CLASS TEST

S.No.: 01SP_ABCDEFG_21062024

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THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 21/06/2024

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (a)

2. (a)

3. (b)

For a heat reversible engine,

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

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

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

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

4. (b)

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

$$\therefore \quad \dot{W}_{rev} = \left(1-\frac{300}{1200}\right)\times 500$$

$$= 375 \text{ kW}$$

Irreversibility rate

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

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

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

5. (a)

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

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

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

6. (b)

Linear interpolation,

°x	°y
50	100
200	50
x	y

$$\frac{x-200}{50-200} = \frac{y-50}{100-50}$$

For $x = y$

$$\frac{x-200}{-150} = \frac{x-50}{50}$$

$$\Rightarrow \quad x = 87.5°x$$

7. (b)

For irreversible system, Clausius inequality

$$\oint \frac{\delta Q}{T} < 0$$

and refrigerator $\oint \delta Q < 0$.

8. (c)

An intensive property is a property of matter that depends only on the type of matter in a sample and independent of mass of matter. Example : Temperature, density, solubility, conductivity, viscosity, pressure, etc.

9. (d)

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

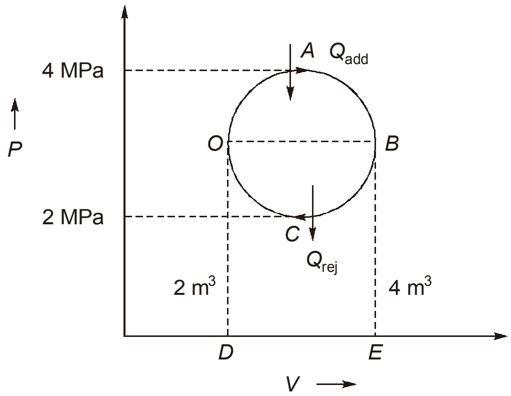
If volume is assumed constant then

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

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

$$T_2 = 39.19°\text{C}$$

10. (d)



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

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

$$= 3141.59 \text{ kJ}$$

11. (a)

$$P_{N2} = 400 \text{ kPa},$$
$$P_{CO2} = 200 \text{ kPa},$$
$$P_{mix} = 250 \text{ kPa}$$
$$n_{N2} = 3 \text{ Kmol},$$
$$n_{CO2} = 7 \text{ Kmol},$$
$$M_{N2} = 28 \text{ kg/Kmol}$$
$$M_{CO2} = 44 \text{ kg/Kmol}$$
$$n_{mix} = n_{N2} + n_{CO2} = 10 \text{ Kmol}$$

$$y_{N2} = \frac{n_{N2}}{n_{mix}} = 0.3$$

$$y_{CO2} = 0.7$$

$$\therefore \quad P_{N2} = y_{N2} \times P_{mix} = 0.3 \times 250 \text{ kPa} = 75 \text{ kPa}$$

12. (c)

Availability for a flow process,

$$= (h_1 - h_2) - T_0(S_1 - S_2) = (400 - 100) - 300 \times (1.1 - 0.7)$$
$$= 300 - [300 \times (1.1 - 0.7)]$$
$$= 300 - 120$$
$$= 180 \text{ kJ/kg}$$

13. (b)

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

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

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

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

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

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

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

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

$$W = 55.15 \text{ kJ}$$

14. (b)

We know by 1st law of thermodynamics,

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

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

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

$$\Delta U = 32.5$$

$$U_2 - U_1 = 32.5$$

$$U_2 - 10 = 32.5$$

$$\therefore \quad U_2 = 32.5 + 10$$

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

15. (d)

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

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

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

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

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

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

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

16. (c)

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

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

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

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

Constant volume process

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

$$\Rightarrow \quad T_2 = 2T_1$$

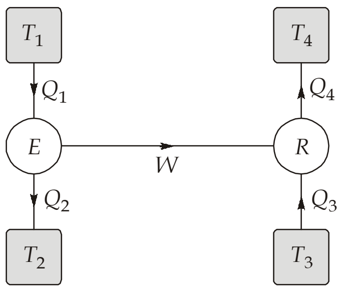
$$\Rightarrow \quad T_2 = 596 \text{ K}$$

$$\text{Heat supplied} = m(C_v)_e \Delta T$$

$$= 2 \times 0.671 \times 298 = 399.916 \text{ kJ}$$

$$\simeq 400 \text{ kJ}$$

17. (a)



