CLASS TEST

S.No.: 01SP_HIJKLMNO_011024

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THERMODYNAMICS

MECHANICAL ENGINEERING

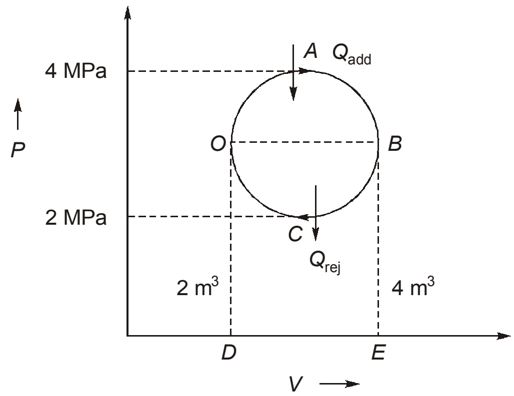
Date of Test : 01/10/2024

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (d)

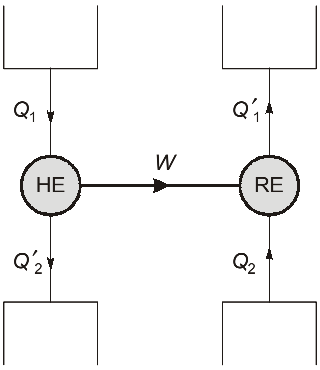


In cycle $Q_{net} = W_{net}$ = Area enclosed by cycle.

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

$$= 3141.59 \text{ kJ}$$

2. (d)



$$\frac{W}{Q_1} = \eta_{engine} = 0.3 \quad ...(1)$$

$$\frac{Q_2}{W} = COP_{ref} = 5 \quad ...(2)$$

Multiplying equation (1) and (2)

$$\Rightarrow \quad \frac{Q_2}{Q_1} = 0.3 \times 5 = 1.5$$

$$\Rightarrow \quad Q_1 = \frac{Q_2}{1.5} = \frac{1000}{1.5} \text{ kJ} = 666.67 \text{ kJ}$$

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. (d)

The mixture of air and liquid air is not a pure substance, because the relative proportions of oxygen and nitrogen differ in gas and liquid phases in equilibrium.

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

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

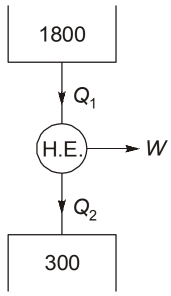
$$\frac{1}{3} = 1 - \frac{300}{T_H}$$

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

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

6. (a)

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,

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

10. (d)

$$P_0A + W = PA$$

$$\Rightarrow \quad P = P_0 + \frac{W}{A}$$

$$P_2 = 100 + \frac{50\times 9.81\times 4}{\pi \times 0.1^2 \times 10^3}$$

$$P_2 = 162.45 \text{ kPa}$$

- $$\frac{T_2}{162.45} = \frac{300+273}{250} \qquad \left(\because \frac{T_2}{T_1} = \frac{P_2}{P_1}\right)$$

$$\Rightarrow \quad T_2 = 372.33 \text{ K or } t_2 = 99.33°\text{C} \simeq 100°\text{C}$$

11. (a)

Ist law of thermodynamics for steady flow through an adiabatic nozzle is given by

$$\left(h_e + \frac{v_e^2}{2}\right) - \left(h_i + \frac{v_i^2}{2}\right) = 0$$

$$\Rightarrow \quad \frac{V_e^2 - V_i^2}{2} = h_i - h_e = c_P(T_i - T_e)$$

$$\Rightarrow \quad \frac{V_e^2 - 10^2}{2} = 1.005 \times 10^3 (200 - 150)$$

$$\Rightarrow \quad V_e = 317.18 \text{ m/s}$$

12. (b)

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

$$\therefore \quad P_1 = \frac{k}{v_1^2}$$

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

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

$$\therefore \quad V_2 = 0.223 \text{ m}^3$$

$$\therefore \quad W = \int_1^2 P dv = \int_1^2 \frac{k}{V^2} dV = k\left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$

$$= P_1 V_1^2 \left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$

$$= 1000 \times 0.1^2 \left[\frac{1}{0.1} - \frac{1}{0.223}\right]$$

$$W = 55.28 \text{ kJ} \simeq 55.3 \text{ kJ}$$

13. (b)

