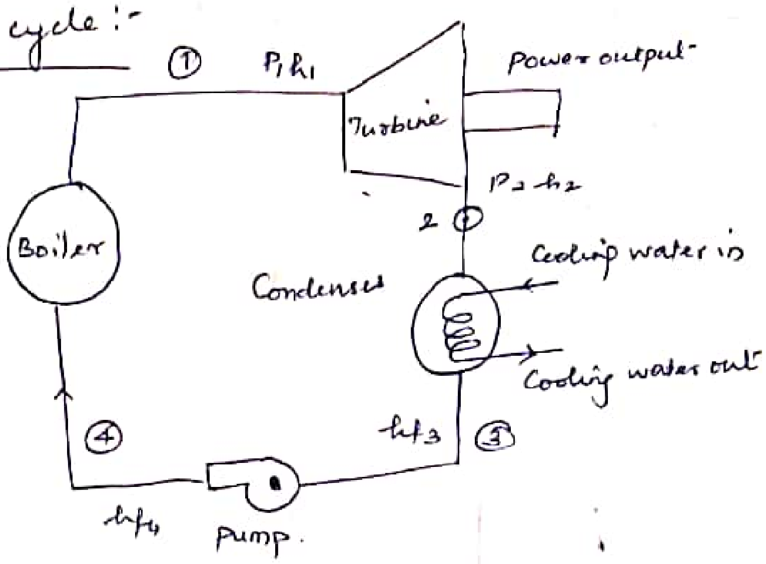
UNIT - I

Coal based Thermal power plants :-

Rankine cycle :-



process 1-2 (Turbine)

$$W_T = h_1 - h_2 .$$

process 2-3 Condenser

$$Q_R = h_2 - h_3 = h_2 - h_{f2} .$$

process 3-4 pump

Workdone by pump, $W_p = h_4 - h_3 = v_3 (P_4 - P_3)$

$$W_p = V_{f3} (P_4 - P_3) = V_{f2} (P_1 - P_2)$$

$$P_4 = P_1 ; \; P_3 = P_2 ; \; V_3 = V_{f2} .$$

Process 4-1 Boiler.

heat supplied during 4-1

$$Q_{S_{4-1}} = h_1 - h_4$$

$$Q_S = h_1 - h_4$$

(or)

$$Q_S = h_1 - (h_3 + W_p)$$

Net work out put :- $W_T - W_p$

$= (h_1 - h_2) - W_p = h_1 - (h_{f2} + W_p)$.

$$\eta = \frac{W}{Q_s}$$

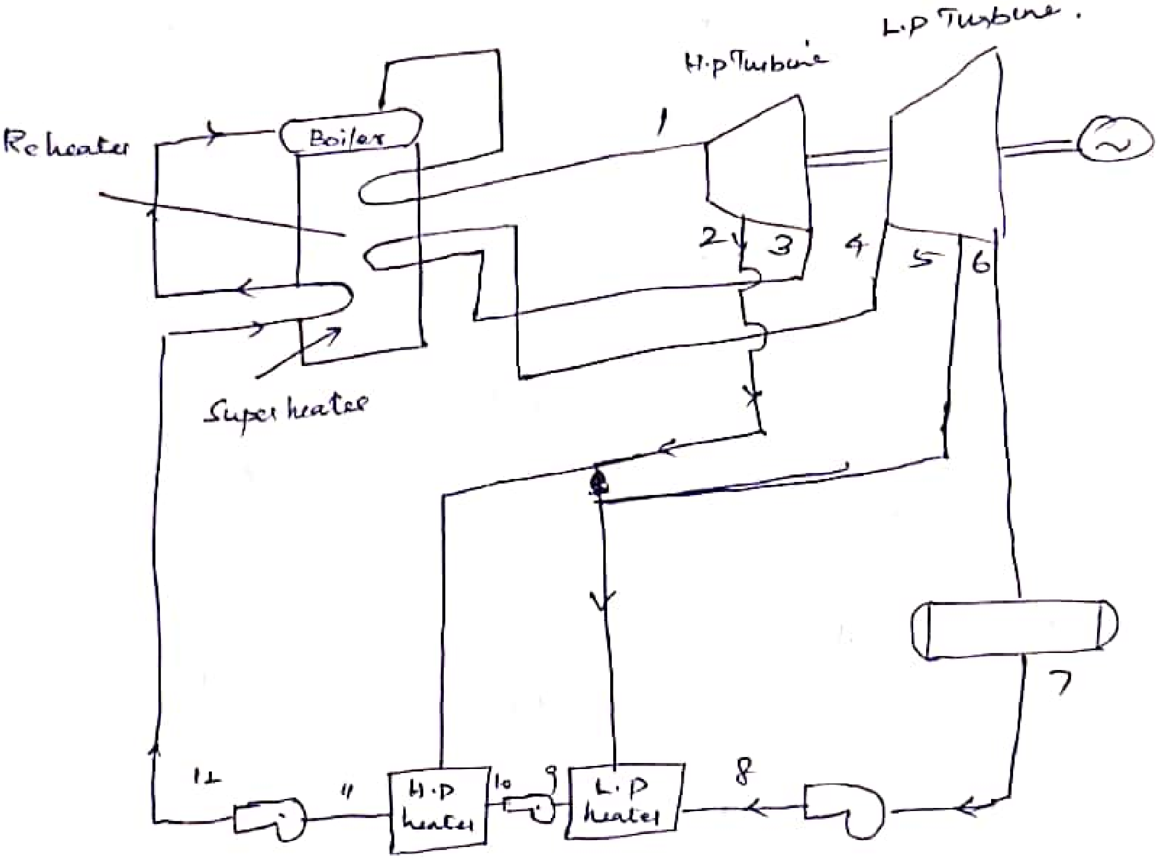
$$= \frac{(h_1-h_2)-W_p}{h_1-h_4} = \frac{(h_1-h_2)-W_p}{h_1-(h_{f_2}+W_p)}$$

