CLASS TEST

S.No. : 01SP_ME_ABCD_16423

MADE EASY

India's Best Institute for IES, GATE & PSUs

Delhi | Bhopal | Hyderabad | Jaipur | Pune | Bhubaneswar | Kolkata

Web: www.madeeasy.in | **E-mail:** info@madeeasy.in | **Ph:** 011-45124612

THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 16/04/2023

ANSWER KEY

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

DETAILED EXPLANATIONS

1. **(c)**

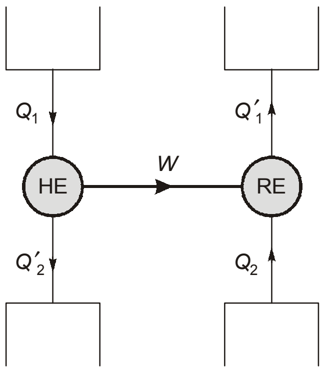
2. **(c)**

Extent of irreversibility of any process is determined by the entropy increase of the universe.

3. **(b)**

$\int PdV$ work is only valid for a Quasi-static process.

4. **(d)**



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

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

Multiplying equation (1) and (2)

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

$$\Rightarrow \quad Q_1 = \frac{Q_2}{1.5} = \frac{1000}{1.5} \text{ kJ} = 666.67 \text{ kJ} \qquad (\text{for } Q_2 = 1 \text{ MJ} = 1000 \text{ kJ})$$

5. **(a)**

6. **(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.

7. **(a)**

$$\text{DOF} = 0$$

Gibbs phase rule fails at critical point.

8. **(a)**

9. **(a)**

If temperature is constant, U will remain unchanged as internal energy for an ideal gas is the function of temperature only.

10. (b)

Given: $P_C = 20$ kPa; $V_C = 0.002\ m^3$; $T_C = 300$ K

We know, $$R = \frac{8P_CV_C}{3T_C} = \frac{8\times20\times1000\times0.002}{3\times300} = 0.355\ J/K$$

11. (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,
$$W_2 = P(V_2 - V_1) = 200 \times (5 - 2) = 600\ kJ$$

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

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

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

12. (c)

$$c_p = 1\ kJ/kgK$$
$$c_v = 0.75\ kJ/kgK$$
$$T = 27°C = (27 + 273)\ K = 300\ K$$
$$p = 1\ bar = 100\ kPa$$

Gas constant: $$R = c_p - c_v$$
$$= 1 - 0.75 = 0.25\ kJ/kgK$$

Applying equation of state in terms of density,
$$p = \rho RT$$
$$100 = \rho \times 0.25 \times 300$$
$$1 = 0.75\ \rho$$

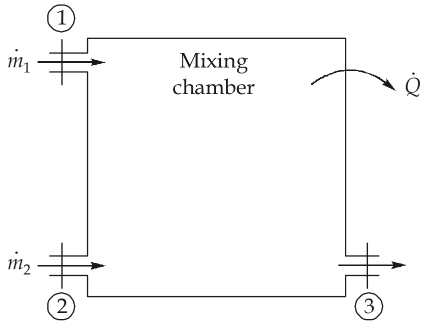
or $$\rho = \frac{1}{0.75} = \frac{100}{75} = 1.33\ kg/m^3$$

13. (b)

For the process 3-4
$$\Delta U = -650\ (kJ)$$
$$\Delta PE = 0\ (kJ)$$
$$\Delta E = -600\ (kJ)$$

Change in total macroscopic energy (ΔE)
$$\Delta E = \Delta U + \Delta KE + \Delta PE$$
$$-600 = -650 + \Delta PE + 0$$
$$\Delta KE = (650 - 600) = 50\ kJ$$

14. (c)



From steady flow energy equation (SFEE), neglecting ΔKE and ΔPE

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{Q} = (\dot{m}_1 + \dot{m}_2)h_3 - \cancel{W_{net}}^{\,0}$$

$$\dot{m}_1 c_p T_1 + \dot{m}_2 c_p T_2 - \dot{Q} = (\dot{m}_1 + \dot{m}_2)c_p T_3$$

$$T_3 = \frac{\dot{m}_1 T_1 + \dot{m}_2 T_2}{\dot{m}_1 + \dot{m}_2} - \frac{\dot{Q}}{c_p(\dot{m}_1 + \dot{m}_2)}$$

15. (c)

In case of throttling of real gas,

$$h_1 = h_2$$

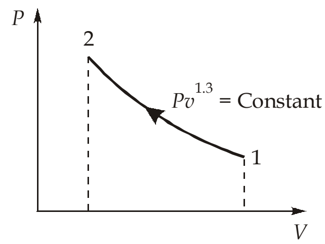
$$u_1 + p_1 v_1 = u_2 + p_2 v_2$$

Internal energy + Flow energy = Constant

Thus, the final outcome of a throttling process will depend on the quantity that increases during the process.

