IC Engine

Heat Engine :—

Heat Energy $\xrightarrow[\text{Substance}]{}$ Mechanical work

1. Internal combustion Engine → Petrol engine, Diesel etc.
2. External Combustion Engine → steam turbine, gas turbine etc.

$\boxed{\text{I C Engine}}$

- ~~Rotary IC engine~~
- Reciprocating IC Engine
  - SI engine (Spark Ignition) Engine
    - 2 Stroke
    - 4 Stroke
  - CI engine (Compression Ignition) Engine
    - 2 Stroke
    - 4 Stroke

Classifications of I.C. Engine :-

1. **No. of strokes per cycle :**

I C engines can be classified as four-stroke engines (4S) and two stroke engines (2S).

→ In four stroke engines, the thermodynamic cycle is completed in four strokes of the piston or two revolutions of the crankshaft whereas.

→ In two stroke engines, the thermodynamic cycle is completed in two strokes of the piston or one revolution of the crankshaft.

2. **Nature of Thermodynamics**

I.C. engines can be classified as

(i) Otto cycle engine
(ii) Diesel cycle engine
(iii) Dual cycle engine

→ In an otto cycle engine, heat addition and heat rejection occur at constant volume, therefore this is also known as constant volume engine. whereas

→ In the Diesel cycle engine, heat addition occurs at constant pressure & heat rejection occurs at constant volume.

→ In dual cycle engine, heat addition occurs partly at constant volume & partly at constant pressure, but heat rejection occurs fully at constant volume.

3. Ignition systems : There are two modes of ignition of fuel inside the cylinder - (i) Spark ignition (ii) self or compress Ignition

→ In spark ignition, sparking starts at the end of the compression stroke from spark plug while
→ In compressed ignition, the temperature of the fuel increased to the self ignition point of the compressing the air alone & at the end of compression fuel is injected into the cylinder by the cylinder.

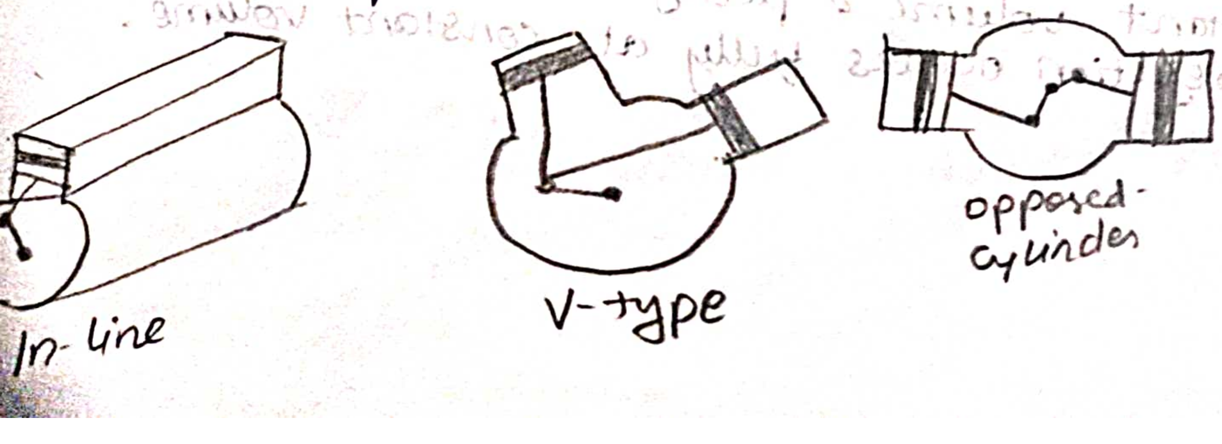
4. Fuel used ⇒

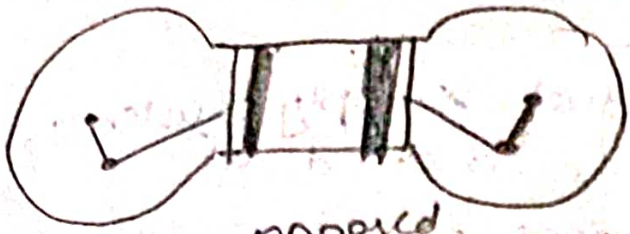
On the basis of fuel used, I.C engine can be classified as (a) gas engines like CNG, natural gas etc
(b) petrol engine
(c) Diesel engine
(d) Bi fuel engine

In a bifuel engine two types of fuel are used like gaseous fuel & liquid fuel.

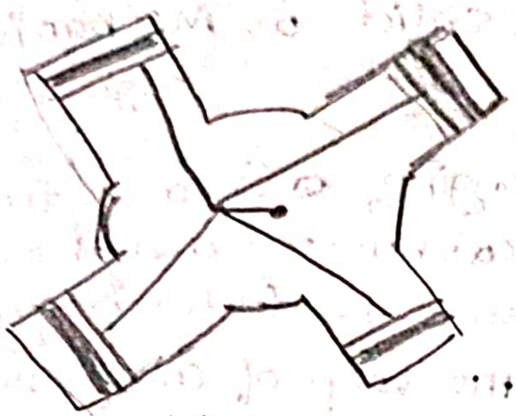
5. Arrangement of Cylinders

According to the arrangements of cylinders I.C. engines can be classified as
(a) In-line engines (b) V-engines (c) opposed cylinder engine
(d) opposed piston engines (e) X-type engines (f) Radial engine





opposed piston



X-type

Radial

Cooling systems

There are two types of cooling systems in I.C. engines
(i) Water Cooling.
(ii) air cooling.

- In water cooling, coolant & radiators are provided to cool the cylinder.
- In air cooling, fins are provided on the surface of the cylinder to radiate the heat into the atmosphere.

→ Low power engines like motorbikes are equipped with air cooling systems, whereas

→ Large power producing engines like a car, bus, truck etc are equipped with water cooling systems.

7. Fuel supply systems

On the basis of fuel supply systems, I C engines can be classified as
(a) carburetor engine
(b) Air injection engine.
(c) Airless or solid or mechanical Injection engines

→ In a carburetor engine, air and fuel are properly mixed into the carburetor and then fed into the cylinder

→ In air injection engines, fuel is supplied to the cylinder with the help of compressed air

→ In mechanical injection engines, the fuel is injected into the cylinder with the help of mechanical pump & nozzle.

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4 S Petrol engine

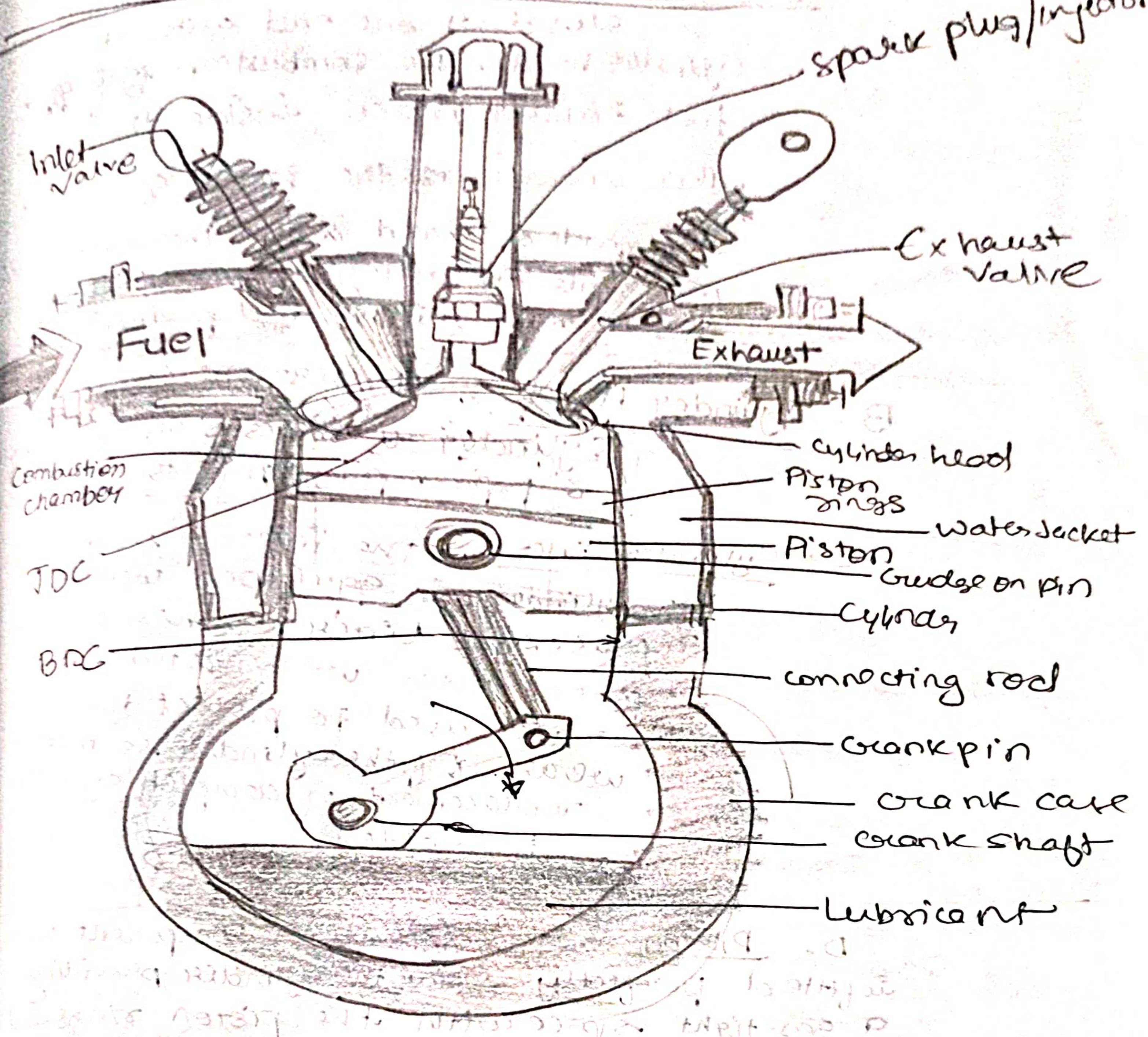
① TDC → BDC → intake

② BDC → TDC → compression

③ Constant Vd → power stroke
TDC → BDC

④ BDC - TDC → exhaust.

Basic structure of I C engine



A. Cylinder. It is hollow cylindrical structure closed at one end with the cylinder head. The combustion of the fuel takes place inside the cylinder, That known as the heart of the engine. It is made of hard & high thermal conductivity materials by casting. A piston reciprocates inside the cylinder and produces power.

B. Cylinder Head: It covers one end of the cylinder & consists of valves/ports & spark plug/injector

C. Cylinder Liner: The internal surface of the cylinder is equipped with a replaceable liner, which can be replaced after wear & tear. The liner is used to protect the wear of the cylinder so that replacement of complete cylinder is avoided.

D. Piston It is cylindrical component which is fitted perfectly inside the cylinder providing a gas-tight space with the piston rings and lubricant. The piston is connected to connecting rod by hardened gudgeon pin. The main function of piston is to transfer the power produced by combustion of the fuel to the crankshaft.

E. Piston Rings :

The outer periphery of the piston is provided with several grooves into which piston rings are fitted. The piston is fitted with these rings. The upper ring is known as compression ring & the lower rings are known as oil rings. The function of the compression ring is to compress the air or air-fuel mixture & the function of oil ring is to collect the surplus lubricating oil on the liner surface.

F. Water Jacket :-

Water jacket is an integral part of the cylinder through which cooling water is circulated to prevent the overheating the engine.

G. Connecting Rod :-

It connects the piston and the crankshaft. One end, called the small end, is connected to the gudgeon pin located in the piston and the other end, called big end, is connected to crank pin. The function of the connecting rod is to transfer the reciprocating motion of the piston into rotary motion of the crankshaft.

H. Crankshaft :-

It is principal rotating part of the engine which controls the sequence of reciprocating motion of the pistons. It consists of several bearings & crank pins.

I. Valves :-

Normally, the two valves are used for each cylinder, which may be of mushroom shaped poppet type. They are provided either on the cylinder head or on the side of the cylinder for regulating the charge coming into the cylinder and for discharging the products of combustion from the cylinder.

The valve mechanism consists of cams, cams follower, push rod, rocker arms & spring.

J. Inlet Manifold :-

This is the pipe which connects the intake system to the inlet valve of the engine & through which air or air-fuel mixture is drawn into the cylinder.

K. Exhaust Manifold :-

This is the pipe which connects the exhaust valve of the engine and through which products of the combustion escapes into the atmosphere.

L. Cams & camshaft :-

Cam is mounted on a shaft which is known as the cam shaft. The function of the cam is to facilitate the control of the timing of opening & closing of the inlet and exhaust valve. It provides to and fro motion to the valve rods to open and close the valves.

M. Spark plug :-

In an SI engine, a spark plug is located near the top of the cylinder & initiates the combustion of the fuel.

carburettor : Carburettor is a device which is used to Control the fuel qualitatively in an S I engine. It atomizes the fuel, mixes with air & vaporizes it and finally sends the air-fuel mixture inside the cylinder through the inlet valve.

O. Fuel Pump & Injector Unit :-

This unit is used in CI engine (nowadays injection system is also used in SI engine as multi-point fuel injection (MPFI). Its function is to supply the fuel to injector under pressure which consists of one or more orifices through which the fuel is sprayed into the cylinder.

P. Crankcase :-

It consists of a cylinder, piston & crankshaft. It helps in lubrication of different parts of the engine.

Q. Flywheel :- It is a heavy wheel mounted on the crankshaft to minimize the cyclic variations in speed. It absorbs the energy during the power stroke and releases it during the non-power stroke. By employing a flywheel, the turning moment becomes uniform at the crank shaft.

Nomenclature

A. Cylinder Bore (d) :-

The nominal inner diameter of a cylinder is called a cylinder bore which is designated by an English letter 'd' & expressed in mm (millimeter).

B. Piston Area (A) :-

The area of the inner diameter of a cylinder is known as piston area. It is measured in cm^2 or mm^2.

C. Stroke (L) :-

The axial distance for which a piston moves inside a cylinder in one stroke is known as stroke length which is designated as L & measured in terms of mm.

D. Dead centers :-

The positions of the piston, at the moments when the direction of the piston motion is reversed are known as dead centers.

There are two dead centers -

- Top Dead center (TDC)
- Bottom Dead center (BDC)

The farthest position of the piston head from the crankshaft is known as TDC and the nearest position of the piston head from the crankshaft is known as BDC.

E. Displacement / Stroke / swept Volume (V_s)

The nominal volume swept by the working piston when travelling from one dead center to the other is called the displacement volume.
It is expressed in cc (cubic centimeter).
and is given by $\boxed{V_s = A \times L = \frac{\pi}{4} d^2 L}$

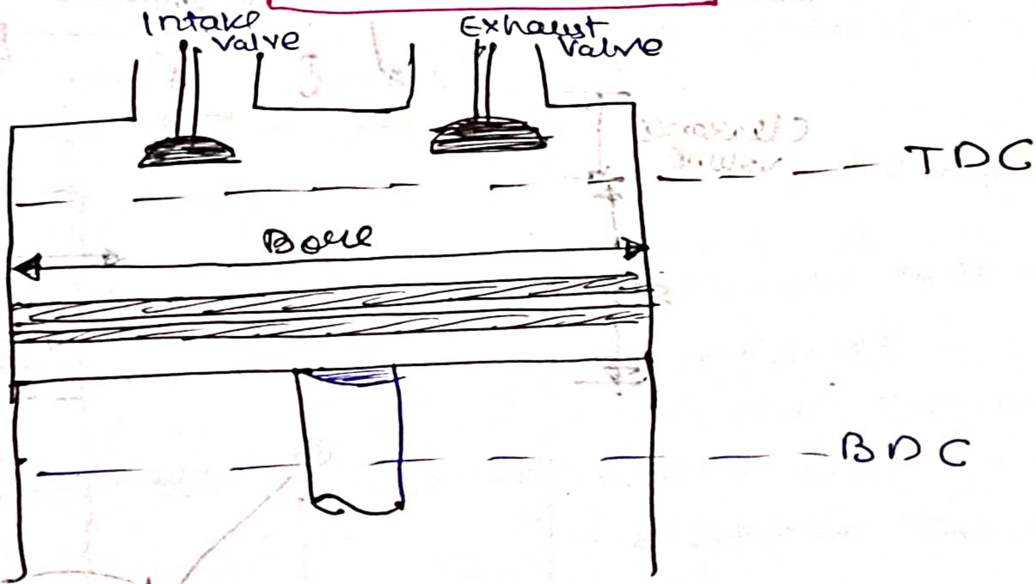
F. Clearance Volume (V_c) :-

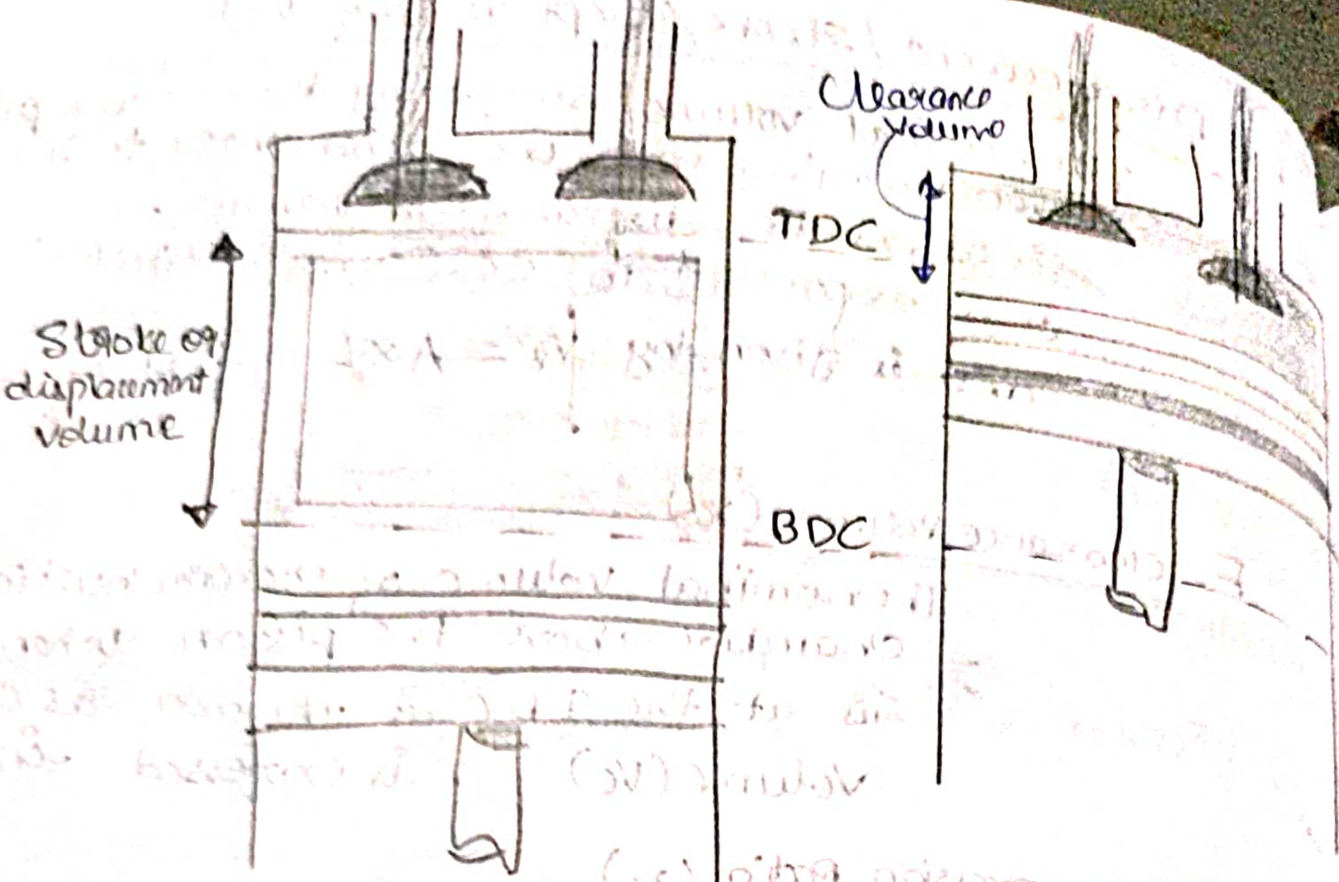
The nominal volume of the combustion chamber above the piston when it is at the TDC is known as clearance Volume (V_c) & is expressed in c.c.

