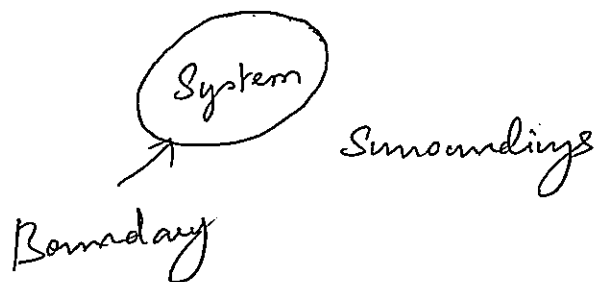# UNIT - I BASIC CONCEPTS AND FIRST LAW OF THERMODYNAMICS

Thermodynamics is the Science of relations between heat, Work and Properties of the System.

System :- A Small part of the universe to which We apply the laws of thermodynamics is called as System.
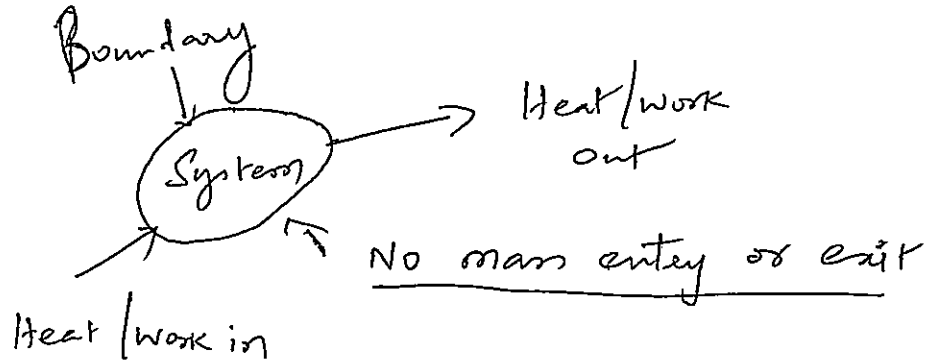
Surroundings :- The rest of the universe Outside the System close enough to the System to have Some Perceptible effect on the System is called Surroundings.

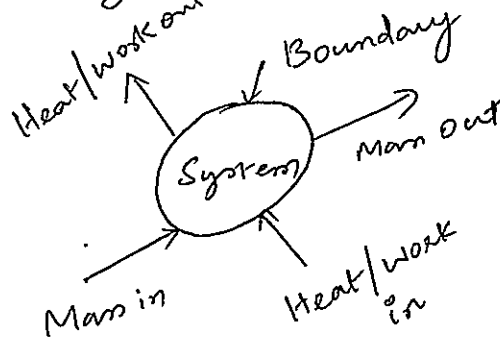Boundaries :- The Surfaces which Separes the System from the Surroundings are called the boundaries.

System

Surroundings

Boundary

Types of System

Closed System :- No mass is Permitted to

cross the System boundary. We do permit heat & work to enter and leave but not mass.

Boundary

System

→ Heat/work out

Heat/work in

No mass entry or exit

Open System

We Permit mass to cross the

System boundary in either direction

Heat/work out

Boundary

System → Mass Out

Mass in

Heat/work in

Isolated System

There is no interaction between System and Surroundings. It is of fixed mass and energy and hence there is no mass and energy transfer across the System boundary.

Microscopic and Macroscopic Approaches

Behavior of matter can be studied by these two approaches

(i) <u>Macroscopic</u> — Certain quantity of matter is considered, without a concern on the events occurring at the molecular level.

       eg. Pressure, temperature

(ii) <u>Microscopic</u> — The effect of molecular motion is considered.

       eg. Pressure of a gas is not constant, Temperature of a gas is a function of Velocity of molecules.

Property

Property is the characteristic of the system to which some physically meaningful numbers can be assigned without knowing the history behind it.

Extensive Property :-

Value depends on the Size or extent of the System

eg. Volume, Mass (V, m)

If Mass is increased the Value of extensive Property also increases.

Intensive Property :-

Value is independent of the Size or extent of the System.

eg. Pressure, temperature (P, T)

Specific Property :-

Value of an extensive property Per unit mass of the System.

eg. Specific Volume, density (v, e)

State :- It is the Condition of a System as defined by the Values of all its Properties.

Any operation in which one or more Properties of a System change is called a Change of State.

Phase :- It is a quantity of mass that is homogeneous throughout in chemical composition and physical structure

eg. Solid, liquid, Vapour, gas

Homogeneous System :- If there is one phase, then it is a homogeneous System.

Heterogeneous System :- phase Consisting of more than one phase is called heterogenous System.
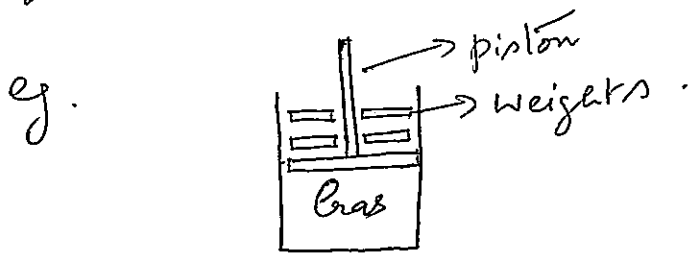
Path :- Succession of States Passed through during a change of State is called the path of the System.

Process :- A System is Said to have gone through a Process if it goes through Series of Changes in State.

Quasi Static Process

A quasi-Static Process is one in which

(i) A deviation from thermodynamic equilibrium is infinitesimal

(ii) All States of the System Passes Through are equilibrium States.

eg.

If we remove the weights slowly one by one the Pressure of the gas will displace the Piston gradually. It is quasistatic.
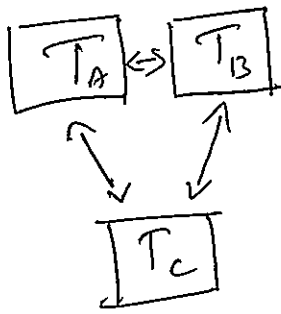
Equilibrium State.

A System is Said to be in an equilibrium State if its Properties will not change without Some Perceivable effect in the Surroundings.

Temperature

It is a Property of a System which determines the degree of hotness.

Zeroth law of Thermodynamics

If two Systems (Say A & B) are in thermal equilibrium with a third System (Say C) Separately, they are in thermal equilibrium themselves that is A & B will be in thermal equilibrium.
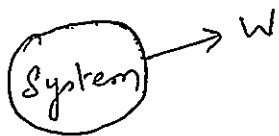
$$T_A \Longleftrightarrow T_B$$
$$T_C$$

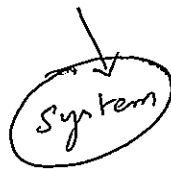$$T_a = T_c \quad , \quad T_b = T_c$$

$$T_a = T_b$$

Work and Heat Transfer

Work is said to be done by a System if the Sole effect on things external to the System can be reduced to the raising of a weight.