If the flow energy increases ($p_2 v_2 > p_1 v_1$), it can do so at the expense of the internal energy. As a result, internal energy decreases, which is usually accompanied by a drop in temperature. If the product pv decreases, the internal energy and the temperature of a fluid will increase during throttling process.

16. (a)



Mass = 1 kg of ideal gas

Initial, P_1 = 100 kPa

T_1 = 250 K

Final, T_2 = 500 K

R = 287 J/kgK

γ = 1.4

$$W_{1\text{-}2} = -\left(\frac{P_2 V_2 - P_1 V_1}{n-1}\right)$$

$$= \frac{-mR(T_2 - T_1)}{n-1}$$

$$U_{1\text{-}2} = U_2 - U_1 = mc_v (T_2 - T_1)$$

$$Q_{1\text{-}2} = U_{1\text{-}2} + W_{1\text{-}2}$$

$$Q_{1\text{-}2} = 1 \times 0.718(500 - 250) - \frac{1 \times 0.287(500 - 250)}{1.3 - 1}$$

$$Q_{1\text{-}2} = -59.666 \text{ kJ}$$
$$Q_{1\text{-}2} = 59.666 \text{ kJ (Heat transfer from piston cylinder to its surrounding)}$$

Alternatively,

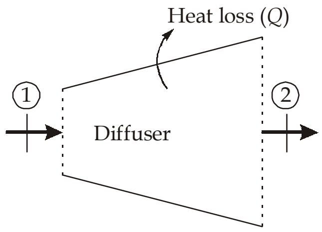
$$Q_{1\text{-}2} = \frac{\gamma - n}{\gamma - 1} \times \left(\frac{P_1V_1 - P_2V_2}{n-1}\right) = \frac{\gamma - n}{\gamma - 1} \times \frac{m \times R \times (T_1 - T_2)}{n-1}$$

$$= \frac{1.4 - 1.3}{1.4 - 1} \times \frac{1 \times 0.287 \times (250 - 500)}{1.3 - 1}$$

$$Q_{1\text{-}2} = -59.666 \text{ kJ}$$
$$Q_{1\text{-}2} = 59.666 \text{ kJ (Heat transfer from piston cylinder to its surrounding)}$$

17. (c)

$\dot{m}_1 = 2$ kg/s,
$P_1 = 100$ kPa,
$T_1 = 273 + 30 = 303$ K;
$V_1 = 200$ m/s



$A_2 = 400 \times 10^{-4}$ m^2,
$T_2 = 273 + 45 = 318$ K,
$Q_{loss} = 4$ kW, $P_2 = ?$

$$\text{Air, } \gamma = 1.4$$

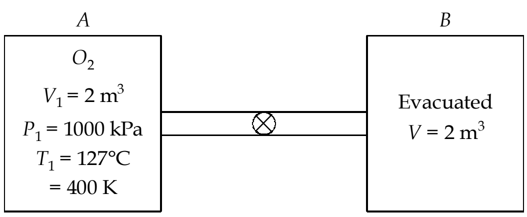
From steady flow energy equation,

$$h_1 + \frac{V_1^2}{2} + Q = h_2 + \frac{V_2^2}{2} + \cancel{W_{net}}^{\,0}$$

$$\left[1005(303 - 318) + \frac{200^2}{2}\right] - 4000 = \frac{V_2^2}{2}$$

$$V_2 = 43.0116 \text{ m/s}$$
$$\text{Mass flow rate} = \rho_2 A_2 V_2$$
$$2 = \rho_2 \times 400 \times 10^{-4} \times 43.0116$$
$$\rho_2 = 1.1624 \text{ kg/m}^3$$
$$P_2 = \rho_2 R T_2$$
$$= 1.1624 \times 0.287 \times 318 = 106.094 \text{ kPa}$$