G. Compression Ratio (r_v)

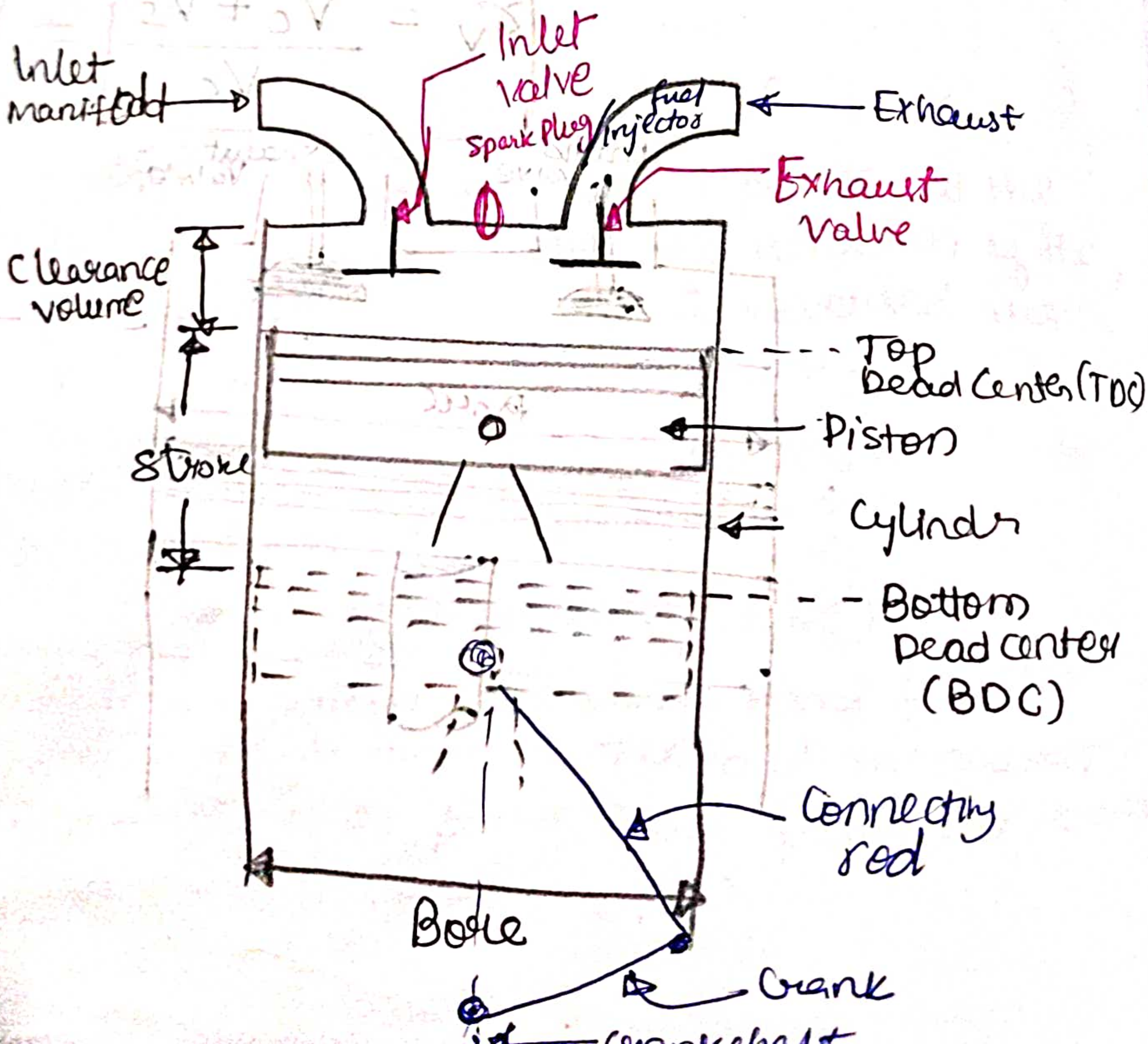
It is the ratio of the total cylinder volume when the piston is at BDC to the clearance volume

$$\boxed{r_v = \frac{V_c + V_s}{V_c}} = 1 + \frac{V_s}{V_c}$$





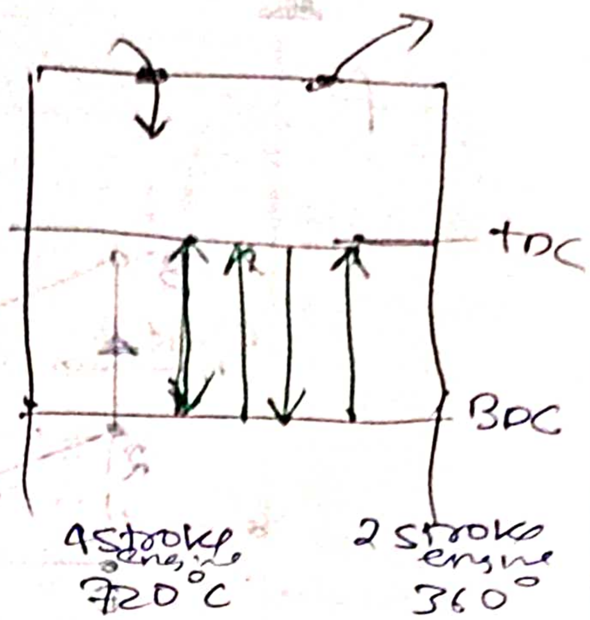
Clearance Volume
TDC
Stroke or displacement volume
BDC



Inlet Manifold
Inlet valve
Spark Plug
fuel Injector
Exhaust
Exhaust Valve
Clearance volume
Top Dead Center (TDC)
Piston
Stroke
Cylinder
Bottom Dead center (BDC)
Connecting rod
Bore
Crank

In a cycle :-

① suction
② compression
③ combustion
④ Expansion (Power stroke)
⑤ Heat Rejection
⑥ Exhaust



TDC → BDC → 180°

spark - Ignition Engine [SI engine] / [Petrol Engine] / [Gasoline engine]

Ideal cycle :- otto cycle [Constant volume cycle]

Substance :- air [Ideal gas]

an otto cycle consist following process :-

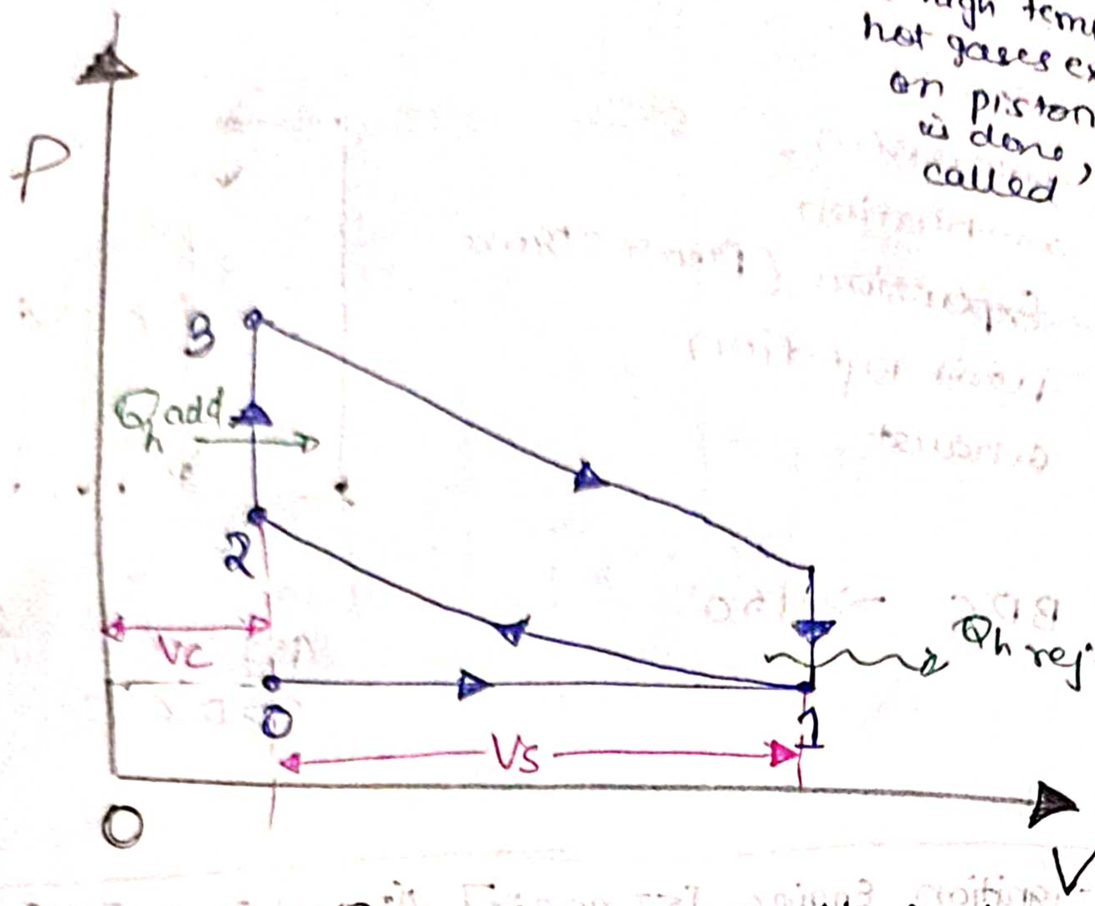
① Reversible adiabatic compression (1-2)
↳ Isentropic Compression

② Constant volume heat addition (2-3)
↳ Isochoric heat addition

③ Reversible adiabatic expansion (3-4)
↳ Isentropic Expansion

④ Constant volume heat rejection (4-1)
↳ Isochoric heat rejection

The high temp. & high hot gases exert pressure on piston. Thus work is done, hence it is called power stroke



P.V diagram for otto cycle

Suction (0 → 1)

Exhaust (1 → 0)

$$pV = mRT$$

$$p \propto T$$

1 → 2 ⇒ Isentropic compression (Rev adiabatic compression)

$\gamma = C_p / C_v$

$pV^{\gamma} = \text{const}$ γ : adiabatic Index

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Air standard efficiency of otto cycle

$$\eta = \frac{O/P}{I/P} = \frac{W_{net}}{Q_{add}}$$

$Q_{add} = Q_{2-3}$

$Q_{rej} = Q_{4-1}$

$$W_{net} = \Sigma Q = \Sigma Q_{add} - \Sigma Q_{rej}$$
$$= Q_{add} - Q_{rej}$$

$$\eta = \frac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \frac{Q_{rej}}{Q_{add}}$$

1-2 (R.A.C)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\boxed{\frac{T_2}{T_1} = r_c^{\gamma-1}} \quad \text{--- (2)}$$

3-4 (R.A.E)

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}$$

$$\boxed{\frac{T_3}{T_4} = (r_c)^{\gamma-1}} \quad \text{--- (1)}$$

from eqn (1) & (2)

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

$$\frac{T_4}{T_1} = \frac{T_3}{T_2}$$

Heat addition (2-3)

Constant volume process

Q = change in internal energy

$$Q_{23} = Q_{add} = U_3 - U_2$$

$$Q_{add} = mC_v(T_3 - T_2)$$

Heat rejection (4-1)

$$Q_{rej} = U_4 - U_1$$
$$= mC_v(T_4 - T_1)$$

$$\eta = 1 - \frac{Q_{rej}}{Q_{add}} = 1 - \frac{\cancel{mC_v}(T_4 - T_1)}{\cancel{mC_v}(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

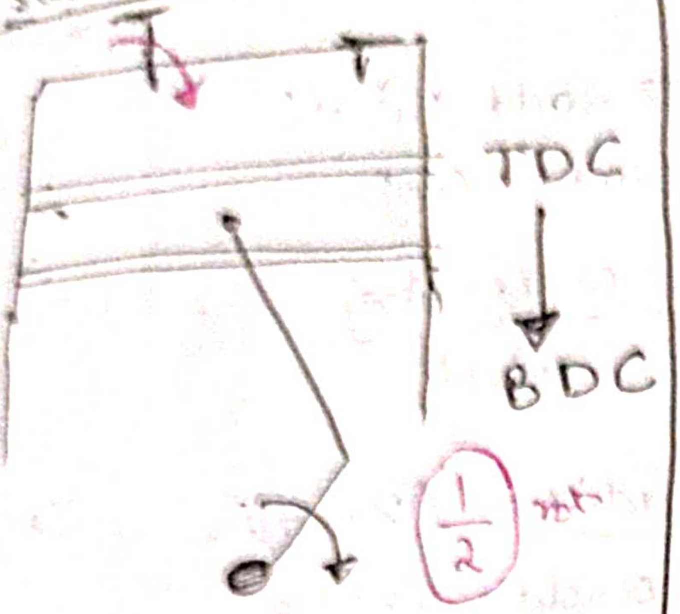
$$= 1 - \frac{T_1\cancel{\left[\frac{T_4}{T_1} - 1\right]}}{T_2\cancel{\left[\frac{T_3}{T_2} - 1\right]}}$$

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

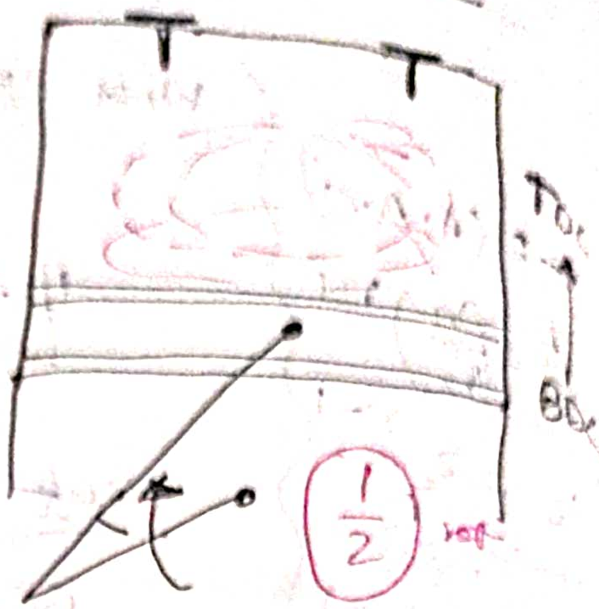
$$\boxed{\eta = 1 - \frac{1}{r_c^{\gamma-1}}} \Rightarrow \boxed{\eta_{air,std} = f(r_c, \gamma)}$$

Q. Explain the working principle of 4-stroke Petrol engine

① Suction stroke



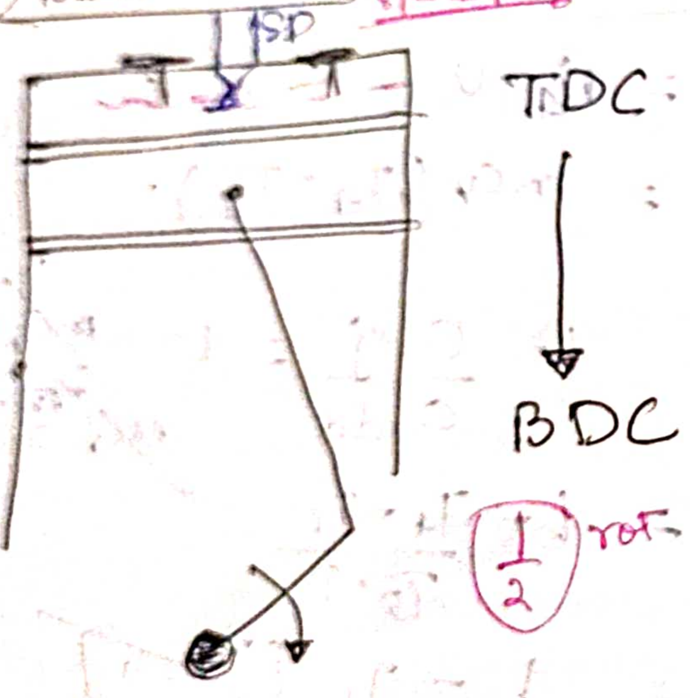
② compression



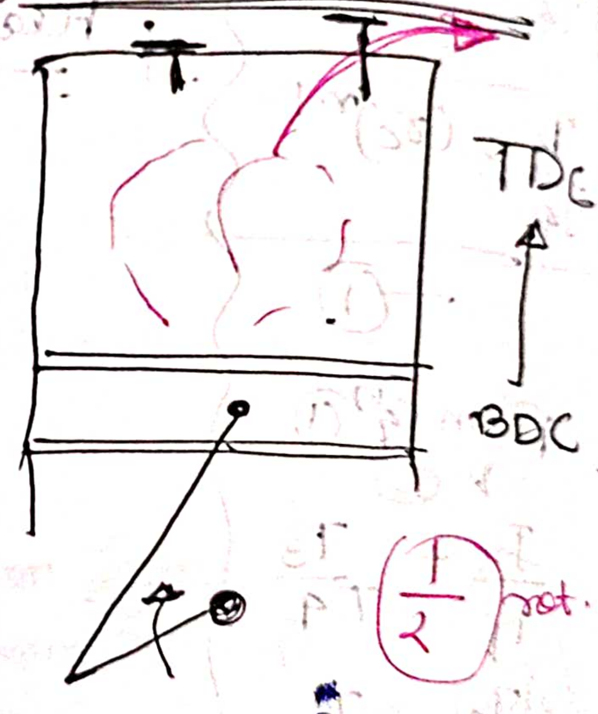
working stroke

③ Power stroke

spark plug



④ Exhaust stroke



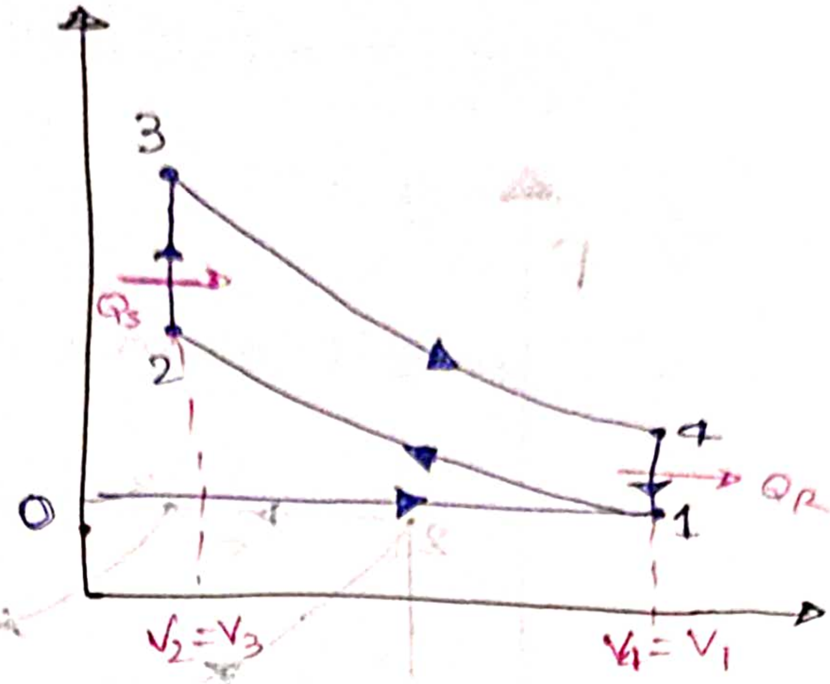
4 - S

Crank 2 Rotation

1 - Power stroke

Petrol Engine

w/ spark plug (SI)



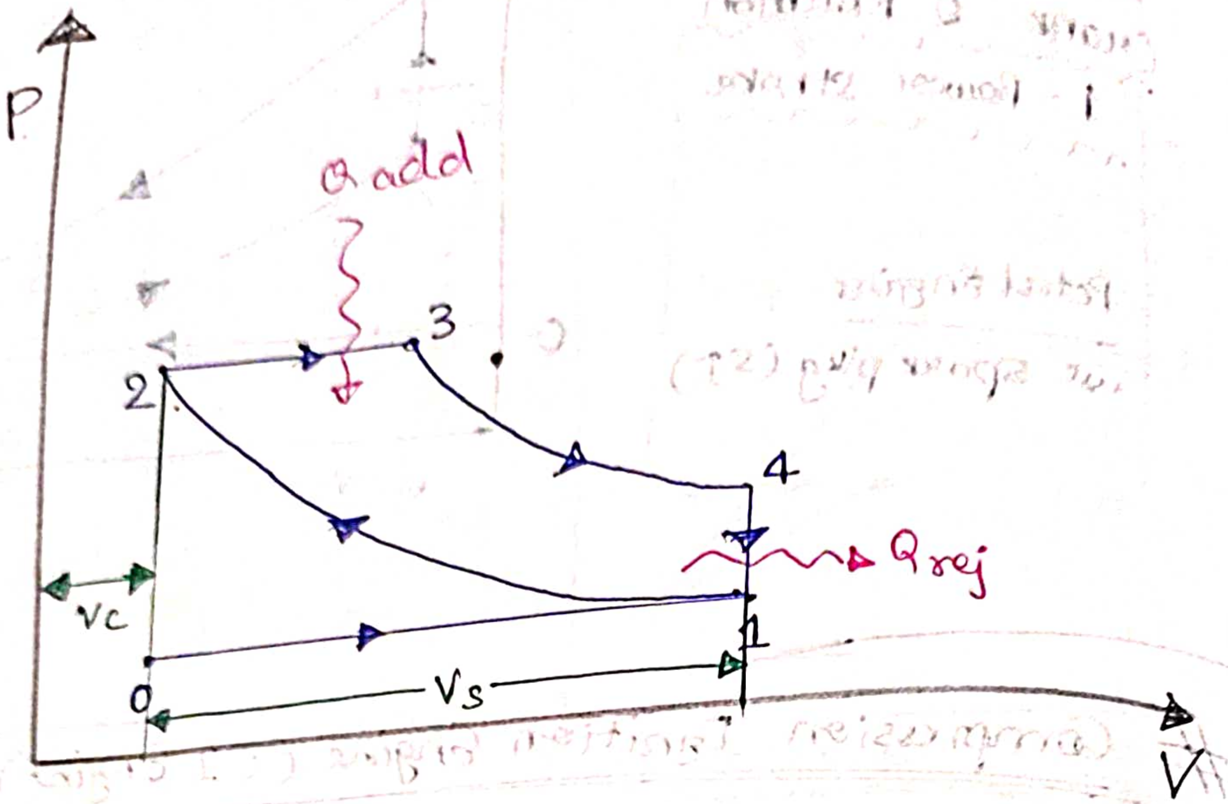
Compression Ignition Engine (CI Engine) or Diesel Engine

Ideal cycle :- Diesel cycle

Substance :- Air (Ideal gas)

An ideal diesel cycle consist following Process :-

1) Rev. adiabatic or isentropic compression (1->2)
2) const. Pressure or isobaric heat addition (2->3)
3) Rev. adiabatic or isentropic expansion (3->4)
4) constant volume or isochoric heat rejection (4->1)



$2 \to 3$. $P = \text{Const}$

$PV = mRT$

$\boxed{V \propto T}$

$4 - 1$

$\text{Vol}^m = \text{const}$

$\boxed{P \propto T}$

Note :- Slope of const vol line is more as compare to slope of const. Press line.

