CLASS TEST

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THERMODYNAMICS

MECHANICAL ENGINEERING

Date of Test : 26/08/2025

ANSWER KEY

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

DETAILED EXPLANATIONS

1. **(d)**

2. **(c)**

During a phase change process, the temperature and pressure of a pure substance are dependent properties.

3. **(b)**

The boundary work can determined by

$$W = \int_1^2 P dV = \int_1^2 (aV+b) dV = a\frac{V_2^2 - V_1^2}{2} + b(V_2 - V_1)$$

$$= \left(-1200 \text{ kPa/m}^3\right)\frac{\left(0.12^2 - 0.42^2\right)\text{m}^6}{2} + (600 \text{ kPa})(0.12 - 0.42)\text{m}^3$$

$$= -\ 82.8 \text{ kJ}$$

4. **(d)**

$$S_2 - S_1 = \int_1^2 \frac{dQ}{T} + S_{\text{gen}}$$

For internally reversible, $S_{\text{gen}} = 0$

So, $$S_2 - S_1 = \begin{cases} = 0 \\ > 0 \\ < 0 \end{cases}, \qquad \left[\text{Depending on} \int_1^2 \frac{dQ}{T}\right]$$

5. **(c)**

Assuming air to be ideal, entropy change for 1 kg of air is

$$\Delta S = C_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{V_2}{V_1}\right)$$

For isothermal process, $T_1 = T_2$

$$\therefore \quad \Delta S = R\ln\left(\frac{V_2}{V_1}\right)$$

$$V_2 = 10V_1$$

$$\therefore \quad \Delta S = 0.287 \ln 10$$

$$\Delta S = 0.66 \text{ kJ/K}$$

6. **(b)**

Power consumed by fan, $E_1 = 25$ W

Power delivered to air, $E_2 = \frac{1}{2}\dot{m}v^2 = \frac{1}{2}0.8 \times 8^2 = 25.6$ W

Since $E_2 > E_1$, this fan violates the first law of thermodynamics. Hence the claim of inventor is impossible.

7. **(d)**

Entropy of an isolated system can never decrease and exergy can never increase.

From exergy balance for isolated system, change in exergy is equal to negative of exergy destruction. And since, exergy destruction is always positive, exergy of an isolated system can never increase.

8. **(a)**

For vaporization Clausius Clapeyron equation is given by

$$\frac{dP}{dT} = \frac{h_{fg}}{T\left(v_g - v_f\right)}$$

At temperature considerably below critical temperature, $v_g >> v_f$ and using ideal gas equation, we get,

$$v_g = \frac{RT}{P}$$

$$\therefore \quad \frac{dP}{dT} = \frac{h_{fg}}{T} \times \frac{P}{RT}$$

$$\text{or} \quad \frac{dP}{P} = \frac{h_{fg}}{R}\frac{dT}{T^2}$$

Integrating from state 1 → 2.

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

9. **(c)**

For an adiabatic process in which work w is done on the gas, as a result of which its state moves from A to B.

$$\text{Work, } w = -(U_B - U_A)$$

If work w is done on the gas, then $U_B > U_A (w < 0)$ and if the gas itself performs work, then $U_B < U_A (w > 0)$.

10. **(a)**

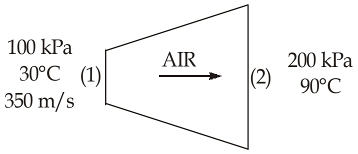
From the first law:

$$_1Q_2 = {}_1W_2 + \Delta U \Rightarrow \Delta U = {}_1Q_2 - \int P dv$$

$$= -25 \text{ kJ} - p(V_2 - V_1)$$

$$= -25 \text{ kJ} - 0.35 \text{ MPa}(0.05 - 0.15)\text{m}^3 = 10 \text{ kJ}$$

11. **(b)**



from steady flow energy equation

$$\dot{m}\left(h_1 + V_1^2/2\right) = \dot{m}\left(h_2 + V_2^2/2\right)$$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

Solving for exit velocity,

$$V_2 = \left[V_1^2 + 2(h_1 - h_2)\right]^{0.5} = \left[V_1^2 + 2c_p(T_1 - T_2)\right]^{0.5}$$

$$= \left[(350\text{ m/s})^2 + 2(1.007\text{ kJ/kgK})(30 - 90)\text{K}\left(\frac{1000\,\text{m}^2/\text{s}^2}{1\,\text{kJ/kg}}\right)\right]^{0.5}$$

$$= 40.74\text{ m/s}$$

12. **(a)**

i. Air is an ideal gas which means $U = f(T)$

ii. Temperature remains constant during quasi-equilibirum isothermal expansion process.

