CLASS TEST

S.No. : 01SP_ME_A+B_120322

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THERMODYNAMICS

MECHANICAL ENGINEERING

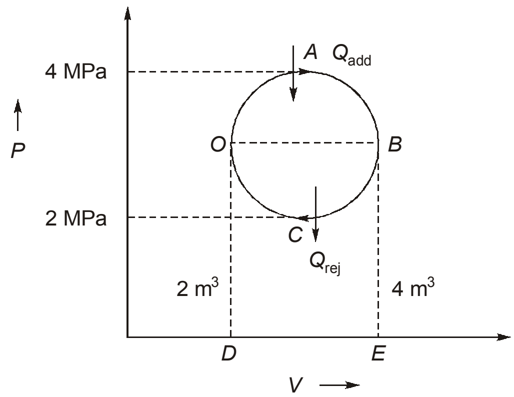
Date of Test : 12/03/2022

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (d)



$$\text{In cycle } Q_{net} = W_{net} = \text{Area enclosed by cycle.}$$

$$= \frac{\pi}{4} \times (4-2) \times (4000-2000)$$

$$= 3141.59 \text{ kJ}$$

2. (c)

3. (b)

According to steady flow energy equation:

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2$$

$$\therefore \quad \dot{W}_{in} = \dot{m}q_{out} + \dot{m}(h_2 - h_1)$$

$$\therefore \quad \dot{W}_{in} = 0.02(16) + 0.02(400.98 - 280.13)$$

$$\therefore \quad \dot{W}_{in} = 2.737 \text{ kW}$$

4. (b)

Hydrogen and Helium when throttled become heated as the maximum inversion temperature is below the normal ambient temperature.

5. (c)

Here,

$$Q_H - Q_L = 100 \text{ J}$$

$$Q_L = 300 \text{ J}$$

$$Q_H = 300 + 100 = 400 \text{ J}$$

$$\text{Efficiency, } \in = 1 - \frac{300}{400} = 0.25$$

This is efficiency of engine

Given $\in_{engine} = 0.75 \in_{carnot}$

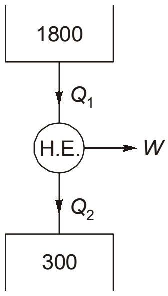
$$\in_{carnot} = \frac{0.25}{0.75} = \frac{1}{3} = 1 - \frac{T_L}{T_H}$$

$$\frac{1}{3} = 1 - \frac{300}{T_H}$$

$$\frac{300}{T_H} = \frac{2}{3}$$

on solving, $T_H = 450 \text{ K} = 177°\text{C}$

7. (a)



$$Q_1 = 5 \text{ MW}$$
$$Q_2 = Q_1 - W = 3 \text{ MW}$$

$$\text{Rate of entropy generation} = \frac{-Q_1}{T_1} + \frac{Q_2}{T_2}$$

$$\Delta S_{gen} = \left(\frac{-5}{1800} + \frac{3}{300}\right) \times 10^6$$

$$\Delta S_{gen} = 7222.22 \text{ W/K}$$

$$\text{Work lost} = T_2 \Delta S_{gen} = 300 \times 7222.22 = 2.16 \text{ MW}$$

8. (d)

$$(P_1)_{abs} = 220 + 95 = 315 \text{ kPa}$$
$$(P_2)_{abs} = 235 + 95 = 330 \text{ kPa}$$

If volume is assumed constant then

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

$$\Rightarrow \quad T_2 = \frac{P_2}{P_1} T_1 = \frac{330}{315} \times 298 = 312.19 \text{ K}$$

$$T_2 = 39.19°\text{C}$$

9. (c)

$$\eta_{Engine} = \frac{W}{Q_1} = \frac{450}{800} = 0.5625$$

$$\eta_{Carnot} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{1600} = 0.8125$$

Second law efficiency,

$$\eta_{II} = \frac{\eta_{engine}}{\eta_{Carnot}} \times 100\% = \frac{0.5625}{0.8125} \times 100\% = 69.23\%$$

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10. (b)

At $t = 0°C;\ P = 3$

$$\Rightarrow \quad 0 = a \log_e 3 + \frac{b}{2} \qquad ...(1)$$

at $t = 100°C;\ P = 8$

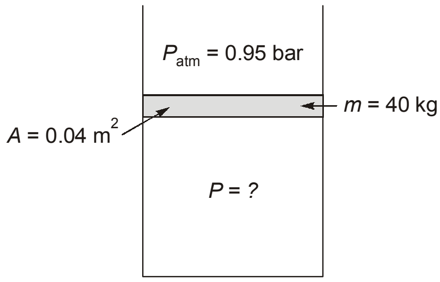
$$\Rightarrow \quad 100 = a \log_e 8 + \frac{b}{2} \qquad ...(2)$$

