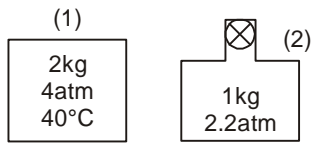


Answer Key

| | | | | |
|--------|---------|---------|---------|---------|
| 1. (a) | 9. (a) | 17. (c) | 25. (a) | 33. (d) |
| 2. (b) | 10. (d) | 18. (d) | 26. (c) | 34. (b) |
| 3. (d) | 11. (c) | 19. (b) | 27. (c) | 35. (c) |
| 4. (d) | 12. (a) | 20. (b) | 28. (b) | 36. (b) |
| 5. (b) | 13. (d) | 21. (a) | 29. (a) | 37. (b) |
| 6. (a) | 14. (d) | 22. (d) | 30. (d) | 38. (d) |
| 7. (c) | 15. (a) | 23. (a) | 31. (d) | 39. (b) |
| 8. (d) | 16. (d) | 24. (a) | 32. (b) | 40. (d) |

1. (a)



$$P_1 v_1 = m_1 R T_1$$

$$\Rightarrow 4 \times v = 2 \times R \times 313 \quad \dots(i)$$

$$P_2 v_2 = m_2 R T_2$$

$$\Rightarrow 2.2 \times v = 1 \times R \times T_2 \quad \dots(ii)$$

Dividing (i) by (ii)

$$\Rightarrow \frac{4}{2.2} = \frac{2 \times 313}{T_2}$$

$$T_2 = 344.3K$$

$$T_2 = 71^\circ C$$

2.(b)

$$P_1 = 600 \text{ kPa}$$

$$T_1 = 300K$$

$$v_1 = 0.5m^3$$

$$T_2 = 300K \text{ (Isothermal)}$$

$$v_2 = 0.1m^3$$

$$w = \int P dv$$

Isothermal process $PV = C, v = C/P$

$$w = \int_1^2 \frac{C}{v} dv = C \ln \frac{v_2}{v_1}$$

$$= P_1 v_1 \ln \left(\frac{v_2}{v_1} \right)$$

$$w = 600 \times 0.5 \times \ln \left(\frac{0.1}{0.5} \right)$$

$$= -482.83 \text{ kJ}$$

(-)ve sign indicates work in done on the system

3.(d)

From 1st law of thermodynamic

$$\delta Q - \delta W = dU$$

$$\Rightarrow tx[0.8 - (-0.12)] = mC_v(\Delta T)$$

$$\Rightarrow 30 \times 60 \times 0.92 = 60 \times 0.718 \times (T - 25)$$

$$T = 63.44^\circ C$$

4.(d)

$$\delta Q - \delta W = dU$$

(Since internal energy for air (ideal gas) is function of temperature alone).

$$\therefore \delta Q = \delta W$$

$$\Rightarrow \delta Q = 250 + 120 + 1800 + 50$$

$$\delta Q = 2220 \text{ W} = 2220 \text{ kJ/s}$$

$$\delta Q = 2220 \times \frac{3600}{1000}$$

$$\delta Q = 7992 \text{ kJ/h}$$

5.(b) $(\delta W = 0) (v = c)$

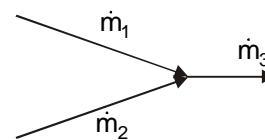
6. (a)

Conservation of mass

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\Rightarrow 4 + 3 = \dot{m}_3$$

$$\dot{m}_3 = 7 \text{ kg/min}$$



Conservation of energy

$$\dot{m}_3 T_3 = \dot{m}_1 T_1 + \dot{m}_2 T_2$$

$$\Rightarrow T_3 = \frac{(4 \times 7) + (3 \times 70)}{7}$$

$$T_3 = 34^\circ C$$

7. (c)

From Refrigerant -134 (a) - Temperature table

at 0.14 MPa, Sat. vapour state, $h_1 = 239.16 \text{ kJ/kg}$

at 0.9 MPa, $60^\circ C$, $h_2 = 295.13 \text{ kJ/kg}$

From steady flow energy equations

$$\dot{m}h_1 + \dot{Q} = \dot{m}h_2 + \dot{w}$$

$$\Rightarrow 0.108(239.16) - 1.1 = 0.108(295.13) + \dot{w}$$

$$\dot{w} = -7.14476 \text{ kW}$$

(-)ve sign implies compression

8.(d)

From R-134 (a) - Temperature Table

at 1.6 MPa $\Rightarrow T_{\text{sat}} \Rightarrow T_H = 57.88^\circ C = 330.88K$

at 0.2 MPa $\Rightarrow T_{\text{sat}} \Rightarrow T_L = -10.09^\circ C = 262.91K$

$$(\text{COP})_{\max} = \frac{T_L}{T_H - T_L} = \frac{262.91}{330.88 - 262.91}$$

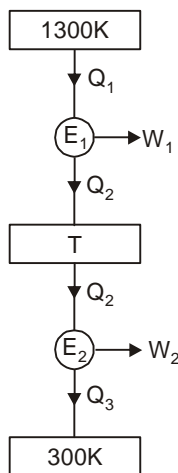
$$= 3.868$$

$$(\text{COP})_{\max} = \frac{(\text{Heat removed})_{\max}}{\text{Power input}}$$

$$\Rightarrow 3.868 = \frac{Q_{\max}}{3}$$

$$Q_{\max} = 11.6 \text{ kW}$$

9.(a)



Let the intermediate temperature be T.

