and evaporator. Additional equipment such as interconnecting piping, miscellaneous valves, and instrumentation and controls are also part of this equipment.

Figure 8.2 shows the simplified pressure-enthalpy diagram for ammonia which is the refrigerant used by Carnation Company. To compare the operation, various points are identified by numbers consistent with Figure 8.1.

At point 1 the refrigerant returns from the evaporator and enters the suction side of the low-stage compressor. The compressors (high- and low-stage) work to drive the refrigeration cycle and pump the ammonia gas through the system by

FIGURE 8.1. Basic Vapor Compression System⁽¹⁾

⁽¹⁾ Numbers refer to Enthalpy diagram, Figure 8.2.

FIGURE 8.2. Pressure-Enthalpy Diagram for Ammonia Refrigeration Cycle

increasing the pressure of the refrigerant. As the pressure increases, the temperature and enthalpy of the gas are both raised, as shown in Figure 8.2, a move from point 1 to 2.

After leaving the compressors, the ammonia gas passes through a condenser where it is cooled from a superheated gas to a saturated gas and then condensed to the saturated liquid state. The ammonia leaves the condenser as a liquid and is stored in the condenser receiver. During the cooling and condensing process (from point 2 to 3), ammonia reduces its enthalpy content (gives up heat). The temperature of the ammonia is reduced to the saturation temperature (point 3) and a slight pressure drop takes place as the gas passes through the condenser. To reduce enthalpy, the condenser coolant must remove large quantities of heat from the ammonia (Q_{out}). (This heat can be recovered and used as an energy source.)

The condenser receiver holds the liquid ammonia and subcools the liquid (point 3 to 4). The ammonia is then passed through an expansion valve (points 4 to 5), where a large reduction in temperature and pressure takes place. No change in enthalpy occurs. At point 5 in the cycle, the ammonia reaches its coldest temperature and is composed of a mixture of gas and liquid.

The cold mixture of gas-liquid ammonia is then sent through an evaporator (point 5 to 1), where the desired refrigeration takes place. As it passes through the evaporator, ammonia increases its enthalpy content and becomes a pure gas rather than a gas-liquid mixture. The increase in enthalpy occurs as the ammonia absorbs the heat energy (Q_{in}) of another fluid, usually air, which passes through the other side of the evaporator. The other fluid is cooled as the ammonia liquid vaporizes. After leaving the evaporator, the ammonia passes through piping to the compressor. This causes some superheating of the ammonia vapor above the saturation temperature. The cycle is now complete and the ammonia is ready to reenter the compressors.

The low-stage compressor suction pressure determines the pressure and temperature of the ammonia (point 1), which in turn sets the lowest temperature the ammonia reaches in the evaporator. The temperature of the freezers or evaporators is based on the compressor operator's pressure regulation. Because of the dual nature of Carnation's compressor system, the compressor operator regulates

the suction pressure of the high-stage unit, which controls the conditions that exist between the two compressors. The suction pressure for the high-stage unit regulates the temperature of the freezers or evaporators and determines the amount of energy expended by the compressors.

PLANT PROCESS MODIFICATIONS

Before operational changes were made, the compressor system was run with little regard for energy consumption. Low compressor suction pressures, therefore, and low evaporator temperatures (about -40°F) were used to prevent "soft" ice cream. This lower than necessary temperature assured a good product with no risks to the operators even though the energy costs were very high. The suction pressure in the high-stage compressor was originally set at about 20 psi (6°F).

Operational changes were instituted at the Los Angeles plant to reduce energy costs in the refrigeration cycle. These changes were made without loss of quality in ice cream. This was done by increasing suction pressure of the high-stage compressor. The ideal setting for the high-stage compressor's suction pressure is 33 psi and 19°F , as compared to previous conditions of 20 psi and 6°F . This translates into the ideal condition for a low-stage compressor suction pressure of 0 psi and -28°F . Electric consumption dropped as soon as operators began using these new settings. Figures 8.3 and 8.4 show the penalty curves for various low-stage and high-stage compressor suction pressures; i.e., additional energy needed for additional compression and cooling. Alternatively, the curves show the energy savings in percent for Carnation's compressors when the suction pressure is reduced. The low-stage power penalty is based on a discharge pressure of 33 psi and 20°F . The power penalty for the high-stage compressor is lower than for the low-stage compressor, but the amount of power involved is usually more. The low-stage compressor operates between 100 to 600 hp a day, whereas the high-stage compressor operates between 1400 to 2500 hp, depending on the load required. Since the changes in operating conditions were implemented, product quality has not changed.