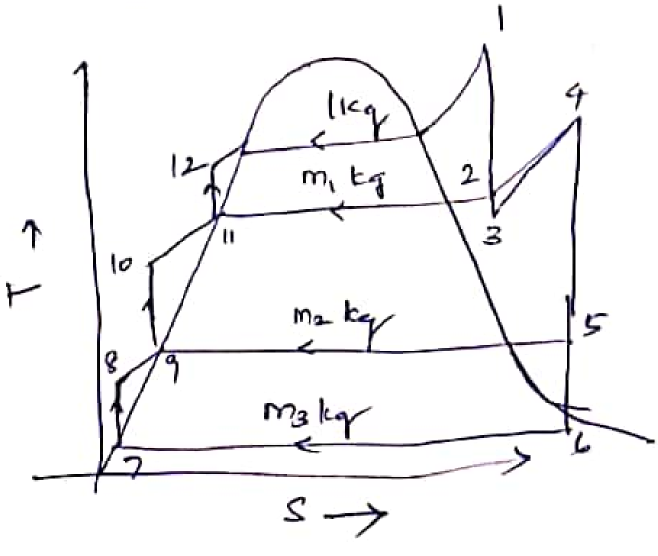
specific steam Consumption:- $\frac{3600}{W}$ in kg/kW h.

$SSF = \frac{3600}{W}$ in kg/kW.

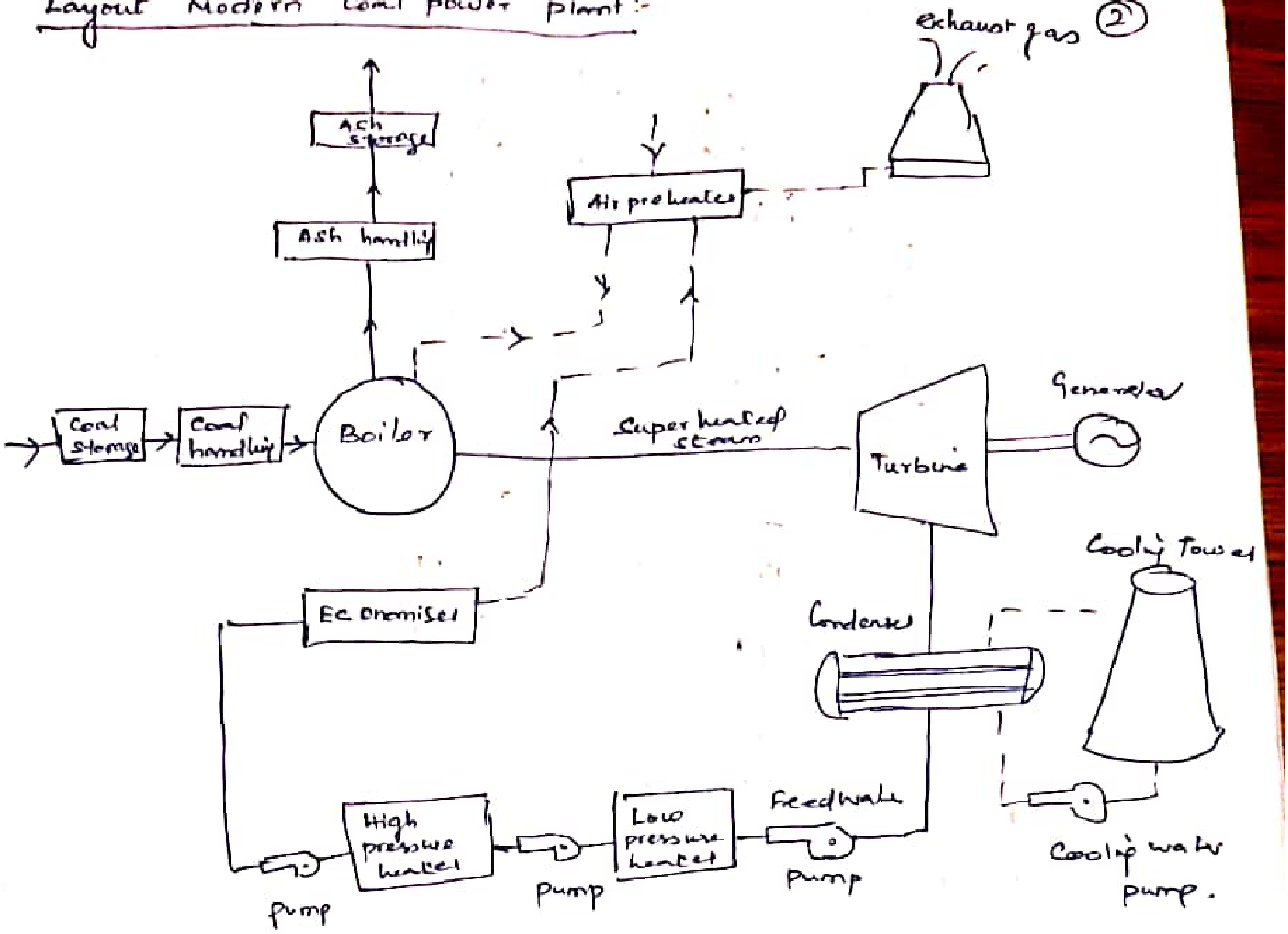
Work Ratio = $\frac{\text{Net work}}{\text{Gross work}} = \frac{W_T - W_p}{W_T}$.

