LECTURE NOTES

ON

THERMAL ENGINEERING – II

4th SEMESTER MECHANICAL

BY

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CH-1 Performance of I.C Engine Dt - 24/12/2019

*) Indicated power :- (I.P)

It is the power Actually Developed by the Engine cylinder.

$$I.P = \frac{K\ P_m L A N}{60} \quad (watt)$$

Where as

P_m = Mean effective pressure

L = Length of the stroke

A = Area of the inside cylinder or piston Area

N = Resolution per Minute

K = No. of cylinder

K = 1 2 (stroke)

K = 2 4 (stroke)

*) Brake power :- (B.P)

It is the power available at the crank shaft.

$$B.P = \frac{2\pi N T}{60} \quad (watt)$$

Where as T = torque

N = No. of Resolution Per Minute

2

Brake Dynometer:-

$$\frac{(W-S)\pi(D+d)N}{60} = \frac{N.M}{Sec} = (Watt)$$

W is weight load

S is spring load

D is Diameter of Drum

d is rope diameter or belt diameter

*) Efficiencies of I.C. Engine:-

① Mechanical efficiency:-

It is the ratio of Brake power to the indicated power.

$$\eta_M = \frac{B.P}{I.P}$$

frictional power:-

It is the lost in overcoming the engine friction is known as frictional power.

$$F.P = I.P - B.P$$

② Overall efficiency:-

It is the ratio of work obtained at the crank shaft in a given time to the

Grerrgy Supplied by the fuel durcing the Same time.

→ Energy Supplied by the fuel perc minute

$$\frac{M_f \times C_V}{60} \text{ KJ}$$

→ work obtain at crank shaft perc minute

$B.P \times 60$ KJ

Overcall efficiency $\eta_0 = \dfrac{B.P \times 60}{\dfrac{M_f \times C_V}{60}}$

$$\boxed{\eta_0 = \frac{B.P \times 360}{M_f \times C_V}}$$

Wherce as

M_f = Mass of the fuel consumption in kg perc hourc.

C_V = Calorcfic value of fuel KJ/kg

③ Indicated thermal efficiency :-

It is the ratio of the heat equivalent to 1 KW hourc to the heat in the fuel perc I.P hourc.

$$\eta_{IT} = \frac{I.P \times 60}{\dfrac{M_f \times C}{60}} = \frac{I.P \times 3600}{M_f \times C}$$

I. H. P = Indicated horse power

→ Where as $\frac{M_f}{I.P}$ is known as "Specific fuel consumption per I. P. per hour".

④ Brake thermal efficiency or overall efficiency:

→ It is the ratio of the heat equivalent to 1 KW hour to the heat in fuel per B. P. hour.

→ It is also known as "overall efficiency"

$$\eta_b = \frac{B.P \times 3600}{M_f \times C.V}$$

→ The ratio of $\frac{M_f}{B.P.}$ is known as "Specific fuel consumption per B.P per hour"

⑤ Air standard efficiency :-

Air-standard efficiency are dual cycle, otto cycle, and diesel cycle.

$$\eta_{otto} = 1 - \frac{1}{r_k^{\gamma-1}}$$

$$\eta_{Diesel} = 1 - \frac{1}{r_k^{\gamma-1}}\left[\frac{r_c^{\gamma-1}}{\gamma(r_c-1)}\right]$$

(6) Relative efficiency:-

It is the reatio of indicated theremal efficiency to the Aire standared efficiency

$$\eta_R = \frac{\eta_{It}}{\eta_A}$$

$$\eta_R = \frac{\frac{I.P \times 3600}{M_f \times C}}{1 - \frac{1}{r_K^{\gamma-1}}}$$ (otto cycle)

(7) Volumetric efficiency:-

It is the reatio of actual volume of charge admitted during the suction stroke at N.T.P (Normal tempereature pressure) to the swept volume of the piston.

$$\eta_v = \frac{V_a}{V_s}$$

*) Define Air-fuel ratio And Calorific value of fuel.

Ans) **Air-fuel ratio :-**

→ Air-fuel ratio is the mass ratio of air to a solid, liquid or gaseous fuel present in a combustion process.

→ The combustion may takes place in a controlled manner such as in an internal combustion engine or industrial furnace, or may result in an explosion.

Calorific value of fuel:-

→ It is defined as the amount of heat released by burning of unit quantity of the fuel.

→ It is also known as "heat value of fuel".

*) Mean effective Pressure and Specific fuel Consumption.

Ans:- **Mean effective pressure :-**

→ It is the algebric sum of the mean pressures on the face of the piston during each stroke over one complete cycle.

→ The pressure are taken as positive when acting in the direction of the piston movement and negative when acting opposite to the movement of the piston.

Specific fuel Consumption :-

It is defined as the amount of fuel Consumed per unit of power developed per hour.

The (specific fuel Consumption)

$$= \frac{\text{fuel consumed in kg/hr}}{\text{power developed}}$$

Ex-1

A Gas Engine has piston diameter of 150mm, length of stroke 400mm and mean effective pressure 5.5 bar, The Engine makes 120 Explosions per minute. Determine the Mechanical efficiency of the Engine, if its B.P. is 5 kW.

Ans- Given data :-

D_P = 150mm = 0.15 m n = 120

L = 400mm = 0.4 m B.P = 5kW

P_m = 5.5 bar = 5.5×10^5

$A = \frac{\pi}{4}(0.15)^2$

$= 0.0176 \ m^2$

$I.P. = \frac{P_m LAN}{60}$

$= \frac{5.5 \times 10^5 \times 0.4 \times 0.0176 \times 120}{60}$

$= 7775.4$ watt $= 7.7$ kw

$\eta_m = \frac{B.P}{I.P}$

$= \frac{5}{7.7} = 0.6497 = 64.97$

Ex-2 An Engine uses 6.5 kg of oil per hour of calorific value 30,000 KJ/kg. If the B.P. of the Engine is 22 kw and Mechanical efficiency 85%.

Calculate:

(i) Indicated thermal efficiency

(ii) Brake thermal efficiency

(iii) Specific fuel Consumption in kg/B.P/hr

Given data :-

fuel of Mass (M_f) = 6.5 kg

Calorific value (C) = 30,000 kJ/kg

B.P. = 22 kW

Mechanical efficiency (η_M) = 85% = 0.85

(i) Indicated thermal efficiency :

By using Mechanical efficiency formula

$$\eta_M = \frac{B.P}{I.P}$$

$$I.P = \frac{B.P}{\eta_M}$$

$$= \frac{22}{0.85} = 25.88 \text{ kW}$$

∴ indicated thermal efficiency,

$$\eta_{it} = \frac{I.P \times 3600}{M_f \times C}$$

$$= \frac{25.88 \times 3600}{6.5 \times 30,000} = 0.48 \text{ or } 48\%$$

(ii) Brake thermal efficiency:

$$\eta_{bt} = \frac{B.P. \times 3600}{M_f \times C}$$

$$= \frac{2.2 \times 3600}{6.5 \times 30{,}000} = 0.406 = 40.6\%$$

3) Specific fuel consumption :-

By using specific fuel consumption

$$= \frac{M_f}{B.P.} = \frac{6.5}{22} = 0.295 \ KJ/B.P/h$$

14/01/2020

Ex-1:- During the test on single cylinder oil Engine, working on the four stroke cycle and fitted with a rope brake, the following readings are taken:

Effective diameter of brake wheel = 630m

Dead load on brake = 200N; Spring balan reading = 30N; Speed = 4.50 R.P.m; Area of indicator diagram = 420 mm²; Length of indicator diagram = 60 mm ; Spring scale = 1.1 bar per mm; Diameter of cylinder = 100 mm ; stroke = 150 mm; Quantity of oil used = 0.815 kg/h ; calorific value of oil = 42,000 KJ/kg.

Calculate brake power, indicated power, Mechanical efficieny, brake thermal efficiency and brake specific fuel consumption.

Soln:- Given data :-

$K = 1$

$l = 60mm$

$D = 630\ mm = 0.63\ m$

$s = 1.1\ bar/mm$

$W = 200N$

$D_c = 100\ mm = 0.1\ m$

$S = 30N$

$L = 150mm = 0.15\ m$

$N = 450\ R.P.M$

$m_f = 0.815\ kg/h$

$a = 420\ mm^2$

$C = 42000\ KJ/kg$

Brake power $= \frac{(W-S)\pi DN}{60}$

$= \frac{(200 - 30)\pi \times 0.63 \times 450}{60}$

$= 2.52\ kw$ (Ans)

Indicated power

$$P_m = \frac{a \times s}{L} = \frac{420 \times 1.1}{60} = 7.7 \text{ bar}$$

Area of cylinder,

$$A = \pi/4 \, (D_c)^2$$

$$= \pi/4 \, (0.1)^2 = 7.85 \times 10^{-3} \, m^2$$

Number of working strokes per min,

$$n = N/2 = \frac{450}{2} = 225$$

<u>Indicated power</u> :-

$$\frac{100 K P_m L A N}{60} = \frac{100 \times 1 \times 7.7 \times 0.15 \times 7.855 \times 10^{-3} \times 225}{60}$$

$$= 3.4 \text{ KW}$$ (Ans)

<u>Mechanical efficiency</u> :-

$$\eta_m = \frac{B.P}{I.P} = \frac{2.52}{3.4} = 0.7418$$

$$= 74.18 \%$$

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Brake thermal efficiency :-

$$\eta_{bt} = \frac{B.P \times 3600}{M_f \times c} = 0.265 \text{ or } 26.5\%$$

(Ans)

Brake Specific fuel consumption :-

$$= \frac{M_f}{B.P} = \frac{0.815}{2.52} = 0.323$$

kg / B.P. / hr (Ans)

Ex:-4 A foure cylinder Engine running at 1200 r.p.m gave 18.6 Kw brake power. The avereage torque when one cylinder was cut out was 105 N.m Determine the indicated theremal η. if the calorific value of fuel is 42000 KJ/kg and the Engine uses 0.34 kg of petrol per brake power houre.

Given data :-

$k = 4$

$C = 42000$ KJ/kg

$N = 1200$ r.p.m

$M_f = 0.34$ kg/B.P./h

$B.P. = 18.6$ KW

$= 0.34 \times 18.6$

$T = 105$ N.M.

$= 6.324$ kg/h

brake power per cylinder

$= \frac{18.6}{4} = 4.65$ KW

∴ Brake power for three cylinders

$= 4.65 \times 3 = 13.95$ KW

The average torque Brake power for the three cylinder

$$= \frac{T \times 2\pi N}{60} = \frac{105 \times 2\pi \times 1200}{60}$$

$= 13200$ W $= 13.2$ KW

frictional power per cylinder

$= 13.95 - 13.2 = 0.75$ KW

∴ Total frictional power for four cylinders,

F.P $= 0.75 \times 4 = 3$ KW

Indicated power

I.P = B.P. + F.P

$= 18.6 + 3 = 21.6$

∴ Indicated thermal efficiency

$$\eta_{it} = \frac{I.P \times 3600}{m_f \times C}$$

$$= \frac{21.6 \times 3600}{6.324 \times 42000} = 0.293 = 29.3\%$$

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Chapter - 2 Air Compressor Date - 02/01/2

*) Compressor ?

→ It is a Machine, which raise the temperature and pressure of Air.

→ An air compressor, is a Machine to compress the air and to raise its pressure.

→ The air Compressor sucks air from the atmosphere, Compresses it and then delivers the same under a high pressure to a Stroage vessel. It Conveyed by the Pipeline to a place where the supply of compressed air is required. the Compression of air requires some work to be done, a Compressor by some prime mover.

*) Classification of Air Compression :-

1. According to Working

(a) reciprocating Compressor

(b) Rotary Compression.

2. According to action.

(a) Single acting Compressor

(b) Double acting Compressor

3. According to number of stages

(a) Single Stage Compressor

(b) Multi-Stage Compressor

*) Application of Air Compressor :-

→ The compressed air is used for many ~~pro~~purposes such as

(i) paint spraying

(ii) lifts

(iii) rams

(iv) pumps

(v) road drills

(vi) jet Engines

(vii) air motors

*) Important terms or Techinical terms :-

(i) inlet pressure

(ii) Discharge Pressure

(iii) Compression ratio

(iv) Compression Capacity

(v) Free-Air delivery

(vi) Swept Volume

(vii) Mean effective Pressure

(i) Inlet pressure :-

It is the absoulte pressure of air at the inlet of a compressor.

(ii) Discharge Pressure :-

It is the absoulte pressure of air at the outlet of a Compressor.

(iii) Compression ratio :-

→ It is also called as "pressure ratio".

→ It is the ratio of discharge pressure to the inlet pressure.

→ The discharge pressure is always more than the inlet pressure, the value of compression ratio is more than unity.

(iv) Compressore Capacity :-

→ it is the volume of air Delivered by a Compressor. when reduced to the normal temperature and pressure Condition.

→ and is Expressed in m^3/min or m^3/s.

(v) Free aire delivery :-

→ It is the actual volume deliverred by a Compressor when reeduced to the normal temperature and pressure condition.

→ The Capacity of a Compressor is generally Given in terms of free aire deliverty.

(vi) Swept volume (V_s):-

→ It is the volume of aire sucked by the Compressor during its suction stroke. the swept volume or displacement of a single acting aire Compressor is

$$V_s = \pi/4 \times D^2 \times L$$

where as, D = Diameter of cylinder bore,

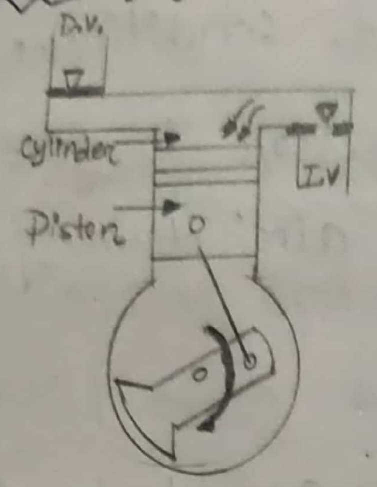
and L = length of piston stroke.

(vii) Mean effective Pressure :

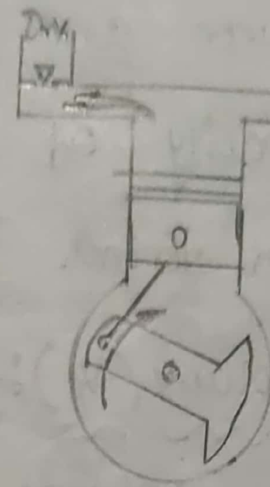
→ Aire pressure on the Compressor piston keeps on changing with the movement of the piston in the cylinder.

→ the Mean effective pressure of the compressor is found out by dividing the work done per cycle to the stroke volume

*) **Working of single stage reciprocating Air Compressor :-**



(suction stroke)



(Delivery stroke)

A single stage reciprocating air compressor, in its simplest form, consists of a cylinder, piston, inlet and discharge valves. from the geometry of the compressor,

When the piston moves downwards, the pressure inside the cylinder falls below the atmospheric pressure. Due to this pressure difference,

→ the inlet valve gets opened and air is sucked into the cylinder, at inlet pressure until the piston completes the outward stroke.

→ When the piston moves upwards, the pressure inside the cylinder goes on increasing till it reaches the discharge pressure.

→ At this stage, discharge pressure/valve gets opened and aire is delivered to the container.

→ At the end of delivery stroke, a small quantity of aire, at high pressure, is left in the clearence space.

→ As the piston starts its suction stroke, the aire contained in the clearence space expands till its ~~press~~ pressure falls below the atmosphere pressure.

→ At this stage, the inlet valve gets opened as a result of which fresh aire is sucked into the cylinder, and the cycle is repeated.

→ In a single stage acting reciprocating aire compressor, the suction, compression, expansion, and delivery of aire takes place in two strokes of the piston or one revolution of the crankshaft.

<u>note:-</u>

In a double acting reciprocating aire compressor the suction, compression and delivery of aire takes place on both sides of the piston. It is thus obvious, that such a compressor will supply double the volume of air than a single acting reciprocating compressor (neglecting volume of piston rod)

Workdone by a single stage reciprocating Air compressor :-

→ In a reciprocating air compressor, the air is first sucked, compressed and then delivered.

→ So there are three different operations of the compressor.

→ The work is done on the piston during the suction of the air.

→ work is done by the piston during compression as well as delivery of the Air. The work done by a reciprocating air compressor is equal to the work done by the compressor during suction.

→ The two important cases of work done are

(i) when there is no clearence volume in cylinder

(ii) When there is some clearence volume.

Workdone by a Single stage reciprocating air compressor without clearence volume.

Consider a single stage reciprocating air compressor without clearence volume delivering air from one side of the piston only.

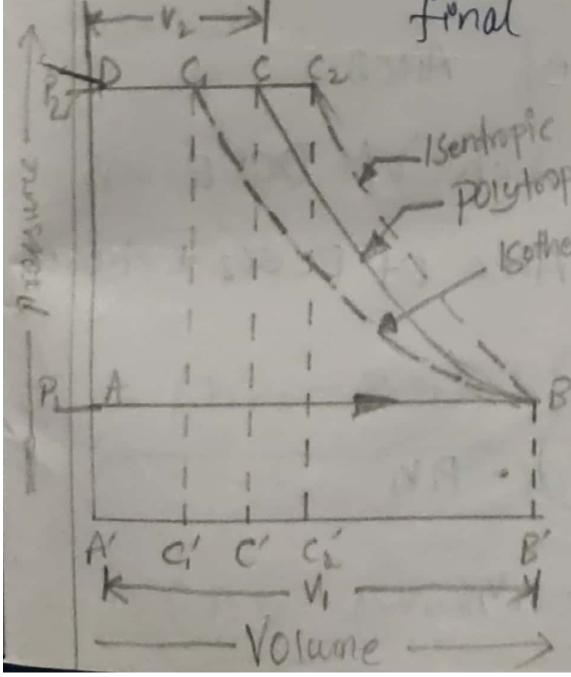
Let P_1 = initial pressure of air. (before compression).

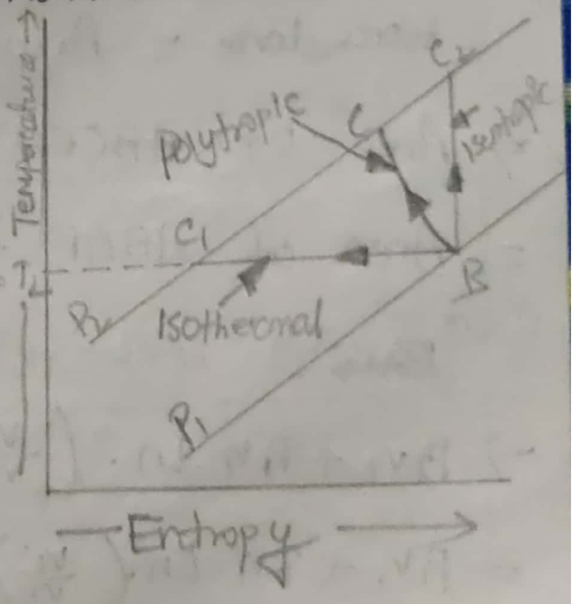
V_1 = initial volume of air. (before compression)

T_1 = initial temperature of air, (before compression)

r = Pressure ratio

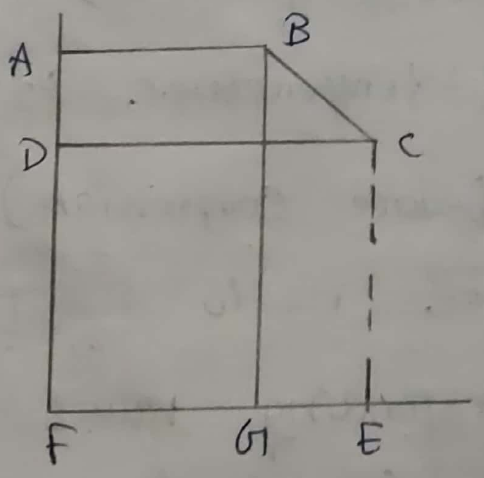
P_2, V_2, T_2 = Corresponding values for the final conditions.





(i) The P-V and T-S diagrams of single acting single stage reciprocating air compressor without clearance volume is shown. We known that during return stroke, the air compressed by the major part at constant temperature. The compression continues till the pressure (P_2) the cylinder is sufficient to force open the delivery valve at C.

(1) <u>Workdone during isothermal Compression:-</u>



Workdone = Area of ABCD

$\Rightarrow$ Area of ABCEF - Area of DCFE

= Area of ABGF + Area of BCGG + Area of BACE

$\rightarrow P_2 V_2 + P_1 V_1 \ln . \left(\frac{V_1}{V_2}\right) - P_1 V_1$

$= P_1 V_1 + P_1 V_1 \ln\left(\frac{V_1}{V_2}\right) - P_1 V_1$

$= P_1 V_1 \ln\left(\frac{P_2}{V_2}\right)$

$= P_1 V_1 \ln(R)$

$= mRT_1 \ln(R)$

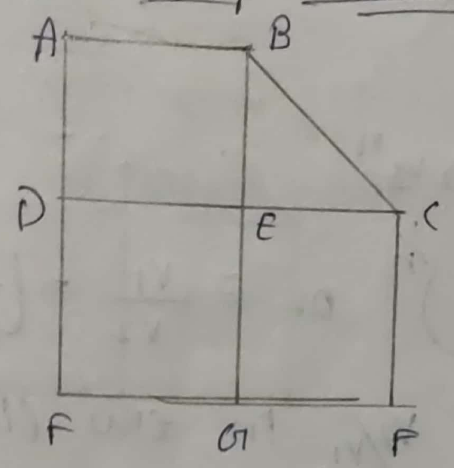
$PV = mRT$

$P_1 V_1 = mRT_1$

$P_2 V_2 = mRT_2$

$P_1 V_1 = P_2 V_2$

(2) <u>workdone during polytropic compressor:-</u>



workdone = Area of ABCD

= Area of ABEF - Area of DCEF

= Area of ABAE - Area of BDCE

$$\text{Workdone} = P_2 V_2 + \frac{P_2 V_2 - P_1 V_1}{n-1} - P_1 V_1$$

$$= \frac{(n-1) P_2 V_2 + (P_2 V_2 - P_1 V_1) - (n-1)(P_1 V_1)}{(n-1)}$$

$$= \frac{n(P_2 V_2 - P_2 V_2) - 1(P_1 V_2 - P_1 V_1 - P_1 n V_1 + P_1 V_1)}{(n-1)}$$

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

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

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

We also know that for polytropic compression.

