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THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 26/09/2022

ANSWER KEY >

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

DETAILED EXPLANATIONS

3. (b)

We know that the temperature at the two scales is related as

$$T(^{\circ}F) = 1.8T(^{\circ}C) + 32$$

∴ Using the condition,

$$T(^{\circ}F) = T(^{\circ}C) = T$$

$$\begin{aligned} \therefore T &= 1.8T + 32 \\ &= -0.8T = 32 \end{aligned}$$

$$\therefore T = -40^{\circ}C$$

5. (a)

Considering compression as a quasi-static polytropic process,

We have, $P_1V_1^n = P_2V_2^n$

Index of compression,

$$n = \frac{\ln(P_1/P_2)}{\ln(V_2/V_1)}$$

$$\therefore n = \frac{\ln(1/6)}{\ln(0.03/0.12)}$$

$$\therefore n = \frac{-1.7917}{-1.3863} = 1.292$$

6. (b)

For a reversible cycle,

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

$$\frac{W + Q_2}{Q_2} = \frac{T}{200}$$

$$\therefore \frac{40 + (1000/60)}{1000/60} = \frac{T}{200}$$

$$\Rightarrow T = 680 \text{ K}$$

8. (b)

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H} = \frac{\dot{W}_{\text{rev}}}{\dot{Q}_H}$$

$$\begin{aligned} \therefore \dot{W}_{\text{rev}} &= \left(1 - \frac{300}{1200}\right) \times 500 \\ &= 375 \text{ kW} \end{aligned}$$

Irreversibility rate

$$\dot{i} = \text{Reversible power} - \text{Useful power}$$

$$\therefore \dot{i} = 375 \text{ kW} - 180 \text{ kW}$$

$$\dot{i} = 195 \text{ kW}$$

10. (a)

$$\frac{W_x}{m} = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2 \times 1000}$$

$$\therefore \frac{W_x}{m} = (3230 - 2660) + \frac{160^2 - 100^2}{2 \times 1000}$$

$$\therefore \frac{W_x}{m} = 577.8 \text{ kJ/kg}$$

12. (a)

$$P_1 = 400 \text{ kPa,}$$

$$P_2 = 200 \text{ kPa,}$$

$$P_{\text{mix}} = 250 \text{ kPa}$$

$$N_1 = 3 \text{ Kmol,}$$

$$N_2 = 7 \text{ Kmol,}$$

$$M_{N_2} = 28 \text{ kg/Kmol}$$

$$M_{\text{CO}_2} = 44 \text{ kg/Kmol}$$

$$N_{\text{mix}} = N_1 + N_2 = 10 \text{ Kmol}$$

$$y_1 = \frac{N_1}{N_{\text{mix}}} = 0.3$$

$$y_2 = 0.7$$

$$\therefore P_{N_2} = y_1 \times P_{\text{mix}} = 0.3 \times 250 \text{ kPa} = 75 \text{ kPa}$$

13. (b)

For the work to be maximum, the final temperature should be the geometric mean of the bodies temperatures.

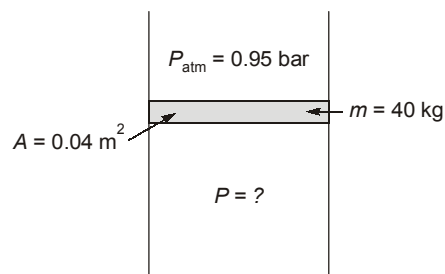
$$\begin{aligned} \therefore T_f &= \sqrt{T_1 T_2} \\ &= \sqrt{900 \times 400} ; \quad T_f = 600 \text{ K} \end{aligned}$$

15. (c)

Availability for a flow process,

$$\begin{aligned} &= (h_1 - h_2) - T_0(S_1 - S_2) \\ &= 300 - [300 \times (1.1 - 0.7)] \\ &= 300 - 120 \\ &= 180 \text{ kJ/kg} \end{aligned}$$

16. (c)



We have:

$$PA = P_{\text{atm}} A + W$$

$$P = P_{\text{atm}} + mg/A$$

$$P = 0.95 \text{ bar} + \frac{(40 \times 9.81)}{0.04 \times 10^5} \text{ bar}$$

$$\Rightarrow P = 1.0481 \text{ bar}$$

17. (a)