By (1) and (2)

$$a = 101.95$$
$$b = -224$$
$$\Rightarrow \quad t = 101.95 \log_e(P) - 112$$

at $P = 6.5;\ t = 78.83°C$

11. (c)



We have:

$$PA = P_{atm}A + W$$
$$P = P_{atm} + mg/A$$
$$P = 0.95 \text{ bar} + \frac{(40 \times 9.81)}{0.04 \times 10^5} \text{bar}$$
$$\Rightarrow \quad P = 1.0481 \text{ bar}$$

12. (b)

$$P \propto \frac{1}{V^2}$$
$$\therefore \quad P_1 = \frac{k}{V_1^2}$$
$$\therefore \quad P_1V_1^2 = P_2V_2^2$$
$$\Rightarrow \quad 1000 \times 0.1^2 = 200 \times V_2^2$$
$$\therefore \quad V_2 = 0.223 \text{ m}^3$$
$$\therefore \quad W = \int_1^2 Pdv = \int_1^2 \frac{k}{V^2} dV = k\left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$
$$= P_1V_1^2\left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$
$$= 1000 \times 0.1^2\left[\frac{1}{0.1} - \frac{1}{0.223}\right]$$
$$W = 55.28 \text{ kJ}$$

13. (b)

At triple point all the three phases exist in equilibrium.

∴ Triple point pressure of liquid and solid X are same.

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

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

14. (a)

$$Tds = dH - Vdp$$

Reversible adiabatic, $Tds = 0$

$$dH = Vdp$$

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

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

$$W_{cv} = -Vdp$$

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

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

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

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

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

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

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

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

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

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

15. (d)

$$\dot{Q}_H = \dot{W}_{net} + \dot{Q}_L$$

$$= 6000 + 3500$$

$$= 9500 \text{ kJ/min}$$

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

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

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

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

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

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

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17. (b)

Heat transferred in the boiler/kg of fluid,

$$Q_1 = (h_1 - h_4) = 2800 - 700 = 2100 \text{ kJ}$$

Heat transferred from the condenser per kg of fluid,

$$Q_2 = (h_3 - h_2) = 550 - 2450 = -1900 \text{ kJ}$$

$$\sum \frac{\delta Q}{T} = \frac{Q_1}{T_1} + \frac{Q_2}{T_2} = \frac{2100}{(220+273)} + \frac{-1900}{(51+273)}$$

$$= -1.6 \text{ kJ/kgK} < 0$$

Hence the cycle will be irreversible.

18. (b)

$$W_{max} = (u_1 - u_2) - T_0(s_1 - s_2)$$

$$= c_v(T_1 - T_2) - T_0\left(c_p \ln\frac{T_1}{T_2} - R\ln\frac{P_1}{P_2}\right)$$

$$= 0.716(300-600) - 300\left[1.004\ln\frac{300}{600} - 0.287\ln\frac{1}{8}\right]$$

$$= -185.06 \text{ kJ/kg}$$

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

$$\Rightarrow \quad \frac{n-1}{n} = \frac{\ln\left(\frac{T_2}{T_1}\right)}{\ln\left(\frac{P_2}{P_1}\right)} = \frac{\ln 2}{\ln 8} = 0.333$$

$$\Rightarrow \quad n = 1.5$$

$$W_{actual} = \frac{mR(T_1 - T_2)}{n-1} = \frac{1 \times 0.287(300-600)}{1.5-1} = -172.2 \text{ kJ/kg}$$

$$\text{Irreversibility, } I = W_{max} - W_{actual}$$

$$= 185.06 - 172.2 = 12.86 \text{ kJ/kg}$$

19. (d)

Mean temperature of mixture = $\frac{T_1 + T_2}{2}$

$$\text{Change in entropy, } \Delta s = C\int_{T_1}^{\frac{T_1+T_2}{2}} \frac{dT}{T} + \int_{T_2}^{\frac{T_1+T_2}{2}} \frac{dT}{T}$$

$$= C\, ln\frac{T_1+T_2}{2T_1} + C\, ln\frac{T_1+T_2}{2T_2}$$

$$= C\, ln\frac{(T_1+T_2)^2}{4T_1T_2} = 2C\, ln\frac{T_1+T_2}{2\sqrt{T_1T_2}}$$

$$= 2C\, ln\frac{\frac{T_1+T_2}{2}}{\sqrt{T_1T_2}} = 2C\, ln\left(\frac{\text{A.M.}}{\text{G.M.}}\right)$$

Since arithmetic mean $\left(\frac{T_1+T_2}{2}\right)$ > geometric mean $\sqrt{T_1T_2}$ therefore $ln\frac{\frac{T_1+T_2}{2}}{\sqrt{T_1T_2}}$ is positive.

