EFFICIENCIES OF MECHANICAL REFRIGERATION SYSTEMS

by
George C. Briley*

SUMMARY

This paper describes various ways to increase the efficiency of a Mechanical Refrigeration System. It compares the cost of operation with capital costs.

Relative energy usage of the various cryogenic refrigerants is discussed in comparison to Mechanical Refrigeration Systems.

An analysis of the costs to chill beef using the conventional methods, using hot boning methods and using a suggested Chill Pack (+28°F) Method indicate substantial savings in energy.

Introduction

During the last three decades most process industries have been expending *energy* in lieu of capital. It was always easy to justify the lowest price. Almost invariably the low-priced refrigeration system had much higher energy requirements than the system with the higher cost. This type of approach was, and, is, brought about by our tax system where energy is an expense and the capital investment must be depreciated over a prolonged period. With low cost energy, this approach is easy to justify.

Now, however, the cost of electricity and most other forms of energy are increasing at such a rapid rate that the plant owner is forced to start investing capital to conserve energy.

In order to put this into perspective, let us compare a mechanical freezing system which freezes 6,000 pounds (2,727 KG) per hour of cooked meat portions per hour.

In 1970, this system would cost approximately $235,000 and require some 535 B.H.P. (400 KW) including compression equipment and all ancillary fans, pumps, and other electrical requirements. In 1970 the cost of electricity was around 1¢/KW hour so that a 4,000 hour per year operation had an electrical cost of about $17,000 year.

Now, let us look at 1979. The capital cost is $470,000 and the cost of electricity has risen five to seven times. At 5¢/KW hour and a 4,000 hour per year operation the electrical cost would be about $85,000 per year. At this point the plant owner must start to analyze the additional cost to reduce the electrical energy requirements. In most cases an additional investment of about 5% to 7% will reduce operating costs by 15% to 20%. As electrical rates increase to 8 to 10¢/KW, as they have in some areas, every plant owner will be forced to pursue every avenue to keep electrical operating costs well below what most people have considered normal.

When you invest in a refrigeration system every horsepower is vitally important. Consider the possibility of 10% inflation per year. A realistic figure by today's standards, 20 years of plant life, a 92% efficient motor, and .03¢/KW electricity, and 24 hour per day operation. Under these conditions 10 HP would cost approximately $153,740 in electrical energy over the 20 year period. If you only operate 2500 hours per year in lieu of 8700 hours, the cost is $44,178.00. Thus, when you analyze a refrigeration system you should compare *total cost* of owning and *operating*, not just the capital investment.

Ways of Improving Refrigeration Efficiency

Here are some ways in which the efficiency of mechanical refrigeration systems can be improved:

1. Select the most efficient refrigeration compression equipment available.
2. Select the evaporators with ample coil capacity and be sure to install a demand-defrost system for defrosting all coils in rooms below 35°F (2°C).

   During hot gas defrost an evaporator coil uses twice the energy used during normal operation under ideal conditions. Most existing defrost systems for evaporator coils are time activated in room at 35°F (2°C) or below. Thus, many coils are defrosted much more often than required. Demand defrost is initiated by the air pressure differential across the coil. As frost builds the air pressure increases and activates the defrost cycle.

*G. C. BRILEY

Vice President, Marketing, Refrigeration Engineering Corporation, 8799 Crown Hill, P.O. Box 3C, San Antonio, TX 78217

Reciprocal Meat Conference Proceedings, Volume 32, 1979.

3. Install a good oil management system. Remove the oil from the refrigerant before it gets to the evaporators. Oil in evaporators decreases evaporator efficiency and in turn decreases the system efficiency.

4. Design the system so that it can operate at low condensing pressure during off peak ambient conditions. By operating at 100 psig (687 Kpa) condensing in lieu of 185 psig (1275 Kpa) (design) the energy requirements are reduced by 30% or more.

5. Install a programmable computer to control the entire refrigeration system. Operating costs (electrical energy) have been reduced dramatically by proper programming of all system functions —to use the minimum of energy.

6. Initiate a maintenance and operation system geared to the efficient use of every kilowatt of electricity. Good maintenance of the refrigeration plant will reduce the use of energy.