Given data:

$$\begin{aligned} V &= 1 \text{ m}^3 \\ T_1 &= 50^\circ\text{C} = 323 \text{ K} \\ p_1 &= 2 \text{ MPa} = 2000 \text{ kPa} \\ m_2 &= 0.5 m_1 \\ p_1 V &= m_1 R T_1 \\ 2000 \times 1 &= m_1 \times 0.287 \times 323 \end{aligned}$$

or

$$\begin{aligned} m_1 &= 21.57 \text{ kg} \\ m_2 &= 0.5 \times 21.57 = 10.78 \text{ kg} \\ m_e &= m_1 - m_2 = 21.57 - 10.78 = 10.78 \text{ kg} \end{aligned}$$

Applying unsteady flow energy equation,

$$\frac{dU}{dt} = m_i h_i + Q - m_e h_e - W_{cv}$$

where

$$\begin{aligned} Q &= 0 && \text{adiabatic process} \\ W_{cv} &= 0 && \text{constant volume} \\ m_i &= 0 && \text{no inlet} \end{aligned}$$

$$\frac{dU}{dt} = \frac{dm}{dt} \times h_e$$

$$c_v \left\{ T \frac{dm}{dt} + m \frac{dT}{dt} \right\} = \frac{dm}{dt} \times c_p \times T$$

$$T \frac{dm}{dt} + m \frac{dT}{dt} = \frac{dm}{dt} \times \gamma T$$

$$m \frac{dT}{dt} = \frac{dm}{dt} \times (\gamma - 1) T$$

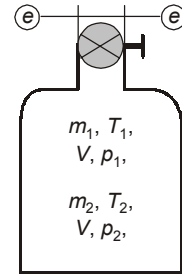
$$\int \frac{dT}{T} = \int \left(\frac{dm}{m} \right) \times (\gamma - 1)$$

$$\ln \frac{T_2}{T_1} = (\gamma - 1) \ln \frac{m_2}{m_1}$$

$$\ln \frac{T_2}{32.3} = 0.4 \ln \frac{1}{2}$$

$$T_2 = 244.788 \text{ K}$$

$$p_2 = \frac{m_2 R T_2}{V_2} = \frac{10.78 \times 0.287 \times 244.788}{1} = 757.339 \text{ kPa}$$



18. (b)

$$P \propto \frac{1}{V^2}$$

$$\therefore P_1 = \frac{k}{V_1^2}$$

$$\therefore P_1 V_1^2 = P_2 V_2^2$$

$$\Rightarrow 1000 \times 0.1^2 = 200 \times V_2^2$$

$$\begin{aligned} \therefore V_2 &= 0.223 \text{ m}^3 \\ \therefore W &= \int_1^2 P dv = \int_1^2 \frac{k}{V^2} dV = k \left[\frac{1}{V_1} - \frac{1}{V_2} \right] \\ &= P_1 V_1^2 \left[\frac{1}{V_1} - \frac{1}{V_2} \right] \\ &= 1000 \times 0.1^2 \left[\frac{1}{0.1} - \frac{1}{0.223} \right] \\ W &= 55.28 \text{ kJ} \end{aligned}$$

19. (b)

We know by 1st law of thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$

$$(40 - 8) = \Delta U + \frac{-500}{1000}$$

$$\therefore 32 = \Delta U - 0.5$$

$$\Delta U = 32.5$$

$$U_2 - U_1 = 32.5$$

$$U_2 - 10 = 32.5$$

$$\therefore U_2 = 32.5 + 10$$

$$\therefore U_2 = 42.5 \text{ kJ}$$

21. (b)

At triple point all the three phases exist in equilibrium.

\therefore Triple point pressure of liquid and solid X are same.

$$\therefore 12.14 - \frac{3000}{T} = 19.76 - \frac{3500}{T}$$

$$\therefore \text{on solving, } T = 65.61 \text{ K}$$

23. (a)

$$Tds = dH - Vdp$$

Reversible adiabatic, $Tds = 0$

$$dH = Vdp$$

$$h_1 + q = h_2 + W_{cv}$$

$$W_{cv} = h_1 - h_2$$

$$W_{cv} = -Vdp$$

$$P_1 = 0.5 \text{ MPa,}$$

$$V_1 = 0.2 \text{ m}^3$$

$$V_2 = 0.05 \text{ m}^3$$

$$PV^{1.3} = \text{Constant}$$

$$\Rightarrow P_2 = P_1 \left(\frac{V_1}{V_2} \right)^n$$

$$\Rightarrow P_2 = 0.5 \times \left(\frac{0.20}{0.05} \right)^{1.3} = 3.031 \text{ MPa}$$