20. (a)

$$\frac{W_1}{Q_1} = 1 - \frac{T}{1100}$$

$$\Rightarrow \quad \frac{Q_1}{W_1} = \frac{1100}{1100 - T} \qquad ...(1)$$

$$\frac{1}{2\left[\frac{1100 - 1100 + T}{1100 - T}\right]} = \frac{T - 300}{T}$$

$$\frac{1100 - T}{2T} = \frac{T - 300}{T}$$

$$1100 - T = 2T - 600$$

$$T = 566.67 \text{ K}$$

21. (c)

$$m_1 = \frac{P_1V_1}{RT_1} = \frac{10 \times 10^5 \times 2}{287 \times 373} = 18.68 \text{ kg.}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$\Rightarrow \quad T_2 = 373 \times \left(\frac{1}{10}\right)^{\frac{0.4}{1.4}} = 193.19 \text{ k}$$

$$m_2 = \left(\frac{P_2V_2}{RT_2}\right) = \frac{1 \times 10^5 \times 2}{287 \times 193.19} = 3.6 \text{ kg.}$$

K.E., $(m_1 - m_2)\frac{C^2}{2} = (m_1\,u_1 - m_2\,u_2) - (m_1 - m_2)h$

$= m_1\,C_V\,T_1 - m_2\,C_V\,T_2 - (m_1 - m_2)\,C_P\,T_2$

$= 18.68 \times 0.718 \times 373 - 3.6 \times 0.718 \times 193.19$

$\quad - (18.68 - 3.6) \times 1.005 \times 193.19$

$= 1575.5 \text{ kJ}$

22. (b)

Mass = 10 g = 0.01 kg

$P = 10^5$ Pa

$dQ = Q_{H_2O\,0° - 100°C} + Q_{H_2O-Steam}$

$= 0.01 \times 4200 \times 100 + 2.5 \times 10^6 \times 0.01$

$= 29200$ J

$dW = P\Delta V$

$$\Delta V = \frac{0.01}{0.6} - \frac{0.01}{1000} = 0.016656 \text{ m}^3$$

$dW = 0.016656 \times 10^5$

$= 1665.67$ J

$dQ = dW + du$

$\Rightarrow \quad du = dQ - dW$

$= 29200 - 1665.67 = 27534.33 \text{ J} = 27.534 \text{ kJ}$

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23. (b)

The paddle wheel does work on the system (the gas) due to the 100 kg mass dropping 3 m. That work is negative

$$W_1 = -F \times d = -100 \times 9.81 \times 3 = -2943 \text{ J}$$

The work done by the system on this friction piston is positive,

$$W_2 = (PA)(h) = PV = (100 + 100) \times 0.002$$
$$= 0.4 \text{ kJ} = 400 \text{ J}$$

$\therefore$ $$W_{net} = -2943 + 400 = -2543 \text{ J}$$

24. (a)

Equation of the line *PQ*

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

$$P - 2P_0 = \frac{P_0 - 2P_0}{2V_0 - V_0}[V - V_0]$$

$$P - 2P_0 = -\frac{P_0}{V_0}[V - V_0]$$

$$P - 2P_0 = -\frac{P_0 V}{V_0} + P_0$$

$\Rightarrow$ $$P = -\frac{P_0}{V_0}V + 3P_0$$

$\Rightarrow$ $$PV = -\frac{P_0}{V_0}V^2 + 3P_0 V$$

$\Rightarrow$ $$n\bar{R}T = -\frac{P_0}{V_0}V^2 + 3P_0 V$$

$\Rightarrow$ $$T = \frac{1}{n\bar{R}}\left(-\frac{P_0}{V_0}V^2 + 3P_0 V\right)$$

For maximum temperature, $\frac{dT}{dV} = 0$

$\Rightarrow$ $$-\frac{2P_0 V}{V_0} + 3P_0 = 0$$

$\Rightarrow$ $$V = \frac{3V_0}{2}$$

$\therefore$ $$T_{max} = \frac{1}{n\bar{R}}\left(-\frac{P_0}{V_0} \times \frac{9V_0^2}{4} + 3P_0 \times \frac{3V_0}{2}\right) = \frac{9P_0 V_0}{4n\bar{R}}$$

25. (a)

Let t_f is the final temperature of the water after mixing

$$m_1 c_p(t_1 - t_f) = m_2 c_p(t_f - t_2)$$

So, $$25 \times 4.2(95 - t_f) = 35 \times 4.2(t_f - 35)$$

$$t_f = 60°\text{C}$$

Entropy change of the water,

$$= (\Delta S)_1 + (\Delta S)_2$$

$$= m_1 c_p \ln\left(\frac{T_f}{T_1}\right) + m_2 c_p \ln\left(\frac{T_f}{T_2}\right)$$

$$= 25 \times 4.2 \ln\left(\frac{333}{368}\right) + 35 \times 4.2 \ln\left(\frac{333}{308}\right)$$

$$(\Delta S)_{system} = 0.97853 \text{ kJ/K}$$

Assuming system to be adiabatic, $(\Delta S)_{surr} = 0$

Decrease in available energy = irreversibility

$$= T_0(\Delta S)_{univ} = T_0\left[(\Delta S)_{sys} + (\Delta S)_{surr}\right]$$

$$= 288 \times 0.97853 = 281.81 \text{ kJ}$$

26. (c)