Compression ratio $[r_c]$ = $\frac{\text{Total vol}^m}{\text{Clearance vol.}}$

$$= \frac{V_c + V_s}{V_c} = \frac{V_1}{V_2} = \frac{V_4}{V_2}$$

Expansion ratio $[r_e]$ $= \frac{V_4}{V_3} = \frac{V_1}{V_3}$

Fuel cutoff ratio $[\alpha_c]$ $= \frac{V_3}{V_2}$

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

$$r_e = \frac{V_1}{V_2} \times \frac{V_2}{V_3}$$

$$r_e = r_c \times \frac{1}{\alpha_c}$$

$$\boxed{r_c = r_e \times \alpha_c}$$

$$[\eta_{\text{air std}}]_{\text{diesel}} = \frac{o/p}{i/p} = \frac{W_{net}}{Q_{add}}.$$

$$\Sigma W = \Sigma Q$$

$$W_{net} = Q_{add} - Q_{rej}$$

$$\eta = 1 - \frac{Q_{rej}}{Q_{add}}.$$

1-2 Rev. adiabatic compression (PV^γ = const)

$$P_1V_1^\gamma = P_2V_2^\gamma$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = (r_c)^{\gamma-1}$$

2-3 const press. heat addition

$$Q_{23} = Q_{add} = H_3 - H_2$$

$$Q_{add} = mc_p(T_3 - T_2)$$

$$= C_p(T_3 - T_2)\ kJ/kg$$

3-4 Rev. adiabatic expansion

$$P_3V_3^\gamma = P_4V_4^\gamma$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = (r_e)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

4 → 1 const - Vol.m heat rejectn

$$Q_{41} = Q_{rej} = U_4 - U_1$$

$$Q_{rej} = mC_v(T_4 - T_1)$$

$$= C_v(T_4 - T_1)$$

$$\eta = 1 - \frac{Q_{rej}}{Q_{add}} = 1 - \frac{\cancel{m} c_v [T_4 - T_1]}{\cancel{m} c_p (T_3 - T_2)}$$

$$\boxed{\frac{c_p}{c_v} = \gamma}$$

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{T_4 - T_1}{T_3 - T_2}\right]$$

$$1 \to 2 \Rightarrow T_2 = T_1 \times r_c^{\gamma - 1}$$

$2 \to 3$ ($P = const$)

$$\frac{\cancel{P_2} V_2}{T_2} = \frac{\cancel{P_3} V_3}{T_3}$$

$$T_3 = T_2 \times \frac{V_3}{V_2}$$

$$\boxed{T_3 = T_2 \cdot \alpha_c}$$

$$T_3 = T_1 \, r_c^{\gamma - 1} \alpha_c$$

$3 \to 4$ $P_3 V_3^{\gamma} = P_4 V_4^{\gamma}$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma - 1}$$

$$r_c = r_e \alpha_c$$

$$r_e = \frac{r_c}{\alpha_c}$$

$$T_4 = T_3 \times \left(\frac{V_3}{V_4}\right)^{\gamma - 1}$$

$$T_4 = T_3 \times \frac{1}{r_e^{\gamma - 1}} = T_3 \left(\frac{\alpha_c}{r_c}\right)^{\gamma - 1}$$

$\gamma - \cancel{1} + 1$

$$T_4 = T_1 \times \cancel{r_c^{\gamma-1}} \alpha_c \times \left(\frac{\alpha_c^{\gamma - 1}}{\cancel{r_c^{\gamma-1}}}\right) \Rightarrow T_4 = T_1 \alpha_c$$

$$T_4 = T_1 \alpha_c^{\gamma}$$

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{T_1\alpha_c^{\gamma} - T_1}{T_1\alpha_c r_c^{\gamma-1} - T_1 r_c^{\gamma-1}}\right]$$

$$\boxed{\left[\eta_{air\,std}\right]_{diesel} = 1 - \frac{1}{r_c^{\gamma-1}}\left[\frac{\alpha_c^{\gamma}-1}{\gamma(\alpha_c-1)}\right]}$$

Bracket factor

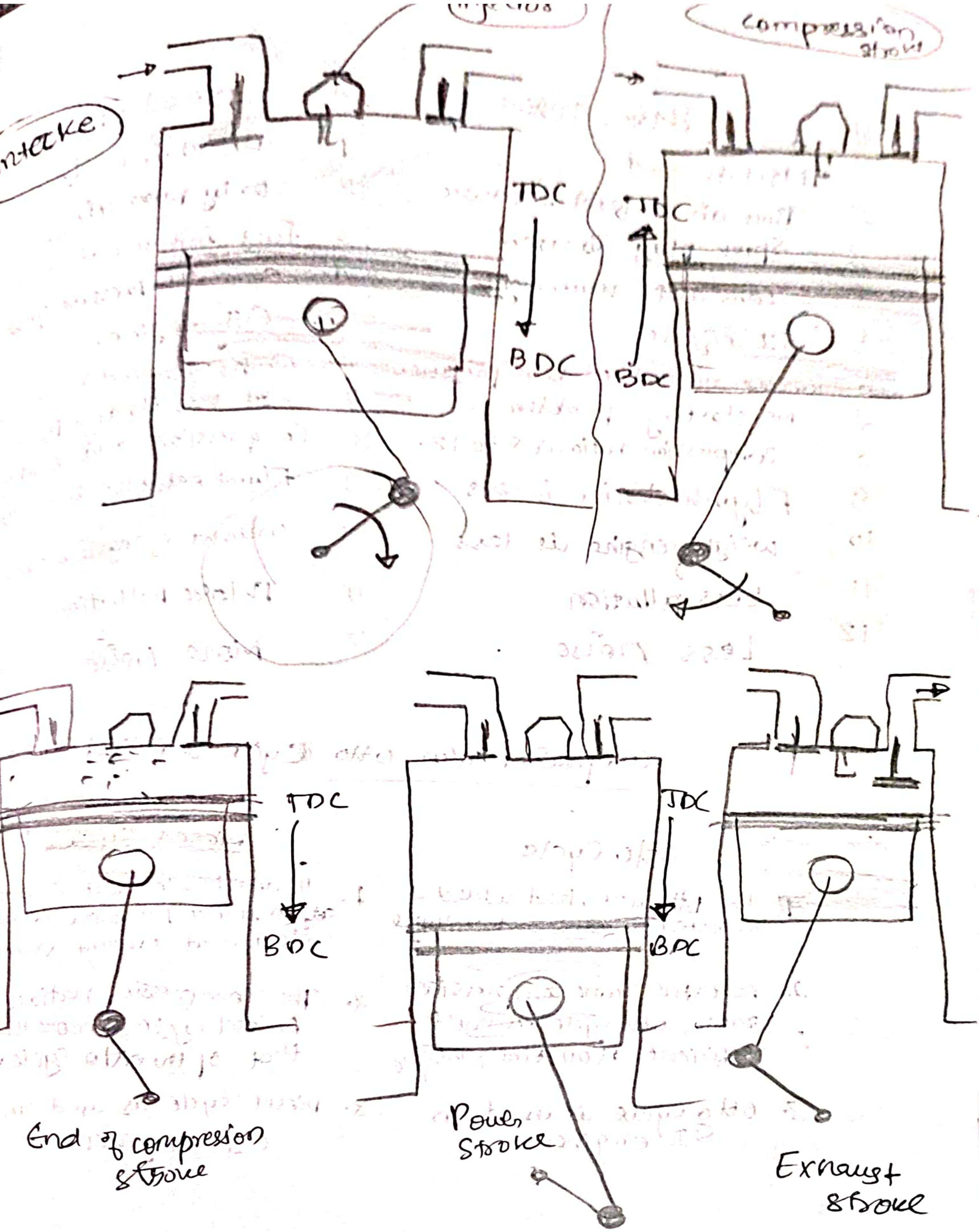
Bracket factor is greater than 1.

$$\left[\eta_{air\,std}\right]_{otto} = 1 - \frac{1}{r_c^{\gamma-1}}$$

S-I	C.I
$r_c \rightarrow 6-10$	$r_c \rightarrow 16$ to 20

For a same compression ratio

$$\eta_{otto} > \eta_{diesel}$$


Intake
Injector
Compression stroke
TDC
BDC
TDC
BDC
TDC
BDC
End of compression stroke
TDC
BDC
Power stroke
Exhaust stroke

Sl. No	Petrol engine	Sl No	Diesel Engine
1	Petrol is used	1	Diesel is used.
2	Pure air & fuel Mixture	2	only pure air
3	Spark plug is used	3	Fuel injector is used
4	Constant volume cycle	4.	Constant Pressure cycle.
5	SI engine	5.	CI engine.
6	works around 10 bar pressure.	6.	works around 33 bar pressure
7	No starting problem	7.	It has starting problem
8	Compression ratio is 8 to 12.	8.	Compression ratio is 14 to 25
9	Flywheel size is less	9.	Flywheel size is more
10	weight of engine is less	10.	weight of engine is more
11	Less pollution	11.	More Pollution
12	Less noise	12.	More Noise

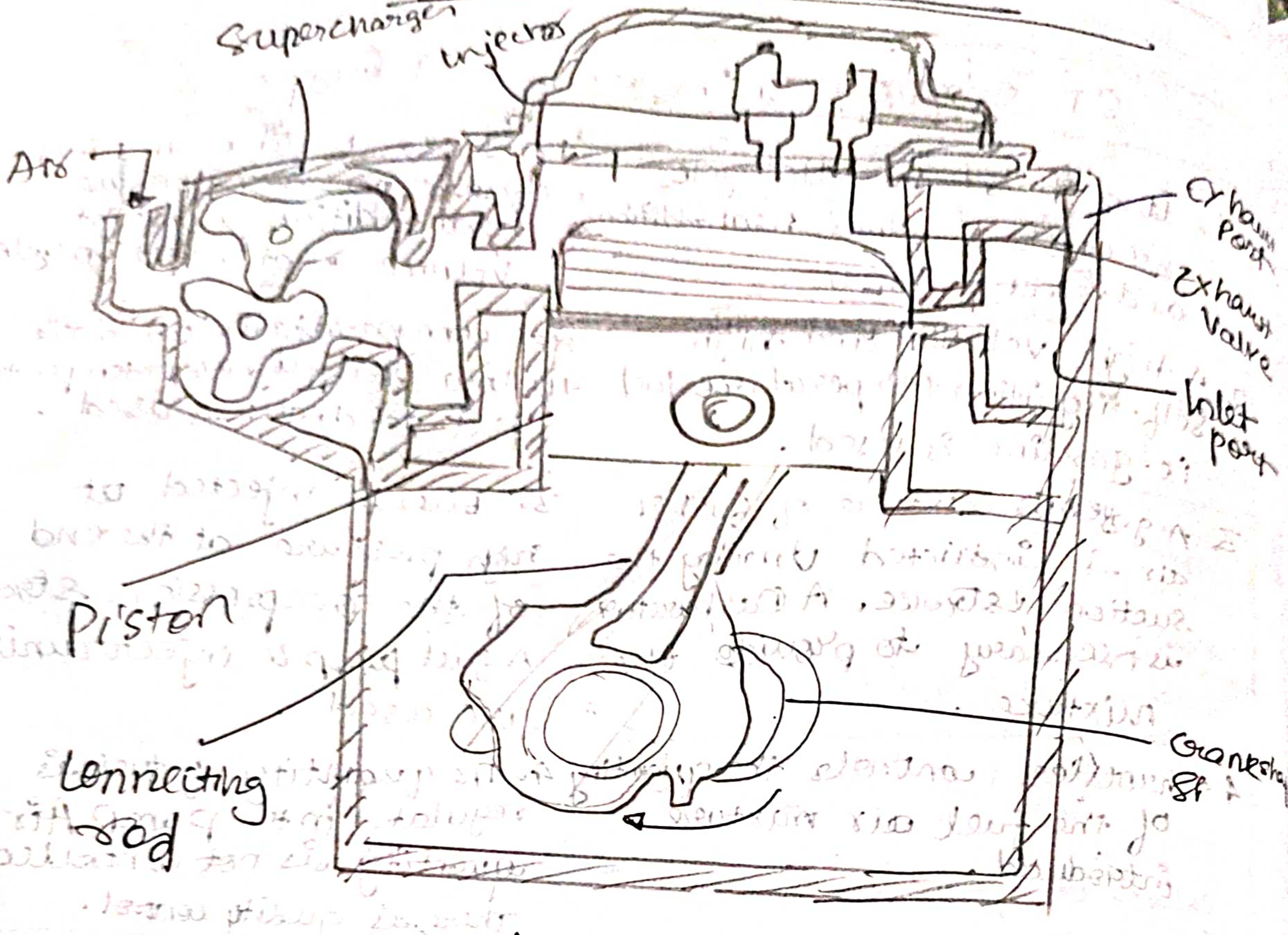
Comparison b/w Otto Cycle & Diesel cycle

	Otto Cycle		Diesel Cycle.
1.	In Otto cycle, heat added & rejected at constant volume	1.	In diesel cycle, heat is added at constant pressure & heat is rejected at constant volume
2.	For the same compression ratio, otto cycle is more efficient than that of Diesel cycle	2.	The compression ratio of Diesel cycle is more than that of the otto cycle.
3.	otto cycle is used in SI engines	3.	Diesel cycle is used in CI engines

comparison b/w SI & CI engine

SI Engine	CI Engine
1. It is based on otto cycle or constant volume heat addition and rejection cycle	1. It is based on a Diesel cycle or constant pressure heat addition & constant volume heat rejection cycle
2. A high volatile and high self-ignition temperature fuel i.e. gasoline is used.	2. comparatively low volatile & low self-ignition temperature fuel i.e. diesel is used.
3. A gaseous mixture of fuel & air is inducted during the suction stroke. A Carburetor is necessary to provide the mixture.	3. Fuel is injected at high pressure at the end of the compression stroke. A fuel pump & injector units are used.
4. Throttles controls the quantity of the fuel air mixture introduced.	4. The quantity of fuel is regulated in the pump. Air quantity is not controlled. There is quality control.
5. For combustion of the charge, it requires an ignition system with a spark plug in the combustion chamber.	5. Auto ignition occurs due to high temperature of air resulting from high-compression
6. compression ratio ranges from 6 to 10	6. compression ratio ranges from 16 to 20.
7. Due to light weight & homogeneous combustion, they are high-speed engines.	7. Due to heavy weight & heterogeneous, they are low-speed engines
8. It has a lower thermal efficiency due to lower compression ratio but delivers more power for same compression ratio.	8. It has a high thermal efficiency due to higher compression ratio and delivers lesser power for the same compression ratio.

