UNIT - 1

THERMODYNAMICS

What is thermodynamics :-
Branch of science that deals with the energy transfer & effects on the state or condition of a system.

Applications of thermodynamics -
1. Power producing devices → chem → heat → mech
→ I.C engines → Gas turbines
→ Water turbines → Steam & nuclear power plants

2. Power consuming devices -
→ Fans → Blowers → Compressors
→ Pumps → RACs

Thermodynamic System :-
A prescribed region or space of finite qty of matter surrounded by an envelop which is known as boundary.

System ← imaginary boundary

⇅

Energy Exchange

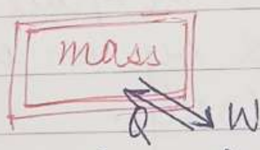
Surrounding :-
The matter & space ext to system that may be influenced by the changes in system.

Boundary :-
The system & surrounding are suspended by an envelope.
Boundary may change the :-
shape, vol, orientation, position

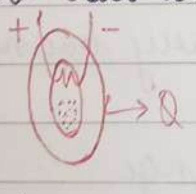
↳ Diathermic :-
Boundaries that do allow heat transfer.

↳ Adiabatic :-
Boundaries that do not allow heat transfer.

Closed System :-
No mass exchange or transfer within its boundary.
Physical nature & chemical composition may change.



ex. bomb calorimeter, pressure cooker, RAC, refridgerator



Open System :-
Both mass & energy can exchange.
ex. water wheel, gas turbine, ~~boilers~~ boilers, steam & ~~n~~ nuclear power plant.

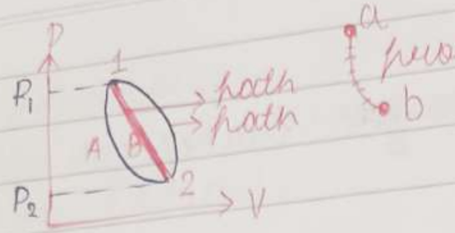
Isolated System :-
No heat or mass ~~transfer~~ transfer.

Adiabatic System :-
No heat transfer

Phase -
Phase is the qty of matter that is uniform in physical & in **chemical** struc.

homogeneous { 1 phase → single phase ex. ~~solid~~ solid ice
heterogeneous sys { 2 phase → mass contained is not uniform
{ 3 phase →

Property of system :-
Every system has certain characteristics by which its physical condition can be described.
ex. pressure, vol, color
Any operation in which one or more prop of a system changes then this is called change of state
The succession of states passes through ~~the path~~ the state it is called the path of a change in the change in state.
When path is defined it is called process.
When in a series of state changes such that the final state is identical to ~~the~~ the first state it is called thermodynamic cycle.



a-b process
1-2 process
1-2-1 therm cycle.

Intensive prop -
Does not depend on mass of system. Its value remains the same.
ex. pressure, temp, composition, viscosity,

Extensive prop -
Does depend on mass of system.
ex. energy, vol, enthalpy

Thermodynamic Eq^m -
When there is no change in macroscopic prop. is seen or registered if the system is isolated from its surrounding.

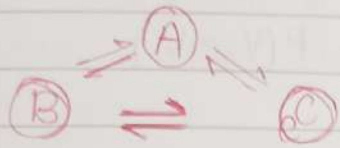
Mechanical Eq^m -
In the absence of any unbalanced force within the system itself & b/w sys & its surr.

Chemical Eq^m -
If there is no chemical r^n or transfer of matter from one part to other part of sys

Thermal Eq^m -
When a sys exist in both mech & chem eq^m if is separated from its surr by a diathermic wall & if there is no spontaneous change in the prop of sys.

Zeroth Law :-

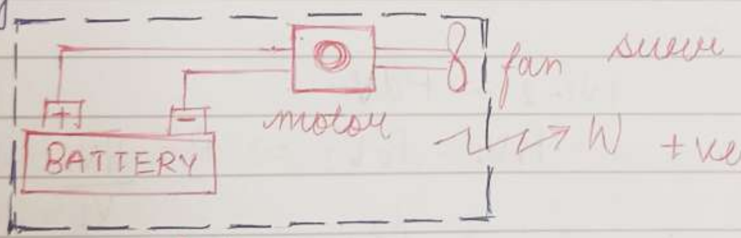
Property



Work :-

When a force acts on a body causes that body to move in the dir^n of force.