18. (d)



Taking chamber A and chamber B together as a system.

$$dQ = dU + dW$$

Since $\quad dQ = dW = 0$

$\Rightarrow \quad dU = 0$

No change in internal energy $\Rightarrow$ No change in temperature of air.

$$\text{Ideal gas equation}, T = \text{Constant}$$

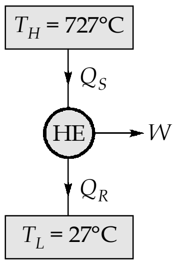
$$\Rightarrow \quad P_1V_1 = P_2V_2$$

$$\Rightarrow \quad P_2 = \frac{P_1V_1}{V_2} = (1000)\times\frac{2}{4} = 500 \text{ kPa}$$

19. (a)

$$T_H = 727 + 273 = 1000 \text{ K}$$

$$T_L = 27 + 273 = 300 \text{ K}$$



The maximum possible efficiency of a heat engine operating between two thermal reservoir,

$$\eta = 1-\frac{T_L}{T_H} = 1-\frac{300}{1000} = 0.7$$

Efficiency claimed by the inventor $\eta_{claim} = \dfrac{W}{Q_1} = \dfrac{0.6}{1} = 0.6$

So, claimed efficiency (0.6) is less than the maximum possible efficiency (0.7) and hence the claimed device is feasible as a heat engine.

20. (c)

Mixture of gas,

$$\text{Oxygen } (O_2) = 0.1 \text{ kmol}$$

$$\text{Nitrogen } (N_2) = 0.1 \text{ kmol}$$

$$\text{Methane } (CH_4) = 0.8 \text{ kmol}$$

Molar mass,

$$O_2 = 32 \text{ kg/kmol}$$

$$N_2 = 28 \text{ kg/kmol}$$

$$CH_4 = 16 \text{ kg/kmol}$$

$$\text{Mass of } O_2 = \text{Mole} \times \text{Molar mass} = 0.1 \times 32 = 3.2 \text{ kg}$$

$$\text{Mass of } N_2 = \text{Mole} \times \text{Molar mass} = 0.1 \times 28 = 2.8 \text{ kg}$$

$$\text{Mass of } CH_4 = \text{Mole} \times \text{Molar mass} = 0.8 \times 16 = 12.8 \text{ kg}$$

$$\text{Mass fraction of } N_2 = \frac{m_{N_2}}{m_{O_2}+m_{N_2}+m_{CH_4}} = \left(\frac{2.8}{3.2+2.8+12.8}\right) = 0.148$$

21. (a)

$$\text{Volume of the balloon is} = m[v_f + xv_{fg}] = 2[0.001053 + 0.85\,(1.1594 - 0.001053)] = 1.971 \text{ m}^3$$

$$\frac{\pi}{6}D^3 = 1.971$$

$$D = 1.55 \text{ m}$$

22. (a)

Given:

$P_1 = 0.8725$ kPa, $T_1 = 273 + 5 = 278$ K, $P_2 = ?$, $T_2 = 10 + 273 = 283$ K, $R = 0.4615$ kJ/kgK, $h_{fg} = 2489.1$ kJ/kg

From Clapeyron equation,

$$\left(\frac{dP}{dT}\right)_{sat} = \frac{P.h_{fg}}{RT^2}$$

$$\left(\frac{dP}{P}\right) = \frac{h_{fg}}{R}\left(\frac{dT}{T^2}\right)$$

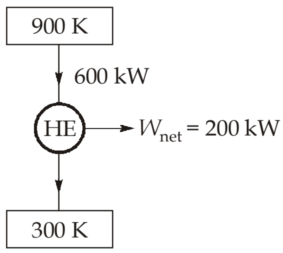
For small temperature internal,

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{h_{fg}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{P_2}{0.8725}\right) = \frac{2489.1}{0.4615}\left(\frac{1}{278} - \frac{1}{283}\right)$$

$$P_2 = 1.229 \text{ kPa} \approx 1.23 \text{ kPa}$$

23. (d)



$$W_{\text{reversible form}} = Q\left(1 - \frac{T_L}{T_H}\right) = 600\left(1 - \frac{300}{900}\right) = 400 \text{ kW}$$

$$\text{Irreversibility} = W_{rev} - W_{actual}$$

$$= 400 - 200 = 200 \text{ kW}$$

24. (a)

