

Engineering Thermodynamics (3ME4-05)

Syllabus

S.No	Contents	Hours
3	Thermodynamic Properties of Fluids: Pure substance, Concept of Phase, Graphical representation of p-v-T data, Properties of steam. Steam tables, Mollier chart	4
	Ideal Gas and Real Gas: Ideal gas, Real gas, Internal energy, enthalpy and specific heats of an ideal gas, equations of state, Dalton's law of partial pressures, Gibbs Dalton law, Thermodynamic properties of gas mixtures.	4

→ First Law of Thermodynamics deals with → Conservation of Energy.

→ Second Law of Thermodynamics defines → Entropy.

→ Kelvin-Planck's Law deals with → Conversion of heat into work.

→ Heat is not a Thermodynamic property.

→ Temperature is an intensive property of a Thermodynamic System.

→ Volume is the Extensive property of a Thermodynamic System.

→ When neither mass nor Energy is allowed to cross the boundary of a system, it is known as isolated system.

→ A definite size or place where some Thermodynamic process are taking place is known as Thermodynamic System.

→ Atmospheric pressure is equal to $\approx 1.013 \text{ bar}$
 $\approx 101.3 \text{ kPa}$
 $\approx 760 \text{ mm of Hg}$

→ When a process or processes are performed on a system in such a way that the final state is identical with initial state, it is then known as Thermodynamic cycle.

⇒ Laws of Perfect Gases:-

Formulated by Robert Boyle in 1662

(i) Boyle's Law:- The absolute pressure of a given mass of perfect gas varies inversely as its volume when the temperature remains constant.

$P \propto \frac{1}{V}$ or, $PV = \text{Constant}$

$P_1 V_1 = P_2 V_2 = P_3 V_3 = \dots = \text{Constant}$

(2) Charles' Law:- Formulated by Frenchman Jacques A.C. Charles in 1787.

$V \propto T$ $\Rightarrow \frac{V}{T} = C$

$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \dots = C$

All perfect gases change in volume by $\frac{1}{273}$ th of its initial or original volume at 0°C for every 1°C change in Temp. when pressure remains constant.

$V_0 = \text{Vol}^m$ of a given mass of a gas at 0°C .
 $V_t = \dots \dots \dots t^\circ\text{C}$.

According to above statement

$V_t = V_0 + \frac{1}{273} V_0 t = V_0 \left(\frac{273+t}{273} \right)$

$= V_0 \left(\frac{T}{T_0} \right)$

or, $\frac{V_t}{V_0} = \frac{T}{T_0}$

where $T = \text{Absolute Temp. at } t^\circ\text{C}$.
 $T_0 = \text{Absolute Temp. at } 0^\circ\text{C}$.

The temperature at which the volume of a gas becomes zero is called absolute zero temperature.

(3) Gay-Lussac Law:-

$$P \propto T \Rightarrow \boxed{\frac{P}{T} = c}$$

at constant volume.

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3} = \dots = c}$$

We already know that from General Gas Equation.

$$\boxed{\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = c}$$

(4) Joule's Law:- The change of internal energy of a perfect gas is directly proportional to the change in temperature.

$$\Rightarrow dE \propto dT$$

$$\Rightarrow dE = mc \, dT = mc (T_2 - T_1)$$

$$\boxed{dE = mc (T_2 - T_1)}$$

\Rightarrow Characteristic Equation of Gas:-

$$Pv = mR\tau$$

$$\Rightarrow P \left(\frac{V}{m} \right) = R\tau \Rightarrow$$

$$Pv_s = R\tau$$

$$P \cdot \frac{P_v}{m\tau} = \frac{N/m^2 \times m^3}{kg \times K} = \frac{N \cdot m}{kg \cdot K} = \frac{J}{kg \cdot K}$$

$$\boxed{[N \cdot m = J]}$$

for atmospheric air

$$R = 287 \text{ J/kg}\cdot\text{K}$$

$$= 0.287 \text{ kJ/kg}\cdot\text{K}$$

$$\therefore P \cdot v = mRT$$

$$\therefore P = \left(\frac{m}{v}\right) RT$$

$$\boxed{P = \rho RT}$$

$$\therefore \left(\frac{m}{v} = \rho\right)$$

(5) Avogadro's law :- Equal volumes of all gases, at same temp. and pressure contain equal no. of molecules.

The density of oxygen at Normal Temperature and Pressure (N.T.P) at 0°C and 1.013 bar is 1.429 kg/m^3 .

\therefore Specific vol^m (of 1 kg) of oxygen at N.T.P

$$V_s = \left(\frac{1}{1.429}\right) \text{ m}^3/\text{kg}$$

and volume of 32 kg (or 1 kg molecule written as 1 kg-mole)

$$= \frac{1}{1.429} \times 32 = 22.4 \text{ m}^3$$

\rightarrow Similarly, it can be proved that the volume of 1 kg-mole of any gas at N.T.P is 22.4 m^3 .

\rightarrow 1 gm-mole (molecular mass expressed in gm) of all gases occupies a volume of 22.4 litres at N.T.P.

(6) Universal Gas Constant or Molar Constant :- \rightarrow It is of gas is the product of the gas constant and the molecular mass of the gas.

$$\boxed{R_u = MR}$$

where $M = \text{kg/mole}$.

For S.I unit $R_u = 8314 \text{ J/kg.mol.K} = \frac{8.314 \text{ kJ}}{\text{kg.mol.K}}$

The value of R_u is same for all gases.

Q.P. 7.5v

\Rightarrow Enthalpy is the sum of the internal energy (u) and the product of pressure and volume (Pv).

This sum ($u+Pv$) is termed as enthalpy and is written as H .

$$\boxed{H = u + Pv}$$

Enthalpy is also a thermodynamic property. For unit mass, specific enthalpy.

$$\boxed{h = u + Pv}$$

Enthalpy is also a thermodynamic property.

When gas is heated at constant pressure from point 1 to 2. Then change in internal energy

$$du = u_2 - u_1$$

we already know that from first law of thermodynamics

$$\delta Q_2 = du + PdV$$

$$= du + P(V_2 - V_1)$$

$$\Rightarrow \delta Q_2 = (u_2 - u_1) + P(V_2 - V_1)$$

$$= (u_2 + P_2V_2) - (u_1 + P_1V_1)$$

$$\Rightarrow \delta Q_2 = \frac{H_2 - H_1}{m}$$

For unit mass,

$$\boxed{q_{1-2} = \frac{H_2 - H_1}{m}}$$

⇒ Molar specific heats of a Gas:- The molar or volumetric specific heat of a gas may be defined as the amount of heat required to raise the Temp. of unit mole of gas through one degree.

$$C_m = M C$$

Molar specific heat at constant volume

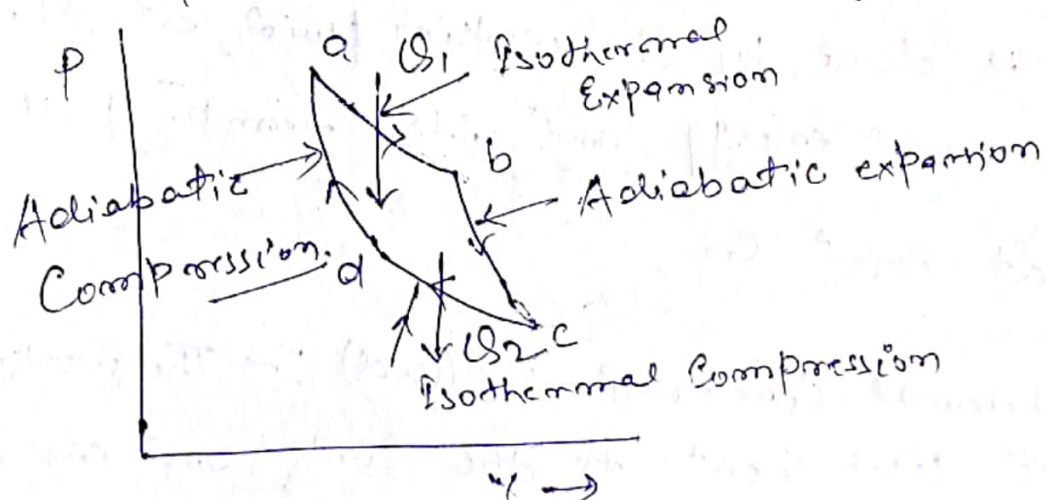
$$C_{vm} = M C_v$$

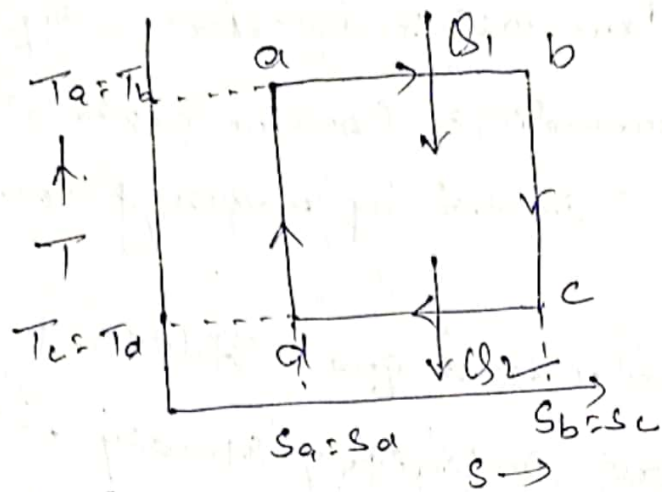
& at constant pressure is

$$C_{pm} = M C_p$$

(6) Regnault's Law:- This law states, The two specific heats of a gas (~~at~~ C_p & C_v) do not change with the change in pressure and temperature of the gas.

