

1st Law of Thermodynamics

IST Law For a Closed System:

Examples:

Sun, Piston Cylinder arrangement
without valves

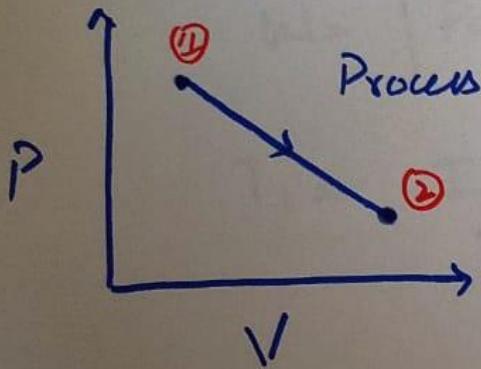
Thermodynamic Cycle:

=> Set of processes so arranged that
initial and final state are the same
points

-> The change in a thermodynamic property
is zero in a thermodynamic cycle

=> Initial and Final state are same.

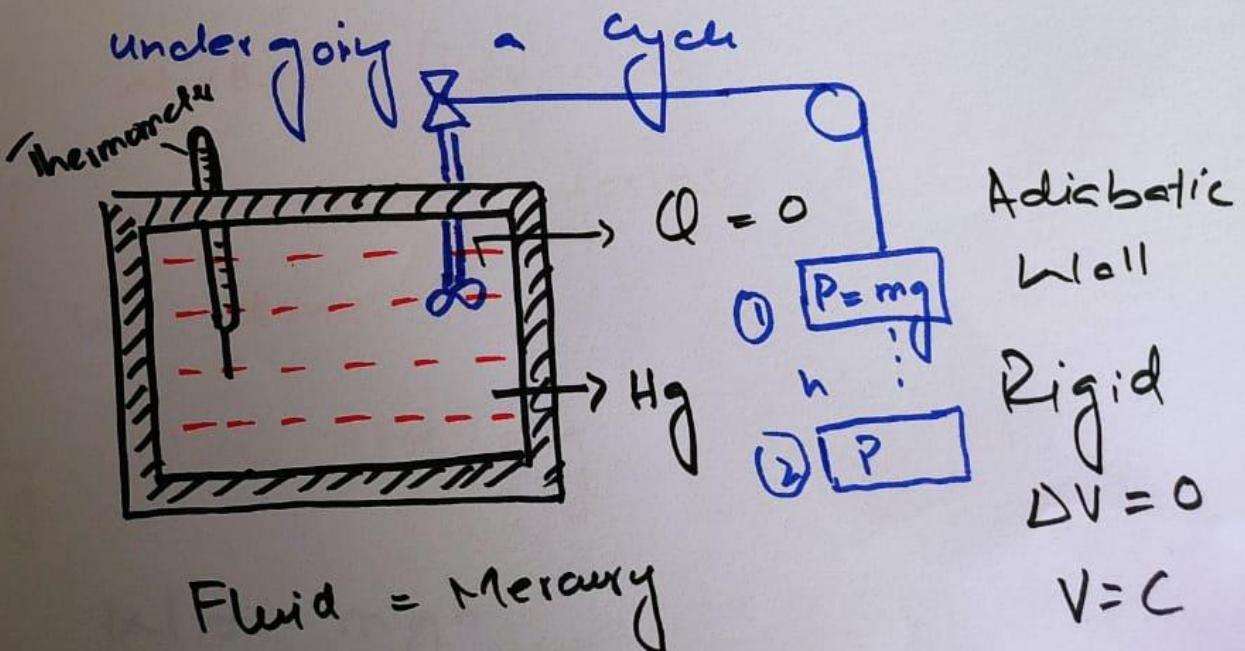
(1)



Thermodynamic Process

Ist Law For a Closed system

Joule's
Experiment
Conservation
of Energy
Proof



$$W = \int P dV = 0$$

T_1 = Initial temperature
of Hg

$T_1 = T_{atm}$ (atmospheric temperature)

Displacement work ($PdV = 0$)

But there are other forms of work
that can be done

Stirring work For e.g.

$$W = mgh$$

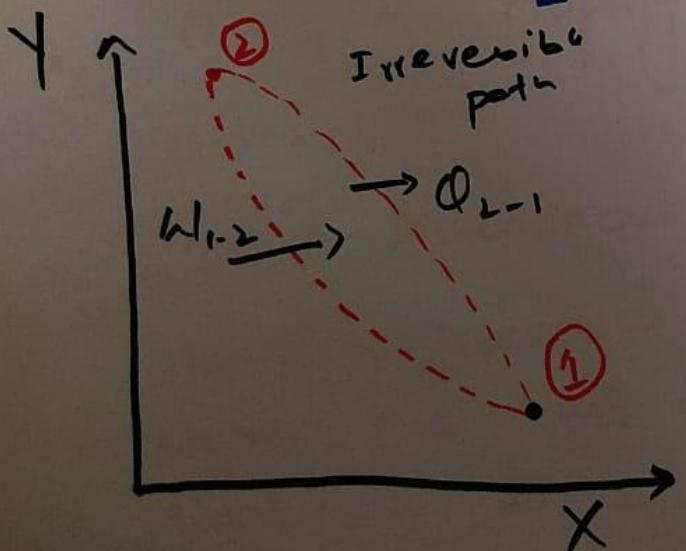
(3)

Shaft Work $W_l = T \theta$

$$W_l = mgh = T \theta$$

Work done on the system

Final temperature $= T_2$



$T_2 > T_1$
Mechanical work gave rise in K.E of the system which in turn has increased the temperature of the system. (4)

Remember:

- ⇒ Stirring Work is a rapid / spontaneous process.
- ⇒ That is why b/w Final and initial states are not in equilibrium.
- ⇒ Intermediate states are not in equilibrium
- ⇒ Irreversible Process
- ⇒ On a Property Diagram paths are represented by Irreversible in dotted lines / Discontinuous lines
- ⇒ In a irreversible process intermediate states are not easily determined because there is no equilibrium. 6

Joule did this experiment with different setups. By changing fluids, Mechanical work setups, Electric work setups.

He found out the amount of work he puts into a system it is received back in the amount of heat. Irrespective of process either reversible & irreversible.

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

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

(Not exact)
amount (6)

The concept of high grade energy
k low grade energy was devised.

$$\sum \text{W} \propto \sum Q$$

$$\oint dW = \oint dQ$$

$$W_{\text{work net}} = Q_{\text{net}}$$

In a cycle.

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

Only valid
for a cycle

(7)

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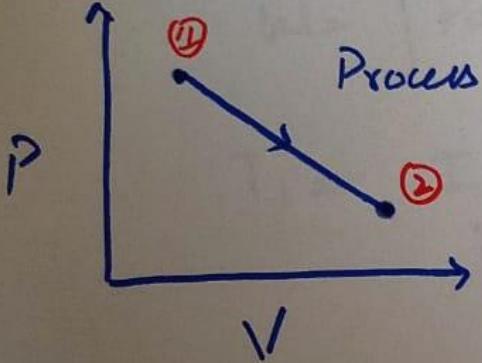
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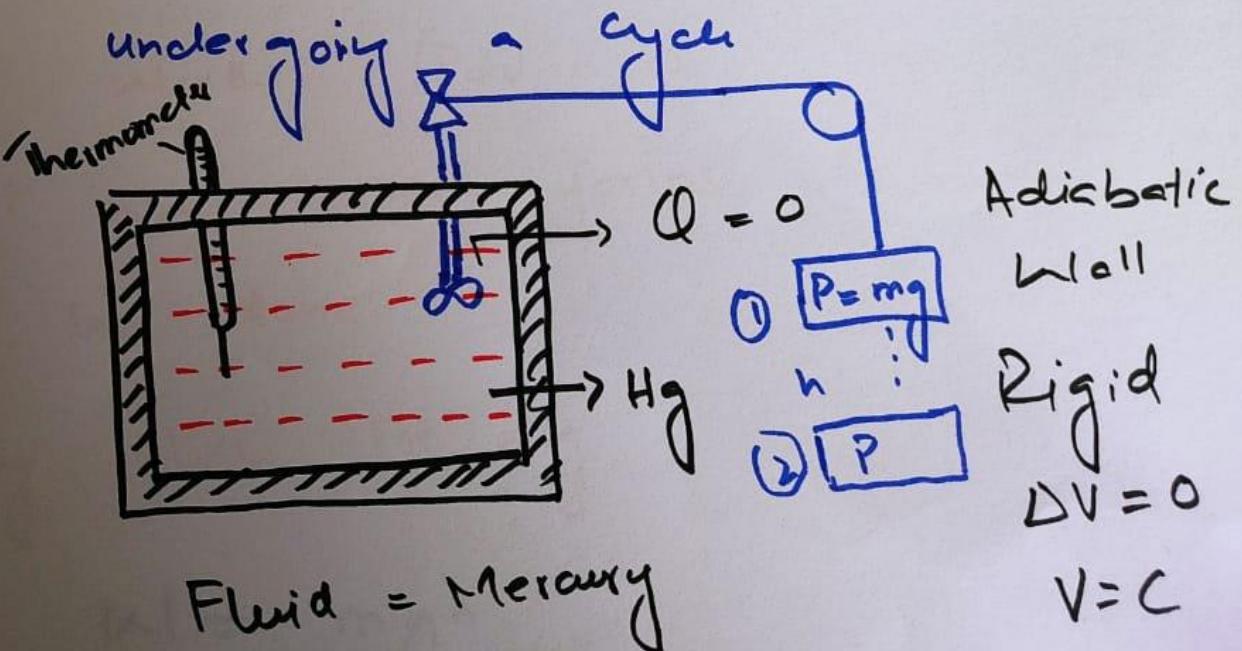


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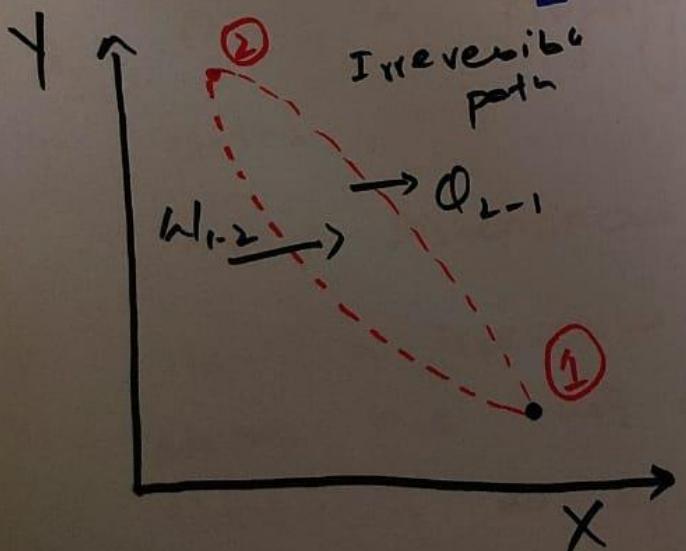
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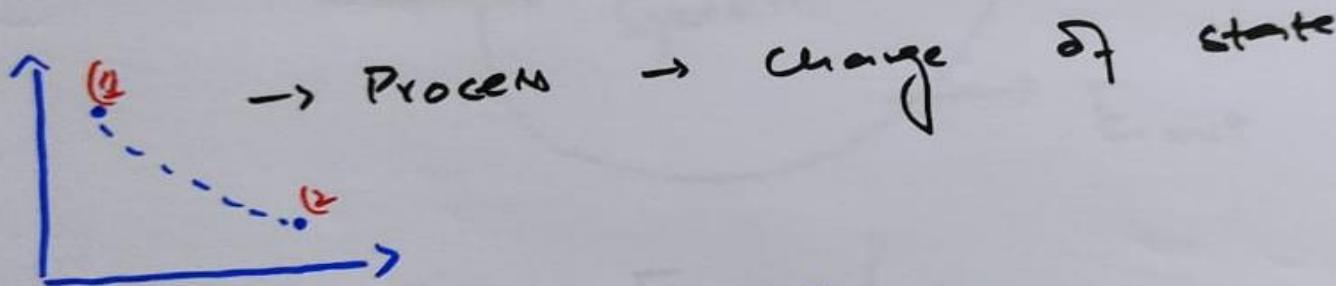
$$\boxed{\oint dW = \oint dQ}$$

Only valid
for a cycle

(7)

First law of thermodynamics for a closed system undergoing a process.

$$\oint dW = \oint dQ \rightarrow \text{cycle}$$

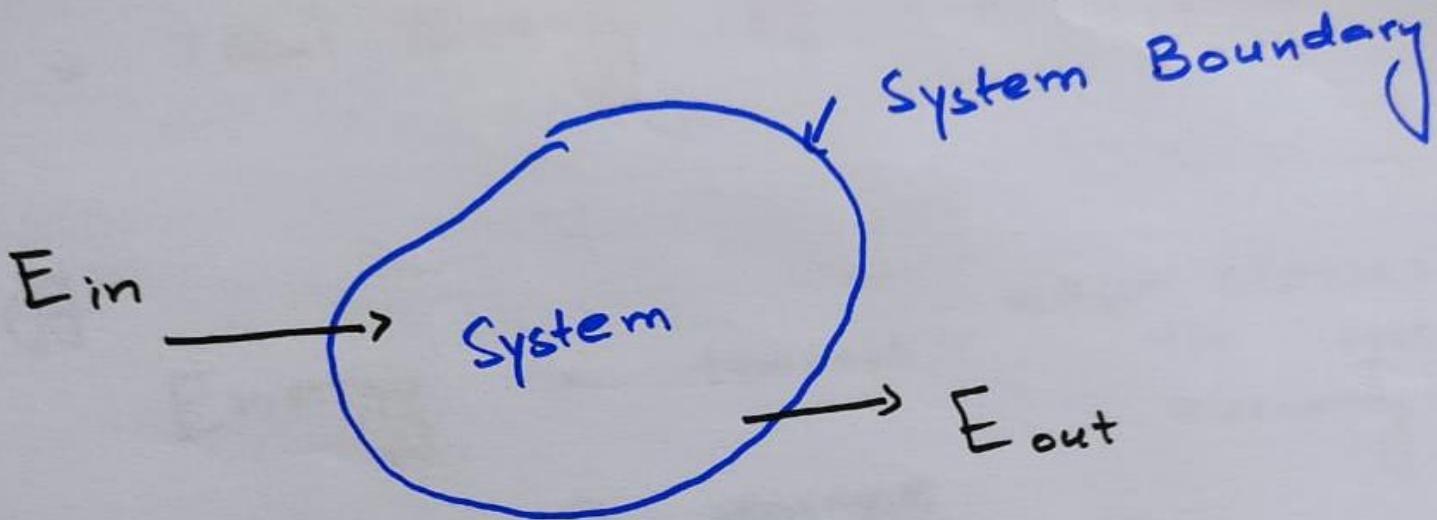


By Joule's Experiment: Conclusion

Work can ~~not~~ be completely converted to heat, but heat cannot be completely converted to heat.

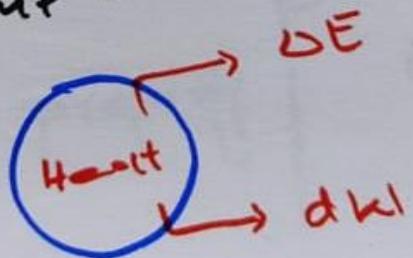
(e)

ENERGY BALANCE



$E_{in} > E_{out} ?$

$$E_{in} - E_{out} = \Delta E \leftarrow \begin{matrix} \text{Stored} \\ \text{Energy} \end{matrix}$$



(9)

$$\textcircled{Q}_{1-2} = W_{1-2} + \Delta E$$

ΔE = Total Energy of the system : Property

Energy:

Energy in transit \rightarrow which crosses the system's boundary

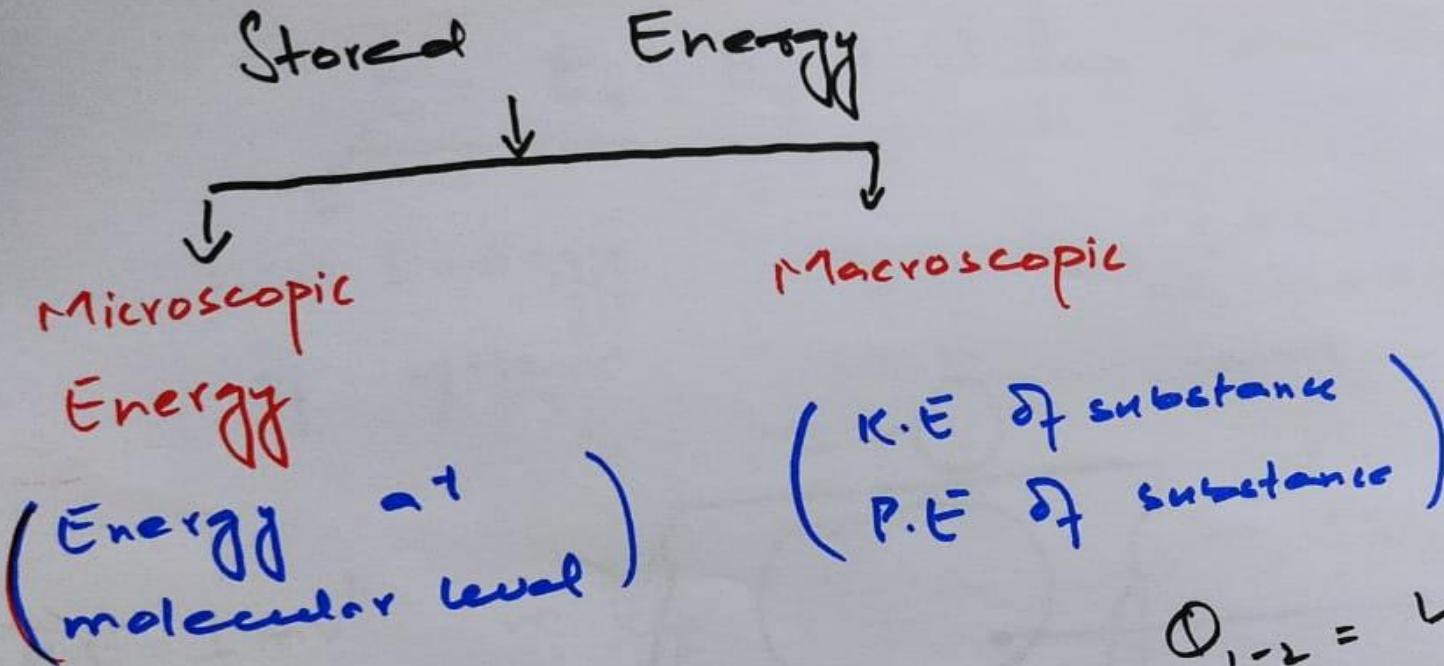
Energy of storage

- Path Functions
 - Inexact Differential
 - They are not property of system
- } Energies in transit

Heat

Work

(10)



* K.E exist in both
in microscopic stored
energies as well as
macroscopic stored
energies.

$$\Theta_{1-2} = \Delta U_{1-2} + \Delta E$$

↓ ↓
 Microscopic Macroscopic
 Internal
Energy

(11)

$$E = E_k + E_p + U$$

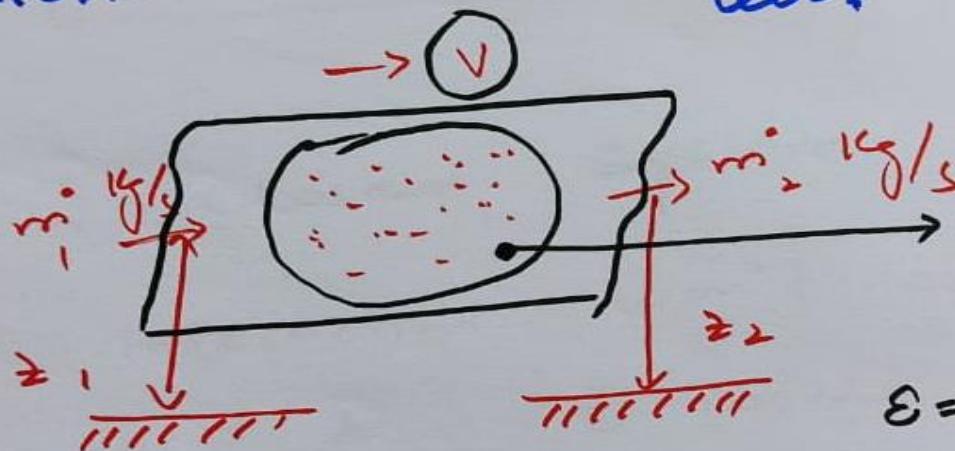
Total Energy of substance at molecular level

Total Energy of system

$$K.E = \frac{1}{2} m v^2$$

$$P.E = m g (z_2 - z_1)$$

if system's P.E & K.E are neglected



E = Energy of one molecule

$$\delta = E_{tran} + E_{rot} + E_{chem} + E_{electron} + E_{nuclear}$$

$$\boxed{\Delta E = \Delta U}$$

(12)

$$Q_{1-2} = W_{1-2} + \Delta E$$

In differential form

Process

$$dQ = dE + dW$$

→ This equation
is valid for
open as well
as closed system.