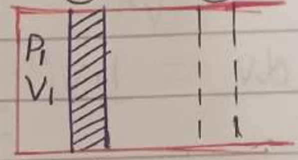
In therm., work transfer occurs b/w the sys & surr., work is said to be done by the sys if the entire effect on the things ext to the sys can be ~~used~~ reduced to the rising of weight.



work done by sys - +ve

work done on sys - -ve.

PdV work or displacement work :-

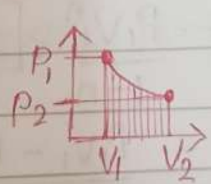


$F = P \times A$

piston moves through a infiniti small dist^n dx -

$dW = F\,dx = PA\,dx = P\,dV$

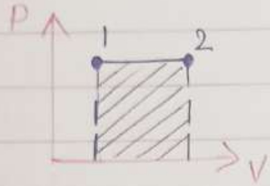
$\int dW = \int_1^2 P\,dV$



$W_{1-2} = P(V_2 - V_1)$

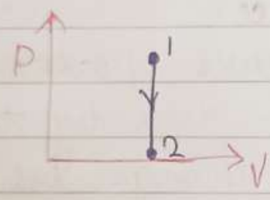
P.dv work process :-

(I) Isobaric :-



$$W_{1-2} = \int_1^2 P\,dv = P(V_2 - V_1)$$

(II) Isochoric -

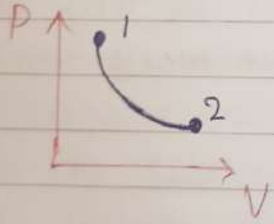


$$W_{1-2} = P\,dv = P(V_2 - V_1)$$

since $V_1 = V_2$

$$W_{1-2} = 0.$$

(III) Isothermal -



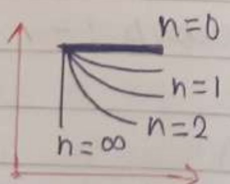
$$W_{1-2} = P\,dv$$

$$P_1V_1 = P_2V_2 \Rightarrow P_2 = \frac{P_1V_1}{V_2}$$

$$W_{1-2} = \int_{V_1}^{V_2} P_1V_1 \frac{dv}{V}$$

$$W_{1-2} = P_1V_1 \ln \frac{V_2}{V_1}$$

(IV) Adiabatic -



$$W_{1-2} = \int P\,dV$$

$$PV^n = C \qquad P = \frac{P_1V_1^n}{V^n}.$$

$$W_{1-2} = \int \frac{P_1V_1^n}{V^n}\,dV = P_1V_1^n \left.\frac{V^{-n+1}}{-n+1}\right|_1^2$$

$$W_{1-2} = \frac{P_1V_1^n}{1-n}\left[V_2^{-1-n} - V_1^{-1-n}\right]$$

$$W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}$$

Heat & Heat transfer :-

Heat is defined as the energy associated with the random motion of atoms & molecules.

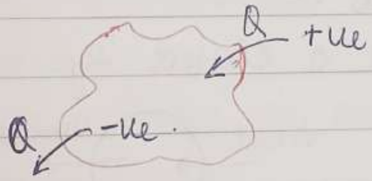
It is a form of energy, it can transfer w/o mass across the boundary of system due to temp difference.

high temp → low temp

Energy transfer due to temp diff is known as Heat Transfer

+ve heat transfer from surr. to sys.

-ve heat transfer from sys. to surr.



There are 3 modes of heat transfer :-

Conduction :- Transfer of heat b/w two bodies in contact.

Convection :- ~~Trans~~ Transfer of heat b/w wall & fluid.

Radiation :- Transfer of heat separated by empty surface or gases through EM

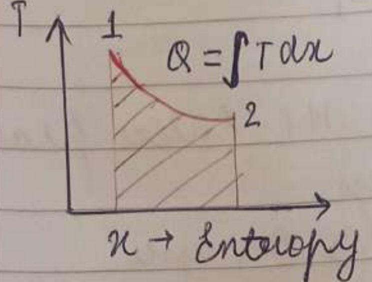
HT → path f^n

↳ depends upon path

↓

intermediate state s through which it passes.