As given:

$$\eta_{I} = \eta_{II}$$

$$\Rightarrow \quad T = \sqrt{T_H T_L} = \sqrt{1300 \times 300} = 624.5 \text{ K}$$

Therefore, the temperature of the intermediate reservoir

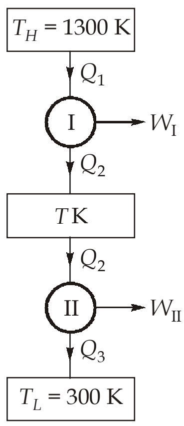
$$T = 624.5 \text{ K}$$

$$\frac{Q_2}{Q_1} = \frac{T}{T_H}$$

$$\Rightarrow \quad Q_2 = \frac{624.5 \times 100}{1300} = 48.038 \text{ kJ}$$

$$\eta_{II} = 1 - \frac{300}{624.5} = 51.96\%$$

$$W_{II} = \eta_{II} Q_2 = 0.5196 \times 48.038 = 24.96 \text{ kJ}$$



25. (c)

$$\text{Volume} = 1\text{ m}^3$$

$$\text{Mole of } CO_2,\ n_1 = 0.2\, n$$

Where n is total number of mole of mixture ($CO_2 + O_2$)

$$\text{Mole of } O_2,\ n_2 = 0.8n$$

$$\text{Initial, } P_1 = 100\text{ kPa}$$

$$\text{Initial, } T_1 = 300\text{ K}$$

$$\text{Final pressure, } P_2 = 500\text{ kPa, Temperature} = 300\text{ K}$$

Assume mole of N_2 as n_3

From ideal gas equation,

$$\frac{PV}{n\bar{R}} = \text{Constant} \qquad [\bar{R} = \text{Universal constant}]$$

$$PV = n\bar{R}T$$

For isothermal process,

$$\frac{P_1V_1}{(n_1+n_2)\bar{R}} = \frac{P_2V_2}{(n_1+n_2+n_3)\bar{R}}$$

$$\frac{100\times 1}{(0.2n+0.8n)} = \frac{500\times 1}{(0.2n+0.8n+n_3)}$$

$$100\,(n+n_3) = 500\times n \qquad \text{... (i)}$$

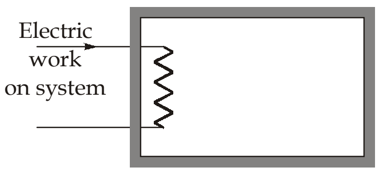
At initial point, $$n = \frac{P_1V_1}{RT_1} = \frac{100\times 1\times 10^3}{8.3145\times 300} = 40\text{ mole}$$

From (i), $$100n + 100n_3 = 500n$$

$$n_3 = \frac{400\times 40}{100} = 160\text{ mole}$$

26. (a)

Insulated rigid tank,



Given: $v = 0.8\text{ m}^3$, $m = 1.5$ kg, $P_i = 100$ kPa, $P_f = 135$ kPa, $T_o = 298$ K,

$PV = mRT$

At V = Constant

$$P \propto T$$

$$\frac{P_i}{P_f} = \frac{T_i}{T_f} \Rightarrow \frac{T_1}{T_2} = \frac{P_1}{P_2}$$

Exergy destroyed, $$\Delta X = T_o S_{gen}$$

$$\Delta X = 298\times\left[mc_v \ln\left(\frac{T_f}{T_i}\right)\right] = 298\times\left[1.5\times 680\ln\left(\frac{135}{100}\right)\right]$$

$$\Delta X = 91.219\text{ kJ}$$

27. (c)

