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# Refrigeration & Air Conditioning

## MECHANICAL ENGINEERING

Date of Test : 01/07/2024

### ANSWER KEY >

- |        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 1. (b) | 7. (a)  | 13. (b) | 19. (b) | 25. (d) |
| 2. (d) | 8. (c)  | 14. (b) | 20. (b) | 26. (a) |
| 3. (d) | 9. (c)  | 15. (a) | 21. (a) | 27. (a) |
| 4. (a) | 10. (c) | 16. (b) | 22. (b) | 28. (d) |
| 5. (a) | 11. (c) | 17. (c) | 23. (d) | 29. (a) |
| 6. (b) | 12. (d) | 18. (a) | 24. (b) | 30. (b) |

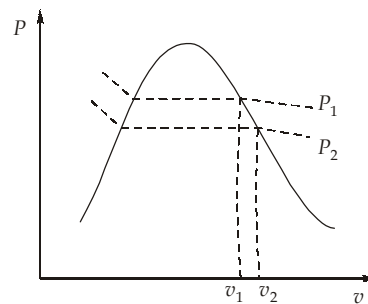
## DETAILED EXPLANATIONS

1. (b)

For the same condensing temperature and refrigerating capacity, a vapour compression refrigeration system operating at a low evaporator temperature is more expensive than a system operating at a higher evaporator temperature, because with decrease in evaporator temperature the refrigeration effect of the cycle decreases and specific volume of refrigerant at exit of evaporator increases. So volumetric refrigeration effect decreases. For the same refrigeration capacity if refrigeration effect decreases we have to increase mass flow rate of refrigerant so size of compressor increases.

2. (d)

As suction line pressure decreases, pressure ratio increases and increase in pressure ratio causes increase in discharge temperature. From, P-v diagram as saturation pressure decreases specific volume at suction increases.



4. (a)

- HRR is the ratio of heat rejected to the heat absorbed (refrigeration capacity).
- For a fixed condenser temperature, as the evaporator temperature decreases the COP decreases and HRR increases. For fixed evaporator temperature as condenser temperature increases the COP decreases hence the heat rejection ratio increases.
- At a given evaporator and condenser temperatures, the HRR of refrigeration systems using hermetic compressor is higher than that of open compressor system.

5. (a)

$$SHL = mc_p \Delta T$$

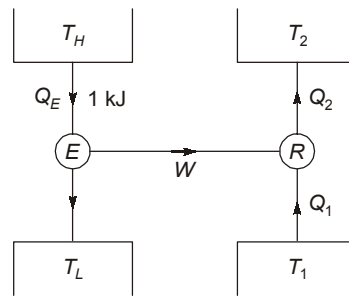
$$0.6 = \frac{(3 \times 10)}{3600} \times 1.2 \times 1 \times \Delta T$$

$$\Delta T = 60 \text{ K}$$

6. (b)

$$\text{Given: } \eta_E = 0.8 = \frac{W}{Q_E} = \frac{W}{1}$$

$$\Rightarrow W = 0.8 \text{ kJ}$$



$$\text{COP}|_R = \frac{Q_2 - W}{W} = 6$$

or  $Q_2 = 5.6 \text{ kJ}$

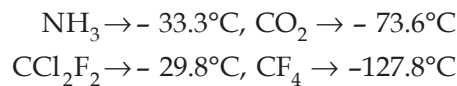
7. (a)

Absorption of ammonia in absorber lowers the pressure which helps to draw more ammonia.

8. (c)

For  $t_w = t_{\text{WBT}}$ , the sensible heat transfer from air to water is exactly equal to latent heat transfer from water to air. Hence no external cooling or heating of water is required.

9. (c)



10. (c)

$$\begin{aligned} \text{As } \text{RSHF} &= 0.75 = \frac{SH}{100} \\ \Rightarrow SH &= 75 \text{ kW} \\ \Rightarrow LH &= 100 - 75 = 25 \text{ kW} \\ \Rightarrow \text{As } RLH &= 50 \text{ cmm } \Delta\omega \\ \Rightarrow 25 &= 50 \times 100 \times (0.01 - \omega_2) \\ \Rightarrow \omega_2 &= 0.005 \text{ kg/kg dry air} \end{aligned}$$

11. (c)

$$\begin{aligned} \omega &= 0.622 \frac{p_v}{p_a} = 0.622 \frac{p_v}{p_t - p_v} \\ 0.0085 &= 0.622 \frac{p_v}{1.01325 - p_v} \\ \Rightarrow p_v &= 0.01366 \\ \phi &= \frac{0.01366}{0.0234} = 0.5837 \end{aligned}$$