$\eta_I \rightarrow$ efficiency of first engine.

$$\eta_I = 1 - \frac{T}{1300}$$

$$\eta_{II} = 1 - \frac{300}{T}$$

$$\eta_I = \eta_{II}$$

$$\Rightarrow 1 - \frac{T}{1300} = 1 - \frac{300}{T}$$

$$\Rightarrow T = \sqrt{1300 \times 300}$$

$$T = 624.5 \text{ K}$$

10. (d)

Maximum power output is obtained when gas expands isentropically.

For ideal gas

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_2}{(750 + 273)} = \left(\frac{0.2}{3} \right)^{\frac{0.667}{1.667}}$$

$$T_2 = 346.176 \text{ K}$$

$$T_2 = 73.176^\circ \text{C}$$

Power output,

$$\dot{w} = \dot{m} C_p (T_1 - T_2)$$

$$= 5 \times 0.52 \times (750 - 73.176)$$

$$\dot{w} = 1759.7 \text{ kW}$$

$$\dot{w} = 1.76 \text{ MW}$$

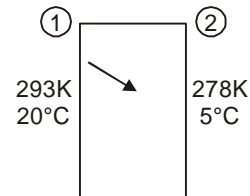
11. (c)

$$\therefore ds = C_p \ln \left(\frac{T_f}{T_i} \right) - R \ln \left(\frac{P_f}{P_i} \right)$$

as $T_2 = T_1$

$$\Delta s = -R \ln \left(\frac{P_2}{P_1} \right) = R \ln \left(\frac{P_1}{P_2} \right)$$

12. (a)



Entropy Balance

$$\dot{S}_1 + \dot{S}_{\text{gen}} = \dot{S}_2$$

$$\dot{S}_{\text{gen}} = \dot{S}_2 - \dot{S}_1 = \frac{Q}{T_2} - \frac{Q}{T_1}$$

$$= Q \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$\dot{S}_{\text{gen}} = 600 \left[\frac{1}{278} - \frac{1}{293} \right]$$

$$= 0.11 \text{ W/K}$$

13. (d)

For reversible adiabatic process of ideal gas.

$$\frac{T_{2s}}{T_1} = \left(\frac{P_{2s}}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\left(\gamma = 1.667 \rightarrow \text{for argon gas} \right)$$

$$C_p = 0.52 \text{ kJ/kgK}$$

$$\frac{T_{2s}}{600 + 273} = \left(\frac{80}{800} \right)^{\frac{0.667}{1.667}}$$

$$T_{2s} = 347.451 \text{ K}$$

Isentropic work produced = $\dot{m} C_p (T_1 - T_{2s})$

$$= 2.5 \times 0.52 \times (873 - 347.451)$$

$$= 683.213 \text{ kW}$$

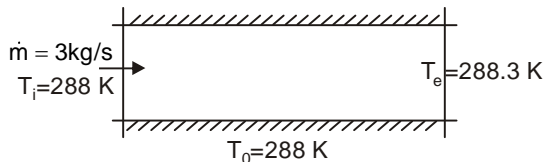
$$\begin{aligned} \text{Actual work produced} &= \eta_{\text{isentropic}} \times W_{\text{isentropic}} \\ &= 0.88 \times 683.213 \\ &= 601.227 \text{ kW} \end{aligned}$$

14. (d)

$$\begin{aligned} \text{Minimum power input} &= \dot{m}RT \ln\left(\frac{P_i}{P_f}\right) \\ &= 0.12 \times 0.287 \times (273 + 15) \ln\left(\frac{100}{700}\right) \\ &= -19.3 \text{ kW} \end{aligned}$$

(-)ve sign indicates power input to compressor

15. (a)



From entropy balance,

$$\begin{aligned} \dot{m}(s_i - s_e) + \dot{S}_{\text{gen}} &= \frac{dS_{\text{cv}}}{dt} \\ \dot{S}_{\text{gen}} &= \dot{m}(s_e - s_i) \\ &= \dot{m}c \ln \frac{T_e}{T_i} = 3 \times 4.2 \ln \frac{288.3}{288} \\ &= 0.013 \text{ kW/K} \end{aligned}$$

