ARYAN SCHOOL OF ENGINEERING & TECHNOLOGY

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LECTURE NOTE

SUBJECT NAME- THERMAL ENGINEERING-I

BRANCH – MECHANICAL ENGINEERING

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Chapter-1 Concepts & Terminology

Thermodynamics → It is defined as the branch of Science which deals with heat energy transfer and its effect on physical property of the substance.

Or.

It may be defined as the science which deals with the conversion of heat into mechanical work or energy by using a suitable medium.

Heat → Heat is a form of energy. or. heat is a state of temperature.

Unit → Joule - In SI.
Calorie - In cgs

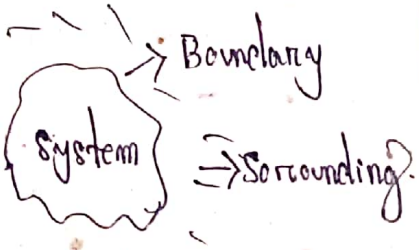
property → In thermodynamic's, a physical property is any property that is measurable. and whose value describes a state of physical system.

Thermodynamic System: —

System → A system is defined as any quantity of matter or a region in space having certain volm upon which our attention is concerned in analysis of problem.

Surrounding → Anything external to the system constitute as surrounding.

Boundary → System is separated from the surrounding by system boundary.
→ Boundary may be fixed or movable.



System are classified into three types —
i) open system ii) closed System
iii) Isolated System.

i) open system → Both mass and energy cross the boundary.
ii) it is also called constant volm.
iii) it is also known as Flow system.
Eg → Turbine, pump, Air compressors.

ii) closed system →
i) Mass within the boundary remains constant only energy interaction betn system and surrounding.
ii) it is also known as Non-Flow System.
Eg. Tea kettle, cylinder piston arrangement.

Isolated System — An Isolated System is one in which there is no Interaction between System and Surrounding.
Eg. Universe, thermoFlask etc.

Macroscopic & Microscopic approach:—

Macroscopic approach → it is used in regard to larger units which is visible in naked eye.
i) Certain quantity of matter is Considered without taking into Consideration the events occurring at molecular level.
ii) otherwise it is Concerned with overall behaviour of matter.
iii) This type of study is also known as classical thermodynamics.

Microscopic approach →
i) Matter is Considered to be Composed of tiny particle called molecules and study of each particle having certain position, velocity, and energy at a given instant.
ii) it is also called statistical thermodynamics.

Concept of Continuum:—

The system is regarded as Continuum if the system is assumed to Contain Continuous distribution of matter.
→ From the Continuum point of View, the matter is seen as being distributed through space and treats the Substance as being Continuous disregarding the action of Individual molecules.
→ There are no voids and values of action of many molecules & atoms.

Notes → Molecule → A group of atoms bonded together, representing the smallest Fundamental Unit of chemical Compound that Can take part in a chemical reaction.

Thermodynamic property:—

Property → A thermodynamic property refers to the characteristic by which the physical change of Condition state of a System Can be described such as Pr, Volm, temp etc.
Pressure → it is defined as Force per Unit area.
Unit → In SI – Pascal(Pa) = 1N/m².

1 Bar = 10^5 N/m^2 = 100 kpa.

1 ATM = 760 mm of Hg or 1.013 bar or 101.325 kpa.

Temperature → It is a thermal state of a body which determines the hotness or coldness of a body.

→ The temp of a body is proportional to the stored molecular energy.

Unit → Degree celsius or kelvin.

Intensive and Extensive property :—

Intensive property → The property which are independent of mass of the system are known as Intensive properties.

→ Its value remains the same, whether one consider the whole system or only a part of it.

Eg. Pre, temp, sp volm, sp energy, sp density.

Extensive property → The property depends upon mass of the system are known as extensive property.

Eg. Volm, Energy, enthalpy, entropy.

Notes State → The condition of physical existance of a system at any instant of time is called state.

Thermodynamic Processes :—

When the property of a system changes, there is a change in state and the system is said to have undergo a thermodynamic process.

Commonly used processes are —

i) Isochoric process — The process which takes place at constant volm is said to Isochoric process.

ii) Isobaric process — Process takes place at const pr.

iii) Isothermal process — Process takes place at const temp.

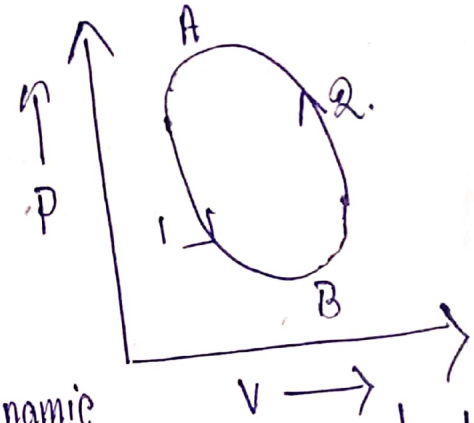
iv) Adiabatic process — Process in which no heat transfer betn the system and surrounding.

Reversible adiabatic process is known as Isentropic proces

The other processes are polytropic, throttling, free expansion, and hyperbolic process.

Thermodynamic cycle:—

When a process is performed in such a way that the Final state is identical with the initial state. it is then known as thermodynamic cycle or cyclic process.



A-1-B and A-2-B represents process. where as A-1-B-2-A represents a thermodynamic cycle.

Thermodynamic Equilibrium:—

A system is said to be in thermodynamic equilibrium when no change in any macroscopic property is registered. if the system is isolated from its surrounding.

Thermodynamics mainly studies the properties of physical system are found in equilibrium state.

A system will be said to be in thermodynamic equilibrium if the following three conditions of equilibrium is satisfied.

1) Mechanical equilibrium.
2) Chemical "
3) Thermal "

1) **Mechanical equilibrium:—**

when there is no unbalanced force on any part of the system or in-between the system and surrounding then the system is said to be in mechanical equilibrium.

Eg. if the pr is not uniform throughout the system then internal changes in the state of the system will take place until the mechanical equi:

Chemical Equilibrium:— when there is no chemical reaction or transfere of matter from one part of the system to another such as diffusion or solution, then the system is said to exist in a state of chemical equlibrium.

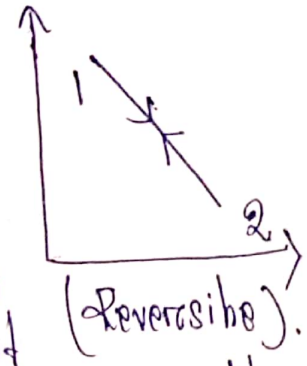
Thermal Equilibrium:— when there is no temp difference betn the parts of the system are betn the system and sorrounding it is then said to be in thermal equlibrium.

Reversible process:—

A process in which act in reversed in dirn and the system retreaces the same continous series of equlibrium state it is said to be reversible process.

→ it carried out with absolute slowere so that the system will be always in equlibrium.

→ In actual practice reversible process can't be attain, but it can be approximated as closely as possible.



(Reversibe).

Irreversible process:—

A process in which the system passes through a sequence non-equlibrium state i.e the properety such as volm, prr, temp is not uniform throughout the system is known as Irreversible process.

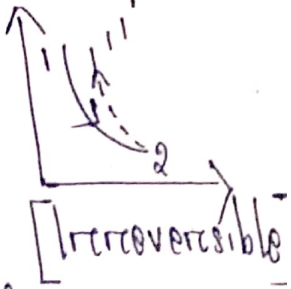
Quasi-static process:—

→ The word quasi means allmost.

→ This process is a succession of equlibrium states and infinite slowness is the characteristic feature of quasi-static process.

→ it is also called as reversible process.

→ The basic difference is not all the point but almost mayore points is in equlibrium condition.



[Irreversible

Energy & Work transfer chapter-2

A closed system interacts with the surrounding by energy transfer and this energy transfer takes place in two ways.

i) Work transfer ii) Heat transfer.

Notes: —

Work — In thermodynamics work is quantity of energy transfer from one system to another. Unit - Joule

Heat & Work are the main mode of energy transfer and there are certain similarities and differences bet^n heat & Work.

→ The heat & Work are boundary phenomena. they observe at the boundary of the system.
→ When a system undergoes a change in state, heat transfer or Work done may occur.
→ Heat & Work are path function and depends upon the process.
→ Work is said to be high grade energy and heat low grade energy.

Work transfer: —

The action of a force on a moving body is identified as work.

→ For work transfer the system has to be such selected that its boundry just move.
→ There can't be work transfer in a closed system without moving the system boundry.