For a closed system

Mass interaction won't exist

K.E & P.E would be zero

So

So :-

$$\Rightarrow \Delta E = \Delta U$$

$$dQ = \Delta U + dW$$

For a closed system

(13)

if there are "N" number of molecules

$$U = N\epsilon$$

Internal energy
of the substance

so

$$\delta Q = dE + dw$$

Open & Closed ✓
system

↳ Reversible for well
as irreversible process

$$\delta Q = dU + dw$$

→ For a closed
System

U (For an Ideal gas)

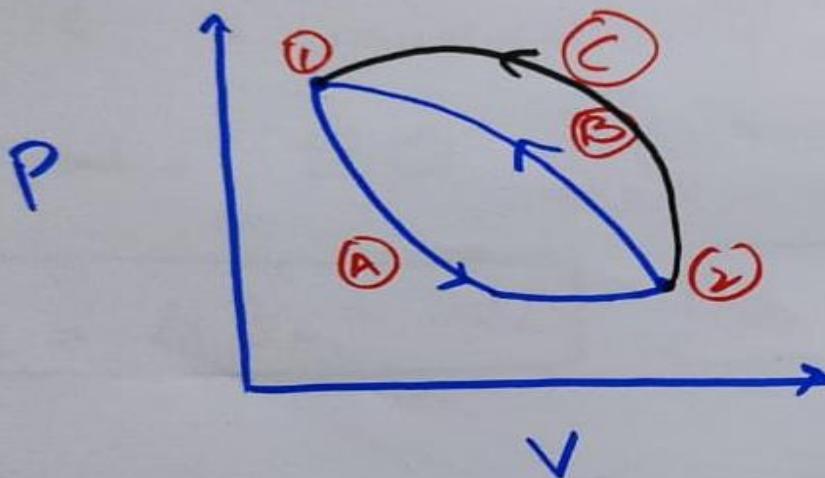
Internal Energy of an Ideal gas

$$U = f(T)$$

• (14)

Energy

property of system



A & B

$$Q_A = \Delta E_A + W_A \Rightarrow Q_A - W_A = \Delta E_A$$

$$Q_B - W_B = \Delta E_B \quad \sum W_i = \sum Q$$

$$W_A + W_B = Q_A + Q_B$$

$$Q_A - W_A = W_B - Q_B$$

(15)

$$\boxed{\Delta E_A = -\Delta E_B} \quad \text{①}$$

Process C is involved \because

A & C

$$\sum w = \sum Q$$

$$\boxed{Q_C = \Delta E_C + W_C}$$

$$\boxed{Q_C - W_C = \Delta E_C}$$

$$W_A + W_C = Q_A + Q_C$$

$$W_A - Q_A = Q_C - W_C$$

$$\boxed{\Delta E_A = -\Delta E_C} \quad \text{②}$$

① & ②

$$\boxed{\Delta E_B = +\Delta E_C} \quad \text{③}$$

(6)

$$\boxed{\Delta E_A = \Delta E_B = \Delta E_L}$$

It means whatever the path followed

b/w state ① & ②.

Change in total energy is coming
out to be same.

$$\text{Stored Energy} = E_K + E_P + U$$

A point function

Exact Differentiation

That's why it is the property of
a system.

For a closed system

$$\delta Q = dU + \delta W$$

it can be a sum of all types of works.

$$\delta W = \delta W_{PdV} + \delta W_{shear} + \delta W_{electric}$$

$$\delta W = \delta W_{PdV}$$

if all other types
of work are neglected
i.e. mechanical or electrical
work.

$$\boxed{\delta Q = dU + PdV}$$

Differential form of 1st law for
a closed system involving only PdV
work.

For an Isochoric Process

1st Law analysis

$$dQ = dU + PdV \quad V=C$$

$$\boxed{dQ = dU}$$

$$\boxed{Q_{1..2} = \Delta U}$$

Heat transfer is equal to change in internal energy for an isochoric process.

∴ Specific Internal Energy

Internal energy
of 1 kg of substance

U/kg of substance

$u \rightarrow \text{sp. Internal Energy}$
unit J/kg

$$\boxed{Q_{1-2} = \Delta U} \quad \text{KJ/kg or J/kg} \quad (\text{Isochoric Process})$$

Specific Heat at Constant Volume : C_V

Heat required to cause unit change in temperature in a unit quantity of substance at constant volume.

$$C_P > C_V$$

For constant volume process

$$\boxed{\delta Q = \Delta U} \quad \text{Change in specific internal energy}$$

$$C_V = \left(\frac{\partial U}{\partial T} \right)_V$$

$$(C_V = \frac{\partial U}{\partial T})_V$$

Heat required to cause a unit change in temperature.

(20)

$$dU = C_V dT$$

$$U_2 - U_1 = C_V (T_2 - T_1)$$

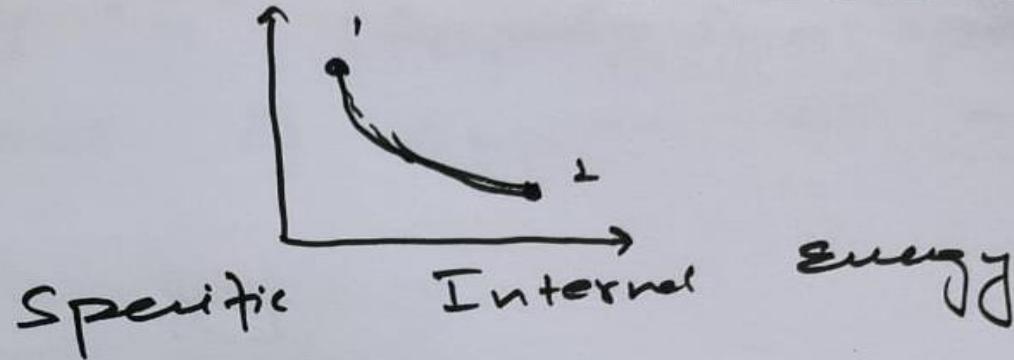
$$\boxed{\Delta U = C_V \Delta T}$$

For m kg of mass

$$\boxed{\Delta U = m C_V \Delta T}$$

$$\therefore \boxed{Q = \Delta U}$$

$$\boxed{Q = m C_V \Delta T}$$



For an Isochoric process

The formula for heat transfer

ENTHALPY "H" (Property of a system)

Total Heat content of a system at a particular state.

Unit KJ, J

For one kg of matter

Specific Enthalpy "h" J/kg, kJ/kg

$$H = U + PV \rightarrow \text{Flow Work}$$

For $\frac{\text{1kg}}{\text{of substance}}$

$$h = u + Pv \rightarrow \text{Flow Work per kg}$$

Heat transfer for an Isobaric process

For a closed system

$$dQ = du + dw$$

$$dw = dw_{PDU} + dw_{mech} + dw_{extern} \dots \dots$$

if no work other than PDU work

$$dQ = du + Pdv$$

Isobaric
Process

$$P = C$$

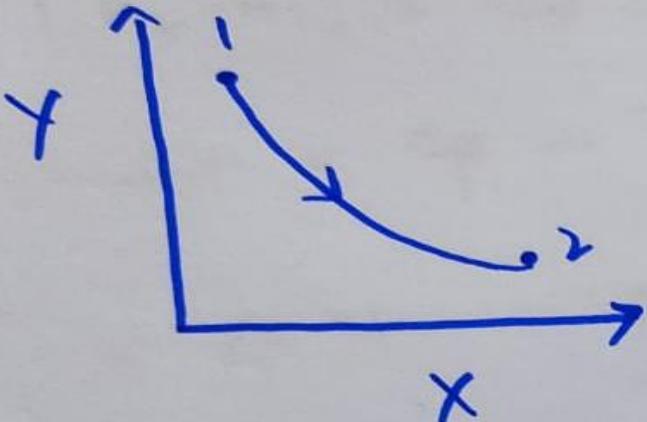
$$dQ = du + d(Pv)$$

$$\frac{dQ}{dQ} = \frac{d(ut + Pv)}{dQ}$$

$$\boxed{dQ = dh}$$

For one kg of
substance undergoing
a isobaric process
in a closed
system.

(23)



$$\dot{Q}_{12} = \Delta h$$

Heat transfer is equal
to change in enthalpy
for an isobaric process
in a closed system

Specific heat at constant pressure: c_p

Heat required to cause a unit change in temperature through a unit quantity of substance in a constant pressure process.

$$c_p = \left(\frac{dQ}{dT} \right)_P^{\text{Thy}}$$

$$c_p = \left(\frac{dh}{dT} \right)_P$$

$$dh = c_p dT \quad \int dh = \int c_p dT \quad (24)$$

$$(h_2 - h_1) = C_p \Delta T$$

$$\Delta h = C_p \Delta T$$

$$\boxed{\Delta H = m C_p \Delta T}$$

$$\delta Q = \Delta H$$

*For undergoing a closed system
undergoing a constant pressure process.*

$$\boxed{\delta Q = m C_p \Delta T}$$



(25)

Heat transfer formulas :-

Iso baric Process

$$\underline{Q = mcp \Delta T}$$

Iso chronic Process

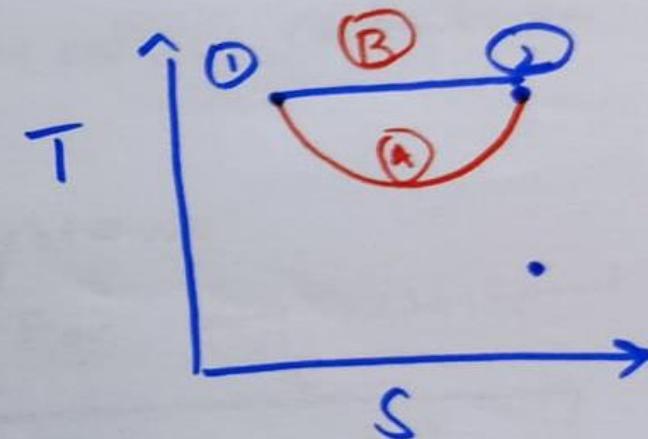
$$\underline{Q = mcu \Delta T}$$

Isothermal Process :-

$$\underline{\frac{1}{T} = C}$$

For an Ideal gas

$\underline{PV = C}$ \rightarrow Hyperbolic equation/ relationship



B is iso thermal

A is not iso thermal
P-path

(26)

$$PV = C$$

→ For ideal gas this relation only represents an Isothermal process.

→ But for pure substances or real gases this $PV = C$ is a hyperbolic relation.

$$\boxed{Q_{12} = \Delta U + W_{12}}$$

Closed system

For any isothermal process

Hence,

$$\boxed{W_{12} = Q_{12}}$$

$$T = C$$

$$\Delta T = 0$$

$$\Delta U = 0$$

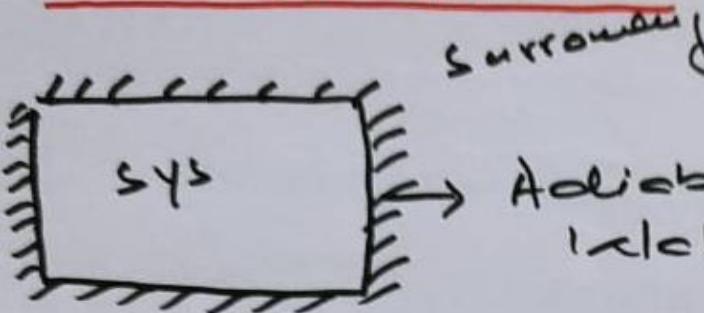
$$W_{12} = P_1 V_1 \ln \frac{V_2}{V_1} = Q_{12}$$

$$\text{or } P_1 V_1 \ln \frac{P_1}{P_2}$$

I same formula

(2)

Adiabatic Process



Adiabatic
Incll

In an adiabatic process if work transfer is taking place it will change the internal energy of the system only.

$$Q_{1 \rightarrow 2} = \Delta U + W_{1 \rightarrow 2}$$

$$Q_{1 \rightarrow 2} = 0 \quad \text{Adiabatic}$$

$$0 = \Delta U + W_{1 \rightarrow 2}$$

$$\boxed{\Delta U = -W_{1 \rightarrow 2}}$$

$$W_{1 \rightarrow 2} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$\gamma = C_p / C_v$$

(28)

Heat transfer formulas :-

Isobaric Process

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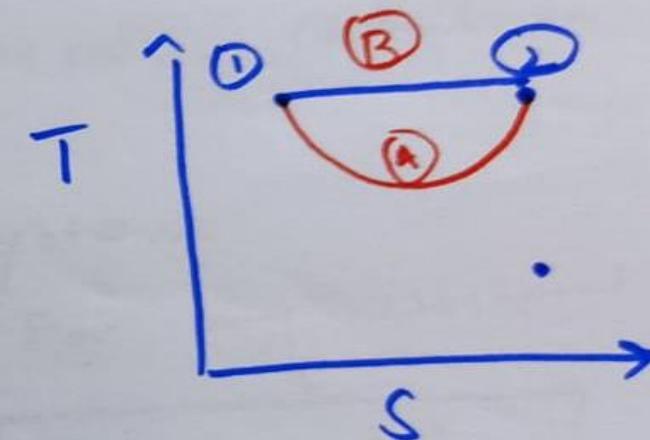
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Closed system

For any isothermal process

$$\boxed{\Delta U = mc_v \Delta T}$$

Hence,

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$$T = C$$

$$\Delta T = 0$$

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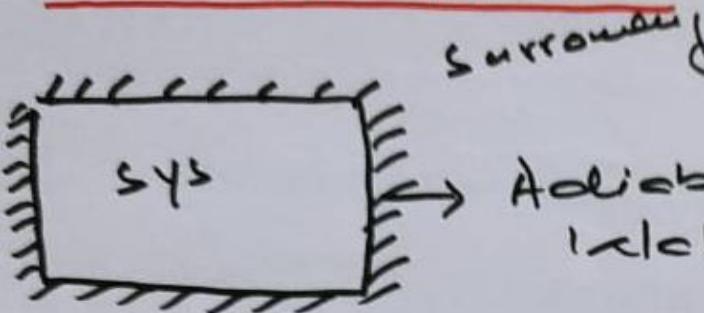
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$$\gamma = C_p / C_v$$

(28)

Energy of an Isolated System

$$dQ = dE + dW$$

Perfectly insulated
 $dQ = 0 \Rightarrow dW = 0$

$$0 = dE + 0$$

$$dE = 0$$

No change in
total energy of
the system

For an isolated system

there is no change in total energy
of system.

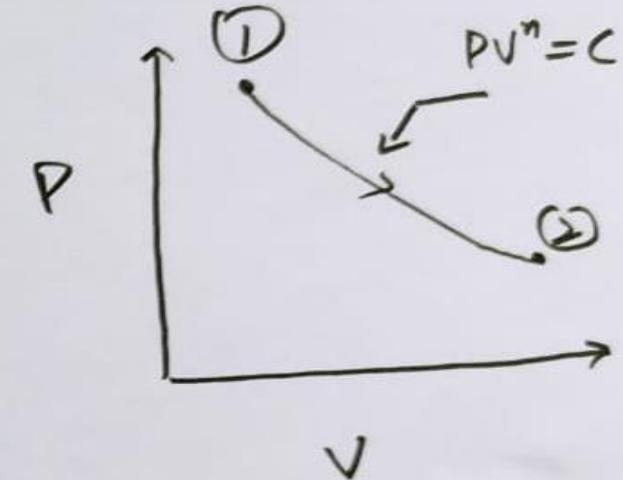
$$\boxed{\underline{E = \text{constant}}}$$

(2)

Heat Transfer in a Polytropic Process

Closed system →

$$Q_{12} = \Delta U + W_{12}$$



$$Q_{1-2} = m c_v (T_2 - T_1) + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$c_v = \frac{R}{\gamma - 1}$$

$$Q_{1-2} = \frac{m R (T_2 - T_1)}{\gamma - 1} + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

(Ans)

for
an ideal
gas

$$PV = mRT$$

$$Q_{12} = \frac{P_2 V_2 - P_1 V_1}{r-1} + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$mRT = PV$$

$$mR(T_2 - T_1) = P_2 V_2 - P_1 V_1$$

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

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

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

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

$$Q_{1-2} = \left(\frac{P_1 V_1 - P_2 V_2}{n-1} \right) \left(\frac{r-n}{r-1} \right)$$

(3)

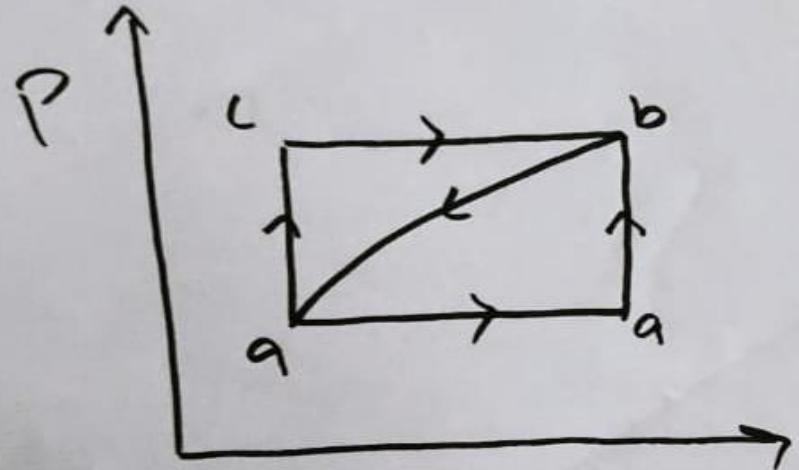
$$\dot{Q}_{1-2} = W_{1-2} \left(\frac{r-n}{r-1} \right)$$

$$\boxed{\dot{Q}_{\text{poly}} = k_{\text{poly}} \left(\frac{r-n}{r-1} \right)}$$

Relationship b/w
heat transfer
↔ work transfer
in a polytropic
process

(32)

Problems..