- ⇒ **Reversible and Irreversible Processes:** - If both the system and surroundings can be restored to their respective initial states by reversing the direction of the process,
- A reversible process is a quasi-static process; a process carried out infinitely slowly with infinitesimal gradient with the system passing through a continuous series of equilibrium states.
 - The reversible processes can be proceed in either direction without violating the second law of thermodynamics.
 - A system going through a reversible process results in max^m efficiency.
 - A reversible process yields the max^m work in engines and requires min^m work in devices such as refrigerators, pumps and compressions.
- ⇒ **Carnot Cycle & Carnot Heat Engines:** -





Isothermal Expansion (a-b): - Heat is supplied to the working fluid at constant Temp. ~~T_1~~ T_1

$$Q_1 = W_{a-b} = P_a V_a \log_e \left(\frac{V_b}{V_a} \right)$$

$$= m R T_1 \log_e \left(\frac{V_b}{V_a} \right)$$

Adiabatic Expansion (b-c): -

At the end of isothermal expansion (at point b), the heat source is replaced by adiabatic cover.

Diathermic Cover.
→ (Perfect heat conductors)

The expansion continues adiabatically and reversibly upto at point c.

Adiabatic Cover →
(Perfect heat insulators)

Work is done by the working fluid at the expense of internal energy and its temp. falls to T_2 at point c.

⇒ Isothermal Compression: - (c-d): - The working fluid ~~fluid~~ loses heat to the sink and its amount

Equals to the work done on the working fluid. This work is represented by area under the curve c-d and its amount is given by:-

$$Q_2 = W_{c-d} = p_c v_c \log_e \left(\frac{v_c}{v_d} \right)$$

$$= m R T_2 \log \left(\frac{v_c}{v_d} \right)$$

⇒ Adiabatic Compression (d-a):-

The Compression now proceeds adiabatically and reversibly till the working fluid returns back to its initial state point a. work is done on the working fluid, the internal energy increases and temp. is raised to T_1 .

$$\eta = \frac{\text{Net work out}}{\text{Heat in}} = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$= \frac{m R T_1 \log_e \left(\frac{v_b}{v_a} \right) - m R T_2 \log_e \left(\frac{v_c}{v_d} \right)}{m R T_1 \log_e \left(\frac{v_b}{v_a} \right)}$$

$$= 1 - \frac{T_2}{T_1} \times \frac{\log_e \left(\frac{v_c}{v_d} \right)}{\log_e \left(\frac{v_b}{v_a} \right)}$$

For the adiabatic expansion processes (b-c) and (d-a)

$$\frac{T_b}{T_c} = \left(\frac{V_c}{V_b}\right)^{\gamma-1} \quad \text{and} \quad \frac{T_d}{T_a} = \left(\frac{V_a}{V_d}\right)^{\gamma-1}$$

Since, $T_b = T_a = T_1$ and $T_c = T_d = T_2$

From the above eqn

$$\frac{T_1}{T_2} = \left(\frac{V_c}{V_b}\right)^{\gamma-1} = \left(\frac{V_d}{V_a}\right)^{\gamma-1}$$

$$\Rightarrow \frac{V_c}{V_b} = \frac{V_d}{V_a} \quad \text{or,} \quad \left(\frac{V_c}{V_d}\right) = \left(\frac{V_b}{V_a}\right)$$

Now,

$$\eta = 1 - \frac{T_2}{T_1} = \frac{T_1 - T_2}{T_1}$$

Following conclusions:—

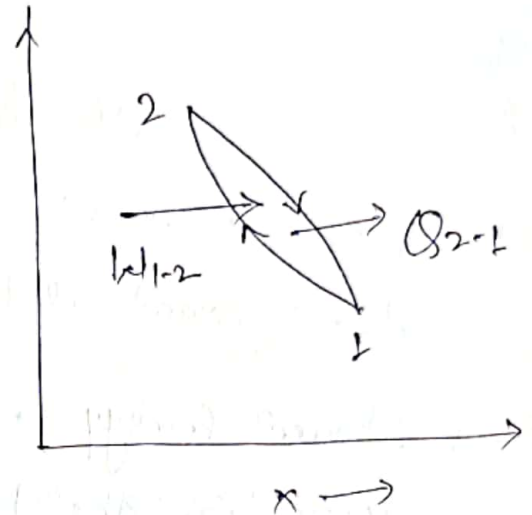
- (i) Efficiency is independent of the working fluid and depends upon the temp. of source & sink.
- (ii) If $T_2 = 0$, the engine will have an efficiency of 100 percent. That means absence of heat sink, which is violation of Kelvin-Planck Statement of the Second Law.
- (iii) The efficiency is directly proportional to temp. difference $(T_1 - T_2)$ betⁿ source and sink.

⇒ First Law of Thermodynamics:—

"The heat and mechanical

work are mutually convertible". According to this law, when a system (closed) goes to a thermodynamic cycle, the net heat transfer is equal to the net work transfer.

W_{1-2} is always proportional to the heat Q_{2-1} , and the constant of proportionality J is called the Joule's Equivalent or the mechanical equivalent of heat.



$$\boxed{(\sum W)_{\text{cycle}} = J (\sum Q)_{\text{cycle}}}$$

or, $(\sum W)_{\text{cycle}} \propto (\sum Q)_{\text{cycle}}$.

or in the form of cyclic integral.

$$\boxed{\oint dW = J \oint dQ}$$

($J = 1 \text{ Nm/J}$). Heat & work → Joule. (Energy)

⇒ The energy can neither be created nor destroyed but it can be only transferred from one form to another form.

According to this law, when a system undergoes a change of state (Thermodynamic process), the both heat transfer and work transfer takes place. The net energy transfer is stored within the system and is known stored energy or Total energy of the system.

$$(\delta Q - \delta W = dE)$$

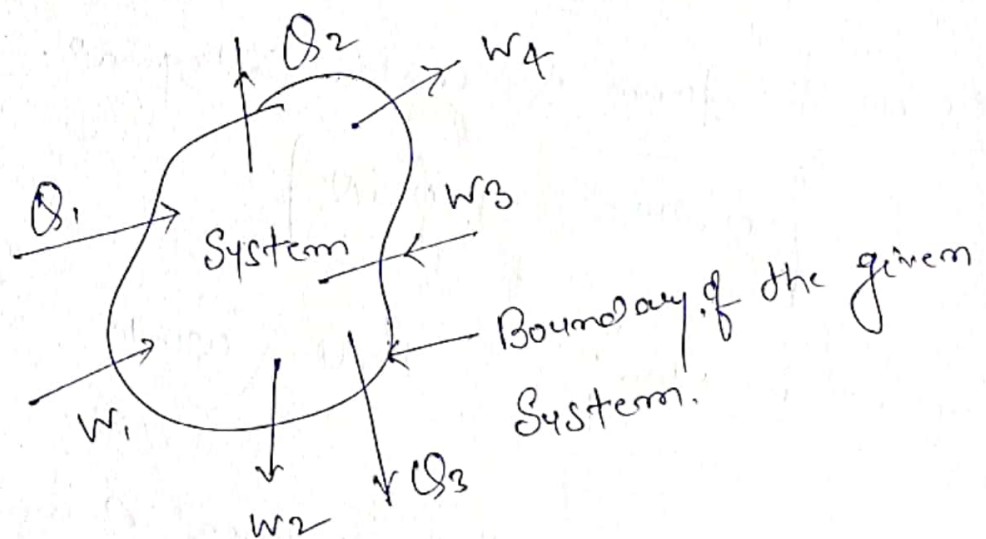
$\delta \rightarrow$ inexact differential

$d \rightarrow$ Exact differential

\rightarrow Stored energy is neither heat nor work and is given in the form of internal energy or energy of the system.

$$\boxed{Q - W = \Delta E}$$

Q, W and ΔE are all expressed in the same unit (Joule).



Now,

$$(Q_1 - Q_2 - Q_3) = \Delta E + (-W_1 + W_2 - W_3 + W_4)$$

$$\Rightarrow (Q_1 - Q_2 - Q_3) = \Delta E + (W_2 + W_4 - W_1 - W_3)$$

for unit mass

$$Q_{1-2} - W_{1-2} = E_2 - E_1$$

$$Q_{1-2} - W_{1-2} = E_2 - E_1$$

Q_{1-2} = Heat transferred to the system during the process from point 1 to 2.

W_{1-2} = Work done by the system on the surroundings during the process.

E_1 = Total energy of the system at point 1

$$= PE_1 + KE_1 + U_1 = mgz_1 + \frac{mv_1^2}{2} + U_1$$

E_2 = Total energy of the system at point 2.

$$= PE_2 + KE_2 + U_2 = mgz_2 + \frac{mv_2^2}{2} + U_2$$

Now from the above equation we get,

$$Q_{1-2} - W_{1-2} = E_2 - E_1$$

$$= (PE_2 + KE_2 + U_2) - (PE_1 + KE_1 + U_1)$$

$$= mgz_2 + \frac{mv_2^2}{2} + U_2 - mgz_1 - \frac{mv_1^2}{2} - U_1$$

$$Q_{1-2} - W_{1-2} = mg(z_2 - z_1) + \frac{m}{2}(v_2^2 - v_1^2) + (U_2 - U_1)$$

for unit mass

$$q_{1-2} - w_{1-2} = g(z_2 - z_1) + \left(\frac{v_2^2}{2} - \frac{v_1^2}{2} \right) + (u_2 - u_1)$$

when there is no change in potential energy,

$$q_{1-2} - w_{1-2} = \left(\frac{v_2^2}{2} - \frac{v_1^2}{2} \right) + (u_2 - u_1)$$

when there is no flow of mass into or out of the system

then

$$q_{1-2} - w_{1-2} = (u_2 - u_1)$$

$$\boxed{q_{1-2} - w_{1-2} = du} \quad \text{---} \quad \textcircled{i}$$

In a closed or non-flow thermodynamic system

$$PE = 0$$

$$KE = 0$$

Thus the above equation is known as non-flow energy equation.