Temp diff → heat transfer



$Q_{1-2} = \int_1^2 T\,dx \Rightarrow dQ = T\,dx \qquad x \rightarrow \text{Entropy}$

$\frac{dQ}{T} = dx$

$S_2 - S_1 = \frac{dQ}{T}$

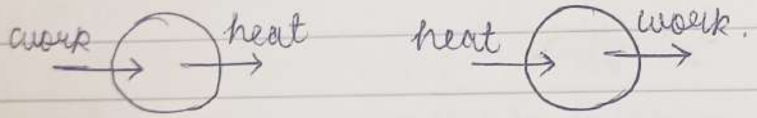
First law of Thermo.

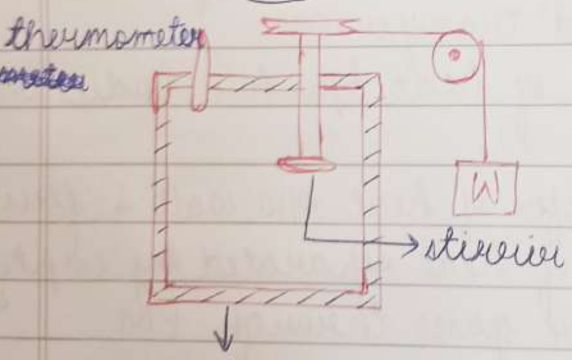
(for a closed sys undergoing cycle)

The transfer of heat & performance of the work causes the same effect in a sys so heat & work are diff forms of the same entity which is called Energy.

Joules Experiment :-

Let us consider a closed sys.





t_1 , t_2

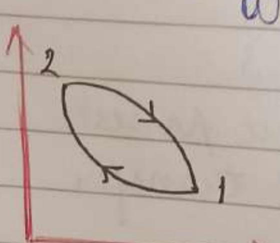
adiabatic → no heat transfer will take place.

Thermal eq^n

adiabatic

Joule concluded that amt of heat transfer Q_{2-1} = amt of work transfer W_{2-1}

$W_{1-2} \propto Q_{1-2}$



if more WD & HT takes place within the sys.

$(\Sigma W)_{cycle} \propto (\Sigma Q)_{cycle}$

J → Joule's const.

$W = Q \times J \quad (J = 1) \quad \therefore W = Q.$

$\Sigma W = \Sigma Q$

$\oint dW = \oint dQ$

Energy can neither be created nor be destroyed but can be created from one form to other
Heat & work are mutually convertible.

When a sys undergoes a thermodynamic cycle, the net heat supplied to the sys by its surr. is equal to the net work done by the sys on its surr.

Total energy of an isolated sys in all its forms remains const.
No machine can produce energy w/o corresponding expenditure of energy.

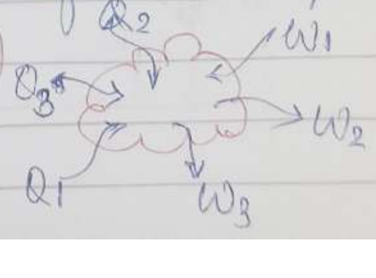
Energy stored (prop. of sys) :-
Algebraic sum of all energy transfer across sys boundaries is zero.
If a sys undergoes a change of state during which heat & work transfer is involved, the net energy transfer will be stored in the sys.

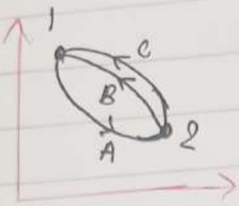
$Q - W = \Delta E$

stored in the sys — ↑ in the energy of sys.

if more no. of heat & work transfer takes place

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





$$Q_A = \Delta E_A + W_A$$
$$Q_B = \Delta E_B + W_B$$
$$Q_C = \Delta E_C + W_C$$

A & B → cycle 1-2-1

$$(\Sigma W)_{cycle} = (\Sigma Q)_{cycle}$$
$$W_A + W_B = Q_A + Q_B$$
$$Q_A - W_A = W_B - Q_B$$
$$\Delta E_A = -\Delta E_B$$
$$\Delta E_A + \Delta E_B = 0$$

