# Tutorial 4

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**Ans 1** $u_1 = 2709.9$ kJ/kg
$u_2 = 2659.6$ kJ/kg

$|Q| = 80$ kJ

\# First law of thermodynamics

$Q = W + \Delta U$

$\Rightarrow 80 = 5(2659.6 - 2709.9) + W_{total}$

$\Rightarrow \boxed{W_{total} = 331.5 \text{ kJ}}$

Now, $W_{total} = W_{kettle-steam} + W_{steam@piston}$

$\Rightarrow W_{S \to p} = 331.5 + 18.5$

$\Rightarrow \boxed{W_{S \to p} = 350 \text{ kJ}}$

**Ans 2** Polytropic Process

$\gamma = 1.2$

$\Delta u = -55$ kJ/kg

$\Rightarrow \boxed{PV^{1.2} = C}$

$\Rightarrow (8)(0.02)^{1.2} = (2)(V)^{1.2}$

$\Rightarrow \boxed{V = 0.0635 \text{ m}^3}$

Now, $W = \dfrac{P_2 V_2 - P_1 V_1}{1-\gamma} = \left[\dfrac{2(0.0635) - 8(0.02)}{1-1.2}\right] \times 10^5$

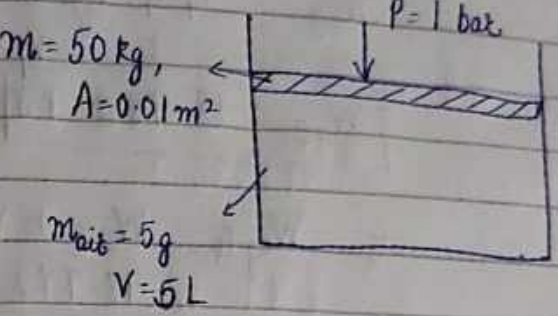
$\Rightarrow \boxed{W = 16.5 \text{ kJ}}$

Now, $Q = W + \Delta U$

$= [16.5 - (0.25)(-55)]$ kJ

$\Rightarrow \boxed{Q = 2.75 \text{ kJ}}$

**Ans. 3** $\Delta u = 260$ kJ/kg




$P = 10^5 + \left(\frac{50 \times 9.8}{0.01}\right)$

$= 1.49$ bar $= 149$ kPa

$\therefore, W = \int P dV = P\Delta V$

$= (149)(0.002 - 0.005)$

$= -0.447$ kJ

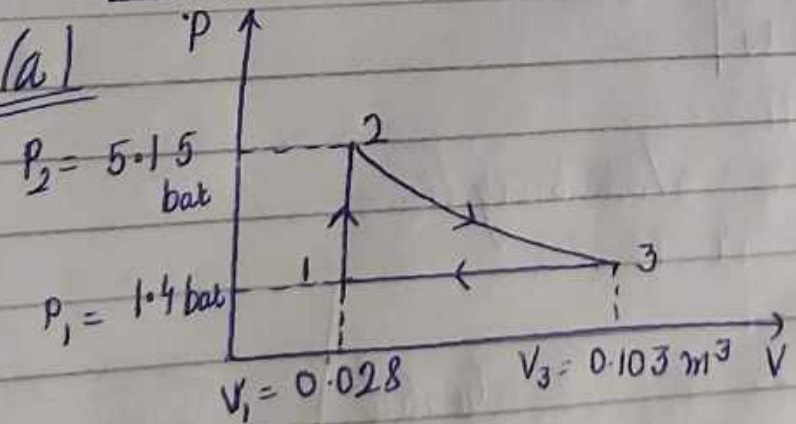
Now, $Q = W + \Delta U$

$= (-0.447) + (5 \times 10^{-3})(-260)$

$= -0.447 - 1.3$

$\boxed{Q = -1.747 \text{ kJ}}$

**Ans. 4** (a)




(b) $W = W_{23} + W_{31}$

Now, $W_{31} = P\Delta V$

$\Rightarrow -10.5 \times 10^3 = (1.4 \times 10^5)(V_1 - V_3)$

$\Rightarrow \boxed{V_3 = 0.103 \text{ m}^3}$

For 2→3, $PV = C$

$\Rightarrow P_2 (0.028) = 8(1.4)(0.0103)$

$\Rightarrow \boxed{P_2 = 5.15 \text{ bar}}$

$\therefore W_{23} = P_1 V_1 \log \frac{V_2}{V_1}$

$\boxed{W_{23} = 18.782 \text{ kJ}}$

$\therefore W_{cycle} = W_{23} + W_3$

$= 18.782 - 10.5$

$\boxed{W_{cycle} = 8.28 \text{ kJ}}$

(c) $Q_{23} = W_{23} + \Delta U_{23}$ ($\Delta U_{23} \to 0$)

