POSTAL Book Package 2021

Mechanical Engineering

Conventional Practice Sets

Refrigeration and Air Conditioning

Contents

MADE EASY Publications

3 CHAPTER Vapour Compression System

Practice Questions : Level-I

Q.1 A refrigerator based on ideal vapour compression cycle operates between the temperature limits of –20°C and 40°C. The refrigerant enters the condenser as saturated vapour and leaves as saturated liquid. The enthalpy and entropy values for saturated liquid and vapour at these temperatures are given in the table below.

T (°C)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kgK)	s_g (kJ/kgK)
–20	20	180	0.07	0.7366
40	80	200	0.3	0.67

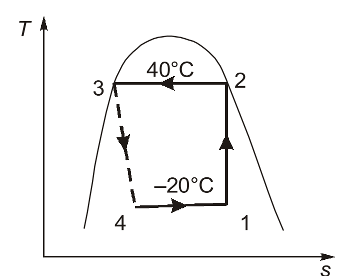
If refrigerant circulation rate is 0.025 kg/s, what is the refrigeration effect and COP of the refrigerator?

Solution:

$$m = 0.025 \text{ kg/s}$$

At $T_C = 40°C$

From given table, we get



$$h_2 = h_g = 200 \text{ kJ/kg}$$
$$s_2 = s_g = 0.67 \text{ kJ/kgK}$$
$$h_3 = h_f = 80 \text{ kJ/kg} = h_4$$

At $T_e = -20°C$

From given table, we get

$$s_f = 0.07 \text{ kJ/kgK},$$
$$s_g = 0.7366 \text{ kJ/kgK}$$
$$h_f = 20 \text{ kJ/kg},\ h_g = 180 \text{ kJ/kg}$$
$$s_1 = s_2 = s_f + x_1(s_g - s_f)$$
$$0.67 = 0.07 + x_1(0.7366 - 0.07)$$

or $x_1 = 0.9$

Specific enthalpy at point 1,

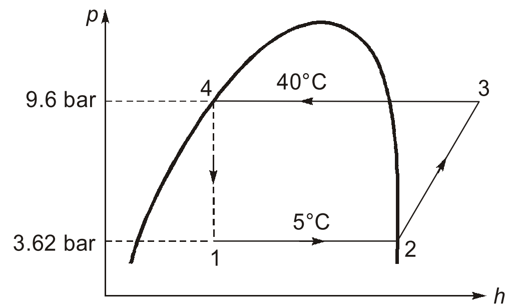
$$h_1 = h_f + x_1(h_g - h_f) = 20 + 0.9(180 - 20) = 164 \text{ kJ/kg}$$

Refrigeration effect, $RE = m(h_1 - h_4) = 0.025\,(164 - 80) = \mathbf{2.1\ kW}$

$$\text{COP} = \frac{\text{Refrigeration effect}}{\text{Work input}} = \frac{RE}{W} = \frac{2.1}{m(h_2 - h_1)} = \frac{2.1}{0.025(200 - 164)} = \mathbf{2.33}$$

Q.2 Two-cylinder reciprocating compressor is designed for 7.5 tons refrigeration capacity at 5°C evaporator and 40°C condenser temperatures. The clearance is 5% of stroke and mean piston speed is limited to 3 m/s. Take $\frac{L}{D} = 0.8$ and compression follows the law $pV^{1.15}$ = Constant. Pressure drops at suction and discharge valves may be taken as 0.2 bar and 0.4 bar, respectively. Determine rpm of the compressor and its dimensions.

Given: v_2 = 0.0525 m^3/kg, Mass flow rate = 0.207 kg/s



Solution:

$$P_s \text{(Suction pressure)} = 3.62 - 0.2 = 3.42 \text{ bar}$$
$$P_d \text{(Discharge pressure)} = 9.6 + 0.4 = 10 \text{ bar}$$

Now, Volumetric efficiency, $\eta_v = 1 - C\left[\left(\frac{p_d}{p_s}\right)^{1/n} - 1\right] = 1 - 0.05\left[\left(\frac{10}{3.42}\right)^{1/1.15} - 1\right] = 1 - 0.077 = 0.923 = 92.3\%$

Piston displacement per cylinder,

$$V_P = \frac{\pi}{4}D^2 L N \eta_v = \dot{m} \times v_2 \quad \text{...(i)}$$

where, $\dot{m}$ is the mass flow of refrigerant per cylinder per minute

$$\dot{m} \times v_2 = \left(\frac{0.207}{2} \times 60\right) \times 0.0525 = 0.326 \text{ m}^3\text{/min-cylinder}$$