ENERGY SAVINGS

After operating conditions were changed, data from the high-stage compressor indicates energy savings were 33,660 horsepower-hour (hp-hr) for one week in

FIGURE 8.3. Power Penalty for Low-Stage Compressors

FIGURE 8.4. Power Penalty for High-Stage Compressors

January 1981. This figure is conservative because the low-stage compressor also used slightly less energy but these savings are not included. Data available were also not typical of an average week in terms of energy usage. Thus, the data were corrected. The adjustment factor provided by Carnation for the week is 1.088 times the energy used. The amount of energy saved can also be determined in terms of kilowatt hours per week using the ratio 0.9 kWh/hp-hr. The energy savings per a 52-week year are estimated to be 1.7 million kWh/yr.

$$\frac{33,660 \text{ hp-hr}}{\text{hp-hr}} \times \frac{0.9 \text{ kWh}}{\text{hp-hr}} \times 1.088 \times \frac{52 \text{ weeks}}{\text{year}} = 1.7 \text{ million kWh/year.}$$

The cost of a kilowatt hour of electricity was \$0.067/kWh when the project began in January 1981. Based on this, the energy cost savings are about \$115,000/year (1.7×10^6 kWh/yr $\times$ \$0.067/kWh). Again, note that this figure is conservative because it does not include the savings due to the low-stage compressor operating changes. Because these savings are small in comparison to those from the high-storage, they were not included in the analysis.

DECISION PROCESS

Carnation Company analyzed this new operating method and decided that the energy savings were worth the potential risk of an occasional batch of soft ice cream. Instituting operational changes in the Los Angeles plant required reorientating managers and plant operators; however, with soaring energy costs, energy savings became increasingly important. Also by paying closer attention to compressor settings, the operators can quickly detect and/or avoid any serious problems that may arise. In addition, the cooperation developed among the plants operating personnel and headquarters staff may lead to further improvements.

Energy savings were the only considerations that prompted Carnation Company to institute the new operating requirements at the Los Angeles plant. Because no capital costs were expended, no payback justification was needed. Since the new procedures were adopted at the Los Angeles plant, no problems have developed with product quality.

REFERENCES

American Society of Heating Refrigerating and Air-Conditioning, Inc. 1981. ASHRAE Handbook 1981 Fundamentals, Atlanta, Georgia.

Casper, M. E. ed. 1977. Energy-Saving Techniques for the Food Industry. Noyes Data Corporation, Park Ridge, New Jersey.

Moody's Investors Services, Inc. 1981. Moody's Industrial Manual. Vol. 1, New York, New York.

U.S. Department of Agriculture. 1980. Agricultural Statistics 1980. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Agriculture. 1981. "Fuels and Electric Energy Consumed." 1979 Annual Survey of Manufacturers, M79(AS)-4.1.

9. CONSERVATION MEASURE: Mechanical Vapor Recompression Evaporator

GENERAL INFORMATION

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Plant Location: Hughson, California

INTRODUCTION/BACKGROUND

Production of dried or condensed dairy products (condensed milk, dry milk, and whey) exceeded 3.5 billion pounds in 1979 (U.S. Department of Agriculture, 1979). Of this amount, over 2.7 billion pounds were produced by the condensed and evaporated milk industry (SEC 2023). Large amounts of energy are required for the evaporation and drying processes. In 1972, the total energy consumption of the condensed and evaporated milk industry was 23 trillion Btu. An approximate breakdown of fuel use by type is shown in the following table (Casper, 1977):

Form of Energy Used by Condensed and Evaporated Milk Industry
(in percent)

Natural Gas	65
Fuel Oils	14
Coal	13
Purchased Electricity	6
Other	<u>2</u>
Total	100

Producing dried or condensed milk is a very energy-intensive process because of the large amounts of water that must be removed from the product. Evaporators are the traditional method of removing water to produce a condensed product, and spray dryers are used to complete the drying when a dry (rather than

condensed) product is required. The energy intensity of the concentration process is dramatically illustrated by the fact that condensing (evaporators) and drying (spray dryers) account for 85% of the total energy used by the condensed and evaporated milk industry (Casper, 1977).

