DETAILED SOLUTIONS

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UPPSC AE 2019
ASSISTANT ENGINEER

MECHANICAL ENGINEERING

Test 2

Part Syllabus Test

Thermodynamics

ANSWER KEY

1.	(d)	11.	(b)	21.	(a)	31.	(a)	41.	(b)
2.	(c)	12.	(b)	22.	(b)	32.	(c)	42.	(b)
3.	(c)	13.	(a)	23.	(c)	33.	(a)	43.	(c)
4.	(b)	14.	(b)	24.	(c)	34.	(b)	44.	(c)
5.	(c)	15.	(d)	25.	(b)	35.	(c)	45.	(b)
6.	(b)	16.	(c)	26.	(c)	36.	(c)	46.	(a)
7.	(c)	17.	(a)	27.	(b)	37.	(b)	47.	(c)
8.	(b)	18.	(d)	28.	(b)	38.	(c)	48.	(c)
9.	(c)	19.	(b)	29.	(d)	39.	(a)	49.	(a)
10.	(a)	20.	(c)	30.	(d)	40.	(a)	50.	(c)

DETAILED EXPLANATIONS

1. (d)

$$\text{For ideal gas } z = 1$$
$$\text{For a non ideal gas } z < 1, \quad z > 1$$
$$\text{but } z \neq 1$$

3. (c)

According to 1st law of thermodynamics,

$$\oint \delta Q = \oint \delta W = Q_{1-2} + Q_{2-1} = W_{1-2} + W_{2-1}$$
$$20 - 10 = 40 + W_{2-1}$$
$$10 = 40 + W_{2-1} \quad \Rightarrow \quad W_{2-1} = -30 \text{ kJ}$$

4. (b)

$$\text{Net heat intraction, } \oint \delta Q = \oint \delta W = \text{Area enclosed in } p\text{-}v \text{ diagram}$$
$$= \pi R^2 = \pi \text{ (1) m}^3 \text{ (1) MPa}$$
$$= \pi \times 1 \text{ m}^3 \times 1000 \text{ kPa} = 3141 \text{ kJ}$$

8. (b)

$$(dS)_{\text{system}} = mc_p \ln\left(\frac{T_2}{T_1}\right) = 4 \times 1 \times \ln\left(\frac{400}{800}\right) = -2.7726 \text{ kJ/K}$$
$$(dS)_{\text{surrounding}} = \frac{mc_p(T_1 - T_2)}{T_o} = \frac{4 \times 1 \times 400}{300} = 5.33 \text{ kJ/K}$$
$$(dS)_{\text{universe}} = -2.7726 + 5.33 = 2.5601 \text{ kJ/kg}$$
$$\text{Unavailable energy} = T_o\, dS = 300 \times 2.5601 = 768.22 \text{ kJ}$$
$$\text{Heat transferred} = mc\, dT = 4 \times 1 \times (800 - 400) = 1600 \text{ kJ}$$
$$\text{Available energy} = 1600 - 768.22 = 831.78 \text{ kJ}$$

19. (b)

For maximum work, heat engine must be reversible,

$$(dS)_{\text{HE}} = 0$$
$$(dS)_1 + (dS)_2 = 0$$

Let m, c_p are the mass and specific heat of body respectively.

$$mc_p \ln\left(\frac{T_f}{T_1}\right) + mc_p \ln\left(\frac{T_f}{T_2}\right) = 0$$

$$\Rightarrow \quad \ln\left(\frac{T_f^2}{T_1 \times T_2}\right) = 0$$

$$\Rightarrow \quad \frac{T_f^2}{T_1 \times T_2} = 1$$

$$\Rightarrow \quad T_f = \sqrt{T_1 T_2}$$

23. (c)

On applying steady flow energy equation for a nozzle,

$$h_1 + \frac{V_1^2}{2000} = h_2 + \frac{V_2^2}{2000} \qquad (W = 0,\ Q = 0,\ \Delta PE = 0)$$

$$V_2 = \sqrt{2000(h_1 - h_2)} = \sqrt{2000 \times 45}$$

$$= \sqrt{90000} = 300 \text{ m/s}$$

24. (c)