Eg. In a cylinder piston arrangement the top of the system is moving system boundary and the work is transferred by the movement of piston.

Work done by the system is considered as positive and work done on the system is taken as negative.

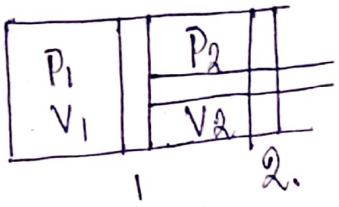
Work done = force x displacement. Unit - N-m or J

The rate at which Work is done upon by the system is known as powerr.

Unit → J/s or watt.

PdV Worek or displacement Work:—

Let us Consicler a gas in cylinder.



Initial prr – P_1

" Volm – V_1

→ The system in thermal equlibrium.

→ The piston is the system boundray which moves due gas prr.

→ Let the piston move out to a new final position 2 which is also in thermodynamic equlibrium specified by P_2 and Volm V_2. when the piston moves an Infinitesimal distance dl it a be the cortea of the piston.

→ The Force Facting on the piston will be

$$F = P \times a.$$

→ The amount of workdone by gas on the piston will be

$$dw = F \cdot dl = P \times a \times dl = P dv.$$

where $dv = a \times dl$.

→ when the piston moves out by position 1 to 2 them the amount of work done b the system will be

$$W_{1-2} = \int_{v_1}^{v_2} P dv.$$

→ The above eqn represents the displacement Work.

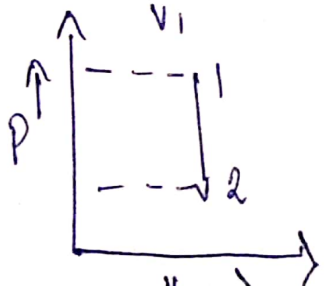
→ ① Displacement Work applied to different thermodynamic process.

1. Isobaric process: —

$$W_{1-2} = \int_{v_1}^{v_2} P dv. = P[v_2 - v_1]$$

2. Isochoric process —

$$W_{1-2} = \int_{v_1}^{v_2} P dv = 0$$



3. Isothermal process —

In this process pV = Constant.

$$pV = p_1V_1 = C$$

$$p = p_1V_1/V$$

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

$$W_{1-2} = p_1V_1 \int_{V_1}^{V_2} dV/V$$

$$= p_1V_1 [\log V]_{V_1}^{V_2} = p_1V_1 \log\left(\frac{V_2}{V_1}\right) = p_1V_1 \log\left(\frac{p_1}{p_2}\right).$$

4. polytropic process —

The process in which expansion and Contraction takes place according to the law $pV^n = C$.

$$pV^n = p_1V_1^n = p_2V_2^n = C$$

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

$$= \int_{V_1}^{V_2} \left[p_1V_1^n/V^n\right] dV$$

$$= p_1V_1^n \left[V^{n+1}/-n+1\right]_{V_1}^{V_2}$$

$$= p_2V_2^n V_2^{1-n} - p_1V_1^n V_1^{1-n} / 1-n$$

$$= \frac{p_1V_1 - p_2V_2}{n-1}$$

Heat transfer : —

Heat is defined as the form of energy that is transferred across a boundary by virtue of which temp diff betn the system and the Surroundings.

→ If the heat flows into the system or the system receives heat then heat transfer Q is taken as +ve, and if heat is rejected from the system then Q is taken as −ve.

The heat transfer takes place by three different modes —

i) Conduction → The transfer of heat betn two bodies in direct Contact is called Conduction.
→ In this heat transfer process transfer of heat from one particle to another in the diren of fall of temp.
→ In Solid particle it occurs.

ii) Convection → The process of heat transfer from one particle to another by Convection Currents i.e transfer of heat betn the wall and fluid System in motion.
→ In this case, the particles of the body move relative to each other.

Radiation :— Heat transfer bet^n two bodies separated by empty space or gases through electromagnetic waves in radiation.

Sensible heat → The heat req to change from liq state to vapour state or boiling point is called Sensible heat.

→ It is the amount of heat absorbed by 1kg of water when heated at Const prr, from the freezing point 0°C to the temp of formation of steam.

Latent heat → It is the amount of heat absorbed to evaporate 1kg of water at boiling point without change of temp.

Specific heat → The amount of heat req to raise the temp of unit mass of a substance through one degree is called sp. heat

Unit → kJ/kg.K

Mathematically heat req to raise the temp of a body is —

$$Q = m \cdot C [T_2 - T_1] \text{ in kJ.}$$

where m = Mass of substance in kg.
C = sp heat in kJ/kg.K
T_1 = Initial temp in degree or Kelvin.
T_2 = Final " " " "

Specific heat → at Const Vol^m [Cv] —

It is defined as amount of heat req to raise the temp of a unit mass of a gas by one degree at Const Vol^m.

Specific heat at Const Prr Cp :—

It is defined as amount of heat req to raise the temp of a unit mass of a gas by one degree at Const prr.

Energy :— The energy is defined as the capacity to do work.

→ In broad sense energy is classified as stored energy and transient energy.

The energy that remains within the system boundary is called store energy. Eg. potential, kinetic & Internal energy.

The energy which crosses the system boundary is known as energy in transition.

Ex. Heat, work, electricity.

Different forms of stored energy —

1. potential Energy – The energy possessed by a body by Virtue of its position or state of rest is known as potential energy.

$$PE = w \times h = mgh.$$

w = wt of the body in N.
M = mass of the body in kg.
g = Acceleration due to gravity.
h = height in mtrs.

2. kinetic energy: —

The energy possessed by a body by Virtue of its motion.

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

V = Vel of the body.

3. Internal energy: —

The energy possessed by a body or a system by Virtue of its molecular arrangement and motion of molecules.

→ The change in temp causes the change in Internal energy.

→ denoted by "U".

→ The Sum of the above three energies is the total energy of the system.

$$E = P.E + K.E + U$$

but when the system is stationary and the effect of gravity is neglected then P.E = 0 & K.E = 0.

Thus E = U.

i.e the total energy is equal to the total energy of a system.

Chapter-3 First law of thermodynamics

Introduction:— Heat & Works are different forms of the same entity called energy.

→ Energy is always Conserved;

→ Energy may enter a system as heat and leave as work and vice-versa.

Energy has two forms —

i) transit energy ii) stored energy.

The Internal energy is the stored energy. whenever heat & work enters a system, stored energy increases and when heat & Work leaves the system stored energy decreses.

First law of thermodynamics:—

Whenever heat is absorbed by a system it goes to increses its Internal energy plus to do some external Work. [pdv work]

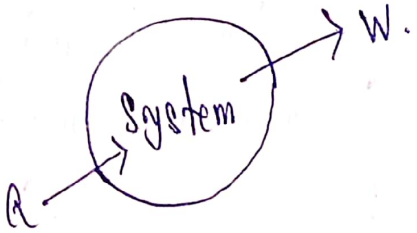
$$\boxed{Q = \Delta E + W}$$

where Q is the energy entering a system.

ΔE increses in Internal energy.

W producing some external Work.

$$\boxed{\delta Q = dE + p\,dv}$$



Sometimes more than two energy transfer, So it becomes —

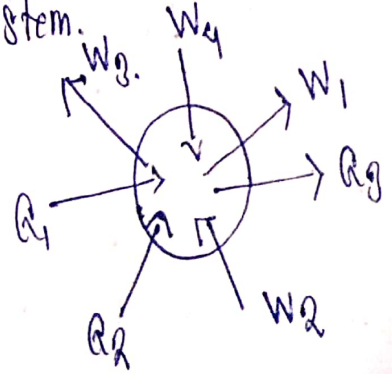
$$Q_1 + Q_2 - Q_3 = \Delta E + W_1 - W_2 + W_3 - W_4.$$

Sign Convention:—

It will be "+Q" if that heat goes into the system and "−Q" if heat goes out of the system.

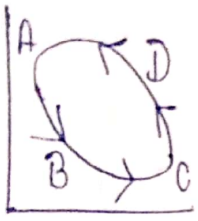
+W → when it is done by the system.

−W → is done on the system.



Cyclic process:— For a cyclic process, the work done is the area enclosed by the PV Curve.

clockwise = +W.
anticlockwise = −W.

