CLASS TEST

S.No. : 02SP_ME_D+E_070522

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THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 07/05/2022

ANSWER KEY

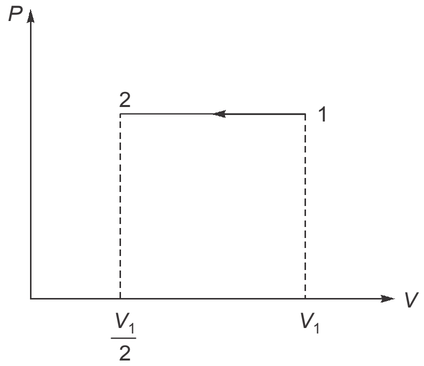
1.	(a)	7.	(b)	13.	(b)	19.	(b)	25.	(d)
2.	(c)	8.	(a)	14.	(b)	20.	(c)	26.	(d)
3.	(c)	9.	(a)	15.	(c)	21.	(c)	27.	(b)
4.	(b)	10.	(a)	16.	(b)	22.	(b)	28.	(c)
5.	(a)	11.	(c)	17.	(b)	23.	(b)	29.	(c)
6.	(d)	12.	(c)	18.	(d)	24.	(b)	30.	(d)

DETAILED EXPLANATIONS

4. (b)

$$\text{Energy entering} = \Delta U$$
$$m_{in} \times h_i = 4000$$
$$m_{in} = \frac{4000}{3264.5} = 1.225 \text{ kg}$$

5. (a)



At constant pressure,

$$(s_2 - s_1) = C_p \ln\frac{T_2}{T_1} = C_p \ln\frac{V_2}{V_1}$$
$$= C_p \ln\frac{V_1}{2} = 1.005 \ln(0.5) = -0.697 \text{ kJ/kg-K}$$

7. (b)

Intensive properties are independent of mass of the system i.e. it is a bulk property or physical property of a system, eg. pressure, temperature, specific volume, specific energy, viscosity, elasticity etc.

Extensive properties depends on mass, eg. energy, entropy, Gibbs free energy, volume, heat capacity at constant pressure and at constant volume.

9. (a)

$$\oint W = \text{Power developed}$$

$\therefore$ $$\text{Power} = +480 - 180 = 300 \text{ kJ/min}$$

or $$P = \frac{300}{60} = 5 \text{ kW}$$

10. (a)

$$Tds = \frac{kC_v}{\beta} dP + \frac{C_p}{v\beta} dv$$

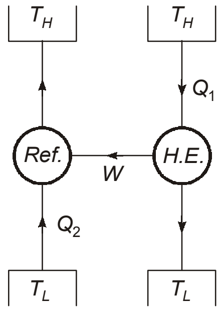
Here, k = isothermal compressibility

$$= \frac{1}{\text{absolute pressure}} = \frac{1}{P} = -\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T$$

$$\beta = \text{Coefficient of volumetric expansion}$$

$$= \frac{1}{T} = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_p$$

11. (c)



$$\eta_{H.E.} = \frac{W}{Q_1} = 0.6 \quad \text{...(i)}$$

$$(\text{COP})_{\text{ref.}} = \frac{Q_2}{W} = 5 \quad \text{...(ii)}$$

Multiplying equation (i) and (ii), we get

$$\frac{Q_2}{Q_1} = 0.6 \times 5 = 3$$

Given, $Q_2 = 1 \text{ tonne} = 3.5 \text{ kJ/sec}$

$$\frac{3.5}{Q_1} = 3$$

$$Q_1 = \frac{3.5}{3} = 1.17 \text{ kJ/sec}$$

12. (c)

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

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

$$= 1.555 \text{ kJ/K}$$

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

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

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

13. (b)

$$P_1V_1 = P_2V_2$$

$$\Rightarrow \quad 50 \times 500 = 1 \times V_2$$

$$\Rightarrow \quad V_2 = 25000 \text{ m}^3$$

$$\text{Availability} = \text{Total work capability} - \text{Work done on atmospheric air}$$

$$= P_1V_1 \ln\frac{V_2}{V_1} - P_{atm}(V_2 - V_1)$$

$$= (50 \times 10^5 \times 500) \ln\frac{25000}{500} - 1 \times 10^5 \,[25000 - 500]$$

$$= 7330 \text{ MJ}$$

14. (b)

$$5 \times C \times (t_f - 27) = 10 \times C\,(97 - t_f)$$

$$\Rightarrow \quad t_f = 73.67°\text{C}$$

$$T_1 = 27 + 273 = 300K = T_o$$

$$T_2 = 97 + 273 = 370K$$

$$T_f = 376.67K$$

$$\text{Unavailable energy} = T_o(\Delta S)_{27°\text{C}}$$

$$= 300 \times mC_p \ln\frac{T_f}{T_1}$$

$$= 300 \times 5 \times 4.18 \times \ln\frac{346.67}{300}$$

$$= 906.58 \text{ kJ}$$

15. (c)

