ASSIGNMENT-4

Q1. Turbine under steady state condition,

At inlet :	At outlet :
$P_1 = 3 MPa$	$P_2 = 10 kPa$
$T_1 = 350°C$	$x = 0.95$
$m_f = 1 kg s^{-1}$	$Z_2 = 5 m$
$V_1 = 50 ms^{-1}$	$V_2 = 120 ms^{-1}$
$Z_1 = 2 m$	Heat Exchange $Q = -5 kJ s^{-1}$

From superheated steam table, at 3 MPa, 350°C

$H_1 = 3115.25 kJ/kg$

From saturated steam table, at 10 MPa, $x = 0.95$

$H_2 = 191.81 + 0.95 \times (2392.82)$ [using h_f and h_{fg}]

$H_2 = 2464.99 kJ/kg$.

From SFEE,

$Q - \dot{W}_s = m_f [(H_2 - H_1) + \frac{1}{2}(V_2^2 - V_1^2) + g(z_2 - z_1)]$

$-5 - \dot{W}_s = 1 \times [-650.26 + \frac{5950}{1000} + \frac{29.43}{1000}]$ (in $kJ s^{-1}$)

$\boxed{\dot{W}_s = 639.28 kJ s^{-1}}$ → output power (positive)

If the changes in potential and kinetic energies are ignored, from SFEE

$Q - \dot{W}_s' = m_f [H_2 - H_1]$

$\boxed{\dot{W}_s' = 645.26 kJ s^{-1}}$

$\% \text{ error} = \left| \frac{\dot{W}_s - \dot{W}_s'}{W_s} \right| \times 100$

$\boxed{\text{Error} = 0.935\%}$

Q2. For the plant:

At inlet
$T_1 = -20°C$
$x = 0.8$
$m_f = 1 kg s^{-1}$

At outlet
$T_2 = 40°C$
Saturated vapour
Adiabatic $\Rightarrow Q = 0$

From saturated Freon-12 temperature table at 40°C
$H_2 = 203.1063$ kJ/kg
$\text{¥}_{11}^{\text{ch}}$ for $-20°C$ and $x = 0.8$
$H_1 = 178.9017 \times 0.8 + 0.2 \times 17.9517$
$H_1 = 146.712$ kJ/kg

Considering SFEE and ignoring PE & KE terms gives us:
$-\dot{W}_s = m_f (H_2 - H_1)$
$\dot{W}_s = -(203.1063 - 146.712)$
$\boxed{\dot{W}_s = -56.394 \text{ kW}}$ → input power (negative)

Q3 For the compressor:

At input
$P_1 = 1$ bar
$T_1 = 300K$
$m_f = 3 kg s^{-1}$

At ~~input~~ output
$P_2 = 6$ bar
$T_2 = 440$ K

Assuming ideal nature of Air, ~~mentioned~~
we can see that $H = f(T)$.
From ideal gas tables for air, we get
at $T_1 = 300K \longrightarrow H_1 = 300.19$ kJ/kg
$T_2 = 440K \longrightarrow H_2 = 440.85$ kJ/kg

$\therefore -\dot{W}_s = m_f (H_2 - H_1) = 3 \times (440.85 - 300.19)$
$\boxed{\dot{W}_s = -421.98 \text{ kW}}$ → input power (negative)

Q4. For the power plant:

At input	At output
$P_1 = 10 kPa$	$P_2 = 3 MPa$
Saturated liq	Adiabatic $\Rightarrow Q = 0$
$m_g = 1 kg s^{-1}$	

For input entropy, $S_1 = \cancel{191}.\ 0.6492\ kJ kg^{-1}$

Since the process is adiabatic $S_1 = S_2$

$S_2 = 0.6492\ kJ kg^{-1}$ for $P = 3 MPa$.

