

(Theory)

Q.1 Explain first laws of thermodynamics for a control mass with reference to conservation of mass & conservation of energy.

$\Rightarrow$  first law of thermodynamics for a control mass:

$\rightarrow$  conservation of mass for a control mass

control mass (closed system) is a system in which energy transfer can take place but mass transfer cannot. Hence, conservation of mass for a control mass can be stated as, "Total mass of a control mass always remains constant."

$$\frac{dm}{dt} = 0$$

for any process between state 1 & 2,

$$m_2 - m_1 = 0$$

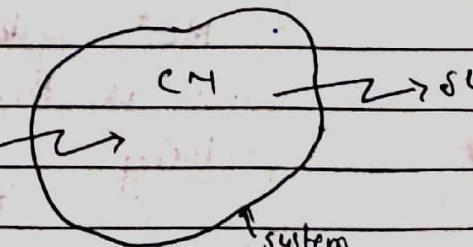
$$m_2 = m_1$$

In terms of rate,

$$\frac{dm}{dt} = 0$$

$\rightarrow$  conservation of energy for a control mass.

Consider a control mass undergoing a process during which so amount of heat is supplied to the control mass & it produces so amount of work. If heat supplied during the process is greater than the work produced by the system then the total energy system increase whereas, if the heat supplied during the process is less than the work,



Hence, conservation

produced by the system, then the total energy of the system decrease. Hence, conservation of energy for a control mass can be stated as; The change in total energy of a control mass is equal to the heat supplied to the control mass minus the work produced by the control mass.

$$dF = \Delta Q - \Delta W$$

In terms of rate,

$$\frac{dF}{dt} = \dot{Q} - \dot{W}$$

for any process 1-2 betw states 1 & 2,

$$F_2 - F_1 = \Delta Q_{12} - \Delta W_{12}$$

where,  $\Delta Q_{12}$  &  $\Delta W_{12}$  are the total heat transferred to the control mass & total work transferred by the control mass during the process respectively.

$$(U + PV + KE)_2 - (U + PV + KE)_1 = \Delta Q_{12} - \Delta W_{12}$$

$$(U + mgz + \frac{1}{2}mv^2)_2 - (U + mgz + \frac{1}{2}mv^2)_1 = \Delta Q_{12} - \Delta W_{12}$$

Most systems encountered in practice are stationary, that is, they do not involve any changes in their velocity or elevation during a process.

Thus for stationary system, the changes in kinetic & potential energies are negligible in compare to the change in internal energy & the total energy change reln reduce to  $\Delta F = \Delta U$  for such systems. Thus, for the stationary piston cylinder we can write,

$$U_2 - U_1 = Q_{12} - W_{12}$$

$$Q_{12} = (\Delta U)_{12} + W_{12}$$

Q. Explain first law of thermodynamics for a control undergoing cyclic process.

$\Rightarrow$  Taking cyclic integral of equation.

$$dF = \oint dQ - \oint dW$$

$$\oint dF = \oint dQ - \oint dW$$

For cyclic process, initial & final states are identical.

$$\oint dF = 0, \oint dQ \neq 0 \text{ & } \oint dW \neq 0, \text{ then,}$$

$$\oint dQ = \oint dW$$

It can also be expressed in the eq. form as,

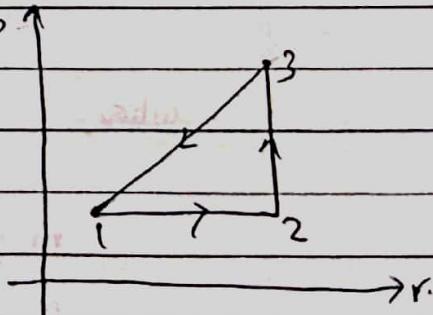
$$\Sigma Q = \Sigma W$$

for a cycle shown, we can write,

$$Q_{12} + Q_{23} + Q_{31} = W_{12} + W_{23} + W_{31}$$

The statement for a power cycle is;

"Whenever a control mass is taken through a cycle, then the heat transferred to the control mass is equal to the net work done by the control mass".



The statement for a refrigeration cycle is, "Whenever a control mass is taken through a cycle, then, the heat rejected by the control mass is equal to the net work done on the control mass".

With reference to conservation energy principle, we can state that, "During a cyclic process, there's no change in total energy of the system & therefore incoming energy should be equal to outgoing energy."

Q3 State & explain conservation of mass for a control vol. Also derive an expression for mass flow rate through a duct.

$\Rightarrow$  Any control vol. (open system) can interact with its surroundings by energy as well as mass transfer.

Hence, conservation of mass for a control vol. can be stated as, "The change in mass within a control vol. is equal to the mass within a control entering into the control vol. minus the mass leaving the volume." Mathematically,

$$\frac{dM_{\text{cv}}}{dt} = \dot{m}_{\text{in}} - \dot{m}_{\text{out}}$$

where,

$\dot{m}_{\text{in}}$  = summation of mass flow at each inlet

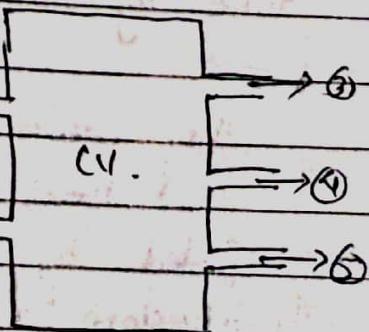
$\dot{m}_{\text{out}}$  = " " " " flow at each outlet