Extra pressure required to raise the whistle, $p = \dfrac{W}{A}$

$$= \frac{0.1 \times 9.81}{5 \times 10^{-6}} = 196200 \text{ N/m}^2$$

$$= 196.2 \text{ kPa}$$

$$P_2 = 100 + 196.2 = 296.2 \text{ kPa}$$

$$\therefore \quad \text{For air, } \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\Rightarrow \quad \frac{100}{300} = \frac{296.2}{T_2}$$

$$\Rightarrow \quad T_2 = 888.6 \text{ K}$$

$$m = \frac{P_1V_1}{RT_1} = \frac{100 \times 1000 \times 10^{-6}}{0.287 \times 300}$$

$$= 1.1614 \times 10^{-3} \text{ kg}$$

Therefore, heat that must be supplied,

$$Q_v = mC_v \cdot dT$$
$$= 1.1614 \times 10^{-3} \times 0.718 \times (888.6 - 300)$$
$$= 0.49 \text{ kJ}$$

16. (b)

Heat transferred in the boiler/kg of fluid,

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

Heat transferred from the condenser per kg of fluid,

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

$$\sum \frac{\delta Q}{T} = \frac{Q_1}{T_1} + \frac{Q_2}{T_2} = \frac{2100}{(220+273)} + \frac{-1900}{(51+273)}$$
$$= -1.6 \text{ kJ/kgK} < 0$$

Hence the cycle will be irreversible.

17. (b)

$$W_{max} = (u_1 - u_2) - T_0(s_1 - s_2)$$
$$= c_v(T_1 - T_2) - T_0\left(c_p \ln\frac{T_1}{T_2} - R\ln\frac{P_1}{P_2}\right)$$
$$= 0.716(300-600) - 300\left[1.004\ln\frac{300}{600} - 0.287\ln\frac{1}{8}\right]$$
$$= -185.06 \text{ kJ/kg}$$

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

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

$$\Rightarrow \quad n = 1.5$$

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

$$\text{Irreversibility, } I = W_{max} - W_{actual}$$
$$= 185.06 - 172.2 = 12.86 \text{ kJ/kg}$$

18. (d)

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

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

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

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

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

19. (b)

$$m = \frac{PV_1}{RT_1} = \frac{4\times10^5\times0.1}{\frac{8314}{34}\times300} = 0.545 \text{ kg.}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\Rightarrow \quad T_2 = 300\times\left(\frac{0.1}{0.2}\right)^{0.3} = 243.67 \text{ K}$$

$$W_{1-2} = \frac{P_1V_1-P_2V_2}{n-1} = \frac{mR(T_1-T_2)}{n-1}$$

$$= \frac{0.545\times\frac{8314}{34}(300-243.6)}{1.3-1}$$

$$= 25.054 \text{ kJ.}$$

$$\Delta U = m\int_{T_1}^{T_2} C_V dT = m\int_{T_1}^{T_2}\left(0.5+2.5\times10^{-4}T\right)dt$$

$$= 0.545\left[0.5T+2.5\times10^{-4}\times\frac{T^2}{2}\right]^{243.6}$$

$$= 0.545\left[0.5T+1.25\times10^{-4}T^2\right]_{300}^{243.6}$$

$$= 0.545\,[129.22-161.25] = -17.456 \text{ kJ.}$$

$$Q = \Delta U + W = -17.456 + 25.04 = 7.6 \text{ kJ.}$$

20. (c)

$$m_1 = \frac{P_1V_1}{RT_1} = \frac{10\times10^5\times2}{287\times373} = 18.68 \text{ kg.}$$

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

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

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

K.E.,
$$(m_1 - m_2)\frac{C^2}{2} = (m_1\, u_1 - m_2\, u_2) - (m_1 - m_2)h$$
$$= m_1\, C_V\, T_1 - m_2\, C_V\, T_2 - (m_1 - m_2)\, C_P\, T_2$$
$$= 18.68 \times 0.718 \times 373 - 3.6 \times 0.718 \times 193.19$$
$$- (18.68 - 3.6) \times 1.005 \times 193.19$$
$$= 1575.5 \text{ kJ}$$

21. (c)