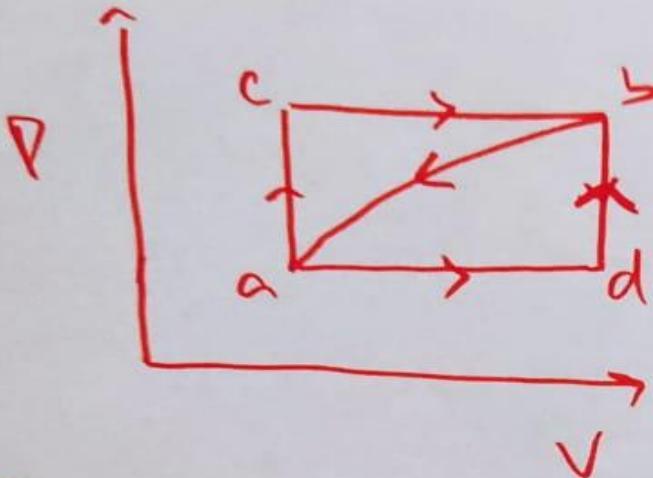
When a system is taken from state "a" to state "b" along path "acb", Q = 1 KJ of heat flows into the system and system does 32 KJ of work.

- 1) How much will the heat flow into the system along path "adb" if the work done is 10.5 KJ.

(33)



Solution:-



For Process acb

$$Q = 84 \text{ KJ} \quad W = 32 \text{ KJ}$$

$$Q_{acb} = \Delta U + W_{acb}$$

$$84 = \Delta U + 32$$

$$\begin{aligned}\Delta U &= 84 - 32 \\ \boxed{\Delta U} &= 52 \text{ KJ}\end{aligned}$$

$\therefore U$ = Point function
Property of the system

(34)

Irrespective of the path followed
Internal energy would be same.

1) Path ad b

$$Q_{ad\text{b}} = \Delta U + k_1 \text{ad} b$$

$$Q_{ad\text{b}} = ?$$

$$\Delta U = 52 \text{ KJ}$$

$$k_1 \text{ad} b = 10.5 \text{ KJ}$$

$$= 52 + 10.5$$

$$\boxed{Q_{ad\text{b}} = 62.5 \text{ KJ}}$$

(35)

(2) When system returns from $b \rightarrow a$ following the curved path work done on the system is -21 KJ . Does the system absorbs or liberates heat?

Solution:

For $b \rightarrow a$

$$Q_{ba} = \Delta U + W_{ba}$$

$$Q_{ba} = -52 - 21$$

$$\boxed{Q_{ba} = -73 \text{ KJ}}$$

(3b)

\therefore ON THE
system
from $b \rightarrow a$

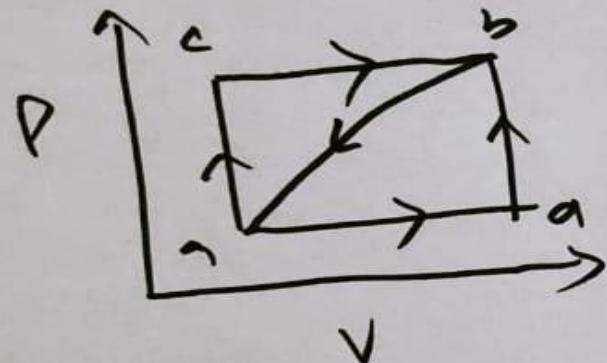
$$\Delta U = -52 \text{ KJ}$$

$$\begin{aligned} b \rightarrow a &= U_b - U_a \\ \Delta U &= 52 \text{ KJ} \end{aligned}$$

Liberates
heat.

$$\begin{aligned} a \rightarrow b &= U_a - U_b \\ \Delta U &= -52 \text{ KJ} \end{aligned}$$

(3) If $U_A = 0$ Find heat absorbed
 $U_B = 42 \text{ KJ}$ in process db



$$Q_{ad\ b} = 62.5 \text{ KJ}$$

$$Q_{d\ b} = ?$$

$$Q_{ad\ b} = Q_{ad} + Q_{d\ b}$$

$$Q_{ad} = ?$$

$$Q_{db} = Q_{ad\ b} - Q_{ad}$$

$$Q_{ad} = \Delta U_{ad} + W_{ad}$$

$$\Delta U_{ad} = U_d - U_b = 42 - 0 = 42 \text{ KJ}$$

$$W_{ad} = ?$$

$$W_{ad} = W_{ad} + k_{b\ b}$$

(37)

$$k_{ads} = 10.5 \text{ KJ}$$

$$k_{ads} = 0 \quad V = C$$

$$W_{ads} = W_{ad} + k_{ads}^0$$

$$\boxed{W_{ad} = 10.5 \text{ KJ}}$$

$$Q_{ad} = 42 + 10.5$$

$$\boxed{Q_{ad} = 52.5 \text{ KJ}}$$

(30)

$$Q_{ab} = Q_{ab} - Q_{ad}$$

$$= 62.5 - 52.5$$

$$\boxed{Q_{ab} = 10 \text{ KJ}}$$

Problem A fluid is confined in a cylinder by a spring loaded friction less piston so that the pressure in the fluid is a linear function of volume

$$P = a + bV$$

The internal energy of fluid is given by

$$U = 34 + 3.15 PV$$

U is in KJ, P is kPa

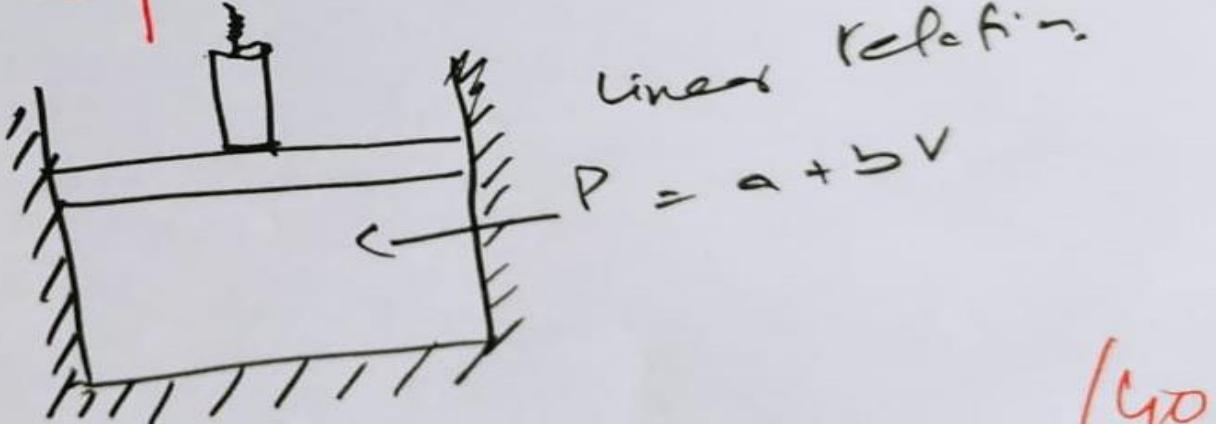
U is in m^3

(B)

if charge in initial state of 170 kPa,
0.03 m³ ~~is~~ to a final state of 400 kPa,
0.06 m³ with no work other than that
done by piston.

Find the direction & magnitude
of net force.

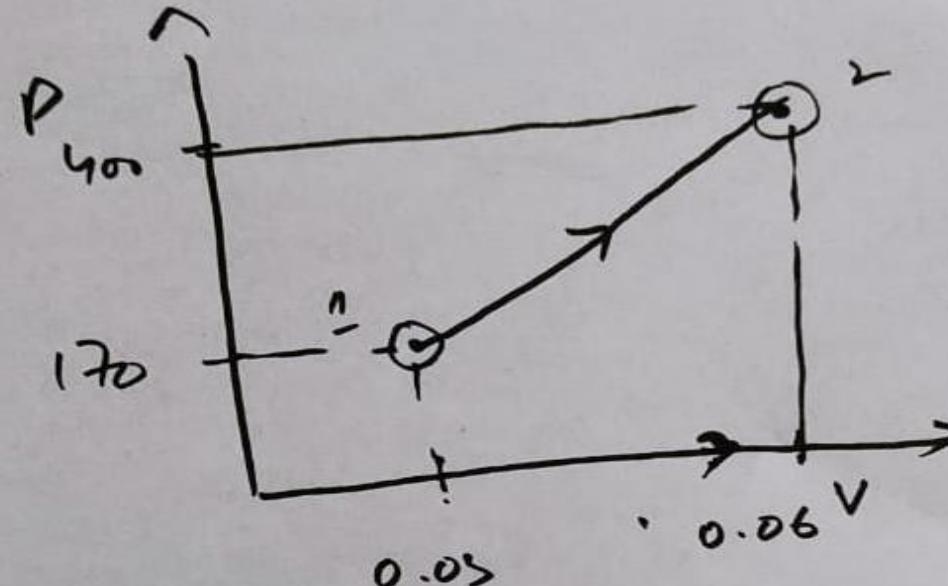
$$\begin{aligned}P_1 &= 170 \text{ kPa} \\V_1 &= 0.03 \text{ m}^3 \\P_2 &= 400 \text{ kPa} \\V_2 &= 0.06 \text{ m}^3\end{aligned}$$



$$Q_{1-2} = \Delta U + W_{1-2}$$

$$\Delta U = ?$$

$$W_{1-2} = ?$$



(4)

$$\Delta U = U_2 - U_1$$

$$U = 34 + 3.15 PV$$

$$U_1 = 34 + 3.15 P_1 V_1$$

$$U_2 = 34 + 3.15 P_2 V_2 = 3.15 (P_2 V_2 - P_1 V_1)$$

$$= 34 + 3.15 (P_2 V_2)$$

$$- 34 - 3.15 (P_1 V_1)$$

$$= 3 \cdot 15 (400(0.06) - 170(0.03))$$

$$\boxed{\Delta U = 59.346 \text{ kJ}}$$

(42)

$$W_{1-2} = ?$$

$$W_{1-2} = \int_{V_1}^{V_2} P dV$$

$$P = a + bV$$

$$P_1 = a + bV_1$$

$$P_2 = a + bV_2$$

$$P_1 = a + b \frac{0.03}{0.06}$$

$$P_2 = a + 0.06 b$$

$$170 = a + 0.03b$$

$$400 = a + 0.06b$$

$$b = 7667 \text{ kPa} \quad a = -60 \text{ kPa}$$

$$W_{1-2} = 8.55 \text{ kJ}$$

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$Q_{1-2} = 59.346$$

$$+ 8.55$$

$$\underline{\underline{Q_{1-2} = 67.896 \text{ kJ}}}$$

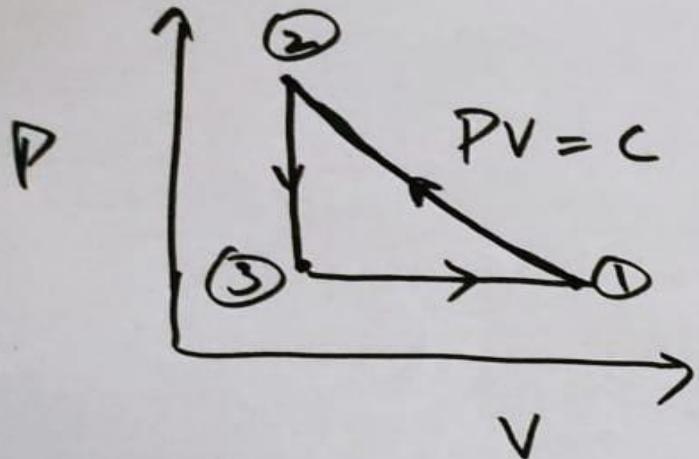
+ve value
Heat is being added
into the system.

(43)

Problem

A gas undergoes a thermodynamic cycle consisting of the process beginning at an initial state where $P_1 = 1 \text{ bar}$, $V_1 = 1.5 \text{ m}^3$ and $T_1 = 512 \text{ K}$. The processes are as follows.

- ① Process 1-2 compression with $PV = \text{constant}$
 $P_2 = 2 \text{ bar}$ $T_2 = 690 \text{ K}$
- ② Process 2-3 $\Delta U_{23} = 0$, $Q_{23} = -150 \text{ kJ}$ (44)
- ③ Process 3-1 $\Delta U_{31} = +50 \text{ kJ}$ Neglecting
KE & PE changes. Determine heat input Q_{12} & Q_{31} ?



$$\boxed{PV = C}$$

$$W_{1 \rightarrow 2} = P_1 V_1 \ln \frac{V_2}{V_1}$$

or

$$= P_1 V_1 \ln \frac{P_1}{P_2}$$

Is it Isothermal
process?

$$\Delta U = 0$$

$$T = C$$

For Isothermal
in an ideal
gas.

$$\boxed{Q_{1 \rightarrow 2} = W_{1 \rightarrow 2}}$$

an isothermal

(45)

So it is not always necessary
that $\boxed{PV = C}$ would mean
process.

Here it represents a hyperbolic relation

$$\Delta U = P_1 V_1 \ln \frac{V_2}{V_1} \quad \text{or} \quad P_1 V_1 \ln \frac{P_1}{P_2}$$

$$Q_{1-2} = \Delta U + \Delta H_{1-2}$$

$$P_1 = 1 \text{ bar} = 100 \text{ kPa}$$

$$P_2 = 2 \text{ bar} = 200 \text{ kPa}$$

$$U_1 = 512 \text{ KJ}$$

$$U_2 = 690 \text{ KJ}$$

$$V_1 = 1.5 \text{ m}^3$$

$$\Delta H_{1-2} = P_1 V_1 \ln \frac{P_1}{P_2}$$

$$= 100 (1.5) \ln \frac{100}{200}$$

$$\boxed{\Delta H_{1-2} = -103.97 \text{ KJ}}$$

(46)

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$= (U_2 - U_1) \rightarrow 103.97$$

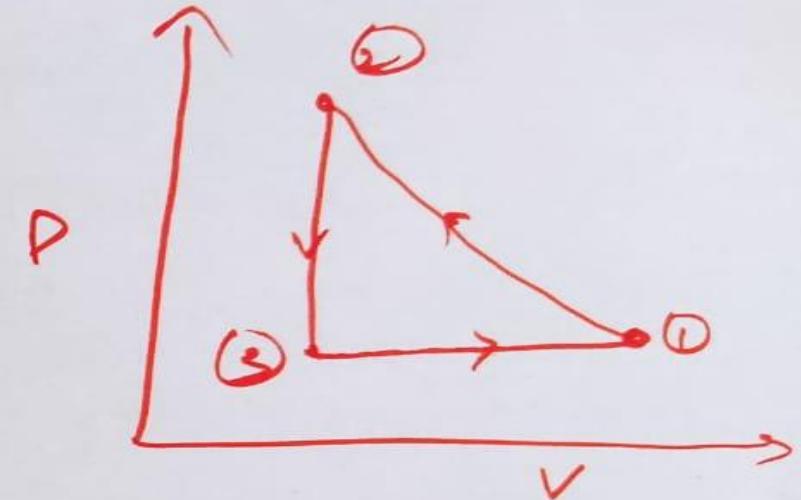
$$= (690 - 512) - 103.97$$

$$\boxed{Q_{1-2} = 74.03 \text{ kJ}}$$

$$\Delta U = U_1 - U_3$$

$$U_1 = 512 \text{ kJ}$$

$$Q_{31} = ?$$



$$Q_{31} = \Delta U + W_{31}$$

$$U_3 = ?$$

(47)

For Process 2-3
 $\Delta U_{23} = 0$

$$Q_{23} = -150 \text{ KJ}$$

$$Q_{23} = \Delta U + \cancel{W_{23}}$$

$$\Delta U = -150 \text{ KJ}$$

$$U_3 - U_2 = -150 \text{ KJ}$$

$$\begin{aligned} U_3 &= -150 + 690 \text{ KJ} \\ U_3 &= 540 \text{ KJ} \end{aligned}$$

(CB)

$$Q_{34} = \Delta U + \cancel{W_{34}}$$

$$\begin{aligned} \Delta U &= U_4 - U_3 \\ &= 512 - 540 \\ \Delta U &= -28 \text{ KJ} \end{aligned}$$

$$W_{31} = +50 \text{ KJ}$$

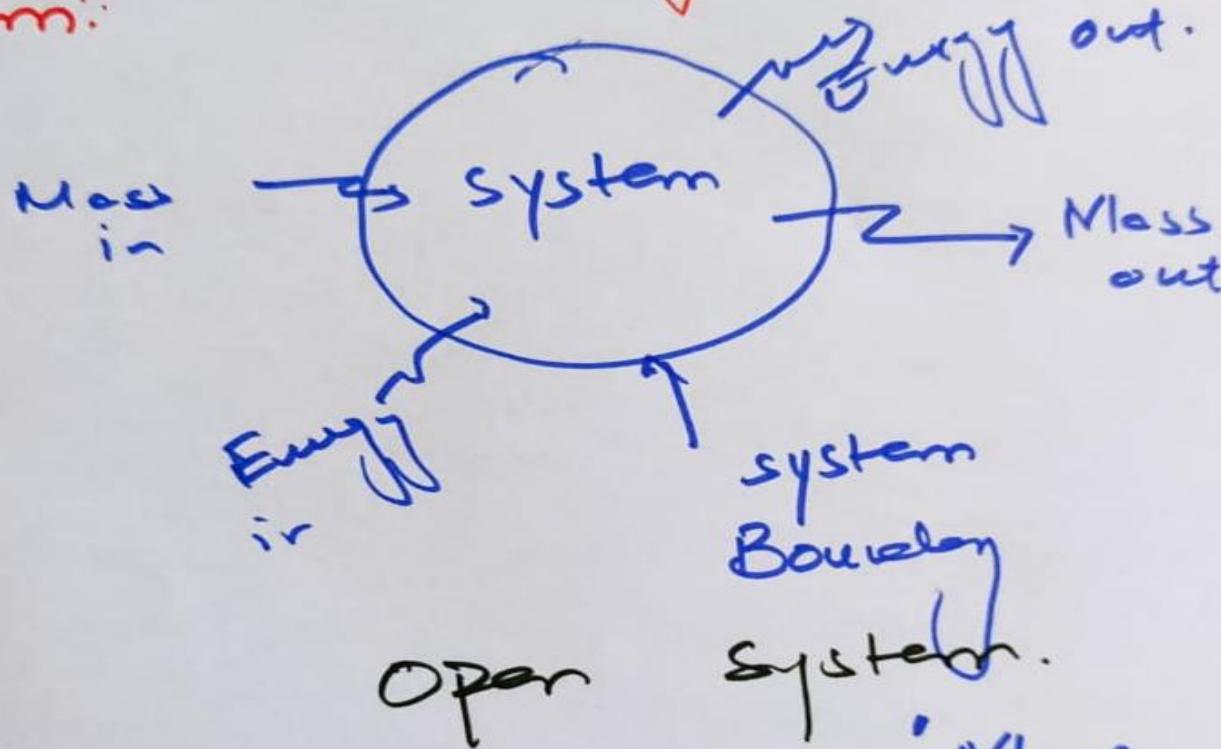
$$Q_{31} = -28 + 50$$

$$\boxed{Q_{31} = 22 \text{ KJ}}$$

(49)

1st Law for Open Systems

First Law of thermodynamics for Open system:



Open system.