from first law: $Q = W + \Delta U$

Net work $= 15 - 3 = 12$ kJ

$\Delta U = 0$ (for isothermal process)

$\therefore \quad Q = W = 12$ kJ

13. **(d)**

Work done during process

$$W_{12} = \int_1^2 PdV = \int_1^2 (A + BV)dV$$

$$W_{12} = A(V_2 - V_1) + 0.5B(V_2^2 - V_1^2)$$

$$W_{12} = A(V_2 - V_1) + 0.5B(V_2 + V_1)(V_2 - V_1)$$

$$W_{12} = 0.5[A + BV_2 + A + BV_1](V_2 - V_1)$$

$$W_{12} = 0.5(P_1 + P_2)(V_2 - V_1)$$

14. **(a)**

This is a closed system since no mass enters or leaves. So change in internal energy is zero.

$$0 = \Delta U(\text{since } Q = W = KE = PE = 0)$$

$$0 = m_1c_v(T_3 - T_1) + m_2c_v(T_3 - T_2)$$

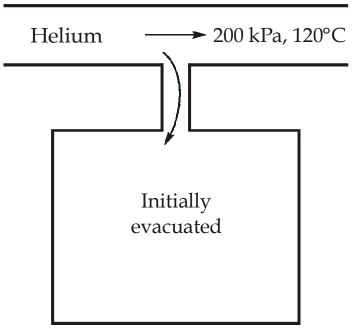
$$(m_1 + m_2)T_3 = m_1T_1 + m_2T_2$$

and $\quad m_3 = m_1 + m_2$

Solving for final temperature, we find

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

15. **(b)**



Noting that the flow work in the supply line is converted to sensible internal energy in the tank, the final helium temperature in the tank is determined as follows

$$u_{\text{tank}} = h_{\text{line}} \quad \text{...(1)}$$

$$h_{\text{line}} = c_p T_{\text{line}} = (5.1926 \text{ kJ/kgK})(120 + 273\text{K}) = 2040.7 \text{ kJ/kg}$$

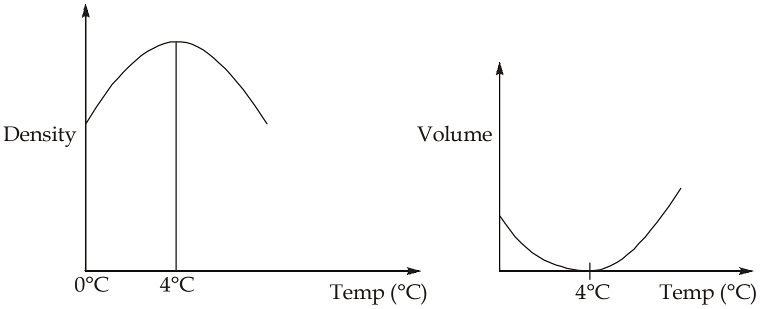
$$u_{\text{tank}} = c_v T_{\text{tank}}$$

$$2040.7 \text{ kJ/kg} = (3.1156 \text{ kJ/kgK}) T_{\text{tank}}$$

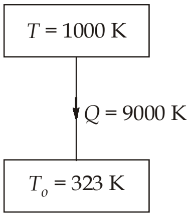
$$T_{\text{tank}} = 655.0 \text{ K}$$

16. **(b)**

This the exception behaviour shown by water.



17. **(c)**



$$\text{Change in universe entropy} = \Delta S_{uni} = Q\left[\frac{1}{T_o} - \frac{1}{T}\right] = 900 \times \left[\frac{1}{323} - \frac{1}{1000}\right]$$

$$\text{Total loss of availability} = I = T_o \times \Delta S_{\text{uni}} = 6093 \text{ kJ}$$

18. **(c)**

$$\Delta s = \int_1^2 \frac{dQ}{T} + s_{\text{gen}}$$

For reversible process, $s_{\text{gen}} = 0$

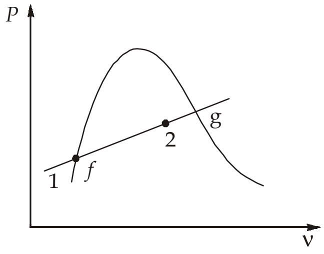
For adiabatic compressor, $dQ = 0$

$\therefore \quad \Delta s_{adi} = 0$ or entropy remains constant

For isothermal compressor, $dQ < 0$ (as it is rejects heat to maintain constant temperature).