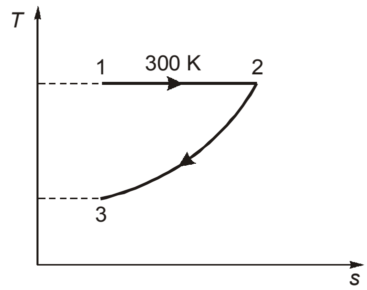
P_1 = 1 bar

T_1 = 300 k

V_1 = 0.18 m^3

V_2 = 0.09 m^3

V_3 = 0.045 m^3



$$m = \frac{P_1V_1}{RT_1} = \frac{1\times 10^5 \times 0.18}{287 \times 300} = 0.209 \text{ kg}$$

$$P_2 = \frac{P_1V_1}{V_2} = 2P_1 = 2\times 1 = 2 \text{ bar}$$

$$T_2 = \frac{T_1V_2}{V_1} = \frac{T_1}{2} = \frac{300}{2} = 150 \text{ K}$$

$$W_{1-3} = W_{1-2} + W_{2-3}$$

$$= \int_{V_1}^{V_2} pdv + \int_{V_2}^{V_3} pdv = mRT_1 ln\frac{V_2}{V_1} + P_2(V_3 - V_2)$$

$$= 0.209 \times 287 \times 300 \times ln\frac{0.09}{0.18} + 2\times 10^5 (0.045 - 0.09)$$

$$= -21476.6 \text{ J} = -21.476 \text{ kJ.}$$

22. (b)

$$\text{Mass of air, } m_a = \frac{PV_{air}}{RT_1} = \frac{1 \times 10^5 \times 100}{287 \times 283} = 123.12 \text{ kg}$$

Mass of oil, $m_o = \rho_{oil} \times V_{oil} = 950 \times 0.1 = 95$ kg

We consider the room and the oil in the radiator as a closed system since no mass is crossing the boundary. The energy balance for this stationary constant volume system can be expressed as:

$$E_{in} - E_{out} = \Delta E_{system}$$

$$\Rightarrow \quad (W_{in} - Q_{out}).\Delta t = \Delta U_{air} + \Delta U_{oil}$$

$$= [m\,C_V(T_2 - T_1)]_{air} + [m\,C\,(T_2 - T_1)]_{oil}$$

$$\Rightarrow \quad (1.8 - 0.35).\Delta t = [123.12 \times 0.718\,(20 - 10)] + [95 \times 2.2 \times (50 - 10)]$$

$$\Rightarrow \quad \Delta t = 6375.17 \text{ sec}$$

$$= 106.25 \text{ min}$$

23. (b)

$$v = \frac{RT}{p} = \frac{0.287 \times (77 + 273)}{300}$$

$$= 0.3348 \text{ m}^3\text{/kg}$$

$$\text{Rate of flow energy, } W_{flow} = m(pv)$$

$$= \frac{15}{60} \times (300 \times 0.3348)$$

$$= 25.11 \text{ kW}$$

Rate of energy transport by mass

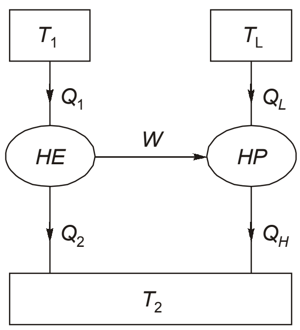
$$E_{mass} = m\,(h + KE)$$

$$= m\left[C_P T + \frac{1}{2}V^2\right]$$

$$= \frac{15}{60}\left[(1.008 \times 350) + \frac{25^2}{2000}\right]$$

$$= 88.27 \text{ kW}$$

24. (b)



$$\eta_{HE} = \frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

$$\Rightarrow \qquad W = \frac{Q_1}{T_1}(T_1 - T_2)$$

$$(COP)_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{T_2}{T_2 - T_L} = \frac{Q_H}{W}$$

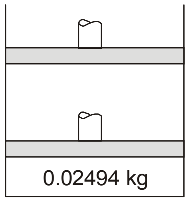
$$\Rightarrow \qquad W = \frac{Q_H}{T_2}(T_2 - T_L)$$