From equation (i), we get

$$\therefore \quad \frac{\pi}{4}D^2 \times (0.8D) N \eta_v = 0.326 \quad \text{...(ii)}$$

Given: $2LN = 3 \times 60 = 180$ m/min

$$\therefore \quad 2 \times 0.8DN = 180$$

$$N = \frac{180}{1.6D} = \frac{112.5}{D} \quad \text{...(iii)}$$

From equations (2) and (3), we get

$$\frac{\pi}{4}D^2 \times 0.8D \times \frac{112.5}{D} \times 0.923 = 0.326$$

$$D^2 = \frac{0.326}{0.923 \times 112.5 \times 0.8} \times \frac{4}{\pi} = \frac{1}{200.132}$$

$$D = \frac{1}{14.1468} = 0.07068 \text{ m} = 7.068 \text{ cm}$$

$$N = \frac{112.5}{0.07068} = 1591.68 \text{ rpm}$$

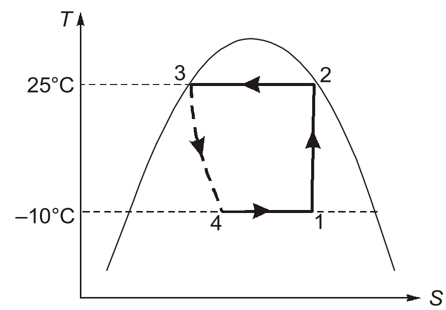
$$L = 0.8D = 0.8 \times 7.068 = 5.6544 \text{ cm}$$

Q.3 A vapour compression refrigerator works between pressure limits of 10 bar and 3 bar. The working fluid is dry at the end of compression and there is no undercooling before the expansion valve. If refrigerant flow rate is 10 kg/min, determine (i) COP and (ii) the capacity of the refrigerant. Table for properties of the refrigerant is as under:

Pressure bar	Saturation Temp. °C	Liquid heat (kJ/kg)	Latent heat (kJ/kg)	Liquid entropy (kJ/kgK)
10	25	298.90	1166.94	1.1242
3	–10	135.37	1297.68	0.5443

Solution:

Consider the vapour compression refrigeration cycle as shown in T-s diagram here



$$\text{Mass flow rate of refrigerant} = 10 \text{ kg/min}$$

$$\Rightarrow \quad \dot{m} = 0.167 \text{ kg/s}$$

For isentropic process 1-2, $s_1 = s_2 = s_{g_{25°C}}$

At constant pressure and temperature

$$T_{sat} = 25°C, \; p_{sat} = 10 \text{ bar}$$

As, $$s_{fg} = \frac{h_{fg}}{T_{sat}}$$

$$\Rightarrow \quad (s_g - s_f)_{25°C} = \frac{h_{fg_{25°C}}}{298}$$

$$\Rightarrow \quad s_{g_{25°C}} = s_{f_{25°C}} + \frac{h_{fg_{25°C}}}{298} = 1.1242 + \frac{1166.94}{298} = 5.04 \text{ kJ/kgK}$$

$$\therefore \quad s_1 = s_2 = s_{g_{25°C}} = 5.04 \text{ kJ/kgK}$$

$$\Rightarrow \quad s_f + x\, s_{fg} = 5.04$$

$$(s_f)_{-10} = 0.5443 \text{ kJ/kgK}$$

$$(h_{fg})_{-10} = 1297.68 \text{ kJ/kg}$$

$$\Rightarrow \quad (s_f)_{-10°C} + x\frac{(h_{fg})_{-10°C}}{263} = 5.04 \Rightarrow x = 0.91$$

$$\therefore \quad h_1 = (h_f)_{-10°C} + x(h_{fg})_{-10°C} = 1316.26 \text{ kJ/kg}$$

$$h_2 = h_{g_{25°C}} = h_{fg_{25°C}} + h_{f_{25°C}} = 1465.84 \text{ kJ/kg}$$

For isenthalpic process 3-4, $h_4 = h_3 = h_{f_{25°C}} = 298.9$ kJ/kg

$$\text{Refrigeration capacity} = \dot{m}(h_1 - h_4) = 0.167 \times (1316.26 - 298.9) = 169.9 \text{ kW}$$

$$\Rightarrow \quad Q_0 = \frac{169.9}{3.5167} \text{ TR} = 48.38 \text{ TR}$$

$$\text{Compressor work, } W = \dot{m}(h_2 - h_1) = 0.167 \times (1465.84 - 1316.26) = 24.98 \text{ kW}$$

$$\text{COP of system} = \frac{Q_0}{W} = \frac{169.9}{24.98} = 6.8$$

Q.4 A VCRS refrigerating machine using R-12 refrigerant produces 10 tonnes of refrigeration at 10°C when the ambient is at 35°C. A temperature difference of minimum 5°C is required at the evaporator and condenser for spontaneous heat transfer. The refrigerant is dry saturated at the outlet and to the inlet of compressor. The adiabatic efficiency of the compressor is 90%. The enthalpy at the end of isentropic compression is estimated to be 370 kJ/kg. Determine:

(i) COP, (ii) Power of the compressor, (iii) Capacity of the condenser

Represent the cycle on hand drawn T-s plane and show the refrigerating effect, compressor work and condenser capacity on the same.

