

Chapter 1

Need of engine Performance testing

I C engine testing :-

⇒ Mean effective Pressure and Torque :-

Mean effective pressure (P_m) is defined as a hypothetical pressure which is thought to be acting on the piston throughout the power stroke.

⇒ mean effective pressure which gives an indication of engine displacement utilization for this conversion.

⇒ mean effective pressure is the true indication of the relative performance of different engines.

⇒ Higher the mean effective pressure, higher will be the power developed by the engine for a given displacement.

⇒ It is not possible to compare engines on the basis of either power or torque.

* Indicated Power :-

It is the total power developed in the working cylinder by the gases on the combustion side of the working pistons.

* Brake Power :-

It is the total power measured at the driving shaft.

* Friction Power :-

It is the power consumed in frictional resistance.

* mechanical efficiency :-

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

$$\eta_{\text{mech}} = \frac{\text{b.p.}}{\text{i.p.}}$$

i.p. is always greater than b.p.

* Fuel Consumption :-

The quantity of fuel consumed by the engine per unit time of the stated operating conditions.

* Specific fuel consumption :-

It is the quantity of fuel consumed per unit of power per unit of time.

* Indicated thermal efficiency :-

It is the ratio of heat equivalent of I.P to the heat energy of the fuel supplied.

$$\text{Indicated thermal } \eta = \frac{3600 \times \text{I.P}}{W_f \times C}$$

where W_f = weight of fuel consumed per hour in kg

C = Calorific Value of the fuel in kJ/kg.

* Brake thermal efficiency :- / Engine efficiency

It is the ratio of heat equivalent of b.p to the heat energy of the fuel supplied.

$$\text{Brake thermal } \eta = \frac{3600 \times \text{BP}}{W_f \times C}$$

* Volumetric efficiency :-

It is the ratio of actual volume of the charge admitted during the suction stroke at N.T.P to the swept volume of the piston.

$$\eta_{\text{Vol}} = \frac{\text{Volume of charge admitted at N.T.P during Suction stroke}}{\text{Swept volume of the piston}}$$

mean effective pressure

⇒ The algebraic sum of the mean pressures acting on the surface of the piston during each stroke over one complete cycle.

Indicated mean effective pressure (P_m)

⇒ the constant pressure acting over the full length of the stroke and capable of producing the same amount of work, as is actually produced during the complete cycle of the engine.

⇒ It is generally denoted P_m .

⇒ As, the pressure in the cylinder varies throughout the cycles and the variation can be expressed with respect to the volume or crank angle rotation to obtain P-V or P-θ diagrams, respectively.

⇒ ~~It~~ It is a mean value expressed in N/m^2 , which when multiplied by the displacement volume or swept volume,

$$P_m = \frac{A \cdot S}{L} \cdot \frac{\text{area of indicator} \times \text{spring no.}}{\text{length of indicator}}$$

Indicated Power :-

The power developed inside the engine cylinder due to combustion of fuel is called as indicated power

$$I.P. = \left(\frac{P_m \cdot L \cdot A \cdot n}{60} \right) K$$

where,

P_m = indicated mean effective pressure in N/m^2

L = Length of stroke

A = Area of the inside cylinder $\frac{\pi}{4} d^2$ (bore diameter of cylinder)

n = Number of working / power / explosions strokes

$n = N \xrightarrow{\text{rpm}}$ for 2 stroke

$= \frac{N}{2}$ for four stroke

K = No. of cylinders.

Piston Indicator

⇒ measurement of I.P. mainly involve evaluation of indicated mean effective pressure.

⇒ It is found from P.V diagram which is obtained from an indicator diagram



a = depends of no. of stroke
for 2 stroke = 1
for 4 stroke = $\frac{1}{2}$
for 6 stroke = $\frac{1}{3}$
for 8 stroke = $\frac{1}{4}$

Frictional Power :-

⇒ Some of the indicated power developed in engine cylinder is lost in overcoming the friction at various engine parts and remaining power is obtained as brake power at crank shaft.

$$\Rightarrow \text{Frictional Power} = \text{Indicated Power} - \text{Brake Power}$$
$$I.P - B.P$$

⇒ It is measured in kilowatts (kW)

Mechanical efficiency :-

⇒ It may be defined as the ratio of the power obtained at the crank shaft, i.e. brake power (BP) to the indicated power (IP).

$$\Rightarrow \text{mechanical efficiency} \cdot \eta_m = \frac{BP}{IP}$$

⇒ mechanical efficiency takes into account the mechanical losses in an engine.

⇒ Friction losses as in case of pistons, bearing, gears valve mechanism.

⇒ It varies from 65 to 85%.

Indicated thermal efficiency :-

⇒ It may be defined as the ratio of heat converted into indicated work to the heat energy supplied by the fuel during a specified period of time.

$$\eta_{ith} = \frac{\text{Heat equivalent to IP per minute}}{\text{Heat energy supplied by fuel per min.}}$$

$$= \frac{IP \times 60}{m_f \times CV}$$

where m_f = mass of fuel supplied to the engine in kg/kg.

CV = lower calorific value of the fuel in kJ/kg.

Brake thermal efficiency :-

⇒ The ratio of heat equivalent to brake power (BP) to the heat energy supplied by the fuel during a specific period of time.

$$\eta_{bth} = \frac{\text{Heat equivalent to BP per minute}}{\text{Heat energy supplied by fuel per minute}}$$

$$= \frac{BP \times 60}{m_f \times CV}$$

⇒ Brake thermal efficiency may be obtained from other efficiencies.

$$\eta_m = \frac{\eta_{bth}}{\eta_{ith}} = \frac{BP}{IP}$$

$$\eta_{bth} = \eta_m \times \eta_{ith}$$

Relative efficiency :-

⇒ It is the ratio of actual thermal efficiency to air standard efficiency of the engine. It is sometimes ~~referred~~ referred as efficiency ratio.

$$\eta_{\text{relative}} = \frac{\text{Brake thermal efficiency}}{\text{Air standard efficiency}}$$

Specific fuel consumption :-

⇒ It is amount of the fuel consumed per hour per unit power developed by the engine.

Indicated specific fuel consumption

⇒ The mass of fuel consumption per hour in order to produce an indicated power of one kilowatt.

⇒ Thus, Indicated specific fuel consumption = ~~1850~~

$$ISFC = \frac{\text{fuel consumed in kg/hr}}{I.P. \text{ of the engine}} \quad \text{kg/kwhr}$$

Brake specific fuel consumption

⇒ The mass of fuel consumed per hour, in order to develop a brake power of one kilowatt.

Air fuel ratio

⇒ It is the ratio b/w the mass of the air and fuel supplied to the engine.

$$A/F = \frac{\text{mass flow rate of air}}{\text{mass flow rate of fuel}}$$

⇒ Stoichiometric air fuel ratio is 15

Combustion of air fuel mix. ratio petrol engine = 12 to 14

diesel engine = 20 to 30

Calorific value of fuels

⇒ The calorific value or heat value of a fuel is defined as the total quantity of heat liberated by the complete combustion of unit quantity of fuel.

⇒ The calorific value of solid or liquid fuels is expressed in kJ/kg.

⇒ It's gaseous fuels is kJ/m³.

⇒ It is two types :- Higher calorific value
Lower calorific value

Higher calorific value (HCV)

⇒ The total amount of heat liberated when unit quantity of the fuel is completely burnt and the products of combustion are cooled to the initial temp. at which fuel and air are supplied usually taken as 15°C

Lower calorific value (LCV)

⇒ The amount of heat liberated by complete combustion of unit quantity of fuel without the condensation of steam formed.

$$L.C.V = H.C.V - m_s L \text{ kJ/kg}$$

where $m_s = 9 H_2$

$$L = 15^\circ\text{C} = 2466 \text{ kJ/kg}$$

$$LCV = HCV - m_s L \text{ kJ/kg}$$

$$HCV = 9H_2 \times 2466 \text{ kJ/kg}$$

Volumetric efficiency

⇒ It is the ratio of actual volume of charge admitted during the suction stroke at NTP to the swept volume of the piston.

$$\eta_{vol} = \frac{m_{act}}{m_{th}}$$

⇒ ~~The~~ at

⇒ It is very important parameter.

⇒ Volumetric efficiency for a naturally aspirated engine is generally about 75%.

Factors affecting :-

⇒ ~~It~~ Volumetric efficiency measure of the ability of an engine.

⇒ It depends :- (i) Engine speed

(ii) compression ratio

(iii) mixture strength

(iv) Inlet air temp.

(v) Cooling water temp.

Specific fuel consumption :-

$$X_{specific} \gamma =$$

Brake specific fuel consumption :- Brake

Here m_{act} is the mass of actual air drawn ($= V_s \times \rho$)

m_{th} is the mass of theoretical air ($= \rho_a \times n \times V_s$)

Where ρ_a is the density of air

V_s is the swept volume

n = number of intake strokes

per min. $= \frac{N}{2}$ = 4 stroke engine

N = 2 stroke engine.

breathing

Relative efficiency

It is defined as the ratio of indicated thermal efficiency to the air standard efficiency.

Volumetric efficiency

Actual value can be calculated from ideal gas calculations

$$P.V = mR.T$$

$$\text{Theoretical swept volume} :- \frac{\pi d^2 L N \times k \times a}{4}$$

Assignment-2

What is the significance of fuel air ratio?

Why fuel air ^{or} ratio is important?

Equivalence ratio :- (ϕ)

It is defined as the ratio of actual fuel air ratio to the theoretical fuel air ratio

$$\phi = \frac{\text{actual fuel air ratio}}{\text{Theoretical fuel air ratio}}$$

If $\phi = 1$ perfect air fuel mixture

$\phi < 1$ Lean air fuel mixture

$\phi > 1$ ~~rich~~ rich air fuel mixture

$\phi = \text{fuel}$
 $1 = \text{air}$

Example-1 D.t. 18-2-25

The following data were recorded a test on engine
speed of the engine $= 1000 \text{ rpm}$
load on the brake $= 1000 \text{ N}$
length of the arm $= 750 \text{ mm}$

- Determine (i) Brake torque
(ii) B.P. of the engine

Sol :- Brake torque, $T = W \times l$
 $= 1000 \times 0.75$
 $T = 750 \text{ N-m}$

Brake power of the engine,

$$\text{B.P.} = \frac{(2\pi NT)}{60} \text{ watt}$$

$$P = \frac{2\pi NT}{\text{rpm} \times \text{N-m}}$$

$$= \frac{\text{N.m}}{\text{min}} = \frac{\text{J}}{\text{min}}$$

$$= \frac{2\pi \times 1000 \times 750}{60}$$

$$= 78,539.8 \text{ watt}$$

$$\text{B.P.} = 78.54 \text{ kW}$$

$$= \frac{2\pi NT}{60} = \frac{\text{Nm}}{\text{sec}} = \frac{\text{J}}{\text{sec}} = \text{Watt}$$

Example-2

A rope brake has rope wheel diameter 600 mm and the diameter of rope is 5 mm the dead load on the brake is 210 N and spring balance reads 30 N if the engine make 450 rpm find the brake power developed.

Given data
Rope wheel diameter (D) $= 600 \text{ mm} = 0.6 \text{ m}$
Diameter of rope (d) $= 5 \text{ mm} = 0.005 \text{ m}$
Dead load on the brake (W) $= 210 \text{ N}$

= Spring balance reads (S) = 30 N

Speed (N) = 450 rpm

To find = Brake power developed = ?

Sol Brake Power (B.P) =
$$\frac{(W-S)\pi(D+d)N}{60} \text{ watts}$$
$$= \frac{(210-30) \times \pi \times (0.6+0.005) \times 450}{60}$$
$$= \frac{180 \times \pi \times 0.605 \times 450}{60}$$
$$= 2565.89 \text{ watts}$$
$$\text{B.P} = 2.57 \text{ kW}$$

Ex-3

A single cylinder 4 stroke diesel engine has a bore of 110 mm, stroke 120 mm, the indicated mean effective pressure is 375 kN/m². Calculate the indicated power at a crank speed of 60 rpm.

Given data

Bore, ϕ = 110 mm = 0.11 m

Piston area (A) = $\left(\frac{\pi}{4}\right)(0.11)^2 = 0.0095 \text{ m}^2$

Stroke (l) = 120 mm = 0.12 m

Indicated mean effective pressure (i.m.e.p) $P_m = 375 \text{ kN/m}^2$

Speed (N) = 60 rpm

To find Indicated power at a crank = ?

$$\text{Sol 1:- I.P.} = \frac{P_m L A \left(\frac{N}{2}\right)}{60}$$

$$= \frac{375 \times 0.12 \times 0.0095 \times 60}{2 \times 60}$$

$$\text{I.P.} = 0.21375 \text{ k.w}$$

Exam-4

In a laboratory experiment the following observations were noted during the test of a stroke diesel engine.

Given :- Area of indicator diagram (a) = 920 mm²
 length of indicator diagram (l) = 62 mm
 Spring number (S) = 1.1 bar/mm
 Diameter of piston (d) = 100 mm
 length of stroke (L) = 150 mm
 Engine Speed (N) = 450 rpm

To find indicated mean effective pressure = ?
 Indicated Power = ?

$$\text{Sol Area of piston } A = \left(\frac{\pi}{4}\right) \times 0.1^2$$

$$= 0.785 \times 0.01$$

$$A = 7.853 \times 10^{-3} \text{ m}^2$$

$$n = \frac{N}{2} = \text{No. of Power Stroke per min}$$

$$= \frac{450}{2} = 225$$

$$(a) P_m = \left(\frac{a \cdot S}{l}\right) = \frac{920 \times 1.1}{62} = 16.45 \text{ bar} \rightarrow 3.30 \text{ k.w}$$

$$(b) \text{ I.P.} = \frac{P_m L A n}{60} = \frac{16.45 \times 0.15 \times 7.853 \times 10^{-3} \times 225}{60} = 198.25$$

Example - 1

Given data = Stroke length (L) = 26 cm = 0.26 m

$$\text{Engine speed (N)} = 350 \text{ R.P.M} = \frac{350}{60} = 5.83 \text{ rps}$$

Here $n = N = 5.83 \text{ rps}$ (2 stroke-engine)

Effective brake wheel diameter (D) = 1.2 m

$$R = \frac{1.2}{2} = 0.6 \text{ m}$$

Net load on brake ($w-s$) = 480 N

No. of cylinder (n) = 1

Bore dia (d) = 20 cm = 0.2 m

Fuel consumption $m_f = 3.6 \text{ kg/hr} = 3.6/3600 = 0.001 \text{ kg/sec}$

Calorific value $CV = 42000 \text{ kJ/kg}$

$$i.m.e.p. = 0.28 \text{ N/m}^2 = 0.28 \times 1000$$

Find :- I.P. = ?

Brake Thermal efficiency = 28% N/m^2

B.P. = ?

Specific fuel consumption = ?

mech. efficiency = ?

$$A = \frac{\pi}{4} (0.2)^2$$

$$= 0.78 \times 0.04$$

$$A = 0.0314$$

$$(i) \text{ I.P.} = P_m \times L \times A \times n \times k$$

$$= 280 \times 0.26 \times 0.0314 \times 5.83 \times 1$$

$$\text{I.P.} = 13.33 \text{ kW}$$

$$(ii) \text{ B.P.} = 2\pi \times N \times (w-s) \times R$$

$$= 2\pi \times 5.83 \times 0.48 \times 0.6$$

$$= 10.54 \text{ kW}$$

$$(iii) \text{ mech. efficiency } (\eta_{\text{mech}}) = \frac{BP}{IP}$$

$$= \frac{10.54}{13.33}$$

$$\eta_{\text{mech}} = 0.7912$$

$$\eta_{\text{mech}} = 79.12\%$$

$$(iv) \text{ Brake thermal efficiency } = \eta_{\text{bth}} = \frac{BP}{m_f \times CV}$$

$$= \frac{10.54}{0.001 \times 42000}$$

$$\eta_{\text{bth}} = 0.25 \text{ or } 25\%$$

(v) Specific fuel consumption :-

$$= \frac{\text{mass of fuel consumed per hour}}{B.P.} = \frac{3.6}{10.54}$$

$$= 0.341 \text{ kg/hr}$$

$$\Rightarrow \text{SFC} = 0.341 \text{ kg/BP-hr}$$

Example - 2 :-

Given data :- Brake Power, B.P. = 24 kW

Fuel consumption = 0.128 kg/min

water circulating the cylinder = 5.9 kg/min;

Temperature rise of cooling water = 49.5°C

Temp. of exhaust gases = 387.8°C

Temp. of engine room = 18.4°C

Air fuel ratio = 20

Calorific value of oil = 45200 kJ/kg

Specific heat of exhaust gas = 1.05 kJ/kg°C

Specific heat of water = 4.2 kJ/kg°C

Sol Heat supplied to the engine

$$Q_s = m_f \times CV$$

$$= 0.128 \times 45200$$

$$Q_s = 5785.6 \text{ kJ/min}$$

(a) Heat energy equivalent to B.P. = 24×60
 $= 1440 \text{ kJ/min}$

(b) Heat carried away by cooling water

$$= m_w (t_2 - t_1)$$

$$= 5.9 \times 4.2 \times 49.5$$

$$= 1226.6 \text{ kJ/min}$$

(c) Heat carried away by exhaust gases :-

$$= m_f (AFR + 1) C_p (t_g - t_e)$$

$$= 0.128 (20 + 1) 1.05 (387.8 - 18.4)$$

$$= 1042.56 \text{ kJ/min}$$

(d) Heat unaccounted or energy to surroundings

$$= Q_s - (a + b + c)$$

$$= 5785.6 (1440 + 1226.6 + 1042.56)$$

$$= 2076.44 \text{ kJ/min.}$$

Example - 3

Compression ratio = 15 = r

Oil consumption = $10.2 \text{ kg/h} = m_f$

Calorific value of fuel = $43890 \text{ kJ/kg} = CV$

Air consumption = $3.8 \text{ kg/min} = m_a$

Speed = $1900 \text{ r.p.m} = N$



Torque on the brake drum (T) = 186 N-m

Quantity of cooling water used (m_w) = 15.5 kg/min

Temp. rise ($T_{w2} - T_{w1}$) = 36°C

Exhaust gas temp. (t_g) = 410°C

Room temp. (t_r) = 20°C

C_p for exhaust gases = 1.17 kJ/kgK

Sol B.P. :- $\frac{2\pi NT}{60 \times 1000}$

$$= \frac{2\pi \times 1900 \times 186}{60 \times 1000} = \frac{2220477.68}{60000} = 37 \text{ kW}$$