W is Positive   W is negative

unit of work is N·m or Joule.

eg. Battery motor System driving a fan

Displacement Work or $\oint p dv$ work

Let the gas in the Cylinder be a System having initially the pressure P_1 and Volume V_1. The System is in thermodynamic equilibrium

the State of which is described by the co-ordinates $p_1 V_1$. Piston is the only boundary which moves due to gas pressure. Let the piston move out to a new final position 2, which is also a thermodynamic equilibrium state Specified by Pressure p_2 and volume V_2. The Intermediate Point in the travel of piston must also be in equilibrium state.
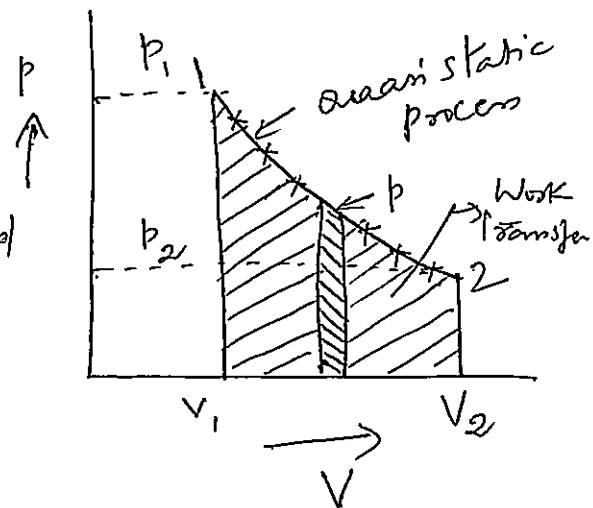
$$dw = F \cdot dl = Pa \cdot dl = pdv$$

$$dV = adl$$

F → Force acting on piston
a → area of the Piston
dl — Infinitesimal distance

When the piston moves from Position 1 to 2 with the volume changing from V_1 to V_2 the amount of Workdone W done by the System will be
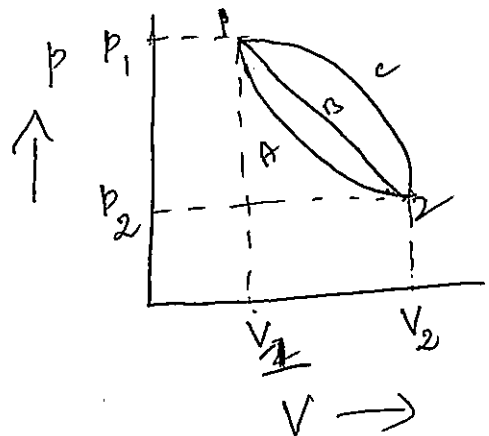
$$\boxed{W_{1-2} = \int_{V_1}^{V_2} pdv}$$

The $\int pdv$ can be Performed only on a quasi static path

Path Function & Point Function

The amount of work involved in each case is not a function of the end state of the process and it depends on the path of the System. Work is called a Path function. dw is an inexact or imperfect differentials.

Thermodynamic Properties are Point functions. It depends on the initial and final states of the System. The differentials of point function are exact.

$$\int_{V_1}^{V_2} dv = V_2 - V_1$$

$$\cancel{dw = \frac{1}{p} dv}$$
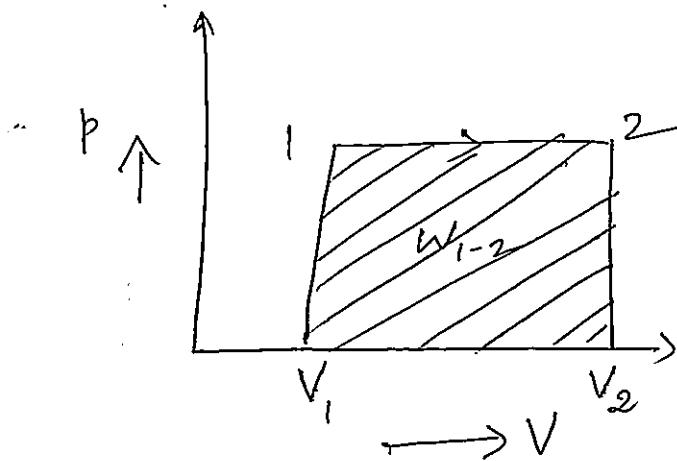
$$dv = \frac{1}{p} dw$$

$\frac{1}{p}$ is an integrating factor. By multiplying Integrating factor $\frac{1}{p}$, the inexact differentials become exact.

The Cyclic integral of a Property is always Zero

$$\oint dv = 0, \quad \oint dp = 0 \quad \oint d_T = 0$$

pdv Work in Various Quasi-Static Processes

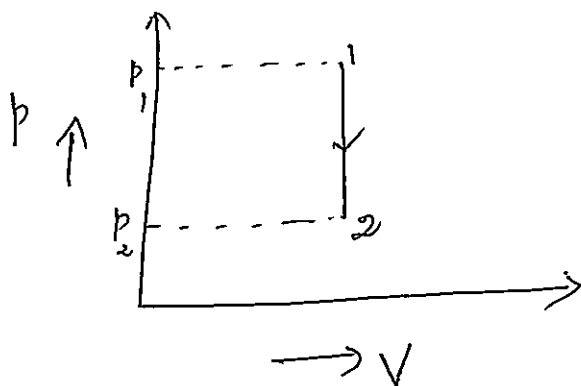(i) **Constant Pressure Process (Isobaric)**

$V = c$

$pv = mRT$

$p \propto T$

$\dfrac{p_2}{p_1} = \dfrac{T_2}{T_1}$

$$W_{1-2} = \int_{V_1}^{V_2} pdv = p\left(V_2 - V_1\right)$$

(ii) **Constant Volume Process (Isochoric Process)**

$p = C$

$pv = mRT$

$V \propto T$

$\dfrac{V_2}{V_1} = \dfrac{T_2}{T_1}$

$$W_{1-2} = \int pdv = 0$$

(iii) <u>Constant Temperature or Isothermal Process</u>

$T \to$ Constant

$Pv = mRT$

$pv = c$, $P_1 V_1 = P_2 V_2 = C$

$p = C/V$

Now,

$$W = \int_{V_1}^{V_2} p\, dv$$

$$= \int_{V_1}^{V_2} C/V \, dv$$

$$= C \int_{V_1}^{V_2} \frac{1}{V} \, dv$$

$$= C \left[\ln v_2 - \ln v_1 \right]$$

$$= C \ln \left(v_2/v_1 \right)$$

$$W = P_1 V_1 \ln \left(v_2/v_1 \right)$$

<u>Isothermal Curves for an ideal gas are rectangular hyperbola</u>

(iv) Adiabatic Process

A process is said to be an adiabatic process in which there is no heat transfer from the system or to the system.

