Module-2

FIRST LAW FOR CLOSED SYSTEM UNDERGOING A CYCLE

Net work transfer = Net heat transfer

$$\oint \Sigma W = \oint \Sigma Q$$

where ΣW is the algebraic sum of all work transfer through the system boundary

$$= W_1 + W_2 + W_3 - - -$$

and ΣQ is the algebraic sum of all heat transfer through the system boundary

$$= Q_1 + Q_2 + Q_3 - - -$$

This law is called as law of conservation of energy or Joule's law

First law for closed system undergoing a change of state

The net energy transfer through the system boundary is stored in the system in the form of internal energy.

If heat added to the system is δQ and work done by the system is δW, then

Net energy transfer through the system boundary that is equal to $\delta Q - \delta W$ is stored in the system as change in internal energy ΔE.

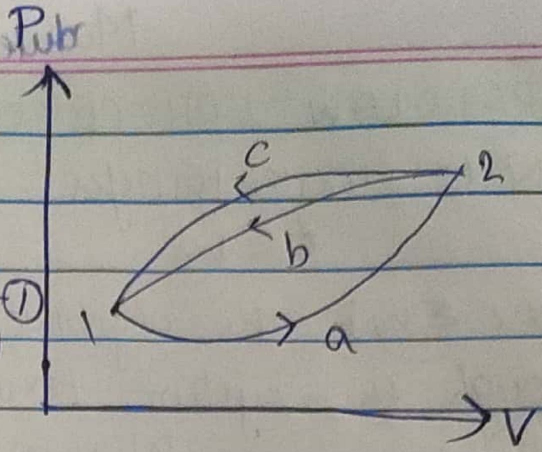
$$\delta Q - \delta W = \Delta E$$

$$\delta Q = \delta W + \Delta E$$

Thus, change in internal energy or simply energy is net energy transfer through the system boundary.

Some important conclusions drawn from first law of Thermodynamics

* Heat transfer is a path function



1-a-2-b-1

$(\delta Q)_{1a2} + (\delta Q)_{2b1} = (\delta W)_{1a2} + (\delta W)_{2b1}$ — (1)

1-a-2-c-1

$(\delta Q)_{1a2} + (\delta Q)_{2c1} = (\delta W)_{1a2} + (\delta W)_{2c1}$ — (2)

(1) - (2) $\Rightarrow (\delta Q)_{2b1} - (\delta Q)_{2c1} = (\delta W)_{2b1} - (\delta W)_{2c1}$

(or) $(\delta Q)_{2b1} - (\delta Q)_{2c1} \neq 0$

$(\delta Q)_{2b1} \neq (\delta Q)_{2c1}$

Though initial and final points are same, heat transfer is different for different paths. Hence, heat transfer is a path function.

* Energy is a property

For the above (1) & (2) eq^{n}s

(1)-(2) = $(\delta Q)_{2b1} - (\delta Q)_{2c1} = (\delta W)_{2b1} - (\delta W)_{2c1}$

$\Rightarrow (\delta Q - \delta W)_{2b1} = (\delta Q - \delta W)_{2c1}$

We observe that $\delta Q - \delta W$ is same for both paths b & c. Hence, ΔE is point function.

$\delta Q - \delta W = \Delta E$

$\Delta E = U + KE + PE$

If the system is stationery i.e. $\Delta K.E$ & $\Delta P.E = 0$

Then $\Delta E = \Delta U \Rightarrow \delta Q - \delta W = \Delta U$

~~If $(\delta W)_{other} = 0$ &~~ $\delta Q = \Delta U + (\delta W)_{boundary} + (\delta W)_{other}$

If $(\delta W)_{other} = 0$ & the process is quasi-static

Then $\delta Q = du + pdv$

* Isolated system is a constant energy system

$$\delta Q - \delta W = \Delta E$$

If the system is isolated, then $\delta Q = 0$ & $\delta W = 0$, then $\Delta E = 0$ or Energy E of the system is constant.

Limitations of the First Law of Thermodynamics.

- First law of thermodynamics does not give direction to the occurrence of any process.

ENTHALPY

In the analysis of processes, we very often come across the expression $U + PV$.