Mass balance:

$$
\begin{aligned}
m_i - m_e &= m_2 - m_1 \\
m_e &= m_1 - m_2
\end{aligned}
$$

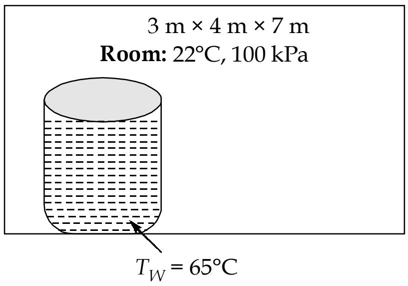
Energy balance:

$$
\begin{aligned}
(\Delta E)_{\text{system}} &= E_{\text{in}} - E_{\text{out}} \\
E_{\text{in}} &= m_i h_i + Q_i + W_i = W_i \qquad (Q_i = 0,\ m_i h_i = 0) \\
E_{\text{out}} &= m_e h_e + Q_e + W_e = m_e h_e \qquad (Q_e = 0,\ W_e = 0) \\
W_i - m_e h_e &= m_2 u_2 - m_1 u_1 \\
W_i - (m_1 - m_2) h_e &= m_2 u_2 - m_1 u_1 \\
m_1 &= \frac{P_1 V_1}{R T_1} = \frac{500 \times 1.7}{0.287 \times 323} = 9.169 \text{ kg} \\
m_2 &= \frac{P_2 V_2}{R T_2} = \frac{200 \times 1.7}{0.287 \times 323} = 3.667 \text{ kg} \\
u_2 &= u_1 = c_v T \\
W_i &= (m_1 - m_2) h_e + m_2 u_2 - m_1 u_1 \\
&= 5.502 \times 1.005 \times 323 + (-5.502) \times 0.718 \times 323 \\
&= 510.04 \text{ kJ}
\end{aligned}
$$

28. (a)

Mass of air in the room,

$$
m_{\text{air}} = \frac{P_1 V}{R T_1} = \frac{(100) \times 3 \times 4 \times 7}{0.287 \times 295} = 99.214 \text{ kg}
$$



By energy balance:

Heat lost by water = Heat gain by air

$$
\begin{aligned}
1000 \times 4.18 \times (65 - T_f) &= 99.21 \times 0.718\, (T_f - 22) \\
58.763(65 - T_f) &= T_f - 22 \\
\Rightarrow \qquad T_f &= 64.28°\text{C}
\end{aligned}
$$

Now,

$$
X_{\text{destroyed}} = T_o S_{\text{gen}}
$$

where,

$$
\begin{aligned}
S_{\text{gen}} &= (\Delta S)_{\text{water}} + (\Delta S)_{\text{air}} \\
&= m c_w \ln\left(\frac{T_f}{T_w}\right) + m_{\text{air}} \times c_v \times \ln\left(\frac{T_f}{T_q}\right) \\
&= 1000 \times 4.186 \ln\left(\frac{273 + 64.28}{273 + 65}\right) + 99.214 \times 0.718 \ln\left(\frac{273 + 64.28}{273 + 22}\right) \\
&= 0.6147 \text{ kJ/K}
\end{aligned}
$$

So,

$$
X_{\text{destruction}} = 283 \times 0.6147 = 173.98 \text{ kJ}
$$

29. (d)

Given: $t = ax^2 + b$

At $x = 5$ cm, $t = 0°$,

$$\Rightarrow \quad 0 = a \times 25 + b$$

$$\Rightarrow \quad -25a = +b \quad \text{... (i)}$$

At $x = 20$ cm, $t = 100°$,

$$\Rightarrow \quad 100 = 400a + b$$

From equation (i), $100 = 400a - 25a$

$$a = \frac{100}{375} = \frac{4}{15}$$

$$\Rightarrow \quad b = -25 \times \frac{4}{15} = -\frac{20}{3}$$

At $x = 15$, $t = \frac{4}{15} \times 15^2 + \left(-\frac{20}{3}\right) = 53.33°\text{C}$

30. (b)

For a rigid closed vessel; $\delta W = 0$ and

$$v_f + x(v_g - v_f) = v_c$$

$$\Rightarrow \quad 0.0010605 + x(0.8857 - 0.0010605) = 0.003155$$

$$x = 2.367 \times 10^{-3}$$

$$u_1 = u_f + xu_{fg}$$

$$= 504.49 + (2.367 \times 10^{-3})\,(2529.5 - 504.49)$$

$$= 509.283 \text{ kJ/kg}$$

$$u_2 = u_c = 2029.6 \text{ kJ/kg}$$

From first law of thermodynamics,

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

$$\delta Q = 0 + m(u_2 - u_1)$$

$$= 2 \times (2029.6 - 509.283)$$

$$= 3040.6 \text{ kJ}$$

■■■■