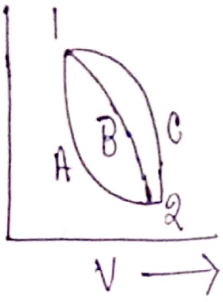


Energy as a System property:—

Let a System changes from state 1 to state 2 via path A path B and path C. which as follows −

Applying 1st law of thermodynamics to path A.

$$Q_A = \Delta E_A + W_A$$



For path B $Q_B = \Delta E_B + W_B$

If process A & B form a Complete cycle —

$$\Sigma Q = \Sigma W.$$

$$(Q_A + Q_B) = \Delta E_A + E_B + (W_A + W_B)$$

$$\Sigma Q = \Delta E_A + E_B + \Sigma W$$

$$\Delta E_A = -\Delta E_B$$

Similarly $\Delta E_B = \Delta E_C$

So it is Independent of path hence a property extensive are in nature.

Different forms of stored energy:—

Energy Can be store in a System by two modes —

i) Macroscopic mode ii) Microscopic mode.

i) Macroscopic mode:— In this mode, the mode is stored energy in two forms.

$$E_{KE} = \frac{1}{2} mv^2.$$

$$E_{PE} = mgz.$$

ii) Microscopic mode — This mode of stored energy refers to energy stored in molecular and atomic structure.

Hence it is called molecular Internal energy. or simply Internal energy.

1. Transitional KE
2. Rotational KE.
3. Vibration K.E.
4. Electronic energy.
5. Chemical energy.
6. Nuclear energy.

$$L = L_{translation} + L_{rotational} + L_{Vib} + L_{Ele} + L_{chem} + L_{Nucl.}$$

Total energy :—

$$\boxed{E = E_{KE} + E_{PE} + U}$$

In absence of motion, gravity $E_{KE}, E_{PE} = 0$.

So $E = U$

$$\boxed{Q = \Delta U + \int p\,dv}$$

First law for a closed System Undergoing a cyclic process —

i) Enthalpy Concept → Enthalpy is a state property of a System.
→ It is denoted by H.

$$\boxed{H = U + PV}$$

→ It is a point function.
→ Intensive property.
→ Sp enthalpy is given by $h = U + \frac{1}{m}PV$
$= U + PV.$

First law for a steady flow process: —

Steady flow → A flow process is one, in which a fluid enters the system and then leaves the system after work interaction.

The mass flow rate, and energy flow rate across the system boundary are constant.

Notes →

Flow work → Whenever a certain amount of mass enters a system, an amount of work is req to push the mass into the system and out of it to maintain the continuity of flow. i.e flow work = pv.

Control Volm :— For Computation of mass and energy rates during a flow process. It is convinient to focus attention upon a certain fixed region in space called Control Volm.

Control Surface —

The boundary line defining Control Volm is called Control Surface.

Stored energy of a system in a flow process:—

During a steady state flow, there is neither any accumulation of mass nor energy.

$$(\text{Mass Flow rate})_{in} = (\text{Mass Flow rate})_{out}.$$

$$\Sigma \text{Energy}_{in} = \text{Energy}_{out}.$$

Now the total energy of a fluid at any section of the Control Volm.

$$E = U + \frac{1}{2}(mv^2) + mgz$$

$$e = U + \frac{1}{2}v^2 + gz$$

As all energy is Conserved

$$\Sigma \text{Energy}_{in} + \text{Heat Flux} = \Sigma \text{Energy}_{out} + \text{Work}_{output}.$$

$$U_1 + \frac{1}{2}mv_1^2 + mgz_1 + P_1V_1 + Q = U_2 + \frac{1}{2}mv_2^2 + mgz_2 + P_2V_2$$

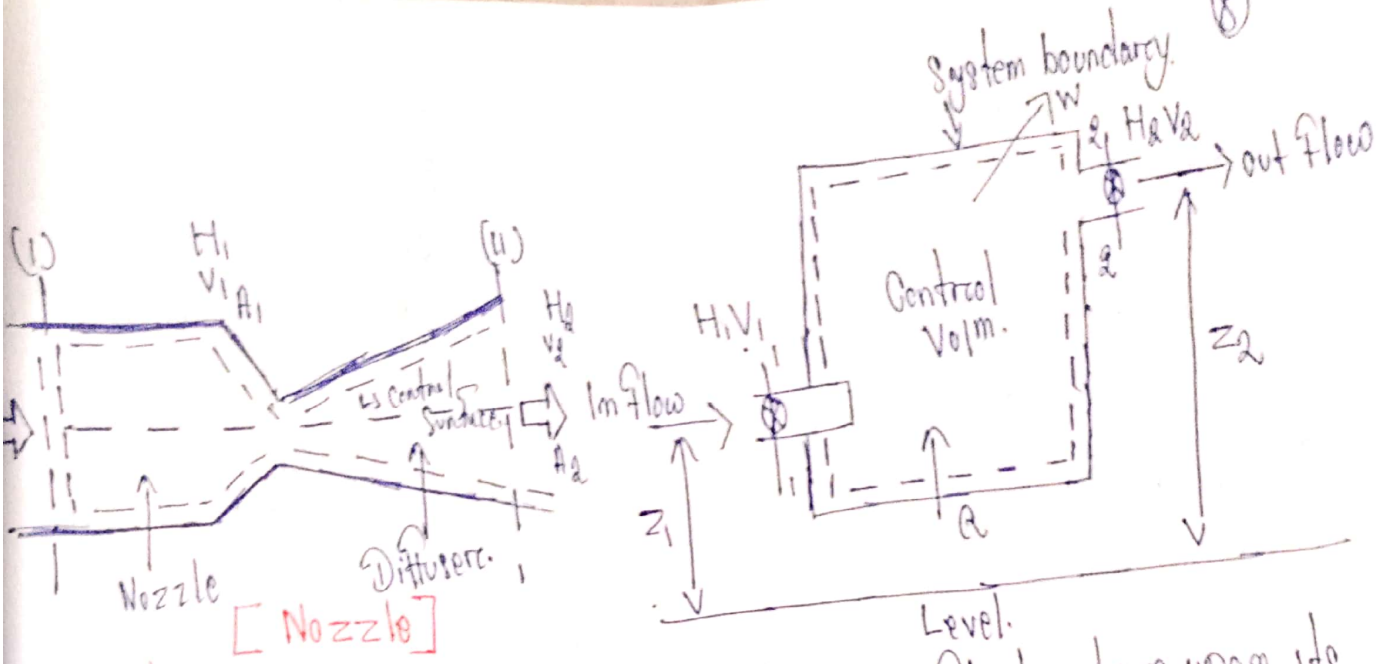
$$\left[h_1 + \frac{1}{2}mv_1^2 + mgz_1 + Q\right] + \left[h_2 + \frac{1}{2}mv_2^2 + mgz_2 + W\right]$$

On the basis of per unit mass rate of flow :—

$$h_1 + \frac{v_1^2}{2} + gz_1 + Q/m$$

$$h_2 + \frac{v_2^2}{2} + gz_2 + W/m.$$

$$\boxed{h_1 + \frac{v_1^2}{2} + gz_1 + Q = h_2 + \frac{v_2^2}{2} + gz_2 + W}$$



[Nozzle]

Nozzle: — It is a device used to throttle a fluid where upon its Pre energy is Converted into K.E.

→ The enthalpy of fluid decreases as the vel of the fluid increases bez of higher fluid vel at the nozzle outlet.

→ A nozzle is harcased to gain a high thrust in rocket and jet engines and drive Impulse type steam and gas turbine.

Compressor: — A compressor Compresses air or gas by harnessing external work fed from a prime mover.

→ The Increase in gas pr is accompained by the temp rise.

→ If the Compressor is perfectly insulated and the Compression is adiabatic then it req minor Work output to Increase the gas pr.

→ All the generated heat of Compression is expanded to Compresses the gas as no heat is allowed to escape.

So $Q = 0$.

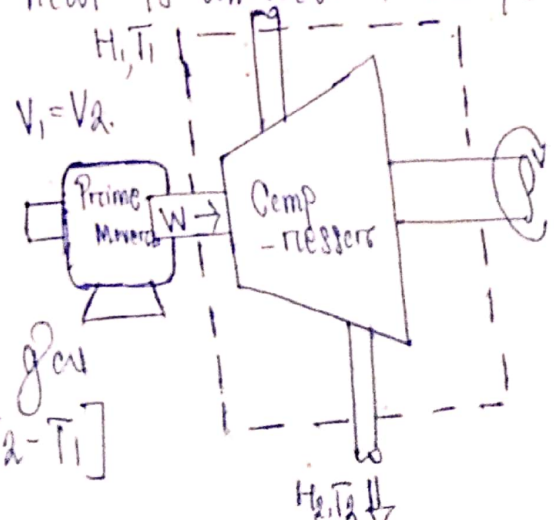
Mass flow route of the gas = M & $V_1 = V_2$.