\Rightarrow For an isolated system for which $Q_{1-2} = W_{1-2} = 0$

then the above equation becomes,

$$\boxed{E_1 = E_2} \quad \text{or.} \quad u_2 = u_1$$

$$\boxed{v_1 = v_2}$$

This equation shows that first law of Thermodynamics is the law of Conservation.

⇒ Energy - A property of the system.

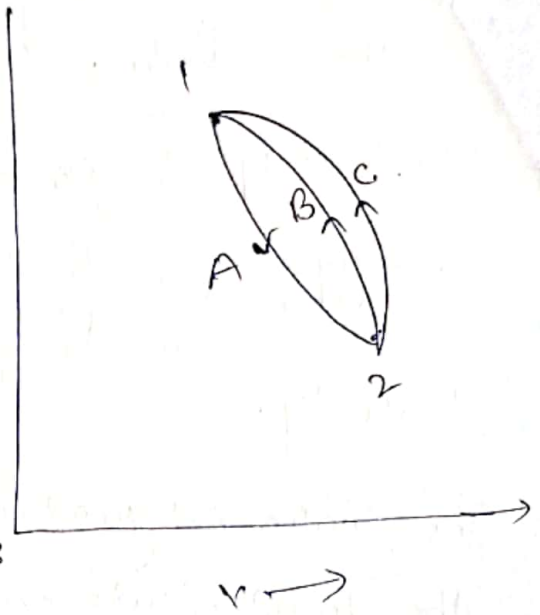
First law for path A.

$$Q_A = W_A + \Delta E_A \quad \text{--- (i)}$$

For path B.

$$Q_B = W_B + \Delta E_B \quad \text{--- (ii)}$$

The processes A and B together constitute a cycle.



$$(\Sigma W)_{\text{cycle}} = (\Sigma Q)_{\text{cycle}}$$

$$\Rightarrow W_A + W_B = Q_A + Q_B$$

$$\Rightarrow Q_A - W_A = -(Q_B - W_B)$$

$$\Rightarrow \boxed{\Delta E_A = -\Delta E_B} \quad \text{--- (iii)}$$

For path A and C, we get

$$\boxed{\Delta E_A = -\Delta E_C} \quad \text{--- (iv)}$$

From above eqn (iii) & (iv), we get

$$-\Delta E_B = -\Delta E_C$$

$$\therefore \boxed{\Delta E_B = \Delta E_C}$$

→ Energy has a definite value for every state of the system. Hence, it is a point function and a property of the system.

→ The energy E is an extensive property. The specific energy, $e = \frac{E}{m} = \left(\frac{J}{kg}\right)$ is an intensive property.

→ The cyclic integral of any property is zero. Because the final state is identical with the initial state.

$$\oint dE = 0, \quad \oint dV = 0.$$

Energy is the capacity of doing work.

In Thermodynamic Energy is in the two form.

(a) Energy in Transit → Work and Heat, observed at the boundaries of a system

(b) Energy in Storage; They are not property of a

system. They are path function. Their magnitude depends upon the path

→ It is a point function, or state function and hence a property of the given system.

Energy in storage is called internal energy.

P-v-T Relations

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma$$

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \quad \&$$

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

\Rightarrow Polytropic process P-v-T relations:-

$$\rightarrow P_1 V_1^\eta = P_2 V_2^\eta = P_3 V_3^\eta = \dots = C$$

$$\rightarrow \left(\frac{T_1}{T_2}\right) = \left(\frac{V_2}{V_1}\right)^{\eta-1}$$

$$\rightarrow \left(\frac{V_1}{V_2}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{1}{\eta}}$$

$$\rightarrow \left(\frac{T_1}{T_2}\right) = \left(\frac{P_1}{P_2}\right)^{\frac{\eta-1}{\eta}}$$

Heat Supplied (Q_{1-2}):-

$$Q_{1-2} = \left(\frac{\gamma-\eta}{\gamma-1}\right) \times \text{work done}$$

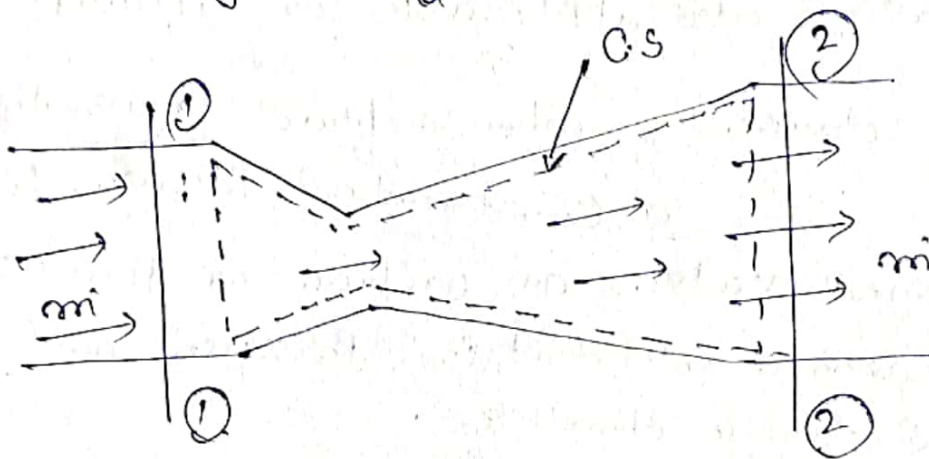
$$Q_{1-2} = \left(\frac{\gamma-\eta}{\gamma-1}\right) \times \frac{P_1 V_1 - P_2 V_2}{(\eta-1)}$$

(i) Nozzle and Diffuser:— A nozzle is a device which increases the velocity or K.E of a fluid at the expense of its pressure drop.

A diffuser increases the pressure of a fluid at the expense of its K.E. The nozzle is insulated.

The steady flow energy equation is given below.

$$h_1 + \frac{v_1^2}{2} + gz_1 + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2} + gz_2 + \frac{dW}{dm}$$



Here, $\frac{dQ}{dm} = 0$, $\frac{dW}{dm} = 0$, and the change in potential energy is zero. Now equation becomes.

$$h_1 + \frac{v_1^2}{2} = h_2 + \frac{v_2^2}{2}$$

From Continuity equation.

$$w = \frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2}$$

When the inlet velocity or velocity of approach is very small as compared to the exist velocity. Then

$$h_1 = h_2 + \frac{v_2^2}{2} \Rightarrow v_2^2 = 2(h_1 - h_2)$$

$$\therefore v_2 = \sqrt{2(h_1 - h_2)} \text{ m/s.}$$

$$(h_1 - h_2) \rightarrow J/\text{kg}$$

Now,

$$\left(\frac{J}{\text{kg}}\right)^{1/2} = \left(\frac{F \cdot S}{\text{kg}}\right)^{1/2} = \left(\frac{\text{m} \cdot \text{a} \cdot \text{s}}{\text{kg}}\right)^{1/2}$$

$$= \frac{\cancel{\text{kg}} \cdot \text{m} / \cancel{\text{s}} \cdot \cancel{\text{s}}}{\cancel{\text{kg}}} = \left(\frac{\text{m}}{\text{s}}\right)$$

The above equation also applicable for diffuser.

(ii) Throttling device : — when a fluid flows through a constricted passage, like a partially opened valve, an orifice or porous plug. There is an appreciable drop in pressure, and the flow is said to be throttled.

$\frac{dS}{dm} = 0$, $\frac{dw}{dm} = 0$. again change in P.E is very small and that is ignored.

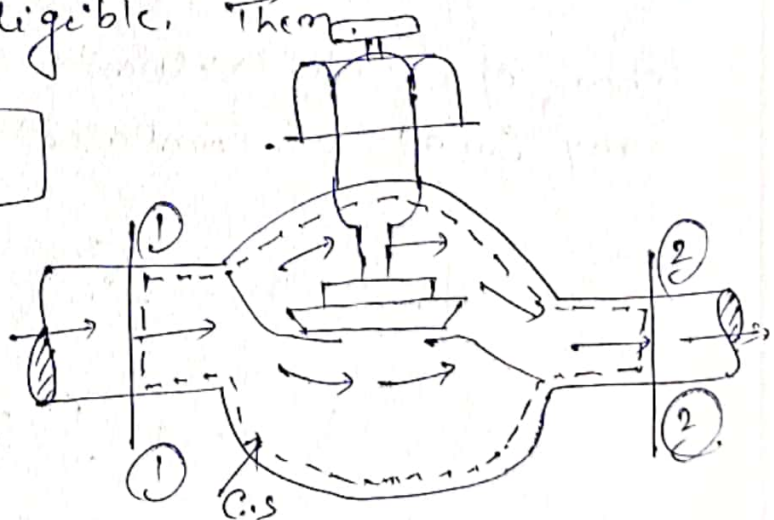
The S.F.E.E is given below.

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

Often the pipe velocities in throttling are so low that the K.E is negligible. Then

$$h_1 = h_2$$

The enthalpy of a fluid before throttling is equal to the enthalpy of the fluid after throttling.