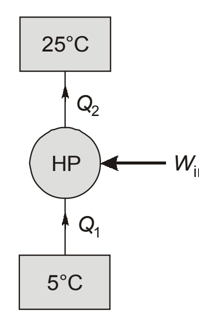
$$(COP)_{HP} = 1 + (COP)_{RE}$$
$$= 1 + 3.4 = 4.4$$

25. (b)

Given: m = 0.2 kg, c_w = 4.2 kJ/kgK, LH of vaporization = 2256 kJ/kg

Rate of heat transfer to water, $\dot{Q} = \frac{m \times LH}{t} = \frac{0.2 \times 2256}{10} = 45.12 \text{ kJ/min}$

28. (b)



$$\dot{Q}_2 = 18000 \text{ kJ/hr} = \frac{18000}{3600} = 5 \text{ kW}$$

$$\dot{W}_{in} = 1.9 \text{ kW}$$

$$(COP)_{HP} = \frac{\dot{Q}_2}{\dot{W}_{in}} = \frac{5}{1.9} = 2.63$$

30. (d)

$C_6H_{14} + x[0.21\ O_2 + 0.79N_2] \rightarrow aCO_2 + bH_2O + cN_2$

On balancing hydrogen, $2b = 14 \Rightarrow b = 7$

On balancing carbon, $a = 6$

On balancing oxygen, $0.21 \times 2x = 2a + b$

$= 2 \times 6 + 7 = 19$

$$x = \frac{19}{0.42} = 45.238 \text{ mole}$$

On balancing nitrogen, $0.79 \times 2x = 2c$

$c = 3.5738$

So, Mole of fraction of CO_2, $y_{CO_2} = \frac{a}{a+b+c} = \frac{6}{6+7+3.5738} = 0.362 = 36.2\%$

31. (a)

Intensive properties are independent of mass.

32. (c)

Let $R = R_0(1 + \alpha t)$

as R = 2.5, at t = 0 $\quad 2.5 = R_0(1 + \alpha \times 0)$

$\Rightarrow \quad R_0 = 2.5$

Again, at t = 100°C, R = 5, $\quad 5 = 2.5(1 + \alpha \times 100)$

$\Rightarrow \quad \alpha = 0.01$

So when, R = 9 Ω, $\quad 9 = 2.5(1 + 0.01 \times t)$

$\Rightarrow \quad t = 260°C$

33. (a)

As $\quad Tds = dh - vdP$

So for constant pressure lines $dP = 0$

$\Rightarrow \quad \left(\frac{dh}{ds}\right)_P = T$ = Slope = always positive as 'T' is always positive for superheated region.

34. (b)

Let methane is burned with x moles of air,

$CH_4 + x[0.21\,O_2 + 0.79N_2] \rightarrow aCO_2 + bH_2O + cO_2 + dN_2$

$\therefore c = 1$

On balancing hydrogen, $\quad b = 2$

On balancing carbon, $\quad a = 1$

On balancing oxygen, $\quad 0.21 \times 2x = 2a + b + 2$

$$= 2 \times 1 + 2 + 2 = 6$$

$$x = \frac{6}{0.42} = 14.2857$$

So, $\quad \frac{\dot{m}_{air}}{\dot{m}_{fuel}} = \frac{14.2857 \times 29}{1 \times (12 + 4 \times 1)} = 25.89$

36. (c)

An isolated system is either of the following:

1. a physical system so far removed from other systems that it does not interact with them.
2. a thermodynamic system enclosed by rigid immovable walls through which neither matter nor energy can pass.

38. (c)

Given: 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: $\quad R = c_p - c_v = 1 - 0.75 = 0.25$ kJ/kgK

Applying equation of state in term of density,

$$p = \rho R T$$

$$100 = \rho \times 0.25 \times 300$$

$$1 = 0.75\,\rho$$

or $\quad \rho = \frac{1}{0.75} = \frac{10}{75} = 1.33\ \text{kg/m}^3$

39. (a)

We know that, $F = 1.8C + 32$ (F = Temp. in Fahrenheit, C = Temp. in Celsius)

If $F = 2C$

$\therefore$ $1.8C + 32 = 2C$

or $0.2C = 32$

or $C = \dfrac{32}{0.2} = 160°C$

41. (b)

1st law of thermodynamic for process,

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

For adiabatic process, $\delta W = -dU$

Adiabatic work is equal to change in internal energy. The internal energy is point function. Thus, adiabatic is also point function.