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

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2} \right)^{1/n} \text{ or } = \frac{V_1}{V_2} = \left(\frac{P_2}{P_1} \right)^{1/n}$$

Substituting V_2/V_1 in equ (ii)

$$W = \frac{n}{n-1} \times P_1 V_1 \left[\frac{P_2}{P_1} \left(\frac{P_1}{P_2} \right)^{1/n} - 1 \right]$$

$$= \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{n-1} - 1 \right]$$

$$= \frac{n}{n-1} \times mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] \text{ — (iii)}$$

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

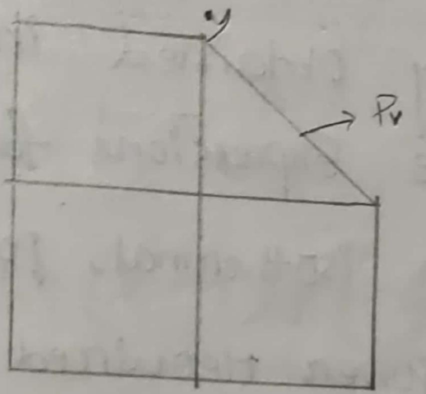
$$= \frac{n}{n-1} \times P_2 V_2 \left[1 - \left(\frac{P_1}{P_2} \right) \left(\frac{P_2}{P_1} \right)^{1/n} \right]$$

$$= n/n-1 \times P_2 V_2 \left[1 - \left(\frac{P_1}{P_2} \right)^{\frac{n-1}{n}} \right]$$

$$= \frac{n}{n-1} \times mRT_1 \left(1 - \frac{T_1}{T_2}\right)$$

$$= \frac{n}{n-1} \times mR \left(T_2 - T_1\right) \quad \text{—— (iv)}$$

Workdone isentropic Compression :-



$$\text{workdone} \quad W = \frac{\gamma}{\gamma-1} \times P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

$$= \frac{\gamma}{\gamma-1} \times mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

$$= \frac{\gamma}{\gamma-1} \times mR \left(T_2 - T_1\right)$$

Specific heat !-

$$\frac{C_p}{C_v} = \gamma, \quad \text{and} \quad C_p - C_v = R$$

$$R = C_p\left(1 - \frac{1}{\gamma}\right) = C_p\left(\frac{\gamma-1}{\gamma}\right)$$

Now workdone, $W = \frac{\gamma}{\gamma-1} \times mR\left(T_2 - T_1\right)$

$= \frac{\gamma}{\gamma-1} \times M C_p \left(\frac{\gamma-1}{\gamma}\right)(T_2 - T_1)$

$= M C_p (T_2 - T_1)$

*) Power required to drive a single - stage reciprocating Air Compressor :-

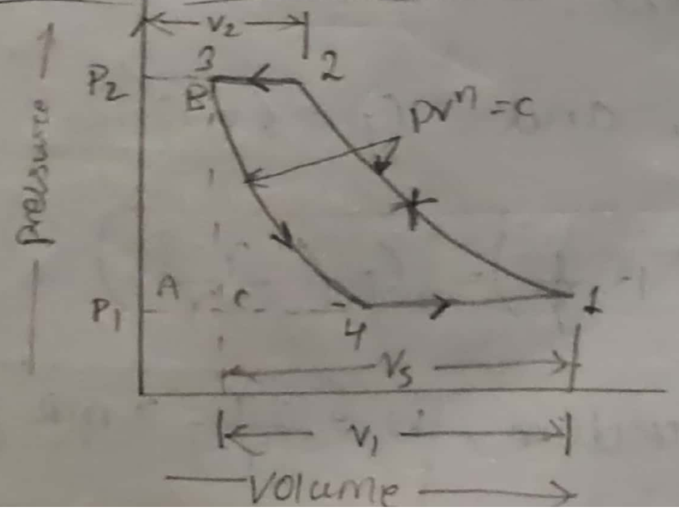
We have already obtained in the last article the Expressions for workdone per cycle during isothermal, polytropic Compression. the power required drive Compressor may relation :-

$$P = \frac{W N_w}{60} \text{ watt}$$

$N_w = N$

$= 2N$

*) Work done reciprocating Air Compressor with Clearence Volume :-



workdone area = 1-2-3-4

Area = A 1-2-B

Area = A-4-3-B

$$= \frac{n-1}{n} \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] - \frac{n}{n-1} P_1 V_4$$

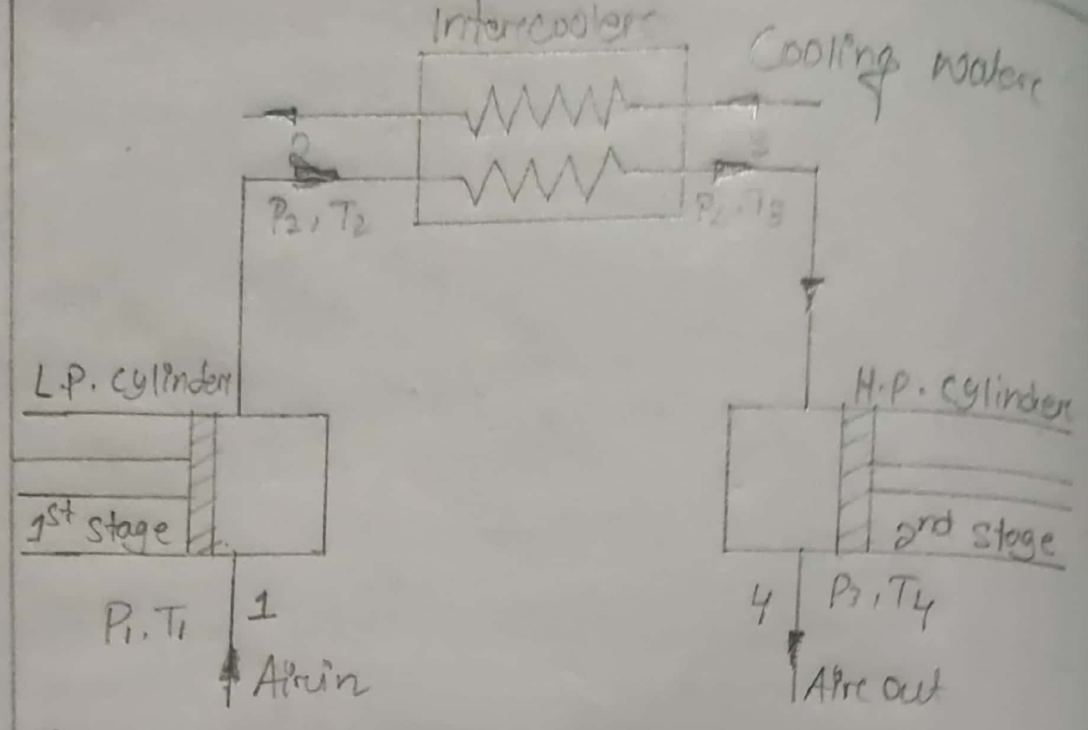
$$\left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{n}{n-1} \times P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{n}{n-1} \times mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

*) <u>Two-Stage Reciprocating Air Compressor with Intercooler :-</u>

1. The effect of Clearence is neglected.
2. There is no pressure to the in the intercooler.
3. The Compression in both the cylinders is polytropic. ($pv^n = c$)
4. The suction and delivery of air takes at constant pressure.



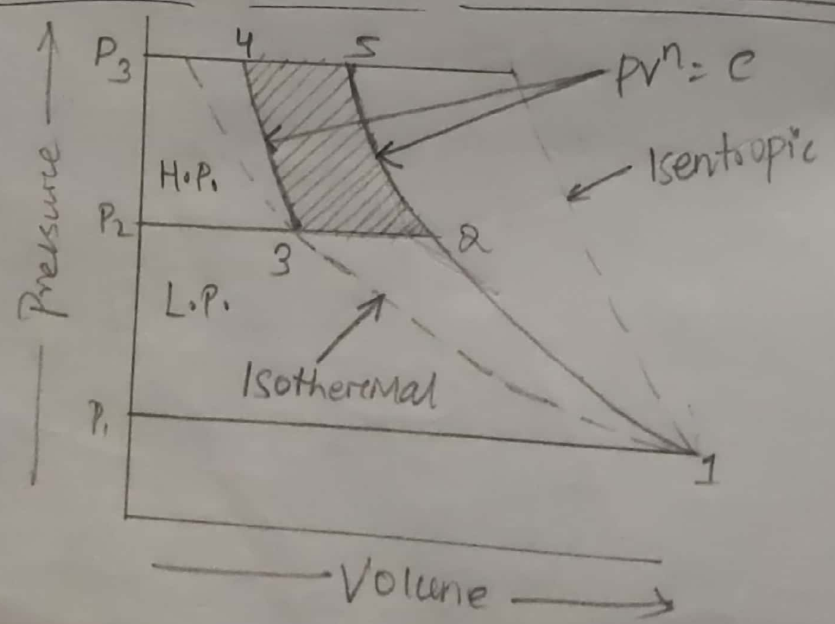
(Two-stage reciprocating Air Compressor with intercooler

Intercooling of air in 2 stage reciprocating air compressor :-

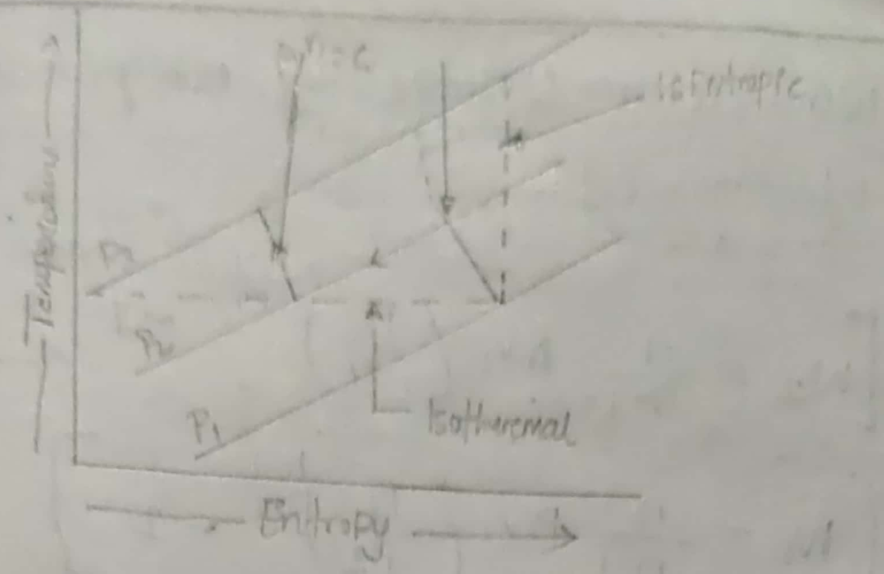
(a) Complete perfect intercooling

(b) Incomplete Imperfect intercooling.

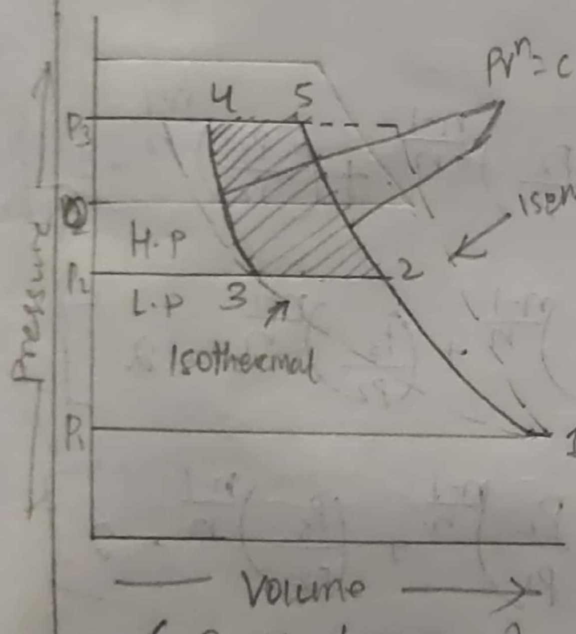
(a) **Complete perfect intercooling :-**



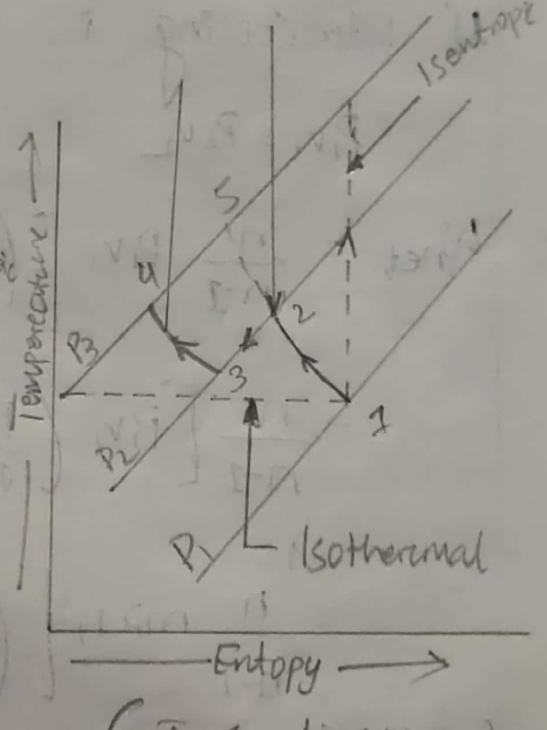
(a) P-V diagram



(Complete intercooling of Air)



(P-V diagram)



(T-S diagram)

Workdone 2 stage by reciprocating Intercooler :-

$$\left[W_1 = \frac{n}{n-1} R v_1 \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right) \right]$$

$$\left[W_2 = \frac{n}{n-1} P_1 V_1 \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1 \right]$$

Incomplete intercooling of air :-

$$\frac{n}{n-1} \left[P_1 V_1 \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right) \right] + \left[P_1 V_2 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

If intercooling is Complete.

$$P_1 V_1 = P_2 V_2$$

$$W_{net} = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{n}{n-1} \left[P_1 V_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

$$= \frac{n}{n-1} mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

minimum work required of 2 stage resiprocating aire compression :-

$$\text{Workdone} = \left[\frac{n}{n-1} P_1 V_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

net work done two different with $\frac{dw}{dp_2} = 0$

$$\Rightarrow \frac{d}{dp_2}\left[\frac{n}{n-1} P_1 v_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2\right] = 0$$

$$\Rightarrow \frac{n}{n-1} P_1 v_1 \frac{d}{dp_2}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2\right] = 0$$

$$\Rightarrow \frac{d}{dp_2}\left[\left(\frac{P_2}{P_1}\right)^{a} + \left(\frac{P_3}{P_2}\right)^{a} - 2\right] \left[\frac{n-1}{n} = a\right]$$

$$\Rightarrow a \frac{1}{P_1^a} P_2^{a-1} - a P_3^a - P_2^{-a-1} = 0$$

$$\Rightarrow a \left[\frac{P_2^{a-1}}{P_1^a}\right] - P_3^a \cdot P_2^{-(a+1)} = 0$$

$$\Rightarrow \frac{P_2^{a-1}}{P_1^a} - P_3^a - P_2^{-(a+1)} = 0$$

$$\Rightarrow \frac{P_2^{a-1}}{P_1^a} = \frac{P_3^a}{P_2^{(a+1)}}$$

$$\Rightarrow P_2^{a-1} \times P_2^{a+1} = P_1^a \cdot P_3^a$$

$$\Rightarrow P_2^{a-1+a+1} = P_1^a \cdot P_3^a$$

$$\Rightarrow P_2^{2a} = P_1^a P_3^a$$

$$\Rightarrow P_2^2 = P_1 P_3 \Rightarrow P_2 = \sqrt{P_1 P_3}$$

Work done :-

$$\left[\frac{n}{n-1} P_1V_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2\right]$$

$\frac{P_3}{P_2} = \frac{P_2}{P_1}$

$$\frac{n}{n-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 2\right]$$

$$\frac{2n}{n-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$2 \times \left[\frac{n}{n-1} P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]\right] \text{ --- (i)}$$

If $\frac{P_2}{P_1}$ or $\frac{P_2}{P_1} = \left(\frac{P_3}{P_1}\right)^{1/2}$ putting the value eqn (i)

$$\left[\frac{n}{n-1} P_1V_1 \left(\frac{P_3}{P_1}\right)^{\frac{n-1}{2n}} - 1\right]$$

If considering 3 stage $\frac{P_2}{P_1} = \left(\frac{P_4}{P_1}\right)^{1/3}$

$$\frac{P_2}{P_1} = \left(\frac{P_4}{P_1}\right)^{1/3}$$

$$3 \times \left[\frac{n}{n-1} P_1V_1 \left(\frac{P_4}{P_1}\right)^{\frac{n-1}{3n}} - 1\right]$$

$$\left[\frac{Mn}{n-1} P_1V_1 \left[\left(\frac{P_{m+1}}{P_1}\right)^{\frac{n-1}{mn}} - 1\right]\right]$$

Qu-1 A two stage compression takes 2.82 m³ of air per minute at a pressure 1.05 bar and temperature 22°c It deliver the at 8.44 bar the compression is carried out in each cylinder According to Law $Pv^{1.2} = C$. The air is cooled its initial temp intercooler. neglecting clearence find the minimum power required to drive compressor.

Given data:-

$V_1 = 2.82 \ m^3/min$

$P_1 = 1.05$ bar

$T_1 = 22°c = 22+273 = 295$ K

$P_3 = 8.44$ bar

$n = 1.2$

$P_2 = \sqrt{P_1 P_3} = \sqrt{1.05 \times 8.44} = 2.9777$ bar

And minimum work required the Compressor:-

$$W = 2 \times \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= 2 \times \frac{1.2}{1.2-1} \times 1.05 \times 10^5 \times 2.82 \left[\left(\frac{2.977}{1.05} \right)^{\frac{1.2-1}{1.2}} - 1 \right]$$

$$= 35.5 \times 10^5 (1.19 - 1) = 674500 \ N\text{-}m/min$$

Power required the Compressor :-

$\Rightarrow \frac{674500}{60} = 11.24$ KW (Ans)

Qu 2 A single acting Reciprocating air Compressor has cylinder diameter stroke 200 mm and 300mm Respectively. The Compressor air at 1 bar and 27° and deliver delivered it at 5.5 bar. if Compressor follows the law $PV^{1.3} = C$ and clearance volume is 5% stroke volume

determine : Rems 300 R.P.M.

Given data :-

$D = 200$ mm $= 0.2$ m

$L = 300$ mm $= 0.3$m

$P_1 = 1$ bar $= 1 \times 10^5$ N/m^2

$T_1 = 20°c = 20 + 273 = 293$ K

$n = 1.3$

$V_c = 5\%$

$N = 500$ R.P.M.

$V_s = \pi/4 \times D^2 \times L = \pi/4 \times (0.2)^2 \times 0.3$

$= 0.00942$ m^3

Clearence volume,

$v_c = 5\% \; v_s = 0.05 \times 0.00942$

$= 0.00047 \; m^3$

$v_1 = v_c + v_s$

$= 0.00047 + 0.00942$

$= 0.00989 \; m^3$

Clearence volume:-

$$V_4 = V_c \left(\frac{P_2}{P_1}\right)^{1/n}$$

$$= 0.00047 \left(\frac{5.5}{1}\right)^{1/1.3}$$

$$= 0.00174 \; m^3$$

Swept volume

$$V_1 - V_4 = 0.00989 - 0.00174$$

$$= 0.00815 \; m^3$$

Compressore per cycle:-

$$W = \frac{n}{n-1} \times P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{1.3}{1.3-1} \times 1 \times 10^5 \times 0.00815 \left[\left(\frac{5.5}{1}\right)^{\frac{1.3-1}{1.3}} - 1\right]$$

$= 9702$ N-m.

Qu-3 A three stage compressor delivers air at 70 bar from pressure at 1 bar 30°c. Assuming the Inter cooling Complete estimate three amount of minimum work Required to deal with 1 kg air Also find amount of heat rejected in each Inter cooler the index of compression 1.2 through take Cp of air = 1.005 KJ/kg.K.