We can calculate the enthalpy by,

$$\frac{H_2 - 191.05}{0.6492 - 0.63734} = \frac{211.92 - 191.05}{0.70243 - 0.63734}$$

$$H_2 = 194.853\ kJ/kg.$$

From saturated steam table for $P_1 = 10 kPa$. and $x = 0$

$$H_1 = 191.81\ kJ/kg.$$

Considering SFEE and ignoring KE & PE terms:

$$-W_s = m_g (H_2 - H_1)$$

$$\boxed{W_s = -3.04\ kW} \rightarrow \text{input power (negative)}$$

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$$\frac{dE}{dt} = \left(\dot{m}_i \left(h_i + \frac{v_i^2}{2} + g z_i \right) + \dot{Q} \right) - \left(\dot{m}_e \left(h_e + \frac{v_e^2}{2} + g z_e \right) + \dot{W}_s \right)$$

Given steady state so $\frac{dE}{dt} = 0$

and initial velocity $\simeq 0$ (given)

$\dot{Q} = 0$ (adiabatic process)

$\dot{W}_s = 0$ (No shaft work involved)

and $\dot{m}_e = \dot{m}_i$ (conservation of mass)

$$\Rightarrow \left(h_i + \frac{v_i^2}{2} \right) = \left(h_e + \frac{v_e^2}{2} \right)$$

$$h_i = h_e + \frac{v_e^2}{2}$$

~~Given~~ Using steam table $h_i = 2859.93$ KJ

Given $v_e = 300$ m/sec.

$h_e = ?$

$$\Rightarrow h_i - \frac{v_e^2}{2} = h_e$$

$$\Rightarrow 2859.93 \times 10^3 - \frac{(300)^2}{2} = h_e$$

$$\Rightarrow h_e = 2814.933 \text{ KJ}$$

Using steam table

at 2 bar and $h_e = 2814.93$ KJ

temp. must be equal to $\boxed{172.71\,^\circ C}$

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Given Temp. at ~~initial~~ inlet = ~~3 bar~~ 300°C

Pressure = 3 bar

Temp. at outlet = $T_2 = ?$

Pressure = 1 bar

since given the gas is ideal we can use

$$\frac{T^4}{P^{4-1}} = \text{constant}$$

$$\Rightarrow \frac{(300+273)^4}{3^{4-1}} = \frac{(x)^4}{} \qquad x = T_2$$

$$\Rightarrow T_2 = 145.63\ ^\circ C$$

$$\frac{dE}{dt} = \left(\dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) + \dot{Q}\right) - \left(\dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right) + \dot{W}_s\right)$$

$\frac{dE}{dt} = 0$ from the question

$\dot{m}_i = \dot{m}_e$ (conservation of mass)

$h_i = 3068.83$ KJ

$V_i \simeq 0$ m/sec

$h_e = 2766.1$ KJ

$V_e = ?$

$$\Rightarrow (3068.83 \times 10^3) - 2766.1 \times 10^3 = \frac{V_e^2}{2}$$

$$\Rightarrow \boxed{V_e = 778.11 \text{ m/sec}}$$

mass flow rate will be $A_1 V_1 \Rightarrow$

$\Rightarrow$ $5 \times 10^{-4} \times 778.11$ ~~m~~

$\Rightarrow$ $\boxed{0.389 \text{ kg/sec}}$

Q9)

State - 1	State - 2
$P = 10$ bar (1 MPa)	$P = 1$ bar (0.1 MPa)
	$T = 110°C$.
Quality $= x$.	Here, T_{sat} at 1 bar is ~~99~~ 99.62°C.
$\therefore h = h_g x + h_l (1-x)$.	Since $T > T_{sat}$, it is superheated steam.
(h_g, h_l at 1MPa).	

From superheated steam tables, at 100kPa,

T (°C)	h (kJ/kg)
100	2672.2
150	2776.4
110	?

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By linear interpolation, h at 110°C, 100kPa is,

$$2672.2 + \left(\frac{2776.4 - 2672.2}{5}\right)$$

$$= 2693.04 \text{ kJ/kg}.$$

Throttling is <u>isenthalpic</u>.

So, $2693.04 = h_g x + h_l (1-x)$.

Q10) **State - 1**

$T = 40°C$.

Saturated liquid.