$$\dot{m}_{\text{in}} = \sum_{\text{in}} \dot{m}_i$$

$$\dot{m}_{\text{out}} = \sum_{\text{out}} \dot{m}_o$$

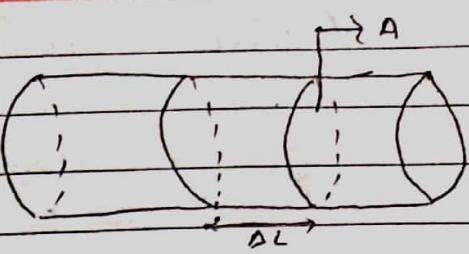
$$\text{eg: } \dot{m}_{\text{in}} = \dot{m}_1 + \dot{m}_2 \quad (1) \rightarrow$$

$$\dot{m}_{\text{out}} = \dot{m}_3 + \dot{m}_4 + \dot{m}_5 \quad (2) \rightarrow$$



Expression for mass flow rate.

Let's consider fluid flowing through a duct as shown in fig having a uniform cross-sectional area  $A$ , where it crosses  $\Delta L$  distance in time interval  $\Delta t$ .



Total mass of fluid crossing the section of length  $\Delta L$  is given by,

$$m = \rho V_{\text{swept}}$$

where,  $\rho$  = density of fluid

$V_{\text{swept}} = \text{vol. swept by the fluid in given interval } \Delta t$

$$m = \rho A \Delta L$$

The mass rate is,

$$\dot{m} = \rho A \frac{\Delta L}{\Delta t}$$

$$= \rho A \bar{V}$$

$$(\text{Mass rate}) = \frac{\Delta \bar{m}}{\Delta t}$$

The conservation of mass for a control vol. can be expressed as,

$$\frac{dm_{cv}}{dt} = \sum_{\text{in}} \left( \frac{A \bar{V}}{\rho} \right) - \sum_{\text{out}} \left( \frac{A \bar{V}}{\rho} \right)$$

Further, if the boundary condition is such that no mass is added or removed from the control volume, then the above equation reduces to the continuity equation,  $\rho_1 A_1 \bar{V}_1 = \rho_2 A_2 \bar{V}_2$ .

Q.4. Derive general energy eqn for a control volume.

$\Rightarrow$  Conservation of energy for a control vol. can be stated as "The change in total energy of control vol. is equal to the net energy transported by the fluid into the control vol. plus the heat transferred to the control vol. minus the heat transfer work done by the control vol."

Mathematically,

$$\frac{dE_{cv}}{dt} = \dot{F}_{net} + \dot{Q} - \dot{W}$$

substituting,

$$\dot{F}_{net} = \dot{F}_{in} - \dot{F}_{out}, \text{ we get,}$$

$$\frac{dE_{cv}}{dt} = \dot{F}_{in} - \dot{F}_{out} + \dot{Q} - \dot{W}$$

where,

$$\dot{F}_{in} = \sum_{in} \{ m (u + \frac{1}{2} \bar{v}^2 + gz) \}$$

$$\dot{F}_{out} = \sum_{out} \{ m (u + \frac{1}{2} \bar{v}^2 + gz) \}$$

Heat transfer always occurs due to the difference in temp. b/w the system & the surroundings whether it's control mass or control vol. i.e.,

$$\dot{Q} = \dot{Q}_{cv}$$

The total work transfer associated with a control vol. includes various modes of work transfer such as flow work, shaft work, expansion/compression work etc. i.e.,

$$\dot{W} = \dot{W}_{flow} + \dot{W}_{shaft} + \dot{W}_{general}$$

To derive an expression for work for any section, consider fluid flowing through an inlet section with a cross-sectional area of  $A$ , where it covers of distance in time interval  $\Delta t$ .

Energy (work) reqd. for the displacement of the fluid is,

$$(i) \text{flow} = f \Delta L$$

where,  $f$  = force acting on the fluid particle, which is given as the product of pressure  $P$  at the section & cross-sectional area  $A$ , where it covers of ~~dist~~ distance in time interval  $\Delta t$ .

~~Energy (work) reqd. for the displacement of the fluid is,~~

~~$$W_{\text{flow}} = f \Delta L$$~~

where,  $f$  =

of the section.

Substituting,

$$f = PA$$

$$W_{\text{flow}} = PA \Delta L$$

$$= PV_{\text{swept}}$$

specific flow work or flow work per unit mass of flowing fluid is,

$$W_{\text{flow}} = PV$$

$$W_{\text{flow}} = m W_{\text{flow}} \\ = m PV$$

Shaft work is associated with the work produced by the shaft (turbine) by consuming energy carried by a fluid or work consumed by shaft

(compressor or pump) to increase fluid energy. So,

$$\omega = - \sum_{in} (m P V) + \sum_{out} (m P V) + \dot{w}_{cv}$$

where,

$$\dot{w}_{cv} = \dot{w}_{shaft} + \dot{w}_{generated}$$

Then,

general energy eq<sup>n</sup> for control vol. reduce to.

$$\frac{d F_{cv}}{dt} = \sum_{in} \{ m (u + \frac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m (u + \frac{1}{2} \bar{v}^2 + gz) \} \\ + \dot{Q}_{cv} \sum_{in} (m P V) - \sum_{out} (m P V) - \dot{w}_{cv}$$

$$\frac{d F_{cv}}{dt} = \sum_{in} \{ m (u + PV + \frac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m (u + PV + \frac{1}{2} \bar{v}^2 + gz) \} \\ + \dot{Q}_{cv} - \dot{w}_{cv}$$

Substituting,  $b = u + PV$ ,

$$\frac{d F_{cv}}{dt} = \sum_{in} \{ m (b + \frac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m (b + \frac{1}{2} \bar{v}^2 + gz) \} \\ + \dot{Q}_{cv} - \dot{w}_{cv}$$

Q.5 Differential bet<sup>n</sup> steady & unsteady state control vol.  
with example.