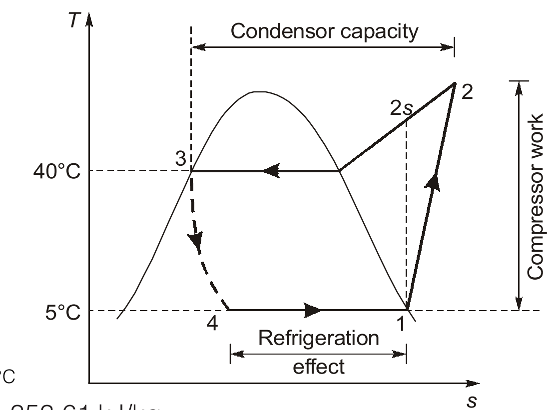
Temperature (°C)	Pressure (bar)	Specific Enthalpy, kJ/kg	
		Sensible	Evaporation
5	3.60	204.64	148.97
10	4.23	209.32	146.37
15	4.91	214.10	143.69
30	7.45	228.54	135.04
35	8.47	233.50	131.90
40	9.60	238.53	128.62

Solution:

Consider vapour compression refrigeration cycle as represented in figure.

Cycle operates between surroundings at 35°C and refrigerated space at 10°C. Since a minimum 5°C temperature difference is required for operation, evaporator and condenser temperatures are 5°C and 40°C, respectively.

Refrigeration effect, compressor work and condenser capacity are as depicted in figure.



$$h_1 = h_{g_{5°C}} = h_{f_{5°C}} + h_{fg_{5°C}}$$

$$h_1 = 204.64 + 148.97 = 353.61 \text{ kJ/kg}$$

$$h_{2s} = 370 \text{ kJ/kg}$$

$$\text{Adiabatic efficiency of compressor, } \eta = \frac{h_1 - h_{2s}}{h_1 - h_2} = 0.9$$

$$\Rightarrow \quad \frac{353.61 - 370}{353.61 - h_2} = 0.9$$

$$\Rightarrow \quad h_2 = 371.82 \text{ kJ/kg}$$

$$h_4 = h_3 = h_{f_{40°C}} = 238.53 \text{ kJ/kg} \quad \text{(Process 3-4 is isenthalpic)}$$

$$\text{Refrigeration effect, } Q_0 = h_1 - h_4 = 353.61 - 238.53 = 115.08 \text{ kJ/kg}$$

$$\therefore \quad \text{Mass flow rate of refrigerant} = \frac{Q_0}{h_1 - h_4} = \frac{10 \times 3.5167}{115.08} = 0.3056 \text{ kg/s}$$

$$\text{Power of compressor, } W = \dot{m}(h_2 - h_1) = 0.3056\,(371.82 - 352.61) = 5.565 \text{ kW}$$

$$\text{COP} = \frac{Q_0}{W} = \frac{10 \times 3.5167}{5.565} = 6.3193$$

$$\text{Capacity of condenser} = \dot{m}(h_2 - h_3) = 0.3056 \times (371.82 - 238.53) = 40.73 \text{ kW}$$

Q.5 A straight-charged thermostatic expansion valve (TEV) is designed to operate at an evaporator temperature of 7°C with a degree of superheat of 5°C. R-134*a* is the refrigerant used in the refrigeration system as well as the bulb.

Find:

(i) The required spring pressure at the design condition,

(ii) Assuming the spring pressure to remain constant, find the degree of superheat, if the same TEV operates at an evaporator temperature of –23°C.

The saturation temperature and corresponding pressure of R-134*a* are given in the following Table :

T_{sat}, °C	–23	–13	–12	–11	2	7	12	13
p_{sat}, kPa	116.39	177.92	185.24	192.8	314.62	374.63	443.01	457.76

Solution:

(i) Evaporator temperature is 7°C and 5°C superheat is need to maintain.

∴ Required spring pressure needed to maintain superheat is difference between saturated pressure at 12°C and 7°C

Required $p = 443.01 - 374.64 = 68.38$ kPa