$= \boxed{18.782 \text{ kJ}}$

(d) $Q_{31} = W_{31} + \Delta U_{31}$

$= W_{31} + (U_1 - U_3)$

$= W_{31} + (U_1 - U_2)$ ($\because U_2 = U_3$)

$= -10.5 - 26.4$

$\Rightarrow \boxed{Q_{31} = -36.9 \text{ kJ}}$

$\because W_{cycle} > 0 \longrightarrow$ Power cycle

Ans 5

At 4 bar:

for sat. vapor

$v = v_g = 0.460444 \text{ m}^3/\text{kg}$

$h = h_g = 2737.7 \text{ kJ/kg}$

saturated vapor P=4 bar

$m = 0.2 \text{ kg}$

$T_i = 143.63°C$

$V = V_1$

Initial

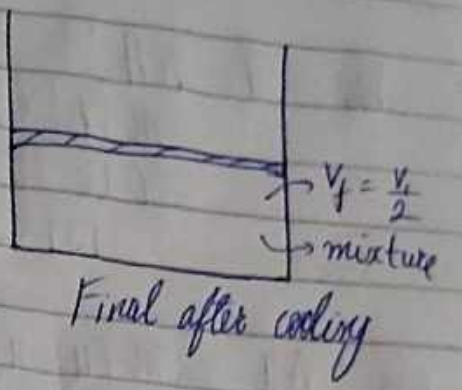
$\Rightarrow \boxed{V_1 = (m v_g) = 0.092 \text{ m}^3}$

After cooling:

$V_f = 0.046\ m^3$

$m = 0.2$

$V_{sp} = 0.23\ m^3/kg$

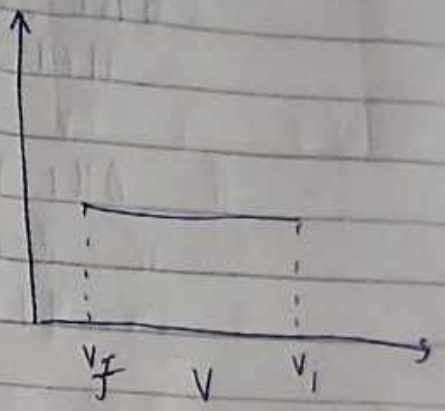


Final after cooling

$\therefore\ V = V_f + x V_{fg}$

$\Rightarrow \boxed{x = 0.4983}$

$\rightarrow \boxed{h = h_f + x h_{fg} = 1667.08\ kJ/kg}$




$Q_p = \Delta H = m(h_2 - h_1)$

$= (0.2)(1667.08 - 2737.7)$

$\boxed{Q_p \approx -214.1\ kJ}$

Ans.6 Initially: $x = 0.7$

$V = 0.1\ m^3$

$P = 2\ bar$, $T = T_{sat} = 120.23^\circ C$

$u = u_f + x u_{fg} = 1921.934\ kJ/kg$

$h = h_f + x h_{fg} = 2045.89\ kJ/kg$

Now, $V_{sp} = V_f + x V_{fg} = 0.61979\ m^3/kg$

$\therefore\ \boxed{m = \frac{V}{V_{sp}} = 0.16\ kg}$

final temp: $T_f = 200^\circ C$ [superheated steam]