Given data :-

$P_4 = 70$ bar

$P_1 = 1$ bar

$T_1 = 30°c = 30 + 273 = 303\ K$

$m = 1$ kg

$n = 1.2$

$C_p = 1.005$ KJ/kg.K

$$W = \frac{3n}{n-1} \times mRT_1 \left[\left(\frac{P_4}{P_3}\right)^{\frac{n-1}{3n}} - 1\right]$$

$$= \frac{3 \times 1.2}{1.2 - 1} \times 1 \times 287 \times 3003 \left[\left(\frac{70}{1}\right)^{\frac{1.2-1}{3 \times 1.2}} - 1\right]$$

$= 417.07$ KJ

$$\Rightarrow \frac{P_2}{P_1} = \left(\frac{P_4}{P_1}\right)^{1/3} = \left(\frac{70}{7}\right)^{1/3} = 4.12 \text{ bar}$$

We know that

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = (4.12)^{\frac{1.2-1}{1.2}} = 1.266$$

$$T_2 = T_1 \times 1.266$$

$$= 303 \times 1.266 = 383.6 \text{ K}$$

$$\therefore C_p = (T_2 - T_3)$$

$$= 1.005\,(383.6 - 303)$$

$$= 81 \text{ KJ} \quad \text{(Ans)}$$

Chapter-3 Properties of steam

*) Difference between Gas & Vapour :-

Vapour :-

(i) A substance which under ordinary condition is a solid or a liquid but under specific conditions is in gaseous state is called "Vapour."

(ii) A vapour is a gas produced by heating a solid or liquid that can return to its liquid or solid state under High pressure at ordinary temperature.

(iii) It is considered to be an unstable state and changes to liquid state at room temperature.

Gas :-

(i) When a substance exists in gaseous state under ordinary conditions i.e., at room temperature, then it is termed as a gas.

ex:- Oxygen, Nitrogen, hydrogen, etc.

(ii) Most of the gasses need High pressure and low temperatures to return to their liquid or solid state.

(iii) It is considered to be a stable state. It does n't change into liquid easily.

* Formation of steam :-

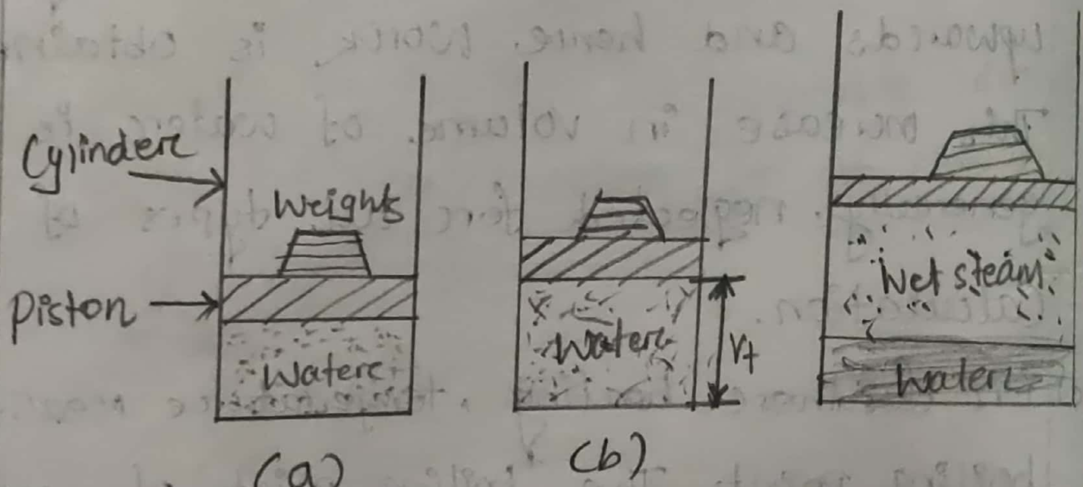
a) The piston and weights maintain a constant pressure in the cylinder. If we heat the water contained in the cylinder, it will be converted into steam as discussed below

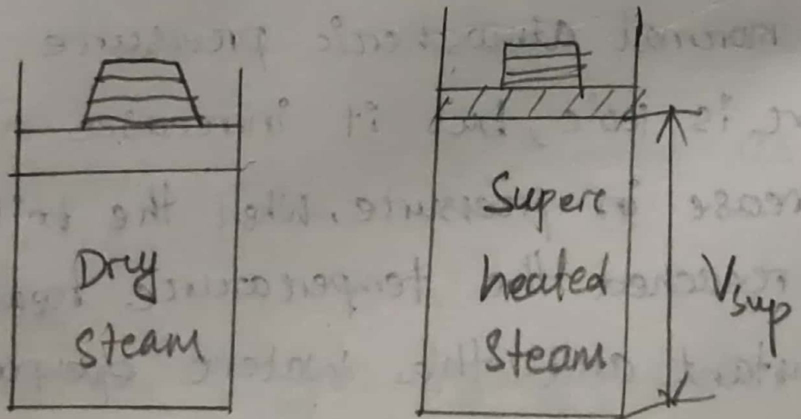
(b) It will cause the piston to move slightly upwards and hence work is obtained This increase in volume of water is generally neglected for all types of calculation.

(c) On further heating, temperature reaches boiling point. The boiling point of water, at normal atmospheric pressure of 1.013 bar is 100°c, but it increases with the increase in pressure. When the boiling point is reached the temperature remains constant and the water evaporates, thus pushing the piston up against the constant pressure.

At this stage, the steam will have some particles of water in suspension and is termed as wet steam. This process will countinue till the whole water is converted into wet steam.

3) on the further heating, the water particles in suspension will be converted into steam. The entire steam in such a state, is termed as dry steam or saturated steam.





(Formation of steam at constant pressure)

* Defination of Steam and its properties :-

→ Steam :- (Defination)

Steam is water in the Gas phase. it is commonly formed by boiling or evoporating water. Steam i.e. saturated of superheated is invisible, however, steam often refers to wet steam, the visible mist or aerosol of water droplets formed as water vapour condenses.

Properties :-

Steam is a vapour of water, and is invisible when pure and dry, it is used as the working substance in the operation of steam engines and steam turbines. Steam does not obey laws of perfect gases, untill it is perfectly dry. it has already been discussed that when the dry vapour is heated further, it becomes superheated vapour which behaves more or less, Like a perfect gases.

*) Important terms for steam :-

i) Wet steam
ii) Dry saturated steam
iii) Supercheated steam
iv) Dryness fraction or Quality of wet steam
v) Sensible heat of water
vi) Latent heat of Vaporisation.
vii) Enthalpy or total heat of Steam
viii) Specific Volume of steam

1. Wet steam :-

When the steam Contains Moisture or particles of water in suspension, it is said to be "wet steam."

2. Dry Saturated steam :-

When the wet steam is further heated, and it does not contain any suspended particles of water, it is known as "dry saturated steam."

3. Super heated steam :-

When the dry steam is further heated at a Constant pressure, thus raising its temperature. It is said to be "super heated steam."

4. Dryness fraction or Quality of wet steam :-

It is the ratio of mass of actual dry steam, to the mass of some quantity of wet steam, and is generally denoted by "x".

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

Where,

m_g = Mass of actual dry steam.

m_f = Mass of water in suspension

m = Mass of wet steam

$= m_g + m_f$

5. Sensible heat of water :-

It is the amount of heat absorbed by 1 kg of water when heated and a constant pressure, from the freezing point (0°C) to the formation of steam, i.e. saturation temperature (F). The sensible heat is also known as "liquid heat."

The specific heat of water = 4.2 KJ/kg.K

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Mass × S.p.f. heat × Rise in temperature

$= 1 \times 4.2 \left[(t+243) - (0+273) \right] = 4.2 \text{ kJ/kg}$.

6. Latent heat of vaporization :-

It is the amount of heat absorb to evaporate 1 kg of water at boiling point / saturation temperature without change of temperature (h_{fg})

Steam Latent heat of vaporization = 2527 kJ/kg.

7. Enthalpy or total heat of steam :-

Total heat of steam = Sensible heat + Latent heat

(i) Wet steam

$$h = h_{fg} + x h_{fg}$$

x = Quality of Steam

(ii) Dry steam

In case of dry steam $x = 1$

$$h = h_g = h_f + h_g$$

(iii) Superheated system :-

In a superheated system

$$h_{sup} = h_f + x h_{fg} + C_p (t_{sup} - t)$$

$= h_g + C_p (t_{sup} - t)$

C = Specific heat

Specific volume of heat :-

It is the ratio of volume with Respect to mass volume of the steam w.r.t mass of the Steam.

→ Wet steam :-

$$V_w = V_f + x \cdot V_{fg} \quad M^3/kg$$

$$V_d = V_g$$

$$V = \frac{V}{m} = M^3/kg$$

→ Super heated steam :-

According to Charle's Law

$$V \propto t$$

$$\frac{V}{T} = C$$

$$\frac{V_1}{t_1} = \frac{V_2}{t_2} = C$$

$$\frac{V_{sup}}{T_{sup}} = \frac{V_{saturated}}{T_{saturated}}$$

$$V_{sup} = \frac{v_g \times T_{sup}}{T}$$

Entropy of steam :-

The change in heat w.r.t to temperature is known as "entropy."

Consider 1 kg of water being heated constant pressure from freezing temperature to boiling temperature than small raising temperature at the heat absorbed 1 kg of water do, then entropy :-

$$ds = \frac{dQ}{dT} \left[dQ = m \times C_w \times dT \right]$$

$$= \frac{m \times C_w \times dT}{T}$$

$$\int_0^x ds = \int_{273}^{T} \frac{C_w \, dT}{T}$$

Entropy = s

$$[s - 0] = 2.3 \, C_w [\log T]^T$$

$$S_F = 2.3 \, C_w (\log T - \log 273)$$

$$= 2.3 \, C_w \log (T/273)$$

Entropy increase during evaporation :-

It is ratio of heat observed to the

absoulte temperature.

$$S_{fg} = \frac{h_{fg}}{T}$$

$$S_{fg} = \frac{x\, h_{fg}}{T}$$

If steam is wet with dryness fraction (x) then,

$$\left[S_{fg} = \frac{x_{fg}}{T} \right]$$

Entropy at wet and dry steam :-

Wet :-

$$S_w = S_f + x \frac{h_{fg}}{T}$$

$$S_w = S_f + x\, s_{fg} \quad KJ/kg.K$$

Dry :-

$$S_d = S_f + x \frac{h_{fg}}{T}$$

$$= S_f + x S_{fg}$$

Super heated steam :-

$$S_{up} = S_g + 2 \log \left[\frac{T_{sup}}{T} \right] \times C_p$$

Thermodynamic Process of Vapour:-

$dQ = du + Pdv$

$= du + dw$

Flow process $= du - Vdp$

$dq = dh$

$= d(u + Pv)$

$= du + Pdv + vdp$

$= du - Vdp$

$dQ = Tds$ → Non-flow process

$dq = MCAT$

1. Isochoric process
2. Isobaric process
3. Isothermal process
4. Hyperbolic process
5. Reversible Adiabatic process
6. polytropic process
7. Throttling process

1. Isochoric process (Constant volume process):-

$dw = Pdv \quad (v = c)$

Volume = Constant

$u_1 = h_1 P_1 v_1$

$u_2 = h_2 - P_2 v_2$

$= h_1 - 100 \times (P_1 \times V_{g_1})$ KJ/kg

$= h_2 - 100\ P_2 \times a \times V_{g_2}$

$= h_2 - 100 P_2 V_{g_2}$

$= h_2 - 100 P_2\ V_{sup}$

$= h_2 - 100\ P_1 V_1$

heat observed :-

$dq = du + PdV$ (→ 0)

$$dq = du$$

(2) Isobaric process :-

(Constant pressure process) :-

$W = Pdv$

$= P(V_2 - V_1) \times 100$ KJ/kg

Workdone :- during the process of

$= P(V_2 - V_1) \times 100$ KJ/kg

Internal Energy :- $U_1 = h_1 - 100\ P_1 V_1$

$$du = u_1 - u_2$$
$$du = u_2 - u_1$$

$dq = du + dw$

$= u_2 - u_1 + wp(V_2 - V_1)$

$= u_2 - P_2V_2 - h_1 + 100 P_1V_1 + 100 P_2V_2 - 100 P_1V_1$

$= h_2 - 100 P_2V_2 - h_1 + 100 P_1V_1 + 100 P_2V_2 - 100 P_1V_1$

$= \boxed{h_2 - h_1 \ kJ/kg}$

③ Isothermal process :-

$PV = \text{Constant}$

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \ldots\ldots \; C}$$

$dw = P_1V_1 \log\left(\frac{V_2}{V_1}\right)$

$w = 100 \, P_1V_1 \log(V_2/V_1) \ kJ/kg$

$du = u_1 - u_2$

$\boxed{u_1 = h_1 - 100 P_1V_1}$

$h = u + PV$

$\boxed{u = h - PV}$

$dq = Tds$

$= dw + du$

$= 100 \, P_1V_1 \log(V_2 + V_1) + (h_2 - 100 P_1V_1) h_1 + 100 P_2V_2$

Adiabatic or isotropic process :-

$$w_{1-2} = \left(\frac{P_1V_1 - P_2V_2}{n-1}\right) 100 \ kJ/kg$$

$h = u_1 - u_1$

$= (h_1 - 100 P_1V_1) - (h_2 - 100 P_2V_2)$

$\Rightarrow dq = 0 \qquad \boxed{T\,ds = 0}$

$Q = dw + du$

$\boxed{dw = -du}$

If you Consider the steady flow Insentropic process :-

$$h_1 + Pv + \frac{v^2}{2g} + z_1 + dQ = h_2 + Pv + \frac{v^2}{2g} + z_2 + dw$$

$$\Rightarrow h_1 + z_1 + dQ = h_2 + z_2 + dw$$

$$\Rightarrow h_1 + dQ = h_2 + dw$$

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

$$\Rightarrow -h_1 - 100 p_1 v_1 + h_2 + 100 P_2 v_2$$

$$\Rightarrow \boxed{-h_1 + h_2}$$

If this polytropic process :-

$$W_{1-2} = \left(\frac{P_2 v_2 - P_1 v_1}{n-1}\right)$$

$$u = u_1 - u_2$$

$$= (h_1 - 100 P_1 v_1) - (h_2 - 100 P_2 v_2)$$

$$dE = du + dw$$

$$dE = \boxed{u_1 + u_2 + dw}$$

Throtting process :-

① No heat supply and Rejected $\boxed{Q_1 = Q_2 = 0}$

② No workdone by expanding fluid $\boxed{W_{1-2} = 0}$

③ No enternal Energy charges of fluid [$du = 0$]

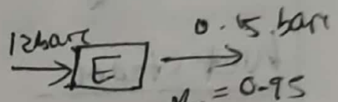
④ Enthalpy remains constant [$h_1 = h_2$]

Qu-1 A steam Enter Engine at pressure 12 bar with a 67°c Supercheat. It is Exhaust at pressure of 0.15 bar and 0.95 bar frictions. Find the 0.15 find the drop in Entropy steam Consider C_{ps}-2 kJ/kg.

Given data :-

Temp = 200°c x = 0.95

v = 0.1693 C_p = 2 kJ/kg



h = 2815.9 kJ/kg h_g = 2784.8 kJ/kg

s = 6.590

T_{sup} = 67° + 273 = 340°c

P_2 = 0.15 bar

$h_{sup} = h_g + C_g (t_{sup} - t)$

$= 2784.8 + (2 \times 340) = 3464.8$ kJ/kg

0.12 bar from steam table :-

h_f = 54.71 kJ/kg h_{fg} = 2470.6 kJ/kg

$h = h_f + x\, h_{fg} = (54.71 + 0.95 \times 2470.6)$

$= 2401.78$ kJ/kg

$dh = t_{sup} - h$

$= 3464.8 - 2401.78 = 1063.08$ kJ/kg.

Qu-2:- The dry steam is Expand in nozzle from pressure 19 bar from to 5 bar if Expansion is super saturated.

(i) The degree cooling

(ii) The degree super suctrotions.

Given data :- $P_1 = 10$ bar

$P_2 = 18$ bar

18 bar from Steam table

$v_g = 0.11042$

Wet steam

$v_f \pm v_f + x v_{fg}$

$= v_f + x(v_f - v_g)$

$v_f = x v_g = 0.9 \times 0.11042 = 0.09937$ m^3/kg

$dv = v_g - v_f$

$= 0.11042 - 0.09937 = 0.01105$ $m^3/kg.m.$

$dw = P dv$

$= 180 \times 0.01105 \times 10^5$ N/m^2

$= 18 \times 0.1105 \times 10^5$

$= 19896$ kg $= 19.8$ KJ/kg

Heat supply :-

$h_g = 2797.1$ kj/kg

$h_f = 884.79$

$h = h_f + 0.9 \times 1912.4 = 2605.95$ KJ/kg

$dh = h_g - h$

$= 2797.1 - 2605.95 = 191.75$ KJ/kg

14 bar from steam table :-

$u =$

$v_f = 0.001149$ m³/kg

$v_g = 0.14084$ m³/kg

$x = \frac{0.11042}{0.14084} = 0.078 \quad x_2 = 78.4\%$

14 steam tablet :-

$h_f = 830.30$

$h_{fg} = 1959.7$ KJ/kg

$h_2 = h_f + x_2 h_{fg}$

$= 830.30 + 0.078 \times 1959.7$

$= 2366.70$ KJ/kg

Internal Energy 18 bar steam table :-

$h = u + PV$

$u = u - PV$

$u_1 = 2797.1 - 18 \times 10^2 \times 0.11042 = 2598.34$

$u_2 = 2366.70 - 14 \times 10^2 \times 0.14084$

$= 2169.52$

$u_1 - u_2 = 2598.34 - 2169.52$

$= 428.82$ KJ/kg

Qu-3:- Calculate the internal Energy of 18 bar of steam at a pressure of 10 bar when the steam (a) 0.9 dry (b) Saturated dry the volume of water neglected.

$D = 10$ bar

10 bar steam table

$h_f = 762.6$ KJ/kg

$h_{fg} = 2013.6$ KJ/kg

$v_g = 0.1943$ m³/kg

(a) Internal Energy of 1 kg steam 0.9 dry $x = 0.9$

$u = h_f + xh_{fg} - 100\, p\, xv_g$

$= 762.6 + 0.9 \times 2013.6 - 100 \times 10 \times 0.9 \times 0.1943$

$= 2574.8 - 174.8 = 2400$ KJ

(b) Internal 1 kg of steam :-

$u = h_f + h_{fg} - 100\, Pv_g$

$= 762.6 + 2013.6 - 100 \times 10 \times 0.1943$

$= 2776.2 - 194.3 = 2581.9$ KJ

Qu-4:- find the internal energy 1 kg of super-heated steam at a pressure of 10 bar and 280°C. If the steam be Expanded to a pressure of 1.6 bar and 0.8 dry, determine the change internal energy super heated steam as 2.1 kJ/kg.

Given data :- $P_1 = 10$ bar $P_2 = 1.6$ bar

$T_{sup} = 280°C$ $x = 0.8$

$C_p = 2.1$ kJ/kg.K

10 bar of steam table

$h_f = 762.6$ kJ/kg

$h_{fg} = 2013.6$ kJ/kg

$v_g = 0.1943$ m³/kg

$t = 179.9°C$

$h_{sup} = h_f + h_{fg} + C_p(t_{sup} - t)$

$= 762.6 + 2013.6 + 2.1(280 - 179.9) = 2986.4$ kJ/kg

$V_{sup} = V_g \times \frac{T_{sup}}{T} = 0.1943 \times \frac{(280+273)}{(179.9+273)} = 0.0237$ m³/kg

$U_{sup} = h_{sup} - 100 P_1 v_{sup}$

$= 2968.4 - 100 \times 10 \times 0.237 = 2749.4$ kJ/kg.

10 bar steam table

$h_f = 475.4$ kJ/kg $h_{fg} = 2220.9$ kJ/kg

$v_g = 1.091$ m³/kg

$u_e = h_f + x h_{fg} - 100 P_2 v$

$= 475.4 + 0.8 \times 2220.9 - 100 \times 1.6 \times 0.8 \times 1.091$

$= 2252.1 - 139.7 = 2112.4$ kJ/kg

Change in Internal Energy

$\Rightarrow U_{sup} - u_e$

$= 2749.4 - 2112.4 = 637$ kJ/kg

CH-4 Steam Generator

Steam generator :-

A steam generator is a closed vessel is to transfer the heat produced by the Combustion of fuel (solid, liquid or gaseous) to water, to generate steam.

Classification of Steam boiler :-

1. According to Contents in the tube.
   - fire tube boiler
   - Water tube boiler
2. According to position of the furnace
   - internal fired boiler
   - External fired boiler
3. According to axis of the Shell.
   - Vertical boiler
   - horizontal boiler
4. According to number of tubes
   - Single-tube boiler
   - multi-tube boiler
5. According to Method of Circulation of water and Steam
   - Natural circulation boiler
   - forced Circulation boiler

6. According to use
Stationary boiler
Mobile boiler

7. According to Source of heat.
Solid,
liquid,
Gaseous,
hizard
Wasteage etc.

Important terms of steam boiler :-

(i) Boiler Shell
(ii) Combustion chamber
(iii) Grate
(iv) Furnace
(v) Heating Surface
(vi) Mountings
(vii) Accessories

Boiler Shell :- It is Made of Steel Plates bent into cylindrical form and inverted are welded together the ends of the shell are closed by means of end plates. A boiler Shell Should have Sufficient capasity to

Contaeint water and steam.

Combustion chamber :-

It is the Space generally below the boiler Shell meant for burning fuel in order to produce steam from the water Contained in the Shell.

Grate :-

It is platform of Combustion Chamber upon which fuel (coal or wood) is burnt the grate generally Consist of Cast iron bars which are Spaced a part so the Air Can pass through them.

Furnace :-

It is Space above the grate and below the boiler shell in which the fuel is actually brunt the furnace is called also fire box.

