Coefficient of Performance

The coefficient of performance of a refrigeration system is the ratio of the refrigerating effect to the work of compression, both expressed in the same units.

The ideal or Carnot coefficient of performance depends upon the temperatures T_1 and T_2 in much the same way as the ideal efficiency of a steam engine depends upon its working temperature, with an inverse relationship.

$$\text{Ideal C. of P.} = \frac{T_1}{T_2 - T_1} \tag{5}$$

Evidently the smaller the compression range, the less power will be required to produce a given refrigerating effect.

The theoretical coefficient of performance of actual refrigerants is always less than the ideal due to the tendency of most refrigerants to superheat when compressed, and due to the heat of the liquid which must be removed. The cycle efficiency is the theoretical C. of P. divided by the ideal for the same temperatures. The cycle efficiency usually changes as the compression temperatures change.

TABLE 7. THEORETICAL COMPARISON OF VARIOUS REFRIGERANTS[1]

Refrigerant	Work per Lb Ft Lb	Equivalent Head Ft	Gas Temp. Leaving Comp. F	Refrig. Effect per Lb	Lb per Min per Ton	Coeff. of Perfor.	Cycle Eff. per cent
Ammonia	53,900	53,900	209	489.8	0.408	7.06	84.8
Carbon Dioxide[a]	9,940	9,940	146	64.0	3.125	5.00	46.9
Dichlorodifluoromethane (F_{12})	6,280	6,280	134	55.74	3.638	6.90	82.9
Methyl Chloride	16,500	16,500	183	156.9	1.275	7.38	88.8
Monofluorotrichloromethane (F_{11})	7,050	7,050	101	74.0	2.605	7.53	90.4
Water[b]	114,300	114,300	360	1010.8	0.181	6.85	82.3
Ideal (Carnot)						8.33	100.0

[1]Evap. Refrig. Temp. = 40 F. Suction Vapor Temp. = 65 F.
Cond. Refrig. Temp. = 100 F. Liquid Temp. = 98 F.
[a]Based on 1057 lb per sq in. (87 F) Condenser Pressure, and 85 F Liquid Temp.
[b]Based on 40 F Temp.

Comparative results of modified theoretical cycles of the refrigerants, are given in Table 7.

Practical Cycle

Fig. 3 illustrates the pressure-volume and temperature-entropy diagrams for an actual cycle. These diagrams are based upon the compressor receiving vapor superheated and upon sub-cooling of the liquid going to the evaporator. The theoretical cycle is $a_1b_1cc_1e_1a_1$. However, the vapor during compression actually follows line a_1b_2 due to superheating as a result of the inefficient work of compression. The theoretical work of compression is $a_1b_1cda_1$. Added to this is the area $b_2b_1g_1h_1b_2$ on the temperature-entropy diagram which represents the inefficient work of compression (assuming no compressor heat losses). The sum of these areas represents the total work of the compressor per pound of refrigerant, and

the ratio of theoretical cycle work to the actual work represents the overall efficiency. It should be noted that area $a_1b_2b_1a_1$ is considered as part of the inefficient work and is commonly termed the superheat loss. The refrigerating effect per pound is the same for the practical as for the theoretical cycle, working with the same sub-cooling of liquid and superheating of vapor, that is, area $e_1a_1g_1f_1e_1$.

Sources of loss which are usually recognized as reflected by the overall efficiency referring particularly to reciprocating and rotary systems, are as follows:

1. The superheat loss.
2. A pressure loss to and from the cylinder of the compressor.

(The line pressure drop between the compressor and the evaporator and condenser, respectively, is usually taken into account separately in the design of the refrigeration system.)

3. Leakage loss through valves and past pistons is quite small in most compressors.
4. With an oil soluble refrigerant, there may be an absorption loss due to absorption and re-evaporation of refrigerant in the oil of the cylinder.
5. Mechanical losses are always present and are usually a large part of the total.

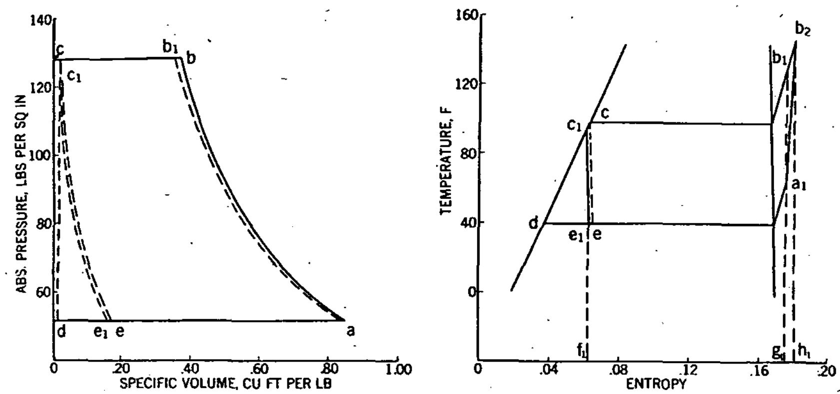

FIG. 3. PRACTICAL DICHLORODIFLUOROMETHANE (F_{12}) CYCLES

Reciprocating and rotary compressors always take in less vapor than that which corresponds to the displacement. The overall volumetric efficiency is the ratio of the suction vapor volume to the piston displacement. Part of this is the re-expansion volumetric efficiency which is the volume, at suction pressure, of the usefully re-expanded vapor which was in the clearance volume. This is expressed by the following equations:

$$\text{Volumetric Efficiency} = 1 - \frac{v_c}{v_d} \times \left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right] \tag{6}$$

where

v_c = clearance volume.
v_d = cylinder displacement volume.