(ii) Brake Specific fuel consumption, b.s.f.c. -

$$\text{b.s.f.c} = \frac{10.2}{37} = 0.2756 \text{ kg/kWh}$$

(iii) Brake thermal efficiency, η_{thb} :-

$$\eta_{thb} = \frac{BP}{mf \times C} = \frac{37}{\frac{10.2}{3600} \times 43890} = 0.2975 \text{ or } 29.75\%$$

Heat balance sheet on minute basis :-

(a) Heat supplied by the fuel per minute :-

$$= \frac{10.2}{60} \times 43890 = 7461 \text{ kJ/min}$$

(b) Heat equivalent of B.P. :- $B.P \times 60$

$$= 37 \times 60 = 2220 \text{ kJ/min}$$

(c) Heat carried away by cooling water :-

$$= m_w \times C_{pw} (T_{w2} - T_{w1})$$

$$= 15.5 \times 4.18 \times 36$$

$$= 2322 \text{ kJ/min}$$



(d) Heat carried away by exhaust gases

$$= m_g \times (c_{pg} \times (T_g - T_r))$$

$$= \left(\frac{10.2}{60} + 3.8 \right) \times 1.17 \times (410 - 20)$$

$$= 1811 \text{ kJ/min}$$

EX-4

Given data

Two stroke engine hence $n = N$

$$\text{Speed } (N) = 350 \text{ rpm}$$

$$\text{Net brake load } (W) = (65 \times 9.81) \text{ N}$$

$$\text{Mean effective pressure } (P_m) = 3 \text{ bar}$$

$$\text{fuel consumption } (m_f) = 4 \text{ kg/h}$$

$$\text{Jacket cooling water flow rate } (m_w) = 500 \text{ kg/h}$$

$$\text{Jacket water temperature at inlet } (T_{wi}) = 20^\circ\text{C}$$

$$\text{Jacket water temperature at outlet } T_{wo} = 40^\circ\text{C}$$

$$\text{Test room Temperature } T_{atm} = 20^\circ\text{C}$$

$$\text{Temp. of exhaust gases } (T_{eg}) = 400^\circ\text{C}$$

$$\text{Air used per kg of fuel } \left(\frac{m_a}{m_f} \right) = 32$$

$$\text{Cylinder diameter } (d) = 22 \text{ cm} = 0.22 \text{ m}$$

$$\text{Stroke length } (L) = 28 \text{ cm} = 0.28 \text{ m}$$

$$\text{Effective brake diameter} = 1 \text{ m}$$

$$\text{mean specific heat of exhaust gases } (c_{p, eg}) = 1 \text{ kJ/(kg}\cdot\text{K)}$$

$$\text{Brake radius} = R = \frac{1}{2} \text{ m}$$

$$C.V = 43,000 \text{ kJ/kg}$$

Sol :- Indicated Power :- (I.P) = $\frac{P_m L A n}{60}$

$$= \frac{3 \times 10^5 \times 0.28 \times \left(\frac{\pi}{4}\right) \times 0.22^2 \times 350}{60}$$

$$= \frac{1109908.8}{60} = 18498 \text{ watts}$$

I.P = 18.49 kW

Brake Power :- B.P = $\frac{2\pi NWR}{60}$

$$= \frac{2 \times \pi \times 350 \times (65 \times 9.81) \times 0.5}{60}$$

$$= \frac{700777.35}{60} = 11680 \text{ watts}$$

$$= 11.68 \text{ kW}$$

Heat balance sheet

Heat supplied in kW = $m_f C_v$

$$= \left(\frac{4}{3600}\right) \times 43000$$

$$= 1.11 \times 10^{-3} \times 43000$$

$$= 47.8 \text{ kW}$$

Heat lost to cooling water = $m_w (C_p)_w (T_{w0} - T_{wi})$

$$= \left(\frac{500}{3600}\right) \times 4.2 \times (40 - 20)$$

$$= 0.138 \times 4.2 \times 20$$

$$= 11.7 \text{ kW}$$

Heat lost in exhaust gases = $(m_a + m_f) (C_p)_{eg} (T_{eg} - T_{aem})$

$$= \frac{(32 + 1) \times 4}{3600} \times 1.0 \times (400 - 20)$$

$$= \frac{132}{3600} \times 1 \times 380$$

$$= 13.93 \text{ kW}$$

Ex-5 cylinder diameter (d) = 25 cm = 0.25 m
 Stroke length (L) = 45 cm = 0.45 m
 Effective diameter of the brake (R) = $\frac{1.6}{2}$ = 0.8 m
 t = 40 min

Total number of revolution (N_{total}) = 8080

$N = \frac{8080}{40} = 202 \text{ RPM}$

$n_{total} = 3230$

$\eta = \frac{3230}{40} = 80.75 \text{ 'exploding' / min}$

Net load on the brake (W) = $80 \times 9.81 \text{ N}$

Mean effective Pressure (P_m) = 5.8 bar

Volume of gas used (V_{total}) = 7.5 m³

Hence $V = \frac{7.5}{40} = 0.1875 \text{ m}^3/\text{min}$

Pressure of Indicated in meter (P_{gauge}) = 136 mm of water

Atmospheric Temp. (T_{atm}) = $17 + 273 = 290 \text{ K}$

Calorific Value of gas (CV) NTP = $19 \times 10^3 \text{ kJ/m}^3$

Temperature rise of cooling water (ΔT_w) = 45°C

Cooling water supplied (m_w) = $\frac{180}{40} = 4.5 \text{ kg/min}$

Atmospheric Pressure (P_{atm}) = 760 mm of mercury

Sol Indicated Power :-

$$I.P = \frac{P_m L A N K}{60000}$$

$$= \frac{5.8 \times 10^6 \times \left(\frac{\pi}{4}\right) \times 0.25^2 \times 0.45 \times 80.75}{60,000}$$

$$= \frac{1027442.813}{60000} = 17.25 \text{ k.W}$$

Brake Power :-
$$\frac{2\pi NWR}{60,000}$$

$$= \frac{2\pi \times 202 \times (80 \times 9.81) \times 0.8}{60000}$$

$$= \frac{796452.71}{60,000} = 13.28 \text{ kW}$$

Pressure of gas supplied

$$P = P_{\text{atm}} + P_{\text{gauge}}$$

$$= \frac{760 + 136}{13.6} = 770 \text{ mm of mercury.}$$

Volume of gas supplied as measured at NTP

$$V_{\text{NTP}} = V \left(\frac{T_{\text{NTP}}}{T} \right) \left(\frac{P}{P_{\text{NTP}}} \right)$$

$$= \frac{0.1875 \times 273 \times 770}{290 \times 760}$$

$$= \frac{39414.375}{220400}$$

$$= 0.17875 \text{ m}^3/\text{min}$$

Heat balance sheet:

(1) Heat supplied by fuel = $Q_R = V_{\text{NTP}}(CV)_{\text{NTP}}$

$$= 0.17875 \times 19 \times 10^3$$

$$= 3396.25 \text{ kJ/min}$$

(2) Heat equivalent of BP in kJ/min = 13.28×60

(3) Heat lost to cooling water in kJ/min

$$= 796.4 \text{ kJ/min}$$

$$= m_w C_p \Delta T_w$$

$$= 4.5 \times 4.2 \times 45$$

$$= 846.5 \text{ kJ/min}$$

(4) Friction power = $1P - bP$

$$= 17.25 - 13.28 \text{ heat loss due to friction}$$

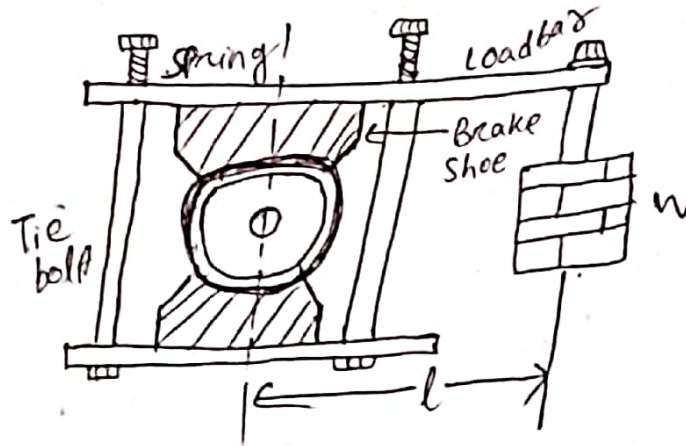
$$= 3.97 \text{ kW Pumping etc.} = 3.97 \times 60$$

(5) Heat lost is exhaust, radiation etc

$$= 3396.25 - (896.4 + 796.4 + 238.2)$$

$$= 3396.25 - 1931 = 1465.15 \text{ kJ/min}$$

Brake Power



Prony brake

W = Brake load in newton

l = length of arm in metres

N = Speed of the engine in r.p.m

B.P = $\frac{\text{Torque in N-M} \times \text{Angle turned in radians through 1 revolution}}{60} \times \text{R.P.M. in watts}$

$$T \cdot \frac{\theta}{l}$$

$$\theta = 2\pi$$

$$\text{Speed} = N \text{ rpm}$$

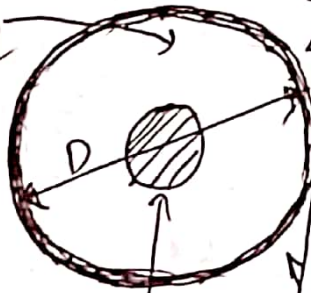
$$= \frac{N}{60} \text{ rps}$$

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

$$\text{or } \frac{W \cdot l \times 2\pi N}{60} \text{ watts}$$

Role brake

Fly wheel



Spring balance

Load

Crank shaft

$$B.P = \frac{(W-S) \pi D N}{60} \text{ watt}$$

$$= \frac{(W-S) \pi (D+d) N}{60} \text{ watt}$$

Chapter - 6 Heat Transfer

Heat Transfer :- It is the study of rates at which exchange of heat takes place betⁿ hot source to cold receiver.

⇒ It is the study of transfer of heat from one body to another.

⇒ When two bodies, heat flows from a body at higher temp. to that at lower temperature.

⇒ Heat is defined as a form of energy which is transit between a hot source and cold receiver.

⇒ The body at higher temp. is called as source body at lower temp. is called receiver.

* Mechanism of heat flow :-

⇒ heat transfer are Three mechanisms :-

(i) conduction

(ii) convection

(iii) Radiation

(i) Conduction :- It is a transfer of heat from one part of a body to another part of a same body from one body to another body, which is an physical contact with it. without appreciable displacement of the particles of a body.

ex:- heat flow in solids

⇒ metal wall of a heat exchanger tube.

Convection :-

⇒ It is the transfer of heat from one point to another point within a fluid by mixing of hot and cold portions of the fluid.

Assignment :- Prove Thermometer is applying zeroth law

Radiation :- It is a transfer of heat from one body to another, not in contact with it, by electromagnetic wave through space.

⇒ If radiation is passing through empty space.

⇒ It is not transformed as heat or any other form of energy.

Example :- Heat transfer from Sun to earth.

Thermal Conductivity :-

It is rate of heat transfer through a unit thickness of the material per unit area per unit temp. difference.

Zeroth law :- If two

* In thermodynamics deals with equilibrium states and changes from one equilibrium state to another. Heat transfer, on the other hand, deals with systems that lack thermal equilibrium and thus it is a nonequilibrium phenomenon.

⇒ The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction.

Application areas of heat transfer :-

① The human body is constantly rejecting heat to its surroundings, and human comfort is closely tied to the rate of this heat rejection. We try to control this heat transfer rate by adjusting our clothing to the environmental conditions.

② Many household appliances are designed, in whole or in part, by using the principles of heat transfer on the basis of minimizing heat loss in winter and heat gain in summer.

Examples :- The electric or gas range, the heating and air-conditioning system, the refrigerator and freezer, the water heater, the iron, and even the computer, the TV, and the VCR etc.

③ Heat transfer plays a major role in the design of many other devices, such as car radiators, solar collectors, various components of power plants and even spacecraft.

④ The optimal insulation thickness in the walls and roofs of the houses, on hot water or steam pipes or on water heaters is again determined on the basis of a heat transfer analysis with economic consideration.

Thermal Conductivity: (k)

It can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.

⇒ It is the measure of the ability of the material to conduct heat.

High value - Good heat conductor

Low value - Poor heat conductor/insulator

⇒ Pure crystals and metals have highest thermal conductivity and gases and insulating materials the lowest.

Unit = $\text{W/m}\cdot\text{K}$ (watt per meter Kelvin)

Thermal Diffusivity (α):

⇒ It is the thermal conductivity divided by density and specific heat capacity at constant pressure.

⇒ It measures the rate of heat transfer of heat of a material from the hot end to the cold end.

Unit $\rightarrow \text{m}^2/\text{s}$

$$\alpha = \frac{\text{Heat Conducted}}{\text{Heat Stored}}$$

$$= \frac{k}{\rho C_p}$$

where C_p = Specific heat capacity ($\text{J/kg}\cdot\text{K}$)

ρ = density (kg/m^3)

k = Volumetric heat capacity ($\text{J/m}^3\cdot\text{K}$)

Larger the value of α , the faster the propagation of heat into the medium.

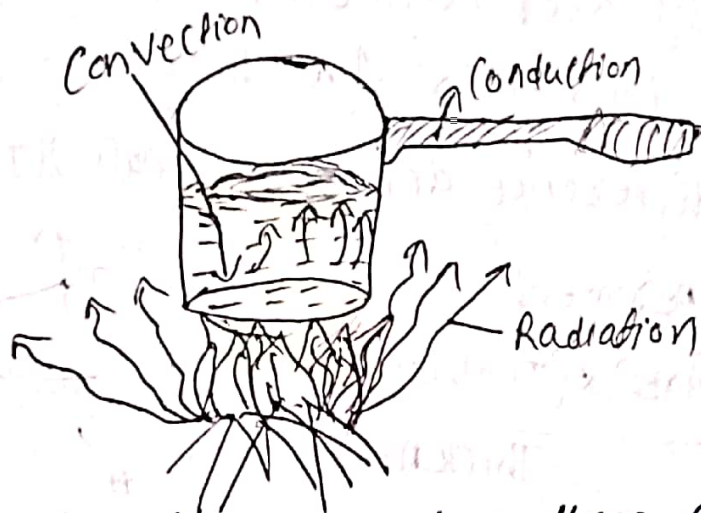
$$\alpha = \frac{k}{\rho C_p} = \frac{\text{W}}{\text{m}\cdot\text{K}} \times \frac{\text{m}^3\cdot\text{K}}{\text{kg}\cdot\text{J}}$$

$$\rho C_p = \frac{\text{J}}{\text{kg}\cdot\text{K}} \times \frac{\text{kg}}{\text{m}^3}$$

$$= \frac{\text{J}}{\text{m}^3\cdot\text{K}}$$

$$k = \frac{\text{W}}{\text{m}\cdot\text{K}}$$

Modes of Heat Transfer



* Heat can be transferred in three different modes:-

- * Conduction
- * Convection
- * Radiation.

Conduction :- Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole.

Conduction can take place in solids, liquids, and gases. It is due to the collisions and diffusion of the molecules during their random motion. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons.

The rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and the material of the medium, as well as the temperature difference across the medium. We know that

wrapping a hot water tank with glass wool reduces the rate of heat loss from the tank. The thicker the insulation, the smaller the heat loss. We also know that a hot water tank will lose heat at a higher rate when the temperature of the room housing the tank is lowered. Further, the larger the tank, the larger the surface area and thus the rate of heat loss.

Fourier's law :-

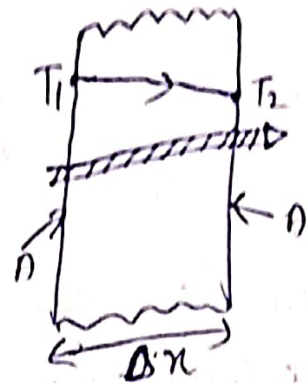
Consider steady heat conduction through a large plane wall of thickness $\Delta n = L$ and area A .

Temperature difference across the wall $\Delta T = T_2 - T_1$

According to experiment

Rate of heat Conduction $\propto \frac{(\text{Area}) \times (\text{Temp. difference})}{\text{Thickness}}$

$$\rightarrow \dot{Q}_{\text{Cond}} = kA \frac{T_2 - T_1}{\Delta n} = -kA \frac{\Delta T}{\Delta n}$$



where, k = Thermal conductivity of the material (proportionality constant) fig: - Heat conduction through a large plane wall of thickness Δn and area A

In differential form $\boxed{\dot{Q}_{\text{Cond}} = -kA \frac{dT}{dn}}$

It is called Fourier's law of heat conduction.

Definition :- It states that the rate of heat conduction through a plane layer is proportional to the temp. difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

Temperature Gradient :-

It can be defined as change in temp. in a particular direction. Change may be rise or fall.

$$\frac{T_1 - T_2}{\Delta n} = \frac{\Delta T}{\Delta n} = \frac{dT}{dn}$$

Convection :-

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.

The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates.

Newton's law of cooling

The rate of convection heat transfer is observed to be proportional to the temp. difference.

$$\dot{Q}_{\text{conv}} = h A_s (T_s - T_{\infty})$$

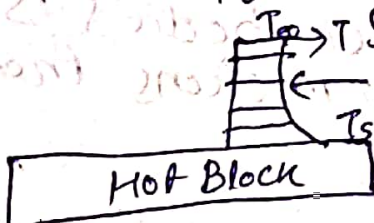
where h = convection heat transfer coefficient ($\text{W/m}^2\cdot\text{K}$)
 A_s = surface area through which convection heat transfer takes place.

T_s = Surface temperature

T_{∞} = Temp. of fluid sufficiently far from the

surface.

Temp. variation $\rightarrow$ As distance increases of air temp. decreases.



Radiation :-

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection the transfer of energy by radiation does not require the presence of an intervening medium. In fact energy transfer by radiation is fastest and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth. Here we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temp. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temp.