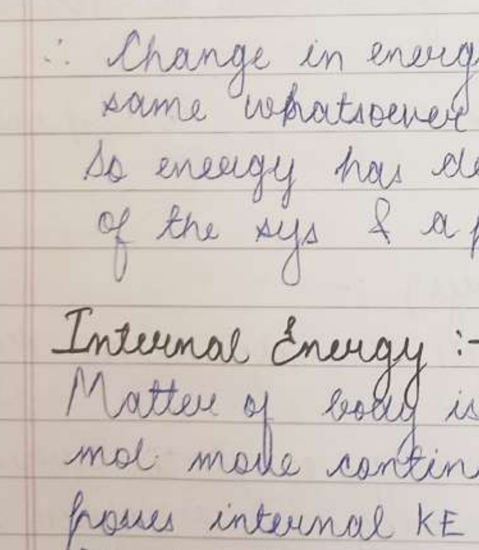
A & C → cycle

$$\Delta E_A = -\Delta E_C$$
$$\boxed{\Delta E_B = \Delta E_C}$$

∴ Change in energy b/w 2 states of a sys is the same whatsoever the path of the sys. be.
So energy has definite value for energy state of the sys & a pt f^n of prop. of sys.

Internal Energy :-

Matter of body is composed of molecules, these mol move continuously & randomly. Matter posses internal KE due to motion of mol & internal PE due to relative position of their mol. Sum of these two energies is known as internal energy.



micro + macro = E

Total E of sys -

$$E = U + E_K + E_P$$

$$E = \underset{\downarrow \\ IE}{U} + \frac{1}{2}mv^2 + \frac{gh}{g}$$

Total E = U + KE + PE + chem E + mag E + elec potential

U → microscopic , rest are macroscopic

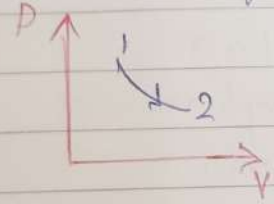
$E = U$

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

Enthalpy :-

Enthalpy is the total energy of a substance due to molecular KE as well as pressurization.

change of enthalpy b/w state ① & ② - ΔH



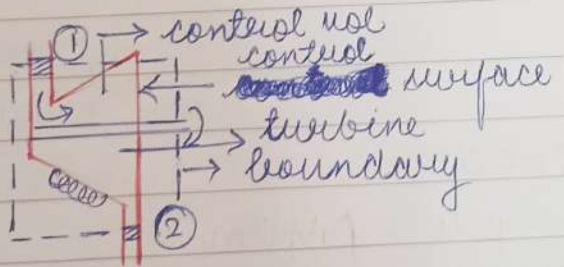
$H = U + PV$

change in enthalpy -

$\Delta H = H_2 - H_1 = U_2 - U_1 + (P_2V_2 - P_1V_1)$

Control Vol. -

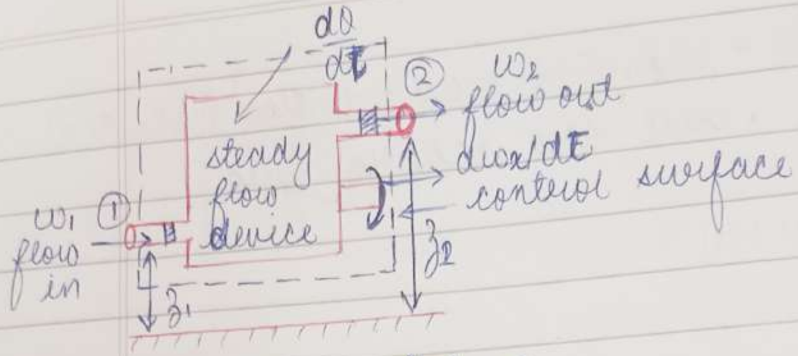
Any fixed region in space through which the moving subst. flows.



Steady flow process -

The rate of flow of mass or energy across the control surface is constant & doesn't alter with time.

Eqn - (SFEE)



arbitrary datum

$A_1 A_2$ = cross secn of stream (m^2)

$w_1 w_2$ = mass flow rate $\left(\frac{kg}{s} = \frac{dm}{dt} = w\right)$

$P_1 P_2$ = absolute pressure (N/m^2)

$V_1 V_2$ = specific vol. (m^3/kg)

$U_1 U_2$ = sp. internal energy (J/kg)

$C_1 C_2$ = inlet & outlet velocity (m/s)

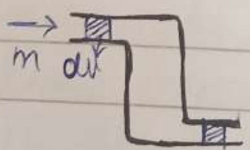
$Z_1 Z_2$ = elevation above datum (m)

$\frac{dQ}{d\tau}$ = net rate of heat transfer (J/s)

$\frac{dw_x}{d\tau}$ = net rate of work transfer (J/s)

τ = time (s)