Heating Surface :-

It is that part of boiler Surface which is Exposed to the fire (hot gases from the fix)

Mountings :-

These are the fittings which are mounted on the boiler for its proper functioning.

Asscessories :-

These are the device which from an integral part of a boiler but are not mounted on it.

Comparision between fire tube & water tube boiler :-

*) **Water tube boiler :-**

→ It generates steam at a higher pressure of 165 bar.

→ The rate of generation of steam is high upto 450 tonnes.

→ It required floor area of steam generation is less

→ overall efficiency is high

→ It transported and rected easily

→ the operating Cost is High.

→ Bursting chances are rale.

→ The bursting doesn't produce any

destruction to the whole boicy.

→ It is used for large power plant.

*) Fire tube boiler :-

→ It can generate steam only 24.5 bar

→ The rate of generation of steam is low upto 9 tonnes.

→ the floor area required more.

→ Overall efficiency is low

→ The transported and erection is difficu

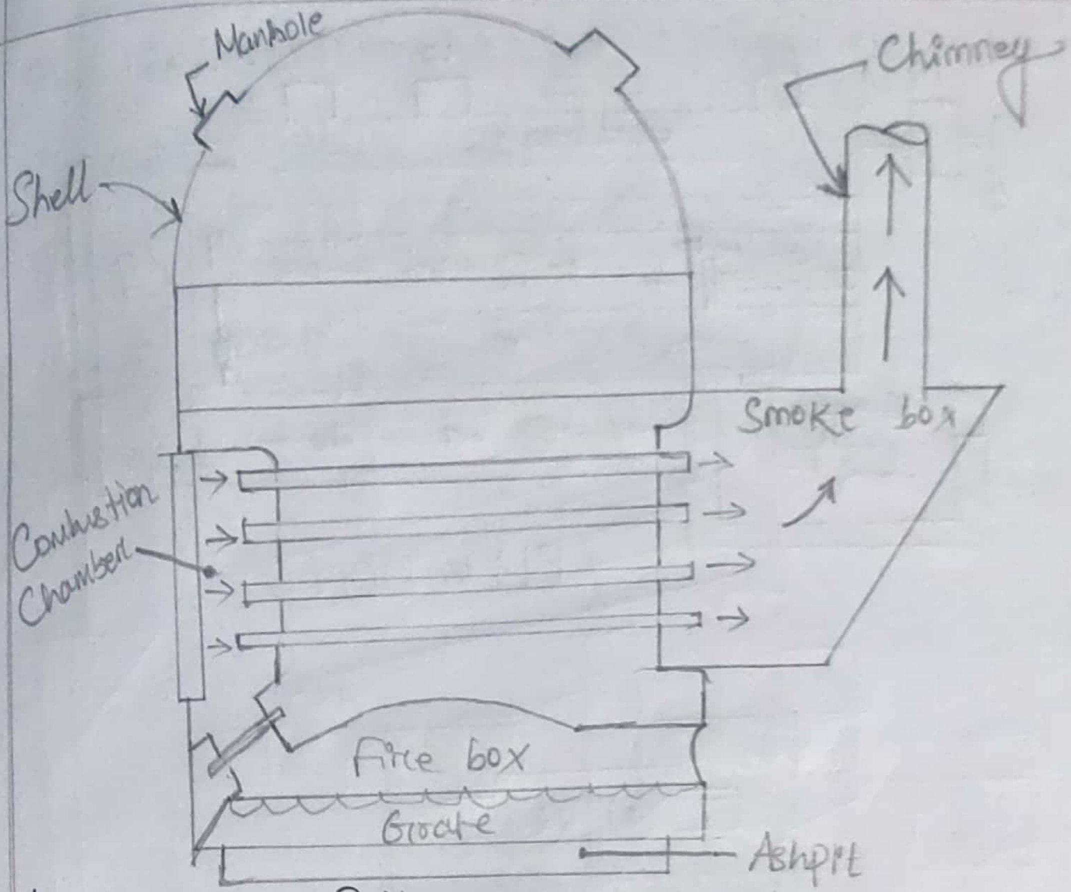
→ The operation cost is low.

→ Bursting produce greater risk.

→ It is not suitable for large plant.

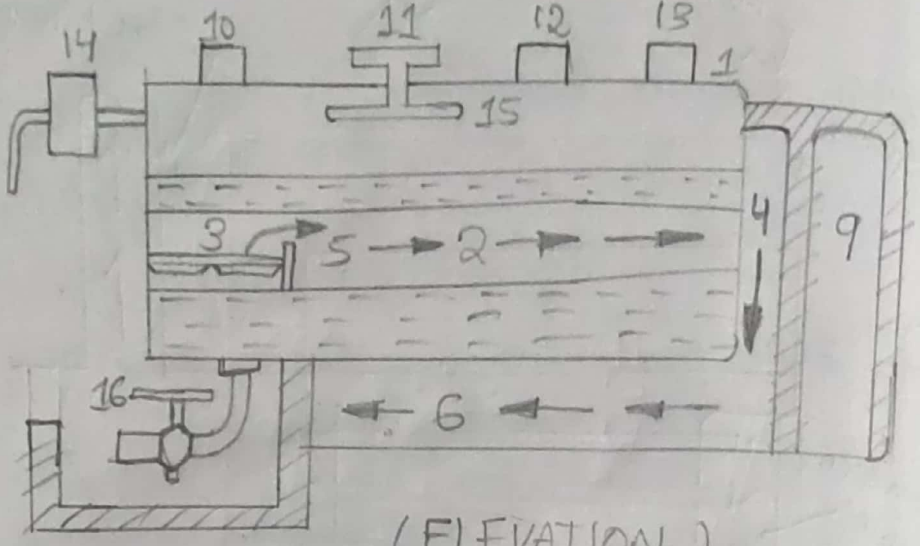
Cochran boiler :-

It is an improved type of simple vertical boiler this boiler consist of an external cylindrical shell and a fire box shell & fire box are both hemispecial the hemispercical crown of the boiler shell sheel gives maximum space and strength to withstand the pressure of steam inside the boiler.

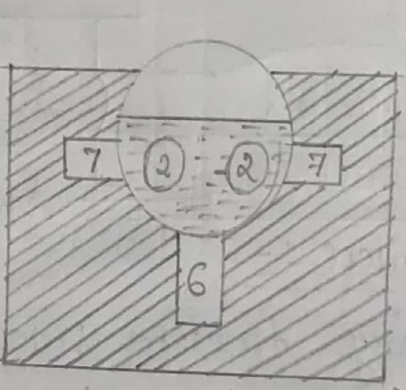


Lancashire Boiler :-

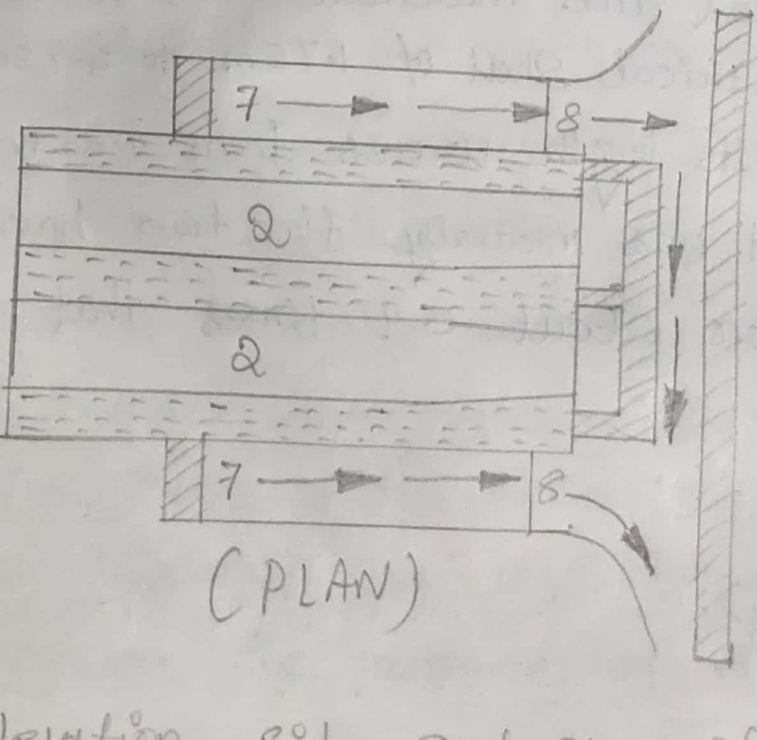
It is a stationary firetube internally fired horizontal and natural circulation boiler it is used while working pressure and powered required are moderate these boilers have a cylindrical shell of 1.75m to 2.75m diameter. Its length varies from 7.25 m to 9m it was internally fire tubes having diameter about 0.4 times that of shell



(ELEVATION)



(SIDE)



(PLAN)

(Elevation, side and plan of lancashire Boiler)

The boiler Consist of a long cylinder

External Shell

i) Built of shell plate

ii) lower port of Boiler

iii) furnace

iv)

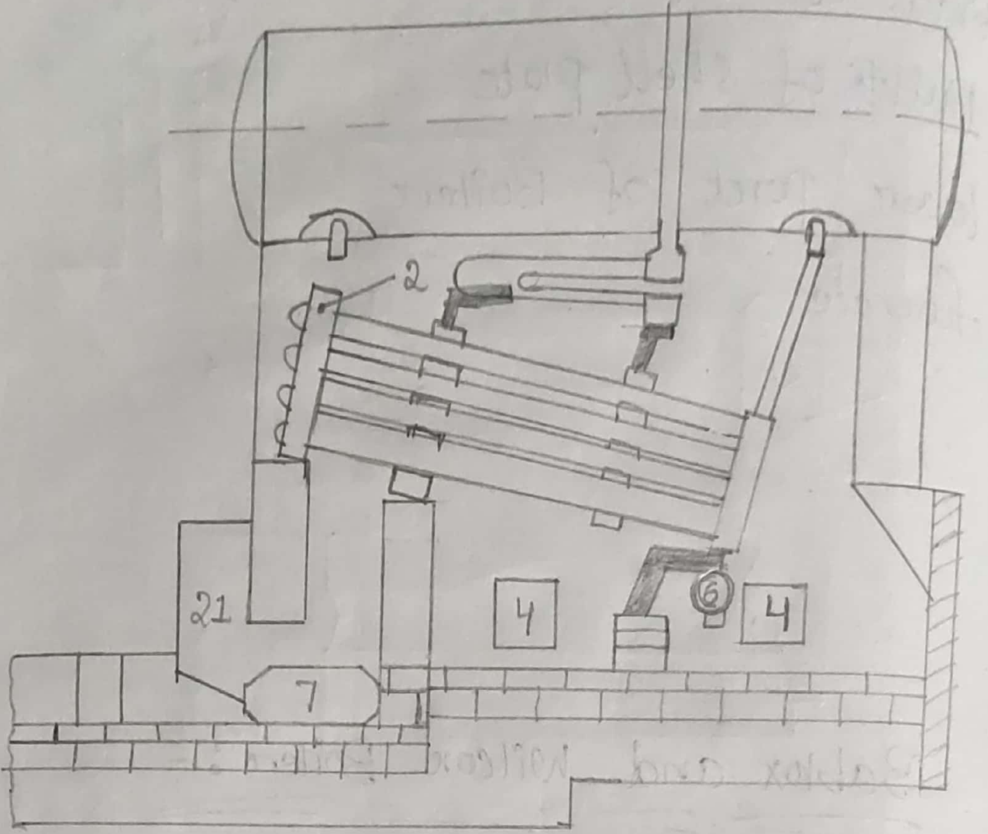
v)

vi)

Bablox and Wilcox Boiler :-

It is a straight tube stationary type water tube boiler it Consist of a steam and water drum it is Connected by a shaft tube with tip take header on riser at the back end.

The water tubes are inclined the horizontal and Connectly uptake header to down take header each row of the tubes is Connected with two headers and the are plenty of such row.



Boilere Drought :-

The fresh aire will Extirced the fuel bed if the gases of Combustion arce Exhausted from the Combustion Chamberc of the boilerc this is passible only if a differcence of pressurce is maintained above and below the firce grate this differcence of pressure is known as drought.

Types of drought :-

There are 3 types of drought :-

i) Mechanical or fan drought
ii) Steam jet drought
iii) Chimney drought

Mechanical or Fan drought :-

The draught, produce by means of a fan or blower is known as Mechanical drough or fan drought.

Steam jet drought :-

It is a simple and cheap method of producing artificial drought in a steam jet drought the exhaust steam from non-condensing steam engine is used for mostly locomotive boiler.

Chimney Boiler :-

The drought produce by means of chimney alone is known as chimney drought.

Advantages of Mechanical draught

i) It is more economical
ii) It is better in control

iii) The reate of Conbustion very high.
iv) low greade fuel can be used.
v) It reduce the almost of smoke
vi) It reduce height of Chimney.

Disadvantage of Mechanical drought:-

i) initial cast is high
ii) Its reunning Cast is also high
iii) Maintaince cast also High.

Comparcison between forced drought and induced drought.

Forced drought

1) The fan is placed before the fire greate
2) The preessure inside the furnace is above the atmosphere preessure
3) It forces fresh air into the Combustion Chamber

Induced drought :-

→ The fan is placed after the fire greate
→ The preessure inside the furnace is below the atmospheric preessure.

→ It sucks Hot gases from the Combustion Chamber and forces them into the Chimney.

Boiler Mountings and accessories :-

Boiler Mountings:-

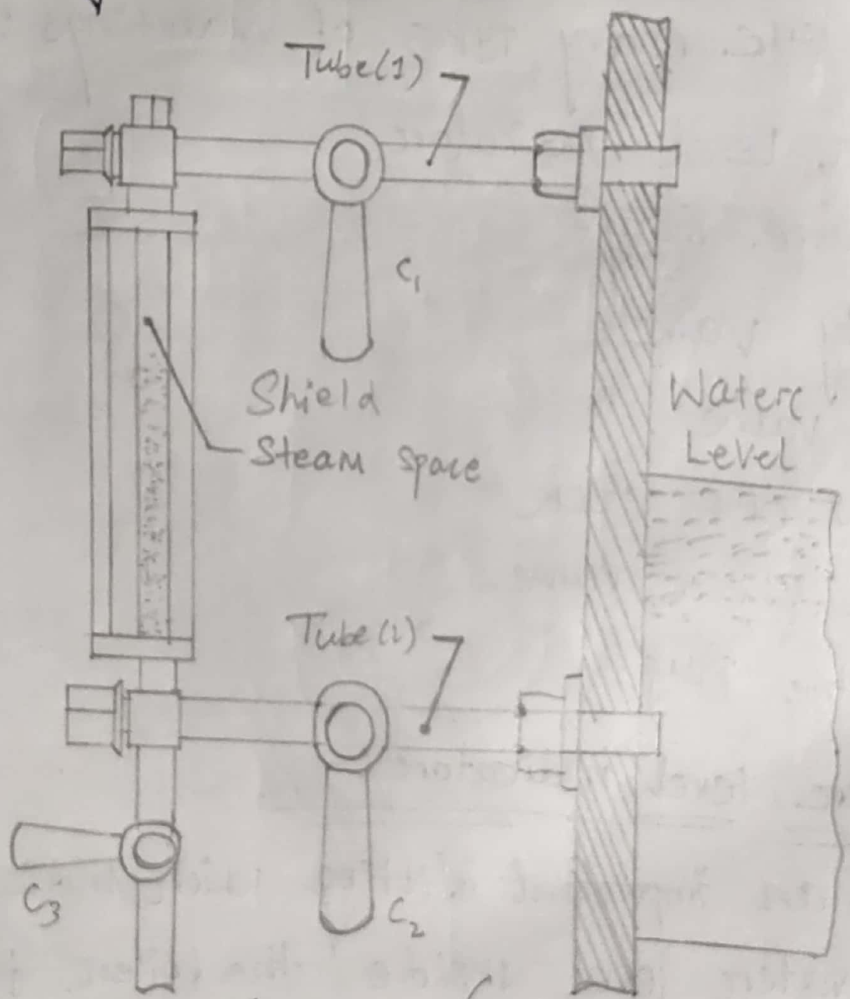
It is fitting which are mounted on the boiler for its proper and safe functioning. There are many types of Mountings :-

1. Water Level indicator
2. Pressure Gauge
3. Safety valve
4. Stop valve
5. Blow off cock
6. Feed check valve
7. fussible plug

Water level indicator :-

It is an important fitting which indicate the Water level inside the boiler to an Observer. it is a Safety device upon with the Correct working of the boiler depends there this fitting May be seen infront of the boiler and are generally two in number.

A water level indicator mostly employed in the steam boiler is it consist by of there cocks and a glass tube steam cocks. keep the glass tube in connection with the steam space water C_2 Puts the glass tube in connection in water tube.



(Water Level indicator)

Pressure Gauge :-

A pressure gauge is used to measure the pressure of the steam inside the steam boiler. it fixed in front of the steam boiler the pressure gauge generally use of bourden tube type

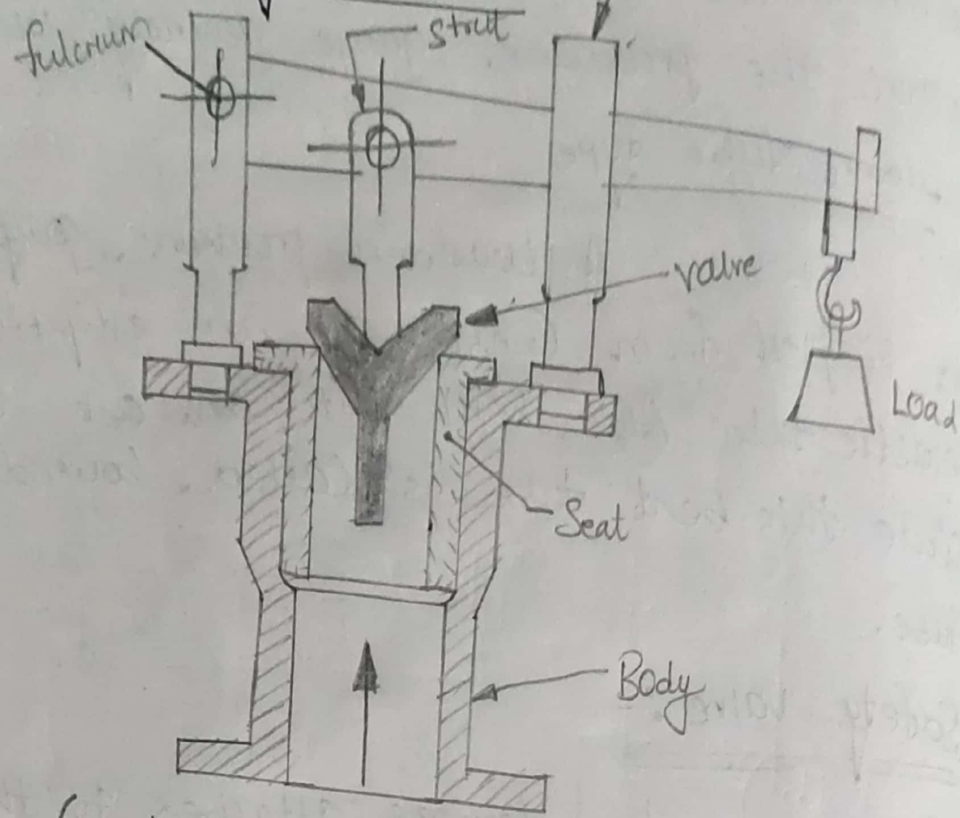
A bourden pressure gauge in its simplest from Consist of an elliptical elastic tube ABC bent into an arc of circle this bent tube is called bourden tube.

Safety valve :-

There are the devices attaches to the Steam Chest for preventing explosions due to excessive internal pressure of Steam.

1) Lever Safety valve
2) Dead Safety valve
3) high steam and low water safety valve
4) Spring loaded safety valve.