All bodies at a temperature above absolute zero emit thermal radiation. Radiation is a volumetric phenomenon, and all solids, liquids, and gases emit, absorb, or transmit radiation to varying degrees. However, radiation is usually considered to be a surface phenomenon for solids that are opaque to thermal radiation such as metals, wood and rocks. Since the radiation emitted by the interior regions of such material can never reach the surface and the radiation incident on such bodies is usually absorbed within a few microns from the surface.

Stefan - Boltzmann law:-

It states that the rate of radiation that can be emitted from a surface is directly proportional to the 4th power of absolute temp. T_s .

$$\dot{Q}_{\text{emit, max}} \propto A_s T^4 \Rightarrow \dot{Q}_{\text{emit, max}} = \sigma A_s T^4$$

in terms of energy it states that the total energy radiated per unit time per unit area of a surface is directly proportional to the 4th power of absolute temp. T_s . $E \propto T^4 \Rightarrow E = \sigma T^4$

where σ = Stefan-Boltzmann constant

Value of $\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$

The law applies only to black bodies, theoretical surface that absorb all incident heat radiation.

Black body radiation:-

A black body in thermal equilibrium (i.e. at constant temp.) emits electromagnetic radiation called black body radiation.

Black body is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence. It is idealized opaque and non-reflective body. It emits radiation at the maximum rate.

The radiation emitted by all real surfaces is less than the radiation emitted by a black body at the same temperature. It can be expressed as $\dot{Q}_{\text{emit}} = E \sigma A_s T_s^4$ where E = Emissivity of the surface

Value of E is in the range

$$0 \leq E \leq 1$$

For black body $E = 1$

The emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation. It is the ratio of the energy radiated from a materials surface to that radiated from a perfect emitter (i.e. black body) at the same temp and wavelength and under same viewing condition.

Absorptivity (α) :- It is a measure of how much of the radiation is absorbed by the body.
Value ranges in $0 \leq \alpha \leq 1$.

Black body is a perfect absorber ($\alpha = 1$) as it is a perfect emitter.

$$\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}}$$

Transmissivity (τ) :-

It is a measure of how much of the radiation is transmitted by the body.

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}, \quad 0 \leq \tau \leq 1$$

Both ϵ and α of a surface depends on the temperature and wavelength of the radiation.

Kirchhoff's law :-

Kirchhoff's law of radiation states that the emissivity and absorptivity of a surface at a given temp. and wavelength are equal.

* What is Diffusion?

The natural movement of particles from an area of higher concentration to an area of lower concentration, due to random molecular motion.

Chapter 2 Air Compressor

Air Compressor :-

It is a machine which compress the air and raise it's pressure, compress air is used.

(1) Pneumatic drills

(2) Paint spraying

(3) In starting and super charging of internal combustion engines.

(4) Jet engines.

Classification of air compressors

According to working

(1) Reciprocating (2) Rotary

According to number of stages

(1) Single stage (2) multi-stage

According to action

(1) single acting (2) Double acting.

Terminology :-

Inlet Pressure :-

It is the pressure at which air enters into the compressor.

Outlet / discharge pressure :-

It is the pressure at which air exit from the compressor.

Compression Ratio or Pressure Ratio:-

* The ratio must be greater than one.
Pressure ratio may be defined as the ratio of discharge pressure to inlet pressure.

Compressor Capacity:-

It can be defined as the volume of air delivered by the compressor.

Unit:- m^3/min or m^3/sec

Free air delivery:-

It is the actual volume delivered by the compressor at NTP (Normal Temperature and Pressure).

Swept Volume:-

It is the volume of air sucked by the compressor per stroke.

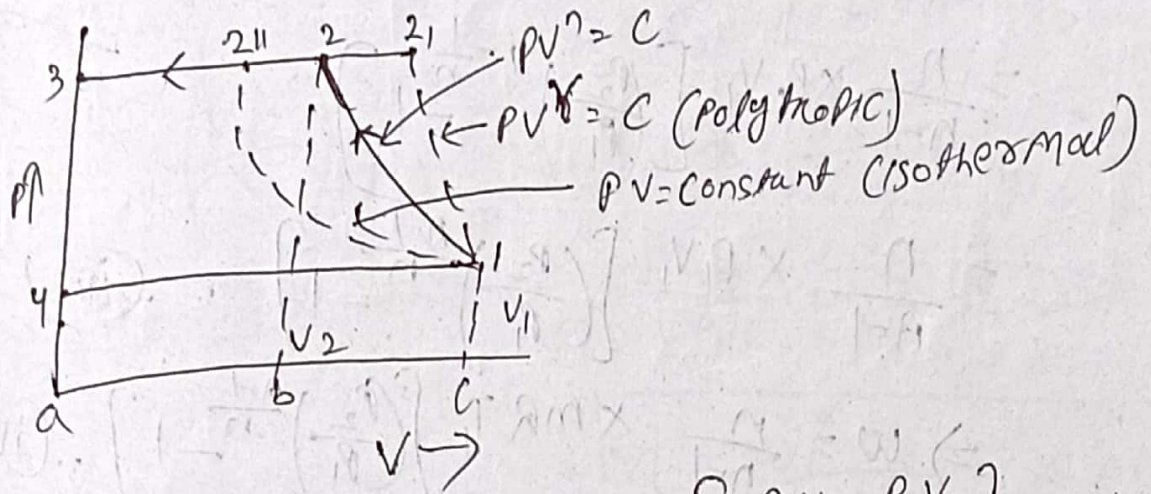
$$= \frac{\pi}{4} d^2 \times l \quad \text{cylindrical} \quad a^2 \times l \quad \text{square} \quad ab \times l \quad \text{rectangular.}$$

mean effective pressure:-

As a matter of fuel air pressure on the compressed piston keeps on changing with the movement of piston, mean effective pressure can be found mathematically by dividing the work done per cycle to the swept volume or stroke volume.

Reciprocating Air compressor

Theoretical P-V diagram for single acting compressor without clearance 5 mark



$$\text{Area of the PV diagram} = P_2 V_2 + \left[\frac{-P_1 V_1 - P_2 V_2}{n-1} \right] - P_1 V_1$$

(-ve) sign indicates work done :-

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

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

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

$$= \frac{n}{n-1} m R (T_2 - T_1) \dots (ii)$$

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

we know that Pressure and temp. relation in Polytropic Process

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

$$\Rightarrow \left(\frac{V_2}{V_1} \right)^n = \left(\frac{P_1}{P_2} \right)$$

$$\Rightarrow \left(\frac{P_2}{P_1} \right)^{\frac{1}{n}}$$

Substituting the value of $\frac{V_2}{V_1}$ in equation

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

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

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

$$\Rightarrow W = \frac{n}{n-1} \times n R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] \quad \text{--- (iv)}$$

$$\Rightarrow W = \frac{n}{n-1} R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

Assignment = Adiabatic process
isothermal process
(P-V diagram)

$$P V^n = C$$

$$P V = C$$

$$W = \int_1^2 P dV$$

$$= \int_1^2 \frac{C}{V^n} dV$$

where

$$C = P V^n$$

$$= C \int_1^2 V^{-n} dV$$

$$= C \left[\frac{V^{-n+1}}{-n+1} \right]_1^2$$

$$= \frac{C V_2^{-n+1} - C V_1^{-n+1}}{-n+1}$$

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

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

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

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

$$K = \frac{V_3}{V_1 - V_3}$$

$$V_1 = \frac{V_1 - V_4}{V_1 - V_3}$$

$$\Rightarrow \left(\frac{P_3}{P_4}\right)^{\frac{1}{\gamma}} = \left(\frac{V_4}{V_3}\right)$$

$$\left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} = \left(\frac{V_4}{V_3}\right)$$

$$\because P_3 = P_2 \text{ and } P_4 = P_1$$

$$V_4 = V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}$$

$$\left(\frac{V_4}{V_3}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}$$

Volume efficiency

$$\frac{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$\eta_v = \frac{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$= \frac{V_3 \left(\frac{V_1 - V_3}{V_3}\right)}{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}$$

$$= \frac{V_3 \left(\frac{V_1 - V_3}{V_3}\right)}{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}$$

$$= \frac{V_3}{V_1 - V_3}$$

$$\Rightarrow \eta_v = \frac{K V_1}{V_3} - K \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}$$

$$\Rightarrow V_1 = V_3 \left(1 + \frac{1}{K}\right)$$

$$\Rightarrow \eta_v = \frac{K \cdot V_3 \left(1 + \frac{1}{K}\right) - K \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$\Rightarrow \eta_v = 1 + \frac{1}{K} - K \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} = 1 + \frac{1}{K} - K \left(\frac{V_1}{V_2}\right)^{\frac{1}{\gamma}}$$

$$\eta = \frac{V_1 - V_4}{V_1 - V_3}$$

$$= \frac{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$= \frac{V_3 \left(\frac{V_1}{V_3} - 1\right)}{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}$$

$$= \frac{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$= \frac{V_3 \left(\frac{V_1 - V_3}{V_3}\right)}{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}$$

$$= \frac{V_1 - V_3 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}}}{V_1 - V_3}$$

$$V_3/K$$

$$K = \frac{V_3}{V_1 - V_3}$$

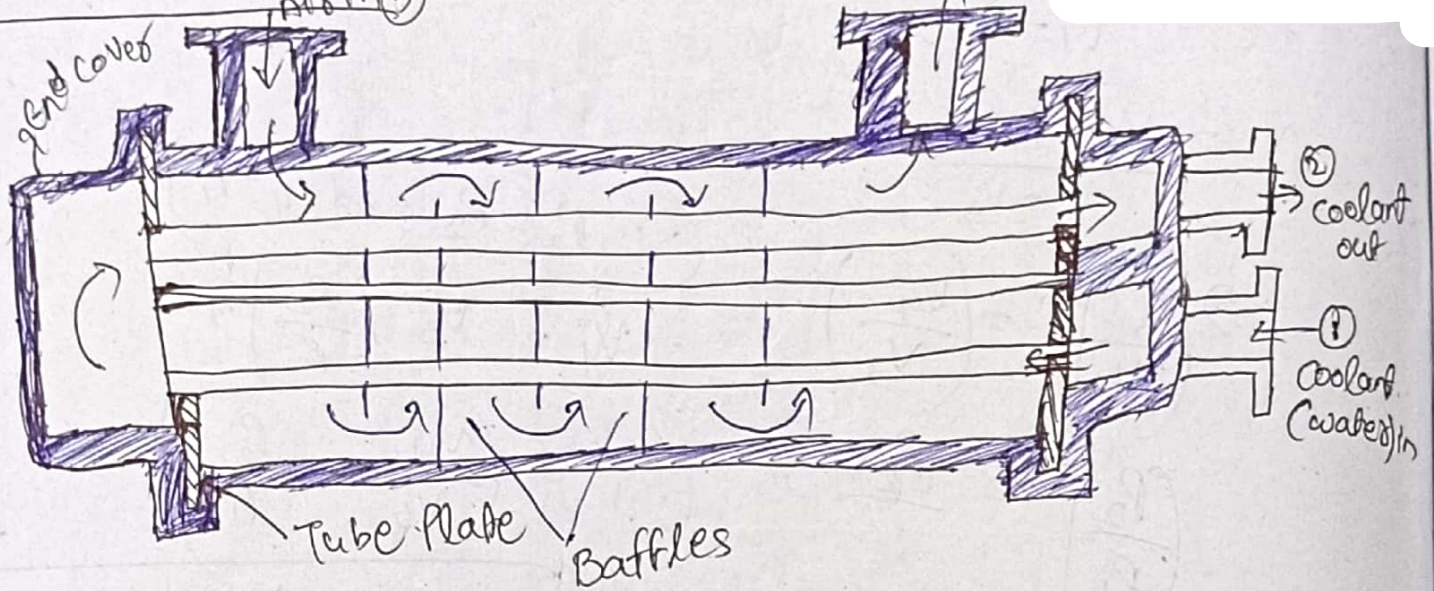
$$\Rightarrow V_1 K - V_3 K = V_3$$

$$\Rightarrow V_1 K = V_3 + V_3 K$$

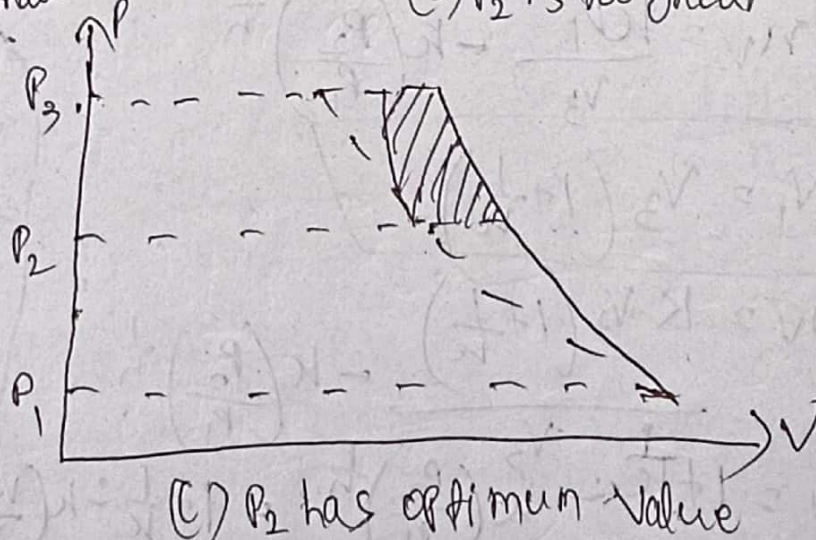
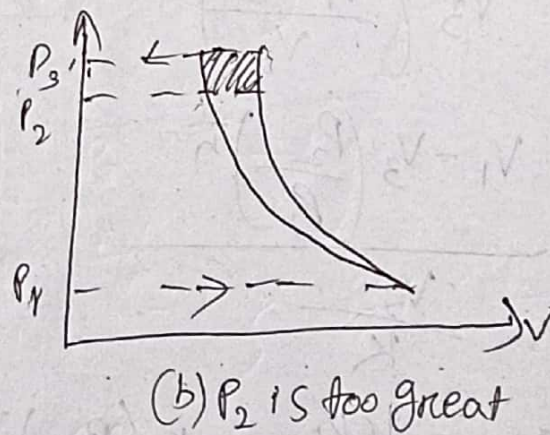
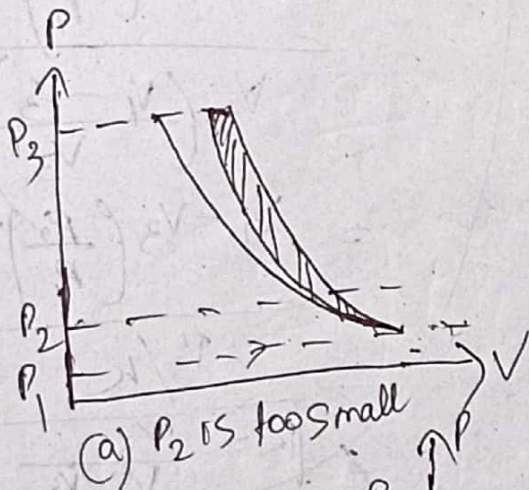
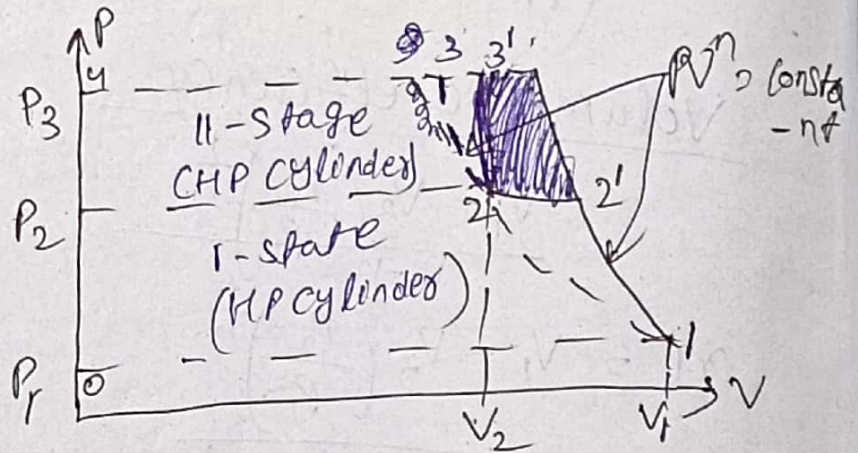
$$\Rightarrow V_1 = \frac{V_3 + V_3 K}{K}$$

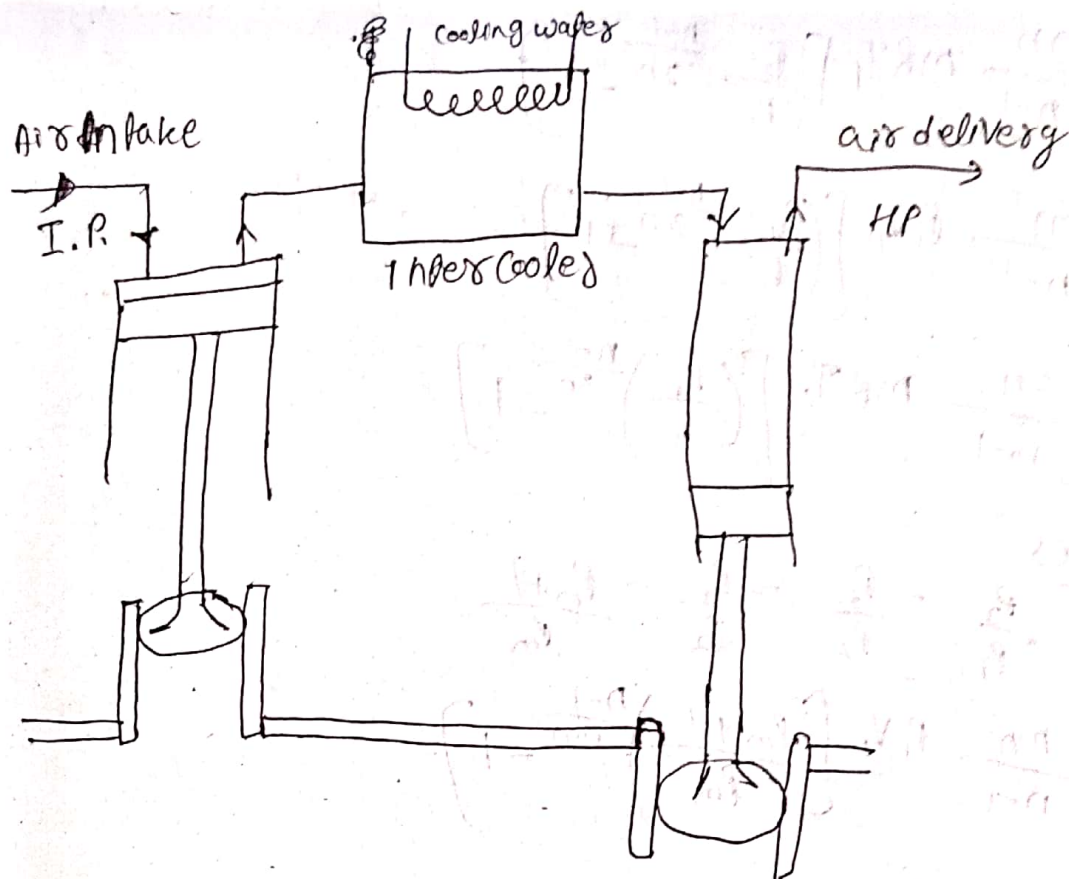
$$\Rightarrow V_3 \left(1 + \frac{1}{K}\right)$$