$h = 2870.46\ kJ/kg$

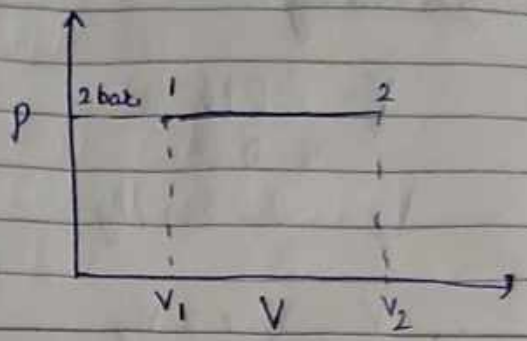
$u = 2654.39\ kJ/kg$

Now, $Q = \Delta H$

$= m(h_2 - h_1)$

$= 0.10\,(2870.46 - 2045.89)$

$= 131.93$ KJ




Now, $\Delta U = m(u_2 - u_1)$

$= 0.16\,(2654.39 - 2045.89)$

$= 117.193$ KJ

$\therefore Q = \Delta U + W$

$\Rightarrow W = Q - \Delta U$

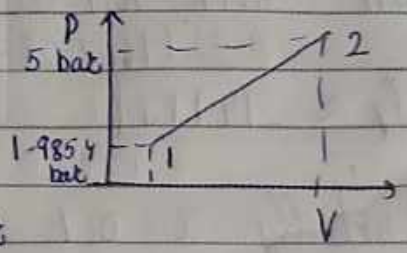
$\boxed{W \simeq 14.7 \text{ KJ}}$

Ans.7 Initially, $m = 0.5$ kg

$T = 120°C$

Sat vapour

$\rightarrow P = P_{sat} = 1.9854$ bar




finally, $P = 500$ kPa $= 5$ bar

At 120°C, $v_g = 0.8915$

$V_1 = m v_g = (0.5)(0.8915)$

$= 0.44575\ m^3$

$$P = \frac{F}{A} = \frac{K(x - x_0)}{A} + P_{atm}$$

$$P = \frac{K(V - V_0)}{A^2} + P_{atm}$$

$$\Rightarrow \boxed{\Delta P = \frac{K}{A^2}\Delta V}$$

$$\Rightarrow 10^5 \times [5 - 1.9854] = \frac{15}{(0.05)^2} (V_2 - 0.44675) \times 10^5$$

$$\Rightarrow \boxed{V_{2sp} = 0.49599 \ m^3/kg}$$

~~$\Rightarrow \boxed{m_2 = 0.99198 \ kg}$~~ $\therefore, \boxed{V_2 = \frac{V_{2sp}}{m} = 0.99198 \ m^3}$

Now, at 5 bar,

$V_g = 0.36812$

$V > V_g \rightarrow$ superheated stem

$800°C \longrightarrow 0.98959$

$900°C \longrightarrow 1.08217$

$$\Rightarrow \frac{T - T_1}{T_2 - T_1} = \frac{V - V_1}{V_2 - V_1}$$

$$\Rightarrow T = 800 + (100)\left(\frac{0.99198 - 0.98959}{1.08217 - 0.98959}\right)$$

$$\boxed{T = 802.588°C}$$

$$\boxed{T \approx 803°C}$$

Now, $\frac{u - u_1}{u_2 - u_1} = \frac{T - T_1}{T_2 - T_1}$

$$\Rightarrow \boxed{u_2 = 3667.9938}$$

Now, $Q = W + \Delta U$

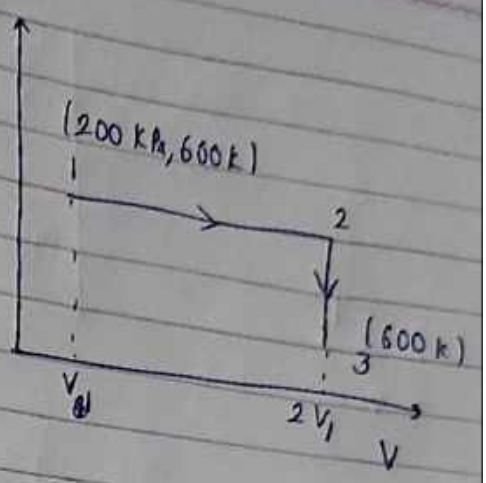
$$= \frac{1}{2}(P_1 + P_2)(V_2 - V_1) + m(V_2 - V_1)$$