Mass Balance :-



$$w_1 = w_2 = w$$

$$dw_{1\,flow} = p\,dV = p_1 V_1\,dm_1$$

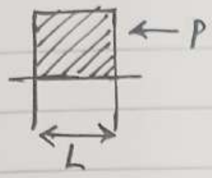
$$dV = v\,dm$$

$$\frac{A_1 C_1}{V_1} = \frac{A_2 C_2}{V_2} = w = \frac{AC}{V}$$

$$dw_{2\,flow} = P_2 V_2\,dm_2$$

Energy balance -

In a ~~flow~~ fluid work, there can be two types of work ext & flow work.



$$E = P \times A \times L = P \times V$$

→ shapework (shear work)

→ elec work.

total work transfer $W = \underbrace{W_x}_{\text{work by sys}} - \underbrace{P_1 dV_1 + P_2 dV_2}_{\text{flow in work.}}$

$$W = W_x - P_1 V_1 dm_1 + P_2 V_2 dm_1$$

in rate form -

$$\frac{dW}{d\tau} = \frac{dW_x}{d\tau} - P_1 V_1 \frac{dm_1}{d\tau} + P_2 V_2 \frac{dm_2}{d\tau}$$

acc. to law of cons. of energy :-

total rate of flow of all energy streams energy entering the const. vol. = total rate of flow of all energy streams energy exiting the const. vol.

$$w_1 e_1 + \frac{dQ}{d\tau} = w_2 e_2 + \frac{dW}{d\tau}$$

$$e_1 = u_1 + e_{k_1} + e_{p_1} + e_{st_1} + \dots$$

$$e_2 = u_2 + e_{k_2} + e_{p_2} + e_{st_2} + \dots$$

$$w_1 e_1 + \frac{dQ}{dt} = w_2 e_2 + \frac{dW_x}{d\tau} - P_1 V_1 \underbrace{\frac{dm_1}{d\tau}}_{w_1} + P_2 V_2 \underbrace{\frac{dm_2}{d\tau}}_{w_2}$$

$$w_1 e_1 + w_1 P_1 V_1 + \frac{dQ}{d\tau} = w_2 e_2 + w_2 P_2 V_2 + \frac{dW_x}{d\tau}$$

$$w_1\left(u_1 + \frac{c_1^2}{2} + z_1 g\right) + w_1 P_1 V_1 + \frac{dQ}{d\tau} = w_2\left(u_2 + \frac{c_2^2}{2} + z_2 g\right) + w_2 P_2 V_2 + \frac{dW_x}{d\tau}$$

$u \to h$

$$\boxed{w_1\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + \frac{dQ}{d\tau} = w_2\left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + \frac{dw_x}{d\tau}}$$

steady flow energy eqⁿ / time

$w_1 = w_2 = w$.

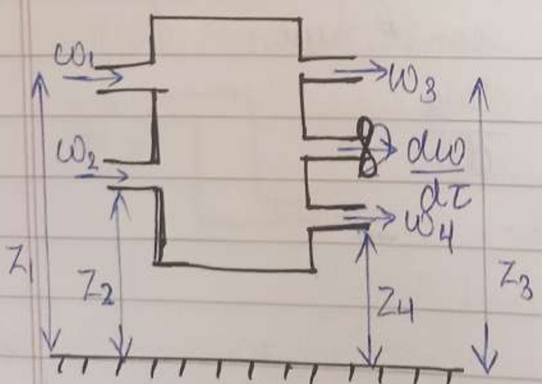
$$w\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + \frac{dQ}{dt} = w\left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + \frac{dw_x}{d\tau}$$

$$\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + \frac{dQ}{w\,dt} = \left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + \frac{dw_x}{w\,d\tau}$$

$$\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + \frac{dQ}{dm} = \left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + \frac{dw_x}{dm}$$

$$Q - W = (h_2 - h_1) + \left(\frac{c_2^2 - c_1^2}{2}\right) + g(z_2 - z_1)$$

pipeline flow, all heat



acc. to mass balance -

$$w_1 + w_2 = w_3 + w_4$$

energy balance -

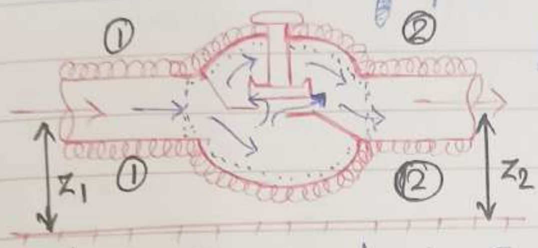
$$w_1 e_1 + w_2 e_2 + \frac{dQ}{d\tau} = w_3 e_3 + w_4 e_4 + \frac{dw}{d\tau}$$

$$\therefore\ w_1\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + w_2\left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + \frac{dQ}{d\tau} =$$

$$w_3\left(h_3 + \frac{c_3^2}{2} + z_3 g\right) + w_4\left(h_4 + \frac{c_4^2}{2} + z_4 g\right) + \frac{dw}{d\tau}$$