=> Steady state

Unsteady state.

- |  |  |
|--|--|
| (1) The properties of the system within control vol. don't change with time                          | (1) The properties of system within control vol. change with time  |
| (2) The properties at the boundaries of the control vol. do not change with time                     | (2) The properties at the boundaries of the control vol. change with time.                                       |
| (3) The heat & work interactions bet <sup>n</sup> the system & surrounding don't change with time    | (3) The heat & work work interact <sup>n</sup> action bet <sup>n</sup> the system & surrounding change with time |
| (4) They continue indefinitely.<br>eg:- Pumps, boilers, condensers<br>heat exchangers, turbines etc. | (4) They start & stop over some finite time.<br>eg: inflating tubes or balloons etc.                             |

Q.6) Derive general expression for mass & energy conservation for a control vol. operating under steady state condition.  
=> For the steady state operation of control vol. its properties (total mass & total energy) should not change with time.

Mathematically,

$$\frac{dm_{cv}}{dt} = 0$$

$$\frac{dF_{cv}}{dt} = 0$$

Applying in the expression of conservation of mass

$$0 = \dot{m}_{in} - \dot{m}_{out}$$

$$\dot{m}_{in} = \dot{m}_{out}$$

Applying in the expression of conservation of energy

$$0 = \sum_{in} \{ m_i (h + \frac{1}{2} \bar{v}^2 + gz) \} - \sum_{out} \{ m_o (h + \frac{1}{2} \bar{v}^2 + gz) \} + \dot{Q}_{cv} - \dot{W}_{cv}$$

$$\therefore \sum_{in} \{ m_i (h + \frac{1}{2} \bar{v}^2 + gz) \} + \dot{Q}_{cv} = \sum_{out} \{ m_o (h + \frac{1}{2} \bar{v}^2 + gz) \} + \dot{W}_{cv}$$

Hence, for steady state operation, incoming mass should be equal to outgoing mass & incoming energy should be equal to outgoing energy

Q.7) Derive general expression for mass & energy conservation for a control vol. operating under unsteady state condition.

$\Rightarrow$  During the unsteady state operation of a control vol its properties (total mass & total energy) change with time i.e. total mass & total energy of system is function of time

Mathematically,

$$\frac{d M_{cv}}{dt} \neq 0$$

$$M_{cv} \neq f(t)$$

$$\frac{d E_{cv}}{dt} \neq 0$$

$$F_{cv} = f_2(t)$$

therefore, the generalized mass conservation & energy conservation equations for the unsteady state device can be derived by integrating above equation with reference to time for the required interval.

For any process 1-2 between state 1 (instant  $t_1$ ) & state (instant  $t_2$ ) mass conservation eqn reduces to,

$$\int_{t_1}^{t_2} \left( \frac{dm_{cv}}{dt} \right) dt = \int_{t_1}^{t_2} \dot{m}_{in} dt - \int_{t_1}^{t_2} \dot{m}_{out} dt$$

$$m_2 - m_1 = m_{in} - m_{out}$$

where,  $m_1$  &  $m_2$  are the masses of the control vol. at state 1 & 2,  $m_{in}$  is the total mass that has entered into the control volume &  $m_{out}$  is the total mass that has gone out from the control vol. during the interval  $t_1$  &  $t_2$ .

Integrating energy conservation eqn?

$$\int_{t_1}^{t_2} \left( \frac{dF_{cv}}{dt} \right) dt = \int_{t_1}^{t_2} \sum_{in} \{ m_i (h + \frac{1}{2} \bar{v}^2 + gz) \} dt - \int_{t_1}^{t_2} \sum_{out} \{ \dot{m} (h + \frac{1}{2} \bar{v}^2 +$$

$$+ gz) \} dt - \int_{t_1}^{t_2} Q_{cv} dt - \int_{t_1}^{t_2} W_{cv} dt.$$

$$\therefore (F_{cv})_2 - (F_{cv})_1 = \sum_{in} \{ m_i (h_{in} + \frac{1}{2} \bar{v}_{in}^2 + gz_{in}) \} - \sum_{out} \{ m_{out} (h_{out} + \frac{1}{2} \bar{v}_{out}^2 + gz_{out}) \}$$

$$+ Q_{12} - W_{12}$$

where,  $h_{in}$  is the specific enthalpy of the incoming fluid,  $v_{in}$  is the velocity of incoming fluid,  $z_{in}$  is the elevation of that inlet section from the reference level &  $h_{out}$ ,  $v_{out}$  is the specific enthalpy of fluid &  $z_{out}$  is the elevation of the outlet section from the reference level.

- 8) Define steady state work application. Write down the general energy eqn for a turbine & compressor & reduce it for an adiabatic turbine or compressor.  
 => Devices which operate under steady state conditions & either produce or consume work are called steady state work application.