Where PV is known as flow work, displacement work or flow energy

For simplicity and our convinience, we define this expression as enthalpy.

i.e. $H = U + PV$

It is an extensive property (depends on mass)

$$\frac{H}{m} = h = u + Pv$$

$h \rightarrow$ specific enthalpy (intensive)

HEAT INTERACTION IN VARIOUS PROCESSES

* Constant volume (Isochoric)

$$\delta Q = dU + \cancel{\delta W_{boundary}}^{\,0} + \delta W_{other}$$

$$\delta Q = du + \delta W_{other}$$

$$du = \delta Q - \delta W_{other} = mC_v dT$$

For ideal gas, U is a fn of temp. only

Conditions :-
- If process is constant volume, then any substance
- If substance is ideal gas, then any process.

* Constant pressure (Isobaric) process

$$\delta Q = dU + \delta W_{boundary} + \delta W_{other}$$

$$\delta Q - \delta W_{other} = dU + PdV$$

$$= dU + d(PV)$$

$$= d(U + PV)$$

$$\delta Q - \delta W_{other} = dH \text{ (energy supplied at cons. pressure)}$$

$$dH = mC_p dT$$

For ideal gas, H is a function of temperature only.

Conditions to use above eqn
- If process is constant pressure, then any substance
- If substance is ideal gas, then any process

Proof of $C_p - C_v = R$ for ideal gas

$$H = U + PV$$

$$H = U + mRT$$

$$dH = dU + mRdT$$

$\cancel{C_p = C_v}$ $mC_p dT = mC_v dT + mRdT$

$$C_p = C_v + R \Rightarrow \boxed{C_p - C_v = R}$$

Also

$$\frac{C_p}{C_v} = \gamma \quad \text{(or)} \quad C_p = \gamma C_v$$

$$\gamma C_v - C_v = R$$

$$C_v = \frac{R}{\gamma - 1} \qquad C_p = \frac{\gamma R}{\gamma - 1}$$

* Constant temperature (Isothermal) process

$\delta Q = \delta U + \delta W$

For ideal gas, $\delta U = mc_v dT$

$\delta Q = mc_v dT + \delta W$

In isothermal process, $dT = 0$

$\boxed{\delta Q = \delta W}$

* Adiabatic process ($\delta Q = 0$)

$\delta Q = \delta U + W$

$\boxed{\delta W = -dU}$

* Polytropic process

$\delta Q = dU + \delta W_{boundary}$

For ideal gas, $\delta Q = m c_v (T_2 - T_1) + \frac{P_1V_1 - P_2V_2}{n-1}$

$$\delta Q = \frac{P_1V_1 - P_2V_2}{n-1} \cdot \left[-\frac{n-1}{\gamma-1} + 1 \right]$$