(iii)

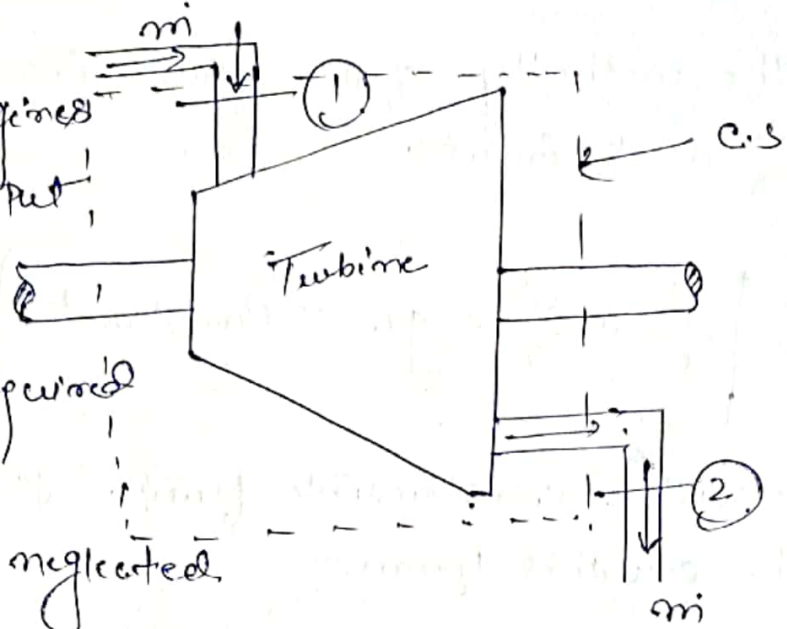
Turbines and Engines

give +ve Power output,

where as the Compressors and pumps require Power input.

Potential energy is neglected.

Flow velocity is very small
MOC,



$$h_1 + \frac{v_1^2}{2} + gz_1 + \frac{dq}{dm} = h_2 + \frac{v_2^2}{2} + gz_2 + \frac{dw_x}{dm}$$

$$\frac{v_1^2}{2} = \frac{v_2^2}{2} \approx 0$$

$$gz_1 = gz_2 \approx 0$$

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

$$h_1 = h_2 + \frac{dw_x}{dm}$$

$$\Rightarrow \boxed{\frac{w_x}{m} = (h_1 - h_2)}$$

It is seen that work is done by the fluid at the expense of its enthalpy.

Similarly, for an adiabatic pump or compressor work is done on the fluid.

$$\frac{dw_x}{dm} = -ve.$$

Now, SFEE is given below.

$$h_1 = h_2 - \frac{dw_x}{dm}$$

$$\therefore \boxed{\frac{w_x}{m} = (h_2 - h_1)}$$

↳ The enthalpy of the fluid increases by the amount of work input.

$$\boxed{\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{Constant}} \rightarrow \text{Bernoulli Equation}$$

which is valid for an inviscid incompressible fluid. It is also written in the another form.

$$\Delta \left[Pv + \frac{V^2}{2} + gz \right] = 0.$$

Bernoulli equation is restricted to frictionless incompressible fluid.

Q.No-1. Air flows steadily at the rate of 0.5 kg/s through an air compressor, entering at 7 m/s velocity, 100 kPa pressure, and $0.95 \text{ m}^3/\text{kg}$ volume of leaving at 5 m/s , 700 kPa , and $0.19 \text{ m}^3/\text{kg}$. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in the compressor jackets absorbs heat from the air at the rate of 58 kW . (a) Compute the rate of shaft work input to the air in kW (b) Find the ratio of the inlet pipe diameter to the outlet pipe diameter.

Solⁿ → Given:-

$V_1 = 7 \text{ m/s}$	$V_2 = 5 \text{ m/s}$
$P_1 = 100 \text{ kPa}$	$P_2 = 700 \text{ kPa}$
$V_1 = 0.95 \text{ m}^3/\text{kg}$	$V_2 = 0.19 \text{ m}^3/\text{kg}$

$$Q = -58 \text{ kW}$$

$$u_2 = (u_1 + 90) \text{ KJ/kg}$$

(a) The SFEE is given below

$$w_1 \left(h_1 + \frac{V_1^2}{2} + gz_1 \right) + \frac{dQ}{dt} = w_2 \left(h_2 + \frac{V_2^2}{2} + gz_2 \right) + \frac{dW_{ax}}{dt}$$

$$\therefore \frac{dW_{ax}}{dt} = \left[(h_1 - h_2) + \left(\frac{V_1^2}{2} - \frac{V_2^2}{2} \right) + g(z_1 - z_2) \right] w + \frac{dQ}{dt}$$

$$= \left[(u_1 + P_1 v_1 - u_2 - P_2 v_2) + \left(\frac{V_1^2 - V_2^2}{2} \right) + g(z_1 - z_2) \right] w + \frac{dQ}{dt}$$

$$= \left[(u_1 - u_2) + (P_1 v_1 - P_2 v_2) + \left(\frac{V_1^2 - V_2^2}{2} \right) + g(z_1 - z_2) \right] w + \frac{dQ}{dt}$$

$$= - \left[(u_2 - u_1) + (P_2 v_2 - P_1 v_1) + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \right] w + \frac{dQ}{dt}$$

$$= - 0.5 \frac{\text{kg}}{\text{s}} \left[90 \frac{\text{KJ}}{\text{kg}} + (7 \times 0.19 - 1 \times 0.95) 1000 \right]$$

$$\frac{\text{KJ}}{\text{kg}} + \left(\frac{5^2 - 7^2}{2} \right) \times 10^{-3} \frac{\text{KJ}}{\text{kg}} + 0 \Big] - 58 \text{ kW}$$

$$= - 0.5 [90 + 38 - 0.012] \text{ KJ/s} - 58 \text{ kW}$$

$$\frac{dW}{dt} = -122 \text{ kW}$$

Rate of work input = 122 kW

(b) From mass balance equation.

$$W = \frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2}$$

$$\therefore \frac{A_1}{A_2} = \frac{v_2}{v_1} \times \left(\frac{v_1}{v_2} \right) = \frac{5}{7} \times \frac{0.95}{0.19} \frac{(\text{m/s})}{(\text{m/s})} \frac{(\text{m}^3/\text{kg})}{(\text{m}^3/\text{kg})}$$

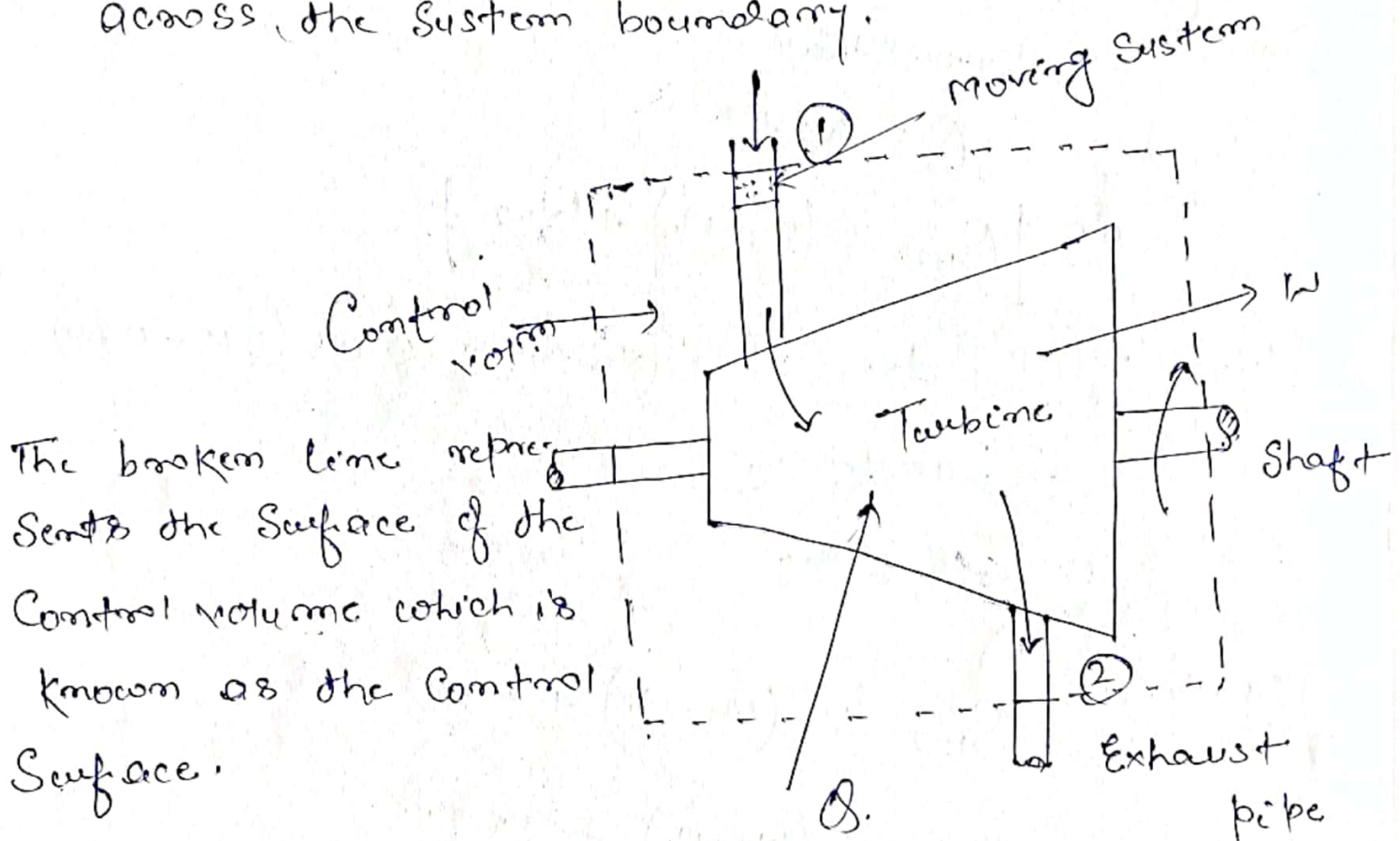
$$\Rightarrow \frac{A_1}{A_2} = \underline{3.57}$$

$$\therefore \frac{d_1}{d_2} = \sqrt{3.57} = 1.89$$

$$\frac{d_1}{d_2} = \underline{1.89} \quad \underline{\text{Ans.}}$$

A certain fixed region in space called a Control volume through which the moving substance flows. This is similar to the analysis of Euler in fluid mechanics.