Trottling device -

When a fluid flows through a constricted passage, like a partially opened value or a orifice or a crack in wall of porous plug, there is drop in pressure then flow is said to be trotted.



used in refridgeration & air conditioning plant.

$\downarrow$ in P $\Rightarrow$ $\downarrow$ in Temp.

SFEE →

$$\left[h_1 + \frac{c_1^2}{2} + z_1 g\right] + \frac{dQ}{dm} = \left[h_2 + \frac{c_2^2}{2} + z_2 g\right] + \frac{dW}{dm}.$$

potential change :- $z_1 = z_2$ $\therefore \Delta z = 0$.

$$\frac{dW}{dm} = 0, \quad \frac{dQ}{dm} = 0$$

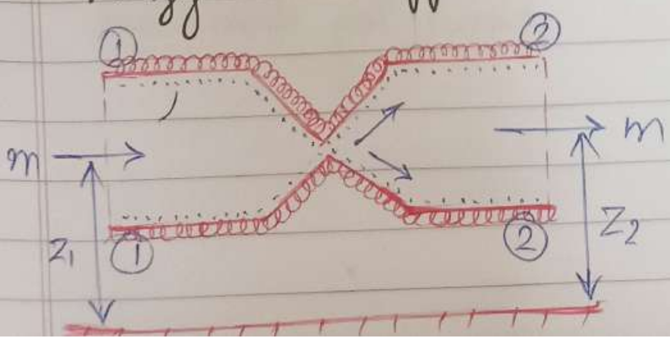
$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}.$$

pipe velocities are often small $\therefore KE = 0$

$$\boxed{h_1 = h_2}$$

ex. refrigerant is present in refrigerators which takes heat from the food item in order to freeze it & itself gets blows off or evaporates.

Nozzels & Diffusers :-



nozzels -
used in aeroplanes or jet propulsions.

Device that ↑ velocity or KE of a fluid at the expense of its pressure drop.

$$h_i + \frac{c_1^2}{2} + z_1 g + \frac{dQ}{dm} = h_2 + \frac{c_2^2}{2} + z_2 g + \frac{dW}{dm}$$

since insulated → $\frac{dQ}{dm} = 0$

since no shaft → $\frac{dW}{dm} = 0$

$z_1 = z_2 \Rightarrow \Delta z = 0$

& $c_1 <<< c_2 \quad \therefore c_1 \approx 0$.

$$\therefore \quad h_1 = h_2 + \frac{c_2^2}{2}$$

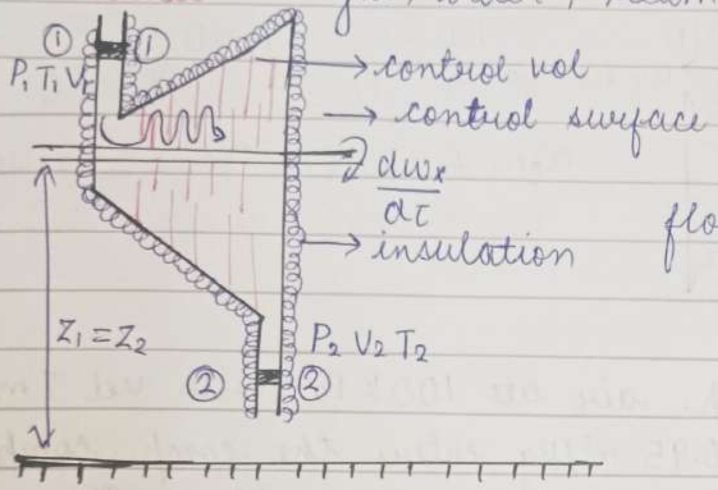
$$\boxed{c_2 = \sqrt{2(h_1 - h_2)}}$$

Diffusers -

Device which ↑ pressure of fluid at the expense of its KE

SFEE — Engines & Turbines
compression & fans

Turbines — gas, water, steam.