(i) Leverr Safety valve :-



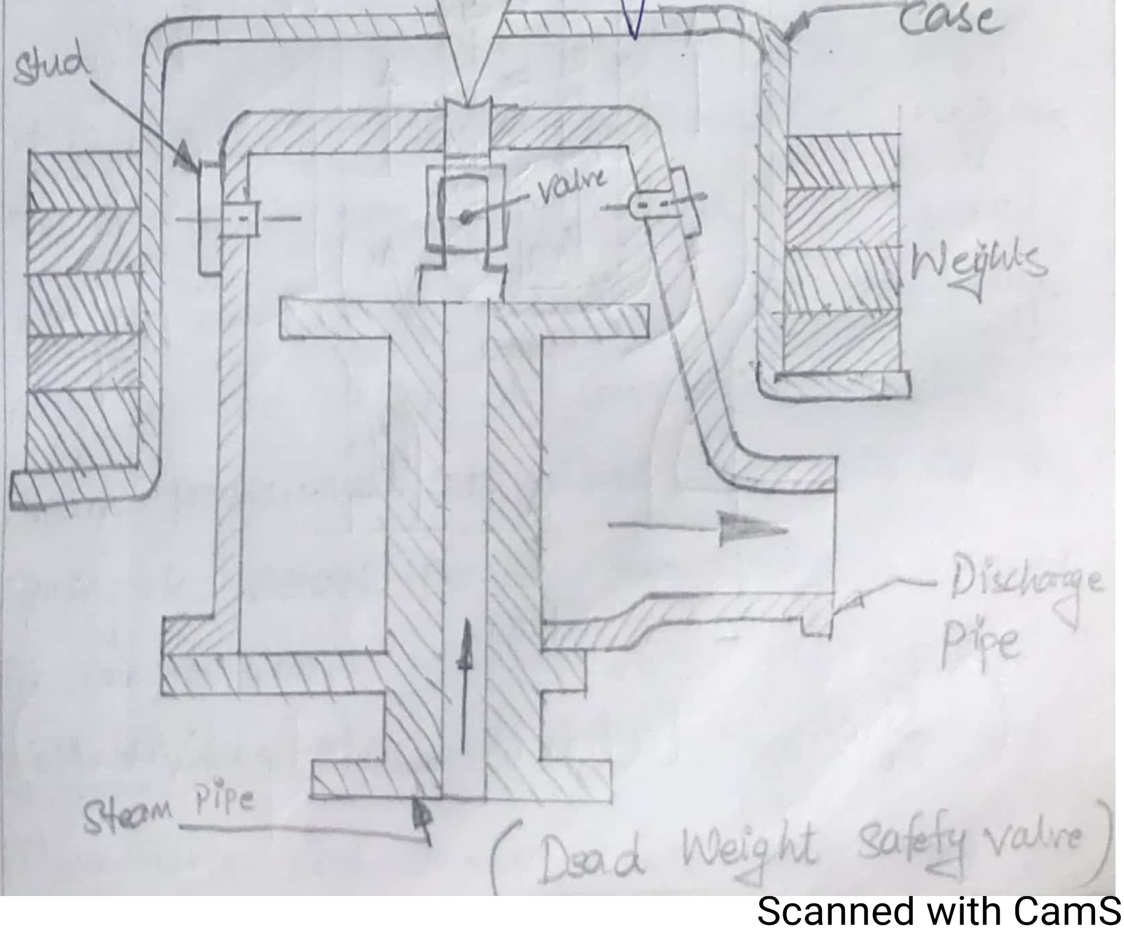
(Leverr Safety Valve)

A Leverr safety valve used on steam boilerr it serrve the purpose of maintaining constant gape preessurre inside the steam body if the pressurre inside the steam boilerr excide the desighn limit the valve lift from it seat and blow off the steam preessurre automattically.

A leverr safety valve consists of a valve body with a flanged fixed to the steam boilerr.

(ii) Dead Weight Safety valve :-

A dead weight Safety valve used for stationary boiler the valve is made of Gun metal and rest on its Gun metal and rest on its Gun metal Seat. It is fixed to the top of a steel pipe. this pipe is bottled to the mountings block, reiverected to the top of the shell both the valve and the pipe are convered by a case which Contains weight there weights keep of the valve on its seat under normal working pressure. The care hugs freely over the valve to which it is searched by means of a nut.

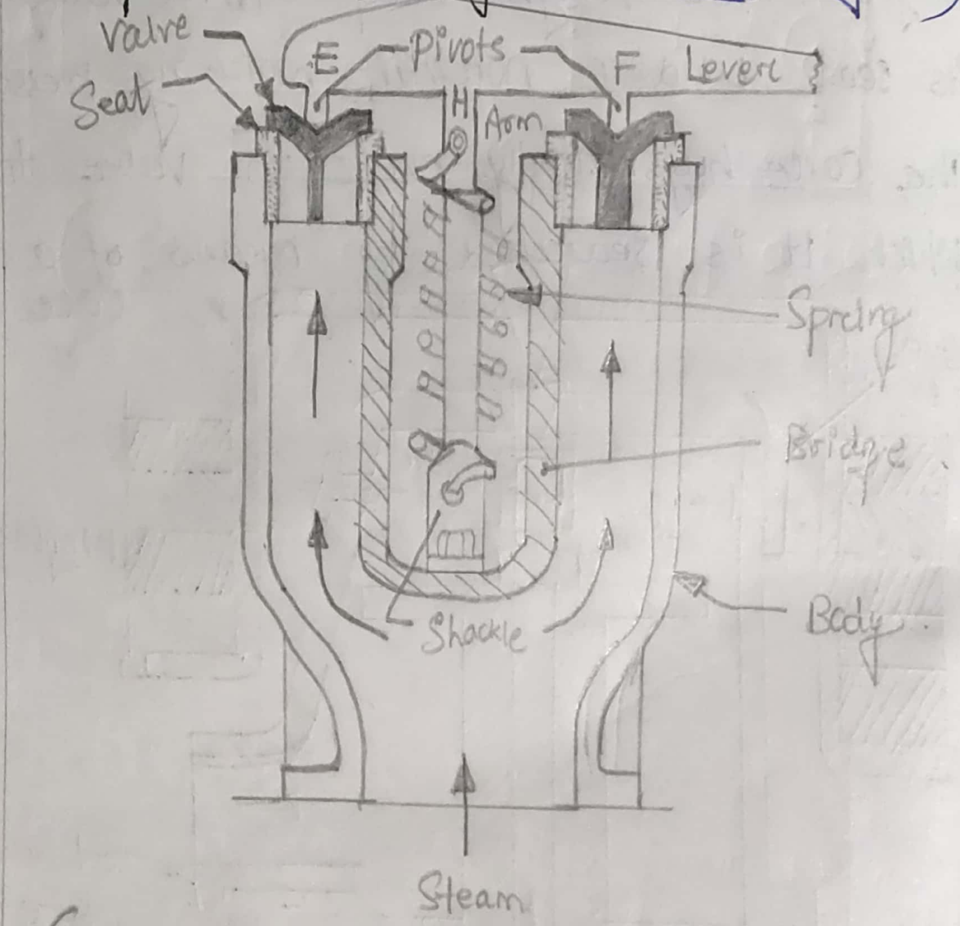


(Dead Weight safety valve)

High Steam low water Safety valve :-

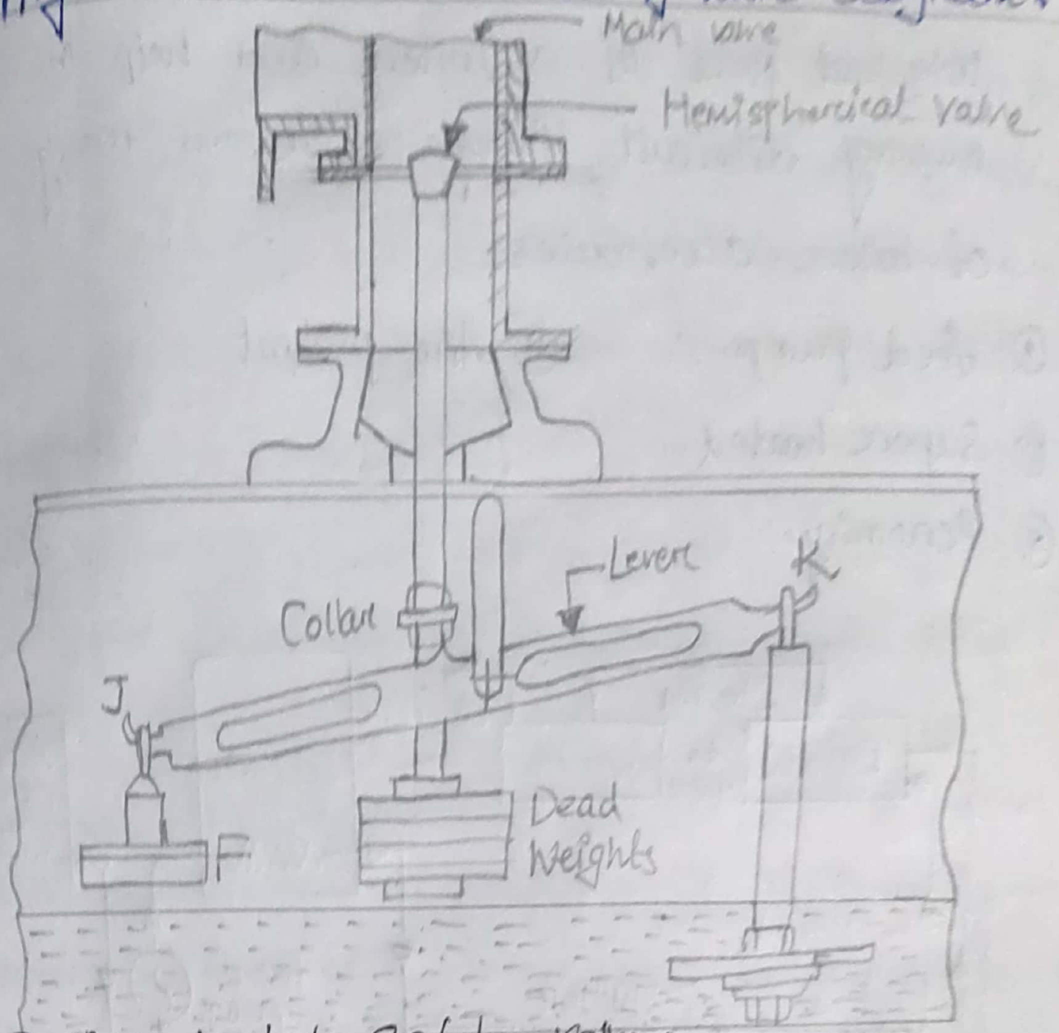
There valves are placed at the top of Cornish and Lancashire boiler only it is Combination of two valves are of which the lever Safety valve which blow off st the working pressure of steam exceed the second valves opereates by blowing off the steam When the water level becomes too low.

<u>Spring loaded Safety valve</u> :- (diagram)



(Spring Loaded Safety Valve)

High steam low water Safety valve diagram :-



Spring loaded Safety valve :

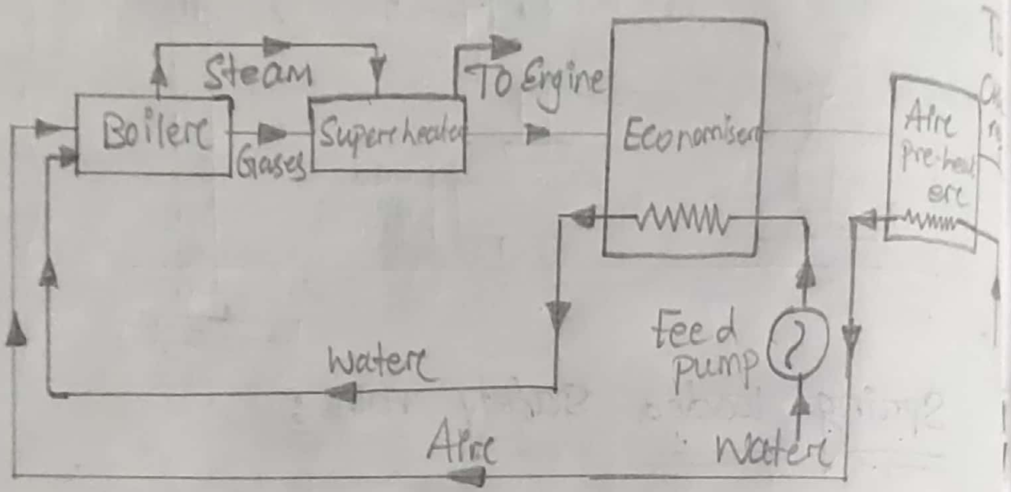
A spring loaded Safety valve is mainly used for locomotive and marine boilers. It is loaded with Spring inserd of weights the spring is made of round of square Spring steel rod is helical from the spring may be in tension of Compression as the Steam pressure acts along the axis of the Spring in actual practice the spring is placed in Compression.

Boiler Accessories :-

There are the device which are used as

intergreal parct of a boilere and help in running difficult through therefore many type of boiler accessories.

① feed pump ④ Aire preheat
② Supere heated
③ Ecnomisy



(schematic diagream of a boilere plant)

Accessories →

① feed pump ③ Economics
② Supere heatere ④ preheater

Feed Pump :-

We know that watere in a boilere is contionusly converted into steam which is used by Engine that we need a feed pump to delivery watere to the boiler.

The pressure of steam inside of a boiler is high So the pressure of feed water has to be increased properctionately before it is made to enter the boiler generally the pressure of fuel water is 20% more than that in the boiler.

Super heater ⇒

A super heater is an importance device of a steam generating unit its purpose is to increase the temperature of saturated steam without raising its pressure it is generally on interegal part of a boiler and is placed in the path of hot fuel gases from the furnace the heat Given up by there fuel gases is used in Supercheating the steam Such super-heaters which are installed with in the boiler are known as interegal Supercheater.

Economisy →

A economises is a device used to heat feed water by utilising the heat in the exhaust fuel gases before leaving through the chimney as the names indicates the economises improves the economy of the steam boiler.

A well known type of economises is green economises it is extensively used for stationary placed is an enlargement of the fuel gases between the boiler and chimney.

pre-heater :-

An pre-heater is used to recover heat from the exhaust fuel gases. It is installed between the economise and the chimney the air required for the purpose of combustion is drawn through the air pre heater where its temperature is raised It is then pass through the tubes of the heater internally which the fuel gases are passed over the outside of the tubes.

Chapter-5 Steam Power Cycles :-

Simple steam power cycle :-

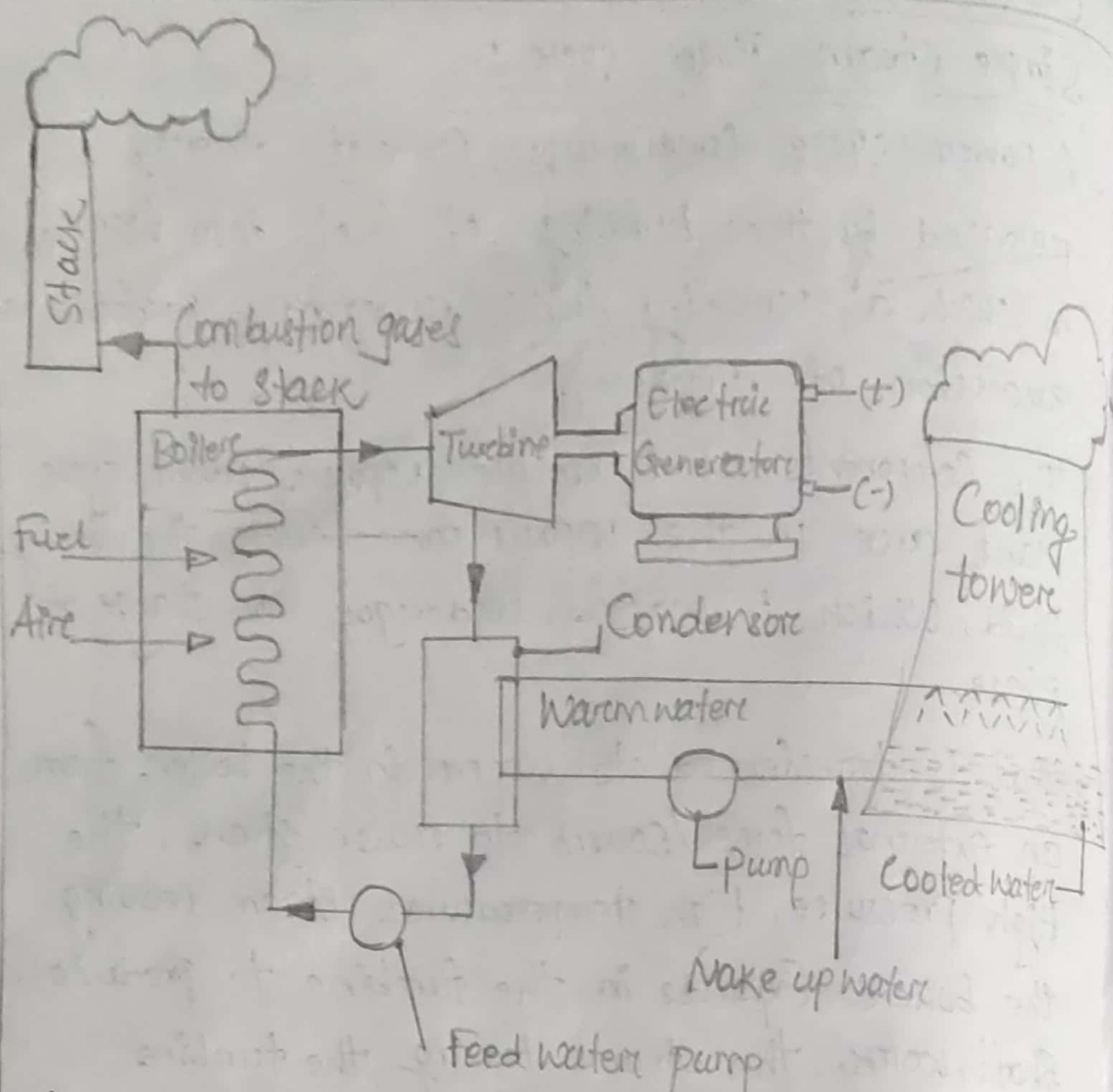
→ A power cycle continuously converts energy released by the burning of fuel into work, in which a working fluid repeatedly performs a succession of processes.

→ The components of a simple vapour power cycle plant are in the vapour power cycle the working fluid, which is water, undergoes a change of phase.

→ Heat is transferred to water in the boiler from an external force / source to raise steam, the high pressure, high temperature steam leaving the boiler expands in the turbine to produce shaft work, the steam leaving the turbine condenses into water in the condenser, rejecting heat, and then the water is pumped to the boiler.

→ how a mass of the working fluid, sometimes in the liquid phase and sometimes in the vapour phase, undergoes various external heat and work interactions in executing a power cycle.

→ The fluid is undergoing a cyclic process, there will be no net change in its internal energy over the cycle, and consequently the net energy transferred to the unit mass of the fluid as heat during the cycle must equal to net energy transfer as work from the fluid.



(Component of a simple vapour power plant)

→ The cyclic heat Engine operating on the vapour power cycle, where the working substance, water, Flows along the B-T-C-P (Boiler - Turbine - Condensor - Pump) path, interacting Externally and Converting net heat input to net work output Contionusly.

$$\Sigma Q_{net} = \Sigma W_{net}$$

$$Q_1 - Q_2 = W_T - W_P$$

Where,

Q_1 = heat transferred to the working fluid. (KJ/kg)

Q_2 = heat rejected from the working fluid (KJ/kg)

W_T = Work transferred from the working fluid (KJ/kg)

W_P = Work transferred into the working fluid (KJ/kg)

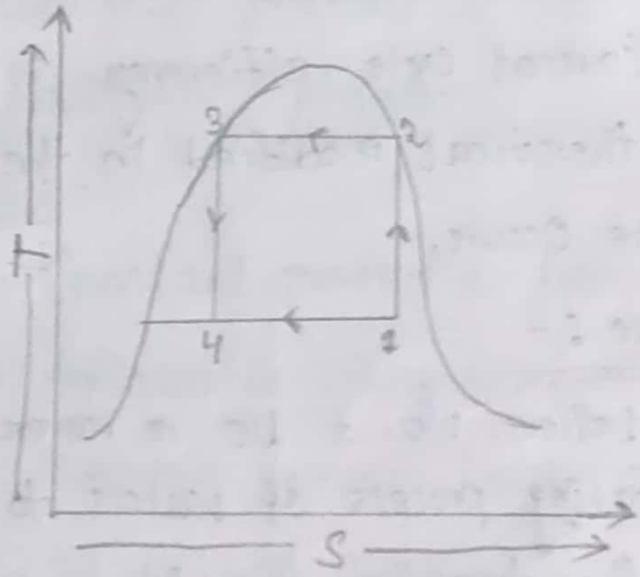
The efficiency of the vapour/vapour power cycle is

$$\eta_{cycle} = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

Carnot cycle :-

2 - Adiabatic process

2 - Isothermal Process



(T-S diagram of Carnot cycle)

Process :-

1-2 = Adiabatic Expansion in ~~to~~ turbine where, Entropy is constant, where there is no heat rejection, No heat injection.

2-3 = Constant temperature heat rejection in Condensor rejection.