$\therefore \quad \Delta s_{iso} < 0$

19. **(c)**



State 1

At $T = 80°\text{C}$, $P_{\text{sat}} = 47.39 < 100$ kPa

State 1 lies in subcooled region.

$$v_1(T, P) \simeq v_f(T)$$

So, $\quad v_1 = 1.029 \times 10^{-3} \text{ m}^3/\text{kg}$

State 2 lies on $P = C \cdot v$ (Pressure is proportional to volume)

$$\therefore \quad P_2 = P_1 \frac{v_2}{v_1}$$

Let, $\quad v_2 = v_{2g} = 0.0501 \text{ m}^3/\text{kg}$ then,

$$P_2 = \frac{100 \times 0.0501}{1.029 \times 10^{-3}} = 4868.8 \text{ kPa} > 3973 \text{ kPa}$$

Since, $\quad P_2 > P_{\text{sat @250°C}} \Rightarrow$, Not possible.

So, the final state is in wet region

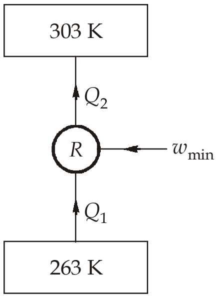
$$P_2 = 3973 \text{ kPa}$$

$$v_2 = \frac{P_2 v_1}{P_1} = \frac{3973}{100} \times 1.029 \times 10^{-3} = 0.0408 \text{ m}^3/\text{kg}$$

$$v_2 = 0.0408 \text{ m}^3/\text{kg}$$

$$x_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.0408 - 1.251\times 10^{-3}}{0.0501 - 1.251\times 10^{-3}} = 0.8$$

20. **(c)**



Heat removed from water, $Q_1 = (30 \times 4.18) + (2.1 \times 10) + 335$

$$= 481.4 \text{ kJ/kg}$$

Entropy of system, $(\Delta S_{\text{sys}}) = c_{p,\text{ water}} \times \ln\left(\frac{T_2}{T_1}\right) + \left(\frac{Q_{latent}}{T}\right) + c_{p,ice} \times \ln\left(\frac{T_3}{T_2}\right)$

Entropy of surrounding,

$$(\Delta S_{\text{surr}}) = \frac{481.4 + w_{\min}}{303}$$

For reversible process (As work is minimum is reversible process) $\Delta S_{\text{unv}} = 0$

$$\Delta S_{\text{sys}} + \Delta S_{\text{surr}} = 0$$

$$c_{p,\text{ water}} \times \ln\left(\frac{273}{303}\right) + \left(-\frac{335}{273}\right) + c_{p,ice} \times \ln\left(\frac{263}{273}\right) + \frac{481.4 + w_{\min}}{303} = 0$$

$$w_{\min} = 46.201 \text{ kJ/kg}$$

21. **(c)**

$$\eta_{\text{II}} = \frac{\eta_I}{\eta_{\text{Carnot}}}$$

$$\frac{\eta_I}{\eta_{\text{II}}} = \eta_{\text{Carnot}}$$

$$\eta_{\text{Carnot}} = \left(1 - \frac{T_0}{T}\right) = \left(1 - \frac{300}{900}\right) = 0.67$$

22. **(b)**

For this case the total flow is 3 mol units.

mole fraction, $$y_A = \frac{n_A}{n_{\text{tot}}} = \frac{1}{3}$$

$$y_B = \frac{n_B}{n_{\text{tot}}} = \frac{2}{3}$$

$$\Delta S = \frac{-n_A}{n_{\text{total}}}\bar{R}\ln(y_A) - \frac{-n_B}{n_{\text{total}}}\bar{R}\ln(y_B)$$

$$\Delta S = -\bar{R}\left[\left(\frac{1}{3}\right)\ln\frac{1}{3} + \left(\frac{2}{3}\right)\ln\frac{2}{3}\right] = +\,0.6365\,\bar{R}$$

