# POTENTIAL OF HEAT RECOVERY UNITS ON MILK REFRIGERATION EQUIPMENT

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## Introduction

Heat recovery units can be effectively used to heat process hot water with the heat that is normally rejected from an air conditioning or refrigeration system to the ambient environment. Substantial reductions in the energy requirements for heating process water can be realized by using a heat recovery unit; while at the same time, there will be a corresponding increase in the efficiency of operation of the refrigeration system (increase in coefficient of performance). The efficiency increase will be evidenced by either a decrease in the electrical energy required to operate the refrigeration system or an increase in the cooling capacity of the refrigeration system for a given electrical input.

Heat recovery units for refrigeration systems are not new products; recovery units have been commercially available since 1935. Until recently, heat recovery units were generally viewed as being an uneconomical means of heating water for dairy farm applications. However, as the price of energy has rapidly escalated in the past decade, the use of heat recovery units offers an economical means of conserving energy.

Usage of hot water on dairy farms has been measured by Wiersma and Armstrong (1979) to range from 1.3 to 1.6 gallons (5 to 6 liters) per cow per day for herringbone parlors and from 2.4 to 2.9 gallons (9 to 11 liters) per cow per day for side opening parlors and prep stalls. Wiersma and Armstrong also found that the settings on water heaters ranged up to 113°F (45°C) for prep washing and general wash water and up to 167°F (75°C) for sanitation wash water. Under typical Florida conditions, the energy required to supply 2 gallons (7.5 liters) per cow per day of hot water at 165°F (74°C) is 1568 BTU (1.65 MJ), assuming a supply water temperature of 70°F (21°C). Assuming an electricity cost of $0.065/per KWH and a heater efficiency of 95%, the cost of providing the hot water is $0.033 per cow per day. For a 1000 cow dairy herd, the yearly cost for energy for heating water is $12,111. If natural gas or fuel oil is used as the energy source for heating the water, the energy cost for heating may then be significantly less than heating with electricity. In most applications, a heat recovery unit that is properly designed, installed, operated, and maintained will provide a major portion of the hot water needs on a dairy farm.

## Principle of Operation

A heat recovery unit is installed in a refrigeration system between the compressor and condenser. (In some applications, the heat recovery unit actually takes the place of the condenser.) The hot refrigerant gas leaving the compressor enters the heat recovery unit, that functions as a counter-flow heat exchanger. The other medium entering the heat recovery unit is the water that is to be heated. The heat transfer process of water being heated by the hot refrigerant and the refrigerant being cooled by the lower temperature water provides the dual benefits of producing hot water and increasing the efficiency of the refrigeration system.

A brief introduction to the operation of a refrigeration cycle will illustrate the potential of heat recovery units. Consider a rather typical dairy refrigeration system (air-cooled) having a condensing temperature of 165°F (73.9°C) and an evaporating temperature of 0°F (-17.8°C) for refrigerant R-12. The corresponding condensing and evaporating pressures are 296.1 psia (2042 kPa) and 23.8 psia (164 kPa), respectively. A pressure-enthalpy (P-h) diagram of the theoretical refrigeration cycle is shown in Figure 1; the temperature-entropy (T-s) diagram of the same cycle is shown in Figure 2. Enthalpy refers to the amount of energy in the refrigerant, while entropy refers to the amount of energy given up or absorbed by the refrigerant as its temperature changes.

The various steps of the refrigeration cycle are labelled in Figure 1, for the case of liquid refrigerant subcooling of 10°F(5.6°C) and refrigerant gas superheating of 20°F (11.1°C). The useful cooling effect of the refrigeration cycle is the heat absorbed by the evaporating liquid refrigerant as represented by line C-D. The energy required to compress the superheated gas refrigerant, denoted as E-F, is the electrical energy demanded by the compressor. The energy released by the hot gas refrigerant as it condenses back into the liquid refrigerant ready to start the cycle again is represented by line F-B. The energy utilized by heat recovery units for heating process water is a portion of the energy released from F to B. The actual portion of the energy released from F to B that is recovered for heating water depends on the design, installation, and operation of the refrigeration/heat recovery system.