Inter cooler



P.V diagram :-





for maximum efficiency

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

$$P_2 = \sqrt{P_1 \cdot P_3}$$

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

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

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

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

$$W = \frac{2n}{n-1} MRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{2n}} - 1 \right]$$

$$W = \frac{3n}{n-1} P_1 V_1 \left[\left(\frac{P_4}{P_1} \right)^{\frac{n-1}{3n}} - 1 \right]$$

$$= \frac{3n}{n-1} MRT_1 \left[\left(\frac{P_4}{P_1} \right)^{\frac{n-1}{3n}} - 1 \right]$$

m stages

$$\frac{P_2}{P_1} = \frac{P_3}{P_2} = \frac{P_4}{P_3} = \dots = \frac{P_{m+1}}{P_m}$$

$$W = \frac{mn}{n-1} P_1 V_1 \left[\left(\frac{P_{m+1}}{P_m} \right)^{\frac{n-1}{mn}} - 1 \right]$$

Alternative expression

$$W_1 = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W_2 = \frac{n}{n-1} P_2 V_2 \left[\left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$W = \frac{n}{n-1} \left[P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\} + P_2 V_2 \left\{ \left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} - 1 \right\} + \dots + P_m V_m \left\{ \left(\frac{P_{m+1}}{P_m} \right)^{\frac{n-1}{n}} - 1 \right\} \right] \quad (i)$$

$P_1 V_1 = P_2 V_2$ (if intercooling is perfect)

Substituting the eqn (i)

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

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

(if intercooling is not perfect)

(if intercooling is perfect)

$$W = \frac{2n}{n-1} m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{mn}{n-1} m R T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

where

$m = \text{no of stages}$

Power required = $\frac{W \cdot N}{60}$
for minimum work

where $N = \text{speed of compressor in RPM}$

$$\frac{dW}{dP_2} = 0$$

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

$$\frac{dW}{dP_2} = \frac{da}{dP_2} \cdot b \left[\left(\frac{P_2}{P_1} \right)^a + \left(\frac{P_3}{P_2} \right)^a - 2 \right]$$

$$= ab \left[\left(\frac{P_2}{P_1} \right)^a \cdot P_1^{-a} + \left(\frac{P_3}{P_2} \right)^a - 2 \right]$$

$$= ab \left[\frac{d}{dP_2} \left(\frac{P_2}{P_1} \right)^a + \frac{d}{dP_2} \left(\frac{P_3}{P_2} \right)^a - \frac{d}{dP_2} 2 \right]$$

$$= ab \left[\left(\frac{1}{P_1} \right)^a \cdot a P_2^{a-1} + P_3^a \frac{d}{dP_2} (P_2^{-a}) - 0 \right]$$

$$= ab \left[a P_2^{a-1} \cdot P_1^{-a} - a P_2^{-a-1} \cdot P_3^a \right]$$

$$\Rightarrow ab \left[a P_2^{a-1} \cdot P_1^{-a} - a P_2^{-a-1} \cdot P_3^a \right] = 0$$

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

(multiply both side P_2^a)

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

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

$$\Rightarrow \left(\frac{P_2}{P_1}\right)^a = \left(\frac{P_3}{P_2}\right)^a$$

$$\Rightarrow \left(\frac{P_2}{P_1}\right)^a = \left(\frac{P_3}{P_2}\right)^a$$

$$\Rightarrow \left(\frac{P_2}{P_1}\right) = \left(\frac{P_3}{P_2}\right)$$

$$\Rightarrow P_2^2 = P_1 P_3$$

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

$$\left(\frac{P_2^{(1+a)-a}}{P_1^{-a}} \right) = P_2^a$$

Positive and nonpositive displacement difference

Reciprocating and Rotary compressor difference

Difference betⁿ gas and vapour

Note Dry saturated vapour is a ^{or super heated} perfect gas

M_f : mass of liquid / fluid

m_g : mass of steam / gas

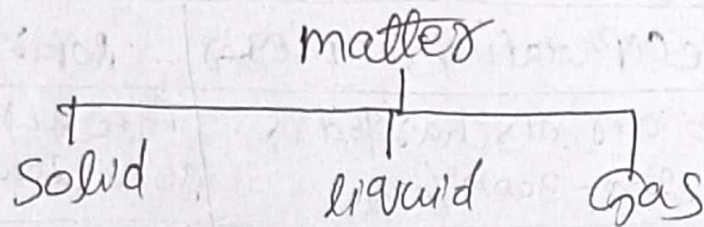
Comparison of reciprocating and rotary compressor

Factors	reciprocating compressor	Rotary compressor
Capacity	Free air discharged is about $250-300 \text{ m}^3/\text{min}$	Free air discharged is about $2000-3000 \text{ m}^3/\text{min}$
Delivery pressure	maximum delivery pressure ranges from 800 to 1000 bars	maximum delivery pressure ranges is 10 bars
Suitability	Suitable for low discharge of air at high pressure	suitable for large discharge at low pressure
Compression	Isothermal compression can be achieved due to low speed.	Adiabatic compression can be achieved due to high speed.
Air supply	Air supply is intermittent	Air supply is continuous
Operational speed	Low, cannot be directly coupled to prime mover.	High, can be directly coupled to prime mover.
Quality of air delivered	Not clean, generally contaminated with lubricating oil	Relatively more clean
Lubrication system	Complicated	Simple
Balancing	Major problem due to cyclic vibrations	Balancing is perfect as compressor is free from vibrations.

Difference betn Positive displacement and non-positive displacement

Positive displacement	Non-positive displacement
⇒ The flow rate does not change with head. ⇒ The flow rate is not much affected by the viscosity of fluid ⇒ Efficiency is almost constant with head. ⇒ High maintenance ⇒ Clean ⇒ High and low pressure areas completely separated	⇒ The flow rate decrease with head ⇒ The flow rate decreases with the viscosity ⇒ Efficiency is increases with head at first and then decreases. ⇒ low maintenance ⇒ not necessary ⇒ not separated (connect hydraulically)

Unit - 3 Properties of Steam



Solid :- It is a substance in which all the molecules are compacted in a fixed position.

- ⇒ The bond betⁿ the molecules is very strong
- ⇒ The distance betⁿ the molecules is very less

liquid :- The bond betⁿ the molecules is weaker than in solid.

- ⇒ the distance betⁿ the molecules is comparatively ~~very~~ -ely large.

Gas :- It is a substance in which all the molecules are in free state.

- ⇒ The bond betⁿ the molecules is very weak
- ⇒ The distance betⁿ the atoms is very large

Vapour :- Evaporated form of liquid is called vapour.

- ⇒ The main difference betⁿ the gas and vapour is

gases	Vapour
⇒ on cooling gases cannot be liquefied,	⇒ on cooling vapour can be liquefied.
⇒ for the gases the gas laws are applicable.	⇒ for vapours the gas laws are not applicable.
⇒ Gases are a state of matter	⇒ Vapour is not a state of matter unlike gases.

⇒ Gas usually contains a single thermodynamic state at room temperature.

⇒ Gas does not have a definite shape when it is observed under a microscope.

⇒ Gases are usually formed above its critical temp. but below critical pressure

⇒ Vapour is a mixture of two or more different phases at room temp. these phases are liquid and gaseous phase

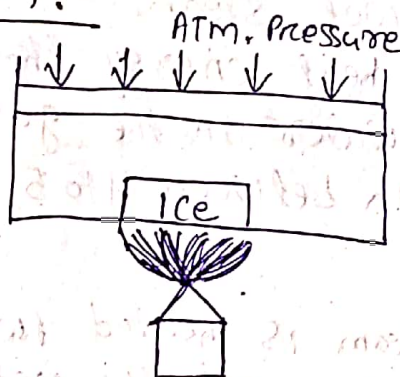
⇒ Vapour has a collection of particles without any definite shape when observed under a microscope.

⇒ Vapours of water are around us all the time at temp. below the boiling point of water

Evaporation :-

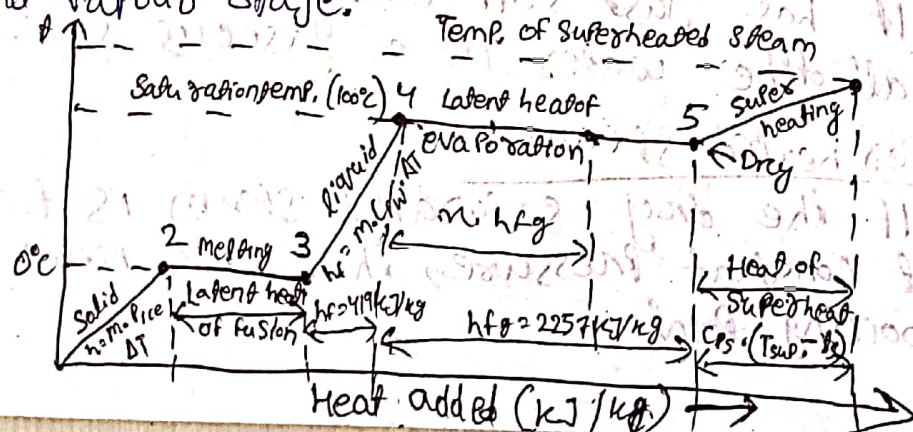
⇒ The change in phase from liquid to vapour at constant pressure and temp. by heating is called evaporation.

Formation of Steam :-



Heating of Ice

The heat supplied can be divided into five stages as solid stage, melting stage, liquid stage, vapourising stage and vapour stage.



⇒ If the dry vapour is further heated, the temp. rises again. This process is called superheating and the steam thus obtained is known as superheated steam.

Conditions of Steam :-

Saturated Steam :- Saturated steam occurs at temp. and pressures where steam and water can co-exist. In other words it occurs when the rate of water vaporisation is equal to the rate of condensation.

⇒ In other words, the steam from which heat can not be abstracted or compressed at constant temp. without partially condensing is known as Saturated steam.

Wet Steam :-
⇒ If steam contains water particles in suspension it is called wet steam.

⇒ It has less heat energy than that required to maintain all water in the gaseous state. Wet steam is obtained in between 4 to 5 during vaporizing stage.

Dry Steam :-

⇒ When wet steam is heated further, a stage will be reached when all the water is converted into steam. This is called dry steam.

⇒ Dry steam does not contain any water particles. It has just sufficient heat energy to maintain all the water in a gaseous state.

Superheated Steam :-

⇒ If the dry saturated steam is further heated at constant pressure, the temp. rises above the boiling point.

⇒ The steam thus obtained is called superheated steam and this steam behaves almost like a perfect gas.

⇒ The heat supplied to the superheated steam above the saturation temp. is known as heat of superheat or superheat enthalpy.

⇒ The difference betn the the temp. of superheated steam and saturation temp. of dry steam is called as degree of superheat.

Dryness fraction :-

⇒ The dryness fraction of steam is defined as the ratio of mass of dry saturated steam to the total mass of wet steam containing it. It is represented by 'x'.

Dryness fraction :-

$$x = \frac{\text{mass of dry steam (kg)}}{\text{Total mass of wet steam (kg)}}$$

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

m_f = mass of ~~dry~~ ^{liquid/fluid} ~~steam~~ (kg)

m_g = mass of steam (kg)

$(m_f + m_g)$ = Total mass of wet steam (kg)

⇒ If dryness fraction < 1 the condⁿ of steam is wet

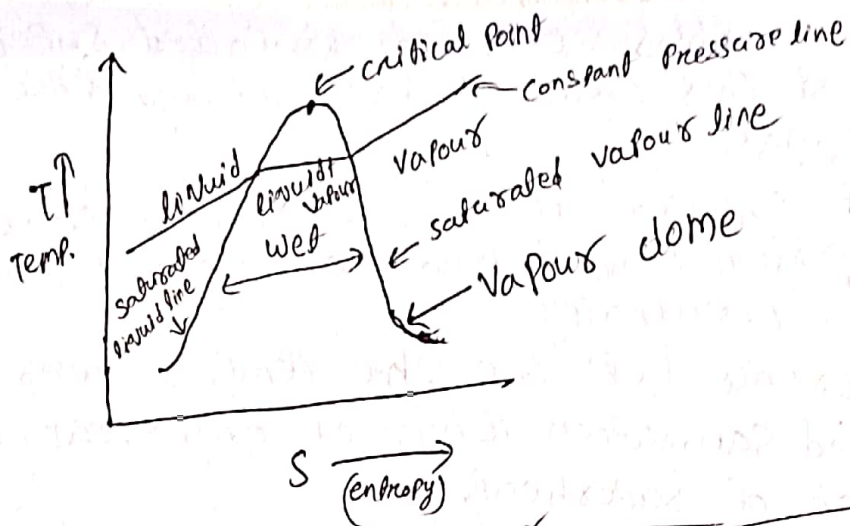
⇒ " " " = 1 The " " " is dry

Saturated

⇒ " " " > 1 " " " is superheated

Note

⇒ The range of value of dryness fraction $0 \leq x \leq 1$



Assignment

If there any affect. If any changes in pressure, what is phenomena of change in pressure

Note

If change the pressure then boiling point is change.

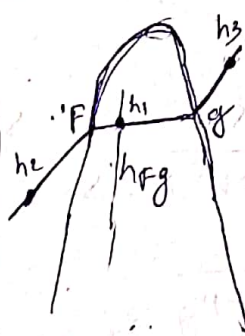
Value

$$T \rightarrow 100$$

$$2 \rightarrow 100 \times \sqrt{2}$$

$$3 \rightarrow 100 \times \sqrt{3}$$

$$4 \rightarrow 100 \times \sqrt{4}$$



Entropy:-

$$h_f + h_{fg} = h_g$$

$$h_{fg} = h_g - h_f$$

$$h_1 = h_f + n_1 h_{fg}$$

$$h_2 = h_f - C_{p, \text{liquid}} (T_f - T_2)$$

$$h_3 = h_g + C_{p, \text{vapour}} (T_3 - T_g)$$

Enthalpy

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

$$\Rightarrow S_f + \frac{S_{fg}}{T} = S_g$$

$$\Rightarrow S_{fg} = (S_g - S_f) \times T$$

$$\Rightarrow h_1 = S_f + n_1 S_{fg}$$

$$\Rightarrow h_2 = S_f - C_{p, \text{liquid}} \ln(T_f - T_2)$$

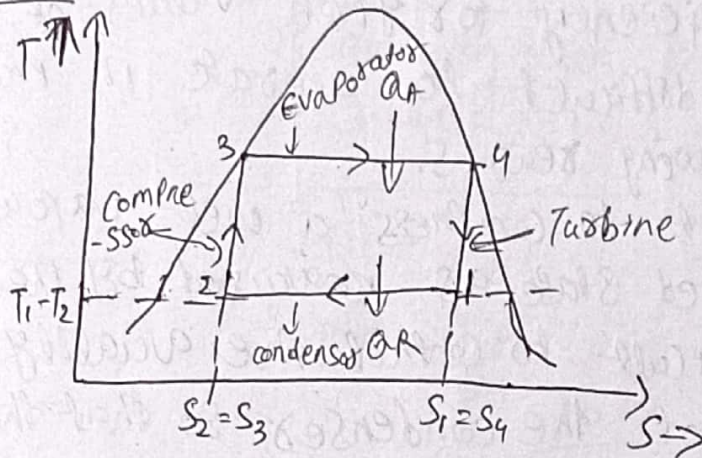
$$\Rightarrow h_3 = S_g + C_{p, \text{vapour}} \ln(T_3 - T_g)$$

$$\int_1^2 dS = \int_1^2 \frac{dh}{T} = \int_1^2 \frac{C_p dT}{T}$$

$$\Rightarrow S_2 - S_1 = C_p \ln \frac{T_2}{T_1}$$

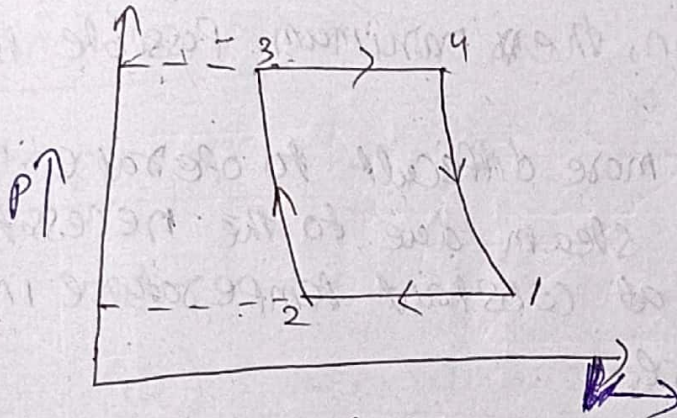
Steam Power cycle

Carnot cycle



- 1-2 :- Isothermal ~~process~~ heat rejection (const pressure heat rejection isobaric)
- 2-3 = Iso entropic compression
- 3-4 = Isothermal heat addition
- 4-1 = Isoentropic expansion

1-2 - Heat rejection at constant ~~pressure~~ pressure



Assignment

Limitation:-

efficiency is maximum for other cycle but it's not give 100% efficiency.

