THEORETICAL SINGLE-STAGE CYCLE USING A PURE REFRIGERANT OR AZEOTROPIC MIXTURE

A system designed to approach the ideal model shown in Figure 7 is desirable. A pure refrigerant or azeotropic mixture can be used to maintain constant temperature during phase changes by maintaining constant pressure. Because of concerns such as high initial cost and increased maintenance requirements, a practical machine has one compressor instead of two and the expander (engine or turbine) is replaced by a simple expansion valve, which throttles refrigerant from high to low pressure. Figure 8 shows the theoretical single-stage cycle used as a model for actual systems.

Applying the energy equation for a mass m of refrigerant yields

$$_4Q_1 = m(h_1 - h_4) \tag{39a}$$

$$_1W_2 = m(h_2 - h_1) \tag{39b}$$

$$_2Q_3 = m(h_2 - h_3) \tag{39c}$$

$$h_3 = h_4 \tag{39d}$$

Constant-enthalpy throttling assumes no heat transfer or change in potential or kinetic energy through the expansion valve.

The coefficient of performance is

$$\text{COP} = \frac{_4Q_1}{_1W_2} = \frac{h_1 - h_4}{h_2 - h_1} \tag{40}$$

The theoretical compressor displacement CD (at 100% volumetric efficiency) is

$$\text{CD} = \dot{m}v_1 \tag{41}$$

which is a measure of the physical size or speed of the compressor required to handle the prescribed refrigeration load.

Example 2. A theoretical single-stage cycle using R-134a as the refrigerant operates with a condensing temperature of 90°F and an evaporating temperature of 0°F. The system produces 15 tons of refrigeration. Determine the (a) thermodynamic property values at the four main state points of the cycle, (b) COP, (c) cycle refrigerating efficiency, and (d) rate of refrigerant flow.

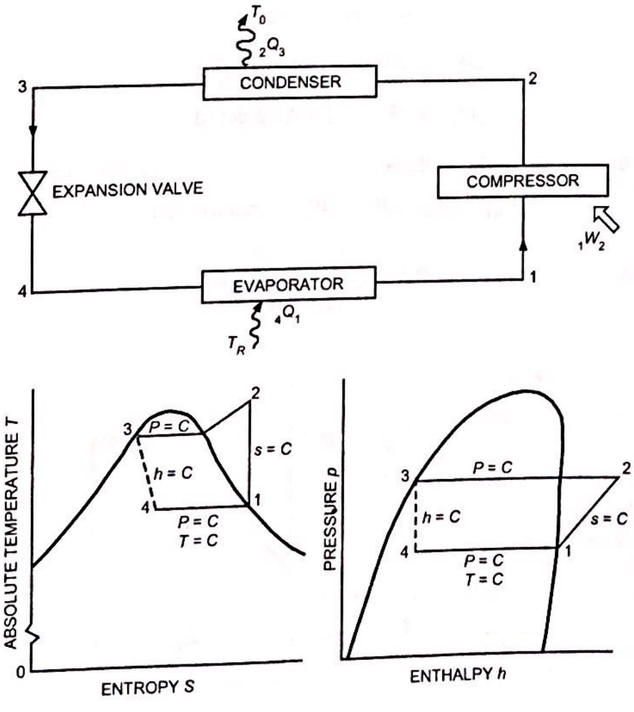

Fig. 8 Theoretical Single-Stage Vapor Compression Refrigeration Cycle

Solution:

(a) Figure 9 shows a schematic p-h diagram for the problem with numerical property data. Saturated vapor and saturated liquid properties for states 1 and 3 are obtained from the saturation table for R-134a in Chapter 30. Properties for superheated vapor at state 2 are obtained by linear interpolation of the superheat tables for R-134a in Chapter 30. Specific volume and specific entropy values for state 4 are obtained by determining the quality of the liquid-vapor mixture from the enthalpy.

$$x_4 = \frac{h_4 - h_f}{h_g - h_f} = \frac{41.645 - 12.207}{103.156 - 12.207} = 0.3237$$

$$v_4 = v_f + x_4(v_g - v_f) = 0.01185 + 0.3237(2.1579 - 0.01185)$$
$$= 0.7065 \text{ ft}^3/\text{lb}$$

$$s_4 = s_f + x_4(s_g - s_f) = 0.02771 + 0.3237(0.22557 - 0.02771)$$
$$= 0.09176 \text{ Btu/lb·°R}$$

The property data are tabulated in Table 1.

(b) By Equation (40),

$$\text{COP} = \frac{103.156 - 41.645}{118.61 - 103.156} = 3.98$$

(c) By Equations (17) and (38),

$$\eta_R = \frac{\text{COP}(T_3 - T_1)}{T_1} = \frac{(3.98)(90)}{459.6} = 0.78 \text{ or } 78\%$$

(d) The mass flow of refrigerant is obtained from an energy balance on the evaporator. Thus,

$$\dot{m}(h_1 - h_4) = \dot{Q}_i = 15 \text{ tons}$$

and

$$\dot{m} = \frac{(15 \text{ tons})(200 \text{ Btu/min·ton})}{(103.156 - 41.645)\text{Btu/lb}} = 48.8 \text{ lb/min}$$

Table 1 Thermodynamic Property Data for Example 2

State	t, °F	p, psia	v, ft³/lb	h, Btu/lb	s, Btu/lb·°R
1	0	21.171	2.1579	103.156	0.22557
2	104.3	119.01	0.4189	118.61	0.22557
3	90.0	119.01	0.0136	41.645	0.08565
4	0	21.171	0.7065	41.645	0.09176

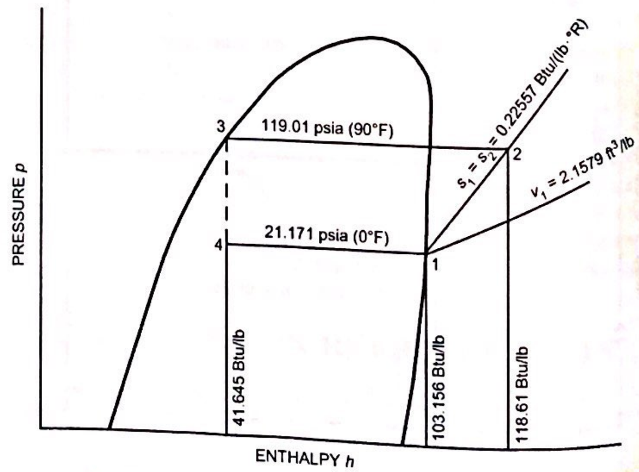

Fig. 9 Schematic p-h Diagram for Example 2