Total electrical work which is converted to heat

$$= (VI)t = 22 \times 1.6 \times 90 = 3168 \text{ J} = Q$$

$$\text{Work done by air} = \int PdV = 1.1 \times 10^5 \times 0.02$$

$$= 2200 \text{ J} = W$$

From Ist law, $\delta Q = \Delta U + \delta W$

$$3168 = \Delta U + 2200$$

$$\Delta U = 968 \text{ J}$$

$$mC_V \Delta T = 968$$

$$0.1 \times 717 \times \Delta T = 968$$

$$\Delta T = 13.5°\text{C}$$

27. (b)

$$T_1 = 21°\text{C} = 294 \text{ K}$$

$$T_2 = 6°\text{C} = 279 \text{ K}$$

$$\dot{Q} = kA\frac{\Delta T}{L}$$

Here,

$$k = 0.71 \text{ W/mK}$$

$$A = 35 \text{ m}^2$$

$$\Delta T = 15 \text{ K}$$

$$L = 0.3 \text{ m}$$

$$\Rightarrow \quad \dot{Q} = \frac{0.71 \times 35 \times 15}{0.3} = 1242.5 \text{ W}$$

Taking the wall as a system, the entropy balance.

$$\frac{dS_{wall}}{dt} = \dot{S}_{transfer} + \dot{S}_{gen\ wall}$$

$$\Rightarrow \quad 0 = \sum \frac{\dot{Q}}{T} + \dot{S}_{gen} \qquad \left(\because \frac{dS_{wall}}{dt} = 0 \quad \text{for steady flow}\right)$$

$$\Rightarrow \quad 0 = \frac{Q}{T_1} - \frac{Q}{T_2} + \dot{S}_{gen}$$

$$\Rightarrow \quad 0 = \frac{1242.5}{294} - \frac{1242.5}{279} + \dot{S}_{gen}$$

$$\Rightarrow \quad \dot{S}_{gen} = 0.227 \text{ W/K}$$

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28. (a)

Unsteady Flow

$$\frac{dm}{dt} = \dot{m}_i - \dot{m}_e$$

$$dm = m_i - m_e$$

$$m_2 - m_1 = m_i - m_e$$

$$m_2 = m_i$$

$$\frac{dE}{dt} = \frac{d}{dt}(m_i h_i) = \frac{dU}{dt}$$

$$\Rightarrow \quad m_2 u_2 - m_1 u_1 = m_i h_i$$

$$\Rightarrow \quad m_2 u_2 = m_i h_i$$

$$\Rightarrow \quad C_v T_2 = C_p T_i$$

$$\Rightarrow \quad T_2 = \gamma T_i$$

$$\Rightarrow \quad T_2 = 1.66 \times 433 = 718.78 \text{ K}$$

$$T_2 = 445.78^\circ\text{C}$$

29. (c)

$$(\Delta s)_{gen.} = (\Delta s)_{ice} + (\Delta s)_{atm.}$$

$$(\Delta s)_{ice} = 1 \times 2.093 \times \ln\frac{273}{268} + \frac{333.3}{273} + 1 \times 4.18 \times \ln\frac{293}{273}$$

$$= 1.555$$

$$Q_{ice} = 1 \times 2.093 \times 5 + 333.3 + 1 \times 4.18 \times 20 = 427.365$$

$$(\Delta s)_{surr.} = \frac{-Q_{ice}}{293} = -1.459$$

$$(\Delta s)_{gen.} = 1.555 - 1.459 = 0.096 \text{ kJ/kg}$$

30. (d)

For polytropic process,

$$PV^n = c$$

$$\Rightarrow \quad P_1 V_1^n = P_2 V_2^n$$

$$\Rightarrow \quad n = \frac{\log_e (P_1/P_2)}{\log_e (V_2/V_1)}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\Rightarrow \quad V_2 = \frac{P_1}{P_2}\frac{T_2}{T_1} V_1 = \frac{125}{100} \times \frac{373}{393} \times 0.08 = 0.0949 \text{ m}^3$$

$$\Rightarrow \quad n = \frac{\log_e\left(\frac{125}{100}\right)}{\log_e\left(\frac{0.0949}{0.08}\right)} = 1.3065$$

$$\text{Work done, } W = \frac{P_1 V_1 - P_2 V_2}{n - 1} = 1668.84 \text{ J}$$

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