Stream Rate / Specific Stream consumption (SSC): -

It is the amount of steam required to produce 1 kWh (3600 kJ) of power.

$$SSC = \frac{\text{mass of steam in kg/h}}{\text{Power of P in kW}} = \frac{\dot{m}_s (\text{kg/h})}{\dot{m}_s (\text{kg/h}) \times w_{net} (\text{kJ/kg})}$$

Limitations of Carnot cycle

Ther
Effic

- ⇒ Though Carnot cycle is simple and has the highest thermal efficiency for given values of T_1 and T_2 , yet it is extremely difficult to operate in practice because of the following reasons.
- ⇒ It is difficult to compress a wet vapour isentropically to the saturated state as required by the process 3-4.
- ⇒ It is difficult to control the quality of the condensate coming out of the condenser so that the state 's' is exactly obtained.
- ⇒ The efficiency of the Carnot cycle is greatly affected by the temp. T_1 at which heat is transferred to the working fluid. Since the critical temp. for steam is only 374°C. therefore, if the cycle is to be operated in the wet region, the maximum possible temp. is severely limited.
- ⇒ The cycle is still more difficult to operate in practice with superheated steam due to the necessity of supplying the super heat at constant temperature instead of constant pressure.

Heat rejected at constant temp.

$$Q_R = T_1 (s_1 - s_2) \text{ or } T_2 (s_1 - s_2)$$

p.v diagram

Heat addition at constant temp.

$$Q_A = T_3 (s_4 - s_3) \text{ or } T_4 (s_4 - s_3)$$

Net workdone = Net heat supplied

$$= \text{Heat Supplied} - \text{heat rejected}$$

$$= T_4 (s_4 - s_3) - T_2 (s_1 - s_2)$$

$$= T_4 (s_1 - s_2) - T_2 (s_1 - s_2) \quad [\because s_1 = s_4 \text{ and } s_2 = s_3]$$

$$\text{Thermal Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{Net workdone in the cycle}}{\text{Heat supplied in the cycle}}$$

$$= \frac{(T_4 - T_2) - (S_1 - S_2)}{T_4 (S_1 - S_2)} = \frac{T_4 - T_2}{T_4}$$

$$\boxed{\eta_{\text{Carnot}} = 1 - \frac{T_2}{T_4}}$$

$$\eta_{\text{thermal}} = \frac{w_{\text{net}}}{Q_{\text{in}}}$$

Date 30-04-25

$$1 \text{ kWh} = 3600 \text{ kJ}$$

$$1 \frac{\text{kJ}}{\text{sec}} \times h = 1 \frac{\text{kJ}}{\text{sec}} \times 3600 \text{ sec} = 3600 \text{ kJ}$$

$$1 \text{ kJ} = \frac{1}{3600} \text{ kWh}$$

Performance criteria

① Efficiency ratio :- Thermal efficiency

$$\text{work ratio (R}_w\text{)} = \frac{\text{Net work o/p of the cycle} \rightarrow \text{Actual}}{\text{Turbine work}}$$

$$\text{Back work ratio (R}_{bw}\text{)} = \frac{\text{Pump work (}w_p\text{)}}{\text{Turbine work (}w_T\text{)}}$$

$$\text{Net work o/p} = w_T - w_p$$

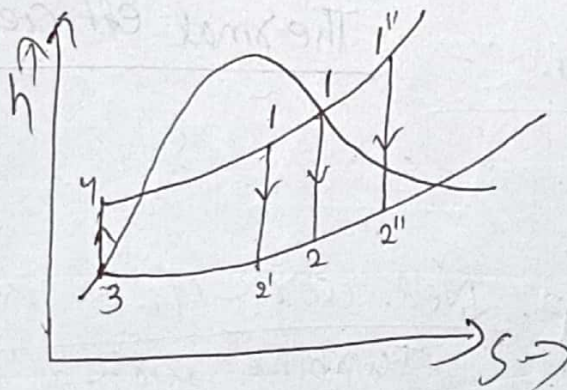
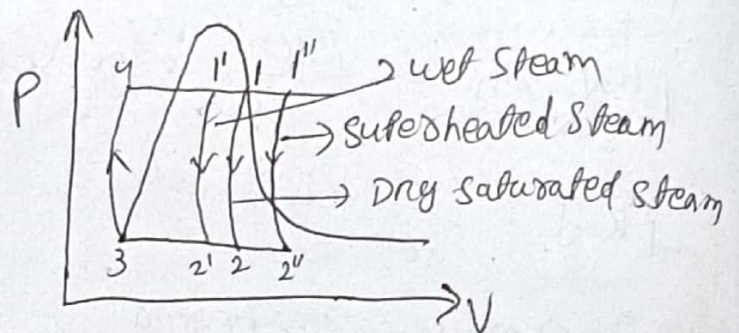
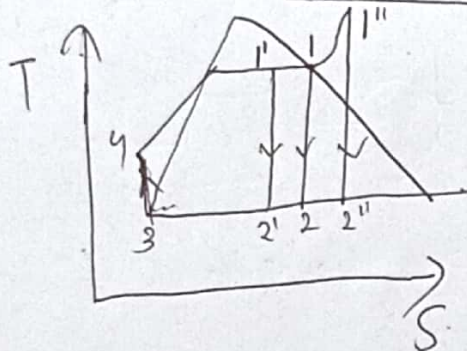
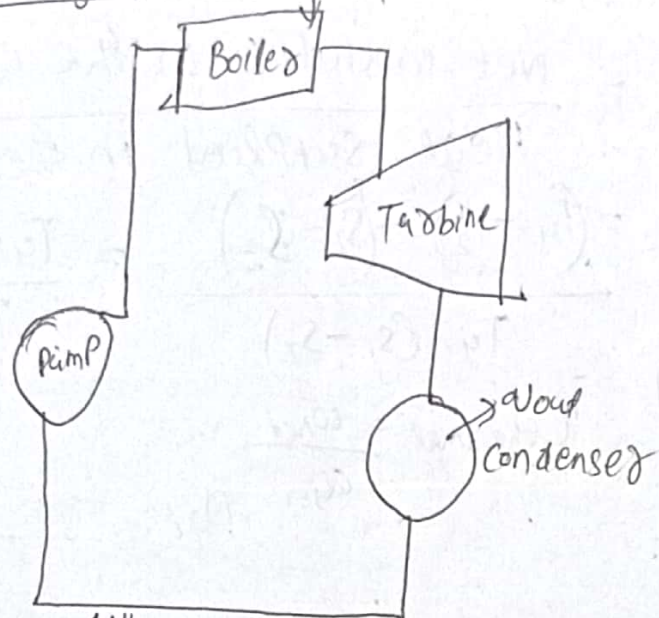
Heat rate :-

It is amount of heat received by a power plant to produce 1kwh of power.

unit :- kJ/kwh

Rankine cycle :-

Rankine cycle :-



1-2 = Reversible adiabatic (isentropic) expansion in the turbine

2-3 = Isobaric heat rejection in the condenser

3-4 = Isentropic compression in the pump

4-1 = Isobaric heat addition in the boiler

Heat supplied $Q_1 = h_1 - h_4$

Heat rejected $Q_2 = h_2 - h_3$

Cycle work, $W = Q_1 - Q_2$

$$W = (h_1 - h_2) - (h_4 - h_3)$$

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

Isentropic expansion $W_T = W_P$

$$h_4 - h_3 = v_3(p_4 - p_3) = W_P$$

$$W_{net} = (h_1 - h_2) - W_P$$

Thermal Efficiency $(\eta) = \frac{W_{net}}{Q_1} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$

where

$$W_{net} = W_T - W_P$$

$$W_T = (h_1 - h_2)$$

$$W_P = (h_4 - h_3)$$

$$Q_1 = (h_1 - h_4)$$

neglecting the Pump work, $(h_3 = h_4)$

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

~~Cycle Eff~~

Effect of operating conditions on Rankine cycle efficiency

- (1) - Increasing boiler pressure
- (2) - Reducing Condenser pressure

$W_P \approx 0$

W_P is very small as compared to W_T

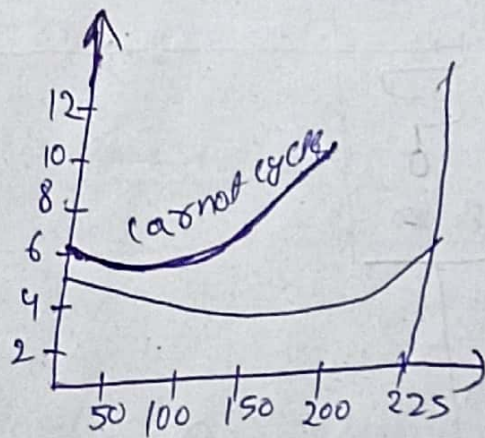
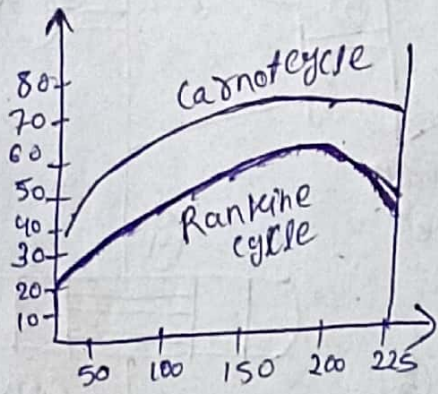
Suppose $W_T = 1000$

$W_P = 5$ very very small

$W_P = 0$

$\Rightarrow h_4 - h_3 = 0$

$\Rightarrow h_4 = h_3$ (throttling)

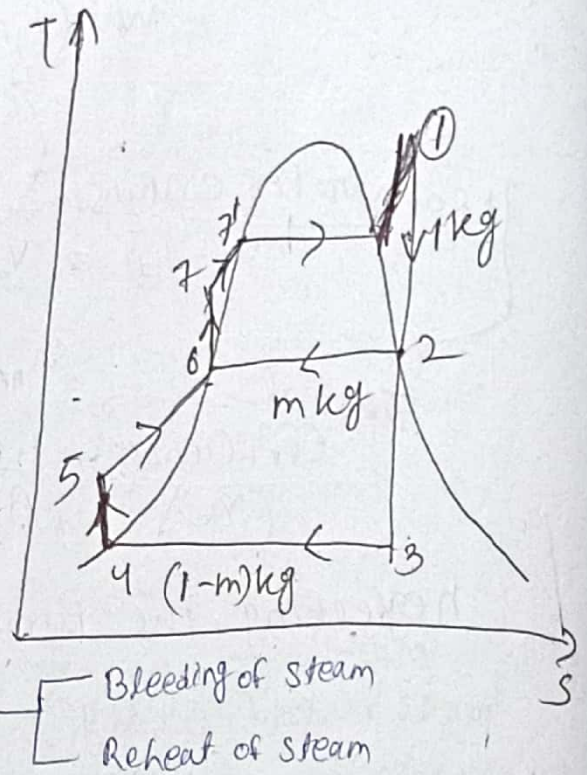
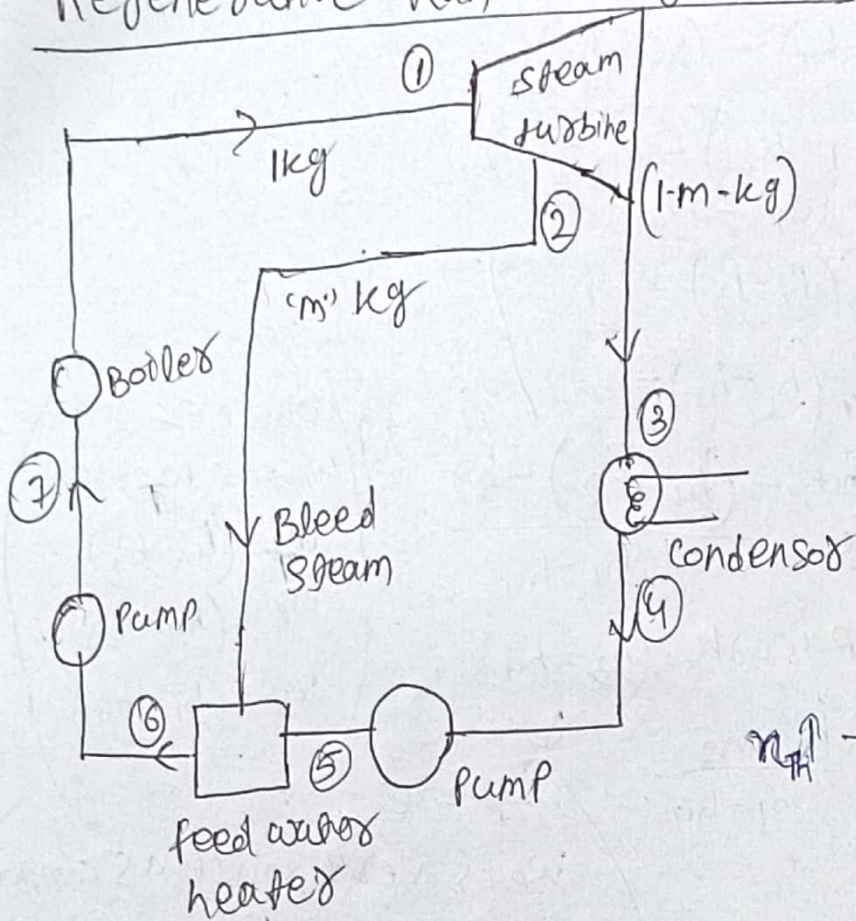


Assignment

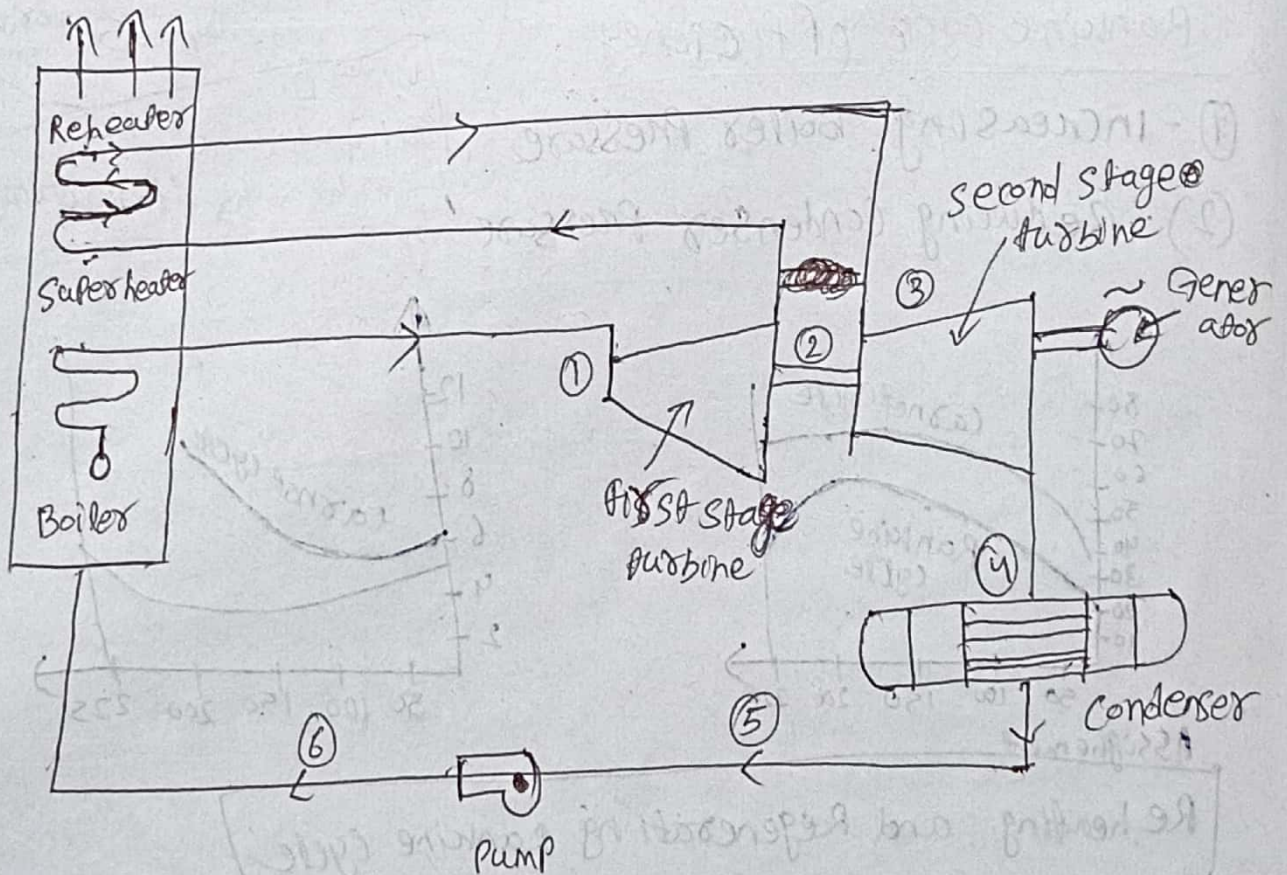
Reheating and Regenerating Rankine cycle

Steam generator:- 4.1, 4.2, 4.3

Regenerative Rankine cycle :-



Reheat Rankine cycle :-



Steam generator

Boiler :-

Boiler is a closed vessel made of high quality steel in which steam is generated from water by the application of heat.

- ⇒ The water receives heat from the heat sources through the heating surfaces of the boiler.
- ⇒ Heating ~~sur~~ surfaces of the boiler are exposed to heat sources on one side and water or steam on the other side.