Rate of Mass transfer

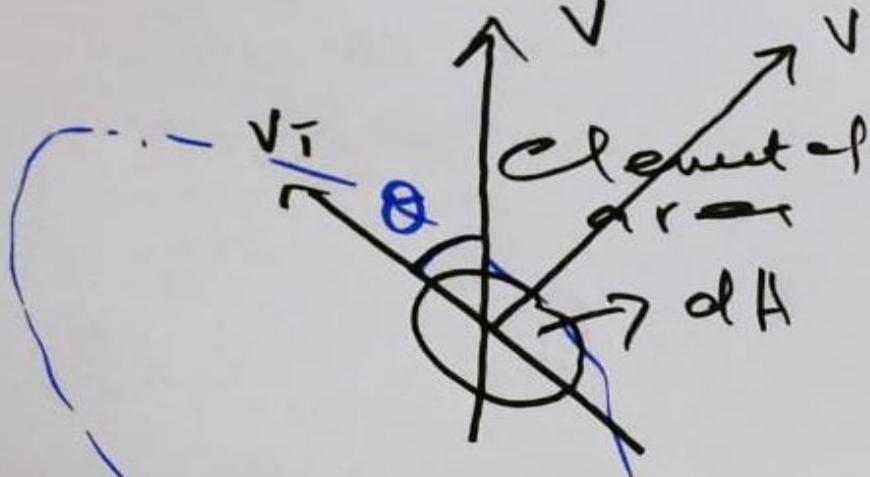
Rate of Energy transfer

"Mass Flow rate"

(1)

Mass Flow rate:-

Amount of mass flowing through
a section per unit time.



v_n = Normal component
of velocity

$$dm = \rho \times v_n \times dA$$

Work transfer
Heat transfer
Mass transfer

Path 1 mass flow rate
is an inexact
function diff erential.

$$\int_{m_1}^{m_2} dm = ? \times$$

Mass Flow Rate
is \propto Path
function. (2)

$$\Rightarrow \int dm = \int \rho V_n dA$$

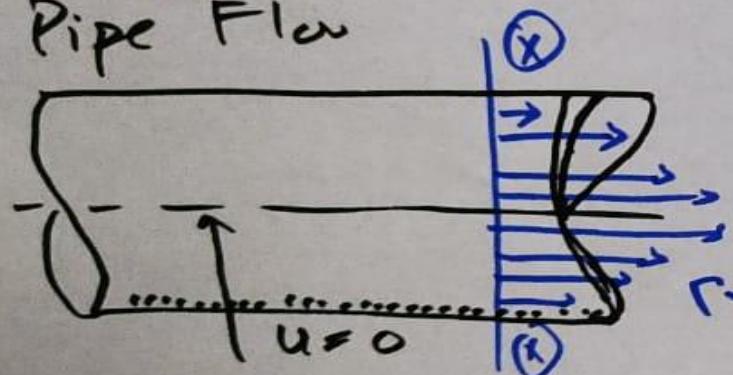
$$\boxed{\dot{m} = \int \rho V_n dA}$$

Valid for

Incompressible / Compressible Fluids.

V_n = Velocity
normal to the
plane.

e.g Pipe Flow



At wall of Pipe velocity $u=0$

u is maximum at center.

velocity Distribution
velocity Profile.

3

$$V_{avg} = \frac{1}{A} \int V_n dA$$

$$\boxed{\dot{m} = \rho V_{avg} A}$$

$$\boxed{\dot{m} = \rho A V_{avg}}$$

$$V = V_{avg}$$

$$kg/s$$

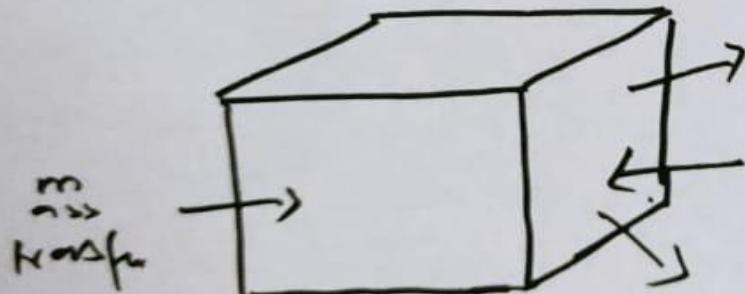
Open System : Control Volume Approach.

Also known as

Eulerian Approach in Fluid Mechanics

Closed System : Control Mass Approach

Also called as Lagrangian approach
in Fluid Mechanics



control
surfaces

mass cannot be created
or destroyed

Conservation
of mass

e.g. 1kg of water 1kg of steam
only change one form to other (4)

Conservation of mass

(Mathematically)



$min > mout$?

Δm_{cv}
= mass
accumulated

$$min - mout = \Delta m_{cv}$$

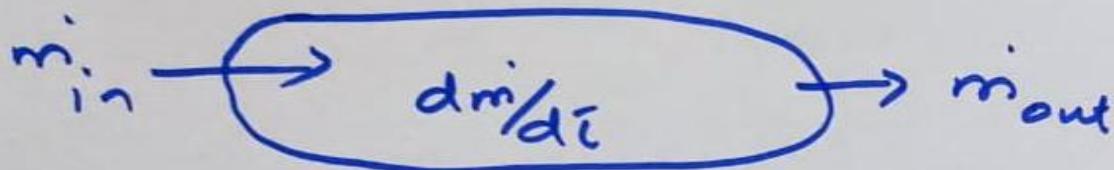
Time Rte \bullet
$$\frac{min - mout}{\Delta t} = \frac{dm}{dt}$$

Δt = time interval.

$\frac{dm}{dt}$ = Rate of mass accumulation

(5)

For Steady Flow



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

Rt_c of accumulation

$$= 0$$

Meaning:

Mass accumulated within the system
with respect to time will remain
constant

$$\dot{m}_{cv} = \text{constant}$$

(6)

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

Conservation of mass For Steady Flow

$$\underline{\underline{m_{in} - m_{out} = 0}}$$

$$\underline{\underline{m_{in} = m_{out}}}$$

$$\boxed{pA_1v_1 = pA_2v_2}$$

Continuity Equation

Valid for compressible as well as incompressible fluids.

Mass Balance

$$\boxed{\dot{m}_{in} - \dot{m}_{out} = \frac{dm}{dt}}$$

Unsteady Flow

Mass Balance

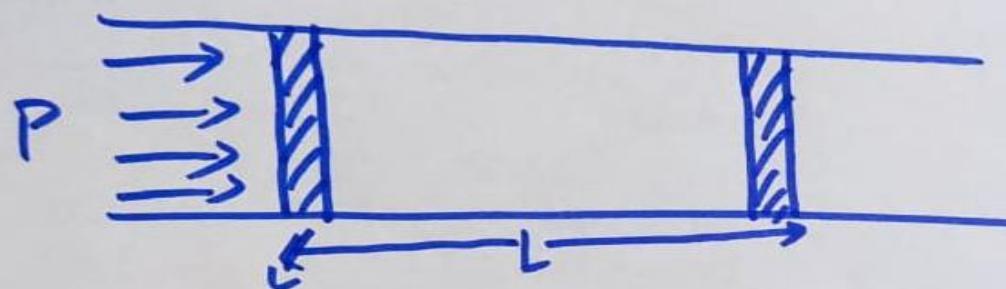
$$\boxed{\dot{m}_{in} = \dot{m}_{out}}$$

Steady Flow

(7)

Flow Work:- Work Required to maintain the flow

Consider a passage



$A \times l$
A Element
l to P

$$W = F \times \text{displacement} \\ = P \times A \times l$$

$$\boxed{W = PV}$$

(8)

Total Energy:-

$$E = \text{Internal Energy} + \text{Kinetic Energy} + \text{Potential Energy}$$

$$\underline{E = U + \frac{1}{2}mv^2 + mgh} \quad \text{KJ / J}$$

Specific Total Energy :-

$$E_s = \frac{U}{m} + \frac{1}{2} \frac{mv^2}{m} + \frac{mgh}{m}$$

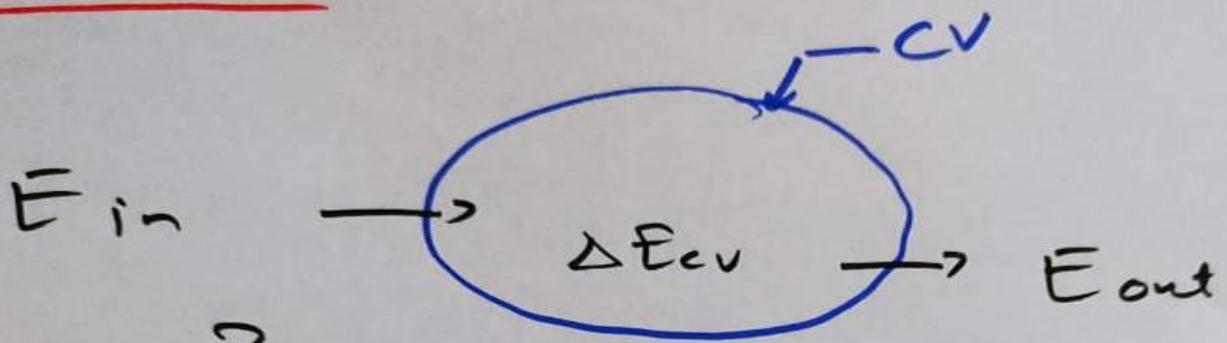
$$\boxed{e = u + \frac{1}{2}v^2 + gh} \quad \text{KJ/kg, J/kg}$$

Energy Balance:-

PTO

(9)

Energy Balance



$E_{in} > E_{out}$?

$$E_{in} - E_{out} = \Delta E_{cv}$$

ΔE_{cv} = Energy
Accumulated
inside the
control volume.

Time Rate:-

$$\frac{E_{in} - E_{out}}{dt} = \frac{dE}{dt}$$

(10)

For Steady Flow

ΔE_{cv} = Constant

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

$$E_{in} - E_{out} = 0$$

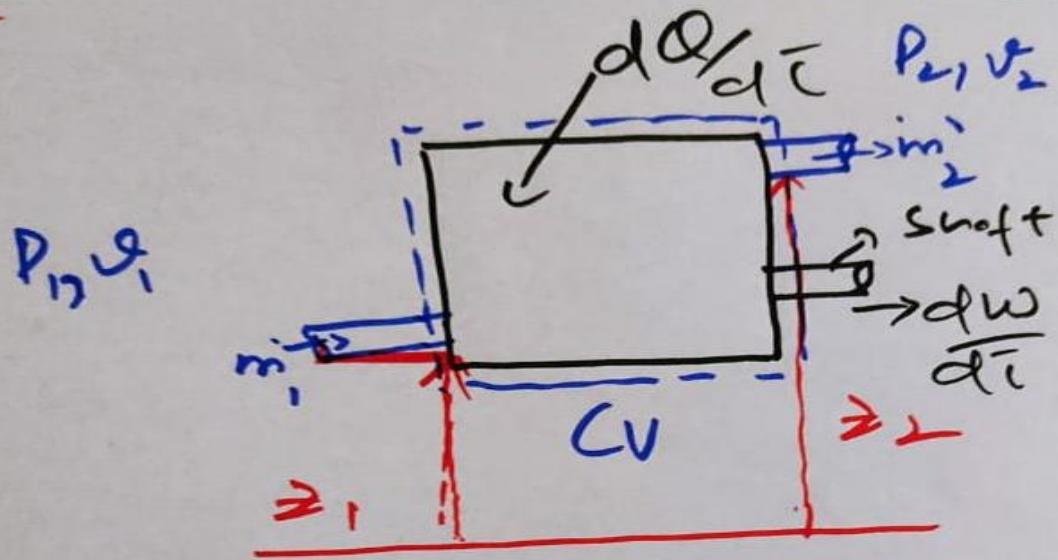
$$E_{in} = E_{out}$$

Steady
Flow

Now to derive t_u
SF EE

(ii)

SFEE



Steady Flow Equilibrium

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

NO mass
in every
accumulation

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

In a steady flow system there are two types of work transfer

→ External Work → Shaft Work

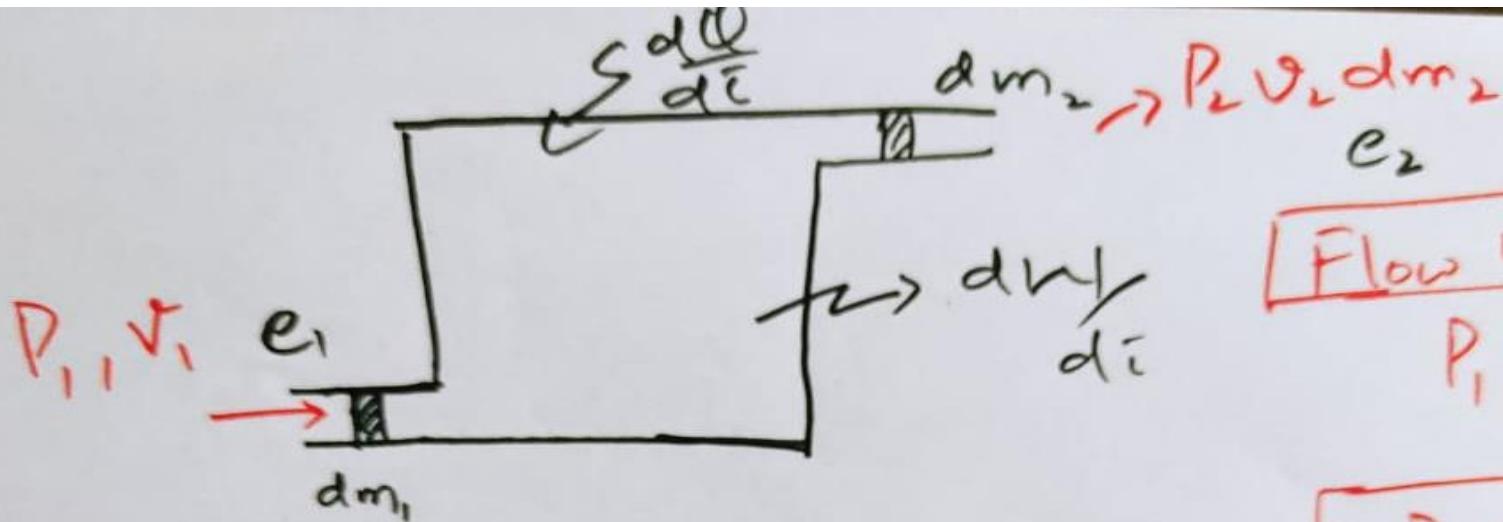
Electric

Work

→ Flow Work

(12)

(B)



Flow work per unit mass

Total work transfer

Flow work $P_1 V_1 dm_1$

$$W = W_{ext} - P_1 V_1 dm_1 + P_2 V_2 dm_2$$

External work

Work added
into the
system

Work done
by the
system

Time Rate

$$\frac{dW}{dt} = \frac{dW_{ext}}{dt} - \frac{P_1 V_1 dm_1}{dt} + \frac{P_2 V_2 dm_2}{dt}$$

$$\frac{dm_1}{dt} = \text{Inlet mass Flow Rate} = m_i$$

$$\frac{dm_2}{dt} = \text{Outlet mass Flow rate} = m_i$$

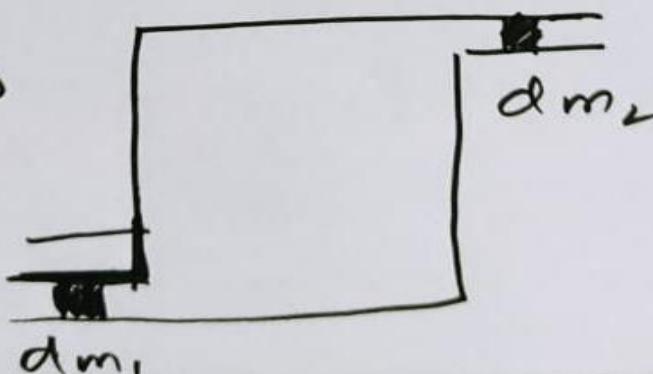
$$\frac{dw}{dt} = \left(\frac{dh_{in}}{dt} \right) - P_1 g_1 m_i + P_2 g_2 m_i$$

Rate of work transfer (Inert + Work)

External Rate of work transfer

$$P_2, g_2, e_2$$

c_i = specific total energy
 P_1, g_1, e_1



(14)

$$m_1 e_1 + \frac{dQ}{dt} = m_1 c_2 \frac{dw}{dt}$$

$$\boxed{e_1 = u + \frac{1}{2} v^2 + gz}$$

$$m_1 \left(u_1 + \frac{v_1^2}{2} + gz_1 \right) + \frac{dQ}{dt}$$

$$= m_2 \left(u_2 + \frac{v_2^2}{2} + gz_2 \right) + \frac{dw}{dt}$$

$$m_1 \left(u_1 + \frac{v_1^2}{2} + gz_1 \right) + \frac{dQ}{dt} = m_2 \left(u_2 + \frac{v_2^2}{2} + gz_2 \right) + \frac{dw}{dt} - P_1 v_1 m_1 + P_2 v_2 m_2 \quad (15)$$

$$m_1 \left(u_1 + \frac{v_1^2}{2} + g z_1 \right) + \frac{dQ}{dt} = m_2 \left(u_2 + \frac{v_2^2}{2} + g z_2 \right) + \frac{dW_x}{dt}$$

$$- P_1 v_1 m_1 + P_2 v_2 m_2$$

$$m_1 \left(h_1 + \frac{v_1^2}{2} + g z_1 + P_1 v_1 \right) + \frac{dQ}{dt} = m_2 \left(h_2 + \frac{v_2^2}{2} + g z_2 + P_2 v_2 \right)$$

$$h = u + Pv$$

$\frac{dW_x}{dt}$ → External Work per unit time.

$$\frac{m_1 (h_1 + \frac{v_1^2}{2} + g z_1) + \frac{dQ}{dt}}{\text{Time}_1} = m_2 (h_2 + g z_2 + \frac{P_2 v_2 \text{time}}{2}) \frac{dW_x}{dt}$$

Steady Flow

$$m_1 = m_2$$

(16)

$m_1 = m_2 = m = \frac{dm}{dt} \therefore$ Steady Flow
SFEE on time basis

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

Dividing by $\frac{dm}{dt}$ we get only $\left\{ + \frac{dk_{hx}}{dt} \right\}$

$$h_1 + \frac{v_1^2}{2} + g z_1 + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2} + g z_2 + \frac{dk_{hx}}{dm}$$

$\frac{dQ}{dm}$ $\frac{K_{IJ}}{Ig} \cdot \frac{J}{Ig}$ SFEE on mass basis (17)
 $\frac{dw}{dm}$ $\frac{K_{IJ}}{Ig} \cdot \frac{J}{Ig}$

Bernoulli Equation is a special case of SFEE.