The general energy eqn for turbine & compressor is:

$$\dot{Q}_{cv} - \dot{W}_{cv} = m [ (h_2 - h_1) + \frac{1}{2} (\bar{v}_2^2 - \bar{v}_1^2) + g(z_2 - z_1) ]$$

for adiabatic condition,  $\dot{Q}_{cv} = 0$

$$\dot{W}_{cv} = m [ (h_1 - h_2) + \frac{1}{2} (\bar{v}_1^2 - \bar{v}_2^2) + g(z_1 - z_2) ]$$

- 9) Define steady state flow application. Write down the general energy eqn for a nozzle & diffuser & reduce it for an adiabatic nozzle & diffuser.

$\Rightarrow$  Device which operate under steady conditions & do not produce work are called steady flow application.

The general energy eqn for nozzle & diffuser. i.e

$$\dot{Q}_{cv} = \dot{m} [ (h_2 - h_1) + \frac{1}{2} (\bar{v}_2^2 - \bar{v}_1^2) + g(z_2 - z_1) ]$$

for adiabatic condition,  $\dot{Q}_{cv} = 0$ . So,

$$h_1 + \frac{1}{2} \bar{v}_1^2 = h_2 + \frac{1}{2} \bar{v}_2^2$$

Q.10) Write down general energy eqn for heat exchanger - Condenser - evaporator & throttling valve. Also mention the relevant assumptions for each.

$\Rightarrow$  Heat exchange as a device used to transfer heat from one fluid to another

Here

1<sub>h</sub> is inlet of hot fluid

2<sub>h</sub> is outlet of hot fluid

1<sub>c</sub> is inlet of cold fluid

2<sub>c</sub> is outlet of cold fluid

Now, general energy eqn of A is,

$$\dot{Q} = m_h (h_{2h} - h_{1h})$$

similarly, of B is,

$$\dot{Q} = m_c (h_{2c} - h_{1c}).$$

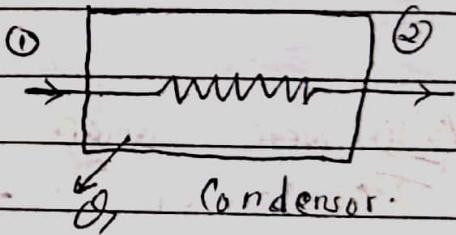
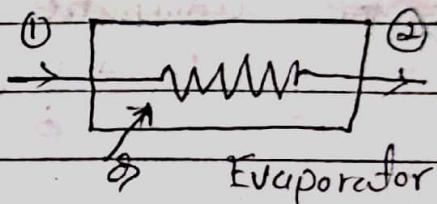
General energy eq<sup>n</sup> of C is,

$$m_n h_{1n} + m_c h_{2c} = m_n h_{2n} + m_c h_{2c}$$

Evaporator & condenser are special types of heat exchanger  
Evaporator converts liquid into vapour by absorbing heat from the surrounding. Condenser converts vapour into liquid by rejecting heat to the surroundings.

The general energy eq<sup>n</sup> is,

$$\textcircled{3} = m(h_2 - h_1)$$

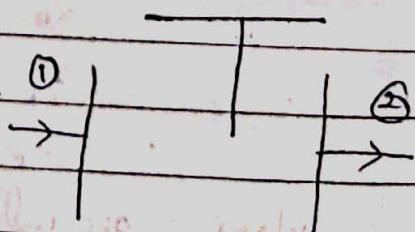


Throttling valve reduces pressure of the fluid without performing work heat transfer, change in potential energy & kinetic energy are also negligible.

The energy eq<sup>n</sup> is,

$$h_2 - h_1 = 0$$

$$h_2 = h_1$$



Q.ii) Define mass & energy conservation eq<sup>n</sup> for gas filling process in which gas is provided to piston cylinder device through valve & it can produce some work by displacing the piston.

⇒ Let's consider a system where gas is supplied through valve when gas is supplied it can produce some work by displacing the piston.

Then mass conservation is,

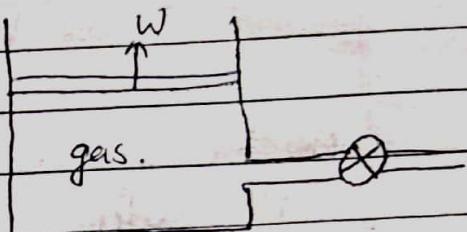
$$m_2 - m_1 = m_{in}$$

Energy conservation is.

$$(E_{in})_2 - (E_{in})_1 = m_{in} \left( h_{in} + \frac{1}{2} \bar{V}_{in}^2 + g^2 z_{in} \right) + Q_{12} - W_{12}$$

As change in potential & kinetic energy is negligible to change in internal energy.

$$m_2 v_2 - m_1 v_1 = m_{in} \left( h_{in} + \frac{1}{2} \bar{V}_{in}^2 + g^2 z_{in} \right) + Q_{12} - W_{12}$$



Q.ii) Define mass & energy conservation equation for gas filling process in a gas station.

⇒ Let us consider, a cylinder to be filled with gas. Then, mass of system increase continuously & does not produce any boundary work

So, mass conservation is.

$$m_2 - m_1 = m_{in}$$

And,

$$(E_{in})_2 - (E_{in})_1 = m_{in} \left( h_{in} + \frac{1}{2} \bar{V}_{in}^2 + g^2 z_{in} \right) + Q_{12}$$



Q.13 State first law of thermodynamics for an isolated system & a control mass undergoing an adiabatic process.

→ For an isolated system

we have the first law,

$$dF = \delta Q - \delta W.$$

As the system is isothermal, there is no interaction bet'n system & surrounding i.e.

$$\delta Q - \delta W = 0,$$

so,

$$dF = 0$$

$$F_2 - F_1 = 0$$

$$\therefore F_2 = F_1$$

Hence,

total Energy of an isolated system is always constant.