$Z_1 = Z_2$.

$h_1 = h_2 + (-W_c)$

-Ve sign refers Workdone on gas

$W_c = M(h_2 - h_1) = MC_p[T_2 - T_1]$



Eg. An air Compressore aire from 0.1 MPa/300k to 1MP. The Compressore Casing is well Insulated. yet there is a heat loss to the Surrounding to the extent of 5%. of the Compressore Worck. cletermine aire temp at outlet and power Input given

$V_1 = 40 m/s$. $V_2 = 100 m/s$. $A_1 = 100 cm^2$ $A_2 = 20 cm^2$

$C_p = 10^3 J kg^{-1} k$

Solution →

$P_2V_2 = RT_2$

$T_2 = P_2V_2/R$.

$V_2 \rightarrow$ Sp Volm.

We have $m_1 = m_2$.

$$\frac{a_1V_1}{V_1} = \frac{a_2V_2}{V_2}.$$

$P_1V_1 = RT_1$

$$V_1 = \frac{RT_1}{P_1} = \frac{287 \times 300}{0.1 \times 10^6} = 0.861 \, m^3 kg^{-1}.$$

$$V_2 = \frac{a_2V_2}{a_1V_1} \times V_1 = \left(\frac{20}{100}\right)\left(\frac{100}{40}\right) \times 0.861 = 0.4305 \, m^3 k$$

$T_2 = P_2V_2/R$.

$$= \frac{1 \times 10^6 \times 0.4306}{287} = 1500 k.$$

$Z_1 = Z_2$.

$Q = 5\%$. W_c.

$-Q$ as rejected

$-W$ Workdone on the system.

$$H_1 + \frac{1}{2}mV_1^2 + (-Q) = H_2 + \frac{1}{2}mV_2^2 + (W_c)$$

$$-0.5W_c + W_c = M[h_2 - h_1] + m[V_2^2 - V_1^2]$$

$$0.95W_c = 0.4646 \times C_p\left[(T_2 - T_1) + \frac{1}{2}(V_2^2 - V_1^2)\right]$$

$$m = \frac{A_1V_1}{V_1}$$

$$= 0.4646 \times \left[10^3(1500 - 300) + \frac{1}{2}(100^2 - 40^2)\right]$$

$= 589$ kW. (An

Nozzle:—

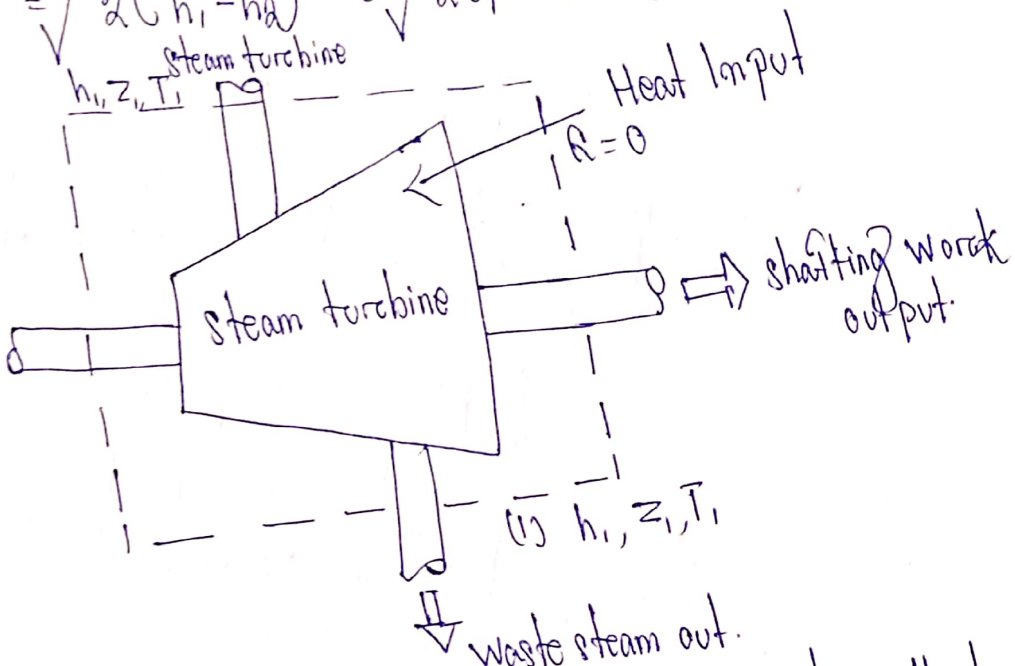
There is no work output = $W = 0$.
No heat influx or escape $Q = 0$
For a horizontal disposition $z_1 = z_2$.
And so the SFEE applied to the nozzle boils down to

$$h_1 + \frac{1}{2}(v_1)^2 = h_2 + \frac{1}{2}(v_2)^2.$$

If $v_2 >> v_1$ then.

$$v_2 = \sqrt{2C(h_1 - h_2)} = \sqrt{2C_p(T_1 - T_2)}$$

Turbine—



→ A steam turbine receives a superheated, high pr steam that experiences it.
→ Enthalpy drop as the system passes over the turbine blades.
→ This enthalpy drop is converted into kinetic energy of rotation of blades mounted on the turbine shaft.
→ The turbine is well insulated which gives rise to the max work output.
→ The turbine is well insulated.
$Q = 0$.
steam vel at the turbine input = The steam vel at the output
i.e $v_1 = v_2$.
the turbine is position horizontally. $z_1 = z_2$

Applying SFEE to the Control Vol^{m} —

$$h_1 = h_2 + w.$$

$$w = h_1 - h_2. = C_p[T_1 - T_2]$$

$$W = m \cdot C_p[T_1 - T_2]$$

Preopetual motion machine: —

It is a hypothetical machine that will continuously churn out work but without absorbing heat from its surrounding.

$$Q = 0.$$

$$\Longrightarrow \boxed{\text{PMMI}} \Longrightarrow W.$$

But such a machine is not feasible from a practical point of view. Here its violates law of conservation of energy.

$$W = 0.$$

$$\Longrightarrow \boxed{\text{PMMI (Reverse)}} \Longrightarrow Q.$$

The reverse of preopetual machine is also not true,

→ It is a hypothetical machine which is not feasible. as it violates the 1st law of thermodynamics.

Notes: —

1st law of thermodynamics: — when a closed system undergoes a thermodynamic cycle, the net heat transfers is equal to the net work transfers.

Second law of thermodynamics chapter 4

Limitation of 1st law:—

There are two basic limitations of 1st law of thermodynamics.

i) 1st law doesn't differentiate betn heat & Work—

It assumes complete Inter-Convertibility of of the two. through Work being a high grade energy can be fully converted into heat but heat can't be completely converted to work.

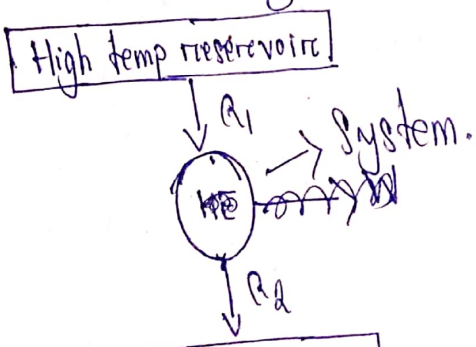
ii) It doesn't permit us to know the dirn of energy transfer. We can't ascertain whether heat will flow from a higher temp body to lower temp body.

Thermal Reservoir:—

A thermal reservoir is a heat source or heat sink that remains at a const temp. regardless of energy Interaction. otherwise a thermal energy reservoir [TER] is a large system body of Infinite heat capacity which is capable of absorbing or rejecting a finite amount of heat without any changes in its thermodynamic Co-ordinates.

The high temp reservoir (T_H) that supplies heat is a source. Sink - low temp reservoir to which heat is rejected.

Ex. Ocean Water and atm air are two good example.