Bernoulli Equation, SFEE

Valid for only
Incompressible
Fluids

Valid for
Incompressible &
compressible
Fluids.

SFEE \rightarrow First law of thermodynamics
for open system. (18)

Problems

09/12/2020

Question 1

Air at a pressure of P_1 and temperature of $25^\circ C$ is contained in a gas tight frictionless piston cylinder device. The initial volume that the air occupies at the initial state is $V_1 = 0.8 \text{ m}^3$. In an isochoric process the air is heated up to 500 K . If the mass of air in the cylinder is 5.2 kg (assume $R_{\text{air}} = 0.287 \text{ kJ/kg.K}$).

- A) Calculate the initial pressure, P_1 (Answer: 5.56 bar)
- B) Calculate the final pressure, P_2 (Answer: 9.33 bar)
- C) Find the work done in the process (Answer: 0 Joule)

Question 2

In a piston/cylinder device during a polytropic process, piston load is increased at such a rate that the gas compresses according to the relationship:

$$PV^{1.2} = \text{constant}$$

At the end of the process the final temperature of the gas is 400°C .

The initial state of the gas is

$$P_1 = 400 \text{ kPa}$$

$$T_1 = 110^{\circ}\text{C}$$

$$V_1 = 0.3 \text{ m}^3$$

Determine the work done during the process.

Question 3

A gas undergoes two processes. First: constant volume @ 0.200 m^3 , isochoric. Pressure increases from $2.00 \times 10^5 \text{ Pa}$ to $5.00 \times 10^5 \text{ Pa}$. Second: Constant pressure @ $5.00 \times 10^5 \text{ Pa}$, isobaric. Volume compressed from 0.200 m^3 to 0.120 m^3 .

- A) Show both processes in a pV diagram:
- B) Calculate the work done during both the processes and the total work

(Answer: 0 Joule, $-4 \times 10^4 \text{ Joule}$, $-4 \times 10^4 \text{ Joule}$)

Question 1

A household fridge with a COP of 1.4 removes heat from the fridge space at a rate of 85 kJ/min.

- (a) Sketch the basic components of a refrigeration system.
- (b) Calculate the electric power consumed by the fridge.
- (c) Calculate the rate of heat transfer to the kitchen air.

Anws b) 60.7 kJ/min, c) 145.7 kJ/min

Question 2

A household fridge that has a power input of 450W and a COP of 2.5 is to cool five large water melons, 10kg each to 8°C. If the watermelons are initially at 20°C determine how long it will take for the fridge to cool them? The watermelons can be treated as water whose specific heat is 4.2 kJ/kg.K.

Answer: 37.3 min

Question 3

An inventor claims to have developed a heat engine that receives 700kJ of heat from a source at 500K and produces 300kJ of net work while rejecting the waste heat to a sink at 290K? Is this a reasonable claim?

Answer: False

Question 4

A geothermal power plant uses geothermal water extracted at 160°C at a rate of 440kg/s as the heat source and produces 22MW of net power. If the environment temperature is 25°C , determine:

$$\left. \begin{array}{l} T_{\text{source}} = 160^{\circ}\text{C} \\ x_{\text{source}} = 0 \end{array} \right\} h_{\text{source}} = 675.47 \text{ kJ/kg}$$

$$\left. \begin{array}{l} T_{\text{sink}} = 25^{\circ}\text{C} \\ x_{\text{sink}} = 0 \end{array} \right\} h_{\text{sink}} = 104.83 \text{ kJ/kg}$$

- a. The actual thermal efficiency
- b. The maximum possible thermal efficiency
- c. The actual rate of heat rejection from this power plant

Answer: a) 8.8% b) 31.2 % c) 229.1 MW

Question 5

The performance of a heat pump degrades (i.e. its COP decrease) as the temperature of the heat source decreases. This makes using heat pumps at locations with severe weather conditions unattractive. Consider a house that is heated and maintained at 20°C by a heat pump during the winter. What is the maximum COP for this heat pump if heat is extracted from the outdoor air at

- a. 10°C,
- b. -5°C
- c. -30°C?

Answer: a) 29.3 b) 11.7 c) 5.86

QUESTION 1 - SOLUTION:

State 1:	State 2:
P_1	P_2
$T_1 = 25^\circ\text{C} = 298 \text{ K}$	$T_2 = 500 \text{ K}$
$V_1 = 0,8 \text{ m}^3$	$V_2 = V_1 = 0,8 \text{ m}^3$

$$m_{\text{air}} = 5,2 \text{ kg}$$

$$\rho_{\text{air}} = 0,287 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

A) from the gas perfect law for state 1:

$$P_1 \cdot V_1 = m \cdot R \cdot T_1 \Rightarrow P_1 \cdot 0,8 \text{ [m}^3\text{]} = 5,2 \text{ [kg]} \cdot 0,287 \left[\frac{\text{KJ}}{\text{kg} \cdot \text{K}} \right] 298 \text{ [K]}$$

$$\Rightarrow P_1 = \frac{5,2 \cdot 0,287 \cdot 298 \text{ [KJ]}}{0,8 \text{ [m}^3\text{]}} = 555,92 \cdot \frac{\text{KJ}}{\text{m}^3} =$$

$$= 555,92 \cdot 10^3 \frac{\cancel{\text{KJ}} \cdot \text{P}_0}{\text{m}^3} \Rightarrow \boxed{P_1 = 5,56 \text{ bar}}$$

B) The ideal gas equation for states 1 & 2 are written below:

$$\begin{aligned} \text{State 1: } P_1 \cdot V_1 &= m R T_1 \quad \text{①} \\ \text{State 2: } P_2 \cdot V_2 &= m R T_2 \quad \text{②} \end{aligned} \Rightarrow \frac{P_1 \cdot V_1 = m R T_1}{P_2 \cdot V_2 = m R T_2} \Rightarrow \frac{P_1}{P_2} = \frac{T_1}{T_2} \Rightarrow$$

$$P_2 = \frac{P_1 \cdot T_2}{T_1} = 5,56 \text{ [bar]} \cdot \frac{500}{298} = \boxed{9,33 \text{ bar}}$$

C) The work done in the process $W = \int_{V_1}^{V_2} P \cdot dV = P [V_2 - V_1]$

$$\Rightarrow \boxed{W=0}$$

QUESTION 2 - SOLUTION

The work during a polytropic process is given by:

$$W = \frac{P_2 \cdot V_2 - P_1 \cdot V_1}{1-n} \quad ①$$

From the ideal gas law for state 1:

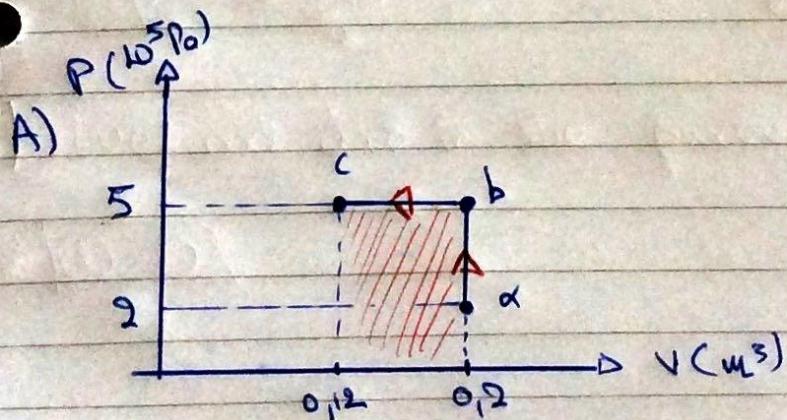
$$P_1 \cdot V_1 = m R T_1 \Rightarrow m \cdot R = \frac{P_1 \cdot V_1}{T_1} = \frac{400 \cdot 10^3 \text{ Pa} \cdot 0,3 \text{ m}^3}{383 \text{ K}} \Rightarrow$$

$$m \cdot R = \frac{120 \cdot 10^3 [\text{Pa} \cdot \text{m}^3]}{383 \text{ K}} = \frac{120 \text{ kJ}}{383 \text{ K}} = \boxed{0,313 \frac{\text{kJ}}{\text{K}}}$$

From equation ① $W = \frac{P_2 V_2 - P_1 V_1}{1-n} \Rightarrow W = \frac{m R T_2 - m R T_1}{1-n} \Rightarrow$

$$W = \frac{m \cdot R [T_2 - T_1]}{1 - 1,2} = \frac{0,313 \left[\frac{\text{kJ}}{\text{K}} \right] \cdot [673 - 383] \text{ K}}{-0,2} = 0$$

$$\boxed{W = -453,85 \text{ kJ}}$$

QUESTION 3 - SOLUTION

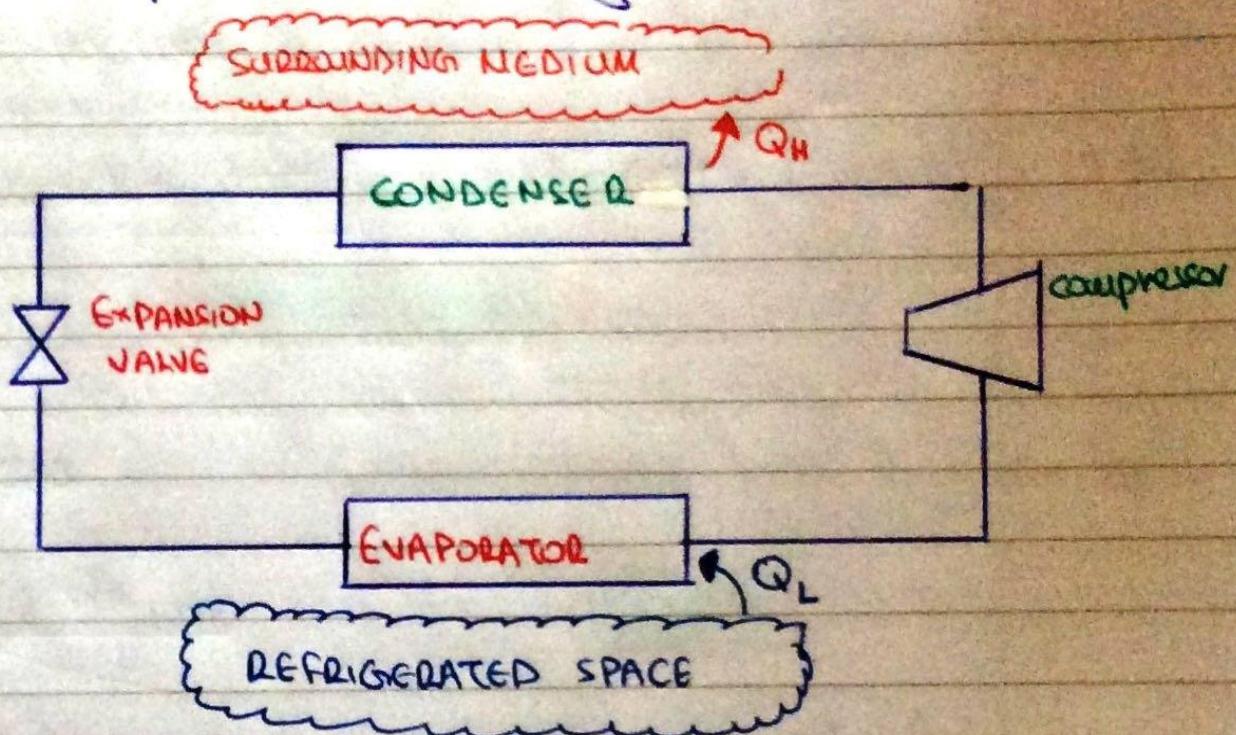
B) The work done during process ab: $W_{ab} = 0$ [Isochoric Process]

The work done during process bc: $W_{bc} = P \cdot dV = P \cdot [V_c - V_b] \Rightarrow$
 $\Rightarrow W_{bc} = 5 \cdot 10^5 \text{ Pa} \cdot [-0,08] \text{ m}^3 \Rightarrow \boxed{W_{bc} = -4 \cdot 10^4 \text{ J}}$

Total Work: $W_{ab} + W_{bc} = -4 \cdot 10^4 \text{ J}$

Question 1:

- a) The basic components of a refrigerator system are presented below



- b) By using the definition of the COP_R , the power input to the refrigerator is determined as

$$\text{COP}_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{\text{net,in}}} \Rightarrow \text{COP}_R = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} \quad \begin{array}{l} \text{Rate} \\ \text{form} \end{array}$$

$$\dot{W}_{\text{net,in}} = \frac{\dot{Q}_L}{\text{COP}_R} = \frac{85 \text{ [kJ/min]}}{2.4} \Rightarrow \dot{W}_{\text{net,in}} = 60.7 \text{ [kJ/min]}$$

- c) From the energy balance will have the following:

$$\begin{aligned} \dot{Q}_H &= \dot{Q}_L + \dot{W}_{\text{net,in}} = 85 \text{ [kJ/min]} + 60.7 \text{ [kJ/min]} \\ &= 145.7 \text{ [kJ/min]} \end{aligned}$$

QUESTION 2:

$\dot{W}_{\text{net,in}} = 450 \text{ W}$ | The total amount of heat that needs
 $\text{COP}_e = 2,5$ | to be removed from the waterworks is
 $m_{\text{L, tot}} = 5 \cdot 20 = 50 \text{ kg}$
 $T_L = 8^\circ \text{C}$
 $T_{\text{in}} = 20^\circ \text{C}$
 $C_p = 4,2 \cdot 1251 \text{ J/kg} \cdot \text{K}$ | $Q_L = [m \cdot C \cdot \Delta T] = 50 \text{ [kg]} \cdot 4,2 \frac{\text{[KJ]}}{\text{[kg]}\cdot\text{[K]}} \cdot 12, \boxed{12, \text{[KJ]}}$
$Q_L = 2520 \text{ KJ}$

The rate at which the refrigerator removes heat is given by

$$\dot{Q}_L = (\text{COP}_e) \cdot \dot{W}_{\text{net,in}} = 2,5 \cdot 450 = \boxed{1125 \text{ W}}$$

The total time required to remove 2520 KJ of heat

$$\Delta t = \frac{Q_L}{\dot{Q}_L} = \frac{2520 \text{ KJ}}{1,125 \frac{\text{KJ}}{\text{s}}} \Rightarrow \boxed{\Delta t = 37,3 \text{ min}}$$

QUESTION 3:

$Q_H = 700 \text{ KJ}$
 $T_H = 500 \text{ K}$
 $W_{\text{net}} = 300 \text{ KJ}$
 $T_L = 240 \text{ K}$

The maximum efficiency of a heat engine is given by

$$\eta_{\text{th,max}} = 1 - \frac{T_L}{T_H} = 1 - \frac{240}{500} = 0,42 \quad [42\%]$$

The actual thermal efficiency is given by the following expression

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_H} = \frac{300 \text{ KJ}}{700 \text{ KJ}} = \boxed{42,9\%}$$

The claim is false as $\eta_{\text{th}} > \eta_{\text{th,max}}$.

QUESTION 4:

$$T = 160^\circ\text{C}$$

$$\dot{m} = 440 \text{ kg/s}$$

$$\dot{W}_{net,out} = 22 \text{ MW}$$

$$T_L = 25^\circ\text{C}$$

$$\left. \begin{array}{l} T_{source} = 160^\circ\text{C} \\ x_{source} = 0 \end{array} \right\} h_{source} = 675,47 \text{ kJ/kg}$$

$$\left. \begin{array}{l} T_{sink} = 25^\circ\text{C} \\ x_{sink} = 0 \end{array} \right\} h_{sink} = 104,83 \text{ kJ/kg}$$

a) The ratio of heat input to the plant is taken as the enthalpy difference between the source and the sink

$$\dot{Q}_{in} = \dot{m}_g \cdot [h_{source} - h_{sink}] = 440 \text{ kg/s} \cdot 570,64 \text{ kJ/kg}$$

$$\dot{Q}_{in} = 252,081,6 \frac{\text{kJ}}{\text{s}} = 252,081,6 \text{ kW}$$

$$\text{So, the actual thermal efficiency } \eta_{th} = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \frac{22 \text{ MW}}{252,081,6 \text{ kW}} \Rightarrow$$

$$\eta_{th} = 8,8\%$$

b) The maximum thermal efficiency is given by the following:

$$\eta_{th,max} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273) \text{ K}}{(160+273) \text{ K}} \Rightarrow \eta_{th,max} = 31,2\%$$

c) The heat rejection is $\dot{Q}_{out} = \dot{Q}_{in} - \dot{W}_{net,out} = 229,1 \text{ MW}$

QUESTION 5:

The COP of the heat pump will be maximum when the heat pump operates in a reversible manner. So, it should be

$$COP_{HP,rev} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \left[\frac{283}{243} \right]} = 29,3 \text{ for outdoor: } 10^\circ\text{C}$$

$$COP_{HP,rev} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \left[\frac{268}{243} \right]} = 11,7 \text{ for outdoor: } -5^\circ\text{C}$$

Finally: $COP_{HP, rev} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \left(\frac{243}{293}\right)} = 5,86$ for outside: -30°C

Application of SFEE.

Nozzle

A device which increases velocity of any fluid.