Given:

$$V = 0.1 \text{ m}^3$$
$$P = 3.5 \times 10^5 \text{ Pa}$$
$$\text{Output} = 10 \text{ Watt}$$
$$P_{amb} = 1 \times 10^5 \text{ Pa}$$
$$\eta_T = 0.6$$
$$t = ?$$

- Energy available in the compressed air bottle

$$= 3.5 \times 10^5 \times 0.1 = 35000 \text{ J}$$

- Energy at dead state $= 1 \times 10^5 \times 0.1 = 10000$ J
- Net available energy $= 35000 - 10000 = 25000$ J
- Energy used/ sec by turbogenerator

$$= \frac{10}{0.6} = \frac{100}{6} = \frac{50}{3} \text{ J}$$

- Time for which the turbogenerator can be operated with 10 W output

$$= \frac{25000}{50/3} = 1500 \text{ sec}$$

$$= 25 \text{ min}$$

14. (c)

Given:

$$Q = 0$$
$$h_1 = 4142 \text{ kJ/kg}$$
$$h_2 = 2500 \text{ kJ/kg}$$
$$\phi_1 = 1700 \text{ kJ/kg}$$
$$\phi_2 = 140 \text{ kJ/kg}$$
$$T_0 = 300 \text{ K}$$
$$\Delta KE = 0$$
$$\Delta PE = 0$$

- Actual work/ kg of steam,

$$Q - W = m(\Delta h + \Delta PE + \Delta KE)$$

$$W_{act} = -\Delta h = -(h_2 - h_1) = (h_1 - h_2)$$

$$= 4142 - 2500 = 1642 \text{ kJ/kg}$$

- Maximum possible work/kg of steam

$$W_{rev} = (\phi_1 - \phi_2)$$
$$= 1850 - 140 = 1710 \text{ kJ}$$

- $$T_0\, s_{gen} = W_{rev} - W_{act}$$

$\Rightarrow$
$$s_{gen} = \frac{W_{rev} - W_{act}}{T_0} = \frac{1710 - 1642}{300} = 0.2267 \text{ kJ/kg K}$$

15. (d)

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

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

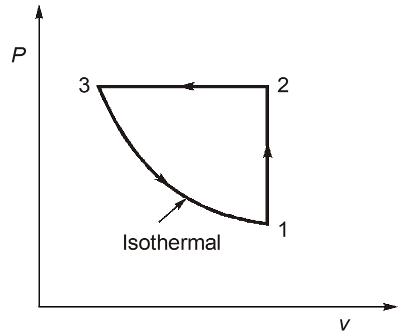
Also,
$$\frac{\dot{Q}_A}{T_A} + \frac{\dot{Q}_B}{T_B} = \frac{3500}{200}$$

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

Solving (1) and (2),
$$\dot{Q}_A = 5000 \text{ kJ/min}$$
$$\dot{Q}_B = 4500 \text{ kJ/min}$$

16. (d)

The cycle followed by the ideal gas as shown in figure.



Given that,
$$T_2 = 2T_1$$
$$T_3 = T_1$$
$$(W_{1-2})_{isometric} = 0$$
$$(W_{2-3})_{isobaric} = P_2\,(v_3 - v_2) \qquad (P_2 = P_3)$$
$$= R(T_3 - T_2) = R(T_1 - 2T_1) = -RT_1$$
$$(W_{3-1})_{isothermal} = \int_3^1 P\,dv = \int_3^1 RT_3 \frac{dv}{v}$$
$$= RT_3\, ln\frac{v_1}{v_3} = RT_3\, ln\frac{v_2}{v_3}$$
$$= RT_3\, ln\frac{T_2}{T_3} = RT_1\, ln\frac{2T_1}{T_1} = RT_1\, ln 2$$
$$W_{net} = W_{1-2} + W_{2-3} + W_{3-1}$$
$$= 0 - RT_1 + RT_1\, ln 2$$
$$= -0.3069\, RT_1$$

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)

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

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

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

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

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

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

$$\Rightarrow \qquad n = 1.5$$

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

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

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

19. (a)

Given: $T_1 = 900$ K

$T_2 = 300$ K

$m = 50$ kg

Final temperature of tank for maximum power production,

$$T_f = \sqrt{T_1 T_2} = \sqrt{900 \times 300} = 519.6\text{K}$$

$$W_{max} = Q_{source} - Q_{sink}$$

$$= mc_v(T_1 - T_f) - mc_v(T_f - T_2)$$

$$= mc_v[T_1 + T_2 - 2T_f]$$

$$= 50 \times 0.718\,[900 + 300 - 2 \times 519.6]$$

$$= 5772.7 \text{ kJ}$$

20. (d)

The iron block will cool to 285 K from 500 K while the lake temperature remains constant at 285 K.