12. (d)

$$\begin{aligned} \text{Density of water vapour, } \rho_{wv} &= \frac{P}{RT} = \frac{4.62 \times 10^3}{0.462 \times 10^3 \times 300} \\ \rho_{wv} &= 0.0333 \text{ kg/m}^3 \end{aligned}$$

$$\text{Now, density of dry air, } \rho_{da} = \frac{P_{da}}{RT} = \frac{(100 - 4.62) \times 10^3}{0.3 \times 10^3 \times 300} = 1.0597 \text{ kg/m}^3$$

$$\begin{aligned} \text{Density of atmospheric air, } \rho_{\text{atmospheric}} &= \rho_{da} + \rho_{wv} = 1.0597 + 0.0333 \\ \rho_{\text{atmospheric}} &= 1.093 \text{ kg/m}^3 \end{aligned}$$

13. (b)

$$m_{v_i} = \frac{P_{v_i} V}{R_V T}$$

$$R_V = \frac{8314}{18}$$

$$m_{v_i} = \frac{0.046368 \times 10^5 \times (8 \times 16)}{\frac{8314}{18} \times 311} = 4.1317 \text{ kg}$$

$$m_{v_f} = \frac{0.01227 \times 10^5 \times (8 \times 16) \times 18}{8314 \times 283} = 1.2015 \text{ kg}$$

$$\text{Amount of water vapour condensed} = m_{v_i} - m_{v_f} = 4.1317 - 1.2015$$

$$\therefore \text{Amount of water condensed} = 2.93 \text{ kg}$$

14. (b)

$$\begin{aligned} \text{COP} &= \frac{\text{Refrigeration Effect}}{W_{\text{compressor}} - W_{\text{turbine}}} = \frac{T_1 - T'_4}{(T'_2 - T_1) - (T_3 - T'_4)} \\ &= \frac{263 - 197}{(467 - 263) - (313 - 197)} = 0.75 \end{aligned}$$

15. (a)

- Air passing through silica gel - Chemical dehumidification
- Summer air conditioning - Cooling and Dehumidification
- Winter air conditioning - Heating and humidification
- Cooling tower - Adiabatic evaporative cooling

16. (b)

$$\text{DBT} = 35^\circ\text{C}$$

$$\text{Relative humidity: } \phi = 75\% = 0.75$$

$$\text{At } 35^\circ\text{C, } p_{vs} = 0.05628 \text{ bar}$$

$$\text{Relative humidity: } \phi = \frac{p_v}{p_{vs}}$$

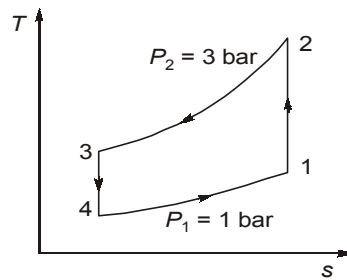
$$0.75 = \frac{p_v}{0.05628}$$

$$\text{or } p_v = 0.75 \times 0.05628 = 0.04221 \text{ bar}$$

$$\text{Specific humidity: } \omega = \frac{0.622 p_v}{p - p_v}$$

$$= \frac{0.622 \times 0.04221}{1.01325 - 0.04221} = 0.0270 \text{ kg/kg of dry air}$$

17. (c)



$$T_1 = 270 \text{ K}; P_1 = 1 \text{ atm}; P_2 = 3 \text{ atm}$$

$$\Rightarrow T_2 = T_1 \times \left[ \frac{P_2}{P_1} \right]^{\frac{\gamma-1}{\gamma}} = 270 \times (3)^{0.4/1.4} = 369.56 \text{ K}$$

$$\Rightarrow T_3 = 300 \text{ K}$$

$$\Rightarrow T_4 = \frac{T_3}{\left[ \frac{P_2}{P_1} \right]^{\frac{\gamma-1}{\gamma}}} = 300 / (3)^{0.4/1.4} = 219.18 \text{ K}$$

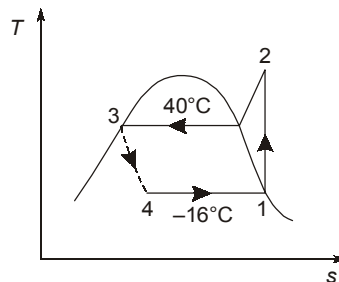
$$\text{Specific volume, } v_1 = \frac{RT_1}{P_1} = \frac{287 \times 270}{1.01 \times 10^5} = 0.767 \text{ m}^3/\text{kg}$$

$$\text{Mass flow rate, } \dot{m} = \frac{\dot{V}}{v_1} = \frac{1.5}{0.767} = 1.9556 \text{ kg/s}$$

$$\begin{aligned} \text{Net power input} &= \dot{m} c_p [(T_2 - T_1) - (T_3 - T_4)] \\ &= 1.9556 \times 1.005 [(369.56 - 270) - (300 - 219.18)] = 36.83 \text{ kW} \end{aligned}$$