$$p v^{\gamma} = c \qquad \gamma \to \text{adiabatic index}$$

$$(\gamma > 1)$$

$$p v^{\gamma} = c$$

$$p = \frac{c}{v^{\gamma}}$$

$$p = c \cdot v^{-\gamma}$$

$$p_1 = c \cdot v_1^{-\gamma}$$

$$p_2 = c \cdot v_2^{-\gamma}$$

Ideal gas equations

$$p v^{\gamma} = e$$

$$p v = m R T$$

$$p = \frac{m R T}{v}$$

$$\frac{m R T}{v} \cdot v^{\gamma} = c$$

$$T \cdot v^{\gamma} = \frac{c}{R T} = c$$

$$T \cdot v^{\gamma - 1} = e$$

Now,

$$W = \int_{v_1}^{v_2} p \, dv$$

$$= \int_{v_1}^{v_2} c \cdot v_1^{-\gamma} \, dv$$

$$= c \int_{v_1}^{v_2} v_1^{-\gamma} \, dv$$

$$= c \left[\frac{-\gamma + 1}{-\gamma + 1} \right]_{v_1}^{v_2}$$

$$p_1 v_1^{\gamma} = p_2 v_2^{\gamma} \qquad \frac{v_1}{v_2} = \left(\frac{p_2}{p_1} \right)^{\frac{1}{\gamma}}$$

$$T_1 v_1^{\gamma - 1} = T_2 v_2^{\gamma - 1} \qquad \frac{v_1}{v_2} = \left(\frac{T_2}{T_1} \right)^{\frac{1}{\gamma - 1}}$$

$$\left(\frac{T_2}{T_1} \right)^{\frac{1}{\gamma - 1}} = \left(\frac{p_2}{p_1} \right)^{\frac{1}{\gamma}}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}}$$

$$W = \frac{c}{-\gamma + 1} \left[V_2^{-\gamma+1} - V_1^{-\gamma+1} \right]$$

$$= \frac{1}{-\gamma + 1} \left[c \cdot V_2^{-\gamma} \cdot V_2 - c \cdot V_1^{-\gamma} \cdot V_1 \right]$$

$$= \frac{1}{-\gamma + 1} \left[P_2 V_2 - P_1 V_1 \right]$$

$$= \frac{+ \left(P_1 V_1 - P_2 V_2 \right)}{+ \left(\gamma - 1 \right)}$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

(v) Polytropic Process

A Process is Said to be a Polytropic Process, if Pressure and Volume follows the relation $PV^n = c$ where n is known as Polytropic index

Generally $n > 1$ $n < \gamma$

In Polytropic there is both heat and work transfer takes place

$$PV^n = P_1 V_1^n = P_2 V_2^n$$

$$P = \frac{P_1 V_1^n}{V^n}$$

$$W = \int_{V_1}^{V_2} p \, dV = \int_{V_1}^{V_2} \frac{p_1 V_1^n}{V^n} \cdot dV = p_1 V_1^n \left[\frac{V^{-n+1}}{-n+1} \right]_{V_1}^{V_2}$$

$$= \frac{p_1 V_1^n}{1-n} \left(V_2^{1-n} - V_1^{1-n} \right)$$

$$= \frac{p_2 V_2^n \times V_2^{1-n} - p_1 V_1^n \times V_1^{1-n}}{1-n}$$

$$= \frac{p_1 V_1 - p_2 V_2}{n-1}$$

Ideal gas equations

$$p_1 V_1^n = p_2 V_2^n$$

$$T_1 V_1^{n-1} = T_2 V_2^{n-1}$$

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

Indicator diagram

An Indicator diagram is a Trace made by recording Pressure guage called Indicator attached to the cylinder of a reciprocating Engine. This represents workdone in one engine cycle.

Mean effective pressure

$$(p_m) = \frac{a_d}{l_d} \times K$$

a_d = area of the diagram

l_d = length of the diagram

K = Spring constant ($N/cm^2 \wedge cm$ travel)

Work done in one engine cycle

$$= (p_m \cdot A) \cdot L$$

$L \rightarrow$ Stroke of Piston

A = Cross sectional area of the Cylinder

$= \frac{\pi}{4} D^2$ $D \rightarrow$ cylinder diameter

Two Stroke engine Work done

$$\frac{\text{Work done}}{\text{Work done in one minute}} = P_m LAN$$

Four Stroke engine work done

$$\frac{\text{work done}}{\text{Work done in one minute}} = \frac{P_m LAN}{2}$$

Power developed in cylinder

$$I \cdot p = \frac{P_m LA \left(N \text{ or } \frac{N}{2}\right) n}{60} \; kw$$

$I \cdot p$ = Indicated Power

p_m is in kpa

n is number of Cylinders

Power available at the crankshaft is always less than the I.p due to friction and it is called Brake power or shaft power

$$B.p = T. \omega$$

ω = angular velocity in radian/sec

T = Torque trammitted in mN

$$B.p = \frac{2\pi NT}{60}$$

N = number of revolutions per minute (rpm)

$$\eta_{Mech} = \frac{B.p}{I.p}$$

Electrical Work

$$I = \frac{dc}{d\tau} \qquad \begin{array}{l} c \rightarrow \text{change in Coulombs} \\ \tau \rightarrow \text{time in seconds} \end{array}$$

$$\delta W = E \cdot dc$$

$$= EI \, d\tau$$

$$W = \int_{1}^{2} EI \, d\tau = EI$$

$$= \lim_{d\tau \to 0}$$

$$\text{Electrical power} = EI \qquad \therefore \lim_{d\tau \to 0}$$

Shaft Work

$$W = \int_1^2 T \, d\theta$$

$$\text{Power} = \int_1^2 T \cdot \frac{d\theta}{d\tau} = T \cdot \omega$$

$\omega =$ angular velocity

$T =$ constant in this case.

Paddle Wheel Work or Stirring Work

$$dw = mg \, dz = T \, d\theta$$

$$W = \int_1^2 mg \, dz = \int_1^2 T \, d\theta$$

Flow work

Flow at inlet

$$\left(dw_{flow} \right)_{in} = p_1 V_1 \, dm_1$$

Flow at outlet

$$\left(dw_{flow} \right)_{out} = p_2 V_2 \, dm_2$$

Flow per unit mass

$$dw_{flow} = pv$$

Workdone in Surface film

$$W = -\int_1^2 \sigma \, dA$$

σ = Surface Tension in N/m

Workdone in Magnetised Solid

$$W = -\int_{I_1}^{I_2} H \, dI$$

$H \rightarrow$ Field Strength

$I \rightarrow$ Component of magnetization field in direction of field.