$x = 0$.

State - 2

$T = -26°C$.

$x = ?$

From Freon-12 tables,

$$h_l \text{ at } 40°C = 74.55 \text{ kJ/kg}.$$

$$\Rightarrow h_1 = 74.55 \text{ kJ/kg}.$$

Also,

T (°C)	h_l (kJ/kg)	h_g (kJ/kg)
−30	8.84	174.19
−20	17.79	178.73

By linear interpolation,

$$h_l \text{ at } -26°C = (8.84 \times 0.6) + (17.79 \times 0.4)$$

$$= 12.42 \text{ kJ/kg}.$$

$$h_g \text{ at } -26°C = (174.19 \times 0.6) + (178.73 \times 0.4)$$

$$= 176 \text{ kJ/kg}.$$

$$\therefore h_2 = 176x + 12.42(1-x).$$

Since throttling is isenthalpic,

$$h_1 = h_2.$$

$$\Rightarrow 74.55 = 176x + 12.42(1-x)$$

$$\Rightarrow x = 0.38. \quad \text{Ans.}$$

Q11)

State-1	State-2
5 bar (0.5MPa)	1 bar (0.1MPa)
$v_1 = 2\,m/s$	Velocity = ?

By steady state energy balance of a flow system,

$$0 = \sum_{in} \dot{m}_{in}\left(\hat{h}_1 + \frac{1}{2}v_1^2 + gz\right)_{in} - \sum_{out} \dot{m}_{out}\left(\hat{h}_2 + \frac{1}{2}v_2^2 + gz_2\right)_{out} + \dot{Q} + \dot{W}_s$$

Since adiabatic and no other work done, and $z_1 = z_2$, $\dot{m}_{in} = \dot{m}_{out}$, so,

$$\hat{h}_1 + \frac{1}{2}v_1^2 = \hat{h}_2 + \frac{1}{2}v_2^2.$$

From Freon-12 tables,

$\hat{h}_1 = h_g$ at 5 bar $= 194.06\ kJ/kg.$

$\hat{h}_2 = h_g$ at 1 bar $= 174.25\ kJ/kg.$

So, $v_2^2 - v_1^2 = 2\left(\hat{h}_1 - \hat{h}_2\right)$

$= 2\left(194.06 - 174.25\right) \times 10^3\ J/kg$

From here after calculation,

$V_2 = 199.3\ m/s.$ **Ans.**

From pressure-based steam table,

at 1 MPa, $h_g = 2778.1$ kJ/kg

$h_l = 762.79$ kJ/kg.

Thus, $(2778.1)x + 762.79(1-x) = 2693.04$

From here, $x = 0.96$. Ans.

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$$\frac{dE}{dt} = \left(\dot{m}_i\left(h_i + \frac{v_i^2}{2} + gz_i\right) + \dot{Q}\right) - \left(\dot{m}_e\left(h_e + \frac{v_e^2}{2} + gz_e\right) + \dot{w}_s\right)$$

From the question itself $\frac{dE}{dt} = 0$

Now given $\dot{m}_i = 5\,kg/s = \dot{m}_e$ (conservation of mass)

$h_i = 3068.83$ KJ (calculated using steam table)

$v_i = 0$ (negligible given in the question)

$\dot{Q}_i = -50$ KJ/sec (given in the question)

No change in height

$h_e = 2874.8$ KJ

$v_e = ?$, $w_s = 0$ (No shaftwork involved)

$$5\times\left(3068.83\times10^3\right) - 50\times10^3 = 5\times\left(2874.8\times10^3 + \frac{v_e^2}{2}\right)$$

$$\left(3068.83\times10^3\right) - 10\times10^3 = 2874.8\times10^3 + \frac{v_e^2}{2}$$