→ By reducing pressure Pressure Energy is converted K.E

& Diffuser

Increases pressure
Decreases velocity

Mach Number:-

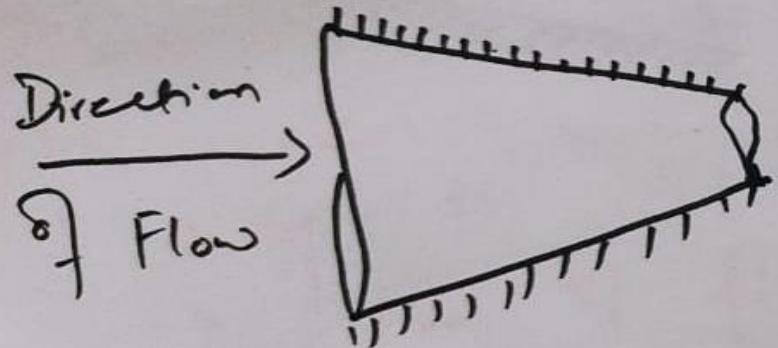
$$= \frac{\text{velocity of fluid}}{\text{Sonic velocity}}$$

In an ideal gas
sonic velocity = $\sqrt{\gamma RT}$ (1)

$M > 1$	(Supersonic Flow)	Velocity	Fluid $>$ Sonic Velocity
$M < 1$	(Subsonic Flow)	Velocity	Fluid $<$ Sonic Velocity
$M = 1$	(Sonic Flow)	Velocity	Fluid = Sonic Velocity

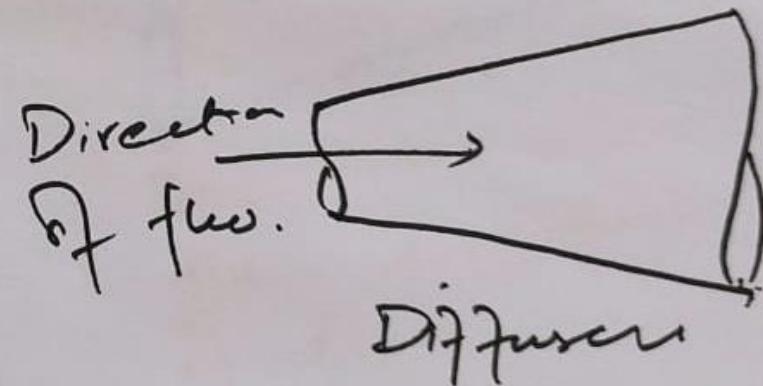
Subsonic Flow

$$M < 1$$



Nozzle

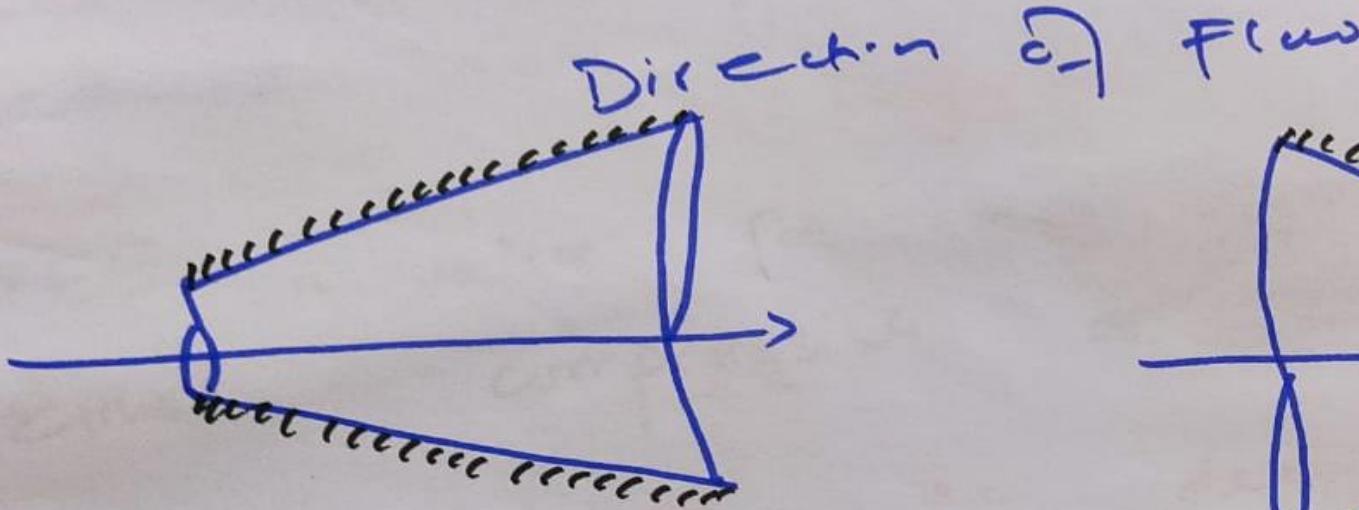
Cross section area
decreases along the direction of flow.



Cross section area
increases along (2)
the direction of flow.

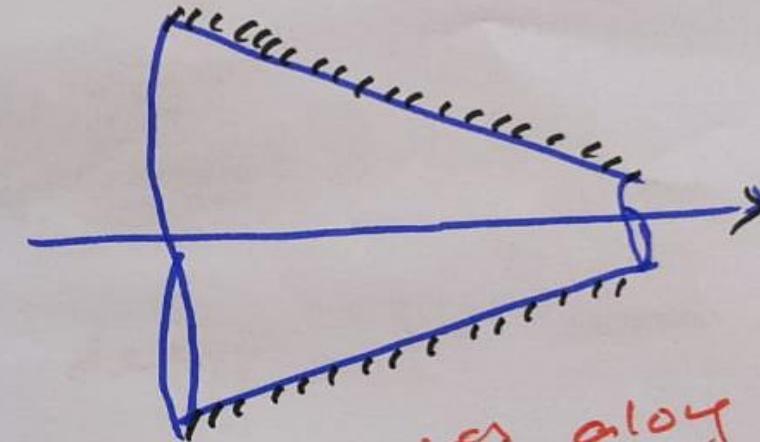
Supersonic Flow

$$M > 1$$



Increases
along the
direction of flow

Nozzle



Decreases along
the direction
of flow

Diffuser

(3)

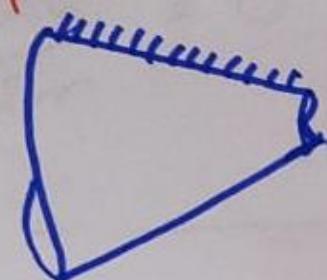
= For compressible fluid flow

→ When the velocity is high, its volume is reduced.
(Importance)

→ SFEE is valid for any type of fluid.
Either compressible or incompressible.

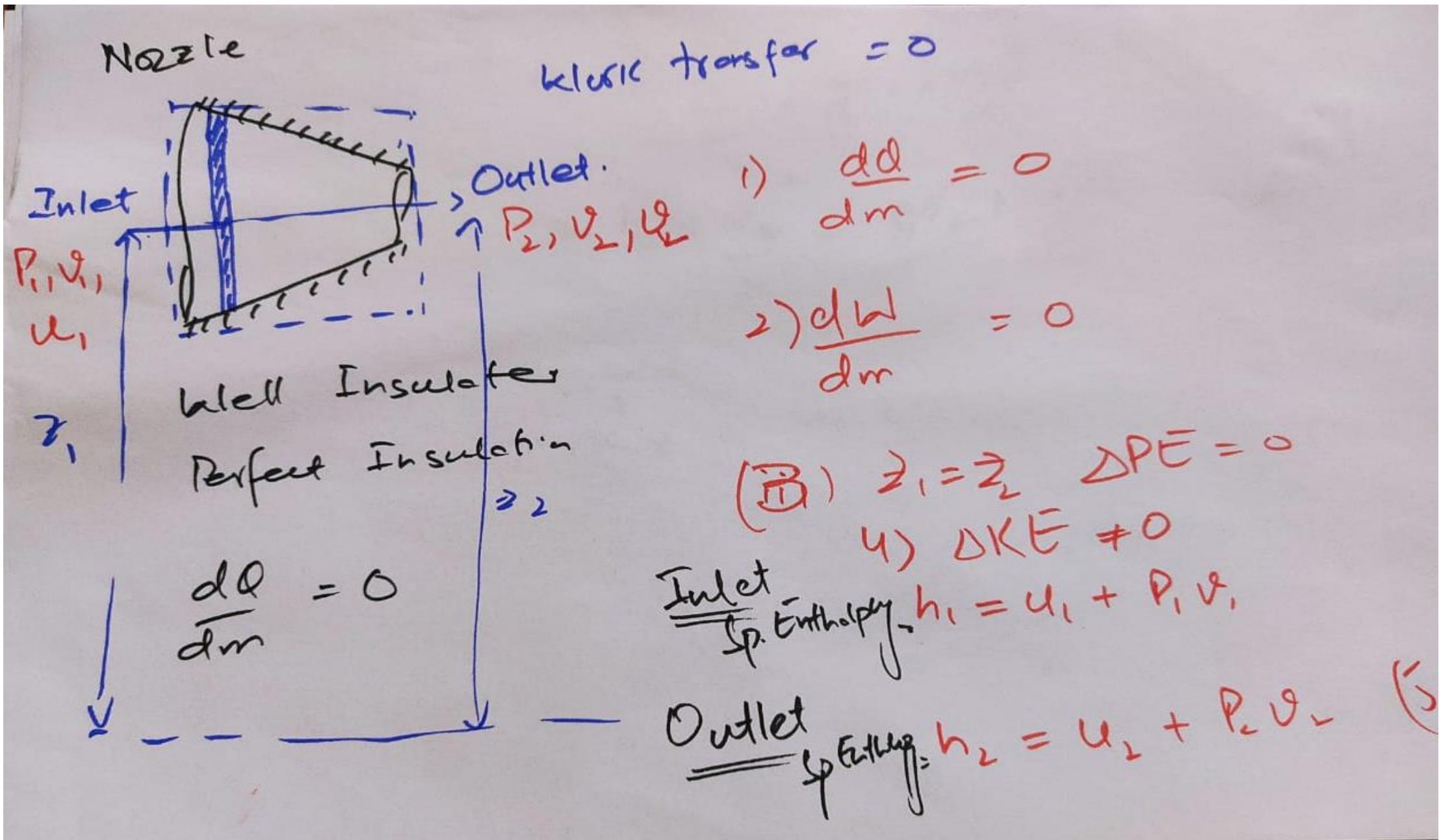
What would be the design for ~~sub~~ sonic flow?

$$M = 1?$$



For a fluid to have $M = 1$ is not feasible for longer period of time.

(4)



SFEE

$$h_1 + \frac{v_1^2}{2} + g^2_1 + \frac{d\phi}{dm} = 0$$

$$= h_2 + \frac{v_2^2}{2} + g^2_2 + \frac{d\phi}{dm} = 0$$

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

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

if $v_2 \gg v_1$

(b)

v_1^2 = neglected

$$\left[\frac{v_2^2}{2} = h_1 - h_2 \right] \quad v_2^2 = 2(h_1 - h_2)$$

$$v_2 = \sqrt{2(h_1 - h_2)}$$

Unity
J/kg

SFEE:

$$\frac{J}{kg} \rightarrow \boxed{h_1 + \frac{v_1^2}{2} + g z_1 + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2} + g z_2 + \frac{dW}{dm}}$$

$$K.E = \frac{1}{2} m v^2 \rightarrow \text{Nm or Joule}$$

$$\bar{E} = U + K.E + P.E$$

"Divided by mass"

$$e = U + \frac{v^2}{2} + gz$$

→ "F/g"

$\downarrow \text{m/s}^2$ (Dimension of "g")

$$\frac{m^2}{J} \approx \frac{J}{Fg}$$

$J = \text{Nm}$

$N = \text{kgms}^{-2}$

$\frac{\text{kgms}^{-2} \cdot \text{m}}{\text{kg}} = \text{m/s}^2$ "

(B)

so

$$v_2 = \sqrt{2(h_1 - h_2)} \Rightarrow \text{J/g}$$

KJ/g

SFE E:

$$h_1 + \frac{v_1^2}{2000} + \frac{g z_1}{1000} + \frac{dQ}{dm} = h_2 + \frac{v_2^2}{2000} + \frac{g z_2}{1000} + \cancel{\frac{dQ}{dm}}$$

$$\begin{array}{c} \hookrightarrow \\ \text{KJ/g} \end{array} \quad \begin{array}{c} \hookrightarrow \\ \text{KJ/g} \end{array}$$

$$\boxed{v_2 = \sqrt{2000(h - h_2)}} \\ \boxed{v_2 = 44.72 \sqrt{\Delta h}}$$

(9)

Four Required eqn

$$1) \frac{d\phi}{dr} = 0 \quad H\bar{T} = 0 \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{Almost always}$$

$$2) \frac{dh}{dr} = 0 \quad W\bar{T} = 0$$

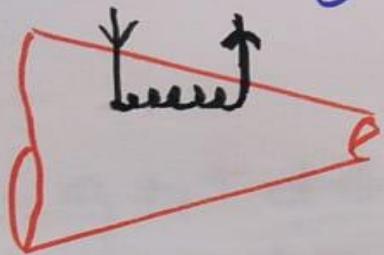
$$3) \Delta PE = 0 \quad z_1 = z_2$$

$$4) \Delta KE \neq 0 \quad v_2 = \sqrt{2gh} \\ v_2 = \sqrt{2g(h_1 - h_2)}$$

(10)

Special ~~case~~ case

This can
happen



Electric Work = Power

$$\downarrow \text{Heat} \quad \frac{dW}{dt}$$

$$= UI$$

$$= I^2 RT \rightarrow dQ$$

• But heat transfer
is always zero.

In case of Diffuser "same approach"
will be used

Possibility Different " h_1 & h_2 value". (1)

Turbine & Compressor

S.F.E.E

$$h_1 + \frac{V_1^2}{2} + g z_1 + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + g z_2 + \frac{dh}{dm}$$

External Work \rightarrow Shaft Work External Work \downarrow
 \downarrow Electrical Work.

Turbine: Rotodynamic Machine

Provides us Shaft Work. (ii)

Turbine :-

and

Consumes thermal Energy
Enthalpy (in case of steam)
produces work (shaft work)

Turbine :-

[Thermodynamic System]
Work from system (+ve)

Compressor :-

Reciprocity { work done
on +ve system (-ve)
&
Centrifugal

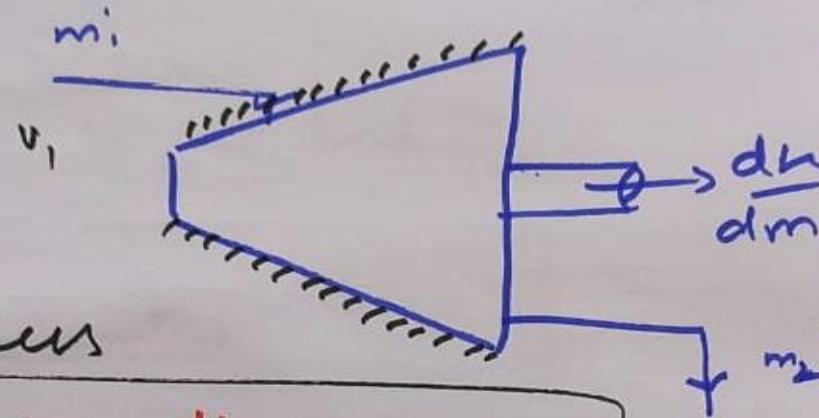
(15)

S.F.E E for turbine:

Assumpt:

No Friction

Loss / Friction less



$$m_1 = m_2 = m$$

$$\frac{dh}{dm} + \frac{dm}{di}$$

1) ~~assumption~~ :- Heat lost
= 0

4) $z_1 = z_2 \Delta P E$

2) Isentropic (Friction less)

$dS = 0$ (Reversible) + Adiabatic

3) $v_1 = v_2$ $\Delta K \cdot E = 0$

Inlet outlet

(M)

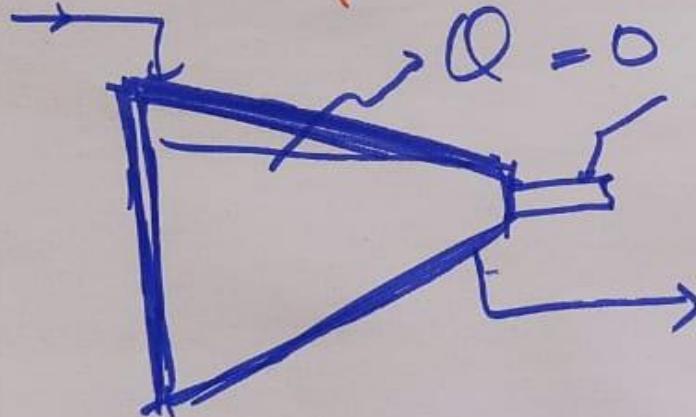
$$h_1 = h_2 + \frac{dw}{dm} \quad S F E E$$

$$\Rightarrow h_1 = h_2 + w \quad \frac{dw}{dm} \approx w_i \frac{\dot{V}}{\dot{m}}$$

$\frac{\dot{V}}{\dot{m}} \quad \boxed{h_{nl} = h_1 - h_2}$

or $\frac{\dot{V}}{\dot{m}}$ work transfer for turbine.

Compressor :-



- 1) $\Delta KE = 0$
- 2) $\Delta PE = 0$
- 3) $\Delta Q = 0$

(15)

$$h_1 = h_2 + wl$$

$$h_1 = h_2 + (-w)$$

$$\boxed{wl = h_2 - h_1}$$

KJ/kg or J/kg

SFEE \Rightarrow compression

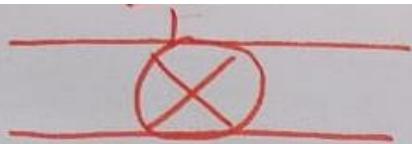
Throttling

Process:-

Irreversible
process

Rapid reduction of pressure.

(16)



① Examples of throttling process

→ Capillary tube

is example of
throttling process.

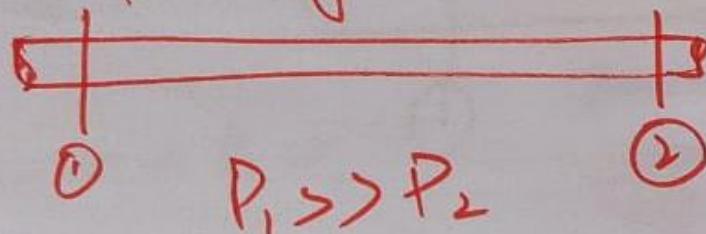


values / tubes

" → Partially open valve.

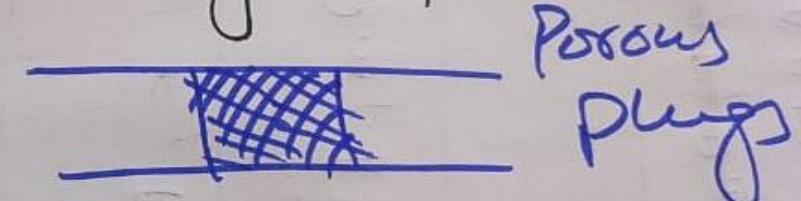
→ Adjustable valve

! → capillary tube ②



By virtue of friction
pressure is reduced

③



$$P_1 \gg P_2$$

$$P_2 \ll P_1$$

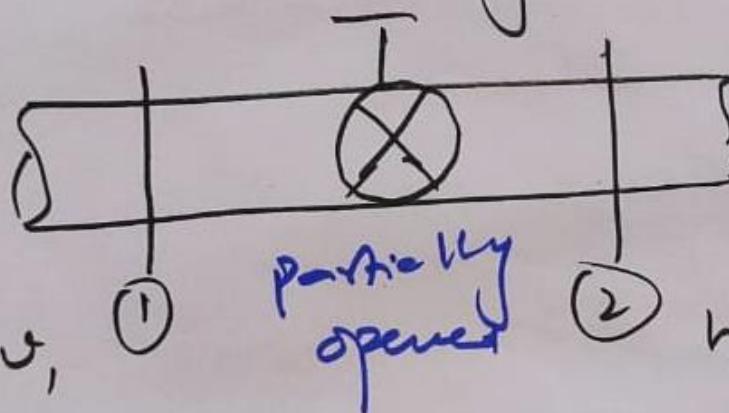
(17)

Throttling process

\Rightarrow Isenthalpic Process $[h_1 = h_2]$

"But it doesn't mean all Isenthalpic processes are throttling process"

Refrigeration :-



$$h_1 = u_1 + P_1 v_1$$

$$h_2 = u_2 + P_2 v_2$$

(1B)

if

$$P_1 v_1 \gg P_2 v_2$$

$$\frac{u_1 - u_2 = P_2 v_2 - P_1 v_1}{[u_1 - u_2 = -ve]}$$

Temp will increase along flow

$$[u_2 > u_1] \quad [T_2 > T_1]$$

if $P_2 v_2 \gg P_1 v_1$ }
 $T_1 > T_2$ {
 means
 Temp will decrease
 along the direction
 of flow)

So it doesn't mean that temperature
will always reduce in case of throttling
because of reduction in pressure.