The Control volume boundary remains fixed and unaltered. Again, while matter usually crosses the Control volume boundary, no such flow occurs across the system boundary.



⇒ Steady Flow Processes:—

As the fluid flows through a certain Control volume, its Thermodynamic Properties may vary along the space coordinates as well as with time.

If the rate of flow of mass & energy through the Control surface change with time, the mass & energy within the Control volume also would change with time.

Steady flow means that the rate of flow of mass and energy across the control surface are constant.

⇒ Mass balance and Energy balance in a Steady flow Process.

A_1, A_2 : Cross-section of stream (m^2)

\dot{m}_1, \dot{m}_2 : mass flow rate (kg/s)

p_1, p_2 = Pressure, absolute (N/m^2)

v_1, v_2 : Specific volume (m^3/kg)

u_1, u_2 : Specific internal Energy (J/kg)

V_1, V_2 = Velocity (m/s)

Z_1, Z_2 : Elevation above arbitrary datum (m)

$\frac{dQ}{dt}$ = Net rate of heat transfer through Control Surface, (J/s)

$\frac{dW_{sh}}{dt}$ = Net rate of work transfer through the Control Surface, (J/s)

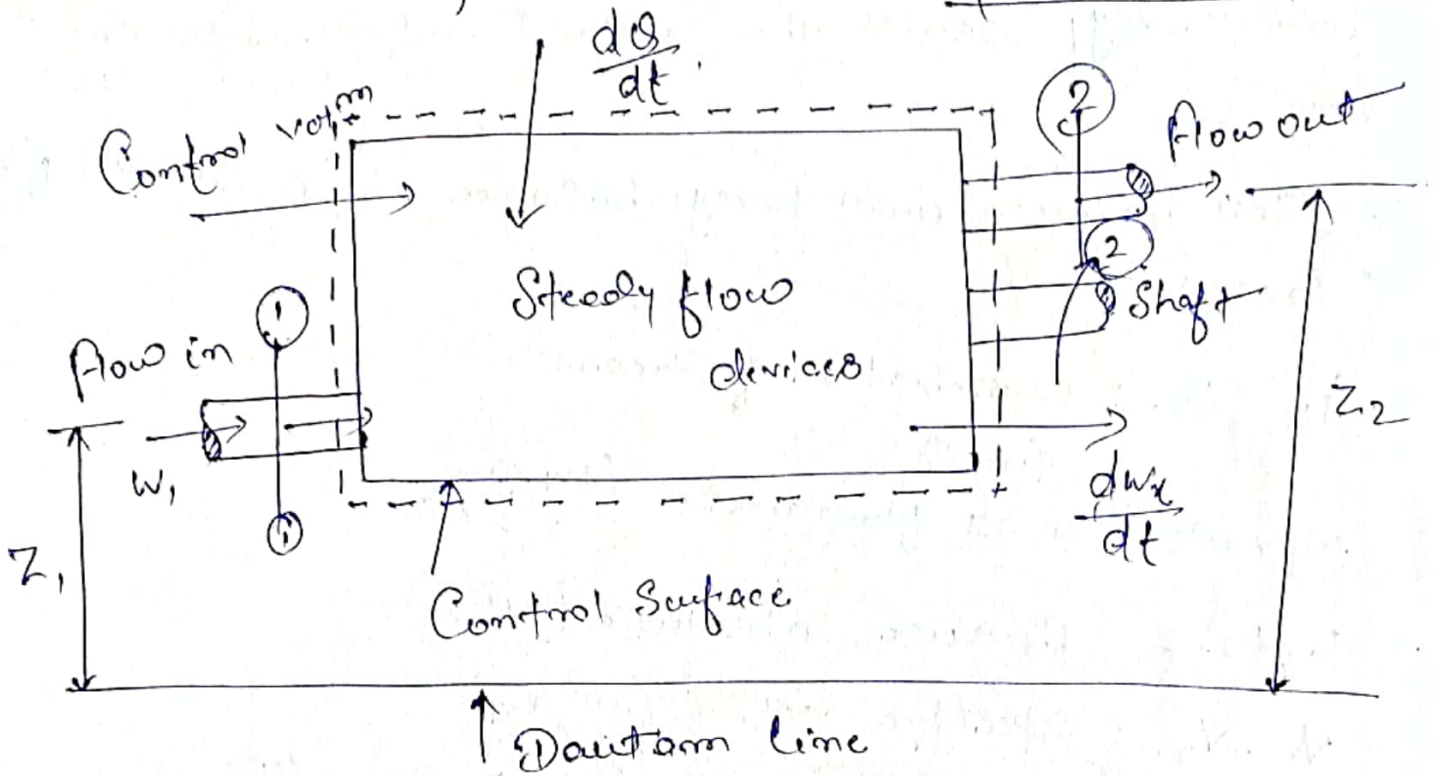
t : time, (s)

⇒ Mass Balance: → The mass flow rate entering must equal the mass flow rate leaving.

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

⇒ $\left[\frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2} \right]$

The above eqn is known as Equation of Continuity.



⇒ Energy Balance:-

Energy flow per unit time: $w_1 \left(h_1 + \frac{V_1^2}{2} + gz_1 \right) + \frac{dQ}{dt} =$

$w_2 \left(h_2 + \frac{V_2^2}{2} + gz_2 \right) + \frac{dW}{dt}$

and we already know that

$$w_1 = \frac{dm}{dt}, \quad w_2 = \frac{dm}{dt}$$

Since, $w_1 = w_2$ let $\therefore w_1 = w_2 = w = \frac{dm}{dt}$

Now, The above equation becomes.

$$\left(h_1 + \frac{V_1^2}{2} + gz_1 \right) + \frac{dQ}{dm} = \left(h_2 + \frac{V_2^2}{2} + gz_2 \right) + \frac{dW}{dm}$$

Energy flow per unit mass. ————— (B)

The above eqⁿ (A) & (B) are known as Steady flow Energy equation. (SFE) 26

The above eqⁿ in the form of

$$Q - W_{out} = (h_2 - h_1) + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1)$$

in the differential form we get.

$$\boxed{dQ - dW_{out} = dh + v dv + g dz}$$

For more than one stream -

Mass balance is

$$w_1 + w_2 = w_3 + w_4$$

$$\Rightarrow \frac{A_1 v_1}{v_1} + \frac{A_2 v_2}{v_2} = \frac{A_3 v_3}{v_3} + \frac{A_4 v_4}{v_4}$$

Energy equation is given below.
Per unit time,

$$w_1 \left(h_1 + \frac{v_1^2}{2} + g z_1 \right) + w_2 \left(h_2 + \frac{v_2^2}{2} + g z_2 \right) + \frac{dQ}{dt} =$$

$$w_3 \left(h_3 + \frac{v_3^2}{2} + g z_3 \right) + w_4 \left(h_4 + \frac{v_4^2}{2} + g z_4 \right) + \frac{dQ}{dt}$$

Steady flow Energy equation applies to a wide variety of processes like pipe line flow, heat transfer process, mechanical power generation in engines and turbines, combustion processes and flow through nozzles and diffusers.

and $Q_{1-2} = +ve$ Heat Supplied 27

Adiabatic Compression, $W_{1-2} = -ve,$

$$\Delta U = -ve \quad \& \quad Q_{1-2} = -ve.$$

(ii) ISOCORIC PROCESS (Gay-Lussac Law).

$$V = C$$

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2} = C}$$

work done by the gas

$$f_w = P \Delta V$$

$$W_{1-2} = P(V_2 - V_1) \geq 0.$$

Change in internal Energy

$$\Delta U = m c_v dT = m c_v (T_2 - T_1)$$

Heat Supplied

$$Q = \Delta U + f_w$$

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$

$$Q_{1-2} = (U_2 - U_1) + 0$$

$$\boxed{Q_{1-2} = m c_v (T_2 - T_1)}$$

change in enthalpy

$$dH = du + d(pv)$$

$$\int_1^2 dH = \int_1^2 du + \int_1^2 p(dv)$$

$$H_2 - H_1 = (U_2 - U_1) + (P_2 v_2 - P_1 v_1)$$

$$= m c_v (T_2 - T_1) + m R (T_2 - T_1)$$

$$= m (T_2 - T_1) (c_v + R)$$

$$\boxed{H_2 - H_1 = m c_p (T_2 - T_1)}$$

$$du = m c_p (T_2 - T_1)$$

$$H_2 - H_1 = m c_p (T_2 - T_1)$$

$$\therefore \boxed{du = H_2 - H_1}$$

At a particular pressure, S_f is the specific entropy of saturated water,

S_g is specific entropy at saturated vapour line.

The entropy change of the system during the phase change from liquid to vapour, at constant pressure is given below.

$$S_{fg} = (S_g - S_f)$$

The value of S_{fg} decreases as the pressure increases and becomes zero at the critical point.