$\Rightarrow$ 60 . $\boxed{v_e \cong 607.12\ m/sec}$ Ans

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So given saturation pressure in pipe

equals to 10 bar

At 10 bar $h_f = 762.88 \times 10^3$ KJ/Kg

$h_g = 2777.7 \times 10^3$ KJ/kg

~~$h_g >> h_f$~~

and 1 bar and 120°C $h_g = 2716.3$ KJ/Kg

$\Rightarrow m_i h_i = m_e h_e$

$\Rightarrow$ ~~$m_i = 2777.7$~~

* taking basis equals to 1Kg

$\Rightarrow x h_g + (1-x) h_f = 1 \times h_e$

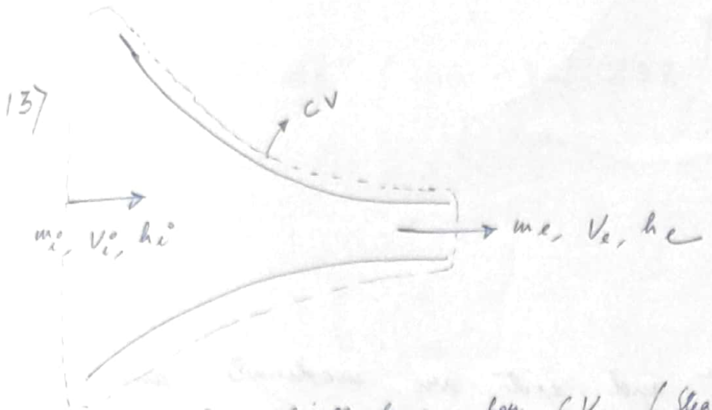
$\Rightarrow x(2777.7) + (1-x) 762.88 = 1 \times 2716.3$

$\Rightarrow x = 0.97$ Ans

Assignment - 4

Adiabatic - Reversible Nozzle

13)



Applying first law for CV (Steady State Steady flow process)

$$0 = \dot q - \dot W_s + \dot m_i \left[h_i + \frac{V_i^2}{2} + g z_i\right] - \dot m_e \left[h_e + \frac{V_e^2}{2} + g z_e\right]$$

$\dot q = 0$ [Adiabatic process]

$\dot W_s = 0$ [No shaft work]

$g z_i = g z_e$ [No potential Energy Difference]

$$0 = \dot m_i \left[h_i + \frac{V_i^2}{2}\right] - \dot m_e \left[h_e + \frac{V_e^2}{2}\right]$$

From mass balance:

Since there is one inlet & one outlet

$$\dot m_i = \dot m_e = \dot m$$

$$\therefore 0 = \dot m \left[h_i + \frac{V_i^2}{2}\right] - \dot m \left[h_e + \frac{V_e^2}{2}\right]$$

$$\Rightarrow (h_i - h_e) + \left(\frac{V_i^2}{2} - \frac{V_e^2}{2}\right) = 0$$

$$\Rightarrow \boxed{h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}} \longleftarrow (1)$$

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Now, Fluid (Air)

$P_i = 3$ bar

$T_i = 200°C = 473K$

$V_i = 0$

$P_e = 2$ bar

$T_e = ?$

$V_e = ?$

Here pressures at inlet and exit are moderate and Temp at inlet is not too high such that c_p & c_v would change. So we can treat air as an ideal gas & calorically perfect gas (c_p & c_v are constant).

Since the nozzle is reversible and adiabatic so,

$$T^{\gamma} P^{1-\gamma} = \text{constant}$$

$$\gamma = 1.4 \text{ (air)}$$

$$T_i^{\gamma} P_i^{1-\gamma} = T_e^{\gamma} P_e^{1-\gamma}$$

$$\Rightarrow T_e^{\gamma} = T_i^{\gamma} \times \left(\frac{P_i}{P_e}\right)^{1-\gamma}$$

$$\Rightarrow T_e = \left[(473)^{1.4} \times \left[\frac{3}{2}\right]^{(1-1.4)}\right]^{\frac{1}{1.4}}$$

$$= 421.259 K$$

From ①,

$$\therefore h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}$$

$$\Rightarrow (h_i - h_e) = \frac{V_e^2}{2} \quad [V_i = 0]$$

Scanned with CamScanner

$$c_p (T_i - T_e) = \frac{V_e^2}{2}$$

$$\Rightarrow \frac{V_e^2}{2} = (1.004) \left[473 - 421.259 \right] \times \left(\frac{kJ}{kg \cdot K} \right) \times K \times \left(\frac{1000\,J}{1\,kJ} \right)$$