Concept of heat engine:—

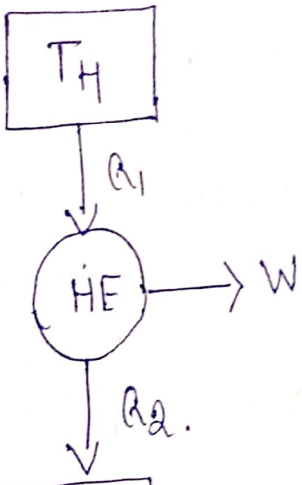
A heat engine is a device that can operate continuously to produce work rejecting heat from a high temp T_H and.

rejecting non-converted heat to a low temp sink.

$$\text{Effect} = \frac{\text{output}}{\text{Input}} = \frac{W}{Q_1}$$

but $W = Q_1 - Q_2$ in a cycle.

$$\eta_{\text{thermal}} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}.$$



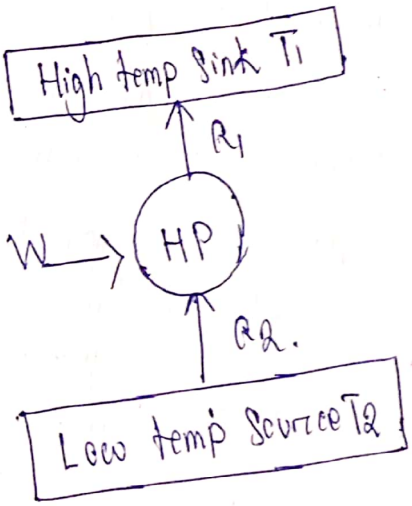
Heat pump:—

A heat pump is a reversed heat engine.

→ It receives heat from a low temp reservoir and rejects it to high temp reservoir. Here which an external work which is supplied to the pump.

→ The efficiency of a heat pump cycle is usually called the Co. of performance. (C.O.P).

→ It is the desired effect upon the external work supplied here obtaining that desired effect.



$$COP = \frac{\text{Desired effect}}{\text{Work Input}}$$

$$COP_{HP} = Q_1 / W.$$

Again $\sum Q_{\text{cycle}} = \sum W_{\text{cycle}}$.

$$Q_1 - Q_2 = W$$

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$

Refrigerators:— A refrigerators is similare to heat pump.

→ It operates as a reversed heat engine.

→ Its duty is to extract heat as much as possible from the cold body and delivers the same to high temp body.

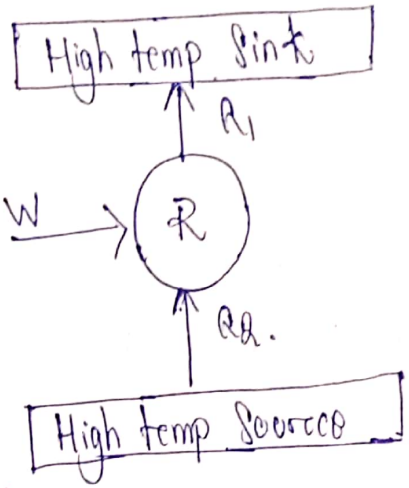
The desired effect of a refrigerators is to remove Q_2 heat Infiltrating into the cold space.
By using the external work it rejects Q_1 heat to the high temp reservoire.

$$(CoP)_{ref} = \frac{Q_2}{W}$$

Again $\sum Q = \sum W$.
cycle cycle.

$$Q_1 - Q_2 = W.$$

$$CoP_{ref} = \frac{Q_2}{Q_1 - Q_2}.$$



Statement of 2nd law of thermodynamics:—

Clausius statement:— It is Impossible to Construct a device that will produce no effect other than the transfere of heat from a low temp body to high temp body while opening In a cycle.

Kelvin plank statement —

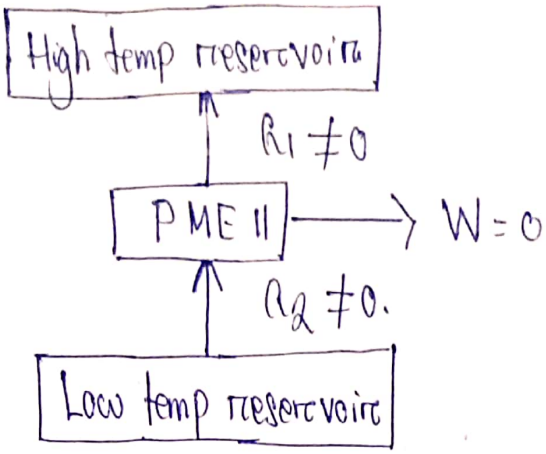
No heat engine, operating In cycle. Can Convert heat Into work.

→ It is Impossible to build a heat engine that Can register 100% efficiency.

Notes:— Kelvin Planck statement is of relevance to a heat engine. The C-statement relates more directly to a reversed heat engine.

Prepetual motion machine II:—

It is a hypothetical machine that will Continously pump out from a low temp reservoire to a high temp reservoire at (T_1) without taking up any Input work from Surrounding.



Carnot cycle:—

Carnot cycle is a hypothetical cycle developed Nicholas Sadi Carnot a French military engineer.

→ It is meant for a heat engine or reversed heat engine.

→ All the process involved in this cycle are reversible. thereby ensuring the best possible device that once could construct

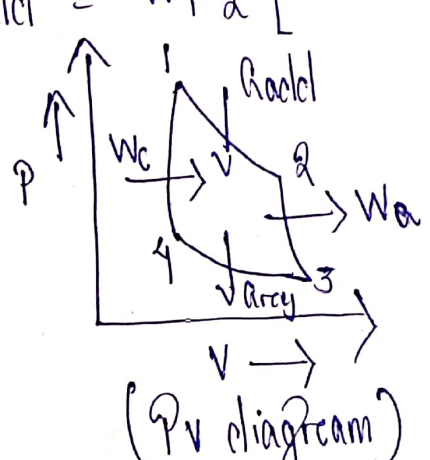
→ This cycle comprises four reversible processes.

Process 1-2:— Reversible isothermal heat addition.

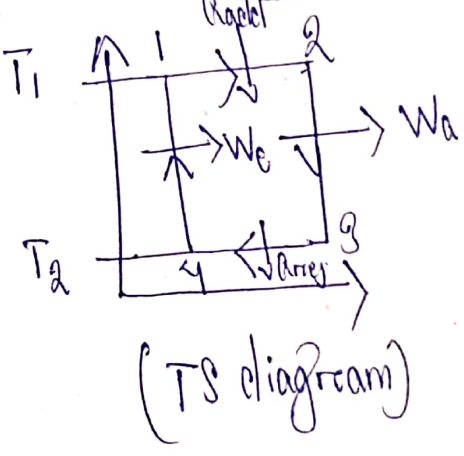
Heat (Q_{add}) flows from a high temp reservoir to the work fluid which is at a constant temp but only infinitesmally below that of the sources.

$$Q_{add} = \Delta U + W_{1-2} \quad (\Delta U = 0)$$

$$Q_{add} = W_{1-2} \quad [\text{as isothermal process}]$$



(Pv diagram)



(TS diagram)

Process 2-3 [adiabatic expansion]

The working fluid expands through a turbine or expander adiabatically producing a net positive work output.

Here $Q = 0$

$0 = \Delta U_{2-3} + W_{2-3}$.

Process 3-4 (Isothermal heat rejection).

Heat is rejected by the fluid to sink both one at a Const temp. but differe only by an intimitesimal amount.

$\Delta U = 0$, Isothermal process.

$-Q_{rej} = -W_{3-4}$.

- Q = Heat has been rejected by the system.
- W = Work has been done on the system.

Process 4-1 (Reversible adiabatic Compression)

The temp of the working fluid is released back to the temp level to high temp through adiabatic Compression. i.e $Q = 0$.

$0 = \Delta U_{4-1} + -W_{4-1}$

$\Delta U_{4-1} = W_{4-1}$

As the two Isothermal and two adiabatic Complete the cycle —

$\text{So } \sum_{\text{cycle}} Q_{net} = \sum_{\text{cycle}} W_{net}$.

$\text{or } Q_{add} + (-Q_{rej}) = W_{1-2} + W_{2-3} - [W_{3-4} + W_{4-1}]$

$Q_{add} - Q_{rej} = W_e - W_c$

So the efficiency

$$\eta = \frac{\text{Net Work output}}{\text{Net heat input}} = \frac{W_e - W_c}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}}$$

Alitere :— Refere to the T-S diagram

Net Workdone W_{net} = Area 1-2-3-4.

= Side 1-4 X Side 1-2.