Workdone in Stretching a wire

$$dW = -J \, dL$$
$$= -E \varepsilon A L \, d\varepsilon$$
$$W = -A E L \int_1^2 \varepsilon \, d\varepsilon$$
$$= \frac{-A E L}{2} \left(\varepsilon_2^2 - \varepsilon_1^2 \right)$$

$E = S/\varepsilon$, $J = SA$

$d\varepsilon = \frac{dL}{L}$ $= E \varepsilon A$

$J \rightarrow$ Tension
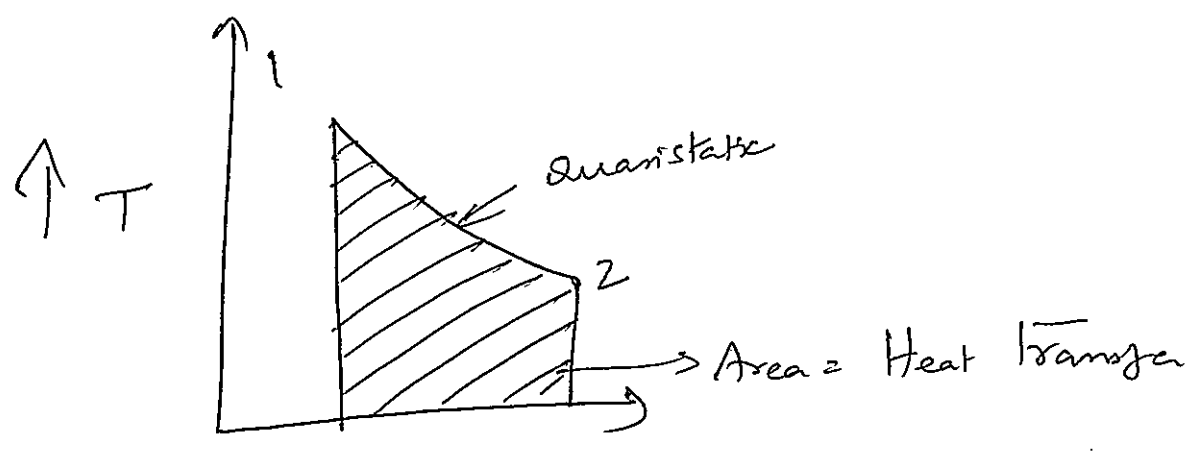
$E \rightarrow$ Modulus of Elasticity

$S \rightarrow$ stress

ε = Strain

$A \rightarrow$ Cross sectional area.

$S \rightarrow$ stress

Heat Transfer

$$Q = \int_{1}^{2} dQ = \int_{1}^{2} T \cdot dx \qquad dx = \frac{1}{T} dQ$$

dQ is an inexact differential. By Multiplying an Integrating factor $\frac{1}{T}$ it becomes the exact differential

Specific Heat and Latent heat

Specific heat is the amount of heat required to raise a unit mass of a Substance through a unit rise in temperature
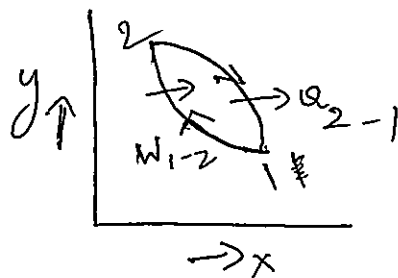
$$C = \frac{Q}{m \cdot \Delta t} \quad J/kg \cdot k$$

Q = amount of heat transfer (J)
m = mass of Substance (kg)
Δt = rise in temperature (k)

Latent heat is the amount of heat transfer required to cause a phase change in unit mass of a Substance at Constant Pressure and temperature.

First Law of Thermodynamics

First law for a closed System undergoing a cycle

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

$$\oint dw = J \oint dQ$$

$J =$ Joules equivalent

$\oint$ denotes the cyclic integral of a closed path.

First law for a closed System undergoing a change of State

$$Q - W = \Delta E$$

$$Q = \Delta E + W$$

$Q = $ amount of heat transfered to the System

$W = $ amount of Work transfered from the System.

$Q, \Delta E, W$ are all expressed in Same unit as joules.
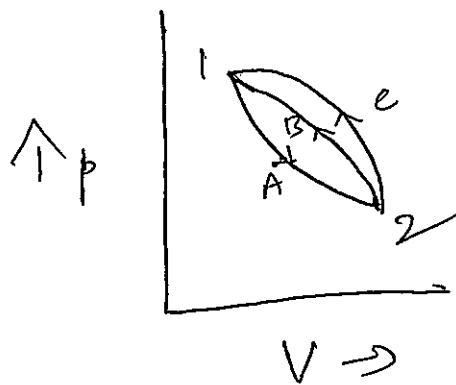
$\Delta E = $ Net energy transfer

If there are more energy transfer quantities involved in the Process

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

Energy – A Property of the System

for Path A

$$Q_A = \Delta E_A + W_A$$

For Path B

$$Q_B = \Delta E_B + W_B$$

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

$$W_A + W_B = Q_A + Q_B$$

$$Q_A - W_A = W_B - Q_B$$

$$\Delta E_A = - \Delta E_B \rightarrow \textcircled{1}$$

If it is returning from State 2 to State 1 following the path c

$$\Delta E_A = - \Delta E_c \rightarrow \textcircled{2}$$

From ① and ② we get

$$\Delta E_B = \Delta E_c$$

Energy has a definite Value for every state of the System. Hence it is a Point function and a Property of the System.