$$\left[c_{p_{air}} = 1.004\, kJ/kg \cdot K \right]$$

$$\Rightarrow V_e = \sqrt{2 \times (1.004) \left[473 - 421.259 \right] \times 1000} \quad m/s$$

$$V_e = 322.328 \; m/s \quad (Ans)$$

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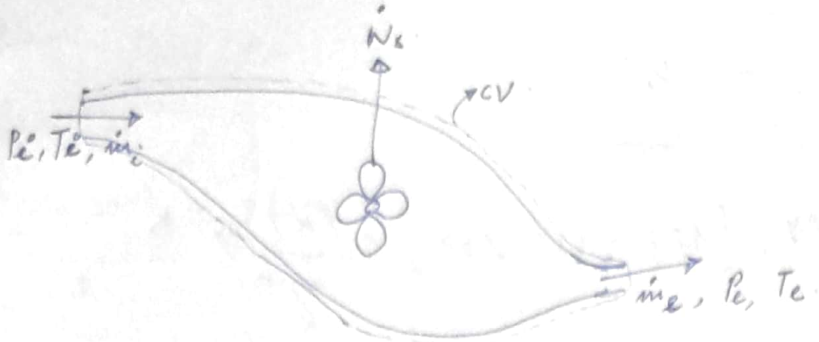


From mass balance:

As there 1 inlet & 1 outlet

$\dot{m}_i = \dot{m}_e = \dot{m}$

Applying first law for CV [Steady State Steady Flow process].

$0 = \dot{q} - \dot{W}_s + \dot{m}_i \left[h_i + \frac{V_i^2}{2} + g z_i \right] - \dot{m}_e \left[h_e + \frac{V_e^2}{2} + g z_e \right]$

$\dot{q} = 0$

$\Delta KE = 0$ [Change in kinetic Energy = 0].

$\Delta PE = 0$ [change in potential Energy = 0].

$\Rightarrow 0 = -\dot{W}_s + \dot{m}[h_i] - \dot{m}[h_e]$

$\Rightarrow h_i - h_e = \frac{\dot{W}_s}{\dot{m}}$

$$\boxed{h_i - h_e = \frac{\dot{W}_s}{\dot{m}}}$$

Now, Fluid (Air).

$P_i = 3$ bar

$T_i = 400$ K

$P_e = 1$ bar

$T_e = 320$ K

$\dot{W}_s = +15$ kW [+ve sign means work is done by turbine].

Since pressure at inlet & outlet are moderate & temperature at inlet & outlet are too high that would change c_p & c_v. So we treat air as ideal gas and calorically perfect gas (c_p & c_v are constant)

$$\therefore \quad h_i - h_e = \frac{\dot{W}_s}{\dot{m}}$$

$$\Rightarrow \left(\frac{15 \text{ kJ}}{\dot{m}}\right) = c_p (T_i - T_e)$$

$$\Rightarrow \left(\frac{15 \text{ kJ/s}}{\dot{m}}\right) = (1.004)\left[400 - 320\right] \times \left(\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right) \times (\text{K})$$

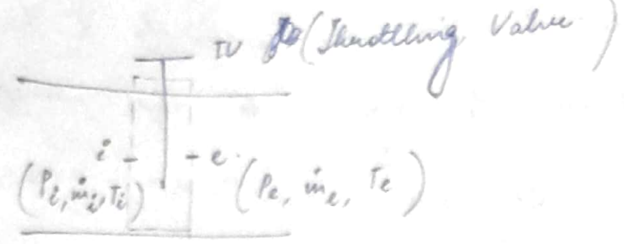
$$\left[c_{p_{air}} = 1.004 \text{ kJ/kg·K}\right]$$

$$\Rightarrow \dot{m} = \frac{15}{1.004\left[400 - 320\right]} \text{ kg/s}$$

$$\Rightarrow \dot{m} = 0.1867 \text{ kg/s}$$

$\therefore$ Flow rate of air $= 0.1867$ kg/s (Ans)