Given: $\eta_E = 0.5$

Also $Q_1 = \frac{1}{2}(Q_2 + Q_4)$

$$W = \eta Q_1 = 0.5Q_1$$

$$\Rightarrow \quad Q_2 = Q_1 - W = 0.5Q_1$$

$$\Rightarrow \quad Q_4 = 2Q_1 - Q_2 = 1.5Q_1$$

$$(COP)_R = \frac{Q_3}{Q_4 - Q_3} = \frac{Q_4 - W}{W}$$

$$= \frac{Q_4}{W} - 1 = \frac{1.5Q_1}{0.5Q_1} - 1 = 3 - 1 = 2$$

18. (d)

Let the final common temperature of 3 reservoirs be T_f

Given: $U = CT$

$\Rightarrow \quad dU = CdT$

Now, $dS = \frac{CdT}{T}$

$\Rightarrow \quad \Delta S = C\ln\frac{T_f}{T_i}$

T_i = Initial temperature

For maximum work, $\Sigma\Delta S = 0$

$\Rightarrow \quad \Delta S_1 + \Delta S_2 + \Delta S_3 = 0$

$\Rightarrow \quad C\ln\frac{T_f}{200} + C\ln\frac{T_f}{250} + C\ln\frac{T_f}{540} = 0$

$\Rightarrow \quad T_f^3 = 200 \times 250 \times 540$

$\Rightarrow \quad T_f = 300\text{ K}$

$$W_{max} = -[\Delta U_1 + \Delta U_2 + \Delta U_3] = -[C[T_f - T_1] + C[T_f - T_2] + C[T_f - T_3]]$$

$$= -[8.4(300-200) + 8.4(300-250) + 8.4(300-540)]$$

$\Rightarrow \quad W_{max} = 756\text{ kJ}$

19. (d)

Given: $V_1 = 0.05\text{ m}^3$

Now, enclosed volume at final state is

$$V_2 = 2V_1 = 0.1\text{ m}^3$$

$\therefore$ Displacement of piston, $x = \frac{\Delta V}{A} = \frac{0.05}{0.25} = 0.2\text{ m}$

Force applied by linear spring at final state,

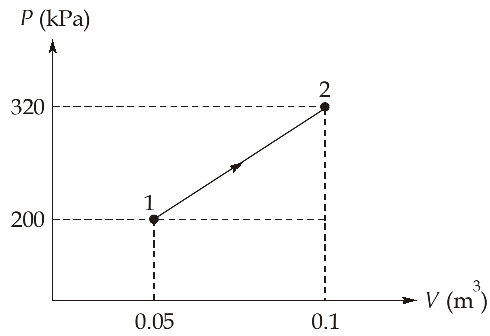
$$F_{spring} = kx = 150 \times 0.2 = 30\text{ kN}$$

Additional pressure applied by spring,

$$P = \frac{F_{spring}}{A} = \frac{30}{0.25} = 120\text{ kPa}$$

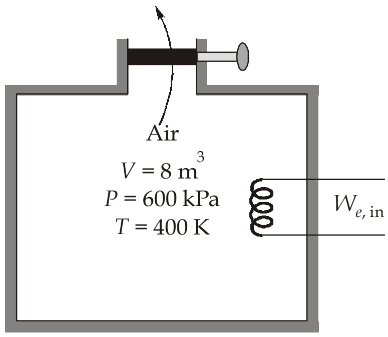
Without the spring, pressure of gas would remain constant at 200 kPa but under the effect of spring, pressure rises linearly from 200 kPa to (200 + 120) = 320 kPa.

Now, total work done by gas = Area under the process (1-2)



$$W = \text{Area} = \left(\frac{200+320}{2}\right)(0.1-0.05)\text{ kJ} = 13\text{ kJ}$$

20. (b)



$$m_1 = \frac{P_1V_1}{RT_1} = \frac{600\times 8}{0.287\times 400} = 41.81\text{kg}$$

$$m_2 = \frac{P_2V_2}{RT_2} = \frac{200\times 8}{0.287\times 400} = 13.94\text{ kg}$$

At 400 K, $h_e = 400.98$ kJ/kg and $u_1 = u_2 = 286.16$ kJ/kg (Given)

Mass balance:

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

$\Rightarrow$ $m_e = m_1 - m_2 = 41.81 - 13.94 = 27.87$ kg

Energy balance:

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

$$W_{e,in} - m_e h_e = m_2u_2 - m_1u_1 \quad \text{(Since } Q \cong KE \cong PE \cong 0)$$

$$m_eh_e + m_2u_2 - m_1u_1 = W_{e,in}$$

$$W_{e,in} = m_eh_e + u(m_2 - m_1) \quad (\because \quad u = u_1 = u_2)$$

$$= m_eh_e + u(-m_e)$$

$$W_{e,in} = m_e(h_e - u)$$

$$= 27.87 \times (400.98 - 286.16)\text{ kJ}$$

$$= 27.87 \times 114.82\text{ kJ}$$

$$= 3200.03\text{ kJ}$$

$$= 0.889\text{ kWh} \quad [\because 1\text{ kWh} = 3600\text{ kJ}]$$

21. (a)

22. (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.