The entropy change of iron block

$$(\Delta s)_{iron} = m(s_2 - s_1)$$

$$= mc_V \ln\frac{T_2}{T_1} = 100 \times 0.45 \times \ln\frac{285}{500}$$

$$= -25.29 \text{ kJ/K}$$

The temperature of the lake water remains constant during this process at 285 K and heat is transferred from iron block to lake water. So entropy change of lake

$$(\Delta s)_{lake} = \frac{Q}{T} = \frac{mc_V(T_2 - T_1)}{T_{lake}}$$

$$= \frac{100 \times 0.45 \times (500 - 285)}{285} = 33.95 \text{ kJ/K}$$

Entropy generated, $(\Delta s)_{gen} = (\Delta s)_{iron} + (\Delta s)_{lake}$

$$= -25.29 + 33.95 = 8.65 \text{ kJ/K}$$

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

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

$$= 18.68 \times 0.718 \times 373 - 3.6 \times 0.718 \times 193.19 - (18.68 - 3.6) \times 1.005 \times 193.19$$

$$= 1575.5 \text{ kJ}$$

22. (b)

Mass = 10 g = 0.01 kg

$P = 10^5$ Pa

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

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

$$= 29200 \text{ J}$$

$$dW = P\Delta V$$

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

$$dW = 0.016656 \times 10^5$$

$$= 1665.67 \text{ J}$$

$$dQ = dW + du$$

$$\Rightarrow \quad du = dQ - dW$$

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

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. (b)

Given: $P_C = 20$ kPa; $v_C = 0.002$ m^3/kg; $T_C = 300$ K

We know, $$R = \frac{8P_C v_C}{3T_C} = \frac{8 \times 20 \times 1000 \times 0.002}{3 \times 300} = 0.355 \text{ J/kgK}$$

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. (b)

$$\text{Heat loss by } m_1 = \text{Heat gained by } m_2 + \text{Heat gained by } m_3$$

So, $$m_1 S(T_1 - T) = m_2 S(T - T_2) + m_3 S(T - T_3)$$

$$m_1 T_1 - m_1 T = m_2 T - m_2 T_2 + m_3 T - m_3 T_3$$

$$T(m_1 + m_2 + m_3) = m_1 T_1 + m_2 T_2 + m_3 T_3$$

$\therefore$ $$T = \frac{m_1 T_1 + m_2 T_2 + m_3 T_3}{m_1 + m_2 + m_3}$$

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.

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

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

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

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

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

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. (a)

Heat required to melt 1 kg of iron at 15°C to molten metal at 1650°C = Heat required to raise temperature from 15°C to 1535°C + Latent heat + Heat required to raise the temperature from 1535°C to 1650°C.

$$= 0.502 \times [1535 - 15] + 270 + 0.534\,[1650 - 1535]$$
$$= 1094.5\text{ kJ/kg}$$

Melting rate $= 5 \times 10^3$ kg/hr

Rate of heat supply required $= 1094.5 \times 5 \times 10^3$ kJ/hr

$$\text{kW rating of furnace required} = \frac{\text{Heat Rate}}{\text{Furnace Efficiency}} = \frac{1094.5 \times 5 \times 10^3}{0.7}\text{ kJ/hr}$$

$$= \frac{1094.5 \times 5 \times 10^3}{0.7 \times 3600}\text{ kJ/s}$$

$$= 2171.6\text{ kW} = 2.17\text{ MW}$$

30. (d)

For polytropic process,

$$PV^n = c$$

$$\Rightarrow \quad P_1V_1^n = P_2V_2^n$$

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

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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

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

$$\text{Work done, } W = \frac{P_1V_1 - P_2V_2}{n-1} = 1668.84 \text{ J} \simeq 1669 \text{ kJ}$$

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