15)



From mass balance

Since there is 1 inlet & 1 outlet

$\dot{m}_i = \dot{m}_e = \dot{m}$

Applying first law for CV (Steady state Steady flow process)

$$0 = \dot{q} - \dot{W}_s + \dot{m}_i \left[h_i + \frac{V_i^2}{2} + gZ_i \right] - \dot{m}_e \left[h_e + \frac{V_e^2}{2} + gZ_e \right]$$

$\dot{q} = 0$ [No heat exchange]

$\dot{W}_s = 0$ [No shaft Work]

$\Delta KE \approx 0$ [No Kinetic Energy Difference]

$\Delta PE \approx 0$ [No potential Energy Difference]

$$0 = \dot{m} \left[h_i \right] - \dot{m} \left[h_e \right]$$

$$\boxed{h_i = h_e} \quad \text{—— (1)}$$

Now, Fluid (Steam)

$P_i = 20$ bar

$T_i = 220°C$

Now from saturated steam table.

$P_{sat} = 20$ bar, $T_{sat} = 212.377°C$

$\therefore T_i = 220°C > T_{sat} = 212.377°C$

$\therefore$ ~~Bas~~ Steam is at super-heated regime at inlet.

$\therefore$ From superheated steam table at $p = 20$ bar & $T = 220°C$

$h_i = 2821.6$ kJ/kg

Now from (1),

$h_i = h_e$

$\Rightarrow h_e = 2821.6$ kJ/kg

$P_e = 5$ bar

$T_e = ?$

From saturated steam table,

$P_{sat} = 5$ bar, $h_{sat} = 2748.1$ kJ/kg

$\therefore h_e = 2821.6$ kJ/kg $> h_{sat} = 2748.1$ kJ/kg

so at outlet, steam is in super-heated regime.

From superheated steam table at $p = 5$ bar,

T	h
180°C	2812.4 kJ/kg
185°C	2823.4 kJ/kg

By Linear Interpolation,

$$\frac{185-180}{2823.4-2812.4} = \frac{T_e - 180}{(2821.6 - 2812.4)}$$

$$\Rightarrow T_e = 184.18\ °C$$

$\therefore$ Temperature of exhaust steam (T_e) = 184.18 °C (Ans)

From super-heated steam table at $p = 5$ bar

$$\left\{\begin{array}{ll} T & v \\ 180°C & 0.40466\ m^3/kg \\ 185°C & 0.40980\ m^3/kg \end{array}\right\}$$

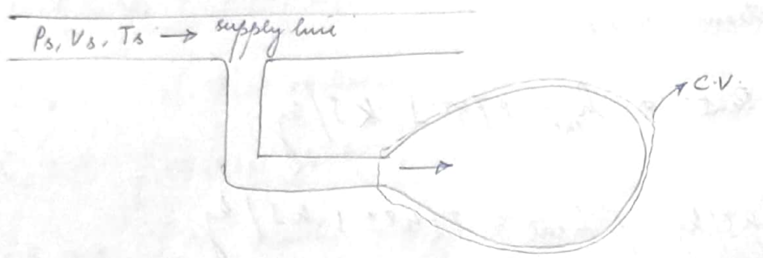
By linear Interpolation

$$\frac{185-180}{(0.4098-0.40466)} = \frac{(184.18-180)}{(v-0.40466)}$$

$$\Rightarrow v = 0.408\ m^3/kg$$

$\therefore$ specific volume of the exhaust steam $(v) = 0.408\ m^3/kg$ (Ans)

16)



