

evaporator to the suction of the compressor. During passage through the compressor the energy added as shaft work goes entirely to increase the enthalpy of the refrigerant and the compression process, which is assumed to occur irreversibly and without external heat transfer, is characterized by constant entropy. Thus the state of the superheated vapor leaving the compressor can be determined from the tables of thermodynamic properties by noting the discharge pressure and fixing also the entropy of the saturated vapor at entrance to the compressor.

Superheated vapor from the compressor flows to the condenser where desuperheating and condensation take place. From the condenser the refrigerant flows to the expansion valve, undergoes a constant-enthalpy pressure reduction and returns to the evaporator where it again removes a quantity of undesired heat. When the evaporator is arranged to permit direct cooling of room air by the refrigerant, the system is said to be

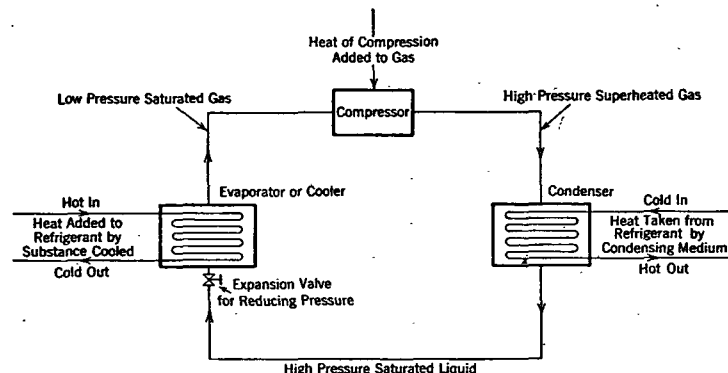


FIG. 1. MECHANICAL REFRIGERATION SYSTEM

of the *direct expansion* type, while a system in which the evaporating refrigerant cools water or brine, which in turn cools the air, is said to be *indirect*. Although many differences exist between most actual systems and that of the simple saturation cycle this latter is nonetheless of great value in that it provides an extremely simple method of rapidly achieving an approximate analysis of probable power requirements, compressor size, etc. Further, the equations used in analysis of a simple saturation cycle form the basis of the more complex treatments required for compound refrigeration cycles. For these reasons a typical simple saturation problem will be worked in detail.

**Example 1.** A simple saturation cycle carries a 7 ton load when operating between suction and discharge pressures of 52.7 psia and 121 psia with F-12 as the refrigerant. Determine: (a) the cooling effect provided by each pound of refrigerant, (b) the refrigerant circulating rate, (c) the horse power required, (d) the quantity of heat to be dissipated from the condenser, (e) the required condenser cooling water, in gallons per minute, if temperature rise of water passing through the condenser is 8 deg, (f) the bore and stroke of a double acting cylinder (neglecting the effect of the piston rod) if speed of compressor is 500 revolutions per minute.

**Solution.** (a) Saturated liquid F-12 at 121 psia leaves the condenser and enters the expansion valve. The enthalpy of this material (from Table 1) is 29.68 Btu per pound and this must also be its enthalpy at entrance to the evaporator. Leaving the evaporator as a saturated vapor at 52.7 psia, its enthalpy is 82.82 so the refrigerating effect must be  $82.82 - 29.68 = 53.14$  Btu per pound.

(b) The refrigerant circulating rate is equal to the total heat to be picked up in unit time divided by the pick-up per pound of refrigerant or,

$$W_r = (7 \text{ ton} \times 200) \div 53.14 = 26.3 \text{ lb per minute.}$$

(c) The horse power required is equal to the increase in energy of the refrigerant passing through the compressor (expressed in Btu per minute) divided by the conversion factor 42.42, which is the number of Btu per minute corresponding to 1 hp,

$$(\text{hp}) = W_r (h_d - h_{vs}) \div 42.42 \quad (5)$$

where

hp = horse power.

$W_r$  = refrigerant circulating rate in pounds per minute.

$h_d$  = specific enthalpy of vapor at condition of discharge from compressor.

$h_{vs}$  = specific enthalpy of saturated vapor entering compressor.

$W_r$  is known from (b) and  $h_{vs}$  is the enthalpy of refrigerant as it enters the compressor in a saturated vapor state at 52.7 psia; thus  $h_{vs} = 82.82$ .

In order to determine  $h_d$ , the state of the refrigerant must first be determined at the compressor discharge. At the known suction state the entropy (from Table 1 for saturated vapor at 52.7 psia) is 0.16828 and, since the compression is assumed to occur isentropically, it therefore follows that the discharge state must have the same entropy at 121 psia. From the table the entropy of vapor superheated 25 deg is 0.17330, so the superheat,  $t_{sd}$ , possessed by the actual gas discharged from this compressor can be obtained by interpolation as,

$$\frac{t_{sd}}{25} = \frac{0.16828 - 0.16608}{0.17330 - 0.16608}$$

from which  $t_{sd} = 7.6$  deg.

As the saturation temperature at 121 psia is 94 F the actual temperature,  $t_d$ , of the vapor leaving the compressor is,  $t_d = 94 + t_{sd} = 94 + 7.6 = 101.6$  F. By the same kind of interpolation the enthalpy of the discharged vapor can be determined from the enthalpies given for vapor superheated 25 F and for saturated vapor,

$$\frac{(h_d - 88.10)}{(92.16 - 88.10)} = \frac{(0.16828 - 0.16608)}{(0.17330 - 0.16608)}$$

from which,  $h_d = 89.34$  Btu per pound.

Then substituting into Equation 5,

$$(\text{hp}) = 26.3 (89.34 - 82.82) \div 42.42 = 4.03$$

(d) The rate of heat loss from the condenser,  $Q_c$ , must be equal to the sum of the energies picked up by the refrigerant in the evaporator and the compressor,

$Q_c = 53.14 + (89.34 - 82.82) = 53.14 + 6.52 = 59.66$  Btu per pound or  $26.3 \times 59.66 = 1569$  Btu per minute. This same figure can, of course, be determined more directly by subtraction of the enthalpy of liquid leaving the condenser from the enthalpy of superheated vapor going into it, thus,

$$Q_c = 26.3 (89.34 - 29.68) = 1569 \text{ Btu per minute.}$$

(e) The cooling water rate (based on a gallon as 8.34 lb) is  $1569 \div (8 \times 8.34) = 23.5$  gpm.

(f) The compressor size is fixed by the volume of gas which must be drawn into the machine per unit time. Saturated vapor at 52.7 psia has a specific volume, from Table 1, of 0.779 cu ft per pound, hence  $26.3 \times 0.779 = 20.49$  cu ft of gas must be handled. Assuming a volumetric efficiency of 90 per cent the compressor must then displace  $20.49 \div 0.9 = 22.8$  cu ft. The speed is given as 500 rpm and as the unit is known to be double-acting the displacement is therefore  $(22.8 \times 1728) \div (2 \times 500) = 39.4$  cu in. If the unit were designed so that bore,  $d$ , and stroke were the same,

$$(\pi d^3) \div 4 = 39.4$$

$$d = 3.69 \text{ in.}$$