7. If your plant requires hot water (and most do) another energy saver is a heat recovery system. Here are the sources of heat and the temperatures to which water could be heated:

   A) High stage compressor discharge

   B) Booster compressor discharge

   C) Refrigerant condensing system

   D) Screw compressor oil cooler

   E) Reciprocating and rotary compressor jackets

In general, incoming water can be heated from 50°F (10°C) inlet to 135°F (57.2°C) to 140°F (60°C) maximum. In an ammonia system approximately 1800 BTU/hour (453 KCAL) can be recovered for each compressor brake horsepower for boiler make-up, scalding systems, clean-up, and domestic hot water. etc.

In most areas a heat recovery system can be paid for out of savings in energy within one to two years. This payout time is rapidly reducing.

Mechanical Refrigeration Least Expensive

Mechanical refrigeration is the least expensive way to chill or freeze a food product. It uses less energy than any other system. Here are some basic comparisons between mechanical refrigeration, liquid carbon dioxide, and liquid nitrogen.

The costs of liquid carbon dioxide normally varies according to the plant location and transportation costs. However, in general, the costs vary from 2¢/pound to 3¢/pound delivered and as energy costs increase these prices must rise. The production of liquid carbon dioxide is energy intensive. The electrical energy required to produce the liquid carbon dioxide equivalent to that provided by a mechanical system is more than *double*. And this is just the start. Some five to seven years ago the cost of transportation of liquid carbon dioxide *exceeded* the cost of production and the cost of gasoline and diesel fuel is going up even more rapidly now. Liquid carbon dioxide costs will rise—and probably at a rate much faster than electrical costs.

Most of the same analysis that apply to liquid carbon dioxide apply to liquid nitrogen. Liquid nitrogen is even more energy intensive than liquid carbon dioxide. Here again, costs vary from 2¢/pound to 5¢/pound depending upon the proximity of liquid nitrogen production to the user, the local electric costs, the competitive situation and the quantity used. Liquid nitrogen is normally the product of an air separation plant, which, in many cases, is designed to produce oxygen for a chemical or other process. Assuming that the pure nitrogen is available *free* the actual electrical energy required to produce an equivalent number of BTU's as a mechanical system is approximately ten or more times. Thus, the costs are certain to rise at a rate much higher than mechanical systems. Again, liquid nitrogen is normally transported by truck or rail and this cost is rising at a rapid rate.

In general, if we assume the costs of mechanical freezing to be one, using liquid carbon dioxide would be two or three and with liquid nitrogen the cost would be four to five.

Objectives of the Refrigeration Industry

Somehow, we in the refrigeration industry have been trying to freeze everything that comes along in the area of food products since somebody around 1848 found that food *could* be preserved by reducing its temperature to 0°F (−17°C) and could be maintained for long periods of time. Quite often we forget that not every item needs to be *frozen* to be preserved for the time period to which existing distribution systems are geared. Sometimes as the alligators nip at us we forget that the objectives are to:

1) Provide a quality food product geared to the existing distribution system.

2) Price at a minimum.

3) Use the minimum amount of energy.

Poultry Industry's Use of Refrigeration

The poultry industry in the U.S. for many years distributed poultry in the form of whole birds packed in ice. Now, this is not a very ingenious system as each pound of ice-packed poultry required about one-half pound of ice during transportation to the sales outlet. The delivered product temperatures were not consistent and varied from 32°F (0°C) to 40°F (4°C), and above. Obviously, transporting 33-1/3% more weight than you sell is self-defeating and expensive. As a result, considerable research was done indicating that frozen poultry was the way of the future. However, some poultry producers decided to take a different approach. The demands of the supermarkets were directed toward pre-packaged and pre-priced poultry "Ready for Sale."

"Chill Pack," a product that was equilibrated at 28°F (–2°C) was a good answer. Today, about half the U.S. Poultry Pack is produced that way and the percentage is rising. This product is produced by transporting the packages through a continuous freezer for a pre-determining time depending upon the type of package. The average time is about 50 minutes. The product is stored at 28°F (–2°C). This prepackaged product has a far superior shelf life to ice-packed poultry.

"Chill Pack" Poultry is produced on several types of automatic or semi-automatic systems. The selection of the type system to be used is basically related to the customer's product handling system.