Two stroke C I Engine



Two stroke diesel engine

2-Stroke

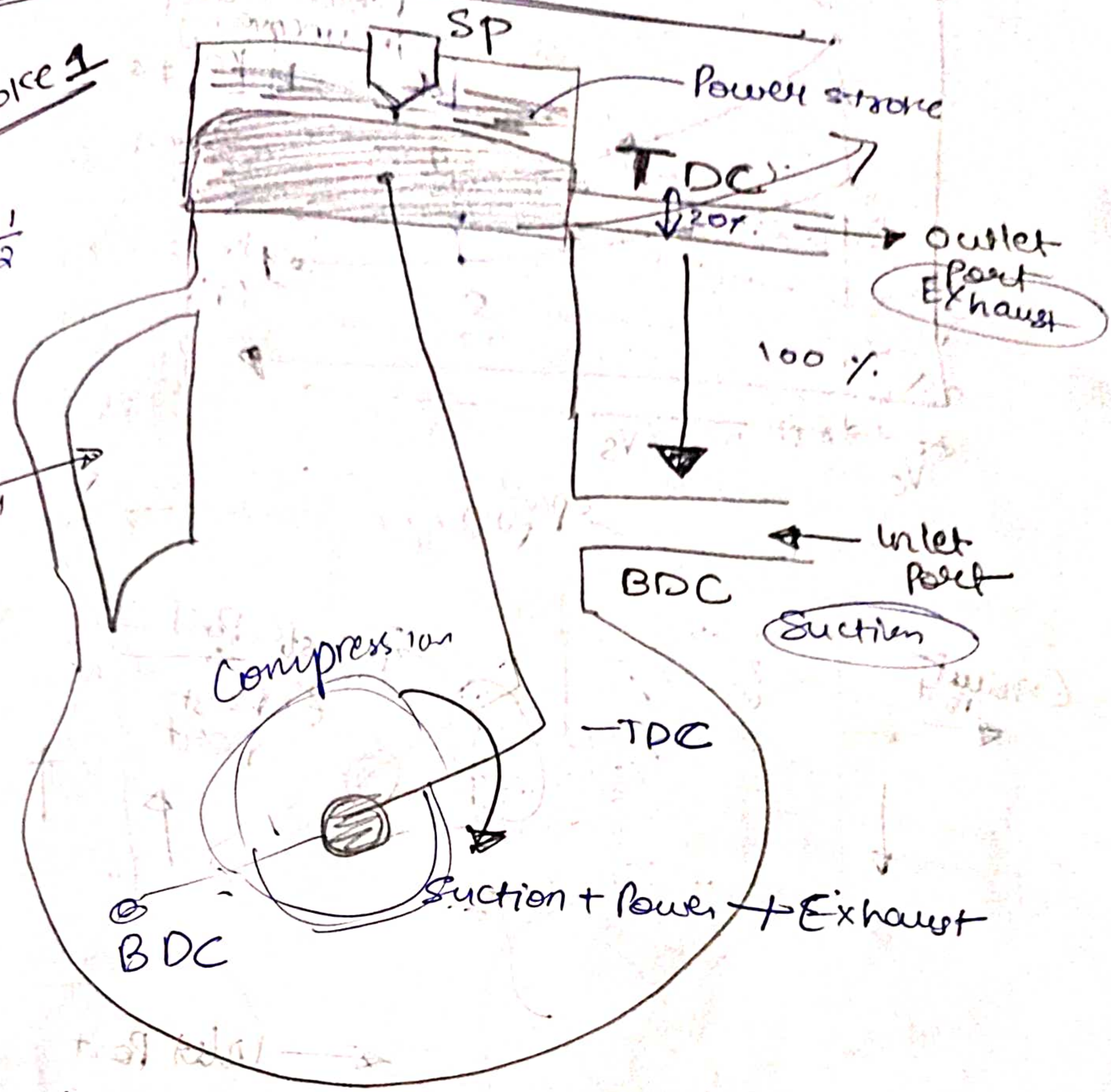
1 rotation of Crank

1 Power Stroke

Working Petrol Engine :-

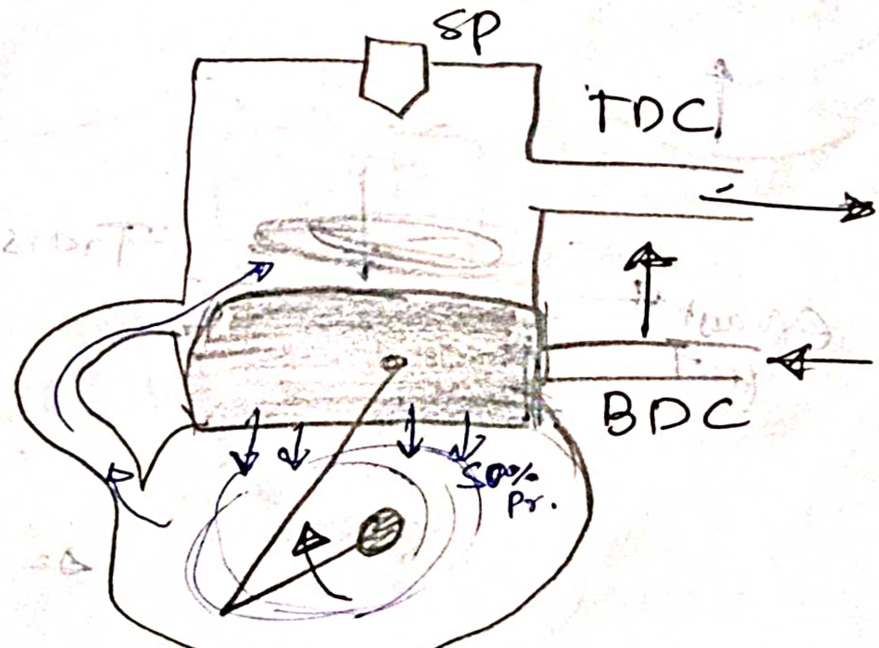
Stroke 1

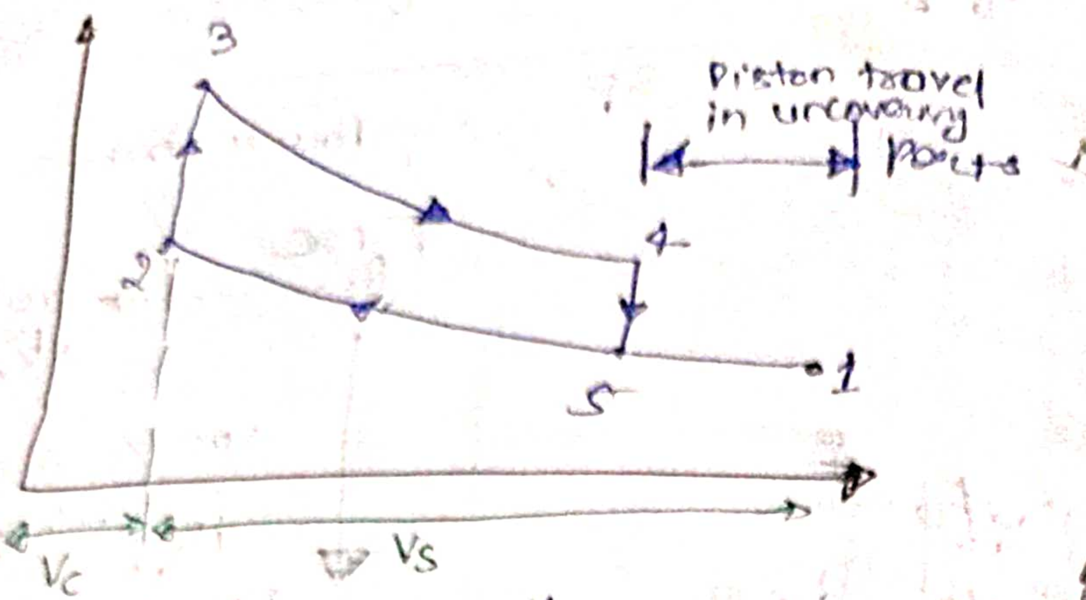
Suction - $\frac{1}{2}$

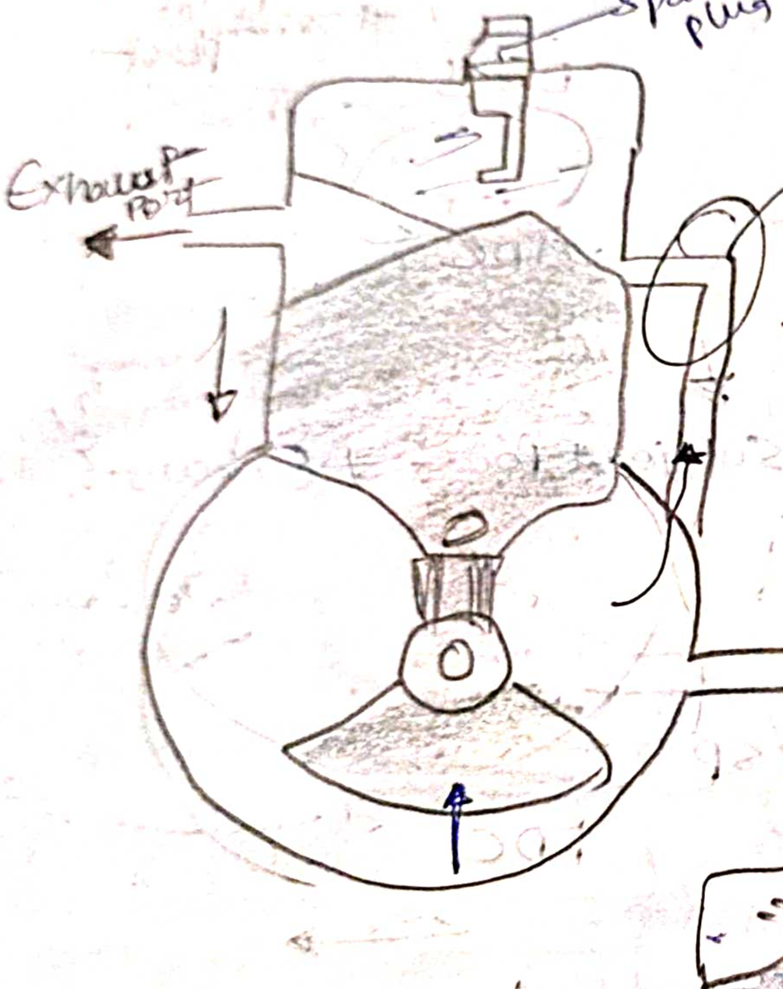


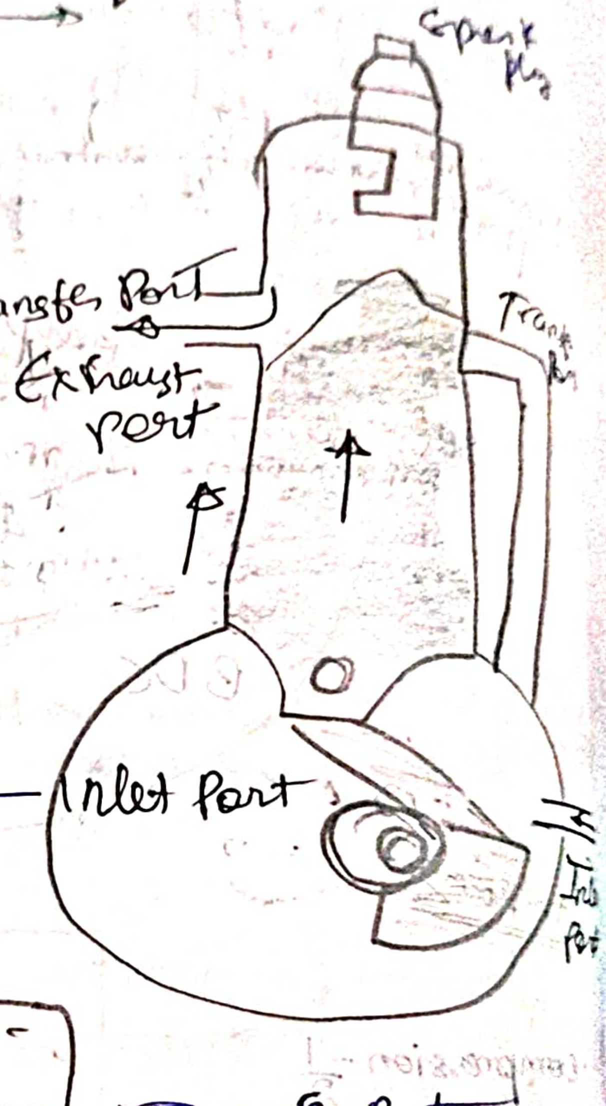
Stroke - 2

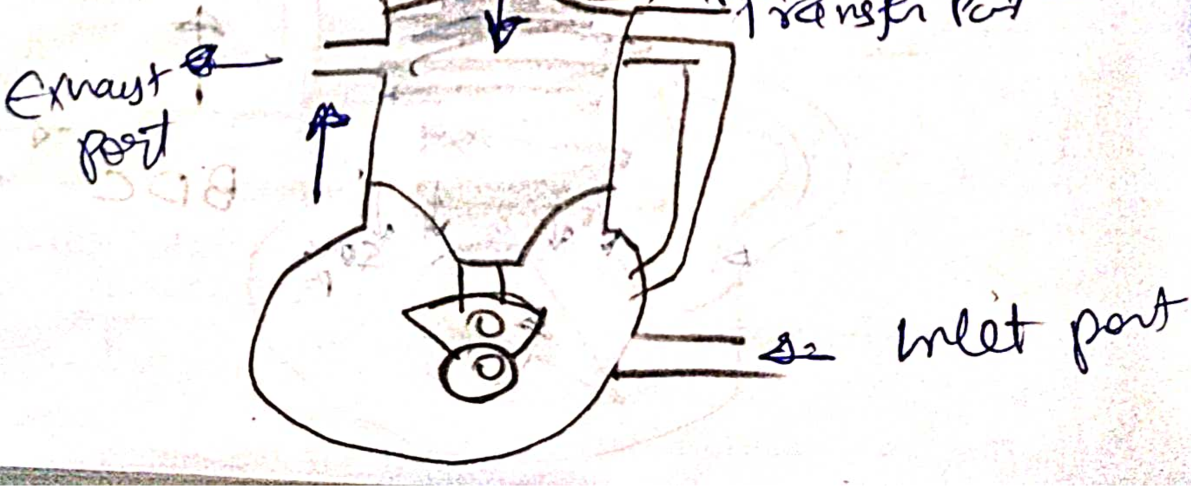
Compression - $\frac{1}{2}$



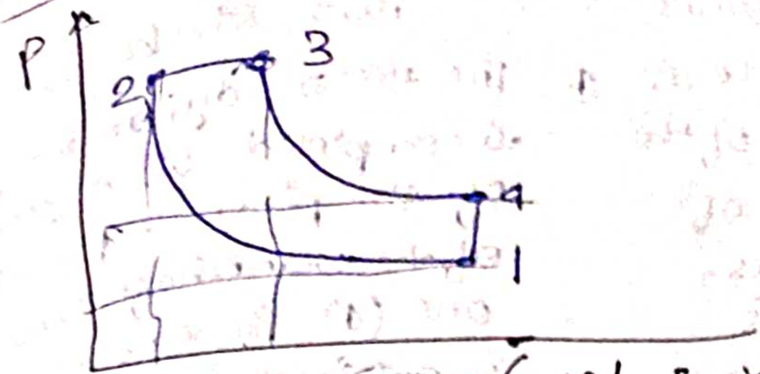

3
2
4
5
1
Piston travel in uncovering ports
V_c
V_s

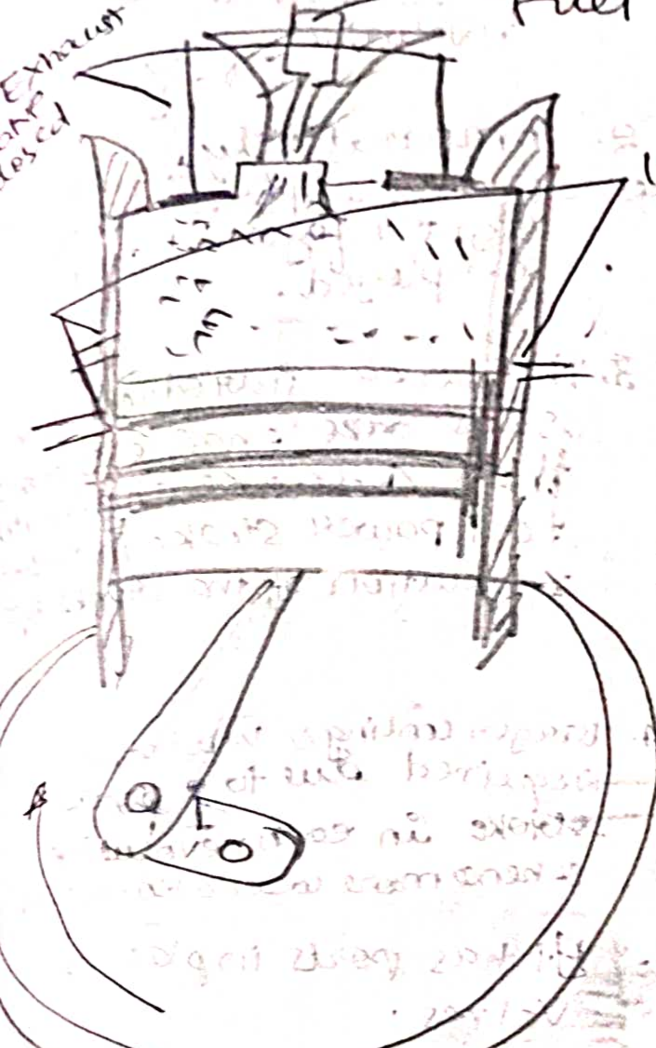

Spark plug
Exhaust port
Transfer Port
Inlet Port


Spark plug
Exhaust port
Inlet port

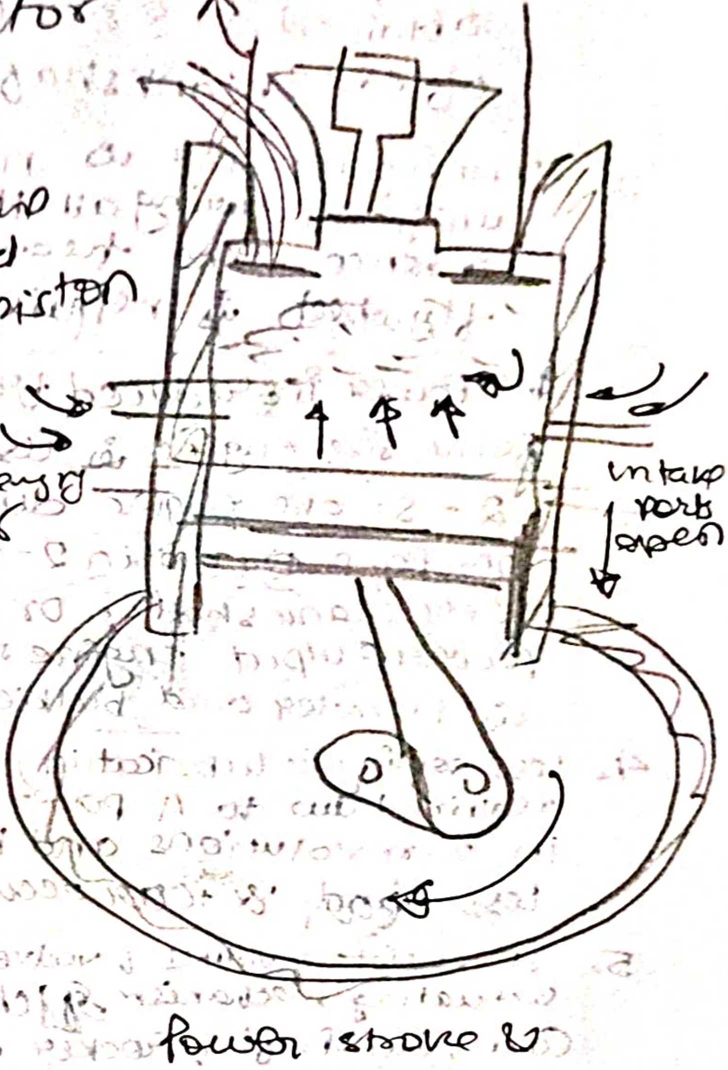

Transfer Port
Exhaust port
Inlet port

working of Two stroke C I Engine





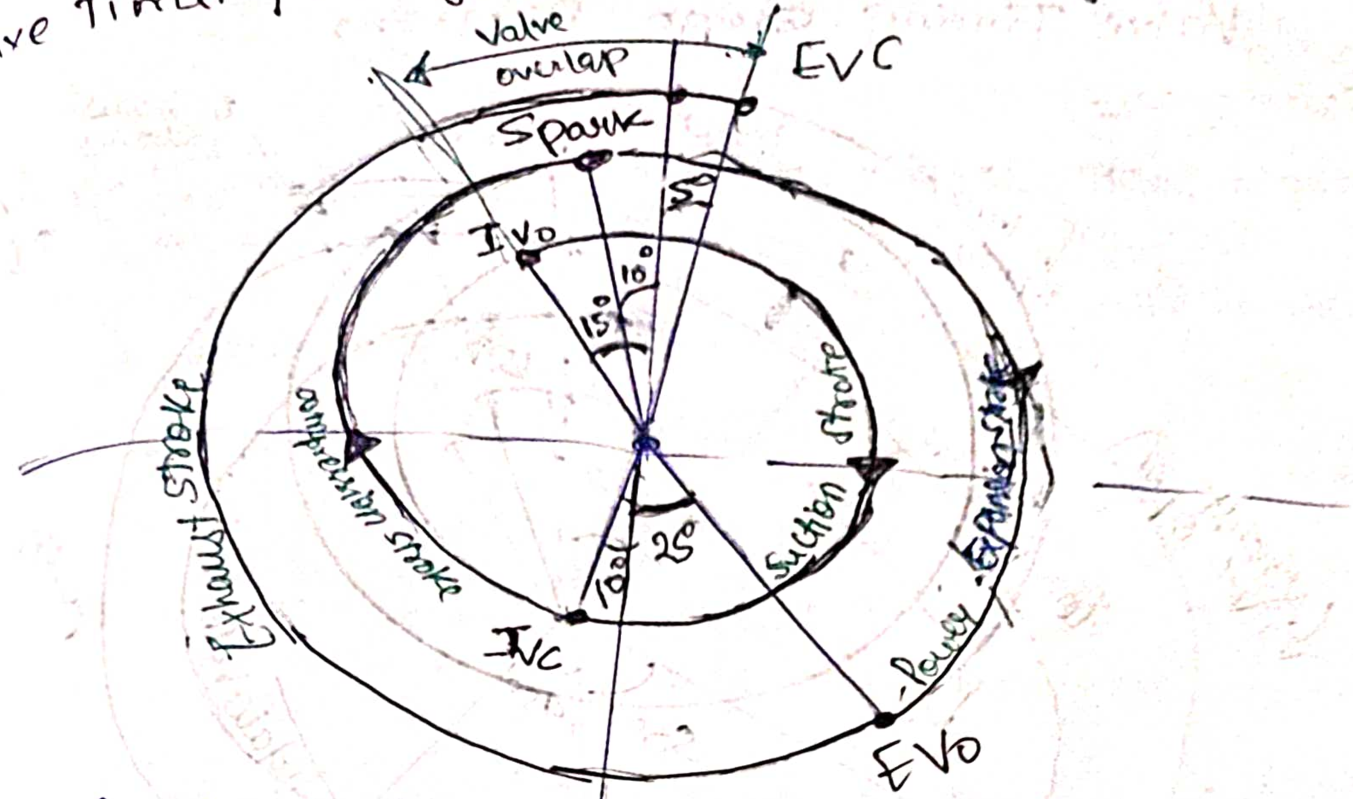
Compression & injection



Power stroke & Exhaust

Four Stroke Engines	Two Stroke Engines
1. The thermodynamic cycle is completed in 4 strokes of the piston & 2 revolutions of the crankshaft. thus, 1 power stroke is obtained in 2 revolutions of the crankshaft	1. The thermodynamics cycle is completed in 2 strokes of the piston & 1 revolution of the crankshaft. Thus one (1) Power stroke is obtained in one (1) revolution of the crankshaft
2. Turning moment is not so uniform during all the 4 strokes & hence, the heavier flywheel is required.	2. Comparatively turning moment is more uniform & hence lighter flywheel can be employed.
3. The Power introduced from same size engine is less than 2-stroke engine due to one power stroke in 2-revolutions of the crankshaft. or for same power output engine required is heavier and bulkier.	3. The power introduced from same size engine is more than 4-stroke engine due to 1 power stroke in each revolution of the crankshaft.
4. Less cooling & lubrication is required due to 1 power stroke in 2 revolutions and hence less wear & tear occurs	4. Larger cooling & lubrication is required due to 1 power stroke in each revolution & hence more wear & tear occurs
5. It consists of valves & valve actuating mechanism such as cam, camshaft, rocker arm, spring valve & valve seat	5. It has ports in place of valves.
6. It has higher volumetric efficiency as the time available for induction of charge is more.	6. Volumetric efficiency is lower due to lesser time available for induction.
7. It has a higher thermal efficiency due to complete combustion of the fuel.	7. It has a lower thermal efficiency due to the partial wastage of fuel through the exhaust port and incomplete combustion.

Valve Timing Diagram 4-stroke SI engine.