Classification of boilers

- ⇒ Based on boiler tube content
 - * fire tube boilers
 - * water tube boilers
- ⇒ Based on circulation of water
 - * Natural circulation
 - * forced circulation
- ⇒ Based on number of tubes
 - * single tube
 - * multi tube
- ⇒ Based on working pressure
 - * Low pressure
 - * medium pressure
 - * High pressure
- ⇒ Based on firing
 - * internally fired
 - * externally fired

* Based on arrangement of boiler shell

- ⇒ Vertical
- ⇒ Horizontal

* Based on application

- ⇒ stationary
- ⇒ mobile

Fire tube boiler :-

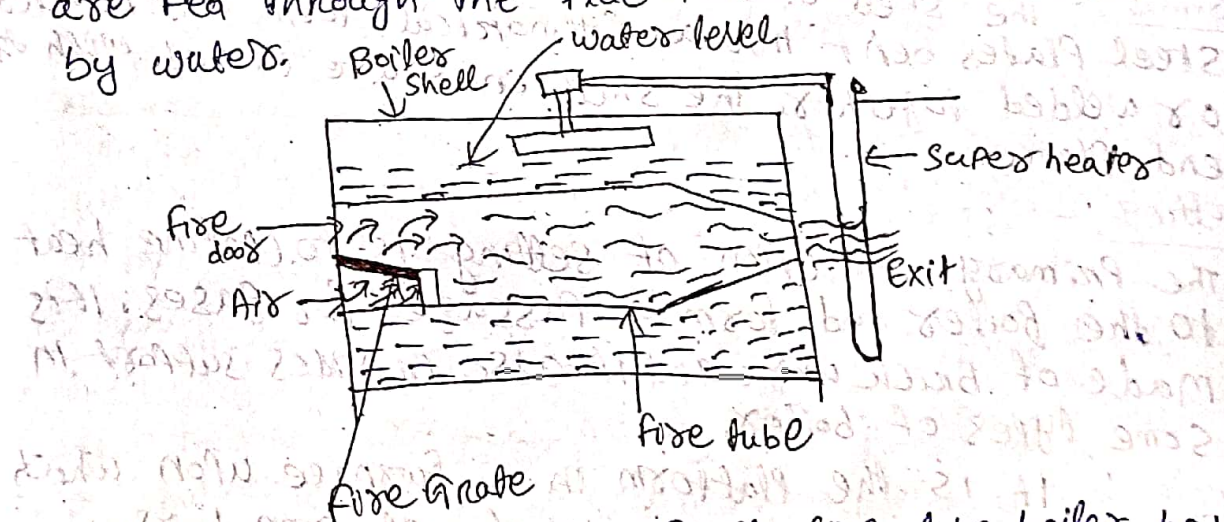
⇒ In these boilers, fire and hot gases flow through the boiler tubes which are completely surrounded by water. Ex:- Cochran boiler

water tube boiler :-

⇒ In these boilers, water flows through the tubes and the tubes are surrounded by hot flue gases. Ex:- Babcock and Wilcox, Stirling etc.

Fire tube boiler :-

⇒ In fire tube boiler the furnace is generally located inside the boiler shell or drum and the hot flue gases are fed through the flue tubes which are surrounded by water.



- ⇒ Essential feature of a simple fire-tube boiler - having a single large tube
- ⇒ The boiler shell contains water and steam under pressure.
- ⇒ The fire tube contains the grate.

- ⇒ Air for combustion of fuel flowing beneath the grate moves upwards through the fire bars.
- ⇒ burnt flow gases pass along the fire tube to the exit
- ⇒ The water surrounding the tube evaporates with the heat of flue gases.
- ⇒ Super heater tubes are generally placed in the path of the flue gases at the exit side.
- ⇒ Fire tube boilers are suitable for capacity upto 10000 kg/hr and low pressure i.e. upto about 20 bar.

Advantages

- ⇒ Simple design
- ⇒ easy maintenance
- ⇒ low initial cost
- ⇒ Suitable for fluctuating loads

Disadvantages

- ⇒ Bigger in size
- ⇒ lower efficiency
- ⇒ Suitable for only low pressure

Important terms of boiler:-

Shell:- The shell of a boiler consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell ends are closed with the end plates.

Setting:-

- ⇒ The primary function of setting is to confine heat to the boiler and form a passage for gases. It is made of brick work and it also provides support in some types of boiler.

Grate:- It is the platform in a furnace upon which fuel is burnt and it is made of cast iron bars. The area of the grate on which the fire rests in a coal or oil fired boiler is called grate surface.

Furnace :-

⇒ It is a chamber formed by the space above the grate and below the boiler shell, in which combustion takes place. It is also called a fire box.

Water Space :-

⇒ The volume of the shell that is occupied by the water is termed water space while the entire shell volume less the water and tubes space is called steam space.

Mountings :-

⇒ The items such as stop valve, safety valves, water level gauges, fusible plug, pressure gauges etc. are termed as mountings and a boiler cannot work safely without them.

Accessories :-

⇒ The items such as superheaters, feed pumps etc. are termed as accessories and they form integral part of the boiler. They increase the efficiency of the boiler.

Water level :-

⇒ The level at which water stands in the boiler is called water level. The space above the water level is called steam space.

Foaming :-

⇒ Formation of steam bubble on the surface of boiler water due to high surface tension of the water.

Scale :-

⇒ A deposit of medium to extreme hardness occurring on water heating surfaces of a boiler because of an undesirable condition in the boiler water.

Blowing off :-

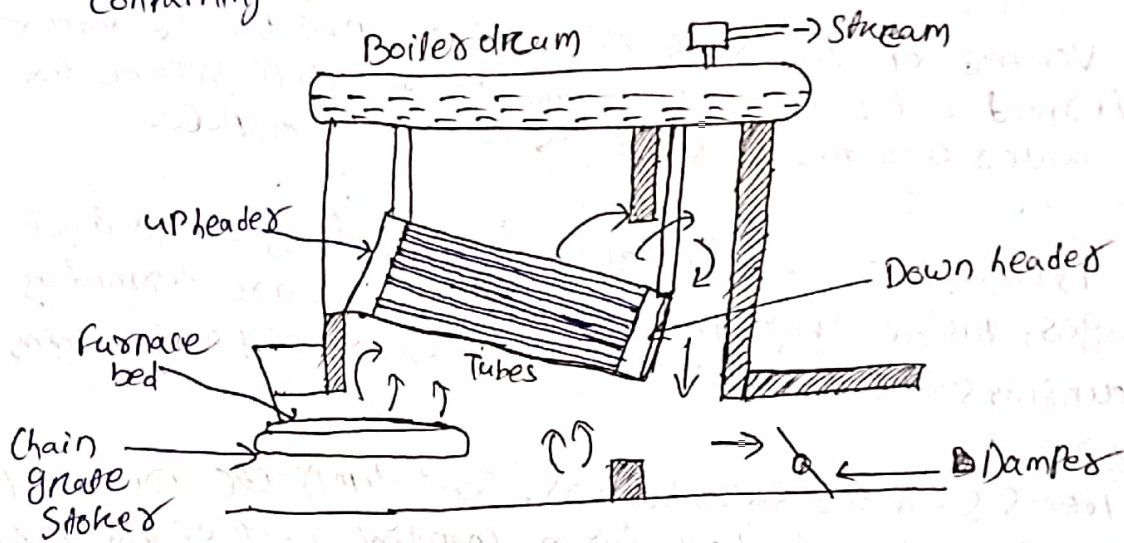
The removal of the mud and other impurities of water from the lowest part of the boiler is termed as 'blowing off'.

Lagging :- Blocks of asbestos or magnesia insulation wrapped on the outside of a boiler shell or steam piping.

Refractory :- A heat insulation material, such as fire brick or plastic fire clay, used for such purposes as lining combustion chambers.

Water tube boiler :-

⇒ In water tube boiler the furnace is located outside the drum, and the hot gases pass outside the small tubes containing the water.



⇒ It consists of a large no. of parallel tubes containing water and connected to boiler drum through the headers.

⇒ Evaporation takes place in the tubes due to heat of flow gases.

⇒ The steam formed is returned to the drum through up take header, and steam leaves the drum through a stop-valve.

⇒ Because of smaller drum, water tube boiler is suitable for high pressure steam generation and less time is required to raise the steam.

⇒ A damper is provided to regulate the supply of air to the furnace and removal of burnt gases.

Advantages of water tube boiler :-

⇒ Quick starting

⇒ Higher efficiency

⇒ Suitable for power plant

⇒ Smaller in size for a given output

⇒ Suitable for high pressure and high capacity.

Disadvantages :-

- ⇒ High Initial Cost.
- ⇒ Complicated design and difficult to inspect.
- ⇒ Impure and dirty water is not suitable as feed water.
- ⇒ Small water content causes the danger of explosion.

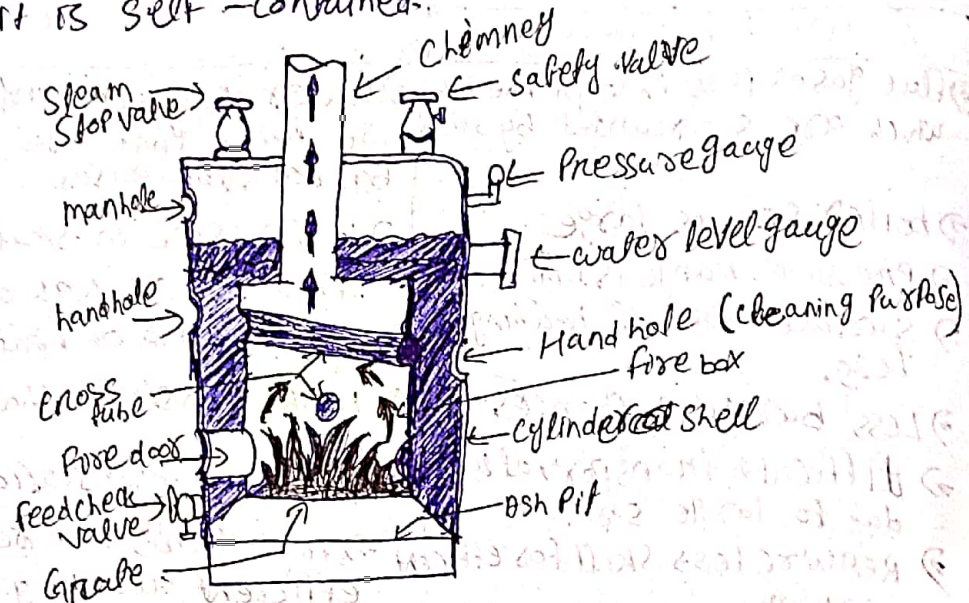
Comparison between fire-tube and water tube :-

fire tube boiler	water tube boiler
⇒ Flue gases pass through the tube which are surrounded by water. ⇒ boiler size is large. ⇒ Pressure range is limited. ⇒ Surface area of heating is less. ⇒ Less bursting chances. ⇒ Difficult transportation due to large size. ⇒ Require less skill for efficient working.	⇒ Water is circulated through the tubes that are surrounded by hot flue gases. ⇒ boiler size is small. ⇒ Pressure as high as 200 bar. ⇒ Surface area of heating is more. ⇒ High bursting chances. ⇒ Easy transportation. ⇒ High skills are required for efficient working.

Simple vertical boilers :-

- ⇒ It consists of a cylindrical shell.
- ⇒ The grate portion full of water and remaining is the steam space.
- ⇒ The bottom of the fire box is grate on which fuel is burnt and the ash from it falls in the ash pit.
- ⇒ The heating increases the surface and circulation of water.
- ⇒ The cross tubes are fitted inclined, this ensures efficient circulation of water.
- ⇒ The end of each cross tube are provided with hand holes to give access for cleaning these tubes.
- ⇒ The combustion gases after heating the water thus converting into steam and escape to the atmosphere through the chimney.

- ⇒ man hole is provided to clean the interior of the boiler and exterior of the combustion chamber and chimney.
- ⇒ ~~the various mounting~~
- ⇒ The rate of production is such a boiler normally does not exceed 2500 kg/hr and pressure is normally limited to 7.5 to 10 bars.
- ⇒ A simple vertical boiler can be transported easily and it is self-contained.



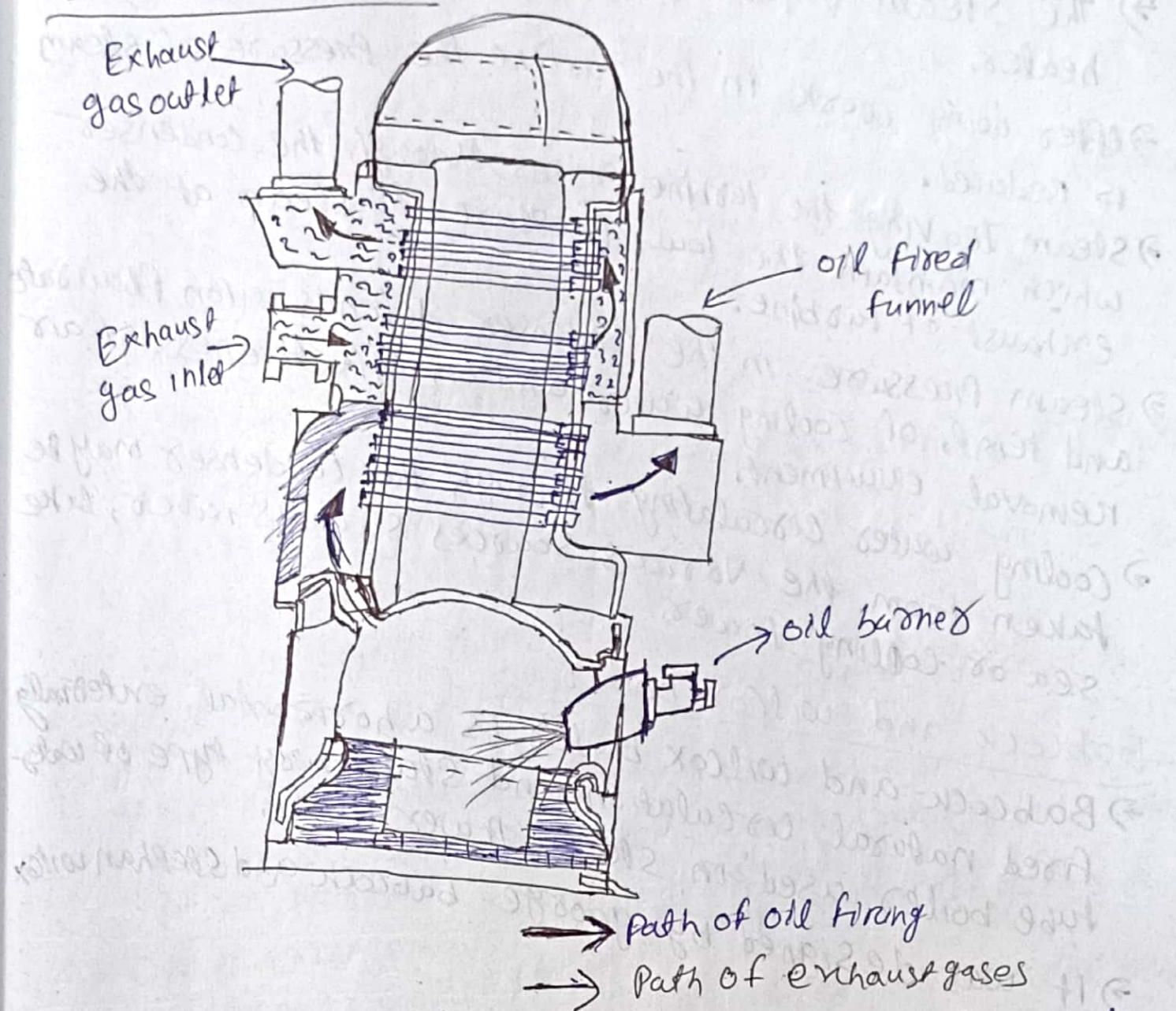
Lancashire boiler :-

- This boiler is reliable has simplicity of design, easy operation and less operating and maintenance costs.
- ⇒ It is commonly used in sugar mills and textile industries where along with the power steam and steam for the process work is needed.
- ⇒ This boiler is used where larger reserve of water and steam are needed.

Specifications :-

- Dia. of the shell = 2 to 3 m.
- length of the shell = 7-9 m
- maximum working pressure = 16 bars
- Steam Capacity = 9000 kg/h.
- efficiency = 50 to 70%

Cochran boiler



- ⇒ Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases.
- ⇒ the hot air then passes through the furnace.
- ⇒ the feed water from hot well is supplied to a storage and boiler through the economiser.
- ⇒ most of the sensible heat is supplied to the feed water while passing through the economiser.
- ⇒ A pump circulates the water at a rate 8 to 10 times the mass of steam evaporated.
- ⇒ this water is circulated through the evaporator tubes and the part of the vapour is separated in the separator drum.

- ⇒ The steam generated is passed through the super-heater.
- ⇒ After doing work in the turbine the pressure of steam is reduced.
- ⇒ Steam leaving the turbine passes through the condenser which maintain the low pressure of steam at the exhaust of turbine.
- ⇒ Steam pressure in the condenser depends upon flow rate and temp. of cooling water and on effectiveness of air removal equipment.
- ⇒ Cooling water circulating through the condenser may be taken from the various sources such as river, lake sea or cooling tower.

Babcock and wilcox boiler

- ⇒ Babcock and wilcox boiler is a horizontal, externally fired natural circulation and stationary type of water tube boiler used on steam power plant.
- ⇒ It was designed by George babcock and Stephen wilcox in 1868.

Specification:-

- ⇒ Dia of the drum = 1.22 to 1.83m
- ⇒ Length = 6.096 - 9.144m
- ⇒ Size of the water tubes = 7.62 - 10.16cm
- ⇒ Size of super heater tubes = 3.84 - 5.71cm
- ⇒ working pressure = 40 bar (max).
- ⇒ steaming capacity = 40,000 kg/h (max)
- ⇒ Efficiency = 60 to 80%.

- ⇒ Babcock and Wilcox boiler with longitudinal drum.
- ⇒ It consists of a drum connected to a series of front end and rear end headers by short riser tubes.
- ⇒ To these headers are connected a series of inclined water tubes of solid drawn mild steel.
- ⇒ The angle of inclination of the water tube to the horizontal is about 15° or more.
- ⇒ Hand hole is provided to fill the drum.
- ⇒ through the fire door the fuel is supplied to the grate where it is burnt.
- ⇒ The hot gases are forced to move upwards between the tubes by baffle plates.
- ⇒ The steam gets collected in the steam space of the drum.
- ⇒ The entire boiler except the furnace are hung by means of metallic slings or straps or wrought iron girders supported on pillars.
- ⇒ This arrangement enables the drum and the tubes to expand or contract freely.
- ⇒ The brickwork around the boiler encloses the furnace and the hot gases.

Advantages :- It occupies less space

- ⇒ Parts are accessible for cleaning, inspection and repair.
- ⇒ Generate steam at high pressure and rate of steam generation is high.
- ⇒ Parts of a boiler can be separated, transported and erected easily.
- ⇒ The fuel is completely burnt due to large heating surface, hence efficiency of boiler is high.

Disadvantages :- Cost is high.