⇒ h_f — Specific enthalpy of saturated water,
 h_g — " " " " " " vapour.

$$h_{fg} = (h_g - h_f) = \text{Latent heat of vaporization at constant pressure.}$$

As the pressure increases, h_{fg} decreases, and at the critical pressure h_{fg} becomes zero.

⇒ Quality or Dryness fraction: —

Let 1 kg of liquid-vapour mixture,

x kg is the mass of the vapour and

$(1-x)$ kg is the mass of liquid. Then x is known as the quality or dryness fraction of

the liquid - vapour mixture.

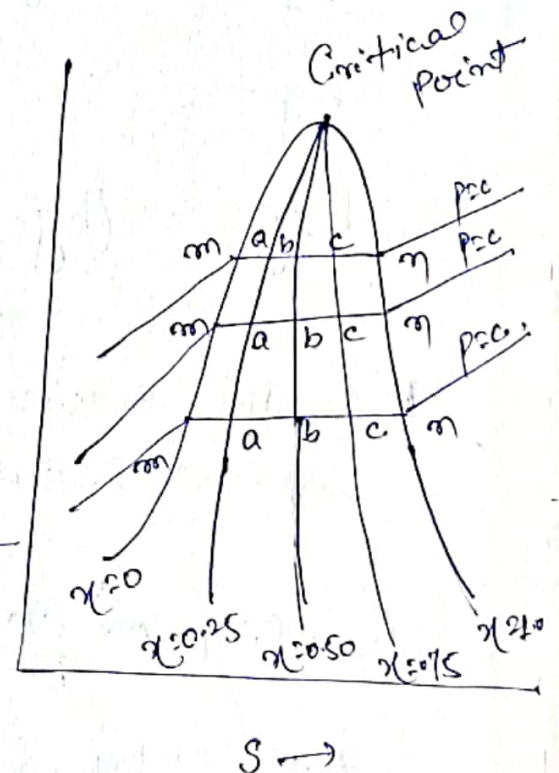
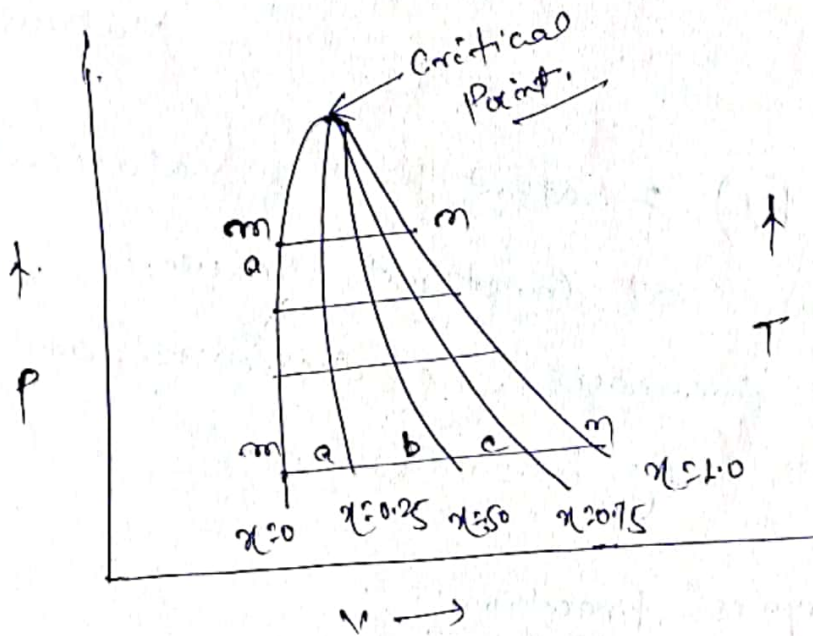
$$x = \frac{m_v}{m_v + m_l}$$

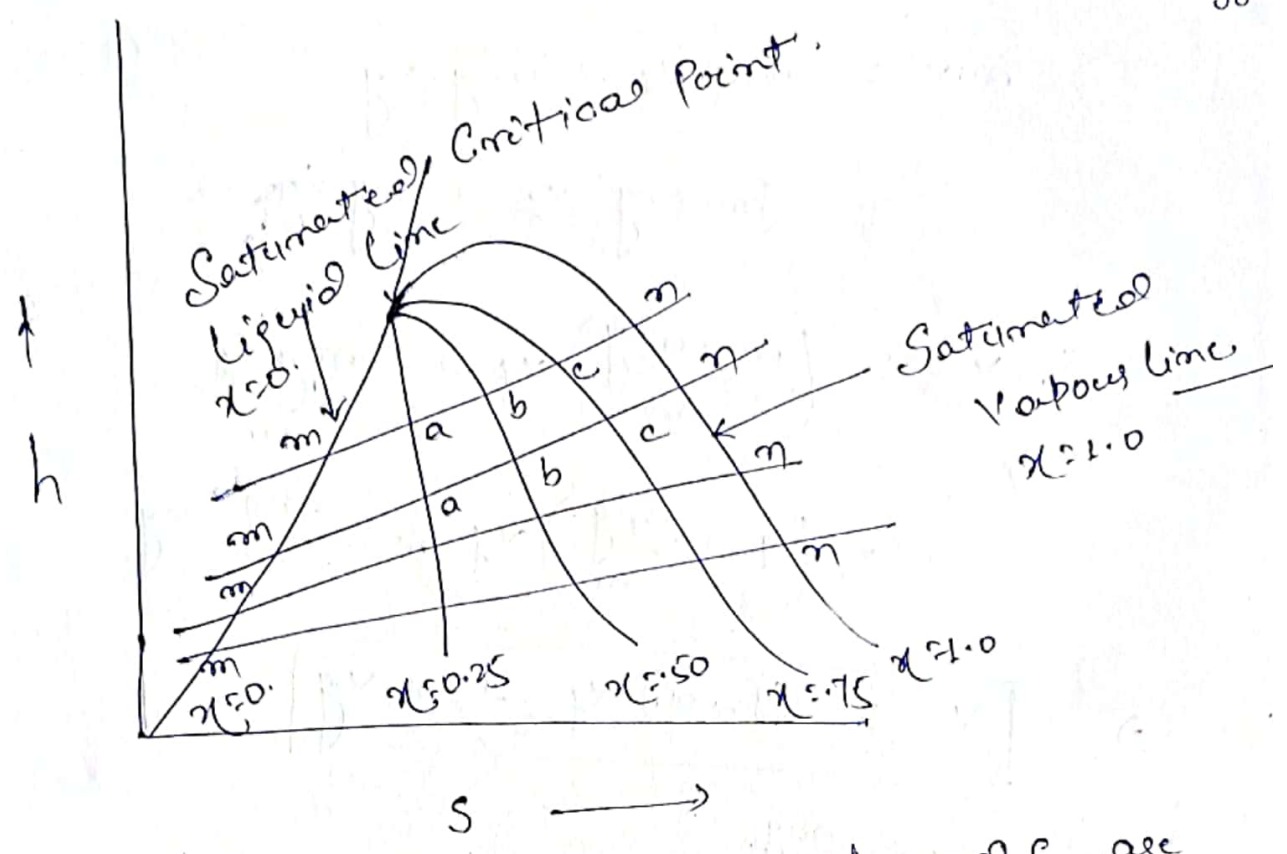
where, m_v = Masses of vapour
 m_l = " " " liquid } in the mixture.

x varies betⁿ 0 and 1.

for saturated water, when water just starts boiling
 $x=0$.

for saturated vapour, when vaporization is complete
 $x=1$ and for which the vapour is said
to be dry saturated.





The lines passing through points a, b, and c are the constant quality lines of 0.25, 0.50, and 0.75 respectively. Constant quality lines start from the Critical Point.

At point a, the mass of liquid is 75% and the mass of vapour is 25% of total mass.

Let, v be the total volume of a liquid vapour mixture of quality x ,

v_f = volume of saturated liquid

v_g = volume " " " " vapour.

and m , m_f and m_g are the corresponding masses.

Now, $m = m_f + m_g$

$v = v_f + v_g$

$$\Rightarrow mv = m v_f + f_a \cdot f_{bu} + f_a \cdot f_{bu} + m v_g$$

$$= (m - m \frac{f_a}{f_{bu}}) v_f + m v_g$$

$$\therefore v = \left(\frac{m - m \frac{f_a}{f_{bu}}}{m} \right) v_f + \frac{m v_g}{m}$$

$$= \left(1 - \frac{m f_a}{m f_{bu}} \right) v_f + v_g$$

$$\Rightarrow \boxed{v = (1 - \alpha) v_f + \alpha v_g}$$

where $\alpha = \frac{m f_a}{m f_{bu}}$

Similarly we obtained

$$\boxed{S = (1 - \alpha) S_f + \alpha S_g}$$

$$\boxed{h = (1 - \alpha) h_f + \alpha h_g}$$

$$\boxed{u = (1 - \alpha) u_f + \alpha u_g}$$

Again,

$$v = (1 - \alpha) v_f + \alpha v_g$$

$$= v_f - v_f \cdot \alpha + \alpha v_g$$

$$= v_f + \alpha (v_g - v_f)$$

$$\boxed{v = v_f + \alpha v_{fg}}$$

where, $\alpha =$ Specific vol^m of liquid vapour mixture.