flowed through heat exchanger
(steam condenser)

flow velocities are small

$KE = 0$, $\frac{dQ}{dm} = 0$ (insulated)

$$h_1 + \cancel{\frac{c_1^2}{2}} + \cancel{z_1 g} + \cancel{\frac{dQ}{dm}} = h_2 + \cancel{\frac{c_2^2}{2}} + \cancel{z_2 g} + \frac{dw_x}{dm}$$

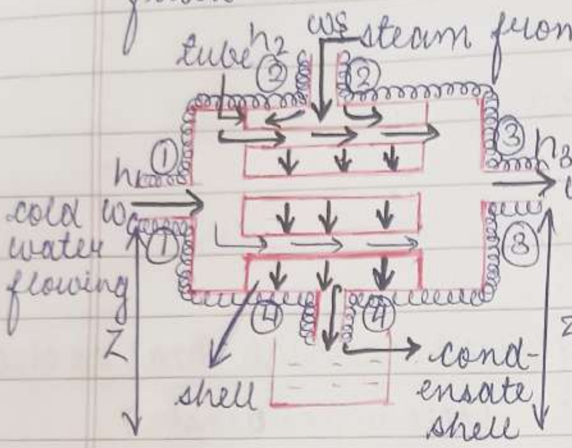
$$h_1 = h_2 + \frac{dw_x}{dm}$$

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

∴ in turbines, WD is by the fluid at the expense of its enthalpy.

Q. Derive the gen SFEE for an open sys. & reduce this expression for pumps, compressors & engines.

Heat exchanger -
Device in which heat is transferred from one fluid to another.



$KE = 0$, $PE = 0$

$dQ = 0$, $dW = 0$

$w_c h_1 + w_s h_2 = w_c h_3 + w_s h_4$

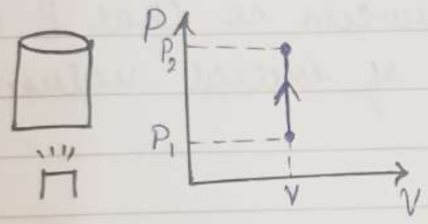
$w_s(h_2 - h_4) = w_c(h_3 - h_1)$

Q. In an air comp. air at 100 K Pa with vel 7 m/s & specific vol 0.95 m^3/Kg enters the comp, comp to 700 K Pa, vel 5 m/s & sp. vol 0.19 m^3/Kg. There is a heat loss from the comp 58 K Watt & due to compression IE of the fluid is ↑ by 90 KJ/Kg. mass flow rate is 0.5 Kg/s. Find the work input given to comp & ratio of inlet to outlet diameter pipe.

$$\frac{\pi}{4}\frac{d_1^2 c_1}{V_1} = \frac{\pi}{4}\frac{d_2^2 c_2}{V_2}$$

Thermodynamic Processes -

Ⓐ Constant vol process -



① relⁿ b/w P, V, T

$$P_1 V_1 = nRT_1$$
$$P_2 V_2 = nRT_2$$
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

since $V_1 = V_2$

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

(ii) WD -

$$W = \int_1^2 P\,dV = P(V_2 - V_1) = 0.$$
$$W = 0$$

(iii) change in IE -

$$\Delta U = U_2 - U_1 = \int mc\,dT = \underset{\substack{\downarrow \\ \text{sp. heat at const vol}}}{mC_v}(T_2 - T_1)$$

$C_v \rightarrow$ rate of change of sp. IE w.r.t. temp when the vol is held const.

$$dU = C_v \int dt \Rightarrow C_v = \frac{dU}{dT}$$

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

(4) Heat Transfer (by 1^{st} law)

$$Q = W + U = 0 + \Delta U$$

$$Q = \Delta U$$

$$Q = \Delta U = m\,C_v(T_2 - T_1)$$

∴ change in IE & heat transfer are equal in const. vol. process.

Q. In a vessel 10 kg of oxygen is heated in a reversible const. vol. process so that P of oxygen is ↑ 2 times that of initial value.

$T_i = 20^\circ c$ (i) find the final temp.

(ii) ΔU

(iii) Δ enthalpy

(iv) heat transfer

take $[R = 0.259\ KJ/Kg$ & $C_v = 0.652\ KJ/Kg\,K]$

Q. A sys recieves 200 KJ of heat at const vol process