Different forms of stored energy

Macroscopic kinetic energy

$$= \frac{1}{2} m v^2$$

Macroscopic Potential energy

$$= mgz$$

$$E = E_k + E_p + \underset{\text{micro}}{\underbrace{U}}$$

$\underbrace{}_{\text{Macro}}$

In the absence of motion and gravity.

$$E = U$$

Equation becomes $Q = \Delta U + W$

In differential forms

$$dQ = dE + p\,dv$$
$$dQ = dU + p\,dv$$

Integral form

$$Q = \Delta E + \int p\,dv$$
$$Q = \Delta U + \int p\,dv$$

Specific heat at Constant Volume

Specific heat at Constant Volume

is defined as the rate of change of Specific internal energy with respect to temperature when the Volume is held constant.

$$c_V = \left(\frac{\partial u}{\partial T} \right)_V$$

A For a Constant Volume Process

$$(\Delta u)_V = \int_{T_1}^{T_2} c_V \cdot dT$$

When Volume is held Constant

$$(\Delta u)_V = (Q)_V$$

$$(Q)_V = \int_{T_1}^{T_2} c_V \, dT$$

Enthalpy

$$h = u + pv$$

For an ideal gas

$$h = u + RT$$

Since the internal energy depends only on temperature

$$h = f(T)$$

Specific heat at Constant Pressure

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

— rate of change of Enthalpy with respect to temperature.

$$(\Delta h)_p = \int_{T_1}^{T_2} c_p \, dT$$

$$(Q)_p \doteq (\Delta h)_p$$
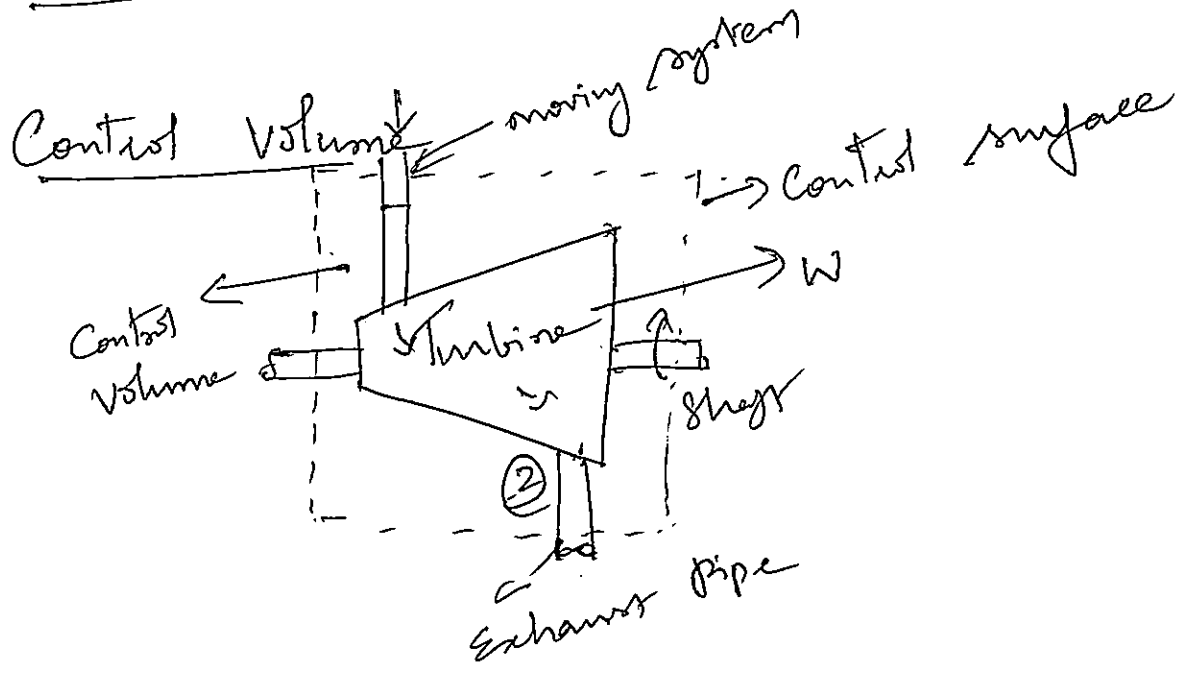
$$(Q)_p = \int_{T_1}^{T_2} c_p \, dT$$

Energy of an issolated System

For an Isolated System, there is no interaction with the Surroundings

$$d Q = 0 \quad dw = 0$$

$$E = Constant$$

First law States the general principle of Conservation of energy. Energy is neither Created nor destroyed, but only gets transformed from one form to another.

First law applied to Flow Processes
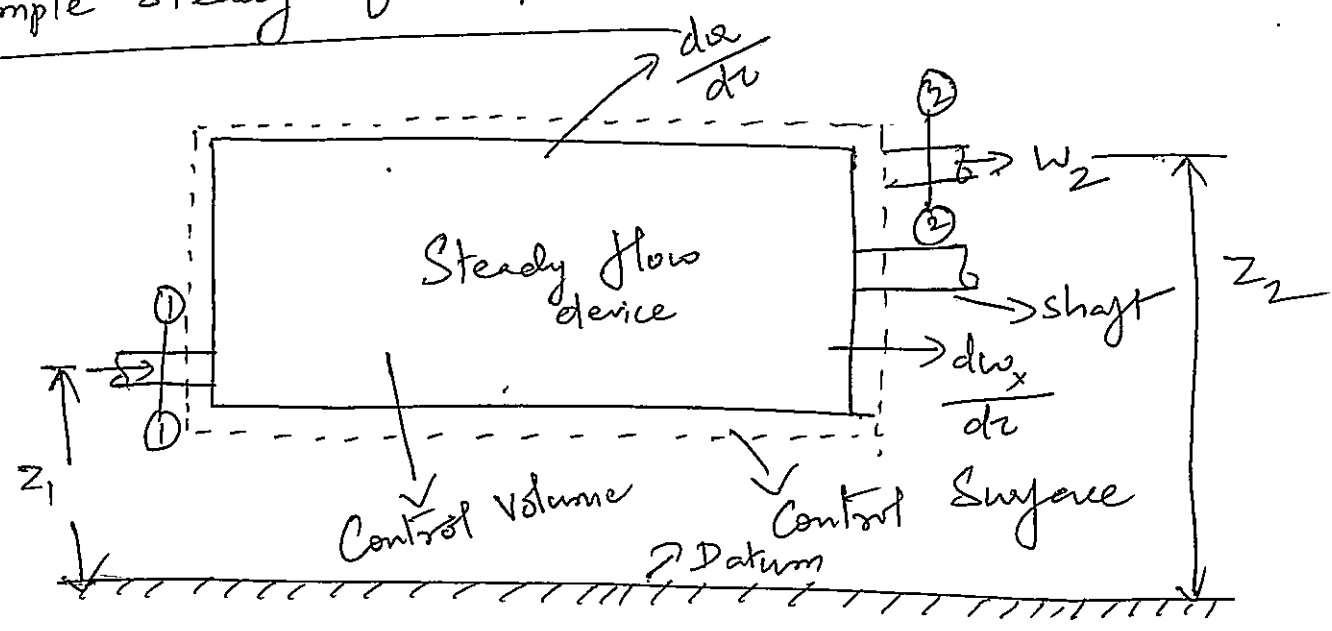
Control Volume

Control Volume is a region in Space through which the moving Substance flows. Surface of the Control Volume is Known as Control surface.

Steady flow Processes

Steady flow means that the rates of flow of mass and energy across the Control surface are Constant.