A semi-automatic system employs a multi-track tunnel freezer with each track independently driven by a variable speed hydraulic drive so that different sizes of packages with different time requirements can be chilled to 28°F (–2°C). Additionally, products can be frozen on one track while two tracks are used for "Chill Pack." The packages are transported through the tunnel in nesting plastic trays which ride on a dolly.

The dollies are then manually moved into a 28°F (–2°C) storage room which holds several days production. The product is unloaded from the dollies, pre-priced, packaged in a master carton and loaded on the delivery truck.

An *automatic system* would normally employ a continuous freezer. This packages transported through a –25°F atmosphere of high velocity air on a conveyor.

This system requires the packages to be put in a master carton before storing in the 28°F (–2°C) holding room. It is not as versatile as the tunnel freezer as all sizes of packages are in the freezer for the same time. This system eliminates some labor, however, its capital cost is approximately double that of the tunnel freezer.

Some processors try to use blast freezers to produce "chill pack." This is usually not successful as it is most difficult to control the *time* that the product is in the freezer so some of the product is frozen and some is not properly chilled. Good "chill pack" products *require precise control.*

The alternative to "chill pack" could be frozen. Let us compare the energy costs of each approach.

The heat removed from the bird for "chill pack" is approximately 47 BTU/Pound. For freezing the heat removed is about 130 BTU/Pound. From this relationship you would expect the cost to be about 2.6 times more to freeze than to "chill pack." However, when all factors are considered, the actual cost is about 2.3 times more. For example, using 3¢/KW electrical power the energy cost of "chill pack" is .06¢ per pound and for freezing it is about .14¢ per pound. Capital costs for equipment would follow at about the rate of 2.5 to 1 for a freezing system versus a "chill pack" system.

Besides the reduced cost of production the cost of transportation is less and storage costs are less for "chill pack."

As an example, the relative energy cost for a 28°F (–2°C) storage versus a –10°F (–23°C) is about two to one, assuming that the heat loss was identical. The basic differences is the electrical requirements are 2.5 BHP/TR at –20°F (–29°C) and 1.4 BHP/TR at 18°F (–7.8°C) for all electrical motors.

The Red Meat Industry Use of Refrigeration

The red meat industry has for many years been geared to the distribution of an approximately 35°F (1.7°C) product either in carcass form or boxed.

Most recent studies regarding hot-boned beef indicates some interesting savings in energy costs. By eliminating the bones, excess fat, etc., the heat removal is reduced by 32% over intact sides of beef. There are other factors effecting the energy requirements and total savings using this system. The hot-boned beef is vacuum packaged in portions of similar size and weight and boxed. Quick chilling in an automated carton freezing system would have advantages. It would minimize shrink, and the product could be chilled in eight to ten hours to 35°F (–1.7°C) equilibrated, assuming that air temperatures of –20°F to –25°F were used. According to data published in the ASHRAE Data Book, conventional beef chill operations have net weight losses of from .7 to 1% in the chill room and holding room losses of from .6 to 1% for 48 hours holding period or a total of from 1.3% to 2%. The type shrink should be practically eliminated with the hot-boned and quick-chill system.

Further, it is suggested that the product be chilled to approximately 26°F to 30°F and remove some 1/3 of the latent heat. The product should then be maintained at 26°F to 30°F during the distribution cycle. Little change would be required as most trucks and storages could be operated at 26°F to 30°F if they presently operate at 33°F to 35°F.

Most red meats take 20 to 25 days from the kill floor to the customer. Its shelf life is 2.5 times longer at 33°*F than at 40°F*. Using a "chill pack" system the shelf life should be many times better and the product could be delivered at least two to three days sooner due to the shortened chill time.

Little data is available on the use of "chill pack" in the red meat industry in the United States. However, we anticipate a trend in that direction as energy costs increase. Compare the cost to chill beef in a conventional manner versus chilling hot-boned beef. Assuming 105°F (40.6°C) product in and using the example in the ASHRAE Guide, Chapter 28 (1965), which describes a design for 520 carcasses weighing 560 pounds each or 291,000 pounds per beef chilled in 20 hours and held for 48 hours using .03¢/KW would cost approximately $139.00 (47.76¢/1000 pounds) and take three days.