$$Q_{polytropic} = W_{polytropic} \left[\frac{\gamma - n}{\gamma - 1} \right]$$

Polytropic Specific heat

$$\delta Q = m(T_2 - T_1) \left[-c_v \frac{\gamma - n}{n-1} \right]$$

→ polytropic specific heat

-ve coz $T\downarrow$ $W > Q$

Free expansion

$\delta Q = dU + \delta W$

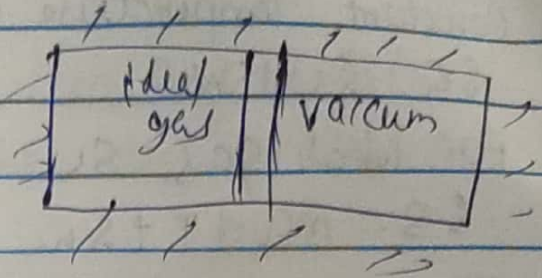
δQ & $\delta W = 0$ (or) $dU = 0$

So, U is constant

$E = U + K.E + PE$

$U_{initial} = U_{final}$

Since it is an ideal gas, $T_{initial} = T_{final}$



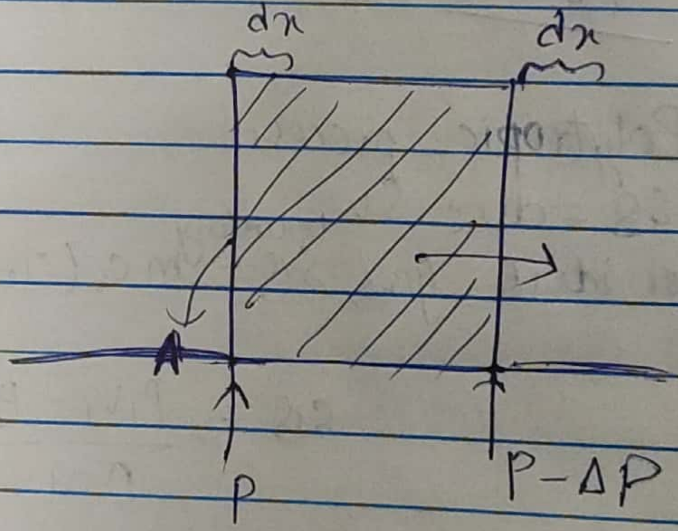
Displacement work / Flow work / Flow energy

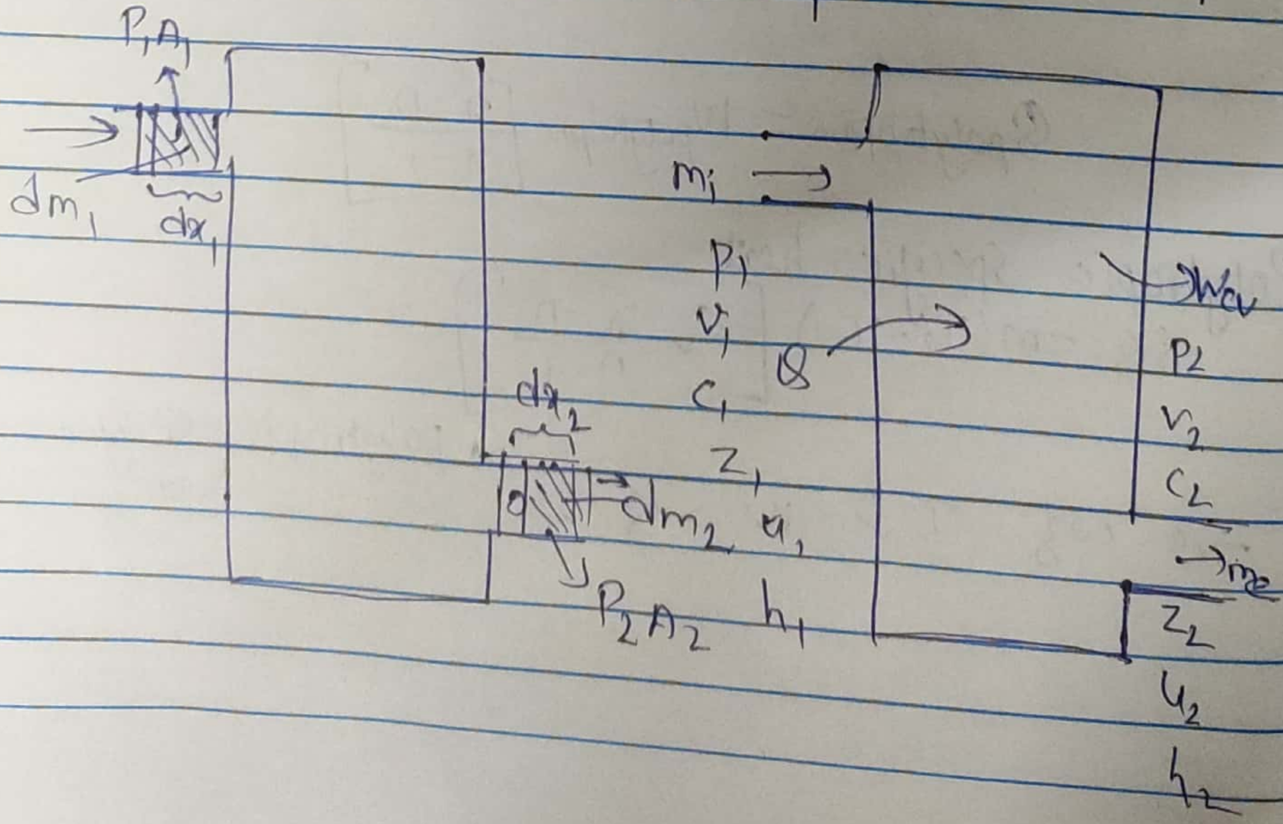
$\delta W = P.A.dx$

$= Pdv$

$\delta W = (P - \Delta P).A.dx$

$= (P - \Delta P) dV$





Steady state condition.