Mass Balance and energy balance in a Simple Steady flow process

$A_1, A_2 \rightarrow$ Cross Sectional area of streams, m^2

$w_1, w_2 \rightarrow$ mass flow rate, kg/s

$p_1, p_2 \rightarrow$ Pressure, absolute, N/m^2

$v_1, v_2 \rightarrow$ Specific Volume, m^3/kg

$u_1, u_2 \rightarrow$ Specific internal energy, J/kg

$V_1, V_2 \rightarrow$ Velocity, m/s

$z_1, z_2 \rightarrow$ elevation above an arbitrary datum, m

$\dfrac{dQ}{d\tau} \rightarrow$ net rate of heat transfer through the Control surface, J/s

$\dfrac{dw_x}{d\tau} \rightarrow$ net rate of Work transfer through the Control Surface, J/s

$\tau \rightarrow$ time, s

Mass Balance

By Conservation of mass, if there is no accumulation of mass within the Control Volume, the mass flow rate entering must equal the mass flow rate leaving.

$$w_1 = w_2$$

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

This equation is known as equation of Continuity.

Energy Balance

In a flow Process, the Work Transfer may be of two types, the external work and the flow work. External work occurs in the form of Shaft Work and flow work is the displacement work done by the fluid of mass dm_1 at inlet Section 1 and that of mass dm_2 at exit Section 2. Which are $- p_1 v_1 dm_1$ and $+ p_2 v_2 dm_2$. The total work Transfer is given by

$$W = W_x - p_1 v_1 dm_1 + p_2 v_2 dm_2$$

In rate form

$$\frac{dw}{dz} = \frac{dw_x}{dz} - p_1 v_1 \frac{dm_1}{dz} + p_2 v_2 \frac{dm_2}{dz} - ①$$

$$\frac{d\omega}{dt} = \frac{d\omega_n}{dc} - \omega_1 p_1 v_1 + \omega_2 p_2 v_2 \quad - ②$$

Since, there is no accumulation of energy inside by conservation of energy, the total rate of flow of all energy streams entering the control volume must equal the total rate of flow of all energy streams leaving the control volume

$$\omega_1 e_1 + \frac{d\alpha}{dt} = \omega_2 e_2 + \frac{d\omega}{dt}$$

Substituting for $\frac{d\omega}{dt}$ from equation ②

$$\omega_1 e_1 + \frac{d\alpha}{dt} = \omega_2 e_2 + \frac{d\omega_n}{dt} - \omega_1 p_1 v_1 + \omega_2 p_2 v_2$$

$$\omega_1 e_1 + \omega_1 p_1 v_1 + \frac{d\alpha}{dt} = \omega_2 e_2 + \omega_2 p_2 v_2 + \frac{d\omega_n}{dt} \longrightarrow ③$$

where

e_1 and e_2 refer to the energy carried

Q_{in} to or out of the control volume with unit mass of fluid

$$e = e_k + e_p + u$$
$$= \frac{V^2}{2} + zg + u$$

Substituting for e in equation ③

$$\omega_1 \left(\frac{v_1^2}{2} + z_1 g + u_1 \right) + \omega_1 p_1 v_1 + \frac{dQ}{dt}$$

$$= \omega_2 \left(\frac{v_2^2}{2} + z_2 g + u_2 \right) + \omega_2 p_2 v_2 + \frac{dW_x}{dt}$$

$$\omega_1 \left(h_1 + \frac{v_1^2}{2} + z_1 g \right) + \frac{dQ}{dt}$$

$$= \omega_2 \left(h_2 + \frac{v_2^2}{2} + z_2 g \right) + \frac{dW_x}{dt}$$

$$\longmapsto ④$$

Where $h = u + pv$

Since $\omega_1 = \omega_2$, let $\omega = \omega_1 = \omega_2 = \frac{dm}{dt}$

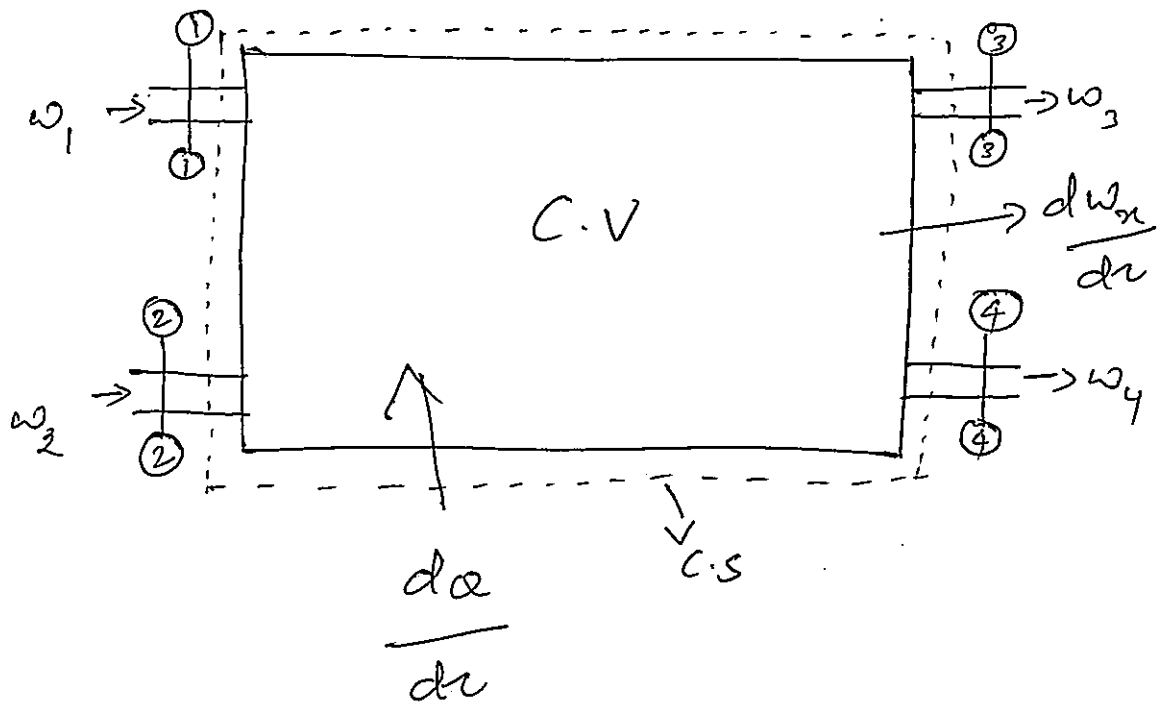Dividing equation ④ by $\frac{dm}{dt}$

$$h_1 + \frac{v_1^2}{2} + z_1 g + \frac{dQ}{dm}$$

$$= h_2 + \frac{v_2^2}{2} + z_2 g + \frac{dW_x}{dm}$$

$$\longrightarrow ⑤$$

Equation ④ and ⑤ are known as Steady flow energy equations for Single Stream of fluid entering and Single Stream leaving the Control Volume.