Chilling hot-boned beef employing a compound compression system and an automated carton freezing system and assuming 10 hours to chill from 105°F (40.6°C) to 35°F (1.7°C) the cost for 291,000 pounds less the 30% bones, trim, etc. would be about $90.00 (44.0¢/1000 pounds net) (30.9¢/1000 pounds gross) on the same basis as the above cost.

This electrical energy savings of over 50% is paralleled by a reduction in space required from 15,500 square feet to about 3,000 square feet, a 60-hour reduction in inventory requirements, and a reduction in capital investment. Depending upon the handling method, it is estimated that the automated hot-boned beef chiller could be installed for a capital cost 10% to 20% less than a chill room and a 48 hour holding cooler. Labor would be reduced also depending upon the packaging method and the chilling system employed.

Most of all, as previously discussed, these savings are in addition to a 1% to 2% shrink savings.

The red meat industry should move in the direction of "chill pack" to take advantage of additional shelf life and less spoilage. Based on the same example, the cost to "chill pack" at 28°F (−2°C) assuming removal of 30 BTU's per pound of latent heat then the cost to "Chill Pack" would be about 48.5¢/1,000 pounds. Thus, we could "chill pack" for about the same energy as we use now. The chill time would increase by 2 to 4 hours over the hot-boned chilling time. However, the installation costs should still be well below the conventional chill room holding room methods.

From previous studies of "chill pack" poultry versus frozen, the same relationship will occur with red meat. The cost to freeze would be 2 to 2.3 times the cost to 'Chill Pack." The cost to store at −10°F (−23°C) would be two to one versus 28°F (−2°C) storage.

You may question the −35°F evaporator temperature for chilling a product to 28°F, however, the low air temperature will glaze the surface of the product rapidly and will eliminate much of the "drip" loss normally associated with chilling meat products. It will also decrease the chilling time.

CONCLUSION

Ways are numerous to reduce the cost of energy in the meat industry. However, none are as promising as hotboning, chilling, and distribution at 26°F to 30°F. This "system" would effectively reduce the energy cost of providing quality meat to the consumer by 30% to 40% over conventional methods.

SLIDE #1

	1970	1979	1979 (1)
Mechanical System Installed	$235,000	$470,000	$502,900
Electrical Energy Costs	1¢/KW/HR	5¢/KW/HR	5¢/KW/HR
Cost for 4,000 Hours Operation	$17,000	$85,000	$68,000
Operating Cost as % of Investment	7.2%	18%	13.5%
Payback	---	---	2 Years