Rate of exergy destruction is pipe,

$$\begin{aligned} \dot{i} &= T_0 \dot{S}_{\text{gen}} = 288 \times 0.013 \\ &= 3.8 \text{ kW} \end{aligned}$$

16. (d)

Maximum amount of electric power generated/exergy

$$\begin{aligned} &= mgh \\ &= 100 \times 10^3 \times 9.8 \times 60 \\ &= 58,800 \text{ kW} \end{aligned}$$

17. (c)

18. (d)

$$\begin{aligned} H &= U + PV \\ dH &= dU + PdV + v dP \\ \therefore dH &= TdS + vdP \\ [\because \text{for a closed and reversible process, } TdS &= \delta Q = dU + PdV] \end{aligned}$$

19. (b)

20. (b)

21. (a)

For isothermal process,

$$PV = \text{constant} = C$$

$$\Rightarrow P = \frac{C}{V} \Rightarrow \frac{dP}{dV} = \frac{-C}{V^2}$$

$$\Rightarrow \frac{dP}{dV} = \frac{-PV}{V^2} = \frac{-P}{V}$$

22. (d)

°N °C

| | | |
|----------------|-----|-----|
| Boiling point | 400 | 100 |
| Freezing point | 100 | 0 |

Let the reading on new scale corresponding to 60°C be x, then

$$\therefore \frac{60-0}{x-100} = \frac{100-0}{400-100} = \frac{100}{300} = \frac{1}{3}$$

$$\Rightarrow x - 100 = 180$$

$$\Rightarrow x = 280^\circ\text{N}$$

23. (a)

At steady state, the internal energy of the resistor and hence its temperature is constant. So, by first law,

$$\dot{W} = \dot{Q}$$

The flow of current represents work transfer. At steady state the work is dissipated isothermally into heat transfer to the surroundings. Since the surroundings absorb Q unit of heat at temperature T,

$$\dot{\Delta S}_{\text{surr}} = \frac{\dot{Q}}{T} = \frac{\dot{W}}{T}$$

At steady state,

$$\dot{\Delta S}_{\text{sys}} = 0$$

$$\therefore \dot{\Delta S}_{\text{univ}} = \dot{\Delta S}_{\text{sys}} + \dot{\Delta S}_{\text{surr}} = \frac{\dot{W}}{T}$$

Here, T = 300 K

$$\dot{Q} = i^2 R t = 0.5^2 \times 100 \times 1800$$

$$\dot{\Delta S}_{\text{surr}} = \frac{\dot{Q}}{T} = \frac{\dot{W}}{T}$$

$$= \frac{0.5^2 \times 100 \times 1800}{300} = 150 \text{ J}$$

$$\begin{aligned}\therefore \dot{\Delta S}_{\text{univ}} &= \dot{\Delta S}_{\text{sys}} + \dot{\Delta S}_{\text{surr}} \\ &= 0 + 150 = 150 \text{ J/K}\end{aligned}$$

24. (a)

$$\Delta S_{\text{sys}} = 100 \times (0.35 - 0.30) = 5 \text{ kJ/K}$$

$$\Delta S_{\text{surr}} = 75 - 80 = -5 \text{ kJ/K}$$

$$\therefore \Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} = 5 - 5 = 0$$

Hence, this is reversible process.

25. (a)

Actual dryness fraction $x = (x_1)(x_2)$

where x_1 = dryness fraction of steam in separating calorimeter = 0.9

and, x_2 = dryness fraction of steam entering throttling calorimeter = 0.95

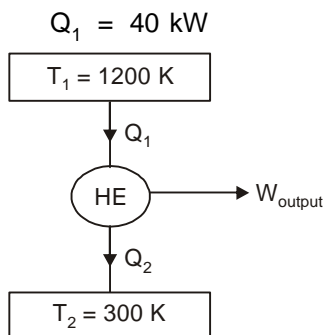
$$\therefore x = 0.9 \times 0.95 = 0.855$$

26. (c)

Work transfer in free expansion is zero, because in free expansion, the pressure against which the gas expands is zero.

Hence, work = $P\delta V = 0$.