$= T_1 - T_2 \times S_2 - S_1$

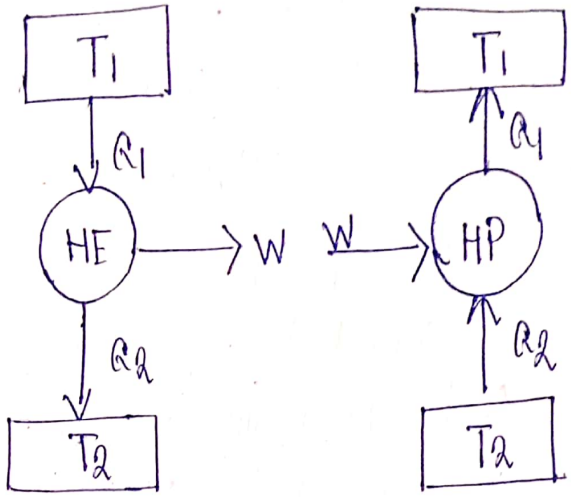
$Q_{add} = T_1 [S_2 - S_1]$

$$\text{Efficiency } \eta = \frac{W_{net}}{Q_{add}} = \frac{(T_1 - T_2)\Delta S}{T_1 \Delta S} = 1 - \frac{T_2}{T_1}$$

Application of 2nd law of heat engine, heat pump, refrigerators and determination of CoP and efficiencies: —

Clausius statement: — According to 2nd law without work input heat can't flow from low temp to high temp.

Case of heat engine: —



Kelvin planck statement: —

No heat engine operating in a cycle can convert entire heat into work. In this engine —

$$Q_1 = Q_2 + W$$

that means, Q_2 is rejected along with W output-

$$Q_1 \neq W$$

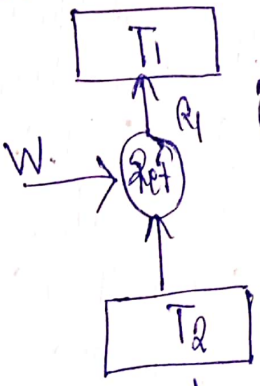
In a heat pump —

$$W + Q_2 = Q_1$$

$$W = 0, \quad Q_2 = Q_1.$$

Which is impossible $W \neq 0$.

In a refrigerators: —



$$(CoP)_{HP} = \frac{D \cdot E}{Work_{input}} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}.$$

as $\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$. [According to Carnot's theorem]

$$(CoP)_{Ref} = \frac{D \cdot E}{Work_{ref}} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}.$$

$$\boxed{1 + (CoP)_{ref} = (CoP)}$$

$$1 + (CoP)_{ref} = 1 + \frac{T_2}{T_1 - T_2} = \frac{T_1 - T_2 + T_2}{}$$

Notes: —

If installed backward your household air conditioner will function as a heat pump. Cooling the surrounding but heating the room

Chapter-5 Working Substance

Pure substance: — Substances whose chemical Composition is Uniform throughout the mass.

It should have the following properties: —

i) Homogeneous in Composition.
ii) Homogeneous in chemical aggregation.
iii) Invariable in chemical aggregation.

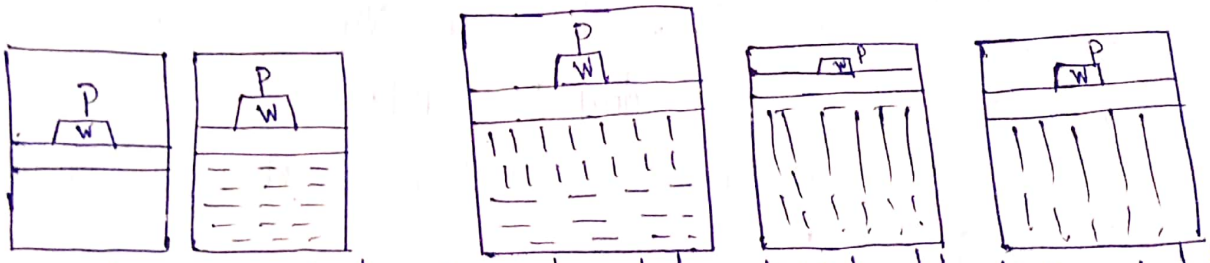
1) Homogeneous in Composition: — Composition of each part of the System is same.

2) Homogeneous in chemical aggregation — chemical elements must be Combined chemically in the same way in all parts of the system.

3) Invariable in chemical aggregation — The state of chemical Combination of the system doesn't change with time.

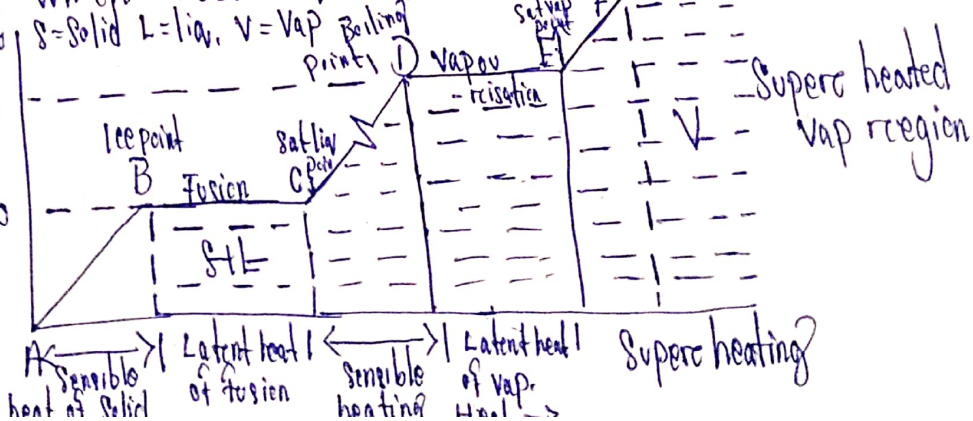
Phase change of pure Substance: —

Let the cylinder and piston machine Contains a Unit mass of ice at -10°C Under pr "p" exerted by a weight W placed on the free frictionless piston.



(i) Solid only (ii) Liquid only (iii) Saturated liq & Vap (iv) Saturated Vap only (v) Superheated Vap.

Let the ice be heated slowly so that its temp is always Uniform The changes which occure in the mass of water is —



Process A-B – Sensible heating of ice.

→ On heating the temp of ice increases from −10°C to 100°C.
→ The volm of ice also increases the point 'B' is called as ice point or freezing point of water. (0°C).

Process B-C [Fusion] –

→ On the heating ice melts into water at a const temp 0°C.
→ The heat added during the process is called as latent heat of Fusion or latent heat of ice.
→ The volm of water decreases in comparision with ice at 0°C. This is a peculiar characteristic of water.
→ but all other pure substance increases their volm during the process
→ The process in opposite dirn [C-B] is called Solidification.

Process C-D [Sensible heating of water]

→ On heating the temp of water increases from 0°C to 100°C.
→ The volm of water increases due to thermal expansion.

Process D-E [Vapourisation]

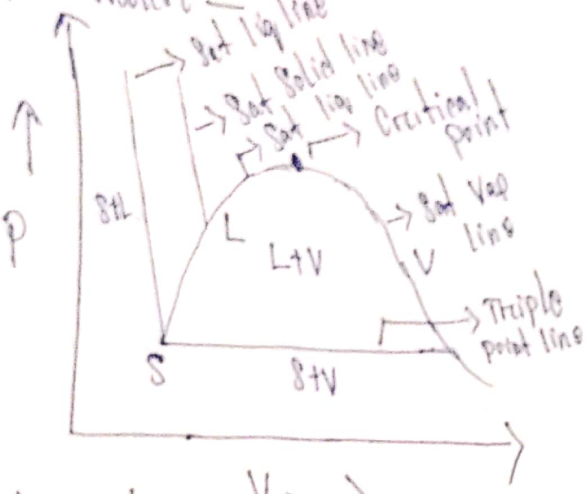
On heating the water starts boiling to vap at const temp of 100°C.
→ The heat added during the process is called latent heat of vap.
→ The volm of the mix of water and vap increases.
→ The vap at state 5 is dry saturated.
→ The process in opposite dirn [E-D] is called Condensation.

Process E-F [Superheating]

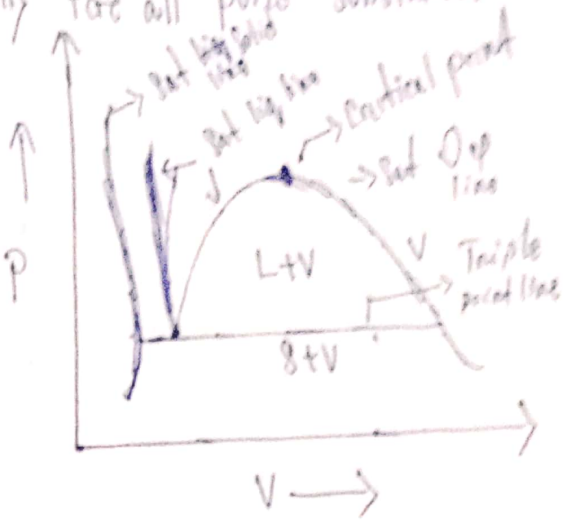
On heating the sat vap at E gets superheated & temp of the vap increases to say 200°C.
→ The volm of the vap also increases to height extent.
→ The rise in temp during the process is called degree of superheat.
→ The heat added during this process is called as heat of superheat.