(1) With Additional Investment for Energy Savings

MECHANICAL FREEZING SYSTEM
6000 Pounds/Hour

SLIDE #2

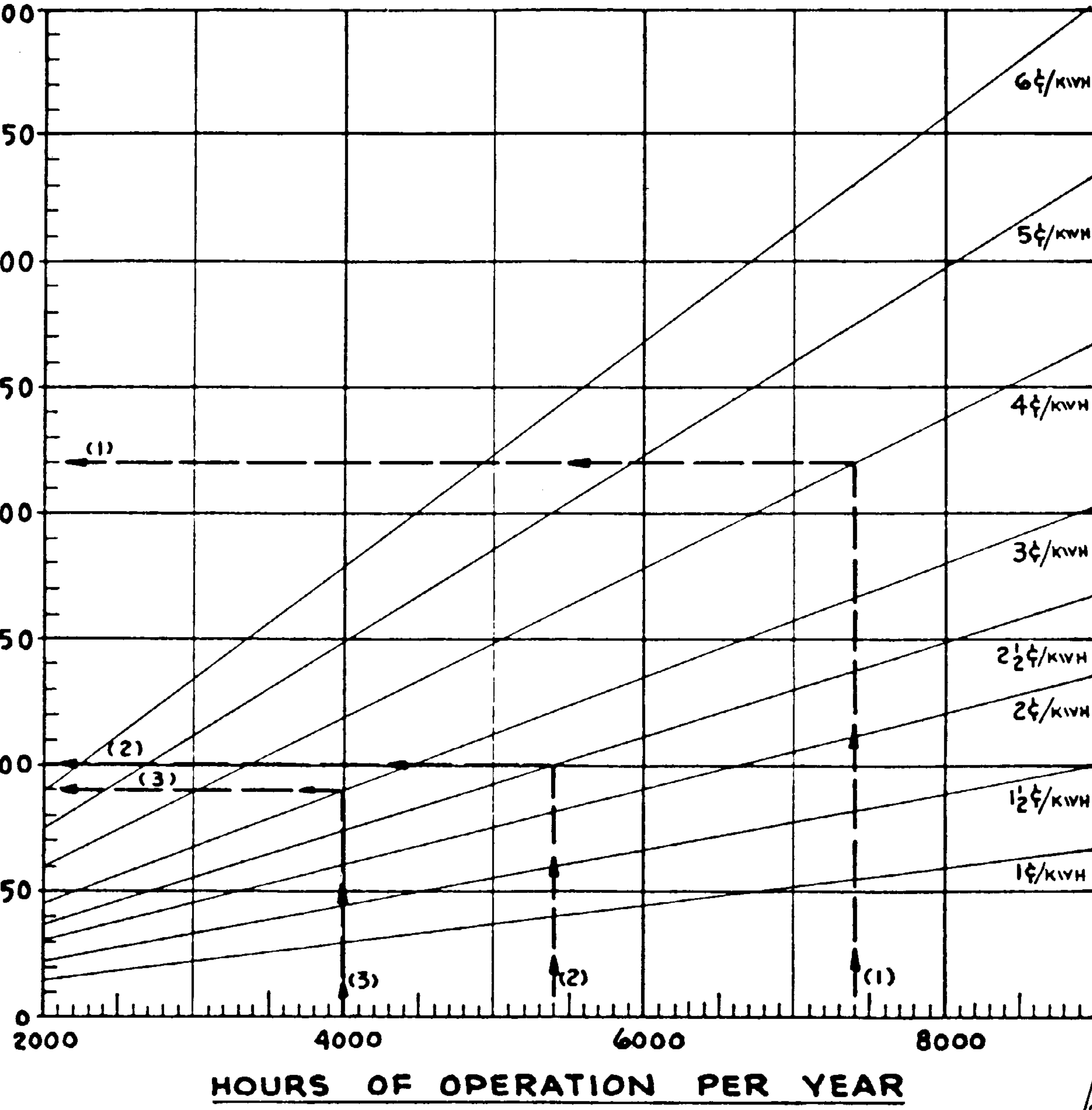
	Chilling Conventional	Chilling Hot Boned	28°F. Chill-Pack
Energy Cost/1,000# (1)	$00.478	$00.443	$00.485
Shrink	1.3 to 2%	.7 to 1%	Neg.
Time Required/Hours	68 to 72	8 to 10	10 to 12
Floor Spare Required (2)	15,000	3,000	4,000
Yield	68 to 7.0%	99%	99%

(1) Based on 3¢/KW Electrical Energy Cost.
(2) For 520 Carcasses/560 Pounds Each.

COST COMPARISONS FOR MEAT PROCESSING

SLIDE #3

OPERATING COST - ELECTRIC MOTORS



$$\frac{\$/HP \times HP}{\text{MOTOR EFFICIENCY}} =$$

OPERATING COST PER YEAR

EXAMPLE : (1)
500 HP, .92 EFFICIENCY
7400 hrs. OPERATION @ 4¢/KW
FROM GRAPH $/HP = 220

$$\frac{220 \frac{\$}{HP} \times 500\ HP}{.92\ \text{EFFICIENCY}} = \$119{,}565\ /YR$$

EXAMPLE : (2)
100 HP, .92 EFFICIENCY
5400 hrs. OPERATION @ 2½¢/KW
FROM GRAPH $/HP = 100

$$\frac{100 \frac{\$}{HP} \times 100\ HP}{.92\ \text{EFFICIENCY}} = \$10{,}869/YR$$

EXAMPLE : (3)
15 HP, .75 EFFICIENCY
4000 hrs. OPERATION @ 3¢/KW
FROM GRAPH $/HP = 90

$$\frac{90 \frac{\$}{HP} \times 15\ HP}{.75\ \text{EFFICIENCY}} = \$1{,}800/YR$$

ESTIMATING MOTOR EFF.

.92 - 100 HP & UP
.88 - 20 HP TO 100 HP
.85 - 5 HP TO 20 HP
.75 - ½ HP TO 3 HP

RECO
Refrigeration Engineerin
Corporation
PO BOX 3-C
SAN ANTONIO,
TEXAS 78217
Ph 512-824-2336