For a control mass undergoing a diabatic process

we know, in a diabatic process,  $\delta Q = 0$

$$\text{so, } dF = -\delta W$$

There, increase in total energy of control mass in adiabatic process is equal to work done on the control mass.

Q.1) Define PMM I. Explain why it is not possible.  
 → A fictitious machine which could continuously supply mechanical work without some other form of energy disappearing simultaneously is perpetual motion machine of first kind (PMM-I).

It is not possible because friction cause the supplied work to decrease eventually stopping the functioning of the machine itself.

### Numerical.

Q.1.

⇒ given.

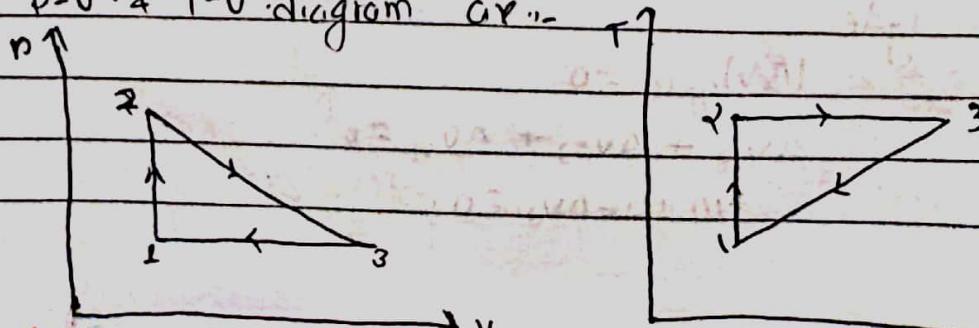
process 1-2 constant volume

$$V_1 = 0.08 \text{ m}^3, P_1 = 100 \text{ kPa}, V_2 - V_1 = +40 \text{ kJ}$$

Process 2-3 Expansion with  $PV = \text{constant}$   $V_3 = V_2$

Process 3-1 constant pressure  $w_{31} = -56 \text{ kJ}$

The P-V & T-V diagram are -



Here, we have,

$$W_{31} = P_1(V_1 - V_3)$$

$$-56 \text{ kJ} = 100 \text{ kPa} (0.08 - V_3)$$

$$\therefore V_3 = -0.08 + 56/100$$

$$\therefore V_3 = 0.64 \text{ m}^3$$

$$\begin{aligned}\text{Net work (W)} &= \Delta U_{12} + W_{23} + W_{31} \\ &= P_2 V_2 \ln\left(\frac{V_3}{V_2}\right) - 56 \\ &= P_3 V_3 \ln\left(\frac{V_2}{V_3}\right) - 56 \\ &= 100 \times 0.64 \times \ln\left(\frac{0.64}{0.08}\right) - 56 \\ &= 77.084 \text{ kJ}\end{aligned}$$

For a cycle, net heat transfer as equal to net work transfer,  
so,

$$\text{Net heat } (Q) = W = 77.084 \text{ kJ}$$

For heat transfer in process 2-3.

$$\begin{aligned}Q_{23} &= (\Delta V)_{23} + W_{23} \\ &= 0 + P_2 V_2 \ln\left(\frac{V_3}{V_2}\right) \\ &= 133.084 \text{ kJ}\end{aligned}$$

for heat transfer in process 3-1

$$Q_{31} = (\Delta V)_{31} + W_{31} \quad \text{--- (1)}$$

for cycle,

$$(\Delta V)_{\text{cycle}} = 0$$

$$\Delta V_{12} + \Delta V_{23} + \Delta V_{31} = 0$$

$$10 + 0 + \Delta V_{31} = 0$$

$$\therefore \Delta V_{31} = -140 \text{ kJ}$$

④ becomes.

$$Q_{31} = -140 - 56 \\ = -196 \text{ kJ.}$$

This is a power cycle because the net work done is positive.

Q. 2) given,

$$\text{vol. of vessel } (V) = 0.4 \text{ m}^3$$

we have,

state 1

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

$$\text{vol. occupied by saturated liquid } (V_1) = 2 \times 0.4 = 0.008 \text{ m}^3$$

$$\text{vol. occupied by vapour } (V_2) = 100 \times 0.4 = 98.1 \times 0.4$$

As it is two-phase mixture from table,

$$T_1 = 99.63^\circ\text{C}, \quad u_g = 1.6943 \text{ m}^3/\text{kg}, \quad u_f = 0.001043 \text{ m}^3/\text{kg}$$

Now,

$$\text{mass of saturated liquid } (m_f) = \frac{V_1}{V_f} = \frac{0.008}{0.001043} = 7.670 \text{ kg}$$

$$\text{mass of saturated vapour } (m_g) = \frac{V_2}{V_g} = \frac{0.392}{1.6943} = 0.231 \text{ kg}$$

$$\text{Quality } (x_1) = \frac{m_g}{m_f + m_g} = \frac{0.231}{7.670 + 0.231} = 0.0292$$

now,

$$V_1 = V_f + x_1 V_g \\ = 0.001043 + 0.029 \times 1.6943 \\ = 0.0506 \text{ m}^3/\text{kg}$$

$$V_2 = V_f + x_1 V_g \\ = 417.41 + 0.029 \times 2028.3 \\ = 477.970$$

Process 1-2 constant volume heating process.

state 2 saturated vapour.