The effect of increasing the refrigerant liquid subcooling can be seen in Figure 1. As the subcooling increases, both lines A-B and C-D lengthen; line E-F does not change. Consequently, an increase in refrigerant subcooling will increase the useful refrigerating effect of the system without an increase in the energy input to the compressor. For the case of a fixed refrigerating load, then the energy input to the compressor would decrease as the refrigerant subcooling increases. Inspection of the P-h diagram will also indicate the effects of increasing the refrigerant gas superheat (line D-E) and/or the condensing pressure. There is a corresponding increase in the heat energy that is available (F-B) for recovery by the heat recovery unit for heating water. Unfortunately, the benefit of the additional heat energy available is more than offset by the increase in the electrical energy required by the compressor (line E-F). The condensing pressure should never be higher than rated conditions, even though one is able to recover more heat by running the system at an elevated condensing pressure. The disadvantages of high condensing pressures are an increase in the cost to operate the compressor and a decrease in the longevity of the compressor. The amount of refrigerant gas superheat (line D-E) can be minimized by insulating the refrigerant gas line form the evaporator to the compressor in order to reduce the load on the compressor.

Even though the condensing temperature in this example is 165°F (73.9°C), the hot gas refrigerant reaches a high temperature of 210°F (99°C) as it exits the compressor, as shown in the temperature-entropy diagram in Figure 2. All steps of the refrigerant cycle are labelled to correspond with the labels in Figure 1. It may be difficult to appreciate the magnitude of heat transfer that occurs in a heat recovery unit of a refrigeration system until one realizes that the refrigerant reaches a temperature considerably higher than the condensing temperature as shown in Figure 2.

Application

The two basic types of heat recovery units on the market today are: 1) desuperheaters; and 2) complete condensers. A desuperheater recovers the superheat (represented by line F-G in Figure 1) and perhaps a small portion of the latent heat of condensation line (G-A). The heat recovered is roughly the heat equivalent of the energy input to the compressor. Heat recovered is approximately one third of the total amount of heat discharged. A conventional condensing unit must be used along with the desuperheater heat recovery unit.

The complete condenser heat recovery unit is capable of recovering nearly 100% of the heat discharged from the refrigeration system (denoted as line F-B); therefore, the condensing unit is no longer necessary. It is advisable, however, to retain the condenser to serve as a back-up and to reduce water wastage. As pointed out by Koelsch (1979), the quantity and timing of the hot water produced by the complete condenser type heat recovery unit necessitates that approximately 40% of the heat recovered must be dumped. This loss of heat, either through warm water being discharged or through conductive and radiant heat losses, is necessary because of design restraints of the heat exchanger that limits the maximum temperature of water. The limit on the maximum temperature of water is to prevent the condensing pressure from rising excessively. One dairy observed by Koelsch was forced to dump one gallon of hot water for each three gallons of hot water utilized. The hot water from the heat recovery unit that must be discharged could be beneficially used for other operations on the dairy.

The value and performance of heat recovery units were evaluated on 18 dairy farms in New York by Koelsch (1979). He concluded that the heat recovery unit can eliminate a major portion of the energy cost for heating water on a dairy. Complete condensing units can eliminate 65 to 85% of water heating costs; while desuperheaters can eliminate about 50% of the energy required for heating water. A properly installed and operated heat recovery unit for recovering the refrigeration system's discharge heat represents an excellent financial investment for most dairy farmers today.

A study of the effectiveness of desuperheaters in California was conducted by Thompson and Fairbanks (1979). They also concluded that properly installed heat recovery units will greatly reduce the energy costs for water heating in dairies and are an excellent financial investment.

One additional benefit of installing a heat recovery unit is that the financial investment is currently recognized by the Internal Revenue Service as an effective energy conservation measure. Therefore, tax benefits are available to effectively decrease the required financial investment.

The use of solar energy for heating water on dairies has been researched for several years and some dairies have installed elaborate solar energy systems. The economics of solar energy systems vs. heat recovery systems for heating water on dairies has been evaluated by Stipanuk et al. (1979) for ten major dairy states. They concluded that solar systems, with an assumed 20 year life, did save money for those dairies currently heating water with electricity. However, the savings were always less than the savings resulting from using heat recovery units.

One note of extreme caution. The favorable results in the studies cited were all for heat recovery units that were properly installed and operated. One dairy in Florida was observed that was using a heat recovery unit. The system was installed so that there would always be "free" hot water. To achieve the "free" hot water supply, a manual pressure regulator was installed on the high pressure side of the compressor. The herdsman was instructed to increase the setting on the pressure regulator whenever he wasn't getting sufficient supply or temperature of hot water. By increasing the pressure, the herdsman was increasing the condensing pressure and temperature. Consequently, he would get more "free" hot water, BUT..... the increased energy required to operate the compressor at the higher condensing pressure more than offset the energy savings in the additional amount of hot water. Furthermore, operating the compressor at higher than rated conditions not only requires more electricity, but also decreases the service life of the compressor. The extra amount of "free" hot water was very expensive. When more hot water is needed than the heat recovery unit can supply, use a conventional water heater to complete the heating.