When more than one stream of fluid enters or leaves the Control volume.

Mass balance equation

$$\omega_1 + \omega_2 = \omega_3 + \omega_4$$

$$\frac{A_1 V_1}{v_1} + \frac{A_2 V_2}{v_2} = \frac{A_3 V_3}{v_3} + \frac{A_4 V_4}{v_4}$$
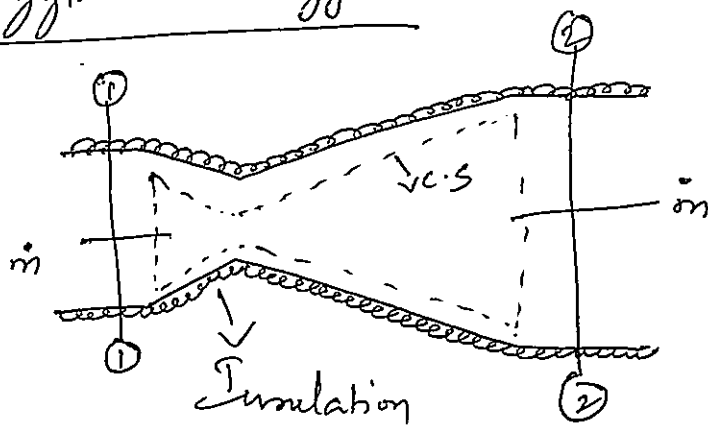
Energy Balance equation

$$\omega_1 \left(h_1 + \frac{V_1^2}{2} + z_1 g \right) + \omega_2 \left(h_2 + \frac{V_2^2}{2} + z_2 g \right)$$
$$+ \frac{dQ}{dt}$$
$$= \omega_3 \left(h_3 + \frac{V_3^2}{2} + z_3 g \right) + \omega_4 \left(h_4 + \frac{V_4^2}{2} + z_4 g \right)$$
$$+ \frac{dW_x}{dt}$$

Steady flow energy equation applies to wide Variety of Processes like pipe line flows, heat transfer Processes, Mechanical Power generation is engines and turbines, flow through Nozzles and Diffusors

1. **Nozzle and Diffuser**

$$h_1 + V_1^2/2 + z_1 g + \frac{du}{dm} = h_2 + V_2^2/2 + z_2 g + \frac{dW_x}{dm}$$

Here $\frac{du}{dm} = 0$, $\frac{dW_x}{dm} = 0$, change in potential energy is zero

$$h_1 + V_1^2/2 = h_2 + V_2^2/2 \quad — ①$$

Continuity equation becomes,

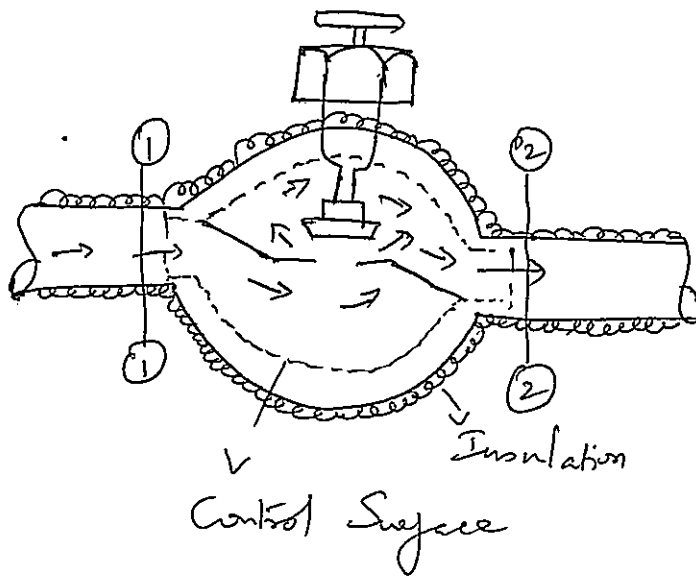$$\omega = \frac{A_1 V_1}{v_1} = \frac{A_2 V_2}{v_2} \rightarrow ②$$

Inlet velocity V_1 becomes negligible compared to exit velocity V_2

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

$$V_2 = \sqrt{2(h_1 - h_2)} \ m/s$$

$h_1 - h_2$ is in J/kg

2. < Throttling Device

$$\frac{du}{dm} = 0, \quad \frac{dw_n}{dm} = 0$$

Insulation

Control Surface

often Pipeline Velocities are so low in Throttling

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

$$h_1 = h_2$$

3. **Turbine and Compressor**

For turbine, the flow velocities are often small, K.E terms are neglected and work is done by fluid

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

$$\frac{W_x}{m} = h_1 - h_2$$

For adiabatic Pump, work is done upon the System, W is negative

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

$$\frac{W_x}{m} = h_2 - h_1$$

4. **Heat Exchanger - Steam Condenser**

$$w_c h_1 + w_s h_2 = w_c h_3 + w_s h_4$$
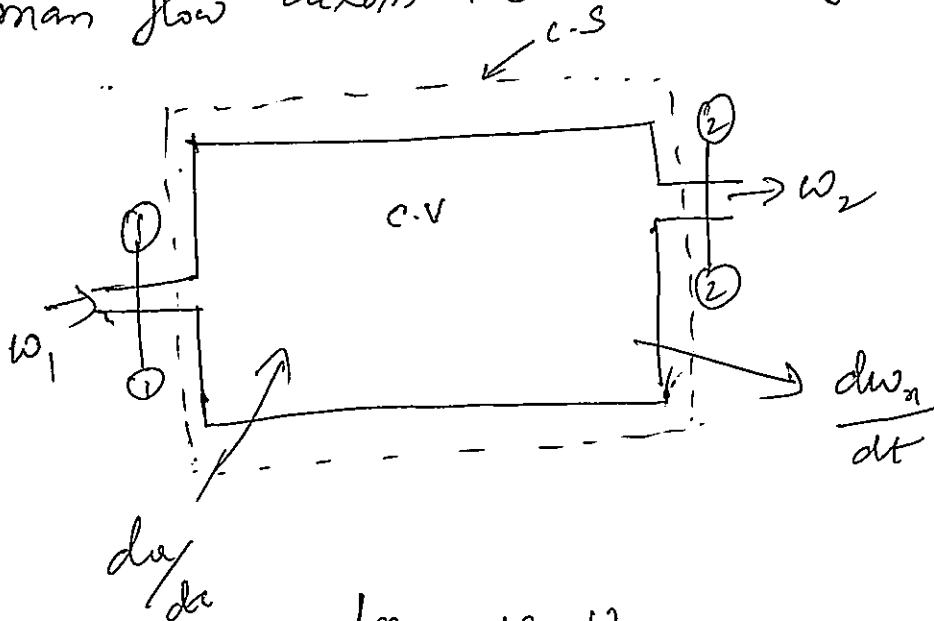
$$w_s (h_2 - h_4) = w_c (h_3 - h_1)$$