$$V_g = 0.0506 \text{ m}^3/\text{kg}$$

Now,

from saturation table

$\vartheta \text{ (m}^3/\text{kg})$	$u \text{ (kJ/kg)}$
0.05318	2602.3
0.0506	$u_2$
0.04977	2601.5

by interpolation,

$$u_2 - 2602.3 = \frac{2601.5 - 2602.3}{0.04977 - 0.05318} (0.0506 - 0.05318)$$

$$u_2 - 2602.3 = -0.6052$$

$$u_2 = 2602.3 - 0.6052$$

$$u_2 = 2601.69 \text{ kJ/kg}$$

now,

total heat transfer is,

$$\begin{aligned} Q_{12} &= (m u)_{12} + w_{12}^{\circ} \\ &= m(u_2 - u_1) \\ &= 77.901 (2601.69 - 477.970) \\ &= 16775.98 \text{ kJ} \end{aligned}$$

Q.3)

= given,

$$\text{mass of piston } (m_p) = 25 \text{ kg}$$

$$\text{area of piston } (A_p) = 0.005 \text{ m}^2$$

$$P_{atm} = 0.101 \text{ MPa} = 101 \text{ kPa}$$

Now,

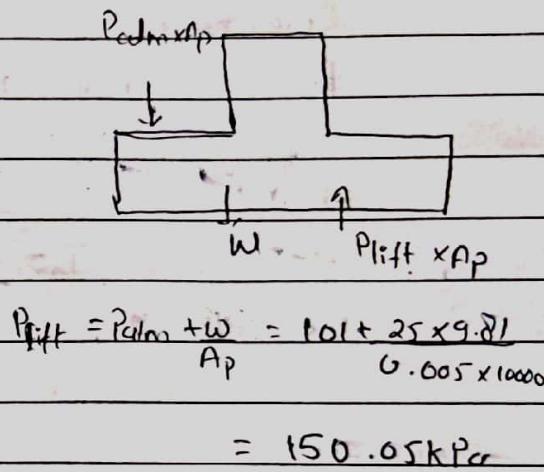
$$P_{atm} = 0.3 \text{ MPa} = 300 \text{ kPa}$$

now,

State 1

$$P_1 = 101 \text{ kPa} \quad T_1 = 20^\circ\text{C} = 293 \text{ K}$$

$$V_1 = A_p \times 0.25$$



$$P_{lift} = P_{atm} + w = 101 + \frac{25 \times 9.81}{0.005 \times 1000}$$

$$= 150.05 \text{ kPa}$$

$$= 0.005 \times 0.25$$

$$= 0.00125 \text{ m}^3$$

Now,

$$P_1 V_1 = m R T_1$$

$$m = \frac{P_1 V_1}{R T_1}$$

$$m = \frac{101 \times 100 \times 0.00125}{287 \times 293}$$

$$= 0.00150 \text{ kg}$$

Now,  $P_1 < P_{lift}$  so further heating is needed

Process 1-2 constant volume heating process.

State 2.

$$P_2 = 150.05 \text{ kPa}, V_2 = V_1 = 0.00125 \text{ m}^3$$

Now  $P_2 > P_{lift}$ , so further heating is needed

Process 2-3 constant pressure heating process,

state 3.

$$P_3 = 150.05 \text{ kPa}$$

$$V_3 = A_p \times (0.1 + 0.45)$$

$$T_3 = ?$$

$$= 0.005 \times 0.35$$

$$= 0.00175 \text{ m}^3$$

we have,

$$P_3 V_3 = m R T_3$$

$$T_3 = \frac{P_3 V_3}{m R}$$

$$T_3 = \frac{150.05 \times 1000 \times 0.00175}{0.00150 \times 287}$$

$$T_3 = 609.96 \text{ K}$$

Hence, temp. when piston reaches the upper stop is 609.96 K, still  $P_3 < P_{\text{final}}$ , so further heating is needed.

Process 3-4 constant vol. heating process

$$P_4 = 300 \text{ kPa} \quad V_{21} = V_3 = 0.00175 \text{ m}^3, T_4 = ?$$

we have,

$$P_4 V_4 = m R T_4$$

$$T_4 = \frac{P_4 V_4}{m R}$$

$$= \frac{300 \times 1000 \times 0.00175}{0.00150 \times 287}$$

$$= 1219.512 \text{ K}$$

now,

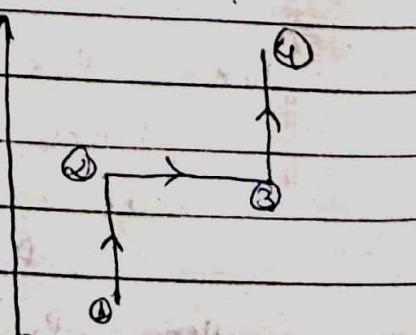
total heat transfer  $Q$

$$Q = (\Delta V)_{34} + w_{14}$$

$$= (m C_v dT) + W_{12}^0 + W_{23}^0 + W_{34}^0$$

$$= \frac{0.00150 \times 717 \times (1219.512 - 93)}{1000} + 150.05 (0.00175 - 0.00125)$$

$$= 1.075 \text{ kJ}$$



Q.4)

 $\Rightarrow$  SOR,

State 1.

$$P_1 = 1 \text{ MPa}$$

$$T_1 = 500^\circ\text{C}$$

(S+V)

$$= 1000 \text{ kPa}$$

From table,

$$v_1 = 0.3541 \text{ m}^3/\text{kg}$$

$$T_{\text{final}} = 30^\circ\text{C}$$

$$u_1 = 5124.5 \text{ kJ/kg}$$

Now,  $T_1 > T_{\text{final}}$  so, further cooling

Process 1-2 cond. vol. cooling process

State 2.