The herdsman should be advised to consult the manufacturer of the refrigeration system before installing and operating a heat recovery unit. It is good practice to obtain a letter from the manufacturer stating the conditions of the warranty on the refrigeration system.

In his report, Koelsch (1979) concluded that "heat recovery units for heating water from the refrigeration system's heat ought to be promoted as standard equipment for most dairy operations. The benefits to the dairyman should make this investment very worthwhile.

References

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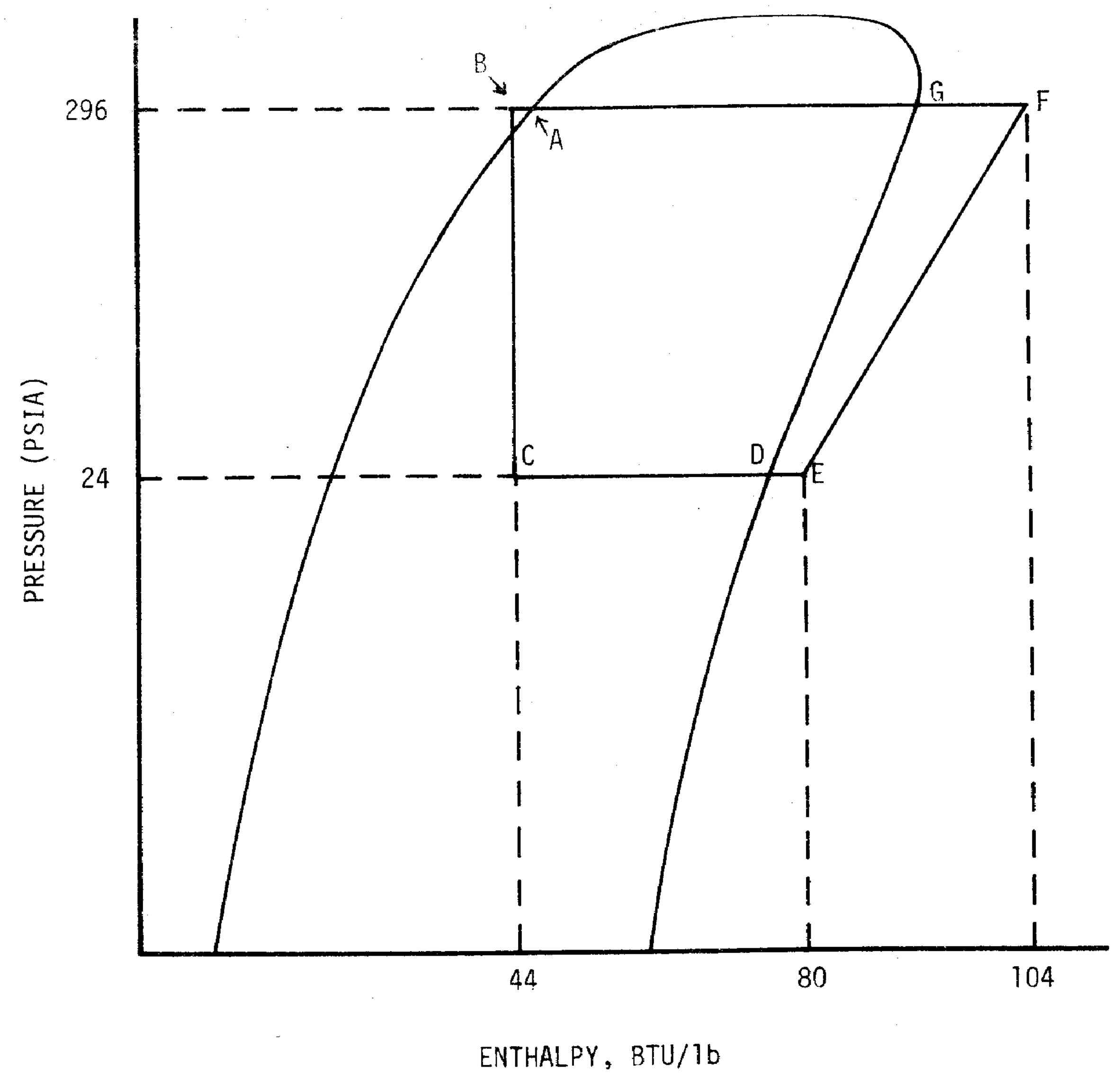


Figure 1. Pressure-Enthalpy (P-h) diagram for R-12.