3-4 = Adia-batic Compression where entropy is Constant No heat rejection, No heat addition it occures pump section

4-1 = Constant temperature heat addition at boiler section.

$$\text{Efficiency } (\eta) = \frac{Q_1 - Q_2}{Q_1}$$

$$= 1 - \frac{Q_2}{Q_1}$$

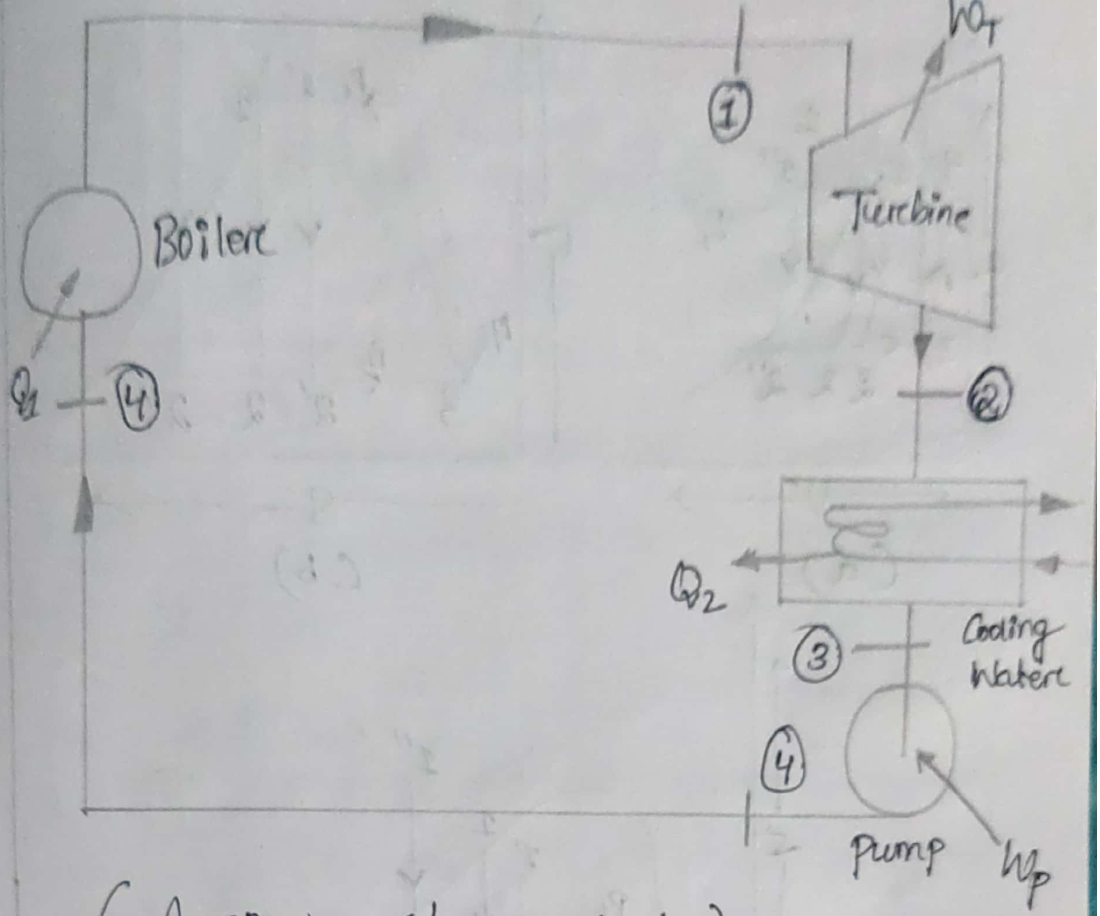
$$= 1 - \frac{T_2}{T_1}$$

from this Carnot cycle, efficiency is more which is possible therctical modified in the rankine cycle will be Occur.

Rankine cycle :-

The steam boiler, would be a reversible Constant pressure heating process of water to form steam, for the turbine the ideal process would be a reversible adiabatic Expansion of this liquid ending at the initial pressure. When all these four process are Ideal, the cycle is an Ideal cycle, called a "Rankine cycle".

This is a reversible cycle.



(A simple steam plant)

2 - Isobaric process

2 - Adiabatic process

<u>Process :-</u>

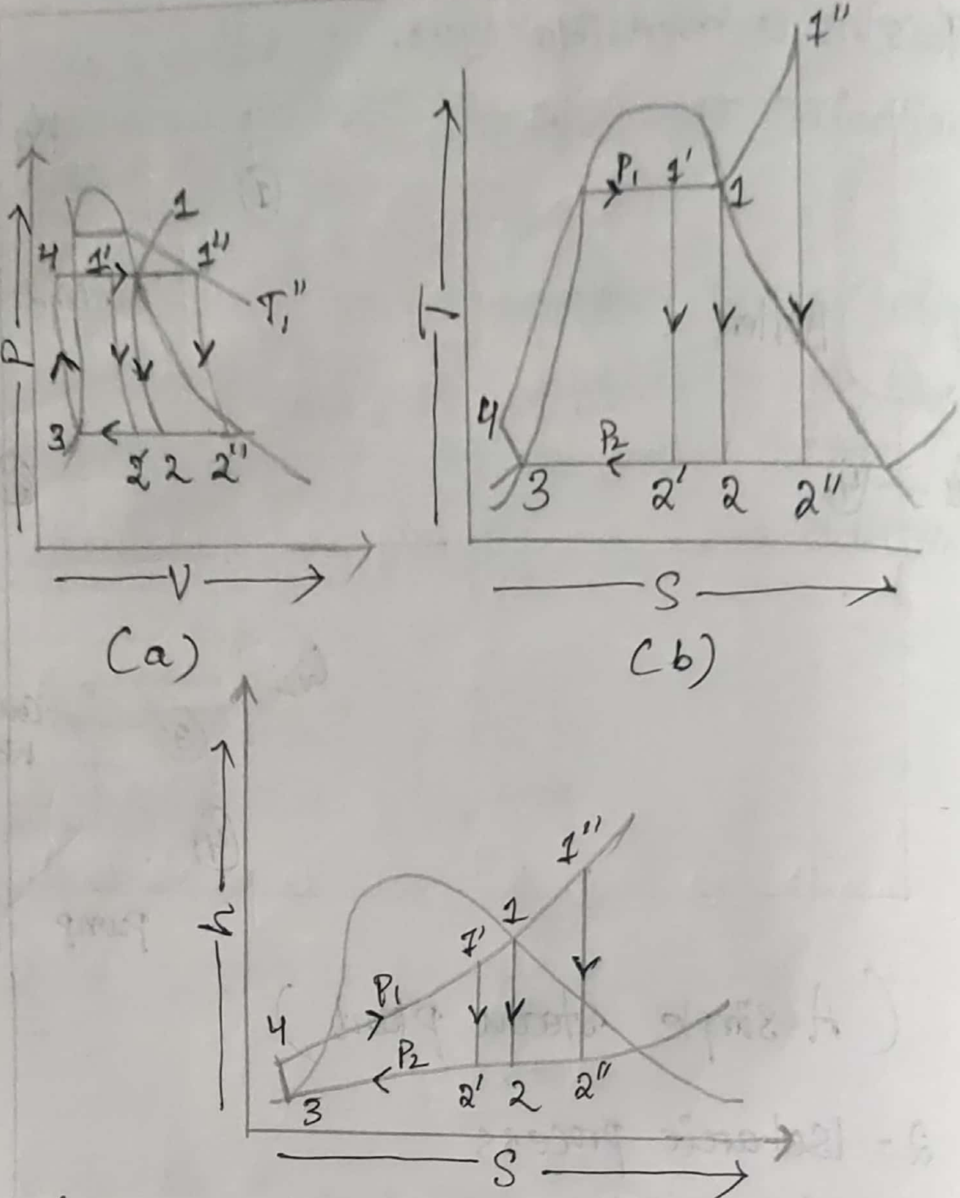
4-1 = Constant pressure heat addition

1-2 = Adiabatic Expansion process

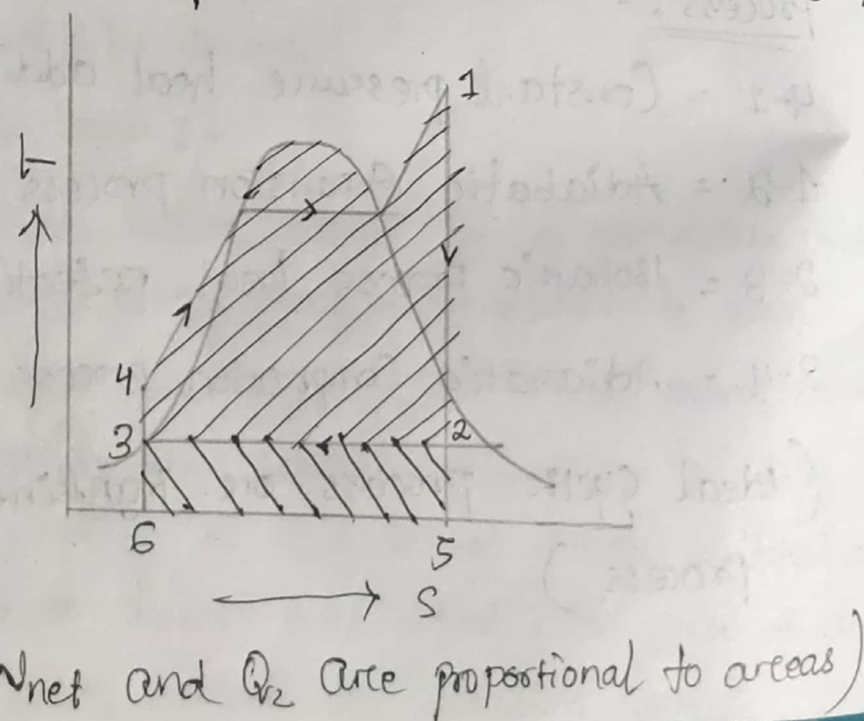
2-3 = Isobaric process heat rejection

3-4 = Adiabatic Compression process in a pump

(Ideal cyclic process, or Rankine cycle process)



(Rankine Cycle P-V, T-s and h-s diagrams)



(Q_1, W_{net} and Q_2 are proportional to areas)

Considere,

1 kg of mass of fluid

According steady flow Energy equation,

(1) $h_4 + Q = h_1$

$$\boxed{Q_1 = h_1 - h_4}$$

(2) $h_1 = W + h_2$

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

(3) $h_2 = Q_2 + h_3$

$$\boxed{Q_2 = h_2 - h_3}$$

(4) $h_3 = W_p + h_4$

$$\boxed{W_p = h_3 - h_4}$$

$$\eta_R = \frac{W_{net}}{Q_1} = \frac{W_T - W_p}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$= \frac{(h_1 - h_2) - (h_3 - h_4)}{Q_1}$$

$$= \frac{(h_1 - h_2) - (h_3 - h_4)}{(h_1 - h_4)}$$

Sometimes Pump work will be neglected.

$$\eta = \frac{h_1 - h_2}{h_1 - h_4} \text{ or } \frac{h_1 - h_2}{h_1 - h_{f3}}$$

Steam reate :-

$$\text{Steam reate} = \frac{1}{W_T - W_P}$$

unit = kg/kJ ore kg/J

According to powere

kg/kW

Steam :-

It is defined as the reate of steam flow reequireed to produce unit shaft output.

$$\frac{1}{W_T - W_P} \text{ kg/kW} \cdot \frac{1 \text{ kJ/s}}{1 \text{ kW}}$$

$$= \frac{1}{W_T - W_P} \text{ kg/kW}$$

$$= \frac{3600}{W_T - W_P} \text{ kg/kW.h}$$

heat reate :-

$$\frac{1}{\eta} \text{ kg/kW.s}$$

$$\frac{Q_1}{Q_1 - Q_2} \text{ kg/kJ} \quad \text{kg/J}$$

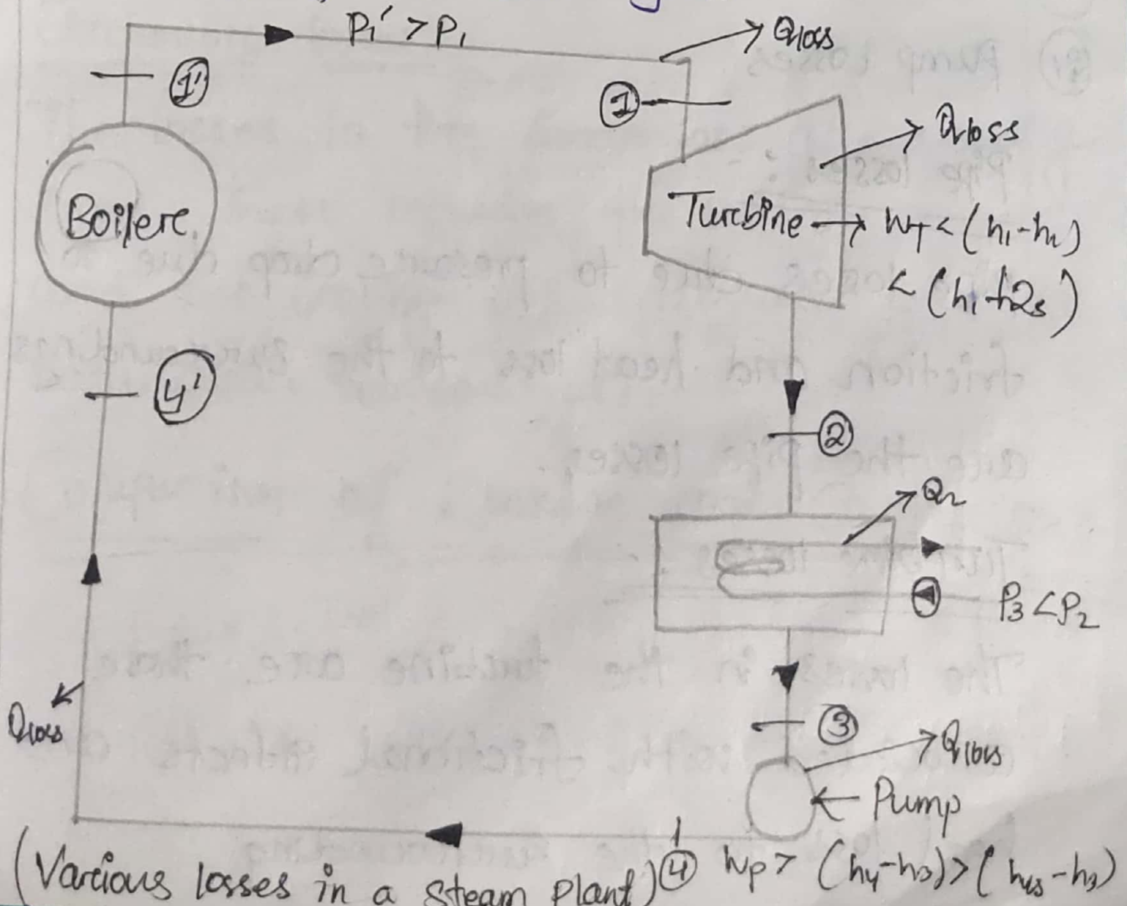
$$\frac{3600}{\eta_{cycle}} \text{ kg/h}$$

Actual Vapoure cycle processes :-

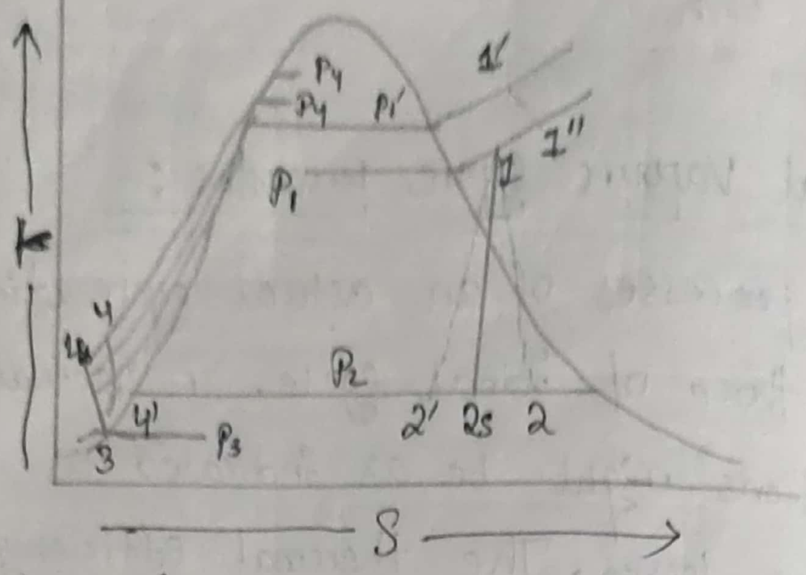
The processes of an actual cycle differe from those of ideal cycle. In actual cycle Conditions might be as indicated as the various losses. The theremal efficiency of the cycle is

$$\eta_{th} = \frac{W_{net}}{Q_1}$$

Where the work and heat quantities are the measured values fore the actual cycle, which are different from the corresponding Quantites of the ideal cycle.



(Various losses in a Steam Plant)



(Various losses on T-s Plot)

(Actual rankine vapoure cycle)

Losses are classified as :-

(i) Pipe losses
(ii) Turbine losses
(iii) Condensore losses
(iv) Pump Losses

Pipe losses :-

Pipe losses due to pressure drop due to friction and heat loss to the surroundings are the pipe losses.

Turbine losses :-

The losses in the turbine are those associated with frictional effects and heat loss to the surrounding.

$$\eta_T = \frac{W_T}{h_1 - h_{2s}} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

W_T is actual turbine work

$(h_1 - h_{2s})$ is the isentropic enthalpy drop in the turbine. (Ideal output).

Pump losses :-

Pump losses due to the irreversible associated with fluid friction. Heat transfer is usually negligible.

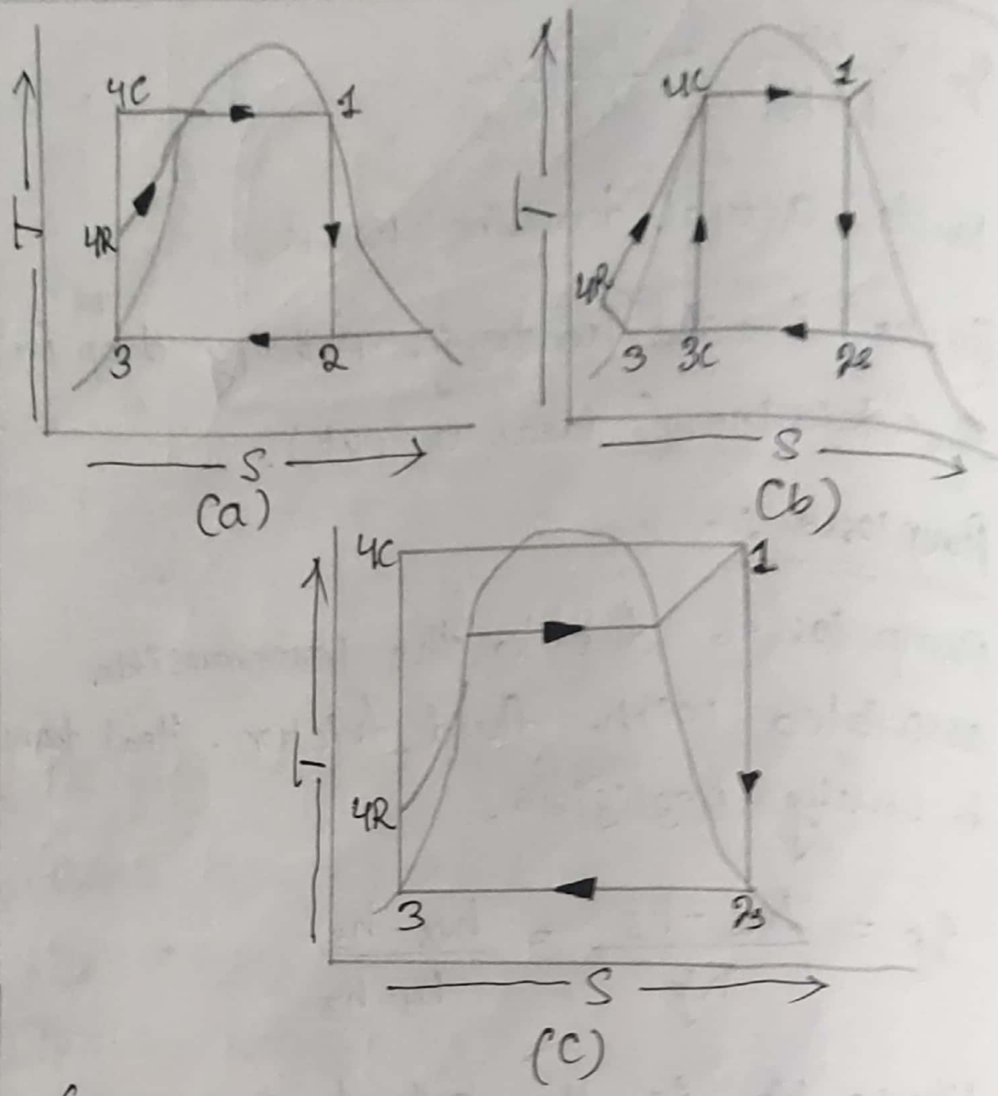
$$\eta_p = \frac{h_{4s} - h_3}{W_p} = \frac{h_{4s} - h_3}{h_4 - h_3}$$

Where W_p is the actual pump work.

Condensor losses :-

The losses in the condensor are usually small. These includes the lost of pressure and the cooling of condensate below the saturation temperature.