The focus in this study is on the concentration process, which is carried out by evaporators. A 1977 report estimated that industry-wide use of evaporators consumed the energy equivalent of 110 barrels of fuel oil per year (ERDA, 1977). Relatively small increases in evaporator efficiency can result in large energy savings for a plant. The largest possible energy savings are achieved by replacing an old, inefficient evaporator with a highly efficient one.

There are two principal types of energy-efficient evaporators available to the dairy industry: either a multi-effect evaporator (four or more effects) with thermal vapor recompression, or a mechanical vapor recompression evaporator. The choice between these options depends on a number of factors, such as the price of electricity relative to fuels, so that the optimal type of evaporator is highly plant specific.

This case study discusses a mechanical vapor compression evaporator installed in the Hughson, California, plant of Foremost-McKesson. The primary product of the Hughson plant is dried skim milk; it also produces butter. The plant is relatively large, with a capacity of over 52,000 lb/hr of skim milk feed.

CONSERVATION MEASURE

The key to the efficiency of today's evaporators is recovery of the heat contained in the evaporated steam. This heat is recovered in two ways, which may be used independently or in conjunction. The first way of recovering heat is by injecting the evaporated steam into an evaporator chamber which is at a lower pressure than the injected steam; this is the basic principle of multi-effect evaporators. The second way of recovering heat is by recompression of the evaporated steam, increasing its pressure and temperature, and reinjecting it into the evaporator. If the recompression is done by a steam jet, the evaporator is termed thermal vapor recompression (TVR). When recompression is done by a mechanical compressor, the evaporator is termed mechanical vapor recompression (MVR).

Multi-effect evaporators achieve greater design efficiencies by adding additional effects. Each effect is a separate evaporation chamber. Evaporation takes place under a vacuum, with pressure decreasing from one effect to the next. As pressure decreases, the boiling temperature of the product also decreases, so that the operating temperature decreases from the first effect to the last. Because of the temperature decrease from one effect to the next, the vapor removed from an effect is at a higher temperature than the boiling product in the next effect. Therefore, the vapor from the first effect can be used to supply part of the heat required in the second effect, and vapors from the second effect supply part of the heat required in the third effect. One pound of process steam can evaporate more than one pound of water as a result of the cascading energy approach.

Vapors cannot be returned to the same effect from which they were extracted because they are at the same temperature as the evaporating product in that effect, with no heat transfer possible. This constraint can be avoided by recompressing the vapors, which raises their temperature and pressure and allows them to be reinjected for heating the same stage from which they were extracted. A thermal vapor recompression scheme uses a steam jet to recompress a fraction of the vapors drawn from an effect. Mechanical vapor recompression is able to recompress all of the vapors leaving an effect, rather than only a fraction, and by doing so, achieves a higher efficiency than a thermal recompression evaporator.

The increased efficiency of MVR evaporators is not without a price. Mechanical vapor recompression evaporators tend to have higher capital cost than TVR units. In addition, MVR evaporators use a high-grade energy source, such as electricity, rather than low-temperature steam. The cost of electricity relative to fuels used to produce steam is often a critical factor in deciding between MVR and TVR evaporators for a given application.

PLANT PROCESS MODIFICATION

Prior to MVR modification the Hughson plant had used a two-effect evaporator with thermal vapor recompression. Modern multi-effect evaporators with thermal vapor recompression are generally efficient units, and are the optimal evaporator choice for some installations. However, the thermal vapor recompression

evaporator used at the Hughson plant was old, inefficient (only two effects rather than four or more) and was becoming obsolete. In addition, it was somewhat underdesigned for the present plant, and prevented the spray dryer from operating at full design capacity. A combination of the unit's age, operating condition, and energy costs led Foremost-McKesson to the decision to replace it with a newer, more efficient system.

