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REFRIGERATION

Refrigeration Theory: Definitions and Basic Concepts, Refrigerants, Vapor Compression Refrigeration Cycles, Suction and Discharge Pressure Effect, Complex Refrigeration Cycles, Air Cycle, Steam Jet, Absorption System; Basic Refrigeration Equipment: Compression Machines and Controls, Condensers, Evaporators and Coolers, Refrigeration Control, Piping and Accessories; Equipment Characteristics and Selection

WITH the increasing use of all-year comfort air-conditioning installations, the importance of refrigeration to the air-conditioning engineer has been greatly magnified. The details of equipment operation, maintenance, and design remain problems for the refrigeration engineer, but the air-conditioning engineer does retain a responsibility to the customer which requires on his part some knowledge of the different refrigeration cycles and the relative merits of each. In order to assist in meeting this need, the present chapter has been divided into four parts, the first covering the fundamental technical relationships which govern the selection and analysis of an operating cycle, the next two presenting brief discussions of basic refrigerating equipment and auxiliaries, and the last, information on selection criteria.

REFRIGERATION THEORY

Definitions and Basic Concepts

The *ton of refrigeration* is a quantity unit which originated in the days when harvested ice was the principal source of summer cooling. By definition the *ton* is the cooling effect realized when one ton of 32°F ice melts to water at 32°F. Since the latent heat of fusion of ice is 144 Btu per pound, the *ton* represents a unit cooling effect of $144 \times 2,000 = 288,000$ Btu. In common practice the *ton* is usually considered a rate (rather than quantity) unit, and is taken as 288,000 Btu per day (24 hours), or 12,000 Btu per hour, or 200 Btu per minute. Thus for air-conditioning calculations, the size of the requisite refrigeration machine, expressed in tons, can be obtained by dividing the heat gain of the structure, expressed in Btu per hour, by 12,000. In equation form:

$$H_r = (\text{Btu per hour heat gain}) \div 12,000 \quad (1)$$

where

H_r = load in tons.

The *working substance*, or *refrigerant*, is the fluid which carries heat through the refrigeration cycle from the evaporator, where heat enters the refrigerant, to the condenser where the heat is discharged to some cooling medium. The great majority of modern refrigeration systems use a liquefiable vapor as the working substance. By altering the pressure of the refrigerant its boiling temperature is changed, allowing the material to *boil* in the evaporator at a temperature sufficiently lower than that of the conditioned space, to insure maintenance of an effective heat transfer rate from the space (or in some cases from a secondary cooling fluid such as brine or cold water) to the refrigerant. The vapor formed in the

evaporator is then raised in pressure (by a compressor, or by the absorber-generator combination of the absorption system) until its new boiling temperature exceeds the temperature of the available cooling medium. Under these conditions, heat transfer is established from the refrigerant vapor to the cooling medium with resultant condensation of the refrigerant. When condensed, the high-pressure liquid refrigerant is reduced in pressure and again allowed to *boil* in the evaporator.

In order to permit evaluation of the effectiveness with which any given cycle operates, some term is desirable that would be comparable to the term *efficiency* used for heat engines. In refrigeration the desired effect is heat extraction, and the cost of achieving this extraction is the amount of energy that must be supplied as shaft work. Thus the ratio of refrigerating effect to the heat equivalent of the compressor work is used as a measure of effectiveness, and is defined as the coefficient of performance.

If the desired effect is the rejection of heat through the condenser instead of heat extraction through the evaporator, the *refrigeration system* is then termed a *heat pump*. In this case the coefficient of performance is the ratio of the heat rejected from the condenser to the heat equivalent of the compressor work. The coefficient of performance for the heat pump is greater than that for a system operating as a refrigerating machine, because all mechanical shaft work required to operate the compressor is dissipated as useful heat through the condenser.

The Carnot cycle, an ideal, thermodynamically reversible cycle consisting of an adiabatic expansion and an isothermal expansion, followed by an adiabatic compression and an isothermal compression to form a closed cycle, may be shown to be a measure of the maximum possible conversion of heat energy into mechanical energy. In its reversed form it is a measure of the maximum performance possible for any refrigeration cycle operating either as a refrigerator or as a heat pump. Although it cannot be applied in an actual machine because of the impossibility of obtaining complete reversibility, it is, nevertheless, extremely valuable as a criterion of inherent limitations. The coefficient of performance (CP) of a reversed Carnot cycle system operating as a refrigeration system is

$$(CP) = \frac{T_c}{T_c - T_e} \quad (2)$$

where

T_c = evaporator temperature, Fahrenheit, absolute.
 T_e = condenser temperature, Fahrenheit, absolute.