STEPS OF
REFRIGERATION CYCLE

| | |
|---|---|
| A-B | Refrigerant Subcooling |
| B-C | Refrigerant Expansion |
| C-D | Refrigerant Evaporation<br>Useful Refrigerating Effect |
| D-E | Refrigerant Superheating |
| E-F | Refrigerant Compression<br>Energy Input Required |
| F-G | Superheat |
| G-A | Refrigerant Condensation |
| F-B | Heat Normally Rejected<br>By Condenser |

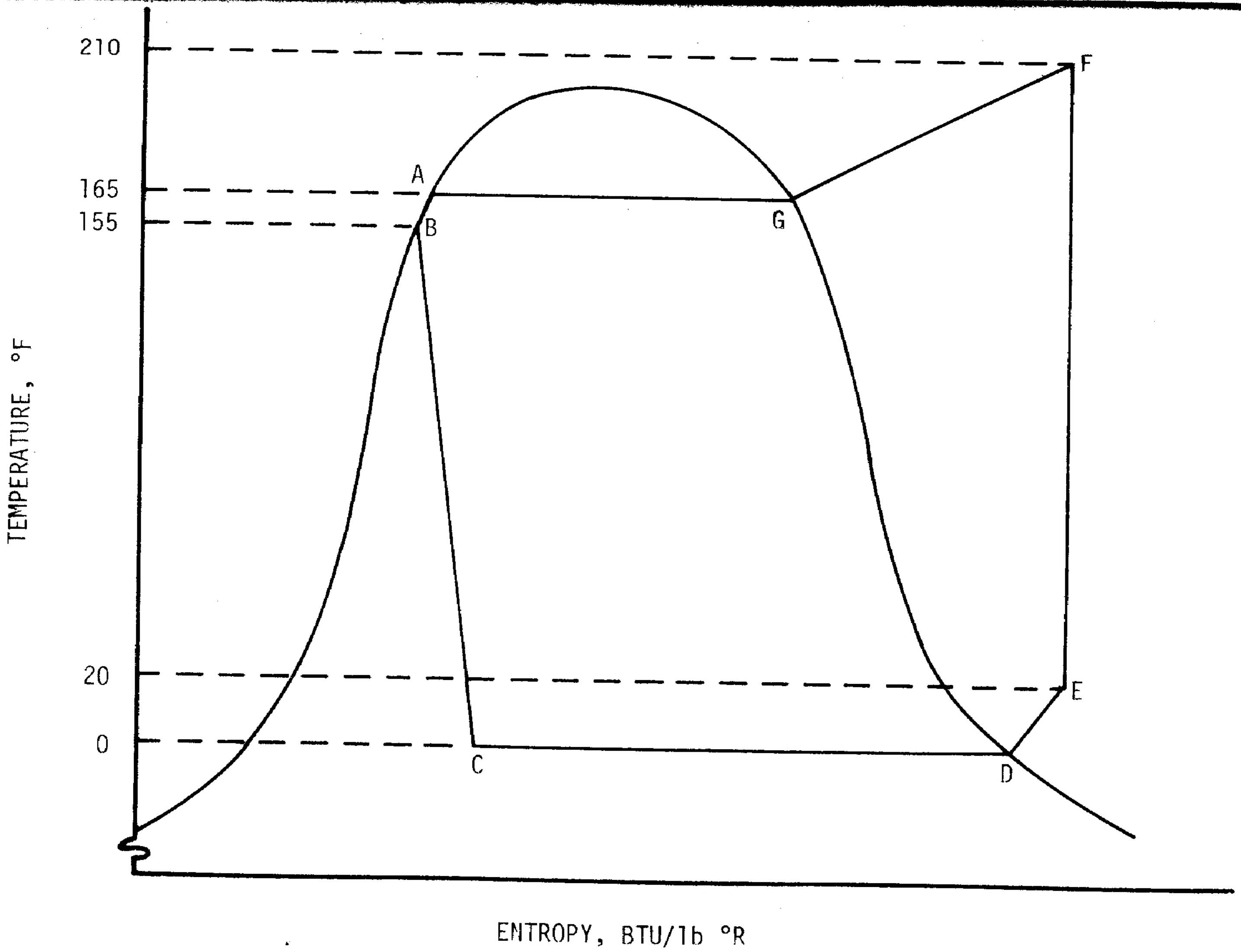


Figure 2. Temperature-Entropy (T-s) diagram for R-12.