*) **Comparison of Rankine and Carnot cycle :-**



(Compareison of carnot & Rankine cycle)

→ The rankine cycle delivers more power at the Expense of additional heat transfer rate at the boiler which results in a the thermal efficiency lower than the carnot efficiency

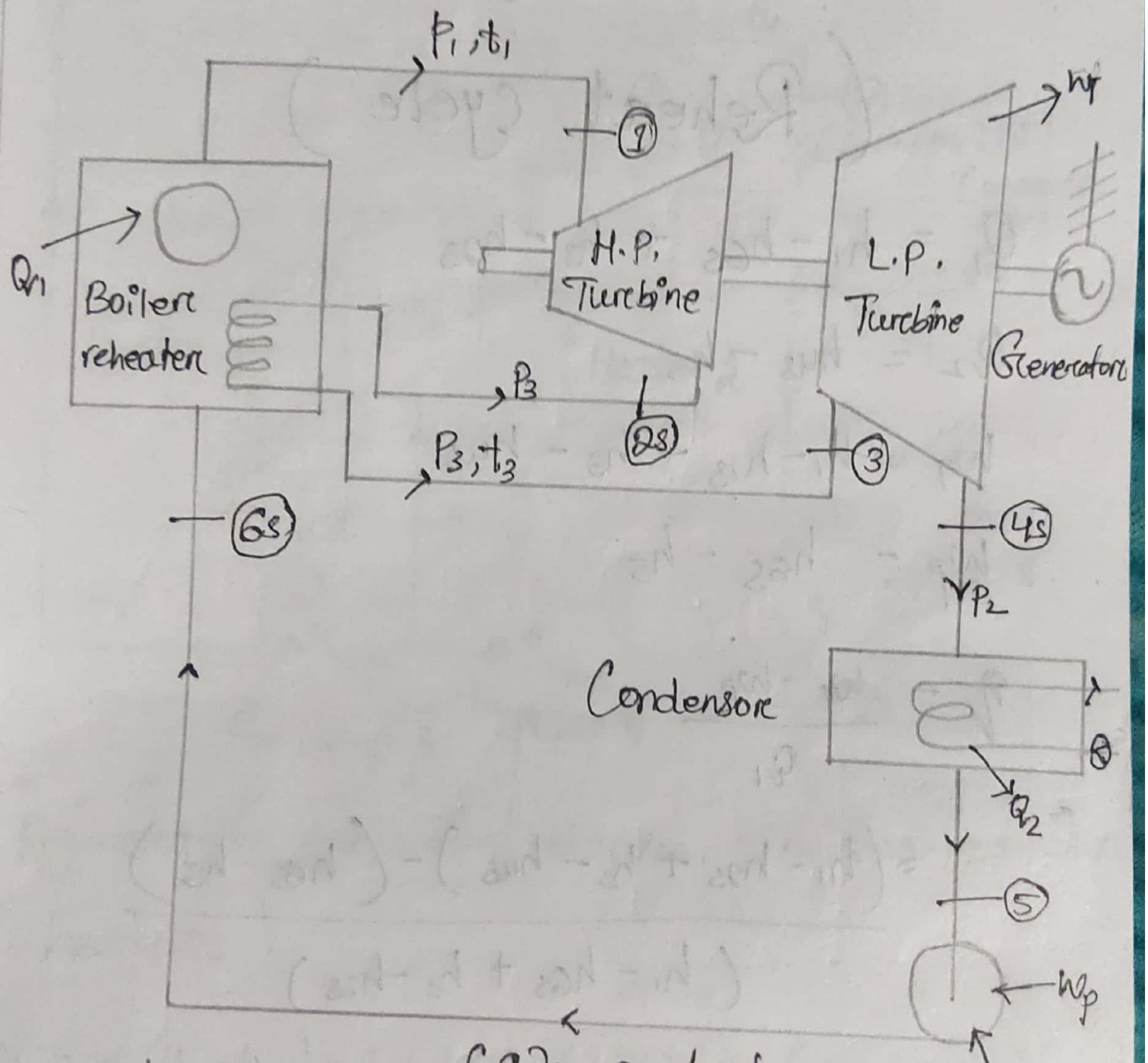
$$\eta_{th} = \frac{W_{net}}{Q_1}$$

→ The Carnot cycle has the highest efficiency but it is not practical, or possible.

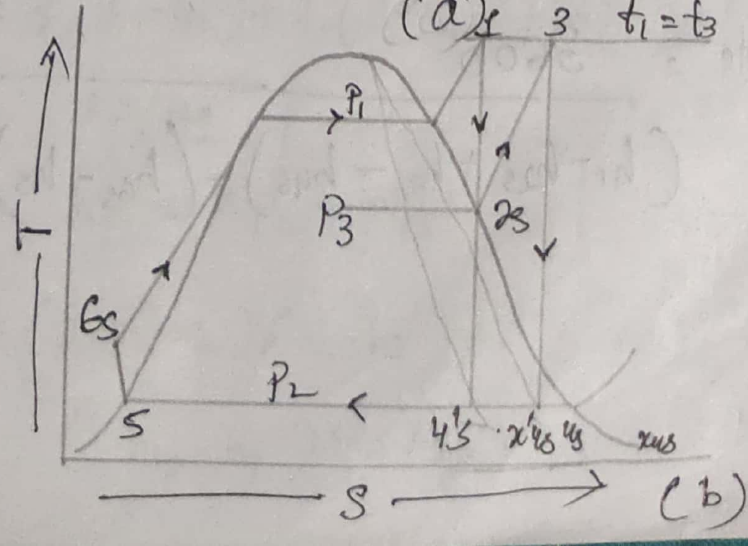
$$\eta_{carnot} = 1 - \frac{T_1}{T_2}$$

Reheat & Regenerative cycle :-

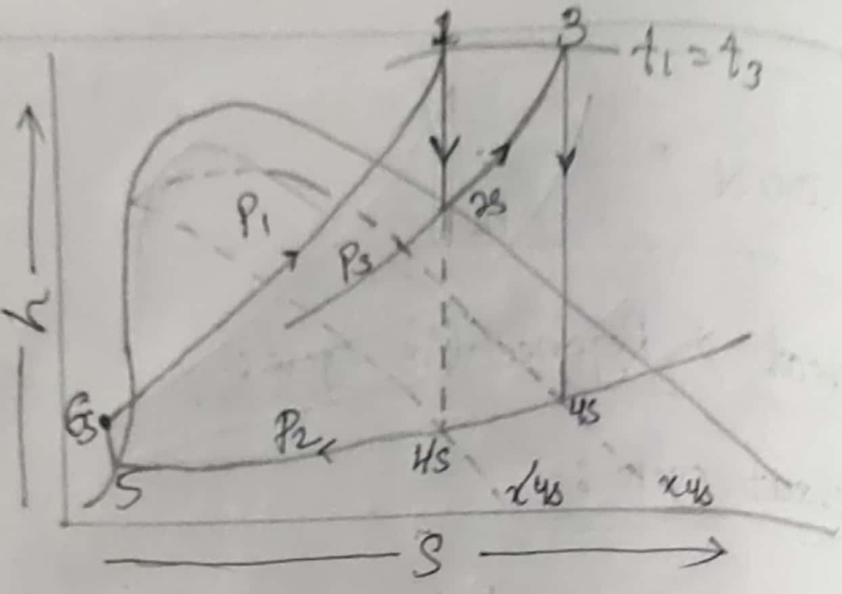
Reheat cycle :-



(a)



(b)



(Reheat cycle)

$$Q_1 = h_1 - h_{6s} + h_3 - h_{2s}$$

$$Q_2 = h_{4s} - h_5$$

$$W_T = h_1 - h_{2s} + h_3 - h_{4s}$$

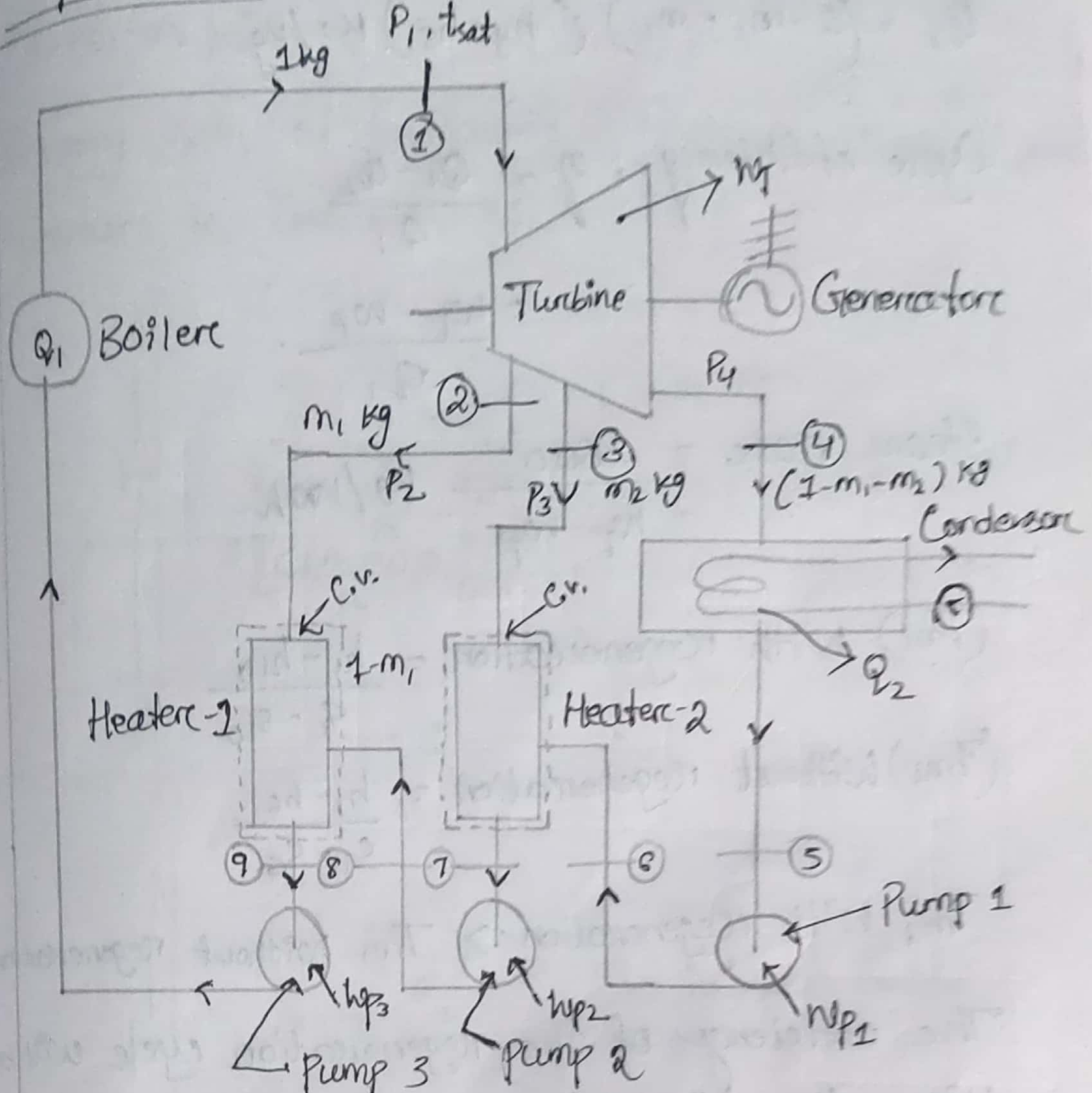
$$W_P = h_{6s} - h_5$$

$$\eta = \frac{W_T - W_P}{Q_1}$$

$$= \frac{(h_1 - h_{2s} + h_3 - h_{4s}) - (h_{6s} - h_5)}{(h_1 - h_{6s} + h_3 - h_{2s})}$$

$$\text{Steam Rate} = \frac{3600}{(h_1 - h_{2s} + h_3 - h_{4s}) - (h_{6s} - h_5)} \text{ kg/kWh}$$

Regenereative Cycle :-



(Regenereative cycle flow diagram with two feedwater heaters)

$W_T = 1(h_1 - h_2) + 1(1-m_1)(h_2 - h_3) + (1 - m_1 - m_2)(h_3 - h_4)$ KJ/kg

$W_P = W_{P_1} + W_{P_2} + W_{P_3}$

$= (1-m_1-m_2)(h_6 - h_5) + (1 - m_1)(h_8 - h_7) + 1(h_{10} - h_9)$ KJ/kg

$Q_1 = 1(h_1 - h_{10})$ KJ/kg

$Q_2 = (1 - m_1 - m_2)(h_4 - h_5)$ KJ/kg

Cycle efficiency, $\eta = \frac{Q_1 - Q_2}{Q_1}$

$= \frac{W_T - W_P}{Q_1}$

Steam rate $= \frac{3600}{W_T - W_P}$ kg/kW.h

(T_{m_1}) with regeneration $= \frac{h_1 - h_{10}}{s_1 - s_{10}}$

(T_{m_1}) without regeneration $= \frac{h_1 - h_6}{s_1 - s_6}$

T_{m_1} with regeneration > T_{m_1} without regeneration.

The efficiency of the regeneration cycle will be Higher than that of the rankine cycle.

The Energy balance for heater 2 Gives

$m_1 h_2 + (1 - m_1) h_9 = 1 h_9$

$m_1 = \frac{h_9 - h_9}{h_2 - h_9}$

The Energy balance for heater 1 Gives

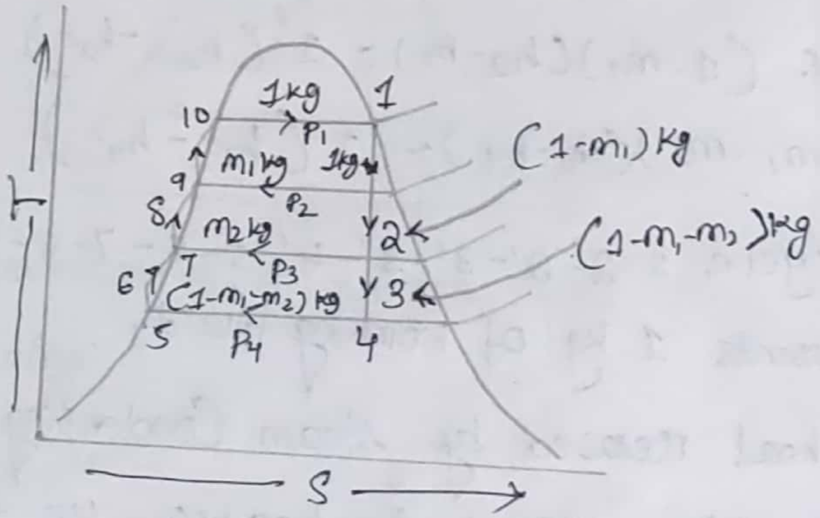
$m_2 h_3 + (1 - m_1 - m_2) h_6 = (1 - m_1) h_7$

$m_2 = (1 - m_1) \cdot \frac{h_7 - h_6}{h_3 - h_6}$

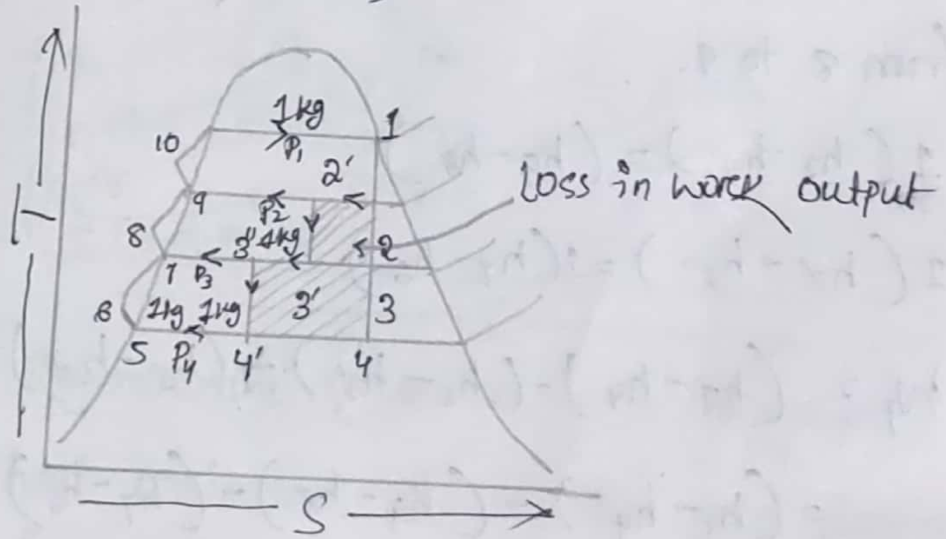
$(1-m_1)(h_9-h_8) = m_1(h_2-h_9)$

$(1-m_1-m_2)(h_7-h_6) = m_2(h_3-h_7)$

Energy gain of feedwater = Energy Given off your vapour in Condensation.



(a)



(Regenerative cycle on T-s plot with decreasing Mass of fluid)

(b) (Regenerative cycle on T-s plot for unit mass of fluid)

Path 1-2-3-4 represent the states of a decreasing Mass of fluid.

For 1 kg of steam, the states would be represented by the path 1-2'-3'-4'.

$$W_T = (h_1 - h_2) + (1-m_1)(h_2 - h_3) + (1-m_1-m_2)(h_3 - h_4)$$

$$= (h_1 - h_2) + (h_{2'} - h_{3'}) + (h_{3'} - h_{4'})$$

where $(1-m_1)(h_2 - h_3) = 1(h_{2'} - h_{3'})$

$(1-m_1-m_2)(h_3 - h_4) = 1(h_{3'} - h_{4'})$

The cycle 1-2-2'-3'-3''-4'-5-6-7-8-9-10-1 represents 1 kg of working fluid.

The heat released by steam condensing from 2 to 2' is utilised in heating up the water from 8 to 9.

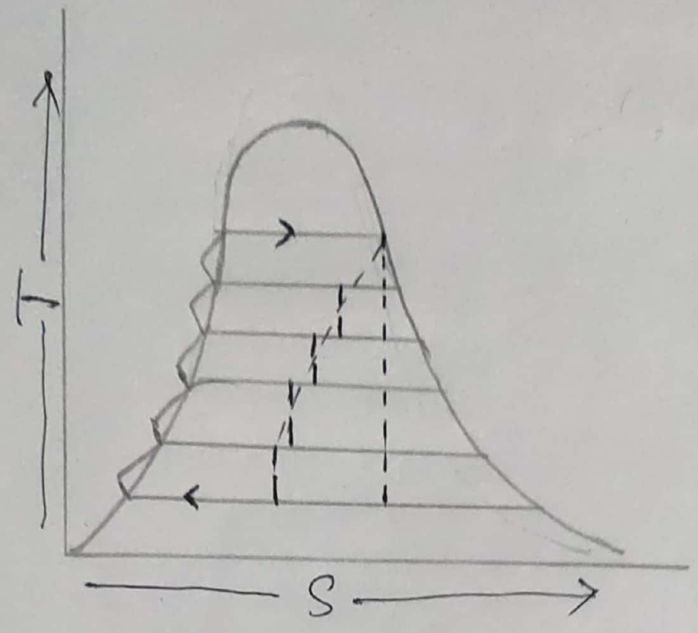
$$1(h_2 - h_{2'}) = (h_9 - h_8)$$

$$1(h_{3'} - h_{3''}) = 1(h_7 - h_6)$$

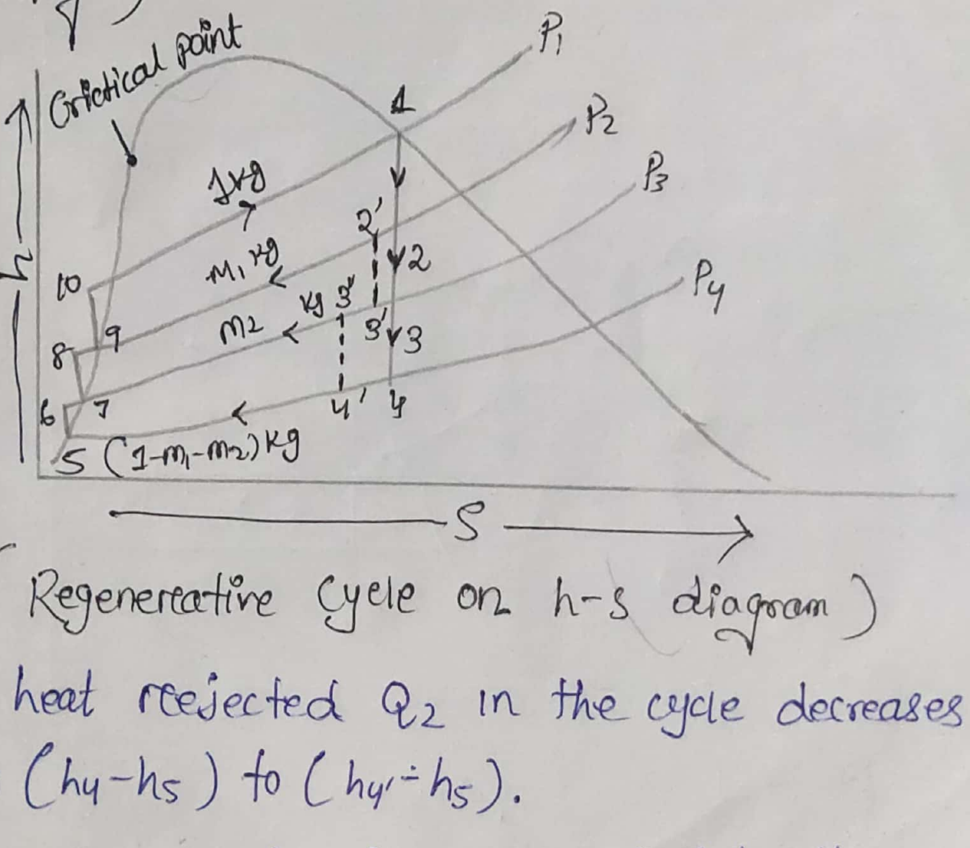
$$W_T = (h_1 - h_{4'}) - (h_2 - h_{2'}) - (h_{3'} - h_{3''})$$

$$= (h_1 - h_{4'}) - (h_9 - h_8) - (h_7 - h_6)$$

The heating of feedwater by steam 'bled' from the turbine, known as "regeneration" Carnotises the rankine cycle.



(Regenerative cycle with many states of feedwater heating)



(Regenerative cycle on h-s diagram)

The heat rejected Q_2 in the cycle decreases from $(h_4 - h_5)$ to $(h_{4'} - h_5)$.

There is also loss in work output by the amount by the hatched area. So the steam rate increase by regeneration i.e. more steam has to circulate per hour to produce unit shaft output.

Chapter - 6 Heat Transfer

Modes of Heat Transfer :-

Heat transfer which is defined as the transmission of Energy from one region to another as a result of temperature Gradient takes

(i) Conduction

(ii) Convection

(iii) Radiation

Conduction :-

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance.

In solids, the heat is conducted by the following two mechanisms :-

(i) By lattice vibration

(ii) By transport of free electrons

In case of gases,

The kinematic energy of a molecule is a function of temperature.