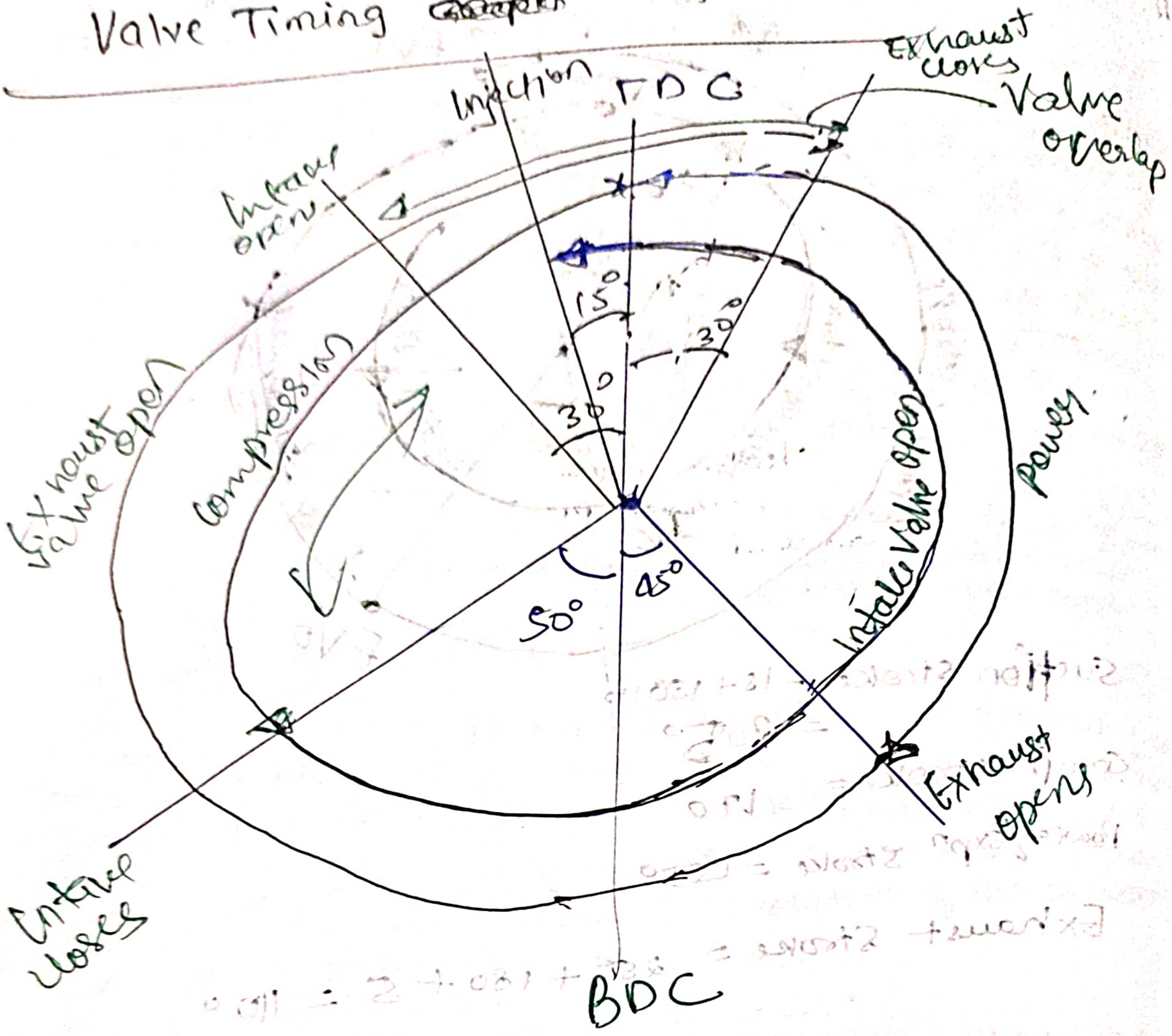
Suction stroke = 15 + 180 + 10
= 205°

Compⁿ stroke = 170°

Power/Expⁿ stroke = 155°

Exhaust Stroke = 25° + 180 + 5 = 110°

Valve Timing ~~graph~~ Diagram



Boilers [steam generators]

It may be defined as "A combination of apparatus for producing furnishing or recovering heat together with apparatus for transferring the heat so made available to water, which would be heated & vaporized to steam form". (ASME)

steam Generator / Boiler :

Definition :- A steam generator or boiler is usually a closed vessel made of steel. Its function is to transfer the heat produced by the combustion of fuel to water and ultimately to generate steam.

open vessels, generating steam at atmospheric pressure are not considered to be boiler.

The steam produced may be supplied to

- Power Generation
- Heating :
  - Space Heating
  - Hot water supply
- Industrial Processes
  - Sugar Mills
  - Chemical industries.

Classification of Boilers :-

① According to Heat Transfer

[Relative Position of hot gas & water]

A. Fire Tube Boiler :-

Hot gases pass through the tubes that are surrounded by water.

eg. Horizontal Return Tubular

Vertical Tubular

Lancashire, Cochran, Cornish,

Locomotive Fire box, scotch marine etc.

B. Water Tube Boiler :-

The tube contain water & the hot gases flow outside.

eg. Babcock & wilcox,

Stirling boiler

Lamont boiler

Benson Boiler

Loeffler Boiler.

② According to Location of combustion

(method of firing)

A. Internally Fired Boiler :-

eg. Lancashire, Locomotive, scotch.

B. Externally fired Boiler :-

eg. Babcock & wilcox.

(3) According to pressure of steam :-

(A) High Pressure (>80 kg/cm²)
eg. Babcock & wilcox, Lamont etc.

(B) Low Pressure (<80 kg/cm²)
eg. Cochran, Cornish & Lancashire, Locomotive.

(4) According to the axis of shaft :-

A. Horizontal (cochran)
B. vertical (Babcock & wilcox)
C. Inclined (Lancashire)

(5) According ~~to~~ method of circulation of water :-

A. Natural circulation [Lancashire, Babcock]
B. Forced circulation [velox, Lamont]

Nature of service to be performed

A. Land boilers (cochran, Lancashire)
B. Portable boilers
C. mobile boilers (Locomotive)

7. Heat Source :-

A. combustion of solid, liquid or gas
B. Electrical or nuclear energy
C. Hot waste gases of other chemical reactions.

8. According to number of tubes

A. Single tube (cornish Boiler)
B. Multi tube (BabCock & wilcox, cochran)

Difference b/w Fire tube & water tube Boiler

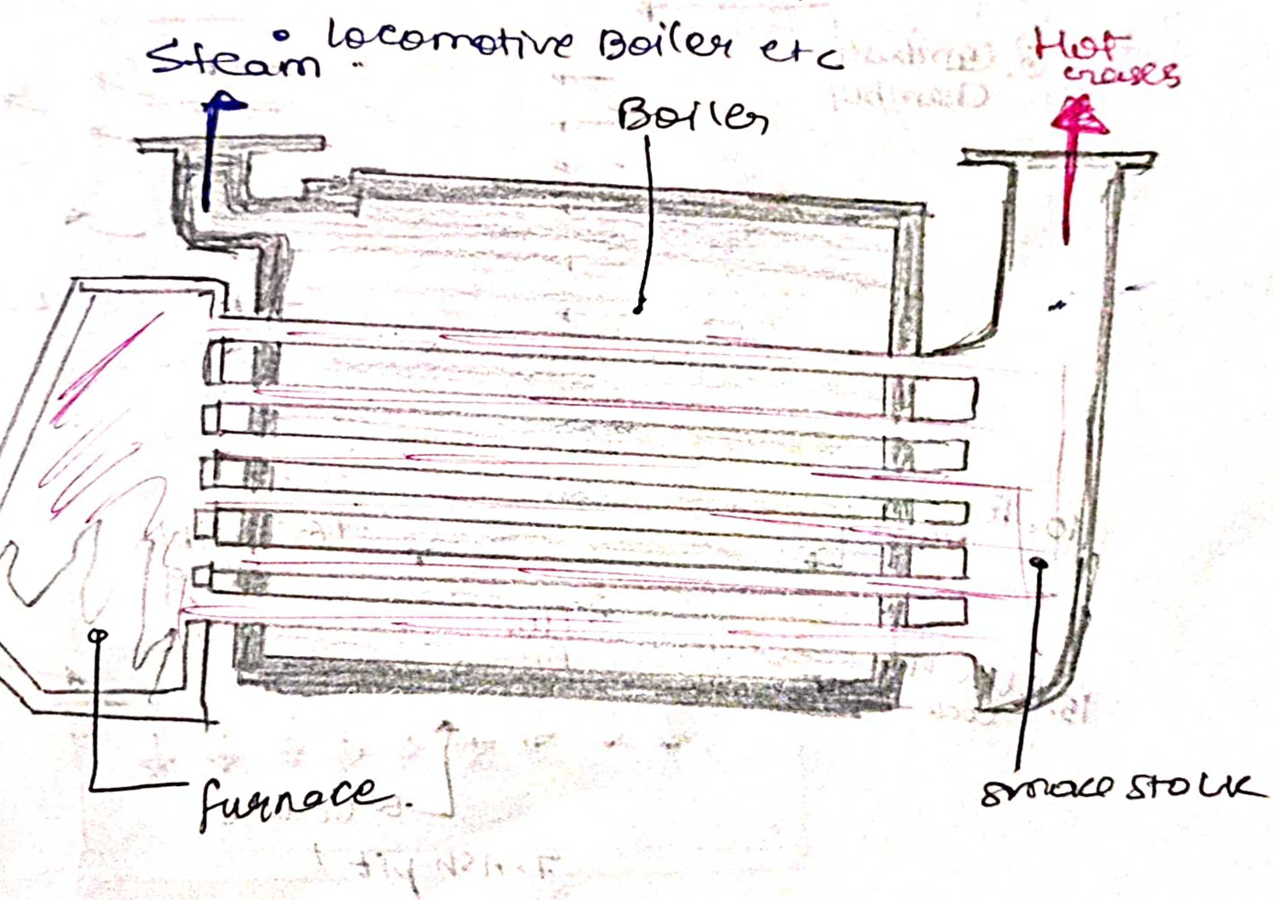
	Fire Tube Boiler		Water Tube Boiler
1.	Hot Gases from the furnace pass through the tubes which are surrounded by water in the shell.	1.	The water circulates inside the tubes which are surrounded by hot gases from the furnace.
2.	eg. Cochran Boiler, locomotive Boiler and Lancashire Boiler	2.	eg. Bobcock & wilcox boiler, Benson Boiler & stirling boiler etc.
3.	Used in Low pressure or medium pressure. Boiler having pressure below 80 bar.	3.	Used in high Pressure. Boiler having the pressure above 80 bar
4.	The rate of generation of steam is relatively low.	4.	The rate of generation of steam is high. (3000 kg/hr)
5.	Overall efficiency is upto 75%	5.	overall, efficiency is upto 90%
6.	It is not preferable for fluctuating loads for a longer time period	6.	It is preferred for widely fluctuating loads
7.	The operating cost is less	7.	The operating cost is high
8.	The bursting chances are less but bursting produces greater risk to the damage of the property.	8.	The bursting chances are higher but bursting doesn't produce any destruction to the whole boiler.
9.	It is generally used for supplying steam on a small scale and is not suitable for large power plants	9.	It is used for large power plants.
10.	Maintanance is difficult as furnace is inside the boiler.	10.	maintanance is easy as Furnace is outside the Boiler
11.	Water treatment is not necessary.	11.	water treatment is required.
12.	used in internally fired boiler	12.	used in externally fired boiler.

Fire Tube Boilers :-

A fire tube boiler is a type of boiler in which hot gases / flue gases (part of combustion) from a fire (heat source) pass through one or more tubes running through a sealed container of water. The heat energy from the gases passes through the sides of the tubes by thermal conduction, heating the water and ultimately creating steam. A fire-tube boiler is sometimes called a "smoke-tube boiler" or "shell boiler" or sometimes just "fire pipe".

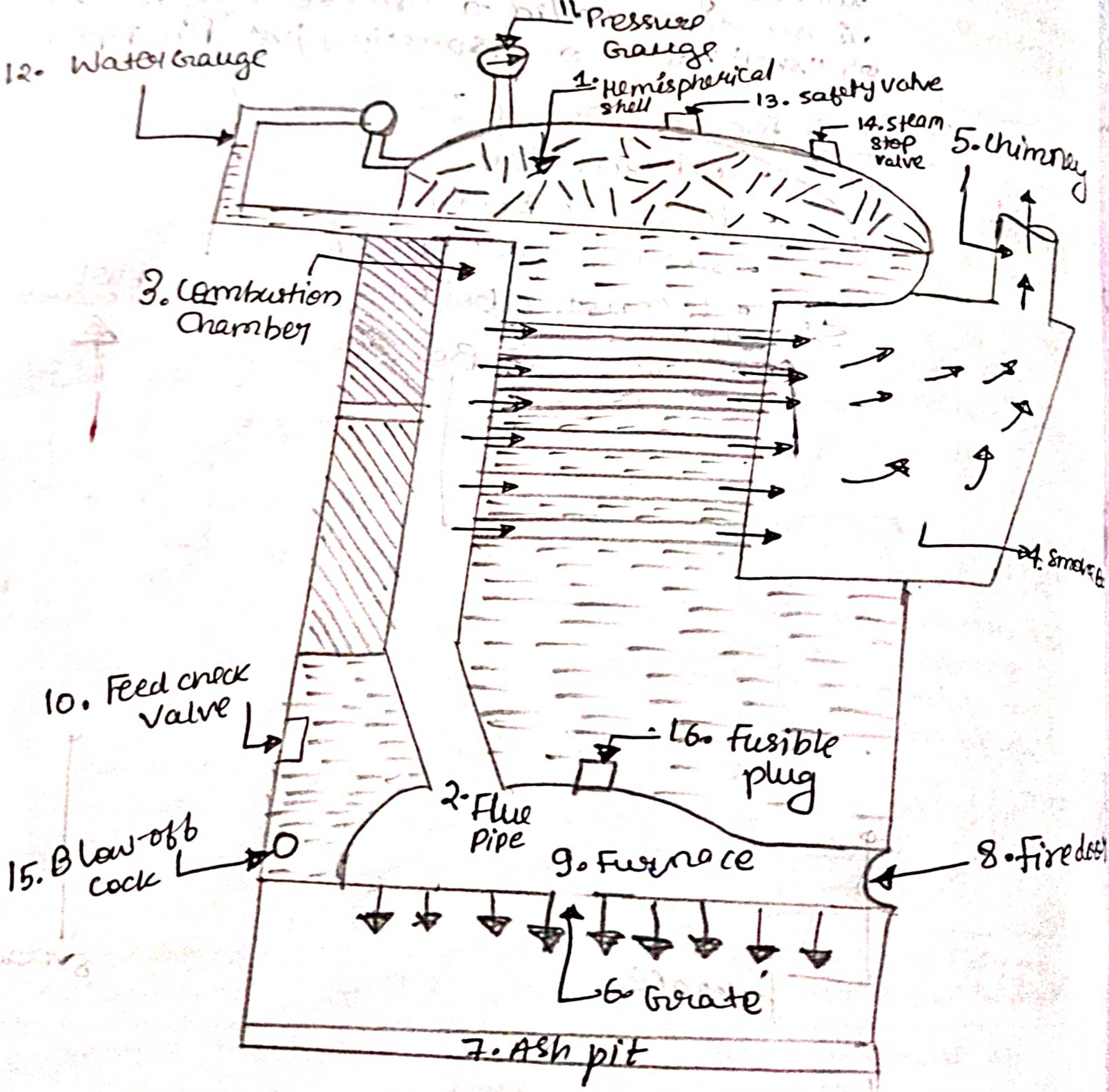
Types of fire Tube Boiler :-

- Cochran Boiler
- Lancashire Boiler
- Scotch Marine Boiler
- Locomotive Boiler etc



A. Cochran Boiler

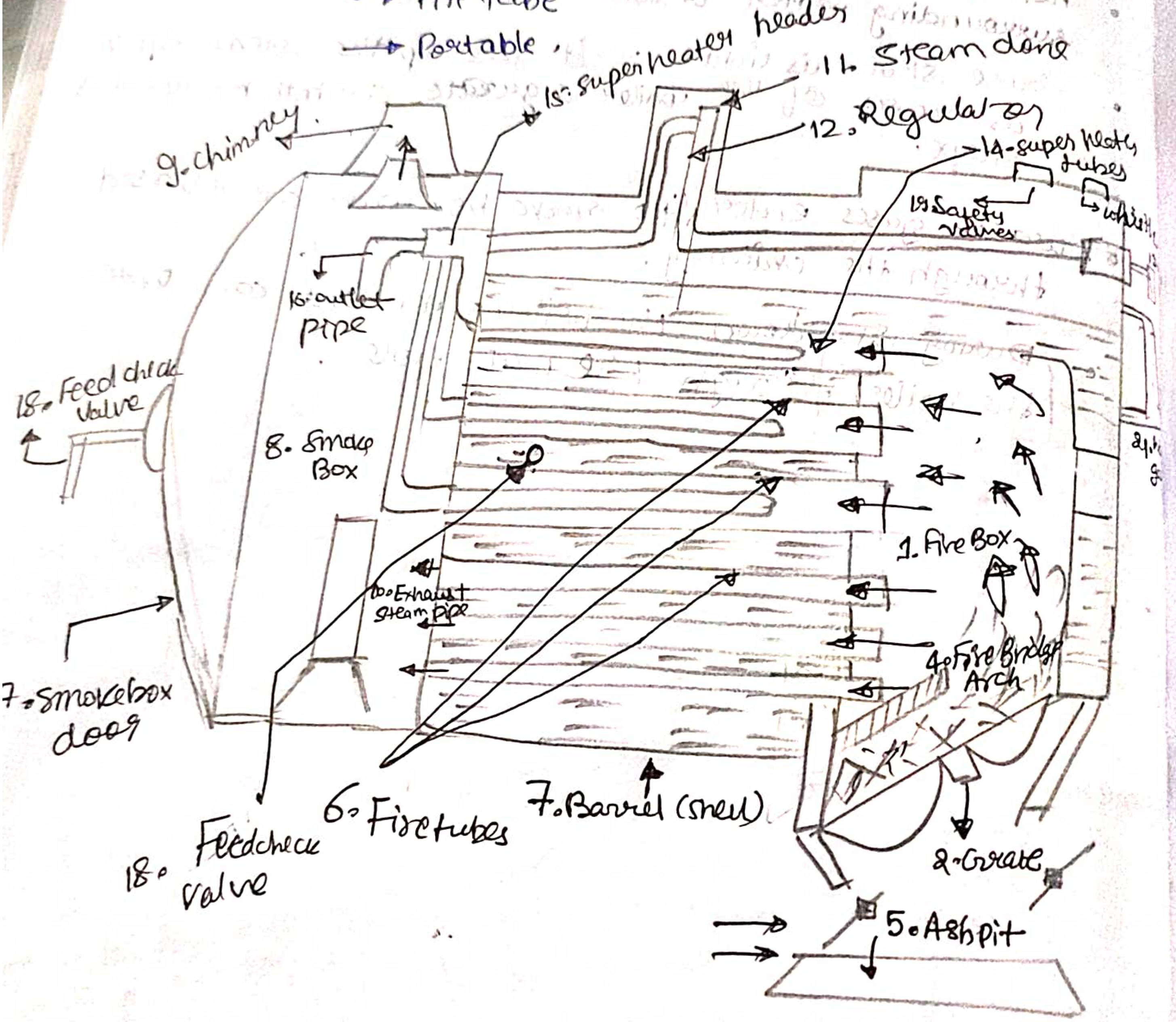
→ Vertical
→ Multitubular
→ internally fired
→ Natural circulation
→ Favourable in small plants
→ Coal or oil burnt.



- consists of an external cylindrical shell and a fire box.
- Fuel is fed into the grate through the fuel door & lighted.
- Fuel is burnt on the grate & hot gases go to the combustion chamber through a short flue tube.
- hot gases pass through fire tubes and heat the surrounding water & convert it into steam.
- Since steam is lighter; it goes up the steam space as crown of the boiler & grate are both hemispherical shape.
- waste gases enter the smoke box and are released through the chimney.
- During shut down the boiler attendant can enter the boiler through the man hole.

B. Locomotive Boiler

- → Horizontal
- → Multitubular
- → Natural circulation
- → internally fired
- → Fire tube
- → Portable.



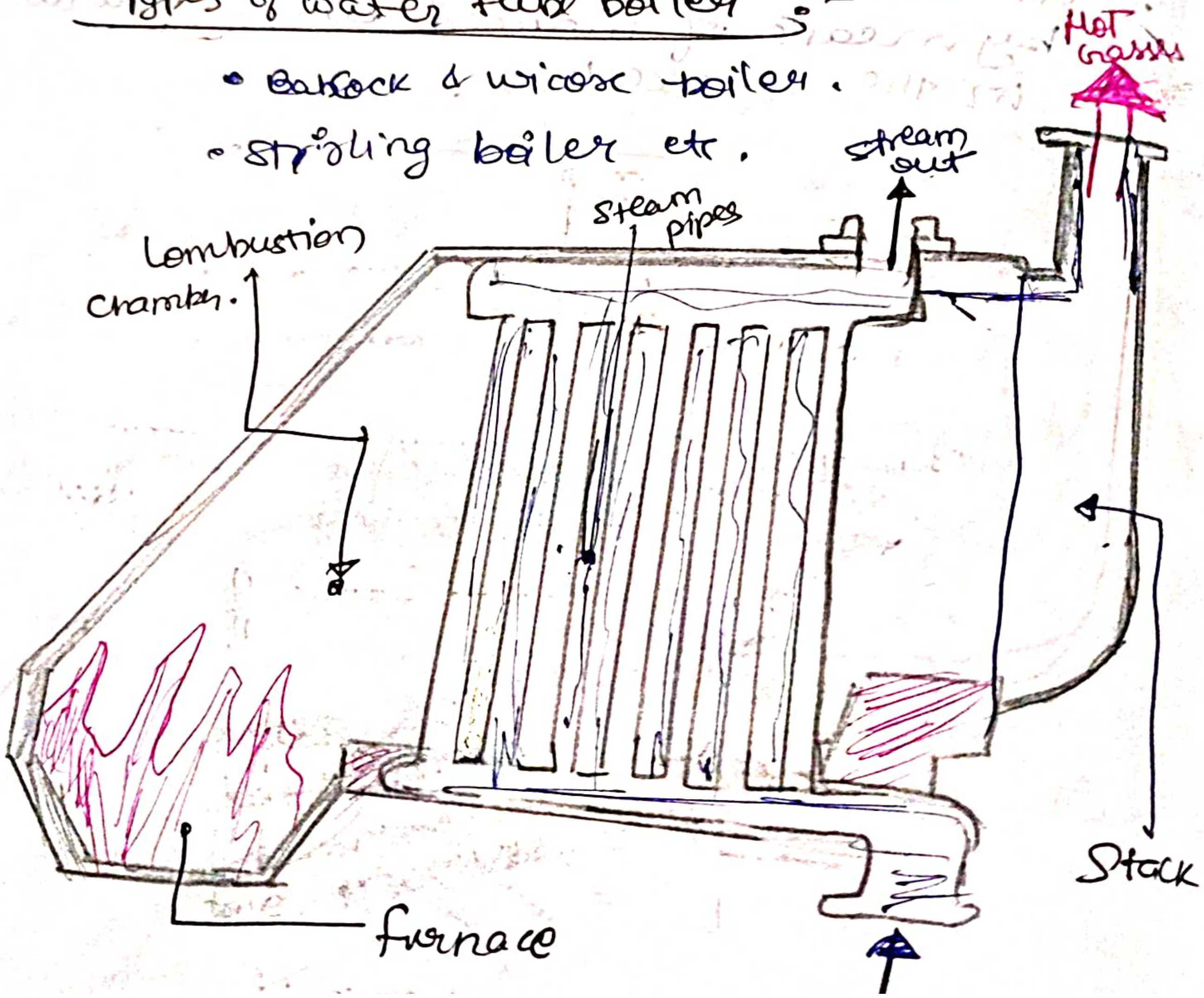
- mostly used for railways
- Designed to capable of meeting sudden & fluctuation demands of steam.
- Fuel is feed into The firebox through Fuel door.
- Air enters through damper & the slots in the grate plate
- The hot gasses pass through large fire tubes & enter the smoke box.
- Circulation of air & hot gases is improved by means of induced draft produced in the smoke box.