18. (a)

Given data:  $h_1 = 389.02 \text{ kJ/kg}$



$$h_3 = 256.41 \text{ kJ/kg} = h_4$$

$$s_1 = 1.7379 \text{ kJ/kgK} = s_2$$

To calculate discharge temperature of compressor,

$$\Rightarrow s_2 = s_{g,40^\circ\text{C}} + c_p \ln \frac{T_2}{T_g} = s_1$$

$$\Rightarrow 1.711 + 1.145 \ln \frac{T_2}{313} = 1.7379$$

On solving,

$$\Rightarrow T_2 = 320.44 \text{ K}$$

Now,

$$\begin{aligned} h_2 &= h_{g@40^\circ\text{C}} + C_p [T_2 - T_3] \\ &= 419.43 + 1.145 [320.5 - 313] = 427.95 \text{ kJ/kg} \end{aligned}$$

Now,

$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{389.04 - 256.41}{427.95 - 389.04} = 3.41$$

19. (b)

$$P_a = 90 \text{ kPa}$$

$$P_s = 4.2469 \text{ kPa}$$

$$\phi = 0.75$$

$$V = 40 \text{ m}^3$$

$$P_v = \phi P_s = 0.75 \times 4.2469 = 3.185 \text{ kPa}$$

$$P_a = P - P_v = 90 - 3.185 = 86.815 \text{ kPa}$$

$$m_a = \frac{P_a V}{RT} = \frac{(86.815) \times 10^3 \times 40}{287 \times 303} = 39.93 \text{ kg}$$

20. (b)

$$(\text{COP})_A = (\text{COP})_B$$

$$\frac{T_L}{T - T_L} = \frac{T}{T_H - T}$$

$$T_L T_H - T_L T = T^2 - T_L T$$

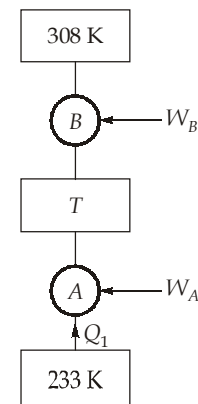
$$T^2 = T_L T_H$$

$$T = \sqrt{T_L T_H} = \sqrt{308 \times 233} = 267.88 \text{ K}$$

$$(\text{COP})_A = \frac{233}{267.88 - 233} = 6.68$$

$$W_A = \frac{Q_1}{(\text{COP})_A} = \frac{3}{6.68}$$

$$= 0.449 \text{ kJ/s} \approx 0.45 \text{ kJ/s}$$



21. (a)

For discharge temperature,  $s_1 = s_2 = s'_2 + c_{p_v} \ln\left(\frac{T_2}{T'_2}\right)$

$$1.72 = 1.7072 + 1.246 \ln\left(\frac{T_2}{273 + 50}\right)$$

$$T_2 = 326.33 \text{ K}$$

Enthalpy at discharge,  $h_2 = h'_2 + c_{p_v} (T_2 - T'_2)$

$$\begin{aligned} h_2 &= 423.4 + 1.246 (326.33 - 323) \\ &= 427.55 \text{ kJ/kg} \end{aligned}$$

Heat rejection in condenser,

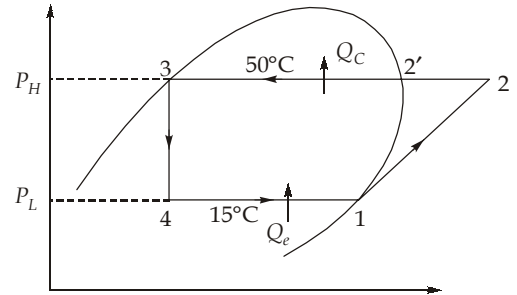
$$Q_C = \dot{m}(h_2 - h_3)$$

$$\frac{100000}{3600} = \dot{m}(427.55 - 271.62)$$

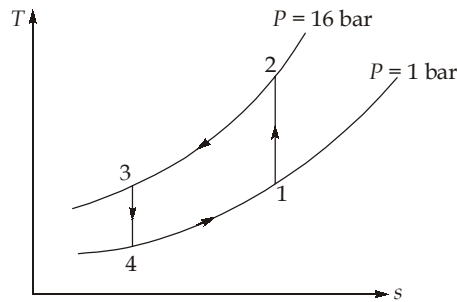
Mass flow rate of refrigerant,  $\dot{m} = 0.178 \text{ kg/s}$

Theoretical piston displacement of compressor,

$$\begin{aligned} \dot{V} &= \dot{m}v_1 = 0.178 \times 0.04185 \\ &= 7.455 \times 10^{-3} \text{ m}^3/\text{s} \end{aligned}$$