It can also increase in direction
of flow, meanwhile pressure decreases

(A)

For Ideal gas

$$h = f(T) \quad \left. \begin{array}{l} \\ \end{array} \right\} \rightarrow \begin{array}{l} \text{Throttling} \\ \text{case} \end{array}$$

" $h_1 = h_2$

$$\boxed{T_1 = T_2}$$

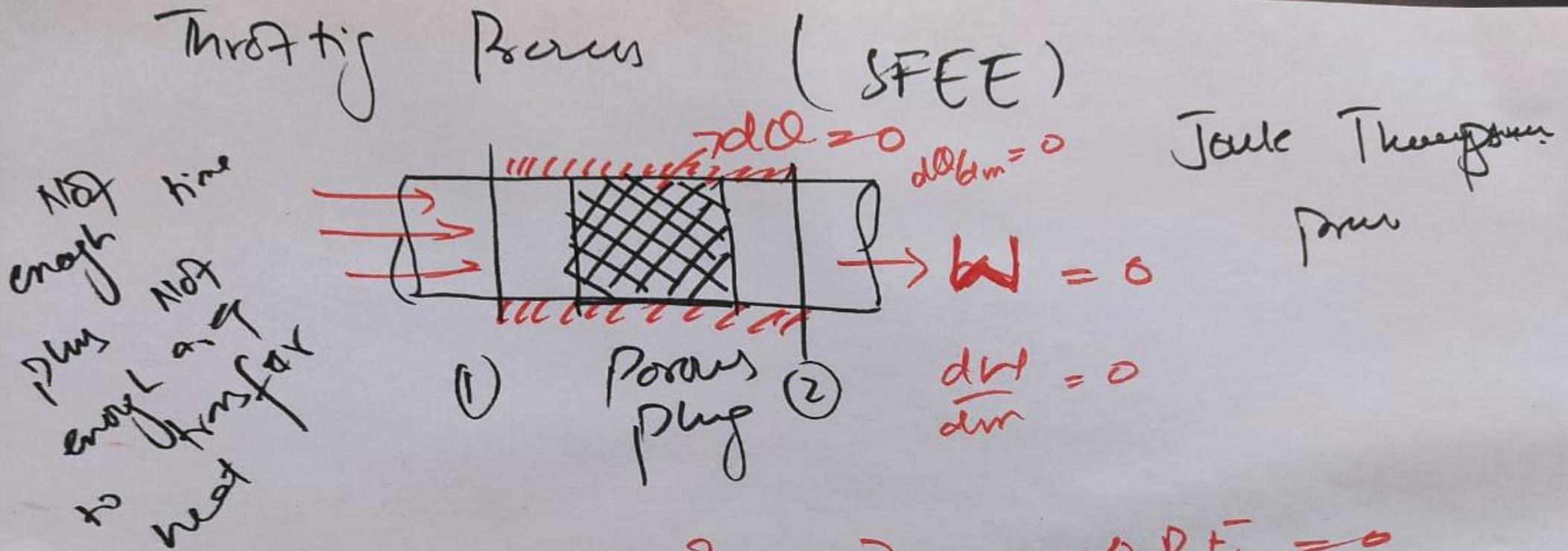
for ideal gases
temperature remain constant.

In case of real gases we are

getting both heating $T_2 > T_1$ &

(cooling) $(T_1 > T_2)$ { Joule's Thompson coefficient of expansion)

(20)



$$z_1 = z_2 \quad] \rightarrow \Delta E = 0$$

$$v_1 = v_2 \quad] \Delta KE = 0$$

SFEE

$$\boxed{h_1 = h_2}$$

(2)

Pure Substances

Pure Substance

- Single component system

Water H_2O

(1)

- Chemical composition is same throughout the mass

Homogeneous Material

Water

H_2O

Milk

H_2O

Starch

+ Calcium

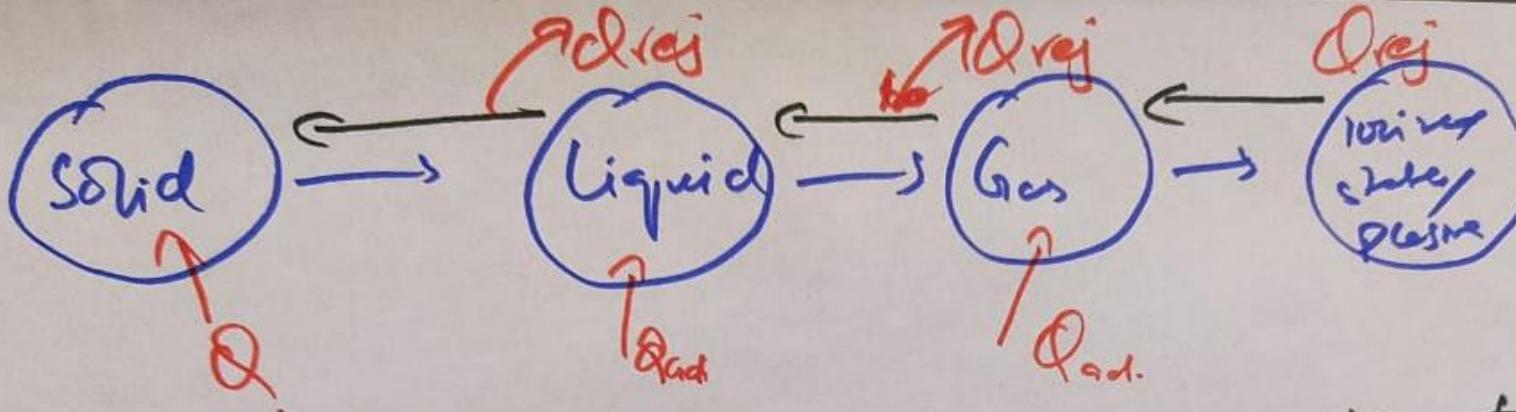
+ Protein

+

Pure Substance

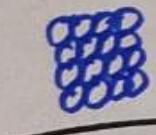
- Can/May exist in more than one phases

(Not a
Mixture Pure Substance)



Sensible Heat / Latent Heat

→ Sensible heat associated with change in temperature (change in K.E.)



⇒ latent heat is the amount of thermal energy to change the phase.

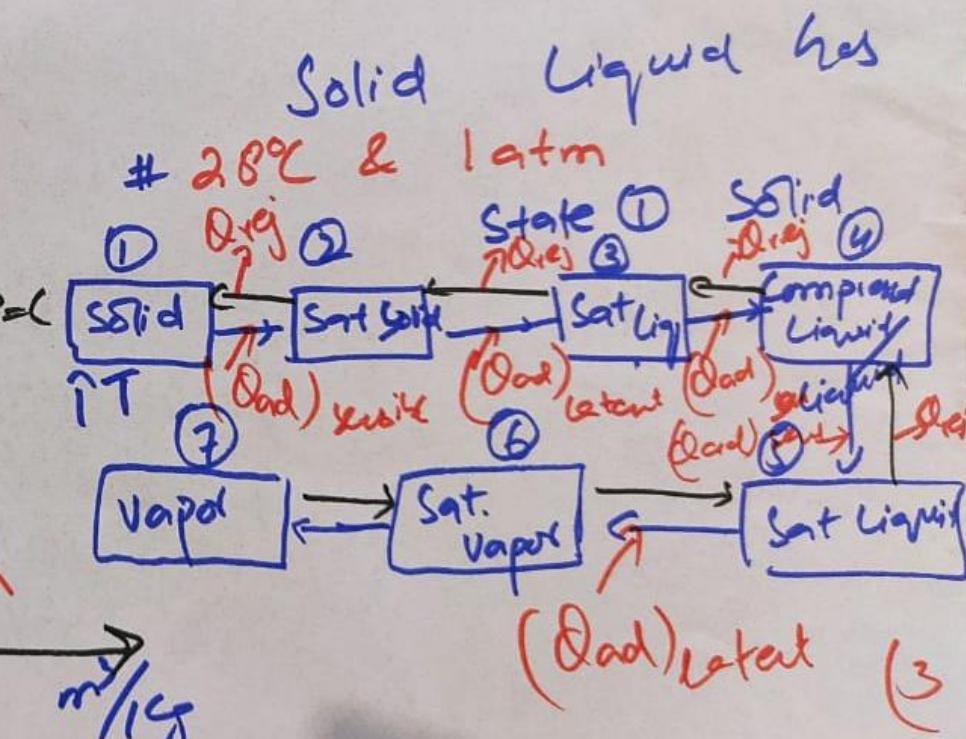
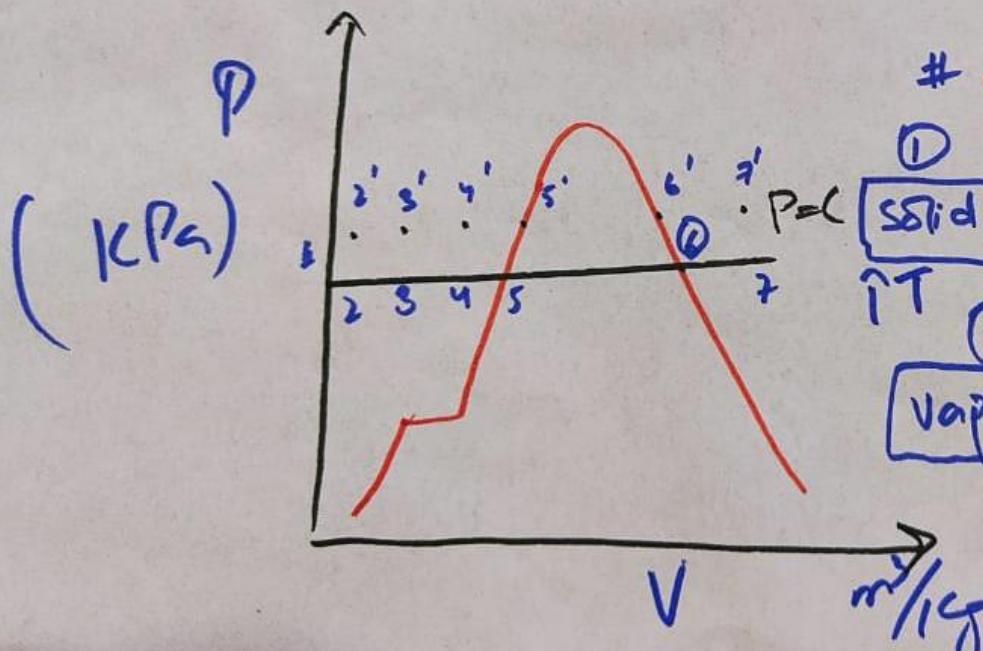
To break this bond (Energy is needed)

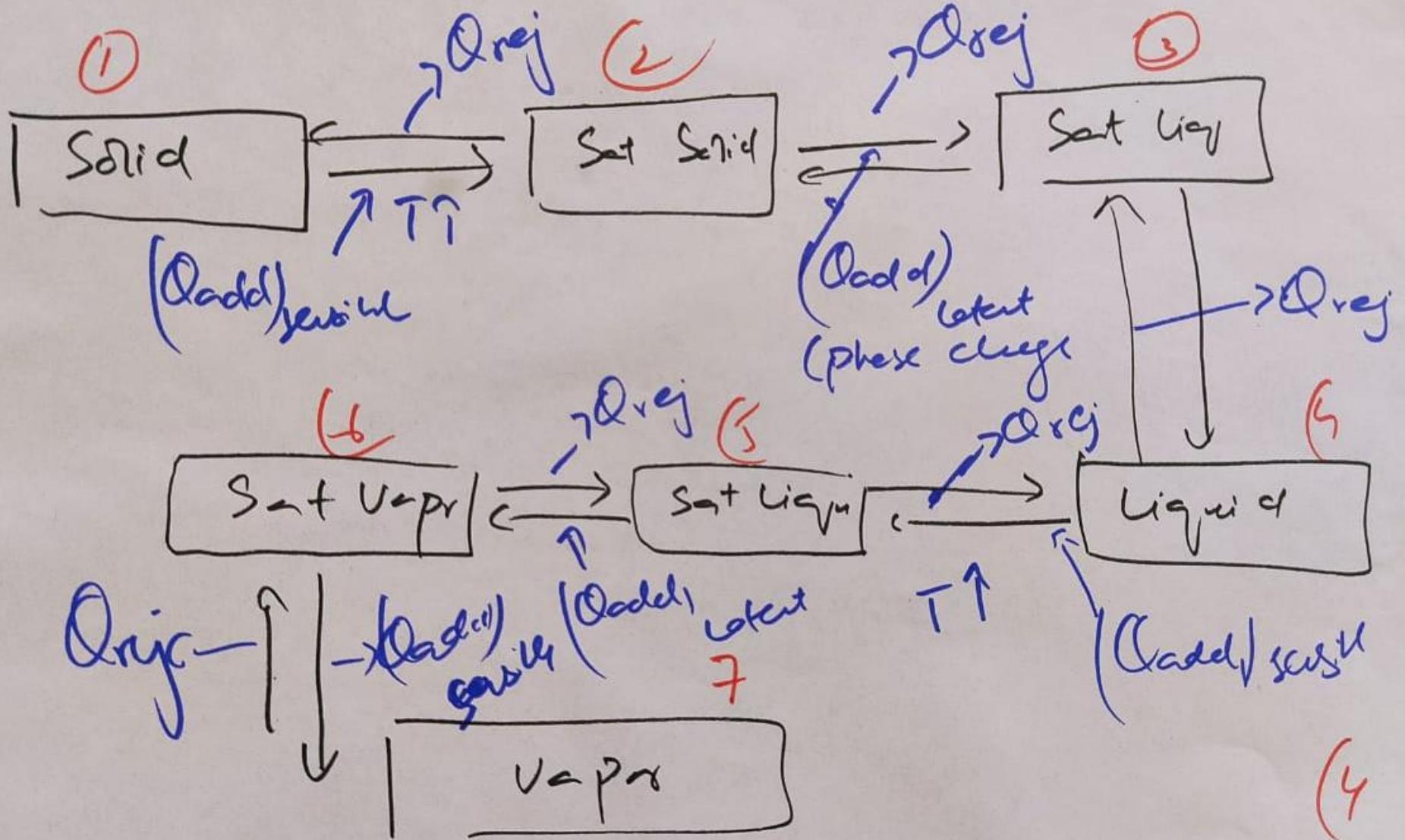
Sens'd Heat
→ Temp change

Latent Heat

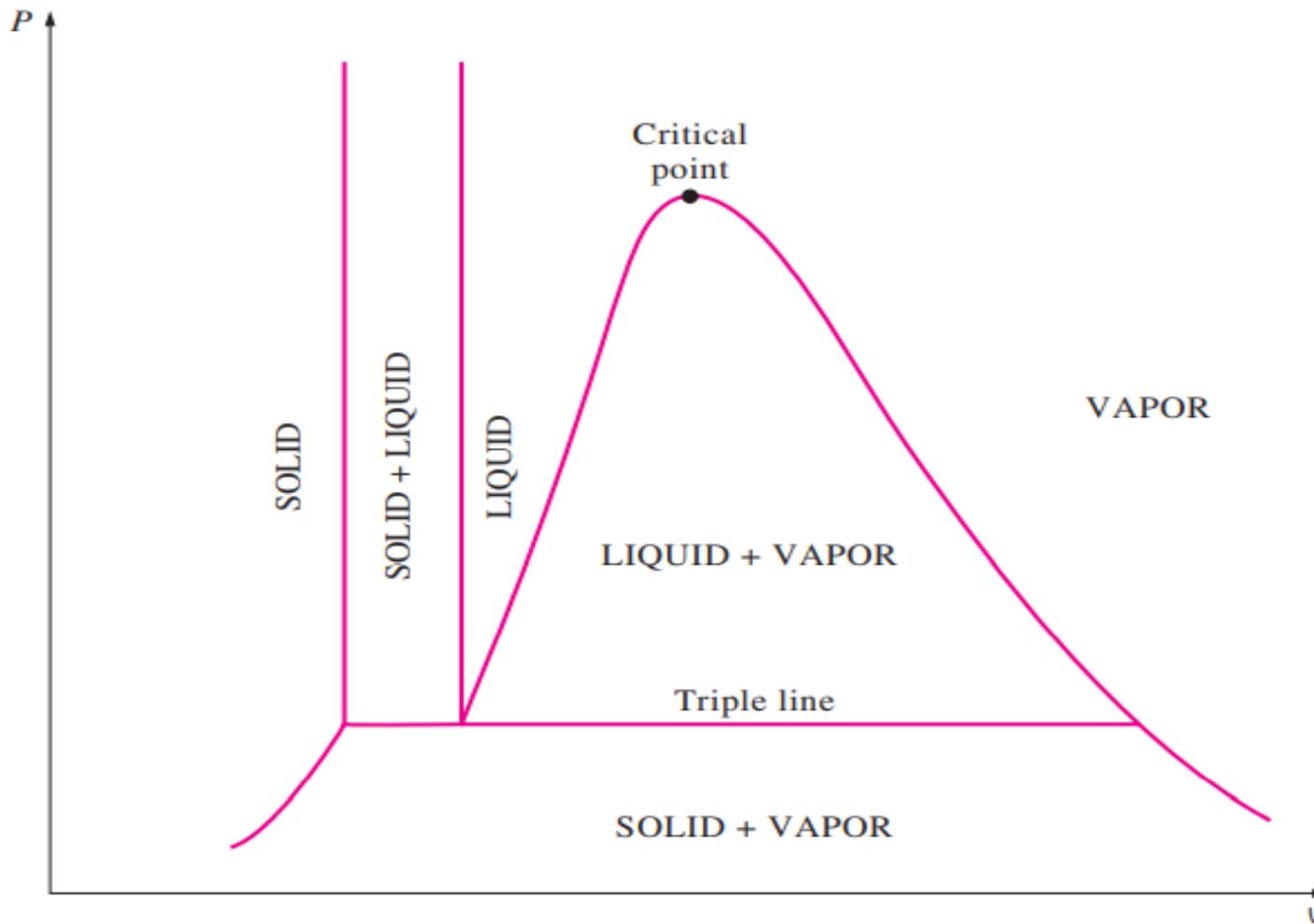
→ Added or removed
at constad Temperature
& Pressure.