Water tube Boiler

A water tube boiler is a type of boiler in which water circulates in tubes heated externally by the hot gases/flue gases. Water tube boilers are used for high pressure boilers. Fuel is burned inside the furnace, creating hot gas which heats up water in the steam generating tubes.

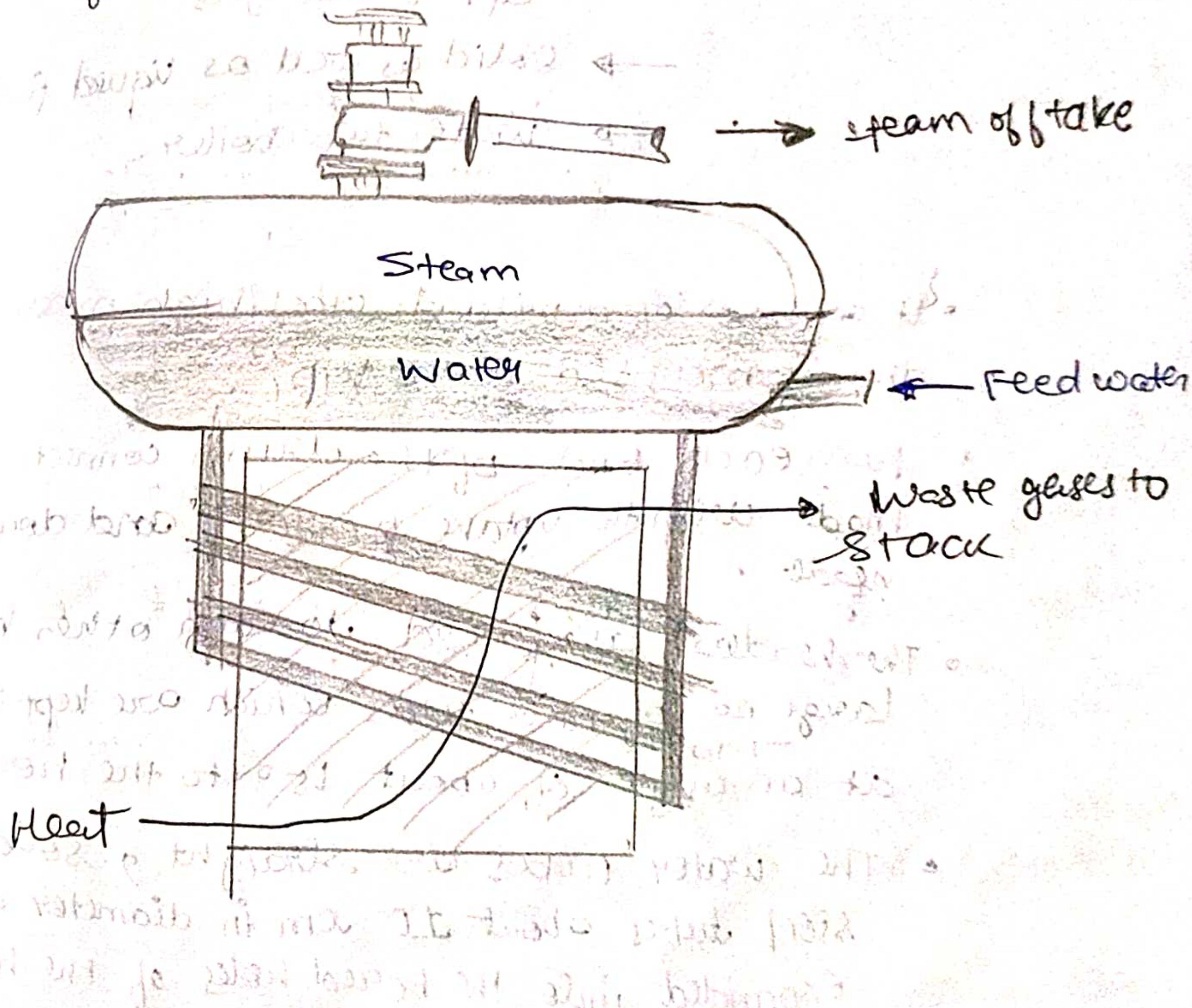
Types of water tube boiler :-

- Babcock & wilcox boiler.
- Stirling boiler etc.



The drums are used for storage of water & steam. As they are not required to contain tubular heating surface, they can be much smaller in diameter than the fire tube shell and can, therefore, be built to resist high pressure.

Generation of steam is quicker as water is subdivided into small volume. The initial cost, operational cost and maintenance costs of water tube boiler is higher than that of an equivalent fire tube boiler.

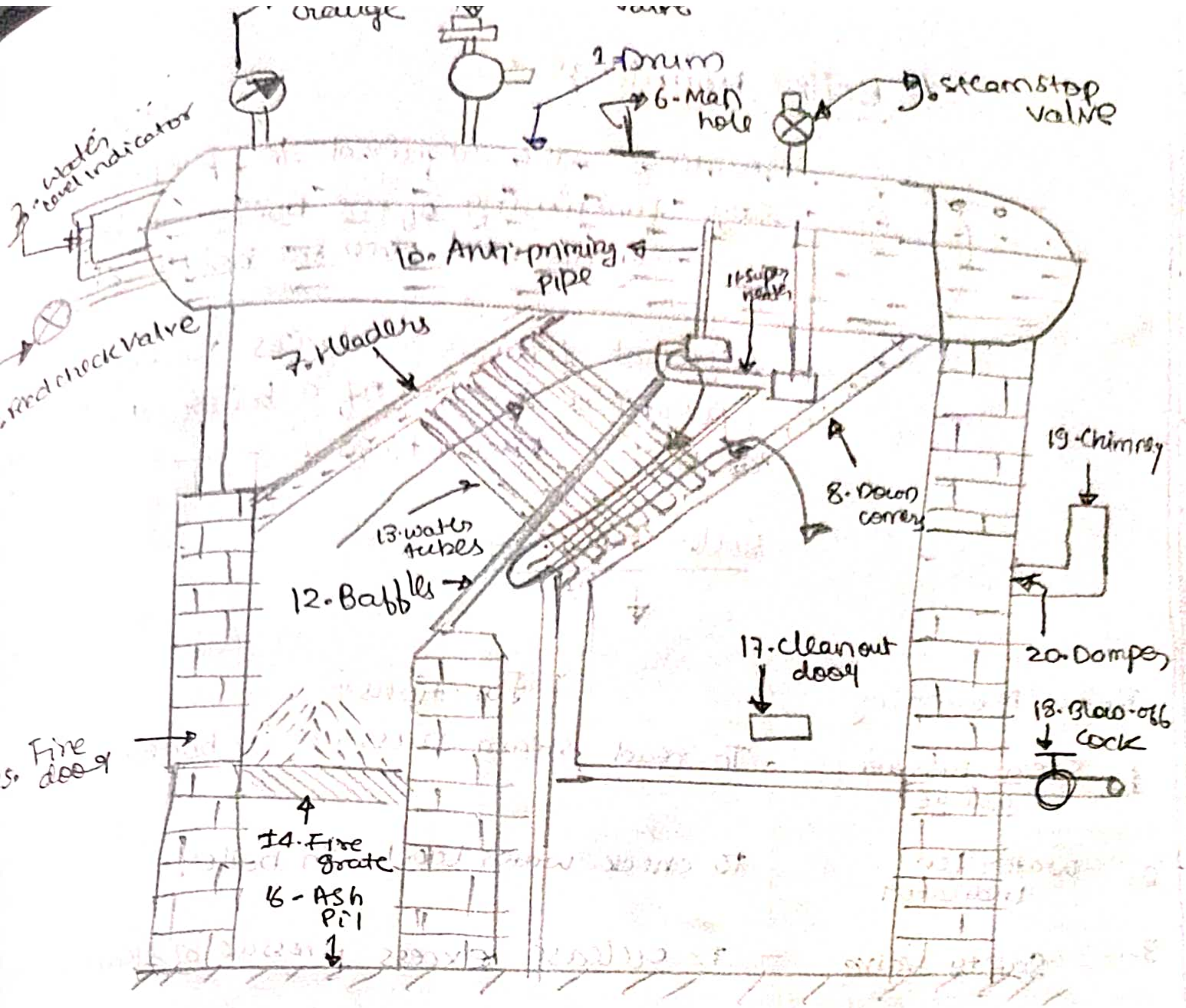


A. Babcock & Wilcox Boiler

Features

- It is a
  - → Multi-tubular
  - → Externally fired
  - → Horizontal
  - → High Pressure
  - → Stationary
  - → Natural circulation of water & steam
  - → Forced circulation of air & hot gas
  - → Solid as well as liquid fuel fired
  - → water tube boiler.

- It consists of a welded steel high pressure drum mounted at the top.
- From each end of the drum connections are made with the uptake header and down take header.
- The headers are joined to each other by a large no. of water tubes which are kept inclined at an angle of about 15° to the horizontal.
- The water tubes are straight, solid drawn steel tubes about 10 cm in diameter and are expanded into the bored holes of the header.



- The heating surface of the unit, forms the outer surface of the tubes & half of cylindrical surface of the water drum which is exposed to flue gases.
- The furnace is arranged below the uptake header
- The coal is fed to the chain gate stoker through the fire door.
- Baffles are provided across the water tubes to act as deflectors to the flue gases and to provide them with gas passes.
- The circulation of water is maintained by convective currents.

Boiler Mountings :-

Mountings are required for proper and safe functioning of the boiler which are generally mounted over the boiler shell.

→ Different fittings & devices necessary for operations & safety of a boiler are known as boiler mountings.

Boiler mounting

↓

Boiler Mounting	Functions
Steam Pressure Gauge	- To read steam pressure in boiler
Water Level Indicator	- To check water level in boiler
Safety Valve	- To release excess pressure of steam in boiler
Feed check valve.	- To feed the water in boiler.
Blow off cock	- To remove scale & impurities from boiler.
Fusible plug	- To stop firing when water level is lower than safe limit.
Steam stop valve	- To stop or allow flow of steam from boiler
Man hole	- For periodic inspection.
Anti Priming pipe.	To separate moisture.

Boiler Accessories :-

- Auxiliary parts which are required for smooth operation of a boiler and to increase efficiency of the boiler.
- Accessories are not compulsory but optional.
- If defective accessories are used then they will reduce only thermal efficiency of a boiler.

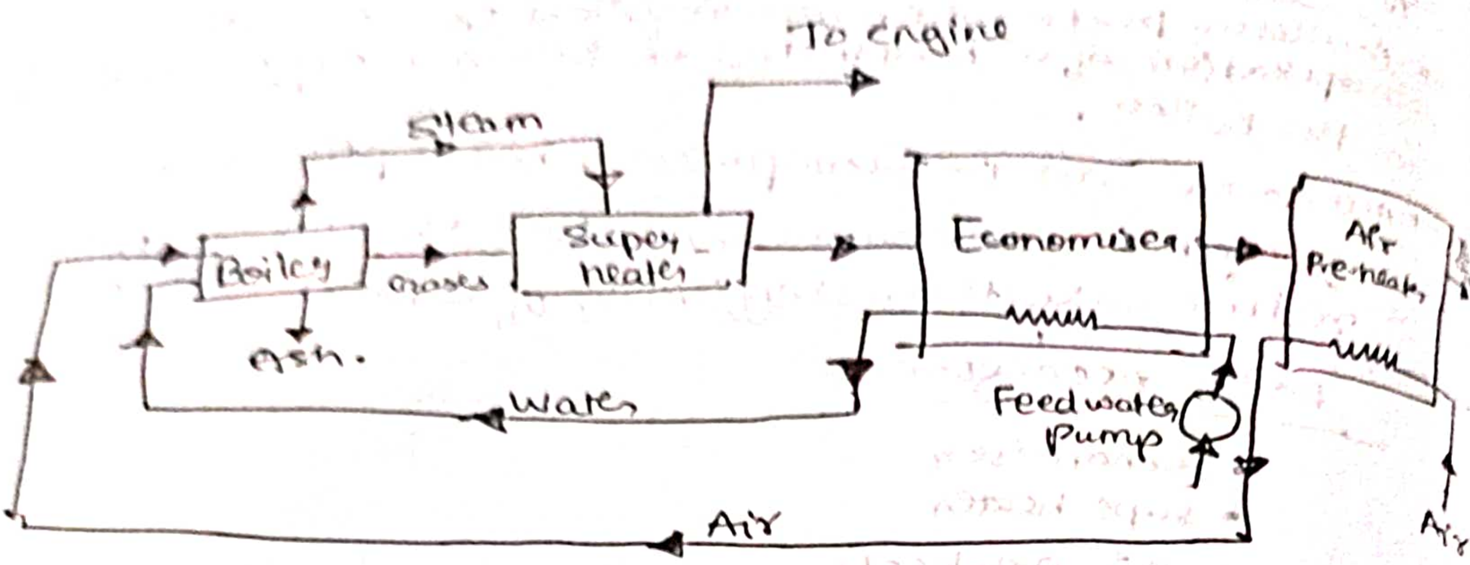
Boiler Accessories

- Economiser
- super heater
- Air pre-heater

1. Economiser → located in path of exhaust gases before air pre-heater & chimney.
    - used to recover some heat being carrying by exhaust flue gases
    - Heat recovered is utilized in raising the temperature of the feed water.
    - Feed water at raised temperature is supplied to the boiler, thus less heat is required for conversion into steam.
    - Prevents thermal shock.

2. superheater → located in boiler shell in the path of flue gas
    - To increase the temperature of steam above saturation temperature.

3. Air preheater :
    - To increase temperature of air before it enters into furnace by using waste heat from exhaust gases
    - boiler efficiency increases about 2% for each 30-35°C rise in air temp.



Essentials of a good boiler

- Capable of generating steam at reqd. pressure & reqd quality quickly and with minimum fuel consumption
- Light in weight
- Occuppy small floor area.
- Initial cost, installation cost & Maintenance cost of the boiler should not be too high.
- Should meet fluctuating demand
- No deposition of mud & foreign particles on heated surfaces.

Boiler performance

Amt of water evaporated is considered as a performance as boiler.

$$Q_r = m_a (h_2 - h_1)$$

$$X = \frac{m_s}{m_s + m_w}$$

Boiler efficiency

$$\eta = \frac{\text{Energy utilized}}{\text{Energy supplied}}$$

$$\eta = \frac{m_s (h - h_0)}{m_f \times HV}$$

Selection of Boiler :-

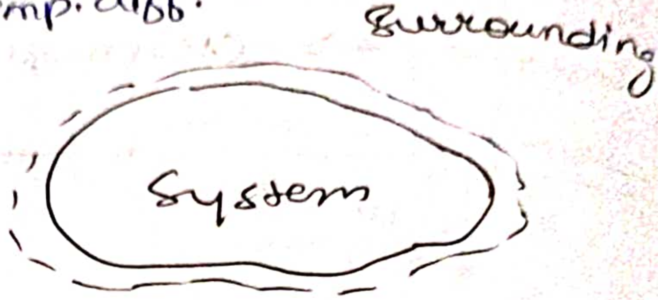
→ Power Required & working Pressure
→ Geographical position of Power house
→ Quality of fuel & water available
→ Steam generation rate.

—o—

Heat Transfer

→ Energy transfer b/w system & surrounding b'coz of temperature difference.

→ Driving Potential ⇒ temp. diff.



Apart from heat transfer any kind of energy interaction is called work transfer

System & Surrounding are interacted by
a) Heat transfer
b) Work transfer
c) Energy transfer by mass.

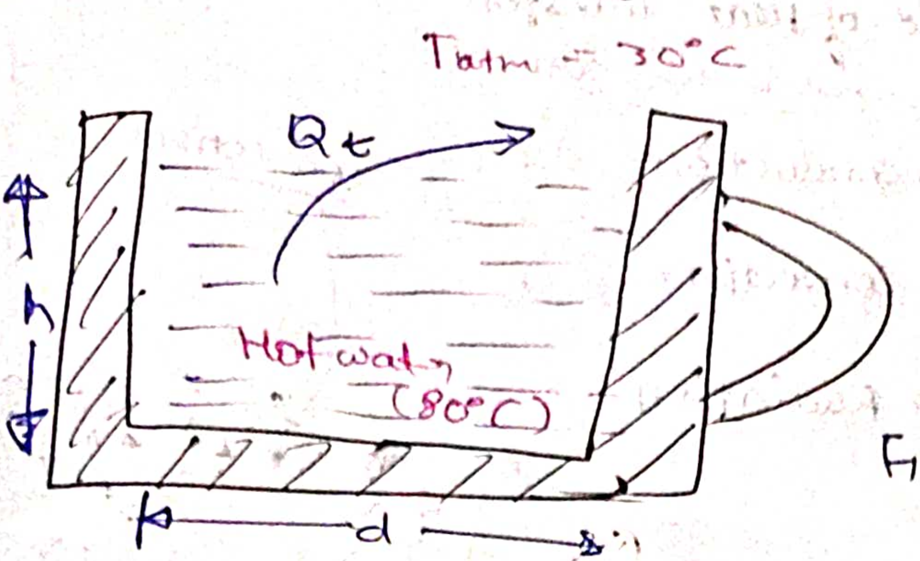
Heat transfer is governed by 2nd Law of Thermodynamics

1st Law of TH ⇒ conservation of energy

2nd Law of TH ⇒ Directional Law

Nature ⇒ High energy → Low Energy

Heat Transfer vs Thermodynamics



$T_i = 80°C$

$T_f = ?$

$T_f = 30°C$

Final temp water

Total Heat transfer = Q_t = change in internal energy of water

$Q_t = m \times c \times \Delta t$

$= \rho \times vol \times c \times \Delta t$ → (80 - 30)

$\rho = \frac{m}{V}$

$m = \rho \times vol$

$\rho = 1000 kg/m^3$

d, h ✓

$c = 4.18$ KJ/kg K

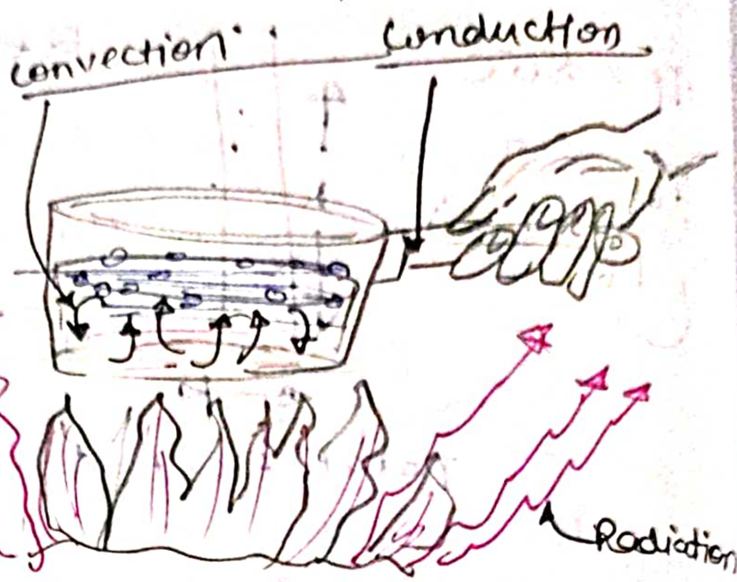
In Heat Transfer

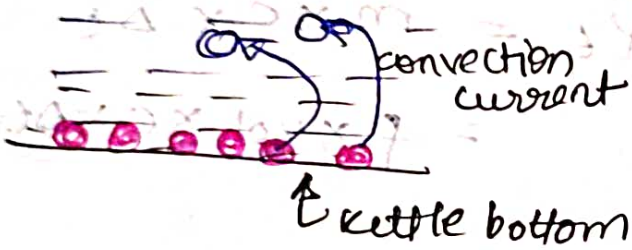
↳ Rate of Heat Transfer

$T = T(\text{space, time})$

Mode of Heat Transfer

- Conduction
- Convection
- Radiation





$T\uparrow \; \rho\downarrow \Rightarrow$ Light

$T\downarrow \; \rho\uparrow \Rightarrow$ Heavy

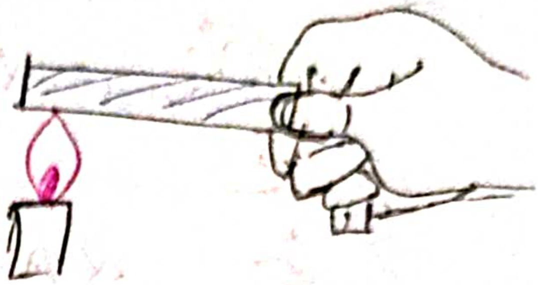
Conduction

It is a mode of heat transfer from a region of high temperature to a region of low temperature within the medium or different medium which are in direct physical contact.