Similarly, we obtained, that

$$h = h_f + x h_{fg}$$

$$s = s_f + x s_{fg}$$

$$u = u_f + x u_{fg}$$

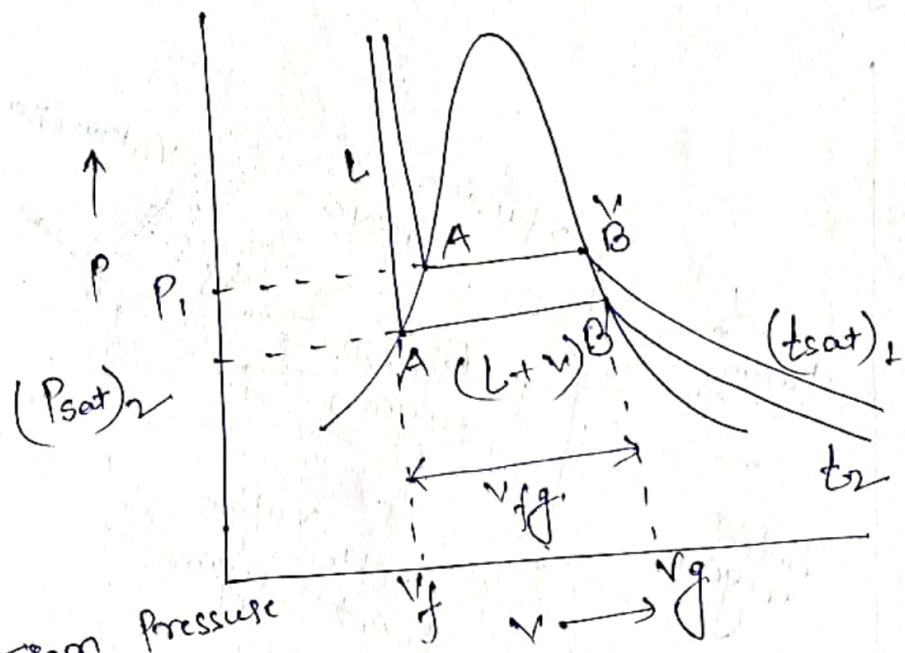
- The internal energy of saturated water at the triple point ($t = 0.01^\circ\text{C}$) is arbitrarily chosen to be zero.
- The entropy of saturated water is also chosen to be zero at the triple point.

The Temperature at which the vapour pressure is equal to 760 mm of Hg is called the normal boiling point.

Phase change occurs at constant pressure and Temp.

→ A pure liquid at a given pressure will transform into vapour only at a particular Temp. known as Saturation Temperature.

→ Similarly, if the Temperature is fixed, the liquid will boil (Condense) only at a particular pressure, called the Saturation Pressure.



Saturation pressure and Temperature.

→ The pressure increases, the saturation temperature also increases.

→ Saturation state exist upto critical point.

V_f - The Specific volume of the Saturated liquid at a given pressure.

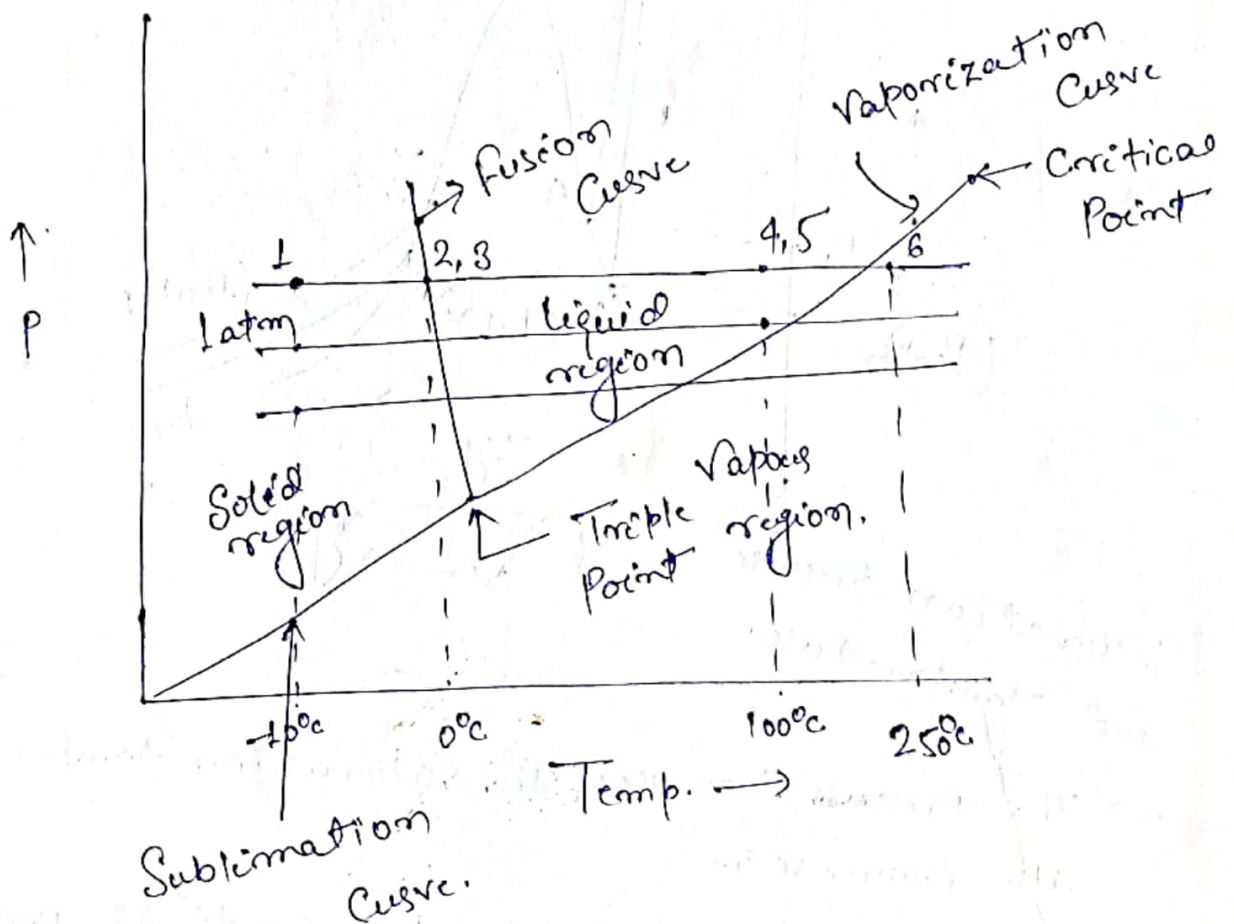
v_g - The Specific volume of the Saturated vapour.

V_{fg} - Change in specific volume during phase transition (boiling or Condensation) at the pressure.

As pressure increases, V_{fg} decreases, at critical point the value of v_{fg} is becomes zero.

$$(V_{fg})_c = 0$$

⇒ P-T diagram for a pure substance: -



Considers 1 atm Constant Pressure.

1-2 is the Solid (ice) heating

2-3 is the melting of ice at 0°C.

3-4 is the liquid heating

4-5 is the vaporization of water at 100°C

5-6 is the heating in the vapour phase.

The Curve passing through the point 2,3 is called fusion curve.

The Curve passing through the 4,5 point is called the vaporization curve. (which indicates vaporization and condensation at different Temp. and Pressure.)

The fusion curve, sublimation curve and vaporization curve is meet at always Triple point.

If the vapour pressure is measured

Q. NO-4. Air undergoes two processes in series.

Process 1-2 Expansion from 300 kPa, $0.019 \text{ m}^3/\text{kg}$ to 150 kPa, follows $Pv = c$.

Constant Pressure Compression in which $v_3 = v_1$. Sketch P-v diagram and determine workdone per unit mass of air in kJ/kg.

Soln

$$Pv = c$$

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

$$= \frac{300 \times 0.019}{150}$$

$$= 0.038 \text{ m}^3/\text{kg}$$

$$W_{1-2} = P_1 v_1 \log \left(\frac{v_2}{v_1} \right)$$

$$= 300 \times 0.019 \times \ln \left(\frac{0.038}{0.019} \right)$$

$$= 3.95 \text{ kJ/kg}$$

for $P=c$ process

$$W_{2-3} = P \int_2^3 dv = P_2 (v_3 - v_2)$$

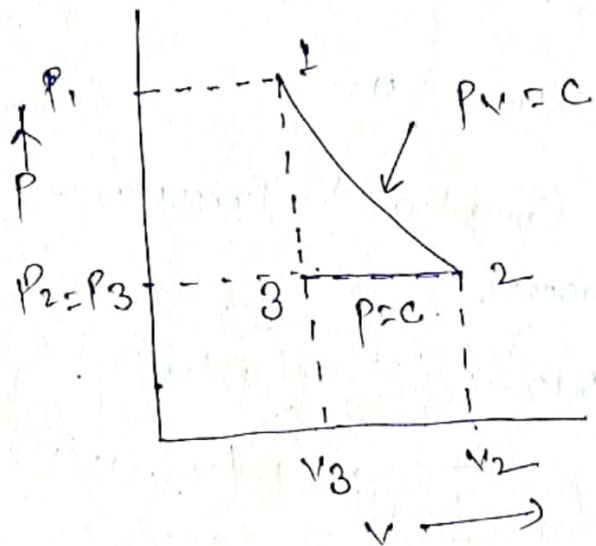
$$= P_2 (v_3 - v_2)$$

$$= 150 (0.019 - 0.038)$$

$$= -2.85 \text{ kJ/kg}$$

$$\therefore W = W_{1-2} + W_{2-3}$$

$$= 3.95 + (-2.85) = 1.1 \text{ kJ/kg}$$



Q. 10-2 5 kg air experiences the three process cycle which is shown in given fig. Calculate the net work done. Take $R = 0.287 \text{ kJ/kg K}$.