Property Diagram:





PV Diagram of a Pure Substance

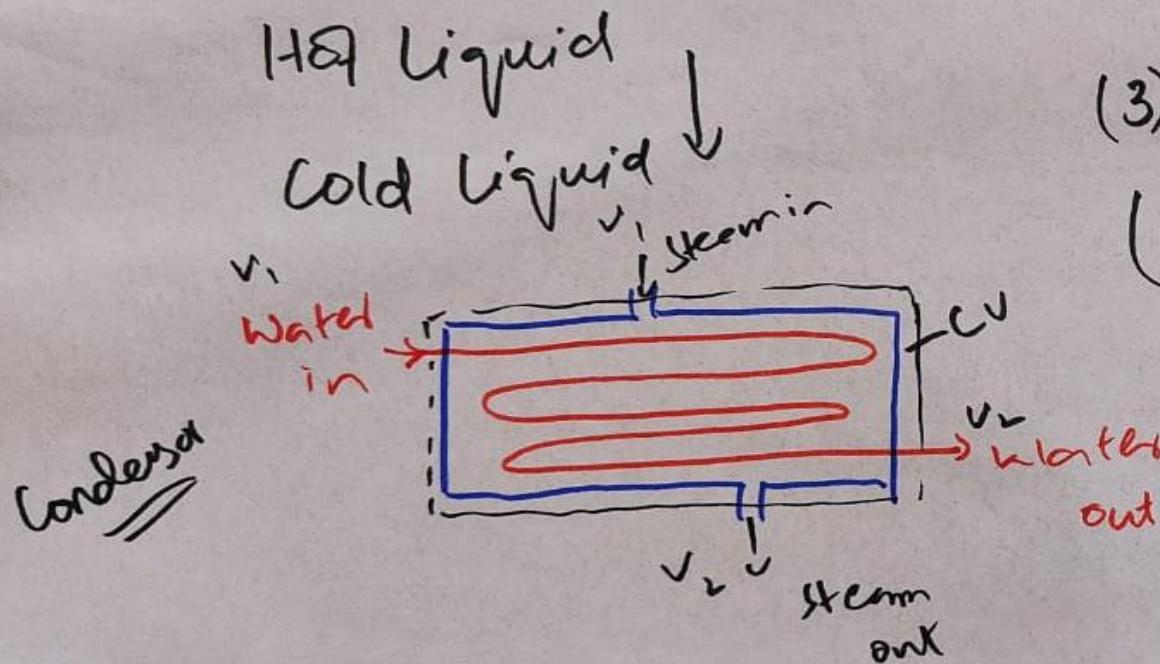


- Book Chapter 3
- PAGE # 111 TO 124

SFEE Applications and Problems

Heat Exchangers (S.F.E.E)

2 Fluids
 ↙ liquid ↘ Gases

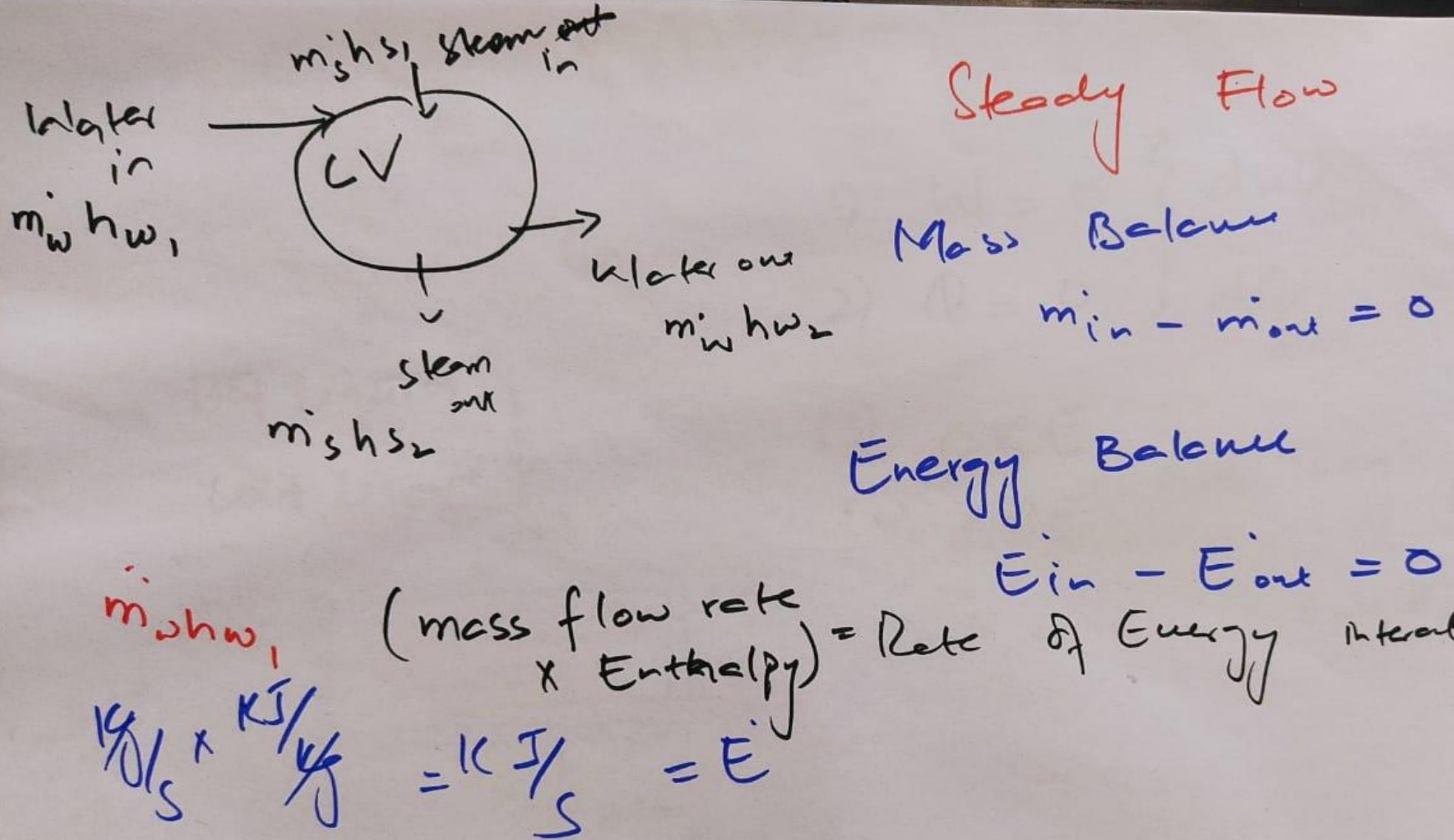


$$\left. \begin{array}{l} W = 0 \\ Q = 0 \end{array} \right\} \frac{dW}{dm} = 0 \quad \frac{dQ}{dm} = 0$$

(3) ΔKE
 (4) ΔPE are negligible

$$V_1 = V_L \quad z_1 = z_2$$

(1)



(2)

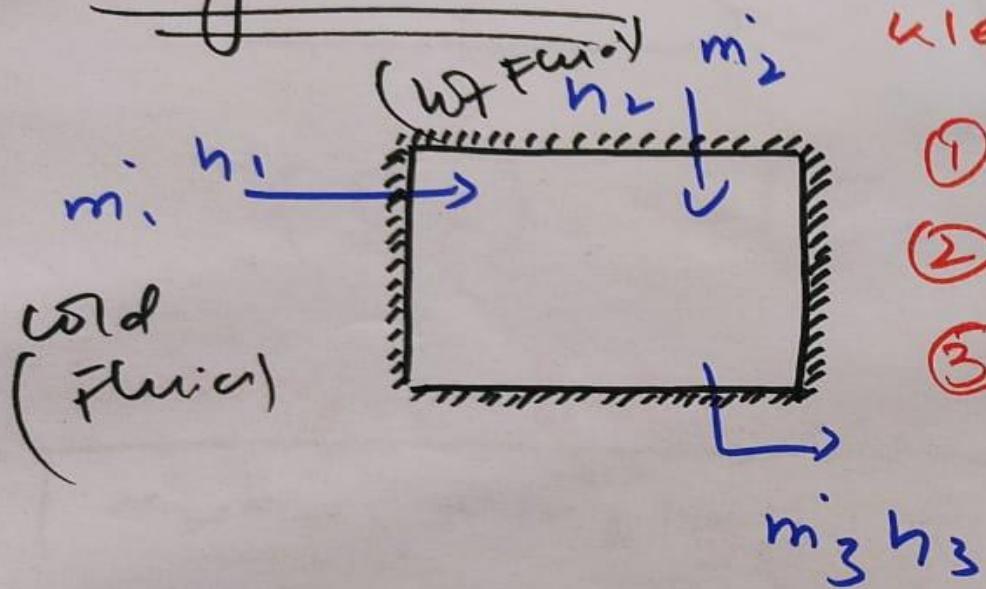
$$\underbrace{m_i \omega h \omega_1 + m_i s h s_1}_{(E_{in})} - \underbrace{m_i \omega h \omega_2 + m_i s h s_2}_{(E_{out})} = 0$$

Energy Balance (SEE for H.E)

$$m_i \omega h \omega_1 + m_i s h s_1 = m_i \omega h \omega_2 + m_i s h s_2$$

(3)

Mixing Chamber



Well Insulated

$$\textcircled{1} \quad Q = 0$$

$$\textcircled{2} \quad W = 0$$

$$\textcircled{3} \quad \Delta KE \& \Delta PE = 0$$

$$v_1 = v_2 \quad z_1 = z_2$$

Assumptions

Mass Balance

(Steady Flow)

$$\underline{\underline{m_{in} - m_{out} = 0}}$$

$$m_1 + m_2 - m_3 = 0$$

$$\underline{\underline{m_1 + m_2 = m_3}}$$

(4)

Energy Balance (Steady Flow)

$$E_{in} - E_{out} = 0$$

$$m_1 h_1 + m_2 h_2 - m_3 h_3 = 0$$

$$\boxed{m_1 h_1 + m_2 h_2 = m_3 h_3 -}$$

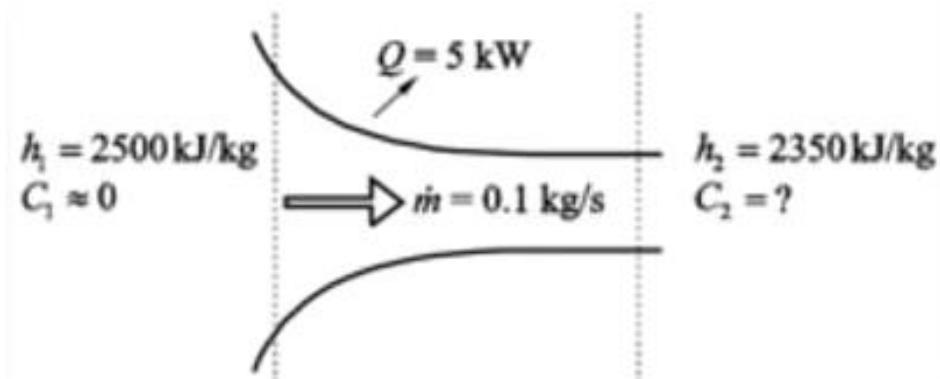
$E = (\text{mass flow rate}) \times \text{Enthalpy}$

(5)

Topic : Steady Flow Energy Equation

Question

Steam flows through a nozzle at a mass flow rate of $\dot{m} = 0.1 \text{ kg/s}$ with a heat loss of 5 kW. The enthalpies at inlet and exit are 2500 kJ/kg and 2350 kJ/kg respectively. Assuming negligible velocity at inlet ($C_1 \approx 0$), the velocity (C_2) of steam (in m/s) at the nozzle exit is _____ (correct to two decimal places).



Nm II: Sol

$$\begin{aligned} h_1 &= 2500 \text{ KJ/kg} & m &= 0.11 \text{ kg/s} & NO_{2} &= 4 \\ v_1 &> 0 & h_2 &= 2350 \text{ KJ/kg} \\ Q &= 5 \text{ KJ} & v_2 &=? \\ 5 \text{ KJ/s} & & & & & \end{aligned}$$

$$1) \quad \omega = 0 \quad 2) \quad \Delta PE = 0$$

SSEE

$$m \left(h_1 + \frac{v_1^2}{2} + g z_1 \right) \text{ J/kg}$$

$$m \left(h_1 + \frac{v_1^2}{2000} + \frac{g z_2}{1000} \right) + Q \quad (1)$$

$$= m \left(h_2 + \frac{v_2^2}{2000} + \frac{g z_2}{1000} \right) + k \quad (2)$$

~~0.1 5 250~~

$$0.1(25000) - 5 = 0.1\left(2350 + \frac{v_2}{2000}\right) + 0$$

km

$$\frac{\frac{150}{s} \frac{100}{g} - 100}{s} = \frac{100}{s}$$

Dimensional
homogeneity

$$v_2 = 447.21 \text{ m/s}$$

(7)

Topic : Steady Flow Energy Equation

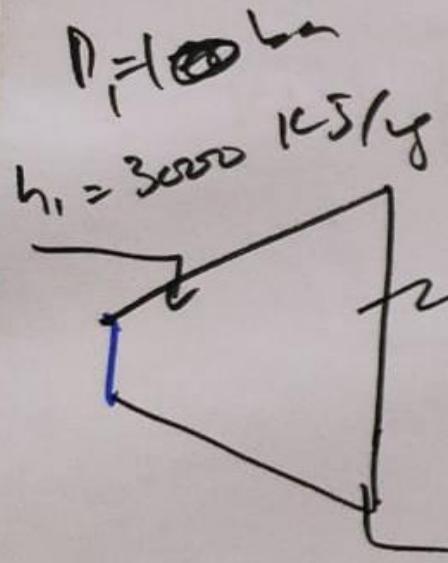
Question

A steam turbine receives steam steadily at 10 bars with an enthalpy of 3000 kJ/kg and discharges at 1 bar with an enthalpy of 2700 kJ/kg. The work output is 250 kJ/kg. The changes in kinetic and potential energies are negligible. The heat transfer from the turbine casing to the surroundings is equal to

- (A) 0 kJ
- (B) 50 kJ
- (C) 150 kJ
- (D) 250 kJ

Given:

Enthalpy at Inlet (h_1)
= 3000 kJ/kg



Pressure for stream at
250 kJ/kg Inlet (P_1) = 10 bar

Enthalpy at outlet (h_2) = 2700 kJ/kg

Isentropic output (w) = 250 kJ/kg
 $Q = ?$
 $P_2 = 1 \text{ bar}$ Pressure (outlet) (θ)

SFEE

$$\frac{m(h_1 + v_1)}{T} + \frac{g(\rho_1)}{1000} + Q = m(h_2 + \frac{v_2}{200} + \frac{g(\rho_2)}{1000}) + w$$

1kg (mass basis) equation

1kg/s (time basis) equation

$$h_1 + Q = h_2 + w$$

$$3000 + Q = b \approx 700 + 250$$

$$\frac{Q}{1000} = \frac{2950 - 3000}{-50 \text{ kJ/kg}}$$

(a)

Given

$$m = 5 \text{ kg/s}$$

$$v_1 = 50 \text{ m/s}$$

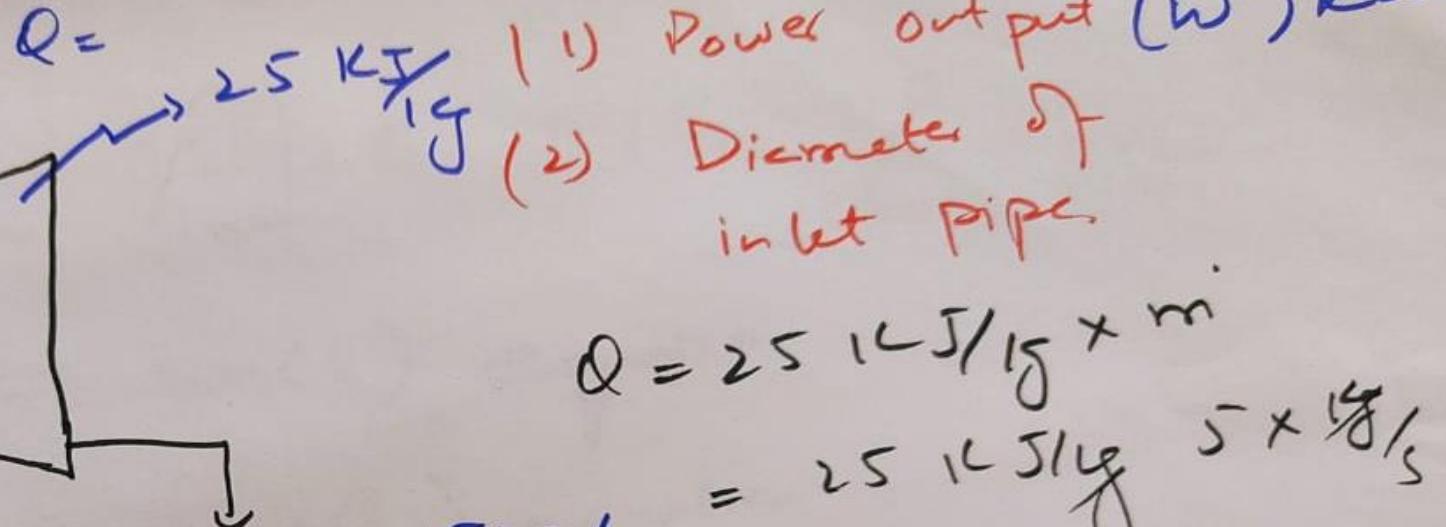
$$h_1 = 900 \text{ kJ/kg}$$

$$R = 0.285 \text{ kJ/kg K}$$

$$C_p = 1.00 \text{ kJ/kg K}$$

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

$$T_1 = 27^\circ\text{C}$$



$$Q = 25 \text{ kJ/s} \times 5 = 125 \text{ kJ/s}$$

$$h_2 = 400 \text{ kJ/kg} \quad \dot{Q} = 125 \text{ kJ/s}$$

$$\boxed{\dot{Q} = 125 \text{ kW}}$$

$\Delta KE \neq 0$ (special case) (b)

SFEF

$$m \left(h_1 + v_1 \frac{v}{200} + \cancel{\frac{900}{1000}} \right) + Q$$

$$= m \left(h_2 + v_2 \frac{v}{200} + \cancel{\frac{900}{1000}} \right) + k$$

$$5 \left(900 + \frac{(50)^2}{2000} \right) - 1251 = 5 \left(400 + \frac{150}{2000} \right) + k$$

$|k| = 2325 \text{ KPa}$

(11)

Topic : Steady Flow Energy Equation

Question

In a gas turbine the gas enters at the rate of 5 kg/s with a velocity of 50 m/s and enthalpy of 900 kJ/kg and leaves the turbine with a velocity of 150 m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surroundings is 25 kG/kg. Assume for gas $R = 0.285 \text{ kJ/kgK}$ and $c_p = 1.004 \text{ kJ/kgK}$ and the inlet conditions to be at 100 kPa and 27°C . Determine the power output of the turbine and the diameter for the inlet pipe.

Diameter δ_1 Inlet Pipe

$$Q = A V$$

$V \rightarrow$ volumetric Flow rate (m^3/s)

$$PV = m RT$$

$$PV = m RT$$

$$PQ = m RT$$

$$100 \times 10^5 \text{ kPa} = 100 \text{ bar}$$

$$T_1 = 27^\circ C = 300 \text{ K}$$

$$P \frac{V^3}{s} = 10^5 s RT$$

$$PQ = m RT$$

$$100 \times 10^5 \times Q = 5 \times 0.287 \times 300$$

$$Q = 0.04305 \text{ m}^3/\text{s} \quad (1)$$

$$Q = A \times V$$

$$0.04305 = \frac{\pi}{4} D^2 v_i$$

$$\sqrt{\frac{4}{\pi} (0.04305)} = \sqrt{D^2}$$
$$D = 0.0331 \text{ m}$$
$$\boxed{D = 33.10 \text{ mm}}$$

(13)