23. **(a)**

The general relation for the specific heat difference $c_p - c_v$ is

$$c_p - c_v = -T\left(\frac{\partial v}{\partial T}\right)_P^2\left(\frac{\partial P}{\partial v}\right)_T$$

For the given gas, $P(v - b) = RT$. Then,

$$v = \frac{RT}{P} + b \rightarrow \left(\frac{\partial v}{\partial T}\right)_P = \frac{R}{P}$$

$$P = \frac{RT}{v-b} \rightarrow \left(\frac{\partial P}{\partial v}\right)_T = -\frac{RT}{(v-b)^2} = \frac{-P}{v-b}$$

Substituting,

$$c_p - c_v = -T\left(\frac{R}{P}\right)^2\left(\frac{-P}{v-b}\right) = \frac{TR^2}{P(v-b)} = R$$

24. **(a)**

As per given information

$$\dot{W} = 2.5\text{ kW} = \frac{\dot{Q}_H}{(COP)_{HP}}$$

$$(\text{COP})_{\text{HP}} = \frac{T_H}{(T_H - T_L)} = \frac{273+40}{40-5} = 8.943$$

$$\dot{Q}_H = \dot{W}\times(COP)_{HP} = 2.5 \times 8.943 = 22.36\text{ kW} = hA\Delta T$$

$$A = \frac{\dot{Q}_H}{h\Delta T} = \frac{22.36\times10^3}{50\times(40-30)} = 44.72\text{ m}^2$$

25. **(c)**

State 1: $v_1 = v_{g@200\text{ kPa}} = 0.8857\text{ m}^3/\text{kg},\ T_1 = 120.2°\text{C}$

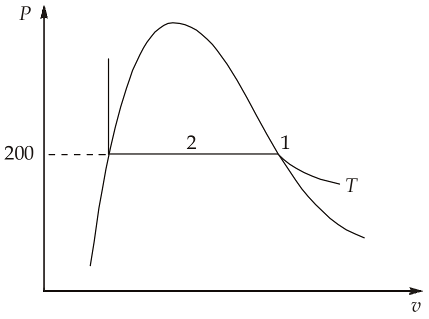
Process, P = constant = 200 kPa

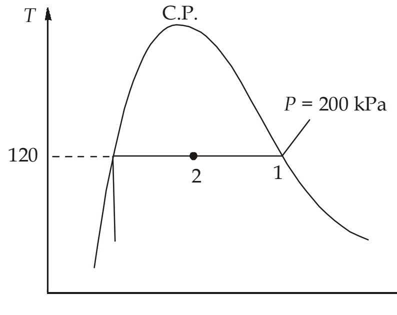
State 2: $P,\ v_2 = v_1/2 = 0.44285\text{ m}^3/\text{kg}$

$v_2 < v_g$ so two phase $T_2 = T_{\text{sat}} = 120.2°$

Height is proportional to volume

$$h_2 = h_1 \times v_2/v_1 = 0.1\text{ m} \times 0.5 = 0.05\text{ m}$$





26. **(c)**

The Third Law of Thermodynamics states that all aspects of entropy approach the value of zero as the temperature of the system approaches zero, if the system is in complete internal equilibrium.

27. **(c)**

State 1: $T = 60°\text{C},\ x = 0.0,\ v = 0.001017\text{ m}^3/\text{kg}$

Process: T = constant = 60°C

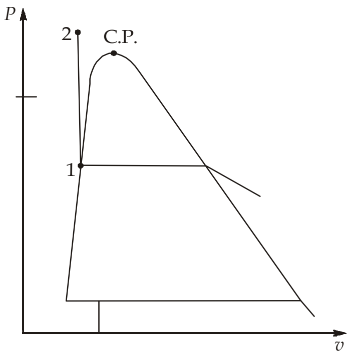
State 2: $T,\ v = 0.99 \times v_{f@60°\text{C}} = 0.99 \times 0.001017 = 0.0010068\text{ m}^3/\text{kg}$