5. **Desuperheater**

$$w_1 h_1 + w_2 h_2 = w_3 h_3$$

Variable flow Processes

Many flow processes such as filling up and evacuating gas cylinders are not steady. Such processes can be analyzed by the Control Volume technique. Consider a device through which a fluid is flowing under non-steady state conditions. The rate at which the mass of fluid within Control Volume is accumulated is equal to the net rate of mass flow across the Control Surface

$$\frac{dm_V}{dt} = W_1 - W_2$$

$$= \frac{dm_1}{dt} - \frac{dm_2}{dt} \longrightarrow \text{①}$$

$$\Delta m_V = \Delta m_1 - \Delta m_2 \longrightarrow \text{②}$$
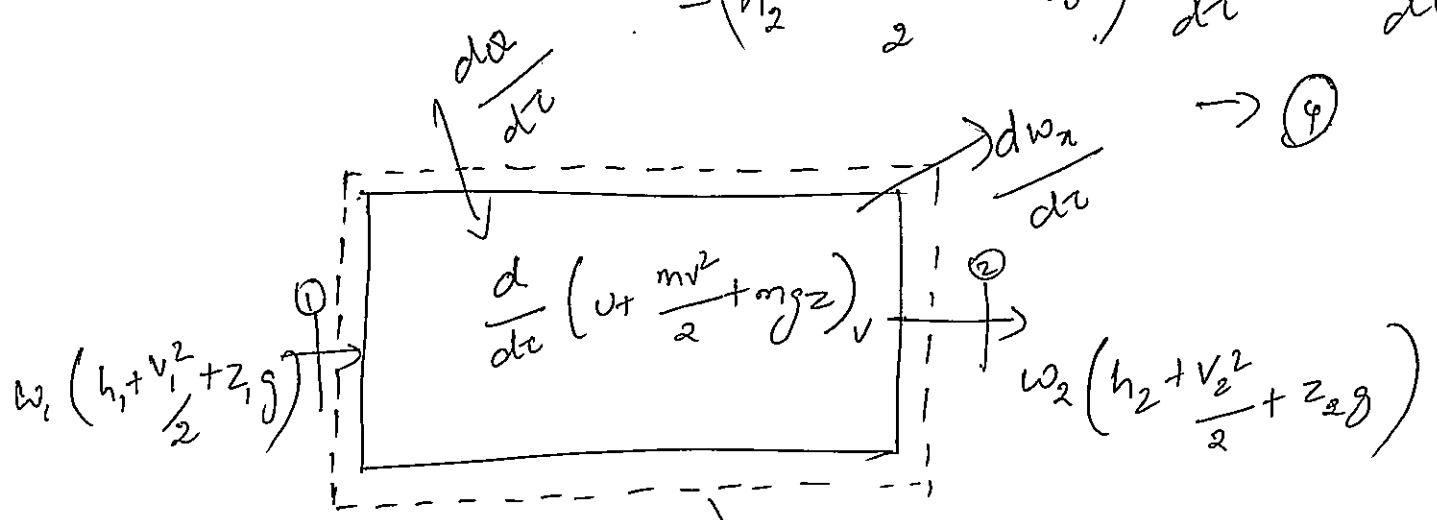
The rate of accumulation of energy within Control Volume is equal to the net rate of energy flow

across the Control Surface. If E_v is the energy of fluid within Control Volume at any instant

$$\frac{dE_v}{d\tau} = \omega_1\left(h_1 + \frac{V_1^2}{2} + z_1 g\right) + \frac{dQ}{d\tau}$$

$$- \omega_2\left(h_2 + \frac{V_2^2}{2} + z_2 g\right) - \frac{d\omega_x}{d\tau}$$

$$\rightarrow \text{(i)}$$

$$E_v = \left(U + \frac{mv^2}{2} + mgz\right)_v$$

$$\frac{dE_v}{d\tau} = \frac{d}{d\tau}\left(U + \frac{mv^2}{2} + mgz\right)_v$$

$$= \left(h_1 + \frac{V_1^2}{2} + z_1 g\right)\frac{dm_1}{d\tau} + \frac{dQ}{d\tau}$$

$$- \left(h_2 + \frac{V_2^2}{2} + z_2 g\right)\frac{dm_2}{d\tau} - \frac{d\omega_x}{d\tau}$$

$$\rightarrow \text{(ii)}$$

$$\Delta E_v = Q - W_x + \int_{c.s}\left(h_1 + \frac{V_1^2}{2} + z_1 g\right)dm_1$$

$$- \int\left(h_2 + \frac{V_2^2}{2} + z_2 g\right)dm_2$$

• For a closed System $w_1 = 0$, $w_2 = 0$ equation ③ reduces to

$$\frac{dE_V}{d\tau} = \frac{da}{d\tau} - \frac{dw_x}{d\tau}$$

Example of Variable Flow

Consider a Process in which a gas bottle in filled from a pipeline. In the beginning the bottle Contains gas of mass m_x at state p_1, t_1, V_1, h_1 and u_1. The Valve is opened and gas flows in to the bottle till the mass of gas in the bottle is m_2 at State p_2, t_2, V_2, h_2 and u_2. The supply to the pipeline is very large so that the state of gas in the pipeline is Constant at p_p, t_p, v_p, h_p, u_p and V_p.

$$E_1 = m_1 u_1 + (m_2 - m_1)\left(\frac{V_p^2}{2} + u_p\right)$$

$$E_2 = m_2 u_2$$

$$\Delta E = E_2 - E_1$$
$$= m_2 u_2 - \left[m_1 u_1 + (m_2 - m_1)\left(\frac{V_p^2}{2} + u_p\right)\right]$$

P.E terms are neglected
K.E terms have been omitted.

Workdone $W = p_p(V_2 - V_1) = p_p\left[0 - (m_2 - m_1)v_p\right]$

$$= -\left(m_2 - m_1\right) b_p V_p$$

$$Q = \Delta E + W$$

$$= m_2 u_2 - m_1 u_1 - \left(m_2 - m_1\right)\left(\frac{V_p^2}{2} + u_p\right) - \left(m_2 - m_1\right) b_p V_p$$

$$= m_2 u_2 - m_1 u_1 - \left(m_2 - m_1\right)\left(\frac{V_p^2}{2} + h_p\right)$$