Since work output of the heat engine is used to drive the heat pump. Therefore:

$$\frac{Q_1}{T_1}(T_1 - T_2) = \frac{Q_H}{T_2}(T_2 - T_L)$$

$$\Rightarrow \qquad \frac{Q_H}{Q_1} = \frac{T_2(T_1 - T_2)}{T_1(T_2 - T_L)}$$

25. (d)



$$\eta_{th} = 1 - \frac{T_L}{T_H} = 1 - \frac{1}{2} = 0.5$$

Also, $$\eta_{th} = \frac{W}{Q_H}$$

$$\Rightarrow \qquad Q_H = \frac{W}{\eta_{th}} = \frac{60}{0.5} = 120 \text{ kJ}$$

$$Q_L = Q_H - W = 120 - 60 = 60 \text{ kJ}$$

and $$q_L = \frac{Q_L}{m} = \frac{60}{0.02494} = 2405.8 \approx 2406 \text{ kJ/kg}$$

$$= h_{fg} \text{ at } T_L$$

Since the enthalpy of vaporization h_{fg} at a given temperature, or pressure represents the amount of heat transfer as 1 kg of a substance is converted from saturated liquid to saturated vapour from saturated liquid to saturated vapour at the T or P. Therefore T_L is the temperature that corresponds to the h_{fg} value of 2406 kJ/kg and from steam stable

$$T_L = 40° \text{ C}$$

26. (d)

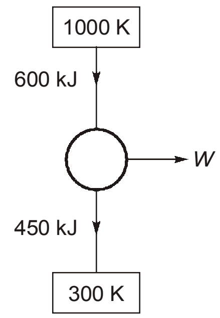
We know efficiency of Carnot engine operating between temperature limits T_H and T_L is

$$\eta = 1 - \frac{T_L}{T_H}$$

$$\therefore \qquad 2\left(1 - \frac{T_L}{T_H}\right) = 1 - \frac{T_L}{T_H'}$$

$$\therefore \text{ On solving,} \qquad T_H' = \frac{T_L T_H}{2T_L - T_H}$$

27. (b)



$$\int \frac{dQ}{T} = \frac{Q_1}{T_1} + \frac{Q_2}{T_2}$$

$$= \frac{600}{1000} - \left(\frac{450}{300}\right) = -0.9 \text{ kJ/K}$$

$$\text{Efficiency} = \frac{Q_1 - Q_2}{Q_1} = \frac{600 - 450}{600} = \frac{150}{600} = 25\%$$

28. (c)

$$\Delta U = \Delta(PE)$$

$$mC_v dT = mgh$$

$$dT = \frac{gh}{C_v} = \frac{9.81 \times 5000}{0.98 \times 10^3} = 50 \text{ K}$$

29. (c)

$$TV^{\gamma - 1} = \text{Const.}$$

$$\therefore \quad T_2 = T_1 \times \left(\frac{V_1}{V_2}\right)^{1.667-1}$$

$$= 300 \times \left(\frac{3.5}{0.775}\right)^{0.667}$$

$$T_2 = 820.07 \text{ K}$$

$$\Rightarrow \quad T_2 = 547.1°\text{C}$$

30. (d)

SFEE in differential form

$$dQ = dh + VdV + gdz + dw$$

For a reversible process $dQ = TdS$

$$\therefore \quad TdS = dh + VdV + gdz + dw$$

$$TdS - dh = VdV + gdz + dw$$

From property relation $TdS = dh - v dP$

$$\Rightarrow \quad TdS - dh = -v dP$$

$$\therefore \quad -v\, dP = VdV + gdz + dw$$

Integrating both sides

$$-\int_{P_1}^{P_2} v dP = -\int_{V_1}^{V_2} VdP + \int_{z_1}^{z_2} gdz + \int dw$$

$$-\int_{P_1}^{P_2} v dP = \left\{\frac{V_2^2}{2} - \frac{V_1^2}{2}\right\} + g(z_2 - z_1) + w$$

$$-\int_{P_1}^{P_2} v dP - \left\{\frac{V_2^2}{2} - \frac{V_1^2}{2}\right\} - g(z_2 - z_1) = w$$

Neglect initial velocity given

Neglect P.E. effect given

$$-\int_{P_1}^{P_2} v\,dP - \left\{\frac{V_2^2}{2} - \cancel{\frac{V_1^2}{2}}\right\} - \cancel{g(z_2 - z_1)} = w$$

P_2

$$w = -\int_{P_1}^{P_2} v\,dP - \frac{V_2^2}{2}$$

$$W_{\text{isothermal}} = -\int_{P_1}^{P_2} \frac{C}{P} - \frac{V_2^2}{2} \qquad [Pv = C, \text{ For isothermal process}]$$

$$W_{\text{isothermal}} = -C\,ln\frac{P_2}{P_1} - \frac{V_2^2}{2}$$

$$= -P_1V_1\frac{P_2}{P_1} - \frac{V_2^2}{2}$$

$$= -RT_1\,ln\frac{P_2}{P_1} - \frac{V_2^2}{2}$$

$$= -0.287 \times (30 + 273)\,ln 3.5 - \frac{90^2}{2000}$$

$$= -112.99 \simeq -113 \text{ kJ/kg}$$

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