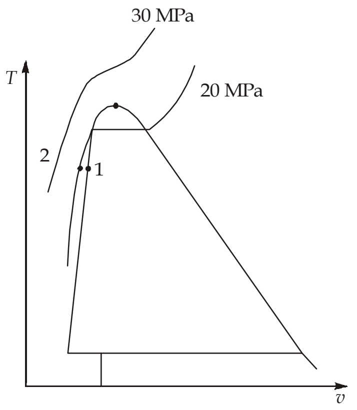
Between 20 and 30 MPa,

So from linear interpolation

$$\frac{P-20}{10} = \frac{0.0010068-0.0010084}{0.0010042-0.0010084}$$

$$P = 23.8\text{ MPa}$$





28. **(d)**

A pure substance is one that has a homogeneous and invariable chemical composition. It may exist in more than one phase, but the chemical composition is the same in all phases. Thus, liquid water, a mixture of liquid water and water vapor (steam), and a mixture of ice and liquid water are all pure substances; every phase has the same chemical composition. In contrast, a mixture of liquid air and gaseous air is not a pure substance because the composition of the liquid phase is different from that of the vapor phase.

29. **(a)**

Air is an ideal gas. The kinetic and potential energies are negligible.

We take the air in the rigid tank as the system. This is a closed system since no mass crosses the sysem boundary during the process. Here the question is the work potential of a fixed mass, which is the nonflow exergy by definition.

Taking the state of the air in the tank to be state 1 and noting that $T_1 = T_o = 300$ K, the mass of air in the tank is

$$m_1 = \frac{P_1V}{RT_1} = \frac{(1000\,\text{kPa})(200\,m^3)}{(0.287\,\text{kPa m}^3/\text{kgK})(300\,\text{K})} = 2323 \text{ kg}$$

The exergy content of the compressed air can be determined from

$$X_1 = m\phi_1$$

$$= m\left[(u_1 - u_0) + P_o(v_1 - v_o) - T_o(s_1 - s_o) + \frac{V_1^2}{2} + gz_1\right]$$

$$= m[P_o(v_1 - v_o) - T_o(s_1 - s_o)]$$

We note that

$$P_o(v_1 - v_o) = P_o\left(\frac{RT_1}{P_1} - \frac{RT_o}{P_o}\right) = RT_o\left(\frac{P_o}{P_1} - 1\right) \qquad (\text{since } T_1 = T_o)$$

$$T_o(s_1 - s_o) = T_o\left(c_p \ln\frac{T_1}{T_1} - R\ln\frac{P_1}{P_o}\right) = -RT_o\ln\frac{P_1}{P_0} \qquad (\text{since } T_1 = T_o)$$

Therefore,

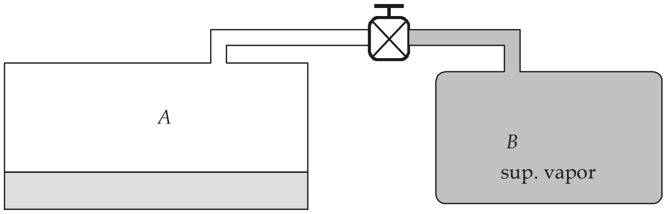
$$\phi_1 = RT_o\left(\frac{P_o}{P_1} - 1\right) + RT_o\ln\frac{P_1}{P_o} = RT_o\left(\ln\frac{P_1}{P_o} + \frac{P_o}{P_1} - 1\right)$$

$$= (0.287\,\text{kJ/kgK})(300\,\text{K})\left(\ln\frac{1000\,\text{kPa}}{100\,\text{kPa}} + \frac{100\,\text{kPa}}{1000\,\text{kPa}} - 1\right)$$

and $$x_1 = m_1\phi_1 = (2323 \text{ kg})(120.76 \text{ kJ/kg}) = 280{,}525 \text{ kJ} = 280.525 \text{ MJ}$$

30. **(a)**

Control volume: Both tanks. Constant total volume and mass process.



State A_1: (P, v) $$m_A = \frac{V_A}{v_A} = \frac{1}{0.5} = 2 \text{ kg}$$

State B_1: (P, T) $$v_B = 0.6173 \text{ m}^3/\text{kg}$$

⇒ $$V_B = m_B v_B = 3.5 \text{ kg} \times 0.6173 \text{ m}^3/\text{kg} = 2.1606 \text{ m}^3$$

Final state: $$m_{\text{tot}} = m_A + m_B = 5.5 \text{ kg}$$

$$V_{\text{tot}} = V_A + V_B = 3.1606 \text{ m}^3$$

$$v_2 = V_{\text{tot}}/m_{\text{tot}} = \frac{3.1606}{5.5} = 0.5746 \text{ m}^3/\text{kg}$$

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