$$V = \left(\frac{C}{P} \right)^{1/1.3}$$

$$\int_{H_1}^{H_2} dH = \int_{P_1}^{P_2} V dp$$

$$H_2 - H_1 = \frac{n[P_2V_2 - P_1V_1]}{n-1} = \frac{1.3[3031 \times 0.05 - 500 \times 0.2]}{1.3-1}$$

$$\Delta H = 223.3 \text{ kJ}$$

24. (d)

$$\begin{aligned} \dot{Q}_H &= \dot{W}_{\text{net}} + \dot{Q}_L \\ &= 6000 + 3500 \\ &= 9500 \text{ kJ/min} \end{aligned}$$

Also, $\dot{Q}_A + \dot{Q}_B = \dot{Q}_H$

$$\dot{Q}_A + \dot{Q}_B = 9500 \text{ kJ/min} \quad \dots(1)$$

Also, $\frac{\dot{Q}_A}{T_A} + \frac{\dot{Q}_B}{T_B} = \frac{3500}{200}$

$$\therefore \dot{Q}_A + 2\dot{Q}_B = 14000 \quad \dots(2)$$

Solving (1) and (2), $\dot{Q}_A = 5000 \text{ kJ/min}$

$$\dot{Q}_B = 4500 \text{ kJ/min}$$

27. (d)

$$\eta = 0.4$$

also $\eta = \frac{W}{Q_1}$

$$\therefore 0.4 = \frac{W}{Q_1}$$

or $W = 0.4 Q_1$

Applying energy balance equation for combined system,

$$\begin{aligned} Q_1 + Q_3 &= Q_2 + Q_4 \\ Q_1 + Q_3 &= 3Q_1 \quad \because Q_2 + Q_4 = 3Q_1 \quad (\text{given}) \end{aligned}$$

or $Q_3 = 2Q_1$

COP of the refrigerator,

$$(\text{COP})_R = \frac{Q_3}{W} = \frac{2Q_1}{0.4Q_1} = 5$$

28. (a)

- At critical point, latent heat of vaporization is zero.
- Triple point of water is 273.16 K.
- Normal boiling point of water is the temperature at which vapour pressure is equal to 760 mm Hg.
- The value of Joule's Thompson coefficient for an ideal gas is zero.

29. (c)

$$R_e = \frac{\Sigma mR}{\Sigma m}$$

$$\Rightarrow R_e = 0.77 \times \frac{8.314}{32} + 0.23 \times \frac{8.314}{28}$$

$$\Rightarrow R_e = 0.268 \text{ kJ/kgK}$$

$$[C_v]_e = \frac{R_e}{\gamma - 1} = \frac{0.268}{0.4} = 0.671 \text{ kJ/kg-K}$$

Constant volume process

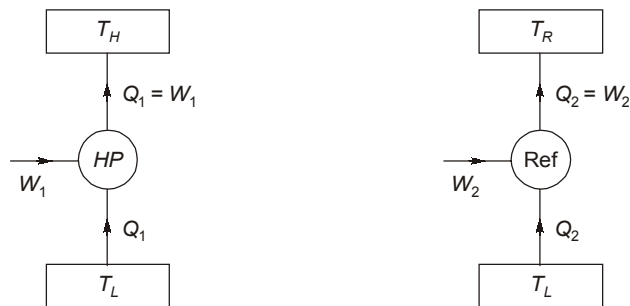
$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

$$\Rightarrow T_2 = 2T_1$$

$$\Rightarrow T_2 = 596 \text{ K}$$

$$\begin{aligned} \text{Heat supplied} &= m(C_v)_e \Delta T \\ &= 2 \times 0.671 \times 298 = 399.916 \text{ kJ} \\ &\simeq 400 \text{ kJ} \end{aligned}$$

30. (c)



For heat pump

$$\frac{T_H}{T_H - T_L} = 5$$

$$\Rightarrow T_H = 5(T_H - T_L)$$

$$\Rightarrow 4T_H = 5T_L$$

$$\Rightarrow T_H = \frac{5}{4}T_L$$

For refrigerator

$$\frac{T_L}{T_R - T_L} = 5$$

$$\Rightarrow T_L = 5(T_R - T_L)$$

$$\Rightarrow 5T_R = 6T_L$$

$$\Rightarrow T_R = \frac{\left(\frac{5}{4}\right)}{\left(\frac{6}{5}\right)} = \frac{25}{24}$$