Soln

Process 1-2
Constant vol^m Process

$$\therefore W_{1-2} = 0$$

2-3 Constant Pressure
Process

$$\therefore W_{2-3} = \int_2^3 P dv$$

$$= P (v_3 - v_2) = 100 (10 - 2) = 800 \text{ kJ}$$

3-1 Isothermal Process

$$\therefore P_3 v_3 = mRT_3$$

$$\Rightarrow 100 \times 10 = 5 \times 0.287 \times T_3$$

$$\therefore T_3 = 696.86 \text{ K}$$

$$\text{Now, } W_{3-1} = mRT_3 \ln\left(\frac{v_1}{v_3}\right)$$

$$= 5 \times 0.287 \times 696.86 \times \ln\left(\frac{2}{10}\right)$$

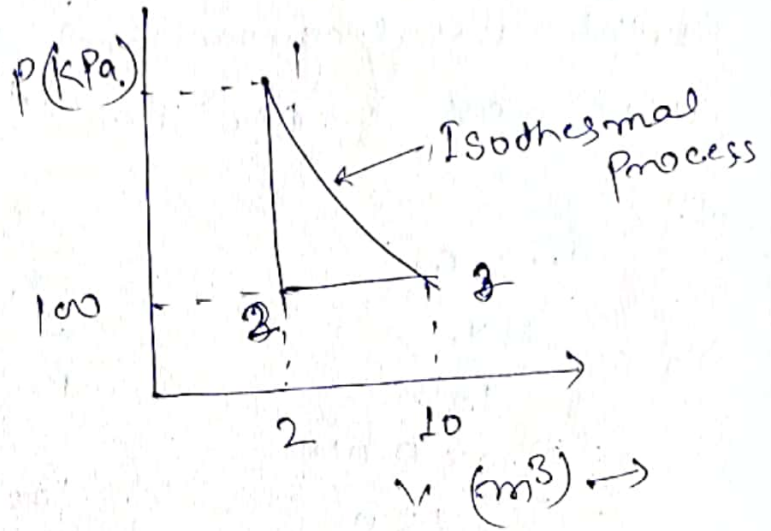
$$= -1609.43 \text{ kJ}$$

\therefore Net work done

$$W_{\text{net}} = W_{1-2} + W_{2-3} + W_{3-1}$$

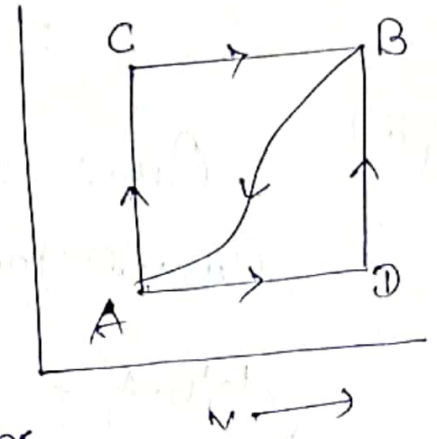
$$= 0 + 800 - 1609.43 = -809.43 \text{ kJ}$$

Ans.



Q. NO-1. When a system is taken from the state A to B in fig. Along the path ACB, 80 kJ of heat flows into the system and the system does work of 30 kJ

(i) How much heat flows into the system along the path ADB, if the work done is 10 kJ.



(ii) when the system is returned from the state B to A along the curved path, the work done on the system is 20 kJ. Does the system absorb or liberate heat and how much heat is absorbed or liberated.

(iii) If the internal energy at A (U_A) = 0, D (U_D) = 40 kJ. Find the heat absorbed in the processes AD and DB.

Soln Given:- $Q_{ACB} = 80 \text{ kJ}$, $W_{ACB} = 30 \text{ kJ}$.

(i) $Q_{ADB} = W_{ADB} + (U_B - U_A)$ — (i)

we already know that

$$Q_{ACB} = W_{ACB} + (U_B - U_A)$$

$$\Rightarrow 80 = 30 + (U_B - U_A)$$

$$\therefore (U_B - U_A) = 80 - 30 = 50 \text{ kJ}$$

Put the value of $(U_B - U_A)$ in the eqⁿ (i), we get

$$\begin{aligned} Q_{A \rightarrow B} &= W_{A \rightarrow B} + (U_B - U_A) \\ &= 10 + 50 = 60 \text{ KJ } \underline{\text{Ans.}} \end{aligned}$$

(ii)

$Q_{B \rightarrow A}$ = Heat absorbed or liberated along the Curved path BA.

$$W_{B \rightarrow A} = -20 \text{ KJ.}$$

We already know that

$$\begin{aligned} Q_{B \rightarrow A} &= W_{B \rightarrow A} + (U_B - U_A) \\ &= -20 + (U_A - U_B) \\ &= -20 - (U_B - U_A) = -20 - 50 \\ &= -70 \text{ KJ. } \underline{\text{Ans.}} \end{aligned}$$

-ve sign indicates that heat is liberated by the system.

(iii) Let Q_{AD} = Heat absorbed in the process AD.

Q_{DB} = Heat absorbed in the process DB.

$$\text{Now, } W_{A \rightarrow B} = W_{A \rightarrow D} + W_{D \rightarrow B}$$

$$W_{A \rightarrow B} = W_{A \rightarrow D} + 0$$

$$\therefore W_{A \rightarrow B} = W_{A \rightarrow D} = 10 \text{ KJ.}$$

$$\begin{aligned} \text{Now, } Q_{A \rightarrow D} &= (U_D - U_A) + W_{A \rightarrow D} \\ &= (40 - 0) + 10 = 50 \text{ KJ } \underline{\text{Ans.}} \end{aligned}$$

$$\Delta Q_{D-B} = (U_B - U_D) + W_{D-B}$$

$$= U_B - U_D = 50 - 40 = 10 \text{ KJ}$$

$$\Delta Q_{D-B} = 10 \text{ KJ Ans.}$$

(i) For ISOBARIC PROCESS:- (CHARGE'S LAW)

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V}{T} = C} \quad \because P_1 = P_2$$

(ii) Work done by the gas

$$\begin{aligned} \delta W &= P \, dV \\ \Rightarrow \int_1^2 \delta W &= P \int_1^2 dV \\ W_{1-2} &= P(V_2 - V_1) \\ &= (mRT_2 - mRT_1) = mR(T_2 - T_1) \end{aligned}$$

$$\boxed{W_{1-2} = mR(T_2 - T_1)}$$

(iii) change in internal energy

$$\Delta U = U_2 - U_1 = m C_v (T_2 - T_1)$$

(iv) Heat Supplied or Heat transferred

$$\begin{aligned} \Rightarrow \delta Q &= dU + \delta W \\ \Rightarrow \int_1^2 \delta Q &= \int_1^2 dU + \int_1^2 \delta W \\ \Rightarrow Q_{1-2} &= (U_2 - U_1) + W_{1-2} \end{aligned}$$

$$= m c_v (T_2 - T_1) + m R (T_2 - T_1)$$

$$= m (T_2 - T_1) (c_v + R)$$

$$\boxed{Q_{12} = m c_p (T_2 - T_1)} \quad \because (c_p - c_v = R)$$

(v) Change in Enthalpy

$$\Delta H = H_2 - H_1 = m c_p (T_2 - T_1)$$

So, $\boxed{\Delta H = Q_{12}}$

If the gas is cooled at constant pressure, there shall be a compression.

During cooling, the Temp. of vol^m will be decrease and work is said on the system or gas.

$$\begin{aligned} \text{Work done on the gas } W_{12} &= P (V_1 - V_2) \\ &= m R (T_1 - T_2) \end{aligned}$$

Decrease in internal energy

$$\Delta U = U_1 - U_2 = m c_v (T_1 - T_2)$$

Heat rejected by the gas

$$\boxed{Q_{12} = m c_p (T_1 - T_2)}$$

During expansion or heating process

$$W_{12} = +ve, \quad \Delta U = +ve,$$

⇒ 1 kg of ice at -5°C to steam at 250°C .

$$C_{p\text{ice}} = 2.093 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

(i) The entropy increases when heated from -5°C to 0°C at 1 atm.

$$\begin{aligned}\Delta S_1 = S_2 - S_1 &= \int_{T_1}^{T_2} \frac{dq}{T} = \int_{T_1}^{T_2} \frac{m c_p dT}{T} = m c_p (\log T)_{T_1}^{T_2} \\ &= m c_p \ln \left(\frac{273}{268} \right) = 1 \times 2.093 \times \ln \left(\frac{273}{268} \right) \\ &= 0.0398 \text{ kJ/kg}\cdot\text{K}.\end{aligned}$$

(ii) The entropy increases of ice as it melts into water at 0°C . (Latent heat of fusion of ice = 334.96 kJ/kg)

$$\Delta S_2 = S_3 - S_2 = \frac{334.96}{273} = 1.23 \text{ kJ/kg}\cdot\text{K}.$$

(iii) The entropy increases of water as it is heated from 0°C to 100°C ($C_{p\text{water}} = 4.187$ kJ/kgK).

$$\begin{aligned}\Delta S_3 = S_4 - S_3 &= m c_p \ln \left(\frac{T_4}{T_3} \right) = 1 \times 4.187 \times \ln \left(\frac{373}{273} \right) \\ &= 1.307 \text{ kJ/kg}\cdot\text{K}\end{aligned}$$

(iv) The entropy increases of water as it is vaporized at 100°C , absorbing the latent heat of vaporization (2257 kJ/kg)

$$\Delta S_4 = S_5 - S_4 = \left(\frac{2257}{373} \right) = 6.05 \text{ kJ/kg}\cdot\text{K}.$$

(v) The Entropy increases of vapour as it is heated from 100°C to 250°C at 1 atm.

$$\Delta S_5 = S_6 - S_5 = m C_p \ln\left(\frac{523}{373}\right) = 0.707 \frac{\text{KJ}}{\text{log-K}}$$