Conduction occurs due to

i) presence of free $\bar{e}$ on outer orbit of an atom.

ii) Lattice Vibration

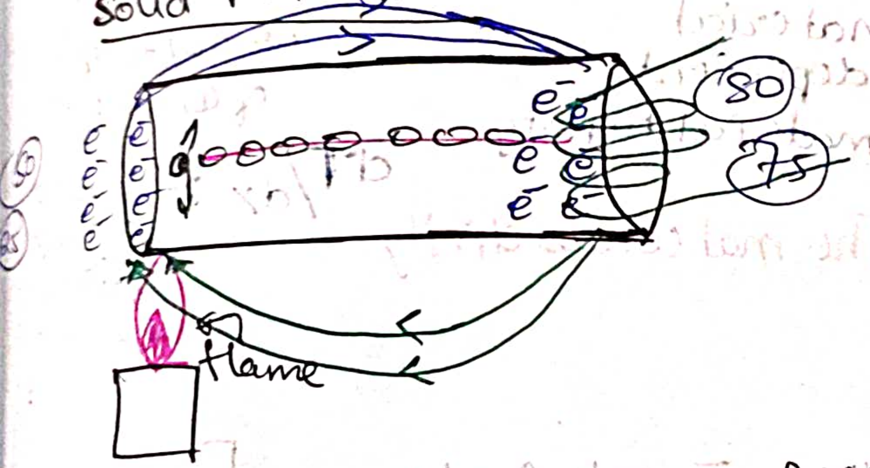


Microscopic mode of heat transfer

conduction heat transfer takes place in all 3 phases (i.e. solid, liquid & gases)

most predominant in solids and least predominant in gases.

Solid Metal Rod



Solid

① Presence of free $\bar{e}$

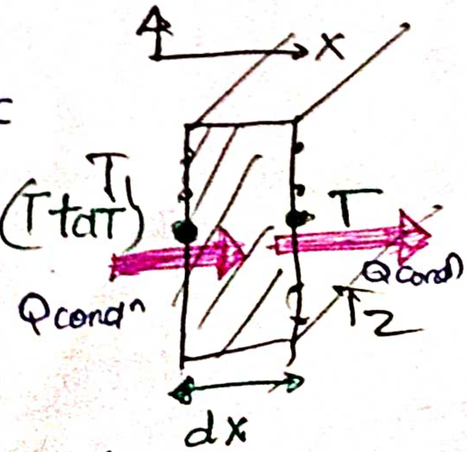
② Lattice Vibration

Governing law for conduction Heat Transfer

Fourier Law of Heat Conduction

Assumptions

- Material is homogeneous & isotropic
- Heat flow is unidirectional (1D)
- No internal heat energy generation.
- Boundary surfaces are isothermal.
- Steady state.



dT, dx

Fourier observation

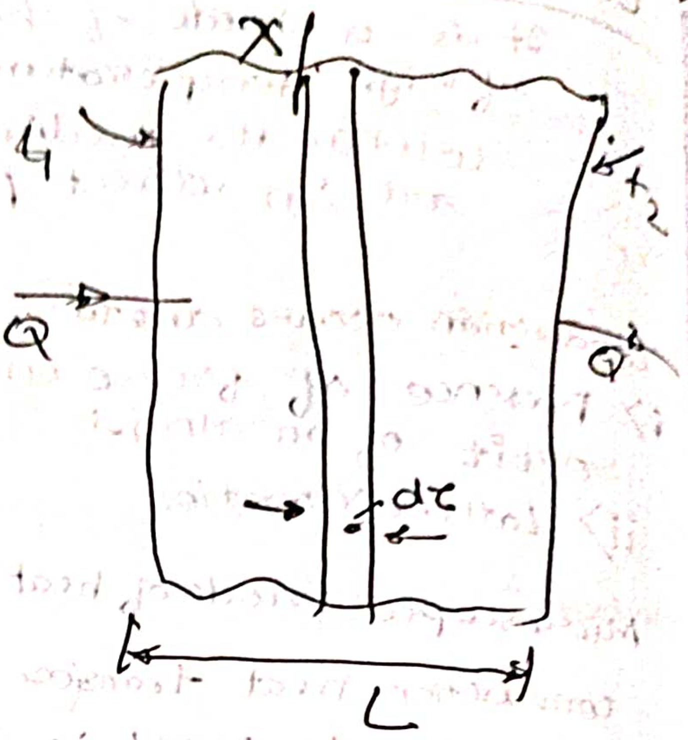
① $\dot{Q}_{cond^n} \propto dT$

② $\dot{Q}_{cond^n} \propto A$

③ $\dot{Q}_{cond^n} \propto \frac{1}{dx}$

$$\dot{Q}_{cond^n} \propto A \frac{dT}{dx}$$

$$\boxed{\dot{Q}_{cond^n} = KA \frac{dT}{dx}}$$



Q_{cond^n} = Rate of cond^n HT

A = Area which is normal to dir^n of cond^n H.T.

dT/dx :- Gradient of temp. in dir^n of cond^n HT

K ⇒ constant
⇒ Material dependent
⇒ material Property
→ Thermal conductivity

$$\dot{Q}_{conduction} = -KA \frac{dT}{dx}$$

$$\boxed{Q_{cond^n} = -KA \frac{dT}{dx}}$$

(−) ⇒ In the dir^n of cond^n H.T T↓

$\frac{dT}{dx} = -ve$

$x \to T\downarrow$

Heat flux $[\dot{q}]$

$$\frac{\dot{Q}_{cond^n}}{A} = -k\frac{dT}{dx}$$

$$q_{cond^n} = -k\frac{dT}{dx}$$

K unit

$$k = \frac{\dot{Q}_{cond^n}}{A\frac{dT}{dx}} = \frac{W}{m^2 \frac{°C}{m}}$$

$$k \Rightarrow \frac{W}{m°C} \text{ or } \frac{W}{mK}$$

$$k \Rightarrow \frac{N\text{-}m}{s\,m\,K} = \frac{MLT^{-2}}{T.\theta}$$

$$k = MLT^{-3}\theta^{-1}$$

Q. The inner surface of plain brick wall is at 60°C & outer surface is at 20°C. Calculate rate of heat transfer per m^2 of surface area of wall which is 260 mm thick. The thermal conductivity of the brick is 0.55 W/mK.

sol^n:- $t_1 = 60°C$ $t_2 = 20°C$ $x = 260\,mm$ $K = 0.55\,W/mK$

$$q = \frac{Q}{A} = -k\frac{dT}{dx} = \frac{-0.55\,W/mK}{0.260}(60°C - 20°C)$$

$$= 84.6\,W/m^2$$

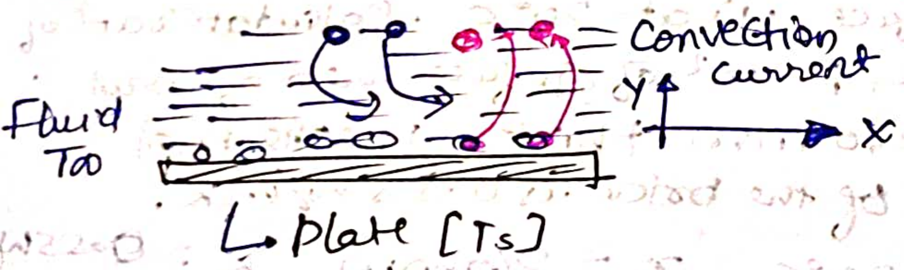
Convection

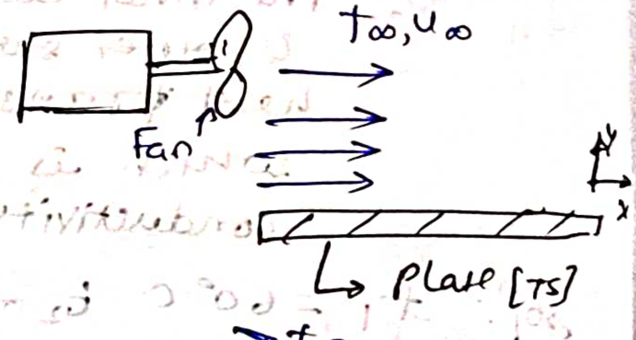
convection H.T.

- Natural or Free convection
- Forced convection

Convection is the term used for heat transfer mechanism which takes place in a fluid b'coz of a combination of condⁿ due to the molecular interactions and energy transport and, the macroscopic ~~m~~motion of the fluid itself.

Convection is governed by Newton's law of Cooling.





$T_s > T_\infty$

at $y=0$ T_∞ / T_s

↳ conduction H.T

$T \uparrow$ $\rho \downarrow$ light

$T \downarrow$ $\rho \uparrow$ heavy

$T_s > T_\infty$

at $y=0$ $U = U_s$

⇒ No relative vel. exist b/w fluid & plate

$y=0, u=0$ [No slip condⁿ]

↳ mode of Heat Transfer = Conduction

$$\dot{Q}_{convection} = h A [T_s - T_\infty]$$

(Watt)

h = Avg convective heat Transfer coefficient
or
heat transfer coeff.

t_s : surface temp
t_∞ : fluid temp.
} °C

$$\frac{\dot{Q}_{convection}}{A} = h [T_s - T_\infty]$$

Heat flux [$\dot{q}_{convection}$] $\Rightarrow \frac{W}{m^2}$

$$\boxed{\dot{q}_{convection} = h [T_s - T_\infty]}$$

Unit of h

$$h = \frac{\dot{Q}_{convection}}{A [T_s - T_\infty]}$$

$$h = \left[\frac{W}{m^2 K} \text{ or } \frac{W}{m^2 °C}\right]$$

$$h - \left[\frac{M \cancel{L} T^{-2}}{T \cancel{L} \theta}\right]$$

$$h \Rightarrow M T^{-3} \theta^{-1}$$

h depends on

1. free/forced convection
2. laminar/Tubulent
3. liquid/Gas
4. smooth Rough
5. orientation

— | /

Radiation Heat Transfer

Any body having temp. above 0K temp continuously emits radiation energy

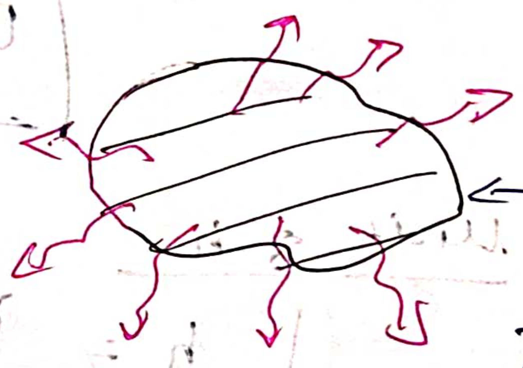
Maxwell's EM wave theory

Planck's Photon theory

Radiation H.T is governed by Stefan's - Boltzmann law

Stefan's Boltzmann Law states that,
Total radiation energy emitted by a black body per unit time per unit area is directly proportional to 4th power of absolute temp.

$E_b \Rightarrow$ Emissive Power $\left[\frac{J}{s m^2} = \frac{W}{m^2}\right]$



Black body
[T]

$T > 0K$

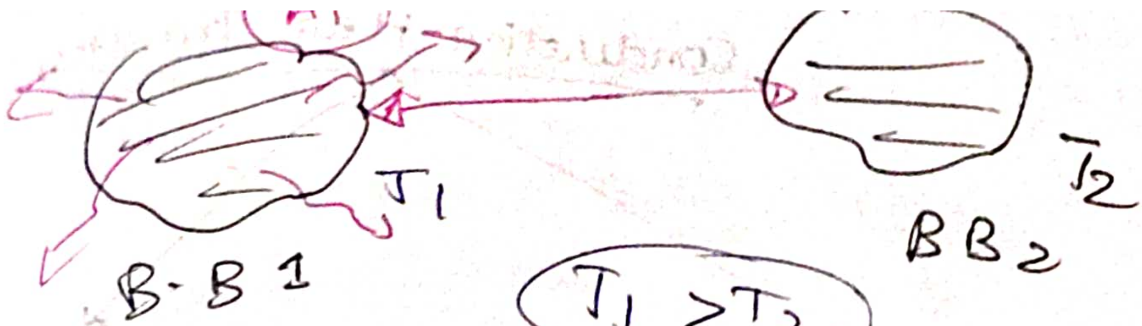
$E_b \propto T^4$

$$\boxed{E_b = \sigma_b T^4}$$

$\frac{W}{m^2}$ $\frac{W}{m^2 K^4}$ K^4

σ_b : Stefann's Boltzmann's constant.

$\sigma_b = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$



$T_1 > T_2$

Net radiation heat exchange b/w two Black bodies,

$$\boxed{Q_{net} = A_1 F_{12} \sigma_b \left[T_1^4 - T_2^4\right]}$$

F_{12} : Shape factor/view factor

$$\boxed{F_{12} = \frac{Q_{12}}{Q_1}}$$

Conduction Heat Transfer

Steady state cond^n H·T

$\Downarrow$

$T = f(\text{space})$

Unsteady State cond^n HT

$T = T(\text{space}, \text{time})$

or

$T = T(\text{time})$

---

a) General Heat Cond^n Eq^n in Cartesian coordinate
[Plane wall, slab]

b) General Heat Cond^n Eq^n in Cylindrical coordinate
[Solid cylinder, Hollow cylinder, pipe]

c) General Heat cond^n Eq^n in Spherical Coordinate
[solid Sphere, Hollow sp, etc

General Heat Cond

Cond^n H.T is governed by Fourier law of Heat Cond^n.

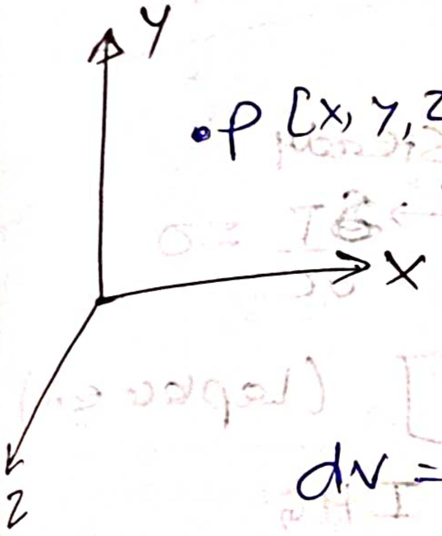
we need general heat cond^n Eq^n in diff. coordinate system.

Conduction

Objective

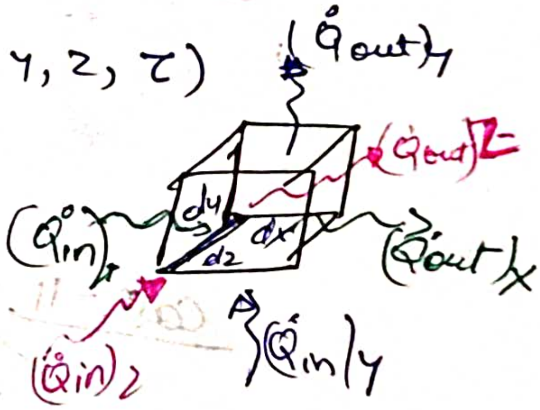
1. Temp variation
2. Rate of cond^n HT

General Heat cond^n. Eq^n in Cartesion coordinate system



T (space, time)

$T(x, y, z, \tau)$



$dV = dx \cdot dy \cdot dz$

Conservation of energy:

$$[\dot{E}_{in} - \dot{E}_{out}]_x + [\dot{E}_{in} - \dot{E}_{out}]_y + [\dot{E}_{in} - \dot{E}_{out}]_z + \dot{E}_g = \dot{E}_s$$

$$\boxed{\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}_g}{K} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}}$$

(Fourier-Biot Eq^n)

q_g : ratio of volumetric heat generation

α = Thermal Diffusivity.

Heat generation is volumetric phenomena.

$\rightarrow \dot{Q}_g = V_2 \times \dot{q}_g$

$V_2 > V_1$

V_1

$\dot{Q}_g = V_1 \times \dot{q}_g$

$\dot{q}_g$ = Rate of volumetric heat generation

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

$$\boxed{\nabla^2 T + \frac{\dot{q}_g}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}}$$

Case-I No I. H. G. + Steady

$\boxed{\dot{q}_g = 0}$ $\quad \hookrightarrow \frac{\partial T}{\partial \tau} = 0$

$\boxed{\nabla^2 T = 0}$ (Laplace eqn)

Case-II Steady + with IHG

$\frac{\partial T}{\partial \tau} = 0$ $\quad \dot{q}_g \neq 0$

$\boxed{\nabla^2 T + \frac{\dot{q}_g}{k} = 0}$ [Poisson eqn]

Case-3 unsteady + without IHG, $\dot{q}_g = 0$

$\frac{\partial T}{\partial \tau} \neq 0$

$$\boxed{\nabla^2 T = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}}$$ Diffusion eqn

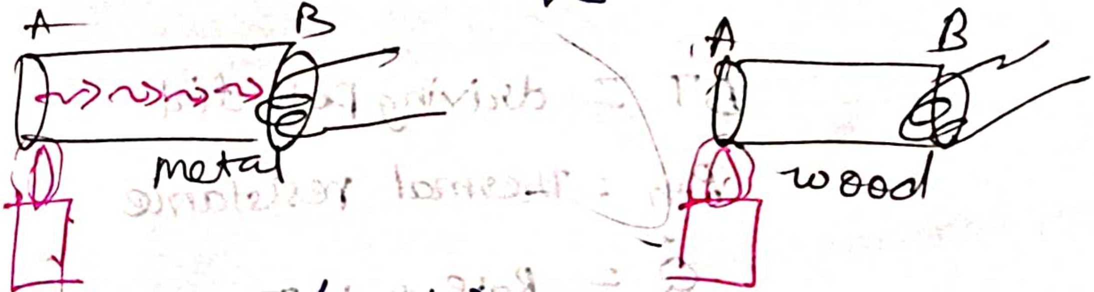
Case-4 1-D [x] + with IHG + steady

$$\boxed{\frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}_g}{k} = 0}$$

$$\Rightarrow \frac{d^2 T}{dx^2} + \frac{\dot{q}_g}{k} = 0$$

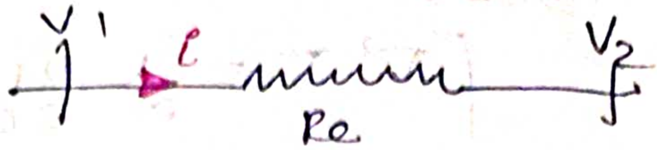
Thermal diffusivity α = $\dfrac{\text{Ratio of Heat energy conducted}}{\text{Ratio of Heat energy stored.}}$

$$\alpha = \frac{Q_c}{Q_s} = \frac{k}{\rho C}$$



$\alpha_{metal} > \alpha_{wood}$

Electrical resistance



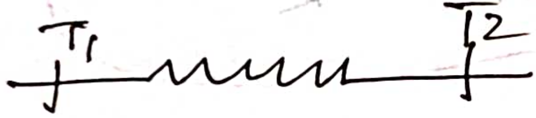
Ohm's law

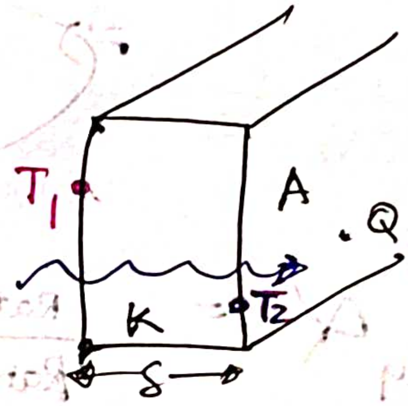
$$\Delta V = i R_e$$

Thermal resistance :

→ Thermal resistance is analogous to electrical resistance.
→ resistance against the heat transfer

Thermal ckt





$$\Delta V \rightarrow \Delta T$$
$$i \rightarrow \dot{Q}$$
$$R_e \rightarrow R_{th}$$