23. (d)

Mean temperature of mixture = $\frac{T_1 + T_2}{2}$ $(\Delta U = 0)$

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

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

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

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

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.

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

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

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

$$= 1575.5 \text{ kJ}$$

25. (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,

$$W_2 = (PA)(h) = PV = (100 + 100) \times 0.002$$
$$= 0.4 \text{ kJ} = 400 \text{ J}$$
$$\therefore \quad W_{net} = -2943 + 400 = -2543 \text{ J}$$

26. (b)

$$T_1 = 21°C = 294 \text{ K}$$
$$T_2 = 6°C = 279 \text{ K}$$
$$\dot{Q} = kA\frac{\Delta T}{L}$$

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.

$$\frac{dS_{wall}}{dt} = \dot{S}_{transfer} + \dot{S}_{gen\ wall}$$
$$\Rightarrow \quad 0 = \sum\frac{\dot{Q}}{T} + \dot{S}_{gen} \qquad \left(\because \frac{dS_{wall}}{dt} = 0 \quad \text{for steady flow}\right)$$
$$\Rightarrow \quad 0 = \frac{Q}{T_1} - \frac{Q}{T_2} + \dot{S}_{gen}$$
$$\Rightarrow \quad 0 = \frac{1242.5}{294} - \frac{1242.5}{279} + \dot{S}_{gen}$$
$$\Rightarrow \quad \dot{S}_{gen} = 0.227 \text{ W/K}$$

27. (d)

For polytropic process,

$$PV^n = c$$
$$\Rightarrow \quad P_1V_1^n = P_2V_2^n$$
$$\Rightarrow \quad n = \frac{\log_e(P_1/P_2)}{\log_e(V_2/V_1)}$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\Rightarrow \quad V_2 = \frac{P_1}{P_2}\frac{T_2}{T_1}V_1 = \frac{125}{100} \times \frac{373}{393} \times 0.08 = 0.0949 \text{ m}^3$$
$$\Rightarrow \quad n = \frac{\log_e\left(\frac{125}{100}\right)}{\log_e\left(\frac{0.0949}{0.08}\right)} = 1.3065$$
$$\text{Work done, } W = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{(125 \times 0.08 - 100 \times 0.0949) \times 10^3}{1.3065 - 1} = 1663.94 \simeq 1664 \text{ J}$$

28. (a)

Given; $P = 200$ kN/m^2; $W_1 = -150$ kJ; $Q = 50$ kJ

We know,
$$H = U + PV$$
$$H_1 = U_1 + P_1V_1$$
$$H_2 = U_2 + P_2V_2$$

∴ Change in enthalpy $\Delta H = H_2 - H_1 = (U_2 - U_1) + P(V_2 - V_1)$

Work done by the system,
$$W_2 = P(V_2 - V_1) = 200 \times (5 - 2) = 600 \text{ kJ}$$

From 1st law of thermodynamics,
$$\Delta Q = \Delta U + \Delta W$$
$$\Delta U = \Delta Q - \Delta W = 50 - (-150 + 600) = 50 - 450 = -400 \text{ kJ}$$

So, $\Delta H = \Delta U + P(V_2 - V_1)$

∴ $\Delta H = -400 + 200\,(5 - 2) = -400 + 600 = 200$ kJ

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.
$$= 0.502 \times [1535 - 15] + 270 + 0.534\,[1650 - 1535]$$
$$= 1094.45 \text{ kJ/kg}$$

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

Rate of heat supply required $= 1094.45 \times 5 \times 10^3$ kJ/hr

$$\text{kW rating of furnace required} = \frac{\text{Heat Rate}}{\text{Furnace Efficiency}} = \frac{1094.45 \times 5 \times 10^3}{0.7} \text{ kJ/hr}$$
$$= \frac{1094.45 \times 5 \times 10^3}{0.7 \times 3600} \text{ kJ/s}$$
$$= 2171.5 \text{ kW} = 2.17 \text{ MW}$$

30. (c)

Maximum work obtainable from a body and TER,
$$W_{max} = m\left[c_p(T - T_0) + T_0 c_p \ln\left(\frac{T_0}{T}\right)\right]$$
$$= 2\left[1 \times (600 - 300) + 300 \times 1 \times \ln\left(\frac{300}{600}\right)\right]$$
$$= 184.1 \text{ kJ}$$

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