22. (b)



$$T_1 = -5^\circ\text{C} = 268 \text{ K}$$

$$T_3 = 30^\circ\text{C} = 303 \text{ K}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = (r_p)^{(\gamma-1)/\gamma} = (16)^{0.4/1.4} = 2.208$$

$$T_2 = 591.74 \text{ K}, T_4 = 137.22 \text{ K}$$

$$\begin{aligned} \text{Refrigeration effect} &= h_1 - h_4 = c_p (T_1 - T_4) \\ &= 1.005(268 - 137.22) \\ &= 131.43 \text{ kJ/kg} \end{aligned}$$

$$\text{Mass flow rate} = \frac{\text{Refrigeration capacity}}{\text{Refrigeration effect}} = \frac{33.5}{131.43} = 0.2548 \text{ kg/s}$$

$$\begin{aligned}\dot{V}_{\text{compressor}} &= \frac{mRT_1}{P_1} = \frac{0.2548 \times 0.287 \times 268}{100} \\ &= 0.196 \text{ m}^3/\text{s} = 11.76 \text{ m}^3/\text{min}\end{aligned}$$

23. (d)

$$\dot{Q}_L = 4 \text{ kW}$$

$$T_L = 24 + 273 = 297 \text{ K}$$

$$T_H = 35^\circ\text{C} = 35 + 273 = 308 \text{ K}$$

COP of carnot refrigerator

$$\text{COP} = \frac{T_L}{T_H - T_L} = \frac{297}{308 - 297} = 27$$

Lower limit of power input required

$$\text{COP} = \frac{\text{Desired effect}}{\text{Power input}}$$

$$\text{Power input} = \frac{4}{27} = 0.148 \approx 0.15 \text{ kW}$$

24. (b)

$$\text{BPF} = \frac{t_3 - t_2}{t_3 - t_1} = \frac{45 - 40}{45 - 20} = \frac{5}{25} = 0.20$$

25. (d)

Cooling capacity = 128 kW

$$m_a = 3 \text{ kg/s}$$

$$h_1 = 85 \text{ kJ/kg}$$

$$\omega_1 = 20 \text{ g/kg of d.a}$$

$$h_2 = 43 \text{ kJ/kg}$$

$$\omega_2 = 10 \text{ g/kg of d.a}$$

$$h_3 = \text{enthalpy of condensate leaving the coil?}$$

Inlet mass of water vapour

$$\begin{aligned}m_{v_1} &= m_a \times \omega_1 \\ &= 3 \times 20 \times 10^{-3} = 60 \times 10^{-3} \text{ kg}\end{aligned}$$

Outlet mass of water vapour

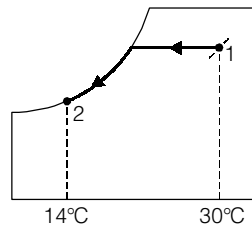
$$\begin{aligned}m_{v_2} &= m_a \times \omega_2 \\ &= 3 \times 10 \times 10^{-3} \\ &= 30 \times 10^{-3} \text{ kg}\end{aligned}$$

Required cooling capacity = Enthalpy of inlet air - Enthalpy of outlet air - Enthalpy of condensate water

$$\begin{aligned}\Rightarrow Q_c &= (m_a h_1 - m_a h_2) - m_v h_3 \\ \Rightarrow 128 &= 3[85 - 43] - 30 \times 10^{-3} \times h_3 \\ \Rightarrow h_3 &= 33.33 \text{ kJ/kg}\end{aligned}$$



28. (d)

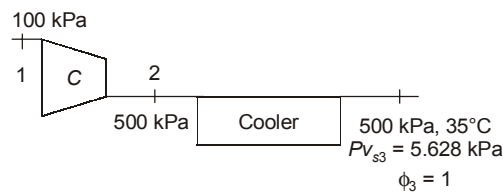


In this case, air is cooled and dehumidified by window a/c. It is a steady flow process where dry air quantity remains constant. Condensate removal takes place during the process. So, all three are applicable.

29. (a)

As the flash chamber reduces the mass flow of refrigerant through the evaporator, it helps in reduction of size of evaporator.

30. (b)



$$\phi_3 = \frac{Pv_3}{Pv_{s3}}$$

$$\therefore \phi_3 = 1 \Rightarrow Pv_3 = Pv_{s3} = 5.628 \text{ kPa}$$

$$Pv_2 = Pv_3 = 5.628 \text{ kPa}$$

$$Pt_2 = 5 \times Pt_1$$

$$\Rightarrow Pv_2 = 5 \times Pv_1$$

$$\Rightarrow Pv_1 = \frac{Pv_2}{5} = \frac{5.628}{5} = 1.1256 \text{ kPa}$$