Conservation of mass, mass flow rate entering = mass flow rate leaving

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

Conservation of energy, Energy at inlet = Energy at exit

$$Energy_{inlet} = Energy_{exit}$$

$$\dot{m}\left[u_1 + P_1 v_1 + C_1^2/2 + gZ_1\right] + \dot{Q} = m\left[u_2 + P_2 v_2 + C_2^2/2 + gZ_2\right] + W_{cv}$$

$$m\left[h_1 + C_1^2/2 + gZ_1\right] + Q = m\left[h_2 + C_2^2/2 + gZ_2\right] + W_{cv}$$

$$h_1 + C_1^2/2 + gZ_1 + q = h_2 + C_2^2/2 + gZ_2 + w_{cv}$$

(Steady flow energy equation)

{First law of thermodynamics for open system under steady state.}

if the system is stationary & the change in P.E is zero, i.e.

$$\Delta KE = 0 \quad \& \quad \Delta PE = 0$$

$$h_1 + \dot{q} = h_2 + w_{cv}$$

or $\delta q = dh + (\delta w)_{cv}$

$$H_2 - H_1 = (U_2 - P_2V_2) - (U_1 - P_1V_1)$$

(or) $H_2 - H_1 = (U_2 - U_1) + (P_2V_2 - P_1V_1)$

Bernoulli Equation from steady flow energy equation

$$h_1 + \frac{C_1^2}{2} + gZ_1 + q_1 = h_2 + \frac{C_2^2}{2} + gZ_2 + w_{cv}$$

(Or), $u_1 + P_1v_1 + \frac{C_1^2}{2} + gZ_1 + q = u_2 + P_2v_2 + \frac{C_2^2}{2} + gZ_2 + w_{cv}$

Conditions

- Steady state
- $u_1 = u_2$
- $w_{cv} = 0$ & $q = 0$

$$P_1 v_1 + \frac{C_1^2}{2} + g Z_1 = P_2 v_2 + \frac{C_2^2}{2} + g Z_2$$

$$\frac{P_1}{\rho_1} + \frac{C_1^2}{2} + g Z_1 = \frac{P_2}{\rho_2} + \frac{C_2^2}{2} + g Z_2$$

If the substance is incompressible, then $\rho_1 = \rho_2 = \rho$

$$\frac{P_1}{\rho g} + \frac{C_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{C_2^2}{2g} + Z_2 \text{ (Bernoulli's eqn)}$$

Some example of steady flow processes

* Nozzle & Diffuser

Nozzle is a device which increases velocity or KE at the expense of pressure energy.

Diffuser is a device which increases the pressure energy at the expense of K.E

Conditions

- Steady state
- Potential energy change i.e. $\Delta PE = 0$
- Control volume work, i.e. $W_{cv} = 0$
- Heat transfer, i.e. $q = 0$

$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

$C_1 <<<< C_2$ So, $h_1 = h_2 + \frac{C_2^2}{2}$

$$C_2 = \sqrt{2(h_1 - h_2)}$$

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Limitations of first law
- Doesn't differentiate btw low grade & high grade
- Direction of heat flow isn't indicated.

* Turbine

15) It gives positive power output

Conditions :-
- Steady state
- $\Delta PE = 0$ & $\Delta KE = 0$
- Heat transfer, $q = 0$

$$h_1 = h_2 + w_{cv} \quad (or) \quad w_{cv} = h_1 - h_2$$

* Compressor

Compressor requires power input

Conditions :-
- Steady state
- ΔPE & $\Delta K.E = 0$
- $q = 0$

$$h_1 = h_2 + w_{cv}$$

$$w_{cv} = -w_{input} \Rightarrow w_{input} = h_2 - h_1$$

* Throttling device

When the fluid flows through a constrained passage like a capillary tube, partially opened valve, orifice, porous plug, there is a significant drop in pressure.

Conditions
- Steady state
- ~~Potei~~ $\Delta PE = 0$ & $\Delta KE = 0$
- $q = 0$
- $w_{cv} = 0$

Characteristics of throttling process :-
- Isenthalpic process
- Highly irreversible

$$h_1 = h_2$$

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