42. (b)

For an ideal gas, $s_2 - s_1 = c_v \ln\dfrac{T_2}{T_1} + R\ln\dfrac{V_2}{V_1}$

$$\frac{V_2}{V_1} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}} \quad \text{(for polytropic process)}$$

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}}$$

$$s_2 - s_1 = \left(\frac{R}{\gamma-1} - \frac{R}{n-1}\right)\ln\frac{T_2}{T_1} \quad \left(c_v = \frac{R}{\gamma-1}\right)$$

$$= \left(\frac{R}{\gamma-1} - \frac{R}{n-1}\right)R\ln\frac{T_2}{T_1} = \left\{\frac{n-1-\gamma+1}{(\gamma-1)(n-1)}\right\}R\ln\frac{T_2}{T_1}$$

$$s_2 - s_1 = \frac{(n-\gamma)R}{(\gamma-1)(n-1)}\ln\frac{T_2}{T_1} = \frac{(n-\gamma)R}{(\gamma-1)(n-1)} \times \ln\frac{T_2}{T_1}$$

$$(S_2 - S_1) = m(s_2 - s_1) = \left(\frac{n-\gamma}{n-1}\right)mc_v \log_e\frac{T_2}{T_1} \quad \left(c_v = \frac{R}{\gamma-1}\right)$$

44. (c)

Given data:

$V_1 = 1\ m^3$

$p_1 = 5\ \text{bar} = 5 \times 10^5\ \text{Pa}$

$V_2 = 2\ m^3$

$p_2 = 5\ \text{bar} = 5 \times 10^5\ \text{Pa}$

Paddle work done on the system,

$W_{Paddle} = 200000\ \text{Nm} = 2 \times 10^5\ \text{Nm}$

Work done by the system,

$$W_{1\text{-}2} = p(V_2 - V_1) = 5 \times 10^5(2-1) = 5 \times 10^5 \text{ Nm}$$

Net work done by the system,

$$W_{net} = W_{1-2} - W_{Paddle} = 5 \times 10^5 - 2 \times 10^5 = \mathbf{3 \times 10^5\ Nm}$$

46. (a)

At initial state

Given: $m_1 = 10$ kg, $T_1 = 300$ K, $V_1 = 1\text{ m}^3$

At final state

Given: $m_2 = ?$, $T_2 = 500$ K, $P_2 = P_1$, $V_2 = V_1 = 1\text{ m}^3$ ($\because$ Rigid tank)

$$P_1V_1 = m_1RT_1$$

$$P_2V_2 = m_2RT_2 \qquad (P_2 = P_1 \text{ and } V_1 = V_2)$$

$$m_1T_1 = m_2T_2$$

$$10 \times 300 = m_2 \times 500$$

or $$m_2 = 6 \text{ kg}$$

$$\text{Mass of air escaped} = m_1 - m_2 = 10 - 6 = \mathbf{4\ kg}$$

47. (c)

$$\text{Thermal reservoir, } ds = \frac{Q}{T}$$

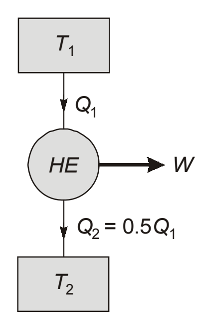
48. (c)

Heat required to convert 1 kg of ice to 1 kg of water = L.H. = 335 kJ/kg

Heat given by water at 25°C = $mc_w \times \Delta T = 1 \times 4.2 \times 25 = 105$ kJ/kg < 335

Hence equilibrium temperature will be 0°C, as at equilibrium mixture of ice and water will be present.

49. (a)



$$T_1 = (327 + 273)\text{K} = 600 \text{ K}$$

$$T_2 = (27 + 273)\text{K} = 300 \text{ K}$$

Carnot efficiency: $$\eta_{Carnot} = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{300}{600} = 1 - 0.5 = 0.5 = 50\%$$

Actual efficiency: $$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{0.5Q_1}{Q_1} = 1 - 0.5 = 0.5 = 50\% = \eta_{carnot}$$