In liquids, The molecules are more closely speed and intermolecular forces come into play.

Convection :-

Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another.

Convection are classified as two types :-

(i) free or Natural Convection

(ii) Forced Convection

Free or Natural Convection :-

"Free or Natural Convection" occurs when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids;

the densore portions of the fluid move downward because of greater force of gravity, as compared with the force on the less dense.

Forced Convection :-

When the work is done to blow or pump the fluid, it is said to be "forced

Convection".

Radiation :-

Radiation is the transfere of heat through space ore mattere by means othere than Conduction ore Convection.

→ Radiation heat is throught of as electro-magnetic waves ore Quanta an emana of the Same nature as light and radio waves.

→ All the bodies radiate heare, So a transfere of heat by radiation occures because hot body emits more heat than it recieves and a Cold body receives more heat that emits.

→ Radiant Eneregy requirees no medium fore propogation will pass through Vaccum.

Fourciere's Laws of heat Conduction :-

"The rate of flow of heat through a Simple homogeneous Solid is directly proportional to the area of the Section at right Angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow."

Mathematically,

$$Q \propto A \times \frac{dt}{dx}$$

Wherer as,

Q = heat flow through a body per unit time (in watts), W,

A = Surface area of heat flow (perpendicular to the direction of flow), m^2.

dt = Temperature difference of the faces of block (homogeneous solid) of thickness "dx" through which heat flows, "c & k. and

dx = Thickness of body in the direction of flow, m.

Then, $Q = -K \cdot A \frac{dt}{dx}$

Where, K = Constant of proportionality and is known as "Thermal Conductivity".

The -ve sign of K is to take care of the decreasing temperature along with the direction of increasing thickness or the direction of heat flow.

→ The tempereature gradient $\frac{dt}{dx}$ is always negative along positive x direction & therefore, the value as Q becomes positive (+ve).

Assumptions :-

(i) Conduction of heat takes place under Steady State Conditions.

(ii) The heat flow is unidirectional.

(iii) The temperature gradient is Constant and the temperature profile is Linear.

(iv) There is no internal heat generation.

(v) The bounding Surfaces are isothermal in character.

(vi) The material is homogeneous and isotropic.

Thermal Conductivity of materials :-

$$K = \frac{Q}{A} \cdot \frac{dx}{dt}$$

The value of K = 1, when Q = 1, A = 1 and $\frac{dt}{dx} = 1$

Now $K = \frac{Q}{1} \cdot \frac{dx}{dt}$ (unit of K $1w \times \frac{1}{m^2} \times \frac{m}{K (or\ ^\circ C)}$)

$= W/mK$ or $W/m^\circ C$

the thermal Conductivity of a material is defined as.

→ "The amount of Energy Conducted through body of unit area, and unit thickness in unit time when the difference in temperature between the forces increasing heat flow is unit temperature difference".

→ This law Conveys that the materials which are good Conductors of electricity are also good Conductors of heat.

<u>Thermal Resistance (Rth)</u> :-

The heat transfer processes may be Compared by analogy with the flow of electricity in an electrical resistance.

As the flow of electric Current in the electrical resistance is directly proportional to potential difference (dv);

Similarly heat flow rate, Q, is directly proportional to temperature difference (dt), the driving force for heat Conduction through a medium.

As per ohm's law

$$\text{Current } (I) = \frac{\text{Potential difference } (dv)}{\text{Electrical resistance } (R)} \quad \text{--- (i)}$$

By anology, the heat flow equation (fourier's equation)

Heat flow reate $(Q) = \dfrac{\text{Temperature difference } (dt)}{\left(\dfrac{dx}{KA}\right)}$ —— (ii)

By comparing eqns (i) and (ii)

I is analogous to, Q ; dv is analogous to dt and R is analogous to the quantity $\left(\frac{dx}{KA}\right)$. The quantity $\frac{dx}{KA}$ is called thermal conduction Resistance $(R_{th})_{cond}$ i.e,

$$(R_{th})_{cond} = \frac{dx}{KA}$$

→ The reciprocal of the thermal resistance is called thermal conductance.

The concept of thermal resistance is quite helpful while making calculations for flow of heat.

Ex-1

Calculate the reate of heat transfer per unit area through a copper plate 45mm thick, whose one face is maintained at 350°c and the other face at 50°c. Take thermal conductivity of copper as 370 W/m°c.

Given data :-

Temperature difference, $dt = (t_2 - t_1)$

$= (50 - 350)$

Thickness of copper plate, $L = 45\,mm$

$= 0.045\,m$

Thermal Conductivity, $K = 370\,W/m°C$

Rate of heat transfer per unit area, q.

$$Q = -KA\frac{dt}{dx} = -KA\frac{(t_2 - t_1)}{L}$$

$$= -370 \times \frac{(50 - 350)}{0.045}$$

$$= 2.466 \times 10^6\ W/m^2$$

$$= 2.466\ MN/m^2 \quad \text{(Ans)}$$

Ex-2

A plane wall is 150 mm thick, and its wall area is 4.5 m². If its conductivity is 9.35 W/m°C and surface temperature are steady at 150°c and 45°C, determine :

i) Heat flow across the plane wall,

ii) Temperature gradient in the flow dirⁿ.

Given data :-

Thickness of the plane wall,

$L = 150\,mm = 0.15\,m$

Area of the wall, $A = 4.5\,m^2$

Temperature difference $dt = t_2 - t_1$

$= 45 - 150$

$= -105°C$

Thermal conductivity of wall material,

$K = 9.35\ W/m°C$

(i) Heat flow across the plane wall, Q :

$$Q = -KA\frac{dt}{dx}$$

$$= -KA\frac{(t_2 - t_1)}{L}$$

$$= -9.35 \times 4.5\frac{(-105)}{0.15}$$

$$= 29452.5\ W$$

(ii) Temperature gradient, $\frac{dt}{dx}$:

$$\frac{dt}{dx} = -\frac{Q}{KA}$$

$$= -\frac{29452.5}{9.35 \times 4.5} = -700°C/m$$

Newton's Law of Cooling :-

It states " Heat transfer from a hot body to a cold body is directly proportional to the Surface area and difference of temperature between the two bodies."

Heat transfer by Convection :-

The rate equation for the convective heat transfer between a Surface and an adjacent fluid is prescribed by Newton's law of Cooling.

$$Q = hA(t_s - t_f)$$

where,

Q = Rate of Conductive heat transfer

A = Area exposed to heat transfer

t_s = Surface temperature.

t_f = Fluid temperature, and

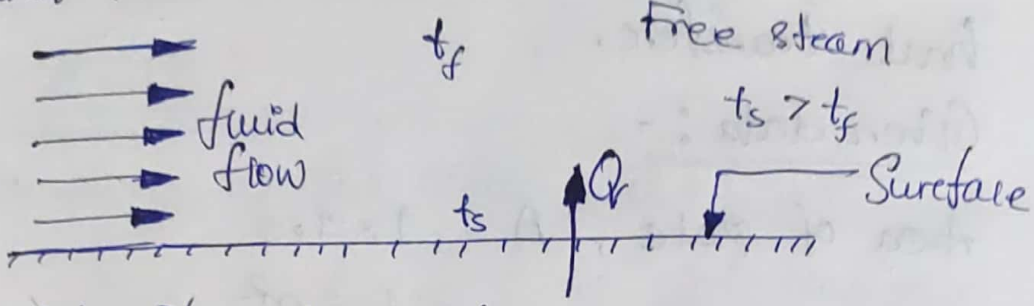
h = Co-efficient of Convective heat transfer

The unit h are

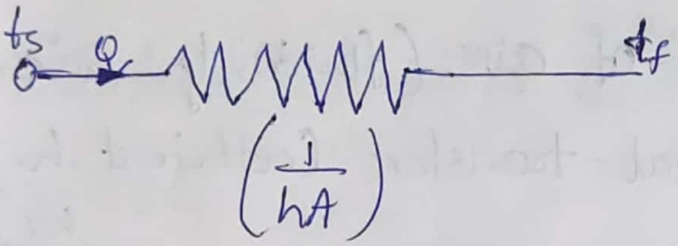
$$h = \frac{Q}{A(t_s - t_f)} = \frac{W}{m^2\,^\circ C} \text{ or } W/m^2\,^\circ C$$

or $W/m^2 K$

The Coefficient of Convective heat transfer "h" defined as " the amount of heat transmitted for a unit temperature difference between the fluid and unit area of Surface in unit time".



(a) Physical configuration



(b) Equivalent circuit

(Convective heat - transfer).

The value of h depends on,

i) Thermodynamic and transport properties (viscosity, density, specific heat etc.)

) Nature of fluid flow

) Geometry of the Surface.

Prevailing thermal Conditions.

Ex-1

A hot plate 1m × 1.5m is maintained at 300
Air at 20°c blows over the plate. If the Convective heat transfer Coefficient is 20 W/m² °c, Calculate the rate of heat transfer.

Given data :-

Area of plate, $A = 1 \times 1.5$

$= 1.5 \, m^2$

Plate Surface temperature, $t_s = 300°c$

Temperature of air (fluid), $t_f = 20°c$

Convective heat-transfer Coefficient, $h = 20 \, W/m^2 °C$,

Rate of heat transfer, Q :-

$Q = hA(t_s - t_f)$

$= 20 \times 1.5 (300 - 20)$

$= 8400 \, W$

$= 8.4 \, KW$ (Ans)

Ex-2

A wire 1.5mm in diameter and 150mm long is submerged in water at atmospheric pressure. An Electric Current is passed through the wire and is increased until water boils at 100°c. under the Condition of Convective heat transfer Coefficient is 4500 W/m²°c find how much electric power must be Supplied to the wire to maintain the wire Surface at 120°c ?

Given data :-

Diameter of the wire, $d = 1.5\,mm$

$= 0.0015\,m$

Length of the wire, $L = 150\,mm$

$= 0.15\,m$

∴ Surface area of the wire,

$A = \pi D L$

$= \pi \times 0.0015 \times 0.15$

$= 7.068 \times 10^{-4}\,m^2$

Wire Surface temperature, $t_s = 120°c$

Water temperature, $t_f = 100°c$

Convective heat transfer Coefficient, $h = 4500\,W/m^2\,°c$

Electric power to be Supplied :

∴ $Q = hA(T_s - T_f)$

$= 4500 \times 7.068 \times 10^{-4}(120 - 100)$

$= 63.6\,W$

Heat Transfer by Radiation :-

Laws of Radiation :-

1. Kirchhoff's Law :-

It states that the emissivity of the body at a particular temperature is numerically equal to its absorptivity for radiant energy from body at the same temperature.

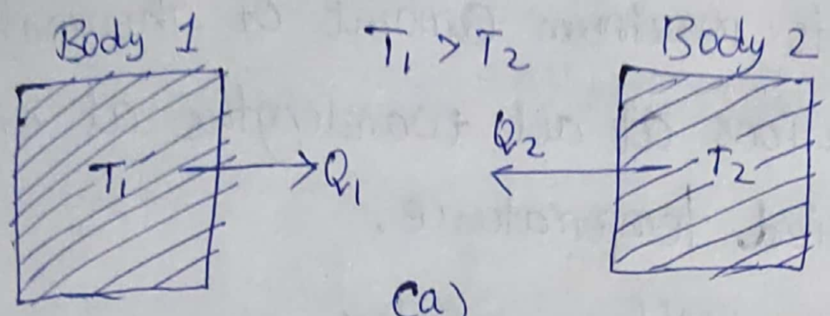
2. Stefan-Boltzmann law:-

The law state that the emissive power of a black body is directly proportional to fourth power of its absoulute temperature.

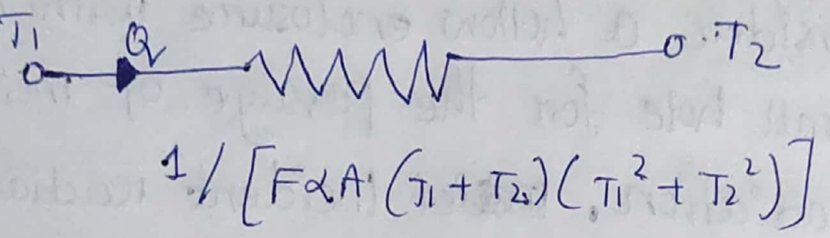
i.e. $Q \propto T^4$

$Q = F \sigma A (T_1^4 - T_2^4)$

where, F = A factor depending on geometry and surface properties.



(a)



(b)

(Heat Transfere by Radiation)

Concept of A Black Body :-

A black body is an object that absorbs all the readiant Energy reeaching its Surface.

The Concept of a Black body is an Idealization with which the readiation charecteristics of real bodies can be Conveniently Compared.

(i) It absorbs all the incident readiation falling on it and does not transmit ore reeflect regaredless of wavelength and direction.

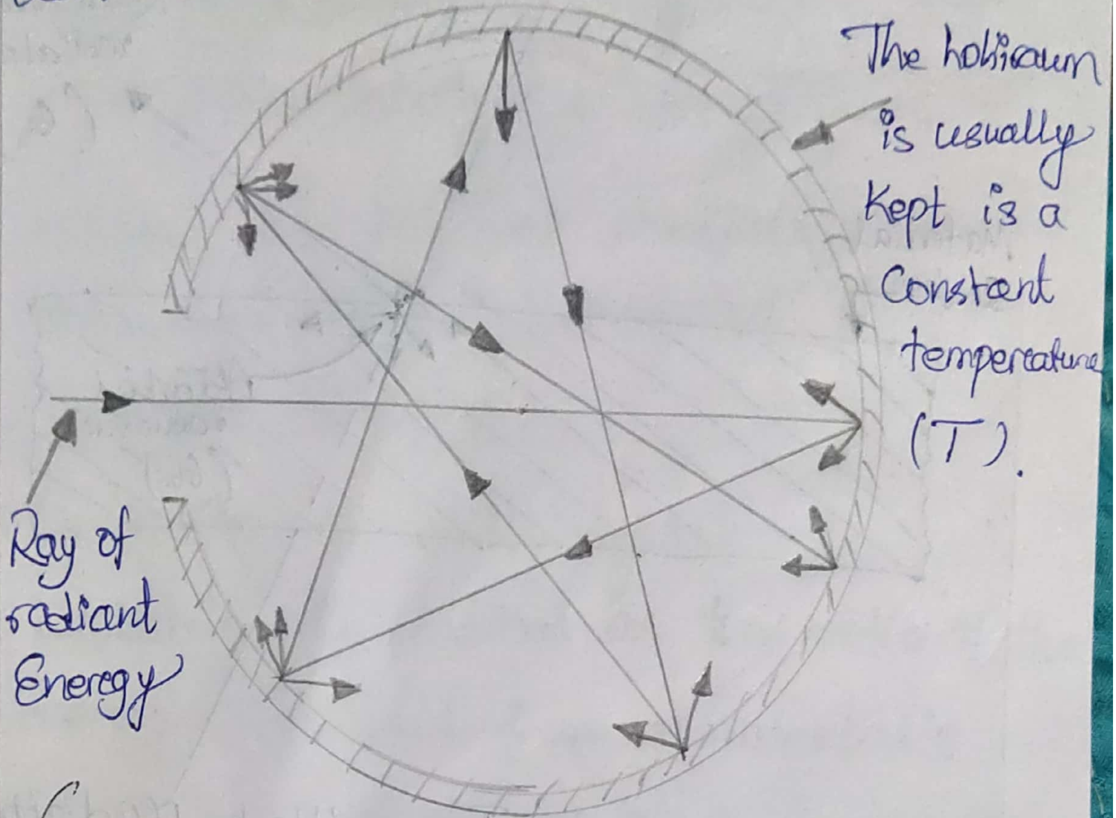
(ii) It emits maximum amount of thermal radiations at all wavelengths at any specified temperature.

(iii) It is a diffuse emitter

→ Consider a hollow enclosure with a very small hole for the passage of incident radiation. Incident radiant energy passes through the small opening. Some of this energy is absorbed by the inside surface and some is reflected.

→ However, most of this energy is absorbed on a second incidence. Again, a small friction is reflected. After a number of such reflections the amount unabsorbed is exceedly small and very little of the original incident energy is reflected back out of the opening.

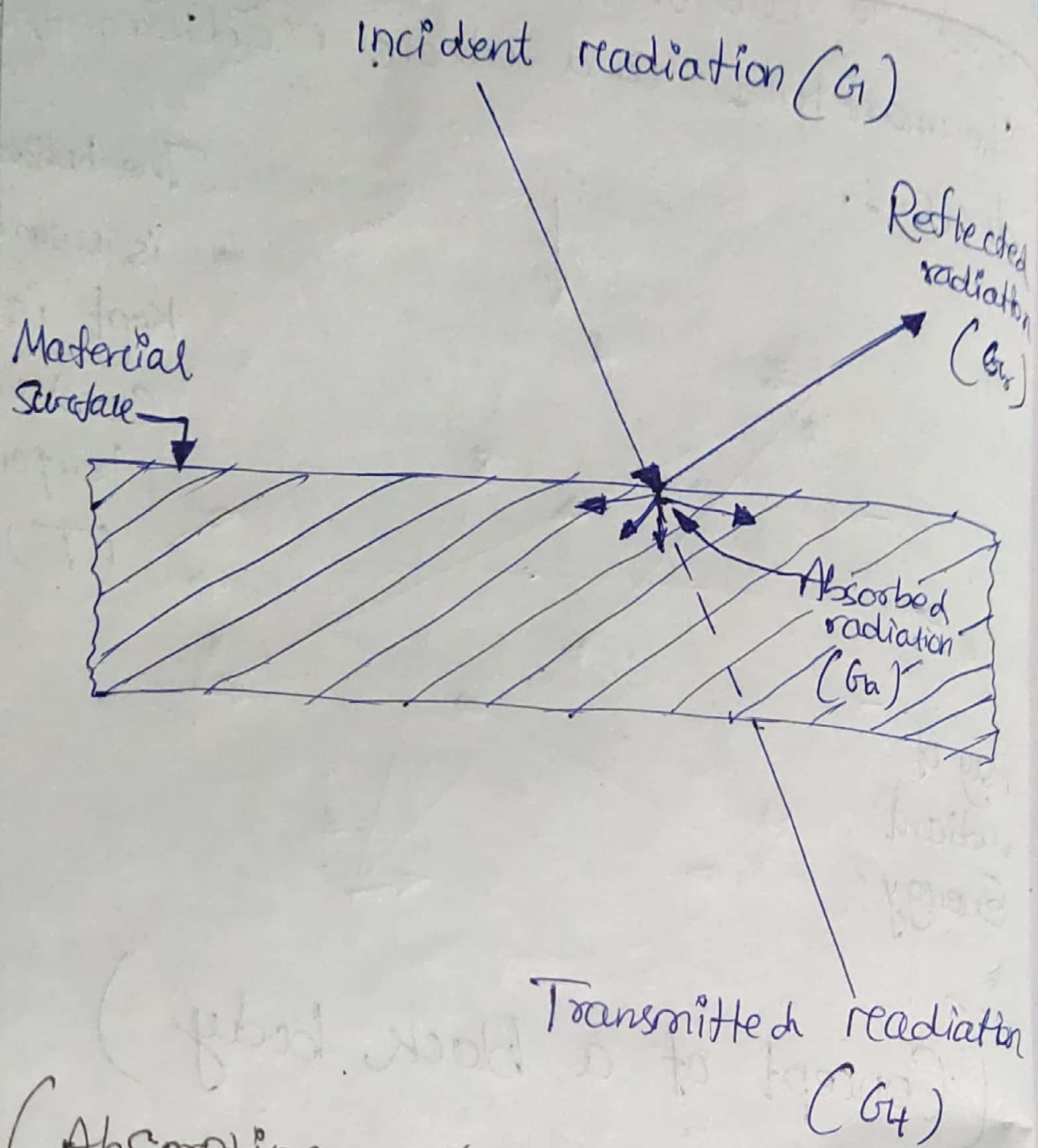
→ A small hole leading into a cavity thus acts very nearly as a black body because all the radiant energy entering through it gets absorbed. Isothermal furnaces, with small apertures approximate a black body and are frequen used to Callibrate heat flux gauges, theremometers and other readiometric devices.



(Concept of a black body)

Absorptivity, Reflectivity and Transmissivity:-

When incident radiation (G) also called irreradiation impinges on a surface, threee things happens; a part is reflected back, (G_r), a part is transmitted through (G_t) and the reminder is absorbed (G_a), depending upon the characteristics of the body.



(Absorption, reflection and transmission of Radiation).

By the Conservation of Energy principle

$$G_{at} + G_t + G_r = G$$

Dividing both sides by G,

$$\frac{G_{at}}{G} + \frac{G_t}{G} + \frac{G_r}{G} = \frac{G}{G}$$

$$\alpha + \rho + \tau = 1$$

where,

α = absorptivity

ρ = reeflectivity

τ = transmissivity

* When the incident readiation is absorcbed, it is converceted into interenal energy.

*) Definition of emissivity?

→ Emissivity is defined as the reatio of the energy radiated from a matercial's surefare to that readiated from a subject perefect emitter, known as black body, at the same temperceaturce and wavelength and underc the same viewing conditions.

*) Definition of Absorptivity?

→ Absorptivity is a measurce of howmuch of the rcadiation is absorbed by the body.

*) Definition of Transmissivity?

→ Transmissivity is an optical propercty of a matercial, which describes howmuch light is transmitted through material in reelation to an amount of light incident on the material.

→ The light was not transmitted was either reflected or absorbed.