From mass balance:

$$\left(\frac{dm}{dt}\right) = \dot{m}_i - \dot{m}_e$$

$\dot{m}_e = 0$ [No ~~a~~ outlet]

$$\left(\frac{dm}{dt}\right) = \dot{m}_i$$

$$\Rightarrow \int_{m_0}^{m_f} dm = \int_0^t \dot{m}_i\, dt$$

m_0 = mass of gas inside cylinder before charging

m_f = mass of gas inside cylinder after charging

$$\boxed{\Rightarrow (m_f - m_0) = \int_0^t \dot{m}_i\, dt}$$

Applying First Law for CV:

$$\frac{dE}{dt} = \dot{q} - \dot{W}_s + \dot{m}_i\left[h_i + \frac{V_i^2}{2} + gz_i\right] - \dot{m}_e\left[h_e + \frac{V_e^2}{2} + gz_e\right]$$

$\dot{W}_s = 0$ [No shaft work]

$\Delta KE = 0$ [change in kinetic energy = 0]

$\Delta PE = 0$ [change in potential energy = 0]

$\dot{m}_e = 0$ [No outlet]

$$\frac{dE}{dt} = \dot{q} + \dot{m}_i\,[h_i]$$

$$\Rightarrow dE = \dot{q}\,dt + \dot{m}_i h_i\,dt$$

$$\Rightarrow \int_{E_i}^{E_f} dE = \int_0^t \dot{q}\,dt + h_i \int_0^t (\dot{m}_i\,dt)$$

$$\Rightarrow (E_f - E_i) = Q + h_i(m_f - m_o) \quad \left[\int_0^t \dot{m}_i\,dt = m_f - m_o\right]$$

$$\Rightarrow (m_f u_f - m_o u_o) = Q + h_i(m_f - m_o)$$

$$\Rightarrow \boxed{Q + h_s[m_f - m_o] = m_f u_f - m_o u_o} \quad [h_i = h_s]$$

Now,

$Q = 0$ [No heat transfer from tank]

$$\Rightarrow \boxed{h_s[m_f - m_o] = m_f u_f - m_o u_o}$$

No. of moles of air before charging, inside cylinder (n_1)

$$= \frac{100 \times 10^3 \times 1}{8.314 \times 300}$$

$$= 40.1$$

$$\therefore m_o = 40.1 \text{ moles} \times \frac{29\text{ gm}}{1\text{ mole air}} \times \frac{1\text{ kg}}{1000\text{ gm}} = 1.1629\text{ kg}$$

$\therefore \quad m_0 = 1.1629\ kg.$

No. of moles of gas after charging, inside cylinder $(n_2) = \left(\dfrac{10^6 \times 1}{8.314 \times T_f}\right)$

$$m_f = n_2 \times \frac{29\ gm}{1\ mole\ air} \times \frac{1\ kg}{1000\ gm}$$

$$m_f = \frac{10^3 \times 29}{8.314 \times T_f}.$$

$$\Rightarrow m_f T_f = \frac{29 \times 1000}{8.314} = 3488.092$$

Now,

$$h_s [m_f - m_0] = m_f u_f - m_0 u_0.$$

$$\Rightarrow (c_p T_s)[m_f - m_0] = m_f [c_v T_f] - m_0 [c_v T_0].$$

$$\Rightarrow \left(\frac{c_p}{c_v}\right) T_s [m_f - m_0] = (m_f T_f) - (m_0 T_0).$$

$$\Rightarrow \gamma\, T_s [m_f - m_0] = m_f T_f - m_0 T_0.$$

Now, $\gamma = 1.4$, $T_s = 600k$, $T_0 = 300k$,

$m_f T_f = 3488.092$, $m_0 = 1.1692\ kg$

$$\Rightarrow 1.4 \times 600 [m_f - 1.1692] = 3488.092 - 1.1692(300).$$

$$\Rightarrow m_f = 4.90411\ kg.$$

$\therefore$ mass of air that entered the tank $= (m_f - m_0)$

$= (4.90411 - 1.1692)$

$= 3.734\ kg$ (Ans).

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$$m_f T_f = 3488.092$$

$$\Rightarrow T_f = \left(\frac{3488.092}{4.9} \right)$$

$$= 711.86\ K$$

$\therefore$ Final Temperature of air in the tank $(T_f) = 711.86\,K$ (Ans).