After an intensive study of the alternatives, a MVR evaporator unit was chosen as the most economical alternative for the Hughson plant. The old evaporator unit was replaced with a single effect, five-stage MVR evaporator, shown in Figure 9.1. In the MVR evaporator, steam is used for system startup, after which the majority of evaporation energy is supplied by vapor recompression. Incoming preheated feed enters the system at 165°F. Evaporation in this system occurs under a vacuum, with the vapor leaving the system at a temperature of 160°F. The vapors are recompressed on a centrifugal compressor, which raises the vapor temperature to 167°F, high enough to transfer the heat to the product. Two interstage heaters supply heat to the product external to the evaporator prior to the product entering stages two through five.

The capacity of the evaporator system was increased when the MVR evaporator was installed. The previous unit evaporated 34,800 lb/hr of water from a feed of 43,300 lb/hr of skim milk to produce 8,500 lb/hr of product at 44% total solids. The MVR unit was designed to evaporate 42,325 lb/hr from a feed of 52,325 lb/hr of skim milk, producing 10,000 lb/hr of concentrate at 45% total solids.

ENERGY SAVINGS

Energy savings obtained through the MVR evaporator, shown in Table 9.1, have been calculated by Foremost-McKesson for a common system operating rate. The MVR unit uses only minimal process steam, where the old evaporator obtained all of the evaporation energy via process steam. Reductions in steam use attained with the MVR evaporator result in a boiler fuel savings of nearly 150,000 x 10⁶ Btu/year. These large savings in fuel oil (or natural gas, the boiler's alternate fuel) were achieved through a relatively minor increase in the amount of electric power used. The increase in electricity consumed was due to the large compressor used in the MVR evaporator, which was not required for the old

FIGURE 9.1. Foremost-McKesson Mechanical Vapor Recompression Evaporator

TABLE 9.1 Energy Savings with MVR Evaporator^(a)
(10⁶ Btu/year)

	Old Evaporator	MVR	Savings
Basic Steam Use	97,200	6,200	91,000
Steam Used in Pasteurizing and Separating	25,000	0	25,000
Total Steam	122,200	6,200	116,000
Electric Power Use	1,590	8,450	-6,860
Overall Energy Savings			

$$\begin{aligned} \text{Boiler Fuel} & \frac{116. \times 10^9 \text{ Btu}}{\text{yr}} \times \frac{.78}{\text{efficiency}} = 148.7 \times 10^9 \text{ Btu/yr} \\ \text{Electric Power} & -6.9 \times 10^9 \text{ Btu/year} \end{aligned}$$

(a) Based on production rate of 52,000,000 lb/year nonfat concentrate at 44% total solids.

evaporator. Energy is saved not only in the evaporation process, but also by using evaporator surplus heat to run the pasteurizer and separator.

The MVR evaporator system was installed in 1977 at a total capital cost of \$1.5 million, which includes the cost of the new building required to house the evaporator. Based on prevailing energy prices in mid-1978, the MVR evaporator was calculated to save \$282,000/year in energy costs. Since 1978, the escalating cost of energy has increased the savings from the MVR evaporator. The Hughson plant currently pays approximately \$4.50/mcF⁽¹⁾ for boiler fuel and \$0.038/kWh for electricity, so savings from the MVR system are currently about \$600,000/year.

Installation of the MVR evaporator has had only minimal effects on the non-energy operating and maintenance costs of the evaporator system. Normal maintenance on the MVR evaporator is probably slightly lower than for the old evaporator because of improved cleaning characteristics, although this effect has

(1) MCF = thousand cubic feet

not been quantified. The same number of operators are required for the MVR evaporator as for the old evaporator.

Note that in achieving the energy savings, a high-grade energy source, electricity, was substituted for lower-grade thermal energy. For Foremost-McKesson's application, the increase in electrical energy costs are small compared to savings in fuel expenses.

DECISION PROCESS

The old evaporator was a significant energy user, and was also old and somewhat undersized. These factors all contributed to the decision to replace it. The MVR evaporator was selected over other evaporator designs on the basis of a detailed engineering study that indicated the MVR unit had the lowest life cycle cost for this application.