$$= \frac{1}{2}(500 + 198.54)(0.49599 - 0.44575) + (0.5)(3667.9138 - 2529.6)$$

$$\boxed{Q \approx 587 \text{ KJ}}$$

**Ans.8** $P_1 = 200\ kPa$

$T_1 = 600\ K$ , $V_2 = 2V_1$




For 1→2: $P \Rightarrow const.$

$\therefore, \frac{T_2}{T_1} = \frac{V_2}{V_1} = 2$

$\Rightarrow T_2 = 1200\ K$

$\therefore, W_{12} = R\Delta T = 0.287\,(600)$

$$\boxed{W_{12} = 172.2\ kJ/kg}$$

From steam table, at 600 K, $h_1 = h_3 = 607.3\ kJ/kg$

at 1200 K, $h_2 = 1277.8\ kJ/kg$

So, $\Delta U = Q - W$

$\Rightarrow Q_{12} = U_2 - U_1 + W_{12} = h_2 - h_1$

$\Rightarrow \boxed{Q_{12} = 670.5\ kJ/kg}$

For 2→3, $V \rightarrow const.$,

$\therefore, W_{23} = 0$

Now, $T_3 = 600$ , $V \rightarrow const.$ $\therefore, \frac{P_3}{P_2} = \frac{T_3}{T_2} = \frac{1}{2}$

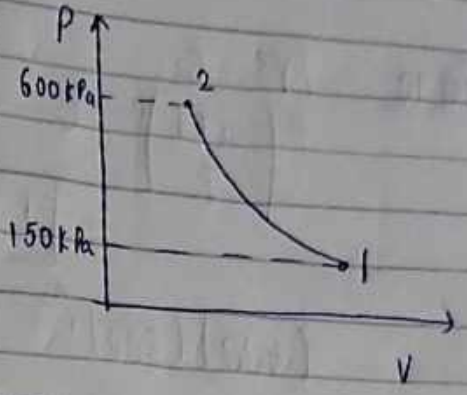
$\Rightarrow P_3 = 100\ kPa$

From steam table, $u_3 = 435.1\ kJ/kg$ (600 K)

$u_2 = 933.4\ kJ/kg$ (1200 K)

$\therefore, \boxed{Q_{23} = \Delta U = -498.3\ kJ/kg}$

**Ans.9** Polytropic Exponent : $n = 1.25$




$$PV^{1.25} = C$$

$$\Rightarrow P_1 V_1^{1.25} = P_2 V_2^{1.25}$$

$$\Rightarrow V_2 = \left(\frac{P_1}{P_2}\right)^{4/5} V_1$$

$$\Rightarrow \boxed{V_2 = 0.000329877\ m^3}$$

$$W = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{(600)(0.000329877) - (150)(0.001)}{1-1.25}$$

$$W = -0.1917\ kJ \approx \boxed{-0.192\ kJ}$$

$$\boxed{W_{by} = -W = 0.192\ kJ}$$

Now, $\Delta U = m C_v \Delta T$

$PV = mRT$

$$\rightarrow m = \frac{(150)(0.001)}{(0.287)(300)} = 0.001742\ kg$$

$$\Rightarrow P_2 V_2 = mRT_2 \rightarrow T_2 = 395.88\ K$$

$$\therefore \Delta U = (0.001742)(0.718)(395.88 - 300)$$

$$= 0.11993\ kJ$$

$$Q = W + \Delta U = -0.072\ kJ$$

$$\boxed{|Q| = 0.072\ kJ}$$

Ans. 10 $PV^n = C$

$P\left(\frac{mRT}{P}\right)^n = C \Rightarrow P^{1-n} T^n = C$

$\Rightarrow \boxed{P T^{\frac{n}{1-n}} = C}$

$(400)(600)^{\frac{n}{1-n}} = (150)(400)^{\frac{n}{1-n}}$

$\Rightarrow \left(\frac{3}{2}\right)^{\frac{n}{1-n}} = \frac{3}{8}$

$\Rightarrow \frac{n}{1-n} = -2.42$

$\Rightarrow \boxed{n = 1.7042}$

$W = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{R \Delta T}{1-n}$

$W = \frac{(0.287)(400-600)}{1-1.7042}$

$\boxed{W = 81.51 \text{ kJ/kg}}$

$q = W + \Delta U$

$= 81.51 + C_v \Delta T = 81.51 + (0.718)(400-600)$

$\Rightarrow \boxed{q \approx -61.89 \text{ kJ/kg}}$