- ⇒ Cost of the boiler is high
- ⇒ Requires pure feed water to avoid scale formation, hence water treatment is essential for water tube boilers.

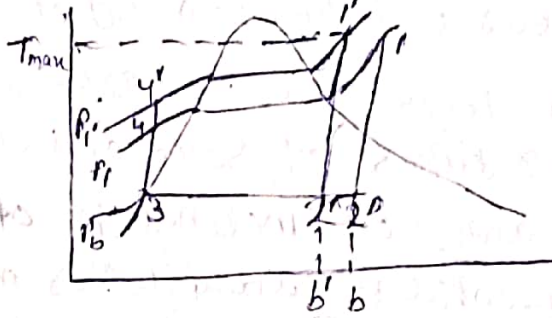
Steam power cycle

Effect of increase in boiler pressure

$Q_{sv} \downarrow$ $W = \text{same}$

$$\eta = \frac{W}{Q_{sv}}$$

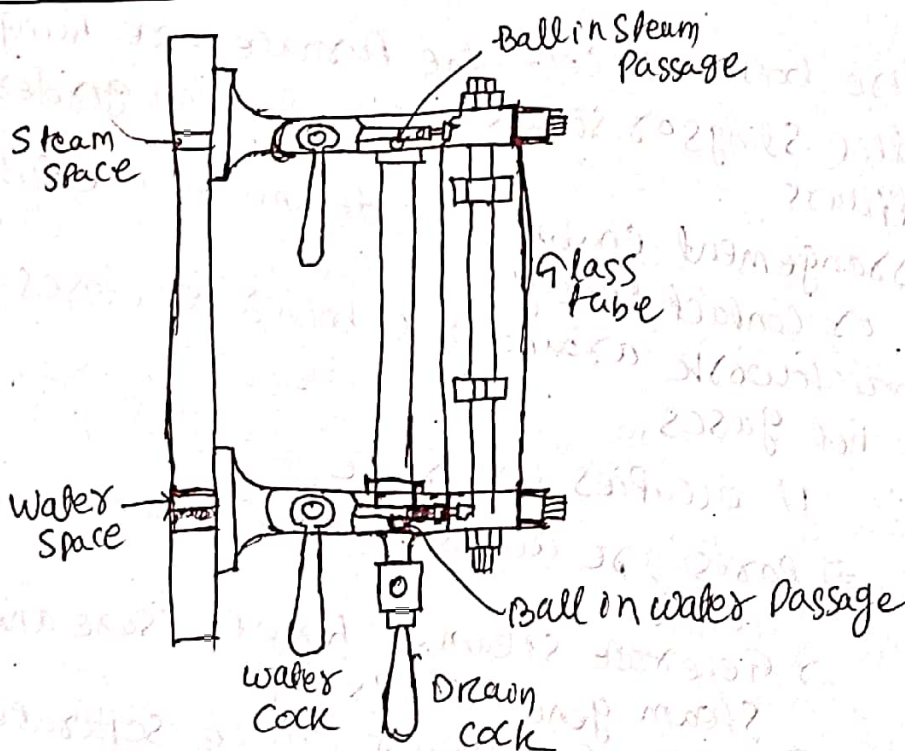
efficiency $\uparrow$



Boiler mounting

⇒ The device or component fitted to the boiler for safety and proper operation is called as boiler mounting. These are integral parts of a boiler.

① Water level indicator :-

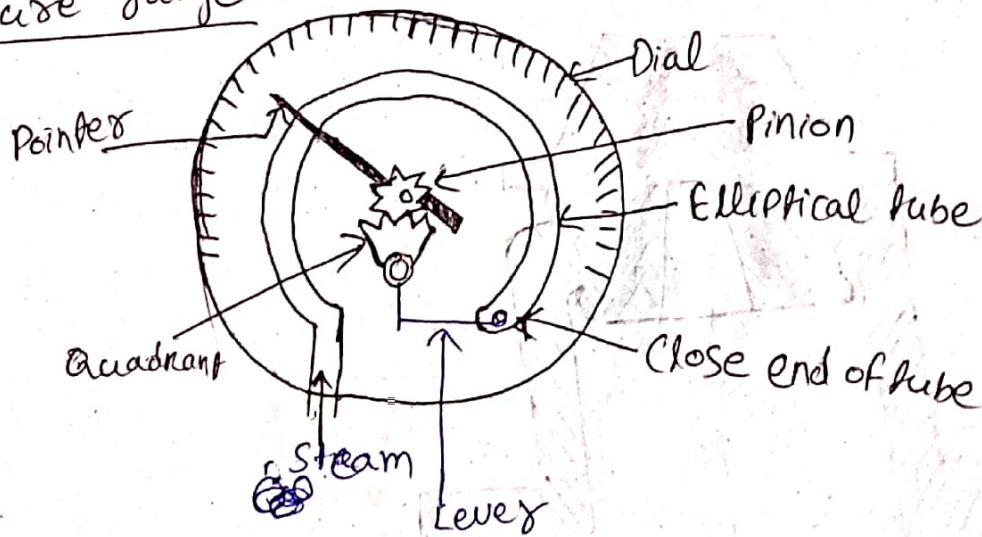


⇒ It is a safety device which is used to indicate the water level inside the boiler shell.

⇒ Usually two water level indicators are fitted in front of the boiler.

- ⇒ It has two horizontal tubes which are bolted to the boiler.
- ⇒ Bottom one is connected to the water in boiler and top the steam space.
- ⇒ Steam and water cocks control the passage between boiler and glass tube.
- ⇒ When the cocks are in vertical position, the passage is open, the water flows into glass tube and stands at the same level as in the boiler.
- ⇒ The steam is occupied above the water.
- ⇒ There are two balls in the steam and water passages which rest in their position during working.
- ⇒ In case the glass tube is broken, the balls are carried along their passage to the ends of the glass tube.
- ⇒ Thus the steam and water will not escape out.
- ⇒ The glass tube can easily be replaced by closing the steam and water cocks.
- ⇒ Drain cock is used to ascertain that the steam and water cocks are clear.

Pressure gauge :-

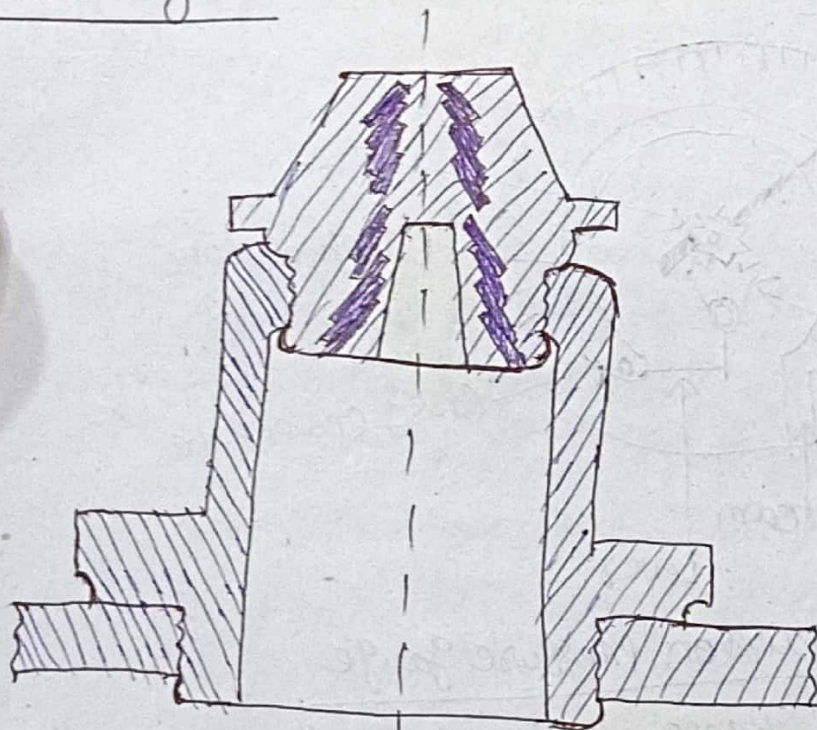


Bourdon Pressure gauge

- ⇒ The function of pressure gauge is to indicate the steam pressure inside the boiler.
 - ⇒ It is usually mounted on the front top of the shell or drum.
- The Bourdon pressure gauge is most commonly used.

- ⇒ It has a spring tube with elliptical cross-section and is made of high quality phosphor bronze.
- ⇒ one end of the tube is closed and attached to the toothed quadrant which is in mesh with a small pinion fitted on central spindle.
- ⇒ The other end is open and connected to steam space of the boiler.
- ⇒ When the steam enters the elliptical tube, the tube tends to become circular which causes the other end of the tube to move outwards.
- ⇒ This movement is communicated to a pointer through a link and sector.
- ⇒ The pressure of the steam in the boiler is recorded on the dial which is graduated to read the pressure above atmospheric pressure.
- ⇒ The pressure gauge is fitted to the boiler through U-tube siphon which is connected to the steam space of the boiler.

Fusible Plug



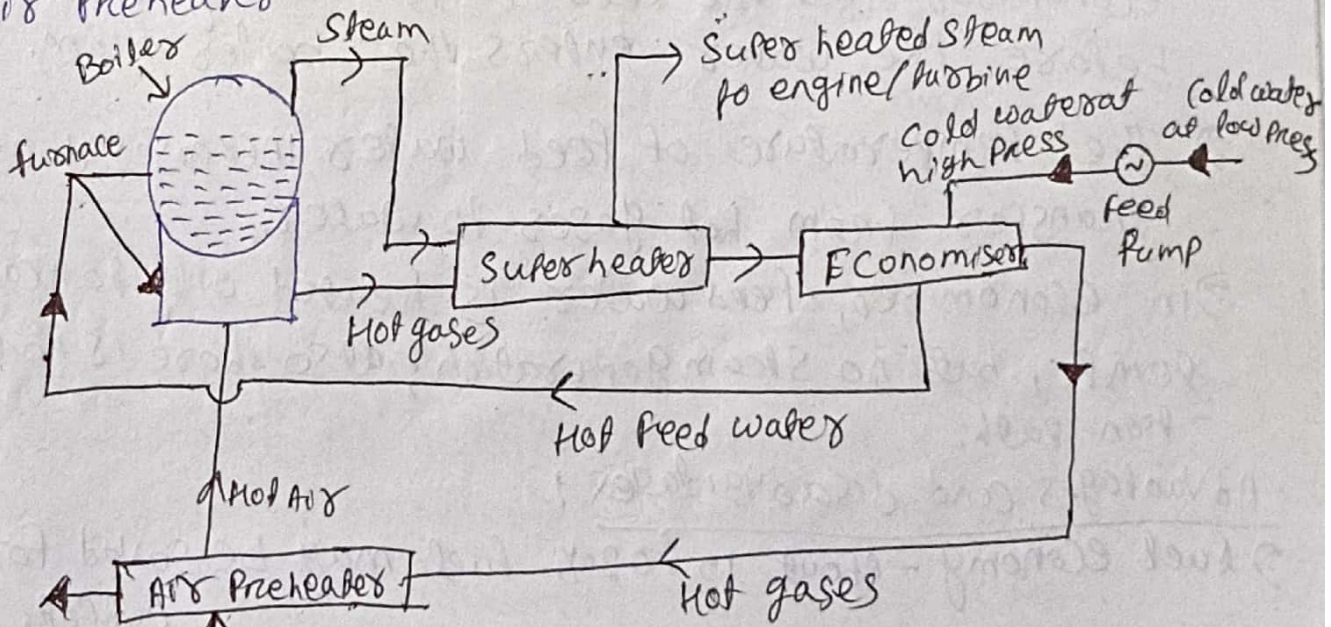
- ⇒ Its function is to put off the fire in the furnace of the boiler when the level of water in the boiler falls to an unsafe limit, and thus avoids the explosion which may take place due to overheating of the furnace plate.

- ⇒ It is fitted to the crown plate of the furnace or the fire box.
- ⇒ It is flange screwed to the furnace crown.
- ⇒ A second hollow gun metal plug is screwed to the first plug.
- ⇒ There is also a third hollow gun metal plug separated by a ring of fusible metal.
- ⇒ The fusible metal is protected from fire by the flange on the lower end of plug.
- ⇒ There is also a contact at the top between plugs so that the fusible metal is completely enclosed.
- ⇒ The fusible plugs must be kept in a good condition and replaced annually.
- ⇒ A fusible plug must not be refilled with anything except fusible metal.

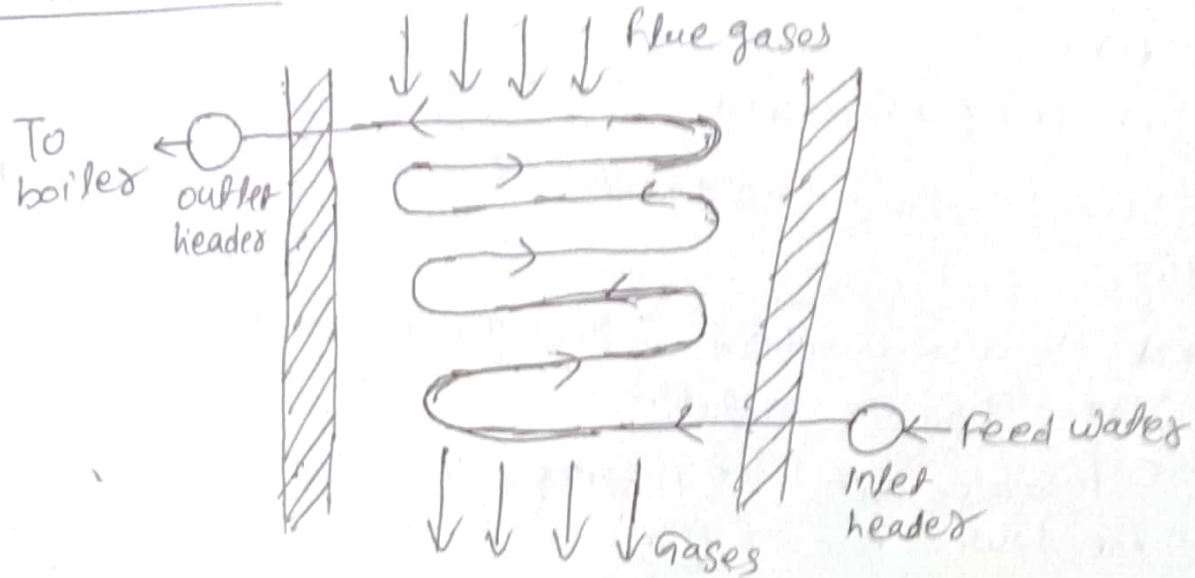
Boiler accessories :-

- ⇒ The auxiliary device installed with the boiler for proper operation and to increase the efficiency of the boiler plant are known as boiler accessories.

- ⇒ Feed pump
- ⇒ Superheater
- ⇒ Economiser
- ⇒ Air preheater



Economiser :-



Economiser

- ⇒ Its function is to preheat the boiler feed water by absorbing heat from outgoing hot flue gases.
- ⇒ flue gases leaving the boiler contain large amount of heat energy at a temperature higher than the steam saturation temp.
- ⇒ Part of this energy can be recovered in an economiser and is used to heat the feed water.
- ⇒ It is usually placed between boiler furnace and air preheater.
- ⇒ The hot gases passing over the tube surface of an economiser heat the feed water flowing in the tube before the water enters the boiler drum.
- ⇒ The temperature of feed water increases due to heat transfer from hot gases to water.
- ⇒ In economiser, feed water is heated only to near saturation temp., but, no steam generation; also there is no recirculation path.

Advantages and disadvantages :-

- ⇒ Fuel economy - About 15 to 20% fuel may be saved for same output.

- ⇒ Increase in steam generation rate of the boiler.
- ⇒ Increase in thermal efficiency of the boiler plant
- ⇒ The life of boiler is increased due to reduction of thermal stresses

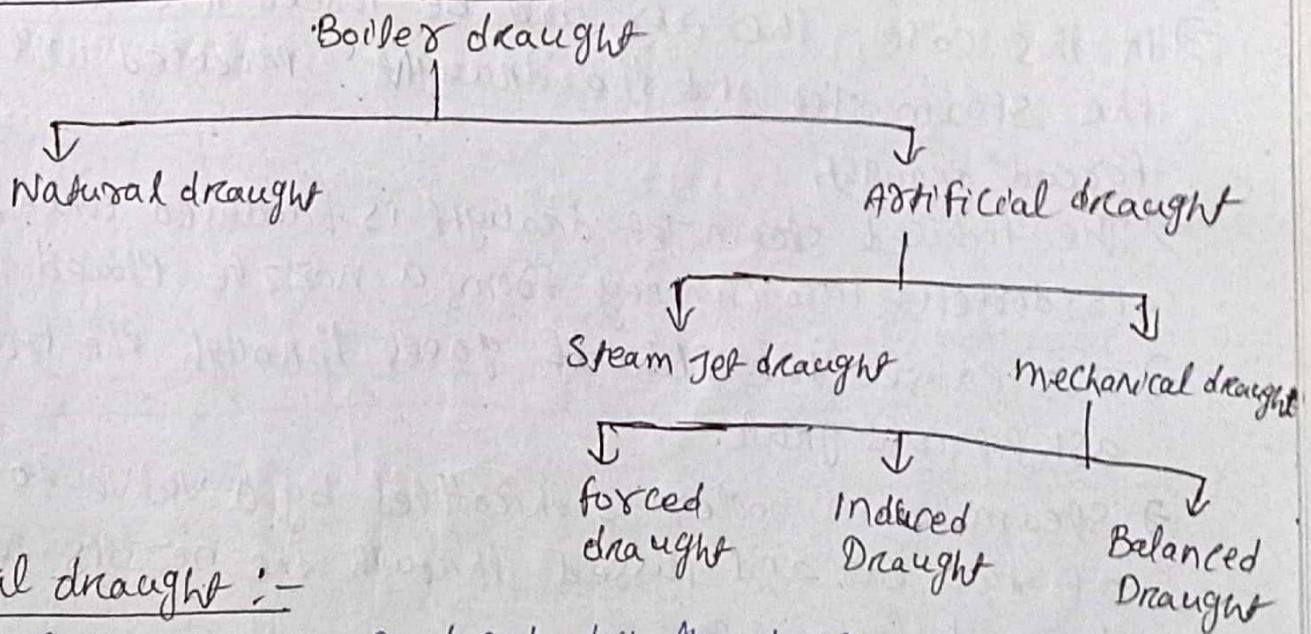
Draught

⇒ It is the difference between absolute gas pressure at any point in a gas flow passage and the ambient atmospheric pressure.