Installation of the new evaporator has resulted in several important benefits to the plant in addition to the energy savings. As previously mentioned, the old evaporator was somewhat undersized, creating a processing bottleneck. The larger capacity MVR evaporator removed this bottleneck, allowing an increase in the overall capacity of the plant. Compared to the old evaporator, the MVR evaporator has also decreased the chances of heat damage to the milk, resulting in a higher quality and more consistent product.

While replacing the old evaporator was a major project, the installation of the MVR evaporator went smoothly with no unusual problems. Space restrictions dictated that a separate building be constructed to house the new evaporator.

REFERENCES

Casper, M. E., ed. 1977. Energy Saving Techniques for the Food Industries. Noyes Data Corporation, Park Ridge, New Jersey.

Energy Research and Development Administration. 1977. Upgrading Existing Evaporators to Reduce Energy Consumption. COO/2870-2, Technical Information Center, Washington, D.C.

10. CONSERVATION MEASURE: Preheating Spray Dryer Air with Recoverable Waste Heat

GENERAL INFORMATION

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Plant Location: Browerville, Minnesota

INTRODUCTION/BACKGROUND

In 1979, over one billion pounds of dry milk were produced in the United States, including nonfat, skim, whole, and buttermilk forms. Nine hundred eighty-five (985) million pounds of butter were also produced in the United States in 1979 (U.S. Department of Agriculture, 1980). Evaporation followed by spray drying are two common processes used to dry milk.

Spray drying of milk often consumes 99% of the direct fuel input (other than boiler input), or 24% of total plant energy consumption in the condensed and evaporated milk industry (SIC 2023). Spray drying processes offer considerable opportunity for energy savings in these applications (Casper, 1977).

Production of creamery butter (SIC 2021) is another energy-intensive process. The energy purchased per pound of output of all dairy products produced in the creamery butter industry was 5,450 Btu/lb in 1972. Purchased electricity for refrigeration, lights and other process equipment comprises 7% of the energy required to produce butter. Refrigeration is the largest single user of electricity but typically uses only 17% of the total electricity consumed in a plant (Casper, 1977).

In 1980, Land O' Lakes, Inc., installed a refrigeration waste heat recovery system in the Browerville plant. The new system is designed to preheat spray dryer air with rejected condenser heat, thereby reducing the amount of natural gas required to produce dry milk in the plant. Other sources of waste heat could also be used to economically preheat spray dryer air, depending on actual plant processing. The two major products of the Browerville plant are creamery butter and milk.

CONSERVATION MEASURE

With conventional refrigeration systems, heat from a product is transferred to a refrigerant traversing a series of coils or tubes. Heated refrigerant is then channeled through evaporator coils where heat is transferred to air passing over the evaporator. In a majority of the cases, air passing over the evaporator coils is supplied from outside the plant and is at ambient temperature. The heated air is then generally vented outside of the plant, resulting in energy waste.

Heat exchangers can be economically used to recover waste process heat from refrigeration systems. By incorporating special heat exchangers at the evaporation stage, refrigerant can be desuperheated and the thermal energy transferred to other secondary process streams within the plant (either liquid or gaseous). In many instances, the available energy is insufficient to heat the secondary process stream to the desired final temperature(s). The heating process must therefore be augmented with other conventional direct heating or heat recovery methods. Under these circumstances, the heat exchanger acts to "preheat" secondary process stream(s).

In a typical heat exchanger, fluid streams come in proximity to each other without actually coming into contact. The separating material is most frequently a metal with high thermal conductance properties. The process streams may consist of gasses, liquids, or solids, or any combination of the above. However, heat exchangers are commonly of two principal types. In the first type, latent heat from a condensing vapor is transferred through tube walls of a heat exchanger providing a sensible heat to a second fluid, which is usually a liquid. In the second type, sensible heat is transferred from one fluid to another.

PLANT PROCESS MODIFICATIONS

Prior to installation of the heat recovery system in 1980, the Browerville plant used a straightforward 300-ton capacity (where 1 ton = 12,000 Btu/hr) refrigeration unit to chill butter and satisfy other cooling needs within the plant. Outside air was passed over condenser coils to desuperheat and condense the ammonia refrigerant. This heated air was then vented to the exterior of the plant where it was released to the atmosphere.