P-V diagram: —

i) For waters —



ii) For all pure substances —



Solid liq mixture region [S+L] : —

The space betn saturated solid line and sat liq line w.r.t the solidification is called solid liq mixture region.

Solid region(S): —

The space left to the sat solid line is called solid region.

Liq. region(L) → The space betn & saturated liq line is called liq region.

Liq vap mixture region [L+V] :→ The space betn sat liq line w.r.t vapourisation and sat vap line is called liq vap mixture region.

Triple point line → It is a line on p-v diagram, where all three phases exist in equilibrium.

Solid vap mixture region (S+V) → The space below the triple point line is called solid vap mixture region.

Critical point →

→ The point at which the sat liq line & sat vap line meet each other is known as critical point.

→ Above the critical point, the liq on heating suddenly converted into vap are the vap on cooling suddenly converted into liq.

→ The pr, temp, & volm w.r.t critical point are known as critical pr, critical temp, critical volm.

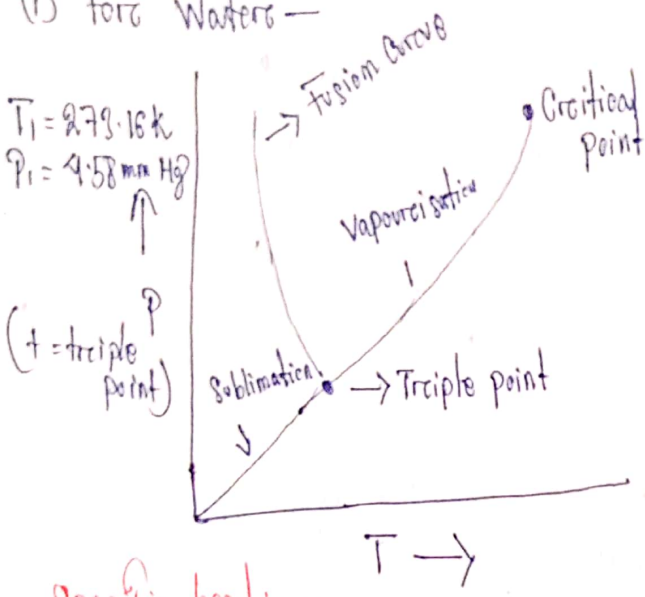
For waters → P_c = 221.2 bar, T_c = 374.15 V_c = 0.00317 m^3/kg.

Sat temp → The temp at which a pure liq [at a given pr] changes into vap.

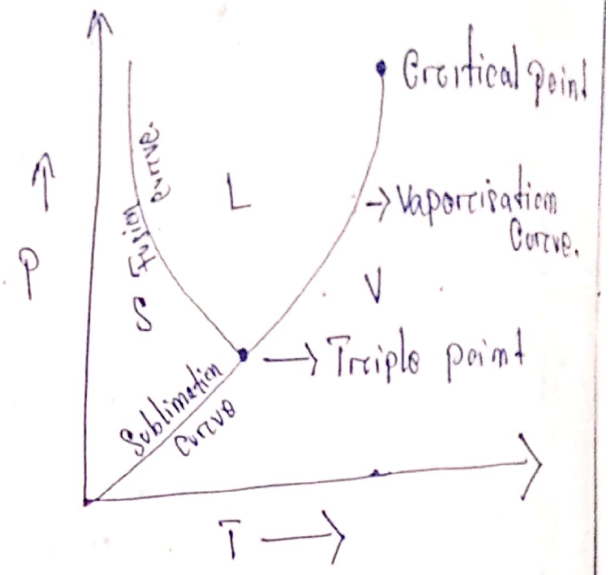
Saturated pressure → At a given temp a pure liq changes into pr. that Critical pr is called saturated pr.

P-T diagram →

(i) For Water —



(ii) For pure substance: —



Specific heat: —

→ It is defined as the amount of heat req to raise the temp of a unit mass of substance through unit degree.

→ $C = \frac{\theta}{m \cdot \Delta t}$ Unit J/kg-K. where — M = mass of substance
Δt = Rise or fall of temp.

→ Sp heat at Const pr is called Cp.

→ Sp heat at Const Volm is called Cv.

→ It doesn't depend upon path.

Quality of dryness fraction: — It is defined as the ratio of mass of dry steam actually present to the total mass of the vap with contains it.

$$\text{Dryness fraction} = \frac{\text{dry steam mass}}{\text{Total mass of Vap}}$$

where —
m_g → Mass of dry Vap.
m_f → Mass of liq particle.
M → Total mass. = $(m_g + m_f)$

$$x = \frac{m_g}{m_g + m_f} = \frac{m_g}{M}$$

$(1-x)$ = wetness fraction.

$$\text{Wetness fraction} = \frac{\text{Mass of liq particle present}}{\text{Total mass of steam.}}$$

Here dry saturated Vap quality = 100%. $x = 1$.

(i) $V = V_f + V_g$.

V_f = Volm of liq particle present.

V_g = Volm of Vap present.

$$V = V_f + x V_{fg}$$
$$S = S_f + x S_{fg}$$
$$U = U_f + x \cdot U_{fg}$$

$V_{fg} = V_g - V_f$
$S_{fg} = S_g - S_f$
$h_{fg} = h_g - h_f$

Head of Superheat $h_s = C_p [T_{sup} - T_{sat}]$

$T_{sup} - T_{sat}$ = Degree of Superheat.

Steam table: — The properties of water are arranged in the steam table as the function of temp & prr.

If temp given — then it is a Case of Superheat.

$$V = V_1 + \frac{V_2 - V_1}{T_2 - T_1} \times \text{given } T.$$

$$h = h_1 + \frac{h_2 - h_1}{T_2 - T_1} \times \text{given } T$$

$$S = S_1 + \frac{S_2 - S_1}{T_2 - T_1} \times \text{given } T.$$

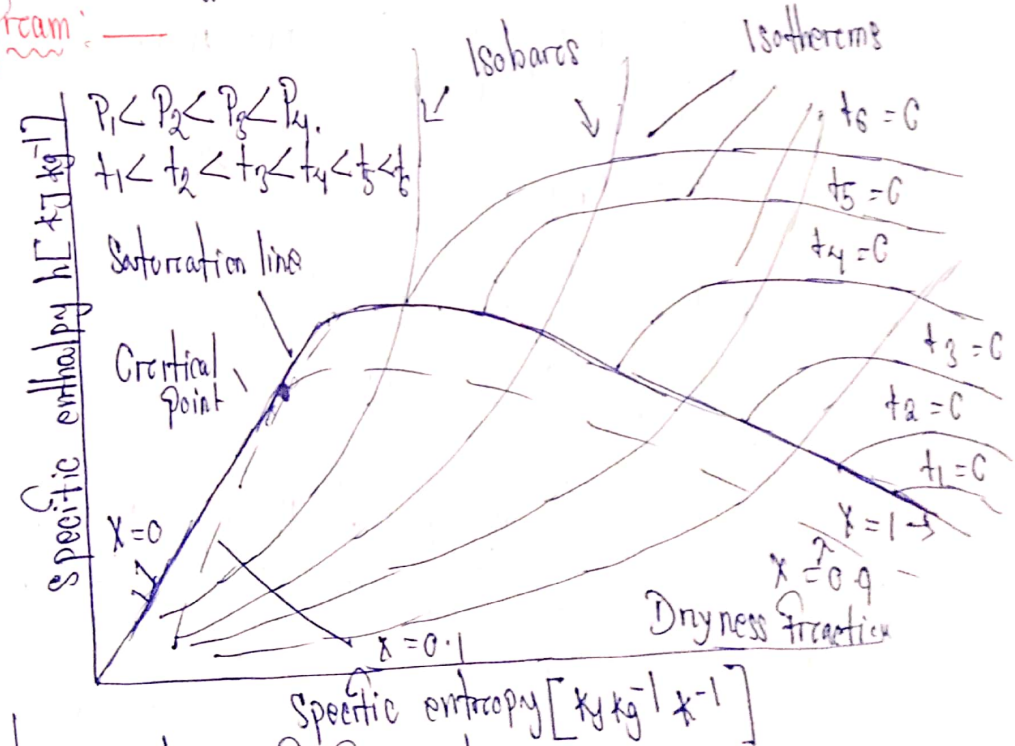
If given Volm → steam table Volm it is a Case of Superheat

$$T = T_1 + \frac{T_2 - T_1}{V_2 - V_1} \times \text{given } T.$$

$$h = h_1 + \frac{h_2 - h_1}{V_2 - V_1} \times \text{given } T$$

$$S = S_1 + \frac{S_2 - S_1}{V_2 - V_1} \times \text{given } T.$$

Molliere diagram: —



Const prr line = $P_1, P_2 \ldots$ etc.