ΔT = driving potential

R_{th} = Thermal resistance

$\dot{Q}$ = Rate of H.T

$$\Delta T = \dot{Q} R_{th}$$

Thermal resistance $\quad R_{Th} = \dfrac{\Delta T}{\dot{Q}} \left[\dfrac{K}{W} \text{ or } \dfrac{°C}{W}\right]$

a) Cond

$$R_{th} = \frac{\Delta T}{\dot{Q}_{condn}}$$

$$R_{th} = \frac{\cancel{\Delta T}}{KA\frac{\cancel{\Delta T}}{\delta}}$$

$$\dot{Q}_{condn} = KA\frac{\Delta T}{\delta}$$

$$\boxed{R_{th} = \frac{\delta}{KA}}$$

b) Convection Resistance :

$$R_{th} = \frac{\Delta T}{\dot{Q}_{convection}}$$

$$R_{th} = \frac{\cancel{\Delta T}}{hA\cancel{\Delta T}}$$

$$\dot{Q}_{convection} = hA\Delta T$$

$$\boxed{R_{th} = \frac{1}{hA}}$$

$h \Rightarrow$ Convective HTC

c) Radiation Resistance

$$R_{th} = \frac{1}{h_r A}$$

$h_r \Rightarrow$ Radiative HTC

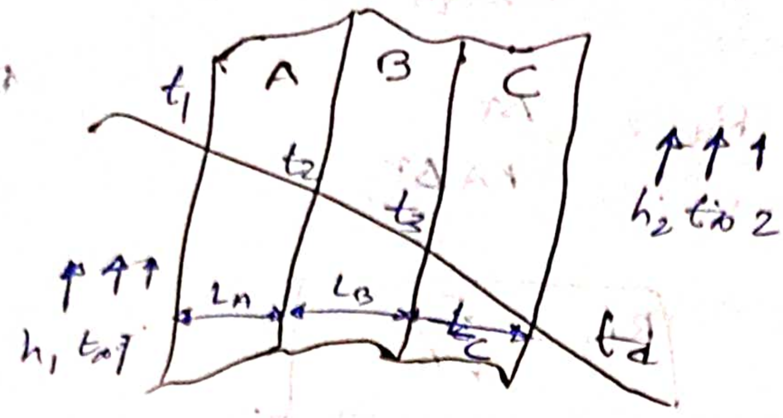
$$R_{th} = \frac{\Delta T}{(\dot{Q}_{net})_R}$$

$$[\dot{Q}_{net}]_R = A_1 F_{12} \sigma_b [T_1^4 - T_2^4]$$

$$= A_1 F_{12} \sigma_b (T_1^2 + T_2^2)\, \Delta T\, (T_1 + T_2)$$

$$R_{th} = \frac{\cancel{\Delta T}}{A_{12} F_{12} \sigma_b \cancel{\Delta T} (T_1^2 T_2^2)(T_1 + T_2)} = \frac{1}{h_r A} \Rightarrow h_r = F_{12}\sigma_b (T_1^2 T_2^2)(T_1 + T_2)$$

Plane walls with convection sides



$$t_{\infty_1} \xrightarrow{R_1} t_1 \xrightarrow{R_2} t_2 \xrightarrow{R_3} t_3 \xrightarrow{R_4} t_4 \xrightarrow{R_5} t_{\infty 2}$$

$$R_1 = \frac{1}{h_1 A} \quad R_2 = \frac{L_A}{K_A A}$$

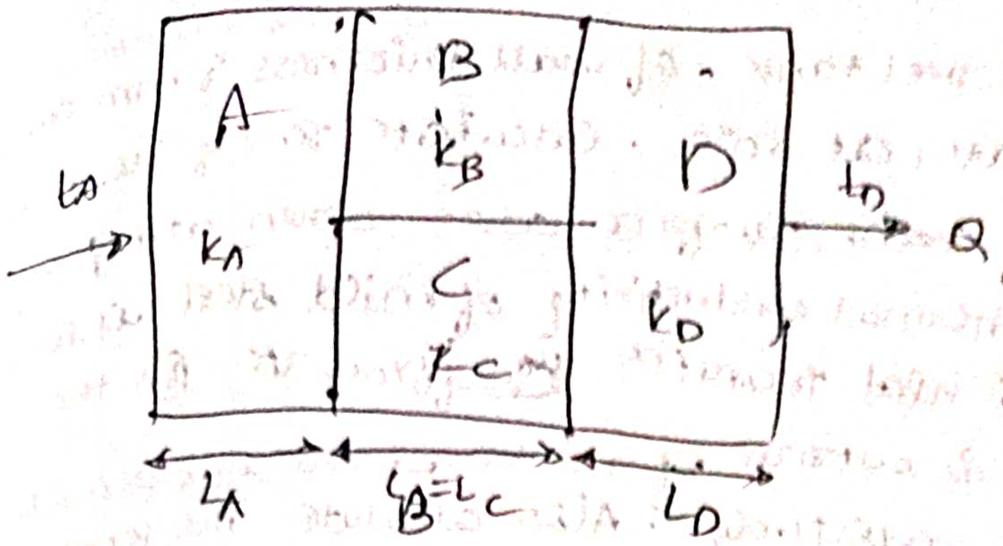
$$R_3 = \frac{L_B}{K_B A} \quad R_4 = \frac{L_C}{K_C A} \quad R_5 = \frac{1}{h_2 A}$$

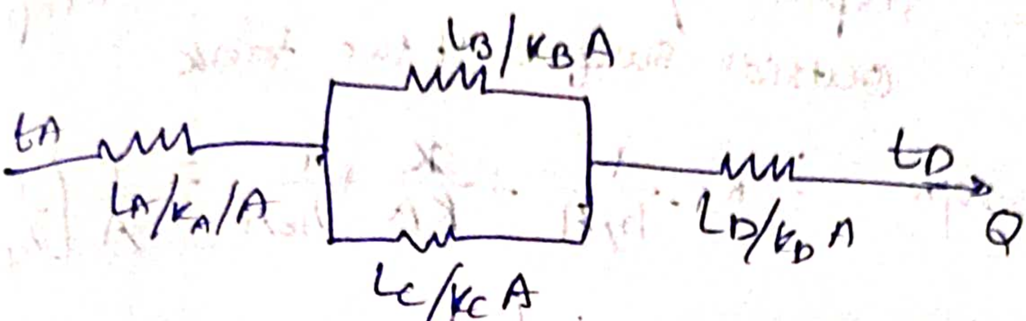
$$R = \frac{1}{h_1 A} + \sum \frac{L}{KA} + \frac{1}{h_2 A} = \frac{1}{h_1 A} + \frac{L_A}{K_A A} + \frac{L_B}{K_B A} + \frac{L_C}{K_C A} + \frac{1}{h_2 A}$$

$$Q = \frac{t_{\infty 1} - t_{\infty 2}}{R} = \frac{t_{\infty_1} - t_1}{\frac{1}{h_1 A}} = \frac{t_1 - t_2}{\frac{L_A}{K_A A}} = \frac{t_2 - t_3}{\frac{L_B}{K_B A}} = \frac{t_3 - t_4}{\frac{L_C}{K_C A}}$$

$$= \frac{t_4 - t_{\infty 2}}{\frac{1}{h_2 A}}$$

$$\boxed{Q = \frac{t_{\infty_1} - t_{\infty 2}}{\frac{1}{h_1 A} + \frac{L_A}{K_A A} + \frac{L_B}{K_B A} + \frac{L_C}{K_C A} + \frac{1}{h_2 A}}}$$





$$R = \sum \frac{1}{kA} = \frac{L_A}{K_A L_A} + \frac{\frac{L_B}{k_B A_B} * \frac{L_C}{k_C A_C}}{\frac{L_B}{k_B A_B} + \frac{L_C}{k_C A_C}} + \frac{L_D}{k_D A}$$

$$Q = \frac{t_A - t_D}{R} = \frac{t_A - t_D}{\frac{L_A}{K_A A} + \frac{\frac{L_B}{k_B A_B} \times \frac{L_C}{k_C A_C}}{\frac{L_B}{k_B A_B} + \frac{L_C}{k_C A_C}} + \frac{L_D}{k_D A}}$$

$$A_B = A_C = \frac{A}{2}$$

Q. A steel tank of wall thickness 8 mm contains water at 80°C. Calculate rate of heat loss per m² of tank surface area when atm temp is 20°C. Thermal conductivity of mild steel is 50 W/mK & heat transfer coefficients for the inside & outside of the tank are 2500 & 20 W/m²K respectively. Also calculate the temp. of the outside surface of the tank

Sol^n $R = \frac{1}{h_1 A} + \frac{x}{KA} + \frac{1}{h_o A} = \frac{1}{A}\left(\frac{1}{h_1} + \frac{x}{k} + \frac{1}{h_o}\right)$

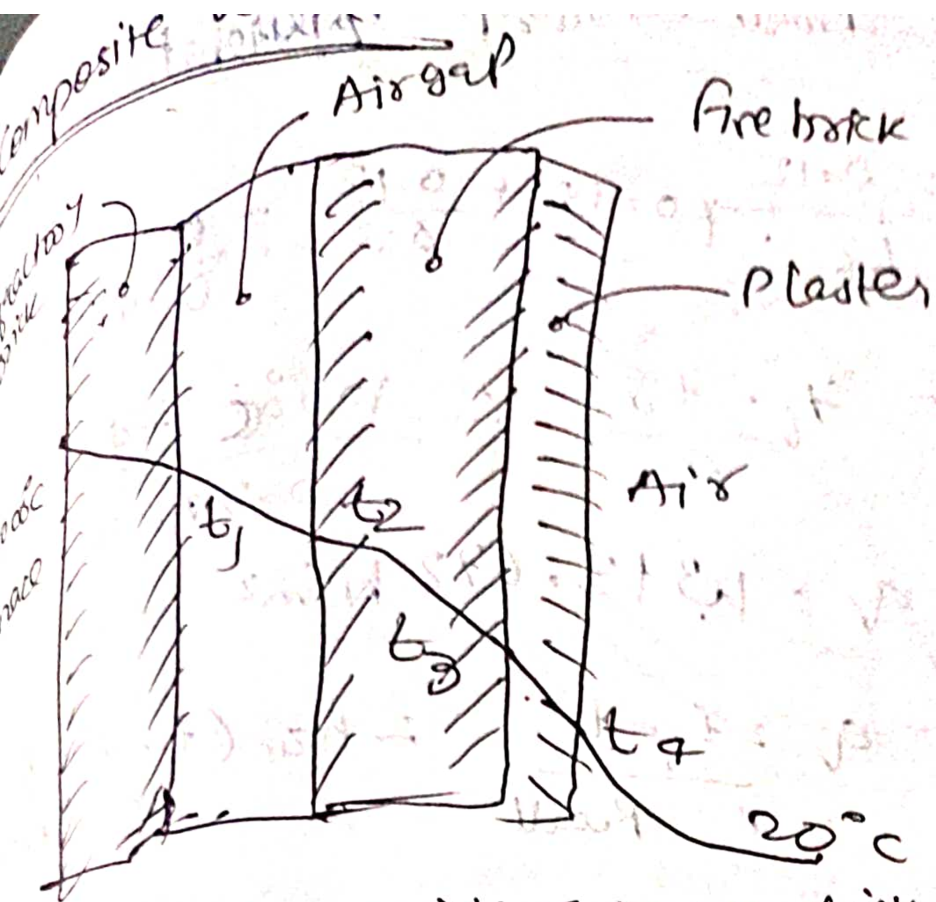
$$= \frac{1}{A}\left[\frac{1}{2500} + \frac{0.008}{50} + \frac{1}{20}\right]$$

$$R = \frac{0.0858}{A}$$

$$q = \frac{Q}{A} = \frac{(80°C - 20°C)}{0.0858} = 699.3\ W/m^2$$

$$q = h_o(t_2 - t_o) \Rightarrow 699.3 = 20(t_o - 20)$$

$$\boxed{t_o = 54.96°C}$$



...urnace wall consists of 120 mm thick refractory brick
...20 mm thick insulating firebrick separated by an air gap.
...utside wall is covered with 10 mm thickness of plaster.
Inner surface of wall is at 1000°C, & room temp is 20°C.
Calculate rate at which heat is lost per m² of wall surface
heat transfer coeff. from outside wall surface
to air in room is 20 W/m²K & resistance to heat
flow of air gap is 0.15 K/W. Thermal conductivity
of Refractory brick, insulating ~~fire~~ firebrick & plaster
are 1.6, 0.3 & 0.14 W/mK. resp.
Calculate each Interface temp of outside of wall.

$x_{wall} = 120mm$ $\quad x_{firebrick} = 120mm$ $\quad x_{plaster} = 10mm$;

$t_f = 1000°C$ $\quad t_\infty = 20°C$

$h_{0e} = 20 W/m^2K$ $\quad K_{wall} = 1.6 W/mK$

$K_{firebr} = 0.3 W/mK$ $\quad K_{plaster} = 0.14 W/mK$

$R_{airgap} = 0.15 K/W$

Soln $R = R_{wall} + R_{air\,gap} + R_{firebrick} + R_{plate} + \frac{1}{h_{air}}$

$$= \frac{0.12}{1.6} + 0.15 + \frac{0.12}{0.3} + \frac{0.01}{0.14} + \frac{1}{20} + 0.7$$

$$q = \frac{t_f - t_0}{R} = \frac{1000^\circ C - 20^\circ C}{0.746\,K/W}$$

$$q = 1313.672\ W/m^2$$

$$q = \frac{t_f - t_1}{R_{wall}} = h_{air}(t_1 - t_2) = \frac{t_2 - t_3}{R_{firebrick}} = \frac{t_3 - t_4}{R_{plate}}$$

$$= h_{air}(t_4 - t_0)$$

$$1313.672 = \frac{1.6(1000 - t_1)}{0.12}$$

$$\boxed{t_1 = 901.474^\circ C}$$

$$1313.672 = \frac{901.474 - t_2}{0.15}$$

$$\boxed{t_2 = 704.423^\circ C}$$

$$1313.672 = \frac{0.3(704.423 - t_3)}{0.12}$$

$$\boxed{t_3 = 178.954^\circ C}$$

$$1313.672 = \frac{0.14(178.954^\circ C - t_4)}{0.01}$$

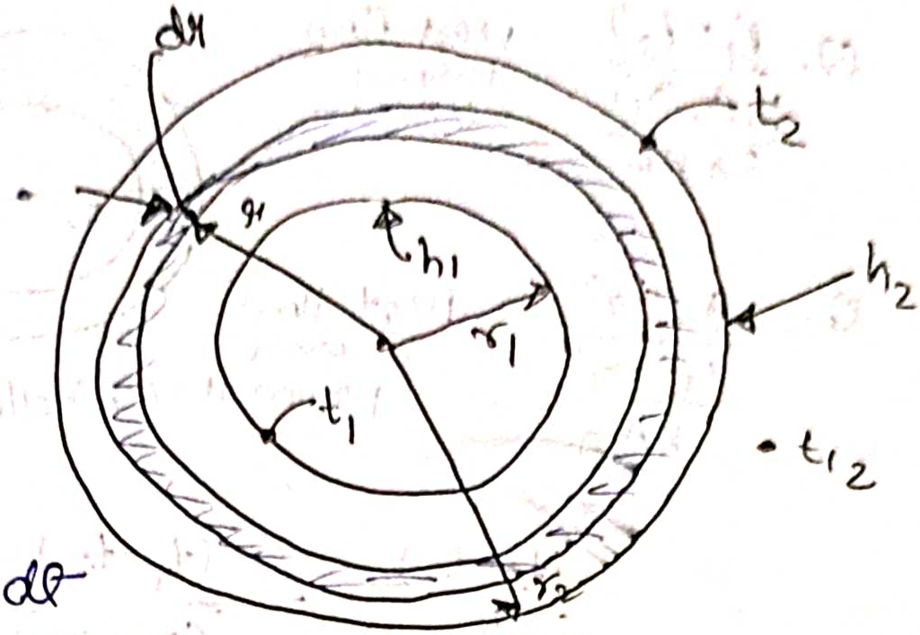
$$\boxed{t_4 = 85.12^\circ C}$$

Heat Transfer through Hollow Cylinder

elemental area of length l.
HT through it

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

$Q = -K 2\pi r l \frac{dt}{dr}$



$Q = -K 2\pi r l \, dt$

$Q \frac{dr}{r} = -K 2\pi l \, dt$

integrating b/w inside & outside surfaces

$$Q \int_{r_1}^{r_2} \frac{dr}{r} = -K 2\pi l \int_{t_1}^{t_2} dt$$

$$Q \ln\left(\frac{r_2}{r_1}\right) = -K 2\pi l (t_2 - t_1)$$

$$Q = \frac{-K 2\pi l (t_2 - t_1)}{\ln\left(\frac{r_2}{r_1}\right)}$$

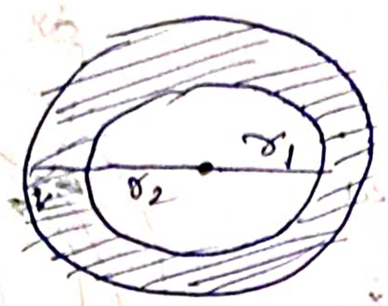
$$\boxed{Q = \frac{(t_1 - t_2)}{\frac{\ln(r_2/r_1)}{2\pi K L}} = \frac{\Delta t}{R_{th}}}$$

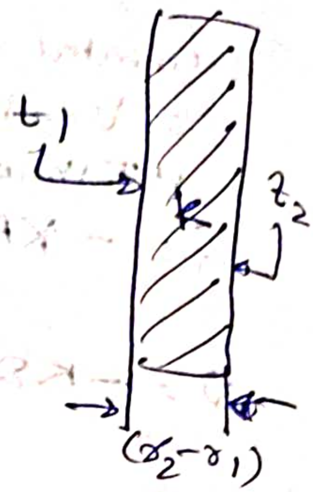
$$R_{th} = \frac{\ln(r_2/r_1)}{2\pi K L}$$

logarithmic mean area for hollow cylinder

$$Q = \frac{(t_1 - t_2)}{\frac{\ln(r_2/r_1)}{2\pi K L}}$$ heat flow through cylinder

$$Q = \frac{(t_1 - t_2)}{\frac{(r_2 - r_1)}{K A_m}}$$ Heat flow through planewall





$$\frac{(t_1 - t_2)}{\frac{\ln(r_2/r_1)}{2\pi K L}} = \frac{(t_1 - t_2)}{\frac{(r_2 - r_1)}{K A_m}}$$

$$A_m = \frac{2\pi L (r_2 - r_1)}{\ln(r_2/r_1)}$$

$$A_m = \frac{2\pi L r_2 - 2\pi L r_1}{\ln\left(\frac{2\pi L r_2}{2\pi L r_1}\right)}$$

$$\boxed{A_m = \frac{A_0 - A_1}{\ln\left(\frac{A_0}{A_1}\right)}}$$

$$A_{av} = \frac{A_i + A_0}{2}$$

$$A_m = 2\pi r_m L$$

$$r_m = \frac{(r_2 - r_1)}{\ln(r_2/r_1)}$$

$$A_m = \frac{\quad}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$R_{inside} = \frac{1}{h_1 A_1} \qquad R_{outside} = \frac{1}{h_2 A_2}$$

A steel pipe of 80 mm bore and 8 mm wall thickness carrying steam at 250°C is insulated with 36mm of a molded high temp diatomaceous earth covering. This covering is in turn insulated with 50 mm of asbestos felt. If the atm temp is 20°C calculate rate at which heat is lost by the steam per m length of pipe. The heat transfer coefficients for inside & outside surfaces are 525 & 27 W/m²K, respectively. & thermal conductivity of steel, diatomaceous earth & asbestos felt are 55, 0.1 & 0.08 W/mK, respectively. Also calculate the temp of the outside surface.

$r_1 = 40$ mm, $r_2 = 48$ mm, $r_3 = 84$ mm $r_0 = 134$ mm

$h_1 = 525$ W/m²K, $h_0 = 27$ W/m²K

$$R = \frac{1}{h_1 A_1} + R_{steel} + R_{diatomaceous} + R_{asbestos} + \frac{1}{h_0 A_0}$$

$$R = \frac{1}{h_1 2\pi r_1} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_{steel}} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_{diam}} + \frac{\ln\left(\frac{r_0}{r_2}\right)}{2\pi k_{asbestos}} + \frac{1}{h_0 2\pi r_0}$$

$$R = \frac{10^3}{525 \times 2\pi \times 40} + \frac{\ln\left(\frac{48}{40}\right)}{2\pi \times 55} + \frac{\ln\left(\frac{84}{48}\right)}{2\pi \times 0.1} + \frac{\ln\left(\frac{134}{84}\right)}{2\pi \times 0.08}$$

$$+ \frac{10^3}{27 \times 2\pi \times 134}$$

$R = 0.0007582$
$+ 0.000229245$
$+ 0.387063 + 0.403713$
$+ 0.044012$

$$\boxed{R = 0.8357\ K/W}$$

$$Q = \frac{t_{fi} - t_{fo}}{R}$$

$$Q = \frac{250^\circ C - 20^\circ C}{0.8357\ K/W}$$

$$\boxed{Q = 242.91\ W/m}$$

$$Q = 242.91 = \frac{t_o - t_{fo}}{h_o A_o} = \frac{t_o - 20}{0.044012}$$

$$\boxed{t_o = 80.69^\circ C}$$