Function of draught

- ⇒ To provide an adequate supply of air for complete combustion of fuel.
- ⇒ To move the hot gases through the system.
- ⇒ To exhaust these gases to the atmosphere through the chimney.

Classification of draught :-



Natural draught :-

- ⇒ Natural draught is produced by the boiler chimney, and is known as chimney draught.
- ⇒ A chimney creates a draught by a simple principle that at high temperature the density of gas is lower.
- ⇒ Under this condition it may be displaced by a more dense gas.
- ⇒ The density of hot gases inside the chimney is less than cold air outside.

The pressure in the chimney is, therefore, less than the outside pressure.

⇒ This pressure difference causes the flow of air into the furnace and pushes the hot gases through the chimney.

Steam jet draught :-

⇒ The exhaust steam from a non-condensing steam engine is discharge through a blast placed below the chimney at high velocity.

⇒ The steam jet draught comes under the category of artificial draught.

⇒ It is also be classified :- (i) forced steam jet draught
(ii) induced steam jet draught

⇒ In the forced steam jet draught, the draught is produced by placing the steam jet on the ash pit which is placed under the fire grate of the furnace.

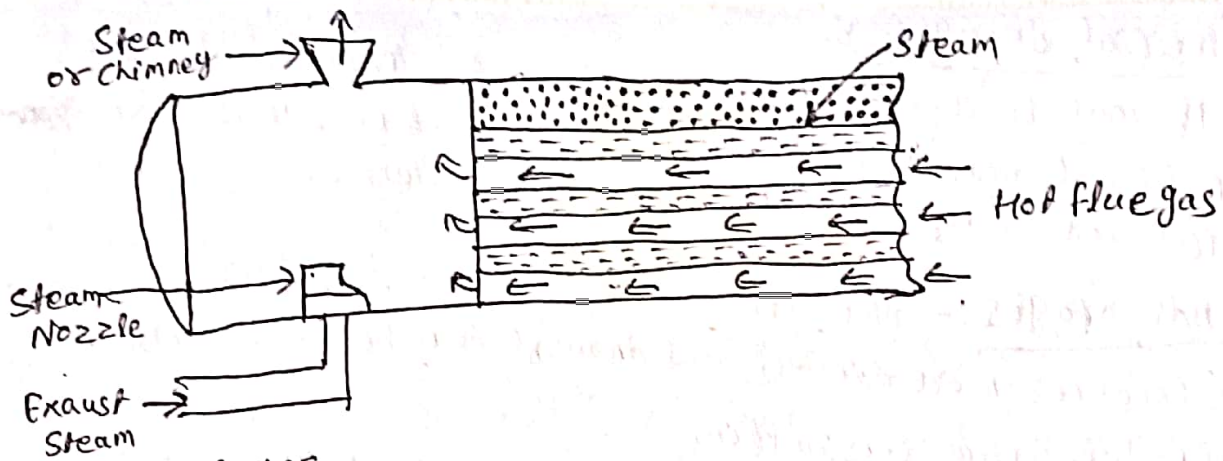
⇒ In this case, the air will be forced into the furnace by the steam jet and the draught produced will be the forced draught.

⇒ The induced steam jet draught is produced when steam jet is directed into chimney from a nozzle placed in chimney.

⇒ This causes the flow of gases through the fire tubes ash pit and grate.

⇒ Steam from boiler is throttled by a valve to a pressure of two bar and passed through the nozzles connected to a diffuser pipe.

⇒ The steam comes out with high velocity from the diffuser and drags the column of air along with it and thus makes way for the fresh air to come inside the furnace.



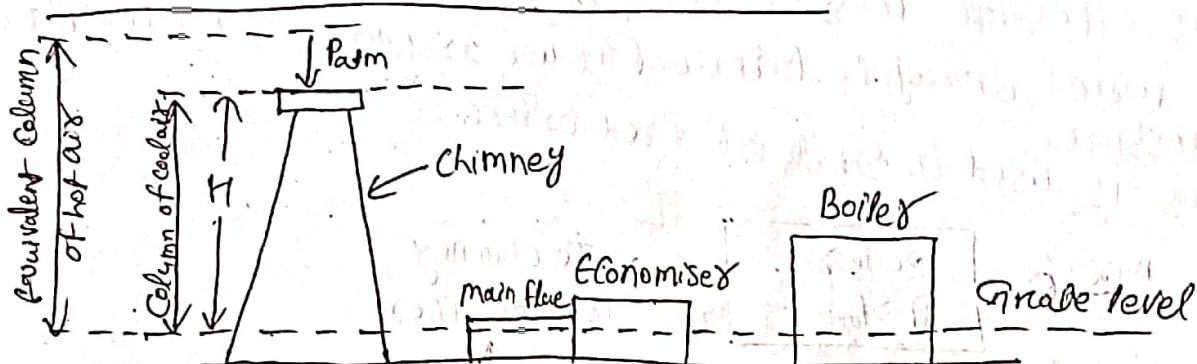
Advantages

- ⇒ simple and economical
- ⇒ occupies minimum space
- ⇒ permits burning of inferior fuel
- ⇒ No maintenance

Disadvantages

- ⇒ It can not start until steam at the required pressure is available.

Natural draught (chimney draught)



- ⇒ Natural draught is cheaper and simple to operate. But sufficient draught cannot be produced by chimney and is suitable only for small boilers.
- ⇒ In this case, the amount of draught produced in the boiler depends on the following factors:
 - * Climatic conditions:- Draught decreases with the increase in outside air temp.
 - * Temp. of furnace gases:- Draught increases with the increase in furnace gas temp.
 - * Height of chimney:- Draught increases with the increase in height of the chimney.

Artificial draught :-

- ⇒ It may be a mechanical draught or a steam/jet draught.
- ⇒ Artificial draught is produced by fan or blower. It is more economical and widely used in large boiler plants.

⇒ Advantages :- Not affected by climatic conditions.

- ⇒ Produces more draught, and draught can be easily controlled.
- ⇒ Reduce fuel consumption.
- ⇒ Reduces height of chimney; Chimney is required only to discharge the flue gases to atmosphere at a convenient height.

Disadvantages :- It is costlier and complex to maintain.

Types of artificial draught :- (i) forced draught

(i) Forced draught :-

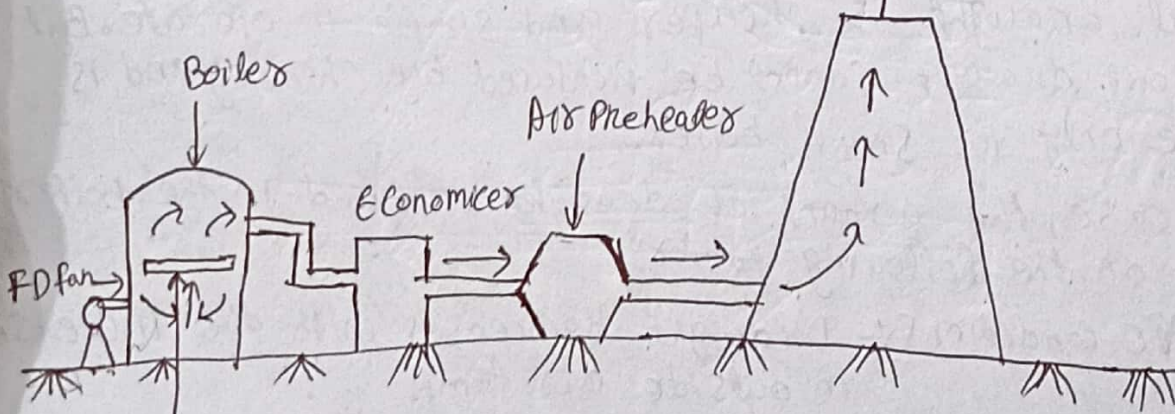
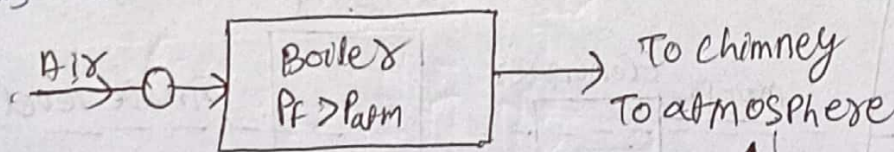
- (ii) Induced "
- (iii) Balanced "

⇒ The draught is produced by a fan.

⇒ It is a positive pressure draught.

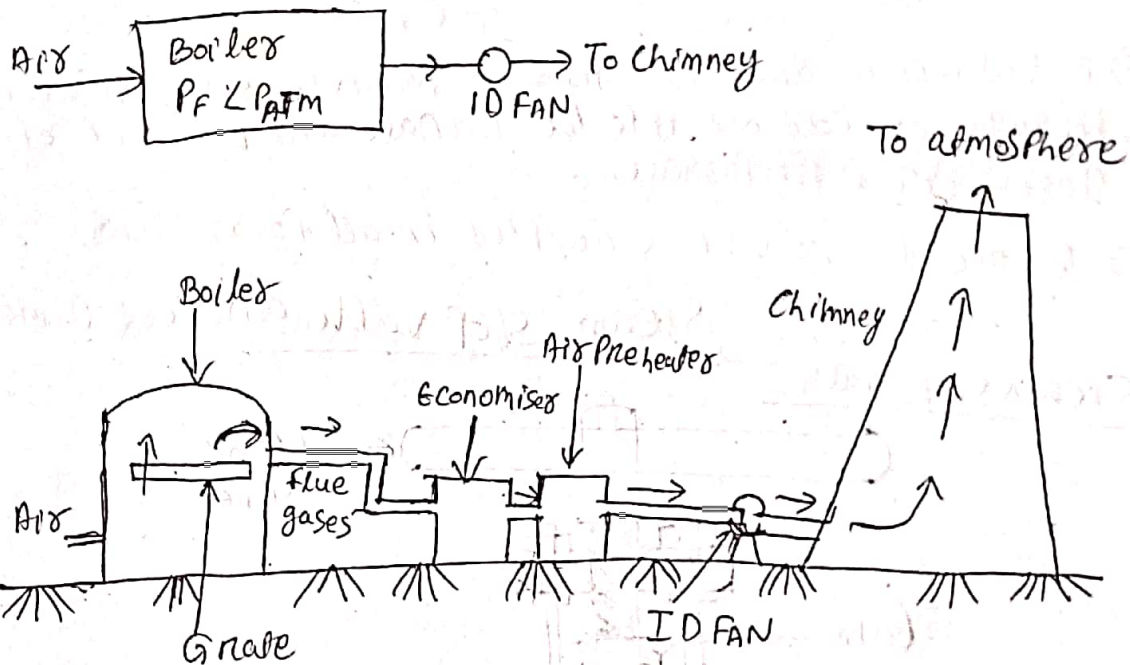
⇒ In forced draught, furnace pressure is higher than atmospheric pressure.

⇒ This is used in small oil fired boilers.



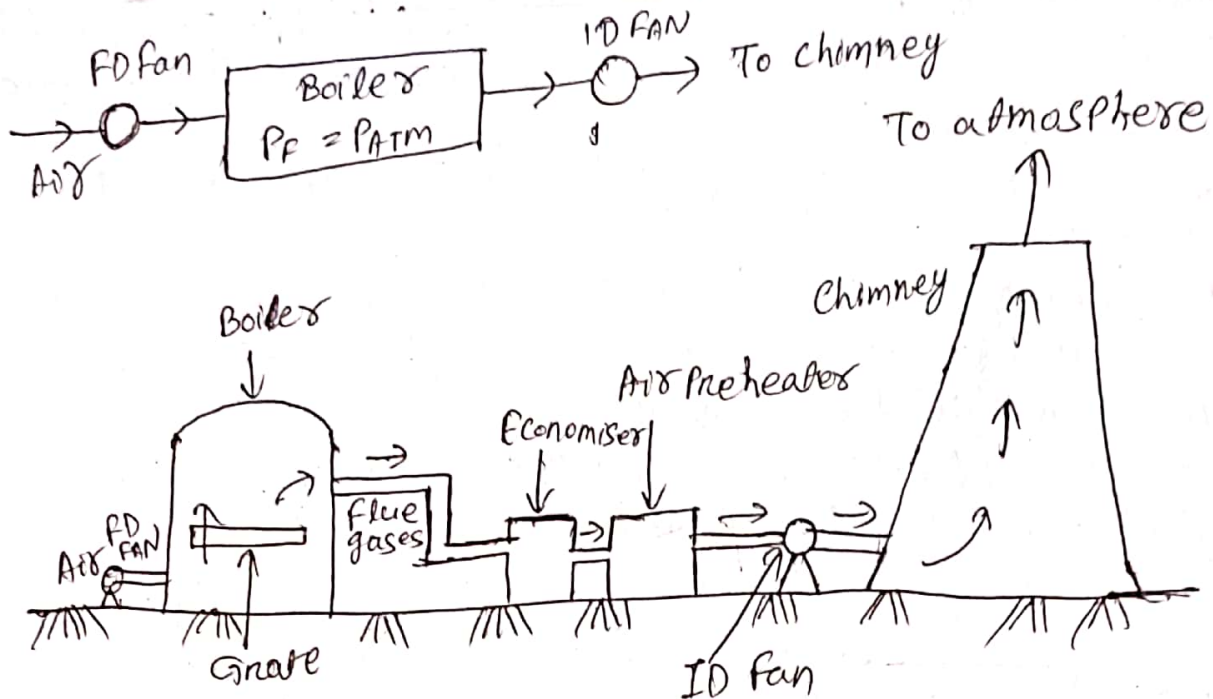
Induced Draught :-

- ⇒ In this system a fan or blower is located at or near the base of the chimney.
- ⇒ The pressure over the fuel bed is reduced below that of the atmosphere.
- ⇒ By creating a partial vacuum in the furnace and flues, the products of combustion are drawn from the main flue and they pass up the chimney.
- ⇒ This draught is used usually when economisers and air preheaters are incorporated in the system.
- ⇒ The draught is similar in action to the natural draught.



Balanced draught

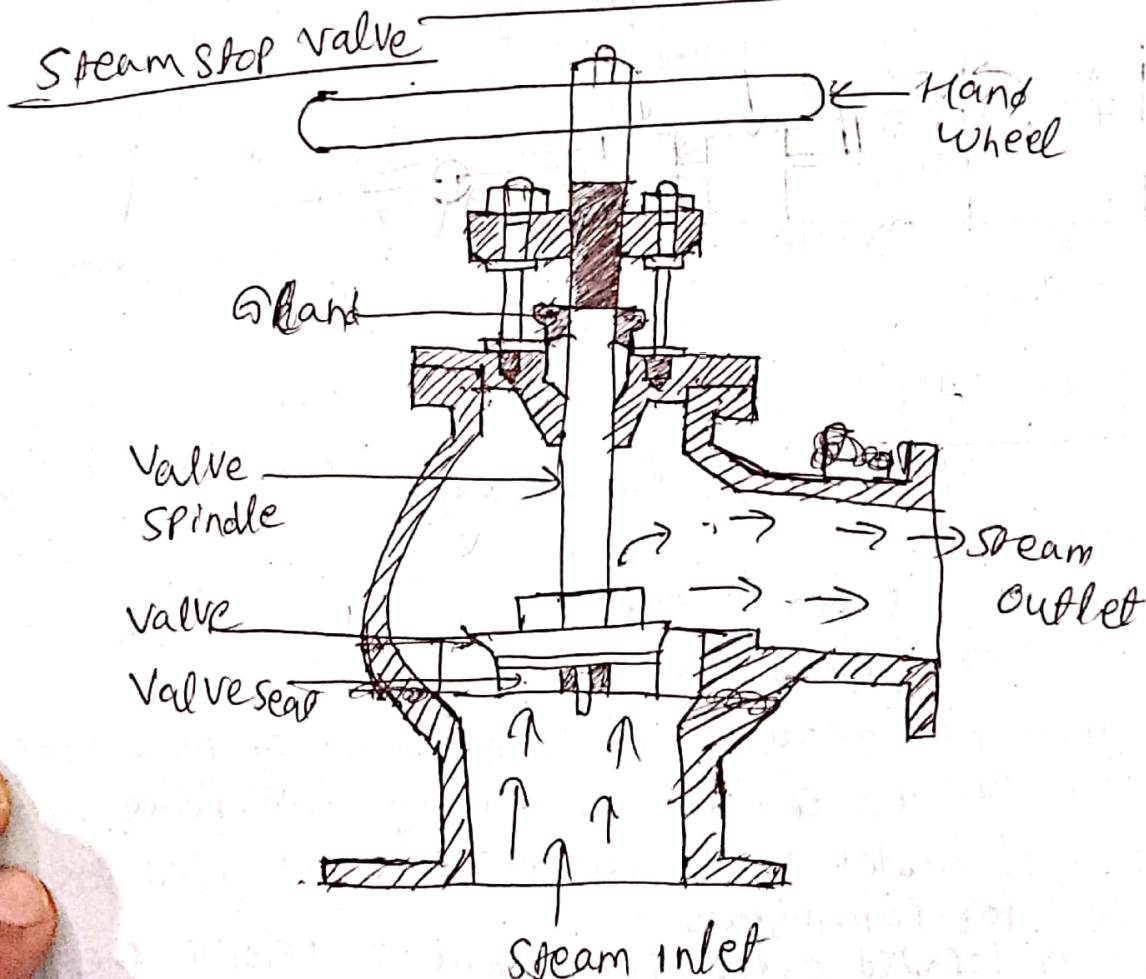
- ⇒ It is a combination of the forced and induced draught systems.
- ⇒ In this case, furnace pressure will be nearly equal to atmospheric pressure.
- ⇒ In balanced draught, the drawbacks of individual draught can be eliminated by using two fans.
- ⇒ FD fan is located before the furnace and used to supply the air for combustion.
- ⇒ ID fan is located after the furnace to remove the gases from the furnace.



⇒ A balanced draught ~~minimise~~ minimise the losses due to leakage of cold air into the furnace and blow off of hot gases from the furnace.

⇒ Balanced draught is adopted in all Power Plants.

Steam stop valve and feed pump



Feed Check Valve

Hand wheel