$$P_2 = 400 \text{ kPa}$$

$$v_2 = v_1 = 0.3541 \text{ m}^3/\text{kg}$$

$$, T_2 = ?$$

$$u_2 = ?$$

from table.

$$v_1 < v_2 < v_g$$

$$\text{so, TPM}$$

$$T_2 = 143.64^\circ\text{C}$$

now,

$$v_2 = v_1 + x_2 v_g$$

$$0.3541 = 0.001084 + x_2 (0.4614)$$

$$x_2 = 0.765$$

now,

$$u_2 = u_1 + x_2 u_g$$

$$= 5124.47 + 0.765 \times (1949.0)$$

$$= 2095.645 \text{ kJ/kg}$$

Still,  $T_2 > T_{\text{final}}$  so further cooling is needed.

Process 2-3 const. pressure cooling process

State 3

$$P_3 = 400 \text{ kPa}$$

$$T_3 = 30^\circ\text{C}$$

$$V_3 = ?$$

$$u_3 = ?$$

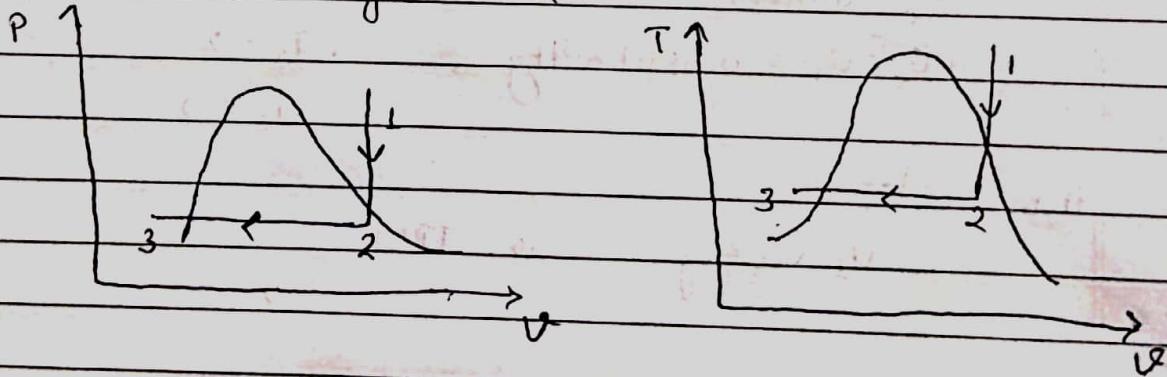
from table,

$T_3 < T_{\text{sat}}$  so, sub-cooled liquid

$$V_3 = V_f = 0.001604 \text{ m}^3/\text{kg}$$

$$u_3 = u_f = 125.67 \text{ kJ/kg}$$

The P-V & T-V diagrams are:



now,

$$\begin{aligned} \text{work transfer (w)} &= u_2 - u_3 \\ &= P_2(V_2 - V_3) \\ &= 400 \times (0.001604 - 0.3541) \\ &= -141.238 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} \text{Heat transfer (Q)} &= (u_3 - u_2) + w \\ &= (u_3 - u_f) + (-141.238) \\ &= -3140.1 \text{ kJ/kg} \end{aligned}$$

Q. 5)

$\Rightarrow$  Here

give,

At Inlet

$$P_{in} = 150 \text{ kPa}$$

$$T_{in} = 150^\circ\text{C}$$

$$\dot{V}_{in} = 200 \text{ mls}$$

At Out

$$P_{out} = 1000 \text{ kPa}$$

$$T_{out} = 500^\circ\text{C}$$

$$\dot{V}_{out} = 100 \text{ mls.}$$

$$A_{out} = 100 \text{ cm}^2$$

Also, given

$$R = 287 \text{ J/kg K}, \quad C_p = 1005 \text{ J/kg K}$$

now,

$$\dot{m} = ?$$

$$\dot{\omega} = ?$$

we know,

$$\dot{m} = \frac{A_{out} \dot{V}_{out}}{V_{out}} \quad \text{--- (1)}$$

But,

$$P_{out} V_{out} = P T_{out}$$

$$\therefore 1000 \times 1000 \times V_{out} = 287 \times 773$$

$$\therefore V_{out} = 0.223851 \text{ m}^3/\text{kg}$$

Then, (1) becomes

$$\dot{m} = \frac{100 \times (10)^{-4} \times 100}{0.223851}$$

$$\therefore \dot{m} = 41.55 \text{ kg/s.}$$

By energy conservation eqn for adiabatic compression

$$\dot{W}_{cv} = m [(h_1 - h_2) + \frac{1}{2} (\bar{v}_1^2 + \bar{v}_2^2) + g(z_1 - z_2)]$$

neglecting PE change &  $h_1 - h_2 = c_p(T_1 - T_2)$

$$\dot{W}_{cv} = 1.5 \times [1005(150 - 500) + \frac{1}{2} (200^2 - 100^2)]$$

$$\dot{W}_{cv} = -1518.74 \text{ kW}$$

Q8)

$\Rightarrow$  sol.