The milk drying portion of the Browerville plant is composed of a steam fed evaporator followed by a single stage spray dryer. The spray dryer is fueled by natural gas and the heated air temperature inside the unit is maintained at approximately 350°F. Before modification, outside air at ambient temperature was fed directly to the spray dryers where it was heated to 350°F. After becoming saturated with water from the moist solids, heated vapor was vented from the unit and dry milk (96% solids) was extracted from the bottom. A diagram of the old system is found in Figure 10.1.

Upon recognizing the opportunities for saving energy, Land O' Lakes modified its process to include refrigeration waste heat recovery. In the modified system, heat exchanger coils have been installed in front of the condenser element in the refrigeration cycle. Cold outside air destined for the spray dryer is channeled over the heat exchanger, where it is preheated 30 to 50°F above the ambient outside temperature. The preheated air then enters the spray dryer where it is heated to the final 350°F temperature, thus driving off most of the moisture contained in the milk. Figure 10.2 shows a diagram of the modified system.

ENERGY SAVINGS

Energy savings resulting from installation of the refrigeration waste heat recovery system are estimated at 5 billion Btu's/year. This value is based on a stated cost savings of \$14,000/year, a natural gas cost of \$3/mcf⁽¹⁾, and an assumed heating value of 1075 Btu/scf⁽²⁾ for natural gas. Actual calculations are performed as follows:

$$\frac{\$14,000 \text{ saved}}{\text{year}} \left| \frac{\text{mcf}}{\$3.00} \right| \left| \frac{1000 \text{ scf}}{\text{mcf}} \right| \left| \frac{1075 \text{ Btu}}{\text{scf}} \right| = 5.02 \times 10^9 \text{ Btu saved/yr}$$

DECISION PROCESS

Refrigeration and spray drying are two energy-intensive processes. Land O' Lakes management recognized the potential energy and corresponding cost savings that could be achieved through refrigeration waste heat recovery and decided to implement an appropriate system in their Browerville plant.

(1) mcf = thousand cubic feet

(2) scf = standard cubic foot

FIGURE 10.1. Plant Process Components Prior to Modification for Waste Heat Recovery

FIGURE 10.2. Preheating Spray Dryer Air with Waste Heat

One of the most effective applications of refrigeration waste heat recovery is the preheating of plant make-up water. In the case of the Browerville plant, however, an abundance of hot water is produced from evaporator condensate. Alternative applications were therefore examined, and a system designed to pre-heat dryer air was considered to be the most practical and beneficial.

The system was installed in 1980 at a cost of \$22,000. Additional modifications connected with the system are planned and will cost \$8,000, making the total installed cost \$30,000. Energy and cost savings should remain unchanged after these final modifications are made. Based on energy cost savings of \$14,000/year, the payback period should be about two years.

The refrigeration waste heat recovery system was easily installed in a short time. Economics were favorable because of the proximity between refrigeration tubing and spray dryer ductwork in the Browerville plant prior to modification. It should be noted that the benefits from this application are greatest for plants where refrigeration tubing and spray dryer ductwork are close together before modification. Heat losses and equipment costs quickly erode the economy of these installations for plants with large distances between refrigerator tubing and spray dryer ductwork. These are important considerations for other plants.

No significant drawbacks in the installation have been noted. However, because of the high efficiency with which heat transfer occurs at the site of the heat exchanger, modifications are planned to combat operational problems that arise during winter months. To prevent premature condensation of refrigerant caused by excessively cold outside air, modifications are planned that should control refrigeration system head pressure and the amount of coil made available in the heat exchanger.

The sole consideration for installing this system was the potential energy savings and corresponding energy cost savings. After almost two years of service, the system has proven quite reliable, requiring very little maintenance and no additional personnel.

REFERENCES

Casper, M.D. 1977. Energy Saving Techniques for the Food Industry. Noyer Data Corporation, Park Ridge, New Jersey.

United States Department of Agriculture. 1980. Agriculture Statistics 1980. U.S. Government Printing Office, Washington, D.C.

SECRET

Casey, M.J. 1977. Control of the Fishery for the Rockfish. Northwest Fisheries Laboratory, Vancouver.

United States Department of Agriculture. 1980. Northwest Fisheries Statistics 1980. U.S. Department of Agriculture, Washington, D.C.