27. (c)



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

$$\begin{aligned}\Rightarrow Q_2 &= \frac{T_2}{T_1} \times Q_1 \\ &= \frac{300}{1200} \times 40 = 10 \text{ kW}\end{aligned}$$

28. (b)

$$s_f = 2.6 \text{ kJ/kJK}$$

$$h_{fg} = 1800 \text{ kJ/kg}$$

$\therefore s_g$ (entropy of saturated vapour)

$$= s_f + \frac{h_{fg}}{T} = 2.6 + \frac{1800}{500} = 6.2 \text{ kJ/kgK}$$

29. (a)

Earlier, temperature $T_1 = 27^\circ\text{C} = 300 \text{ K}$

Pressure $p_1 = 2 \text{ bar}$

Volume $V_1 = 30 \text{ litres}$

Assuming the volume to remain constant at temperature $T_2 = -3^\circ\text{C} = 270 \text{ K}$

$$\text{Hence, } \frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\Rightarrow \frac{2}{300} = \frac{p_2}{270}$$

$$\Rightarrow p_2 = 1.8 \text{ bar}$$

30. (d)

$$\text{Efficiency} = \frac{\text{net work done}}{\text{heat input}}$$

$$= \frac{\text{area enclosed in T-S diagram}}{\text{heat input}}$$

$$= \frac{\frac{1}{2} \times (5-1) \times (800-400)}{800 \times (5-1)} = 0.25$$

31. (d)

Since the chamber is rigid, so volume is constant,

Hence work done $\delta W = 0$

The chamber is insulated,

So, $\delta Q = 0$

From first law of thermodynamics,

$$\delta Q = dU + \delta W$$

$$\Rightarrow dU = 0$$

32. (b)

$$\begin{aligned}\text{Unavailable work} &= Q_1 \times \frac{T_2}{T_1} = \frac{400 \times 300}{800} \\ &= 150 \text{ kJ}\end{aligned}$$

33. (d)

For A-B, $V \propto T$

$$\Rightarrow P = \text{constant}$$

For B-C, $V = \text{constant}$

For C-A, $T = \text{constant}$

$$\Rightarrow PV = \text{constant}$$

34. (b)

$$\eta = \frac{\text{net work done}}{\text{heat input}}$$

$$= \frac{\frac{1}{2} \times (T_h - T_c) \times (s_2 - s_1)}{T_h (s_2 - s_1)} = \frac{0.5(T_h - T_c)}{T_h}$$

35. (c)

Absolute pressure = Gauge pressure + Atmospheric pressure

$$\text{or Absolute pressure} = 25 + 1.03 = 26.03 \text{ bar}$$

36. (b)

$$\text{Initial value } V_1 = 0.03 \text{ m}^3$$

$$\text{Final volume } V_2 = 0.06 \text{ m}^3$$

$$\text{Constant pressure } P = 1 \text{ MPa} = 10^6 \text{ Pa}$$

∴ Work done

$$\begin{aligned} W &= P(V_2 - V_1) \\ &= 10^6 \times (0.06 - 0.03) \\ &= 30 \text{ kJ} \end{aligned}$$

$$\text{Heat absorbed } Q = 84 \text{ kJ}$$

According to first law of thermodynamics,

$$Q = \Delta U + W$$

$$\Rightarrow 84 = \Delta U + 30$$

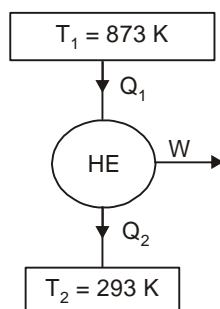
$$\Rightarrow \Delta U = 84 - 30 = 54 \text{ kJ}$$

∴ Change in internal energy

$$\Delta U = 54 \text{ kJ}$$

37. (b)

$$\text{Maximum efficiency } \eta = 1 - \frac{T_2}{T_1}$$



$$1 - \frac{293}{873} = \frac{W}{Q_1} = \frac{1}{Q_1}$$

$$\Rightarrow \frac{873 - 293}{873} = \frac{1}{Q_1}$$

$$\Rightarrow Q_1 = \frac{873}{580} = 1.505 \text{ kW}$$

$$\therefore \text{Heat rejection } Q_2 = Q_1 - W$$

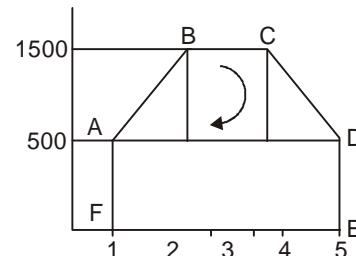
$$= 1.505 - 1$$

$$= 0.505 \text{ kW}$$

38. (d)

Entropy represents the degree of randomness. Increase in entropy means degradation of energy or decrease in available energy.

39. (b)



Work done, $W = \text{area of ABCD}$

$$= \frac{1}{2} \times (BC + AD) \times 1000$$

$$= \frac{1}{2} \times (2 + 4) \times 1000 = 3000 \text{ kJ}$$

Heat rejected, $Q = \text{area of ADEF}$

$$= AD \times AF = 4 \times 500 = 2000 \text{ kJ}$$

$$\therefore \text{Efficiency} = \frac{W}{W + Q}$$

$$= \frac{3000}{3000 + 2000} = 0.60$$

40. (d)

For an isothermal process, change in internal energy $\Delta U = 0$

From first law of thermodynamics,

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

∴ For isothermal process,

$$W = \Delta Q = 100 \text{ kW}$$