Hex for nozzle

inlet

$$P_1 = 4 \text{ MPa} = 4000 \text{ kPa}$$

$$T_1 = 450^\circ\text{C}$$

$$\bar{v}_1 = 50 \text{ m/s}$$

$$A_1 = 80 \text{ cm}^2$$

outlet

$$P_2 = 2 \text{ MPa} = 2000 \text{ kPa}$$

$$T_2 = 300^\circ\text{C}$$

$$\bar{v}_2 = ?$$

$$A_2 = ?$$

$$\dot{Q}_{cv} = -100 \text{ kW}$$

now,

$$m = ?$$

For inlet

The steam is super heated vapour f from table.

$$V_1 = 0.08002 \text{ m}^3/\text{kg}$$

$$h_1 = 3330.4 \text{ kJ/kg}$$

For exit

The steam is super heated vapour f from table

$$V_2 = 0.1254 \text{ m}^3/\text{kg}$$

$$h_2 = 3622.7 \text{ m}^3/\text{kg}$$

now,

$$m = \frac{A_1 \bar{V}_1}{g} = \frac{80 \times (100)^{-2} \times 50}{0.08002} = 1.99872 \text{ kgds.}$$

for diffuser,

$$\Phi_{cv} = m \left[ (h_2 - h_1) + \frac{1}{2} (\bar{V}_2^2 - \bar{V}_1^2) + g (z_2 - z_1) \right] \quad \text{neglecting}$$

$$-100 \times 10^3 = 4998.75 \left[ 3022700 - 3330400 + \frac{1}{2} (\bar{V}_2^2 - 50^2) \right]$$

$$-20005.00125 = -308950 + \frac{1}{2} \bar{V}_2^2 - 1250$$

$$-20005.00125 = -308950 + \frac{1}{2} \bar{V}_2^2$$

$$\frac{1}{2} \bar{V}_2^2 = 2889449988.$$

$$\bar{V}_2^2 = 577889.9975$$

$$\bar{V}_2 = 760.193 \text{ mls.}$$

we know,

$$\frac{A_1 \bar{V}_1}{g} = \frac{A_2 \bar{V}_2}{g}$$

$$A_2 = \frac{A_1 \bar{V}_1 g}{\bar{V}_2 g}$$

$$A_2 = 8.2459 \text{ cm}^2$$

Q. 9)

Ans

At inlet 1,  $h_1 = 90 \text{ kJ/kg}$ ,  $\dot{m}_1 = 210 \text{ kg/h}$ At outlet 2,  $h_2 = 34 \text{ kJ/kg}$ ,  $\dot{m}_2 = 4 \text{ kg/h}$ At outlet 3,  $h_3 = 23.8 \text{ kJ/kg}$ ,  $\dot{m}_3 = ?$ 

Now,

by conservation of mass

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

$$\dot{m}_3 = \dot{m}_1 - \dot{m}_2$$

$$\dot{m}_3 = 210 - 4$$

$$\dot{m}_3 = 206 \text{ kg/h}$$

Now,

$$\Delta h_{cv} = \dot{m}_{out} h_{out} - \dot{m}_{in} h_{in}$$

$$= (\dot{m}_2 h_2 + \dot{m}_3 h_3) - \dot{m}_1 h_1$$

$$= (4 \times 34 + 206 \times 23.8) - 210 \times 90$$

$$= -13861.2 \text{ kJ/h}$$

$$= -3.85 \text{ kJ/sec}$$

$$= -3.85 \text{ kW}$$

Q.F)

 $\Rightarrow$  If ex.

For a adiabatic diffuser.

At inlet

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

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

$$\bar{V}_1 = 200 \text{ m/s}$$

$$A_1 = 100 \text{ mm}^2$$

$$= 100 \times (1000)^2$$

$$= 10^{-4} \text{ m}^2$$

exit,

$$P_2 = ?$$

$$\bar{V}_2 = 20 \text{ m/s}$$

$$n_2 = 860 \text{ m}^{-2}$$

$$= 860 \times 10^{-6}$$

$$= 8.6 \times 10^{-4} \text{ m}^3$$

$$T_2 = ?$$

We know,

$$P_1 \bar{V}_1 = P_2 \bar{V}_2$$

$$\therefore 100 \times 10^3 \times 200 = 287 \times 360$$

$$\bar{V}_2 = 0.861 \text{ m}^3/\text{kg}$$

For adiabatic diffuser.

$$h_1 + \frac{1}{2} \bar{V}_1^2 = h_2 + \frac{1}{2} \bar{V}_2^2$$

$$\therefore h_2 - h_1 = \frac{1}{2} (\bar{V}_1^2 - \bar{V}_2^2)$$

$$\therefore C_p(T_2 - T_1) = \frac{1}{2} (200^2 - 20^2)$$

$$\therefore 1005 \cdot (T_2 - 300) = 19800$$

$$T_2 - 300 = \frac{19800}{1005}$$

$$T_2 - 300 = 19.7$$

$$T_2 = 319.7 \text{ K}$$

now

$$\frac{A_1 V_1}{J_1} = \frac{A_2 V_2}{J_2}$$

$$J_2 = \frac{A_2 V_2 J_1}{A_1 V_1}$$

$$J_2 = \frac{8.6 \times 10^{-4} \times 20 \times 0.861}{10^{-4} \times 200}$$

$$J_2 = 0.74046 \text{ m}^3/\text{kg}$$

&amp;

$$P_2 V_2 = R T_2$$

$$P_2 = \frac{287 \times 319.7}{0.74046}$$

$$P_2 = 123914.72 \cdot P_0$$

$$P_2 = 123.92 \text{ kPa}$$

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