

The most common and least complicated type of refrigeration cycle is called the simple saturation cycle, and is shown diagrammatically in Fig. 2 and plotted upon pressure-enthalpy coordinates in Fig. 3. For this system, saturated vapor flows without gain or loss of heat from the 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.

TABLE 3. PROPERTIES OF MONOFLUOROTRICHLOROMETHANE (F-11)

| SAT. TEMP.<br>°F | ABS. PRESS.<br>LB./SQ. IN. | VOLUME  |        | ENTHALPY AND ENTROPY TAKEN FROM -40 °F |       |         |        |                 |         |                 |         |
|------------------|----------------------------|---------|--------|----------------------------------------|-------|---------|--------|-----------------|---------|-----------------|---------|
|                  |                            | Liquid* | Vapor  | Enthalpy                               |       | Entropy |        | 25 °F Superheat |         | 50 °F Superheat |         |
|                  |                            |         |        | Liquid                                 | Vapor | Liquid  | Vapor  | Enthalpy        | Entropy | Enthalpy        | Entropy |
| 0                | 2.59                       | 0.01020 | 13.700 | 7.81                                   | 90.4  | 0.0178  | 0.1975 | 93.9            | 0.2049  | 97.4            | 0.2120  |
| 5                | 2.96                       | 0.01024 | 12.100 | 8.81                                   | 91.2  | 0.0200  | 0.1974 | 94.7            | 0.2047  | 98.2            | 0.2117  |
| 10               | 3.38                       | 0.01028 | 10.700 | 9.82                                   | 92.0  | 0.0222  | 0.1973 | 95.5            | 0.2045  | 99.0            | 0.2114  |
| 15               | 3.85                       | 0.01032 | 9.530  | 10.80                                  | 92.8  | 0.0243  | 0.1971 | 96.3            | 0.2043  | 99.8            | 0.2111  |
| 20               | 4.36                       | 0.01036 | 8.490  | 11.90                                  | 93.7  | 0.0264  | 0.1970 | 97.2            | 0.2041  | 100.7           | 0.2109  |
| 25               | 4.94                       | 0.01040 | 7.580  | 12.90                                  | 94.5  | 0.0286  | 0.1969 | 98.0            | 0.2039  | 101.5           | 0.2107  |
| 30               | 5.57                       | 0.01045 | 6.770  | 13.90                                  | 95.3  | 0.0307  | 0.1969 | 98.8            | 0.2038  | 102.3           | 0.2105  |
| 35               | 6.27                       | 0.01049 | 6.080  | 14.90                                  | 96.1  | 0.0328  | 0.1968 | 99.6            | 0.2037  | 103.1           | 0.2103  |
| 40               | 7.03                       | 0.01053 | 5.460  | 16.00                                  | 96.8  | 0.0349  | 0.1968 | 100.3           | 0.2036  | 103.8           | 0.2101  |
| 45               | 7.88                       | 0.01057 | 4.920  | 17.00                                  | 97.6  | 0.0370  | 0.1967 | 101.1           | 0.2035  | 104.6           | 0.2099  |
| 50               | 8.79                       | 0.01062 | 4.440  | 18.10                                  | 98.4  | 0.0391  | 0.1967 | 101.9           | 0.2034  | 105.4           | 0.2098  |
| 55               | 9.80                       | 0.01066 | 4.020  | 19.10                                  | 99.2  | 0.0412  | 0.1967 | 102.7           | 0.2033  | 106.2           | 0.2097  |
| 60               | 10.90                      | 0.01071 | 3.640  | 20.20                                  | 100.0 | 0.0432  | 0.1967 | 103.5           | 0.2033  | 107.0           | 0.2096  |
| 65               | 12.10                      | 0.01076 | 3.300  | 21.30                                  | 100.8 | 0.0453  | 0.1967 | 104.3           | 0.2032  | 107.8           | 0.2094  |
| 70               | 13.40                      | 0.01081 | 3.000  | 22.40                                  | 101.5 | 0.0473  | 0.1967 | 105.0           | 0.2032  | 108.5           | 0.2093  |
| 75               | 14.80                      | 0.01086 | 2.740  | 23.50                                  | 102.2 | 0.0493  | 0.1967 | 105.7           | 0.2031  | 109.2           | 0.2092  |
| 80               | 16.30                      | 0.01091 | 2.500  | 24.50                                  | 102.9 | 0.0513  | 0.1966 | 106.4           | 0.2030  | 109.9           | 0.2090  |
| 85               | 17.90                      | 0.01096 | 2.280  | 25.60                                  | 103.6 | 0.0533  | 0.1966 | 107.1           | 0.2029  | 110.6           | 0.2089  |
| 90               | 19.70                      | 0.01101 | 2.090  | 26.70                                  | 104.4 | 0.0553  | 0.1966 | 107.9           | 0.2028  | 111.4           | 0.2088  |
| 95               | 21.60                      | 0.01106 | 1.918  | 27.80                                  | 105.1 | 0.0573  | 0.1966 | 108.6           | 0.2028  | 112.1           | 0.2087  |
| 100              | 23.60                      | 0.01111 | 1.761  | 28.90                                  | 105.7 | 0.0593  | 0.1965 | 109.2           | 0.2027  | 112.7           | 0.2085  |
| 105              | 25.90                      | 0.01116 | 1.620  | 30.10                                  | 106.4 | 0.0613  | 0.1965 | 109.9           | 0.2026  | 113.4           | 0.2084  |

Superheated vapor from the compressor flows to the condenser where de-superheating 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 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 horsepower 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; (g) coefficient of performance.

**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,

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

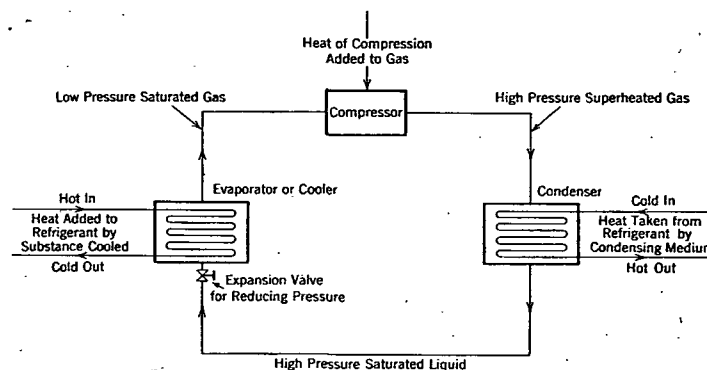


FIG. 2. MECHANICAL REFRIGERATION SYSTEM

(c) The horsepower 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,

$$(\text{hp}) = W_r (h_d - h_{s,s}) \div 42.42 \quad (7)$$

where

hp = horsepower.

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

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

$h_{s,s}$  = enthalpy of saturated vapor entering compressor.

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

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 0.16328 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