" temp " = $t_1, t_2 \ldots$ etc.

Ideal gases & Real gases — Chapter 6

Boyle's law → The Volm of the given mass of gas is Inversely proportional to its abs prr at Const temp.

$V \propto \frac{1}{p}$ at Const Temp. $\boxed{PV = \text{Constant}}$

Charles law → The Volm of a given mass of a gas is directly proportional to its absolute temp at Const prr.

$V \propto T$ [at Const prr.] $= \boxed{\frac{V}{T} = \text{Constant}}$

Ideal gas Law: — From Boyle's law $PV = C$.

Charles law $V/T = C$

Combining both the law $\frac{PV}{T} = C$ i.e $PV \propto T$

$PV = RT$.

This eqn is Called charecteristic gas eqn or Ideal gas eqn —

R = charecteristic gas Constant.

$= 0.287$ kJ/kg-k [for atm air]

Universal gas Constant (R_u): —

In general $PV = mRT$.

m = mass of gas. but $m = nM$.

n = No of kg moles.

M = Molecular mass of the gas.

$PV = nMRT$

$= n(MR)T = nR_uT$

R_u = Universal gas Constant. $= M \cdot R$.

$M \cdot R$ = Constant of all gases.

$\boxed{R_u = 8.314 \text{ kJ/kg}}$

Avogadro's law: — it states that the equal Volm of different Ideal gases at the Same temp & prr Contains equal no of molecules.

$n = \frac{m_1}{M_1} = \frac{m_2}{M_2} = \frac{m_3}{M_3}$

but $M = PV$.

$n = \frac{P_1}{M_1} = \frac{P_2}{M_2} = \frac{P_3}{M_3}$.

Sp Volm molecular weight = Molar Volume

$\boxed{V \cdot M = \bar{V}}$

ρ = Mass density $= 1/V$.

V = Sp. Volm.

$n = \frac{1}{M_1V_1} = \frac{1}{M_2V_2} = \frac{1}{M_3V_3}$.

$M_1V_1 = M_2V_2 = M_3V_3 = C$

Daltons law: — The pre of a mixture of gases is equal to the sum of the partial pre of the constituents.

→ The partial pre of each constituent is that pre which the gas would exact if it occupied alone at that given volm occupied by the mixture at the same temp.

$$P = P_A + P_B$$

→ It is found the dalton's law is more accurately by gas mixture at low pre.

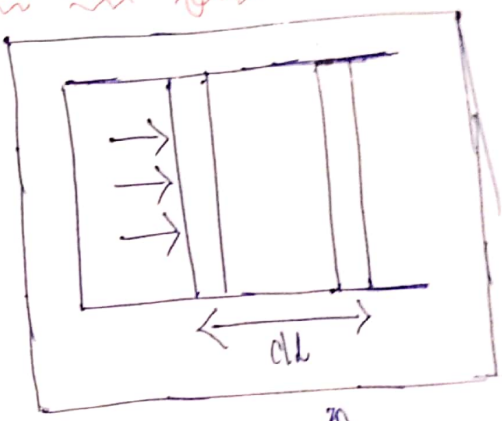
$$P = P_A + P_B + \cdots + P_n = \sum P_i$$

P_i = Partial pre of the constituent.

Workdone in moving the boundaries of a closed system: —

Consider a gas of contained in a piston cylinder arrangement pre exerted by the gas is P on the cross-sectional area of piston A.

Let the piston moves a distance dL.



Workdone = Force x displacement

$= (P \cdot A) \times dL \quad (P = F/A)$

$= P \cdot dv \quad (A \cdot dL = dv)$

Suppose, gas expands from 1 to 2 then $W.D = \int_{V_1}^{V_2} P \cdot dv$

Workdone by the system is +ve.

" " " " " -ve.

Constant volm process: —

$$W.D = P \cdot dV = 0$$

$$dW = 0$$

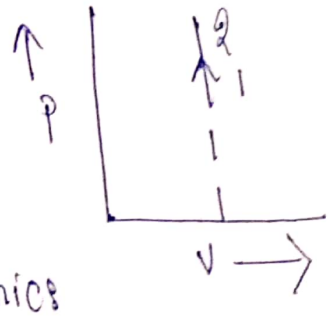
$$dQ = MC_v = dT \quad [\text{Heat supplied}]$$

According to 1st law of thermodynamics

$$dQ - dW = dU$$

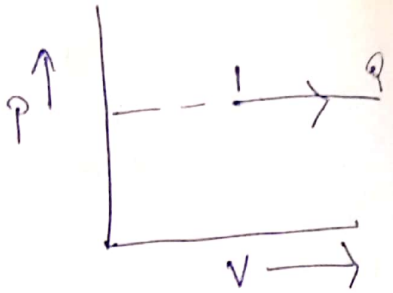
$$MC_v + dT - 0 = dU$$

$$\boxed{\Delta U = MC_v[T_2 - T_1]}$$ Isochoric process



Constant pressure process — Isobaric process

$$dw = \int_1^2 p\,dv = P[V_2 - V_1] = P_2V_2 - P_1V_1$$
$$= MR[T_2 - T_1]$$
$$P_2 = P_1 = P$$



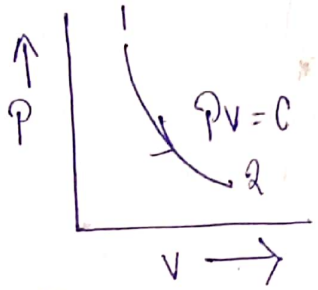
$$dQ = \int_1^2 mc_p\,dT = m \cdot c_p[T_2 - T_1]$$

$$dU = m \cdot c_p(T_2 - T_1) - m \cdot R(T_2 - T_1) = m \cdot c_v[T_2 - T_1]$$

$$\boxed{c_p - c_v = R}$$

Constant temp Process — Isothermal process

$$PV = C$$
$$P = C/V$$

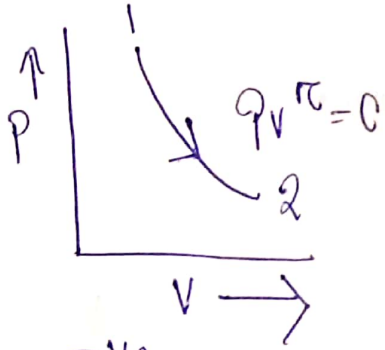


$$dw = \int_{V_1}^{V_2} P \cdot dv = \int_{V_1}^{V_2} \frac{C}{V}\,dv = C[\ln v]_{V_1}^{V_2}$$
$$= C[\ln V_2 - \ln V_1] = C \ln\left[\frac{V_2}{V_1}\right] = P_1V_1 \ln\left[\frac{V_2}{V_1}\right] = P_2V_2 \ln\left[\frac{V_2}{V_1}\right]$$
$$= m \cdot R \cdot T \ln\left[V_2/V_1\right]$$

$$dU = m \cdot c_v[T_2 - T_1] = 0$$
$$T_2 = T_1$$
$$Q - W = \Delta U = U_2 - U_1$$
$$\boxed{Q = W}$$

Isentropic process :—

No heat transfer bet^n the system & the surroundings.



Constant pressure process (Isobaric process)

$$PV^\lambda = C.$$

$$dw = \int_1^2 P \cdot dv = C\int_{V_1}^{V_2} dv/V^\lambda = C\left[\frac{V^{-\lambda+1}}{V^{-\lambda+1}}\right]_{V_1}^{V_2}$$
$$= \frac{C}{1-\lambda}\left[P_2V_2^\lambda V_2^{1-\lambda} - P_1V_1^\lambda V_1^{1-\lambda}\right]$$
$$= \frac{P_1V_1 - P_2V_2}{\lambda - 1}\left[C = P_1V_1^\lambda = P_2V_2^\lambda\right]$$

$$Q = 0$$
$$\boxed{\Delta U = W}$$