Reheat & Regenerative cycle





Layout Modern Coal power plant :-



1. Coal and ash circuit
2. Air and flue gas circuit
3. Water and steam circuit
4. Cooling water circuit

pressure = 10 kg/cm^2

Temp = 250°c to 650°c.

Super critical Boiler :-

→ water tube boiler

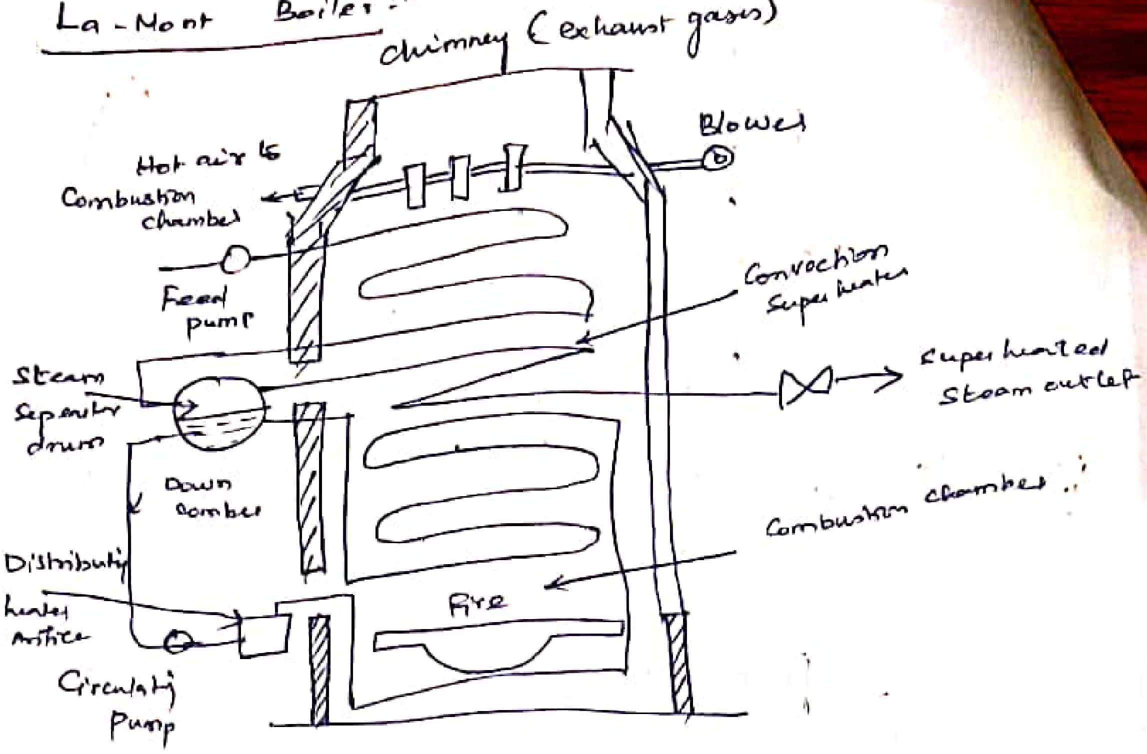
→ Pr-1 125 atm

→ 510°c to 300 atm.

(1) Cornish boiler

(2) Lancashire boiler.

La-Mont Boiler :-



① Steam Separator drum

② Water circulating pump.

③ Distributing header.

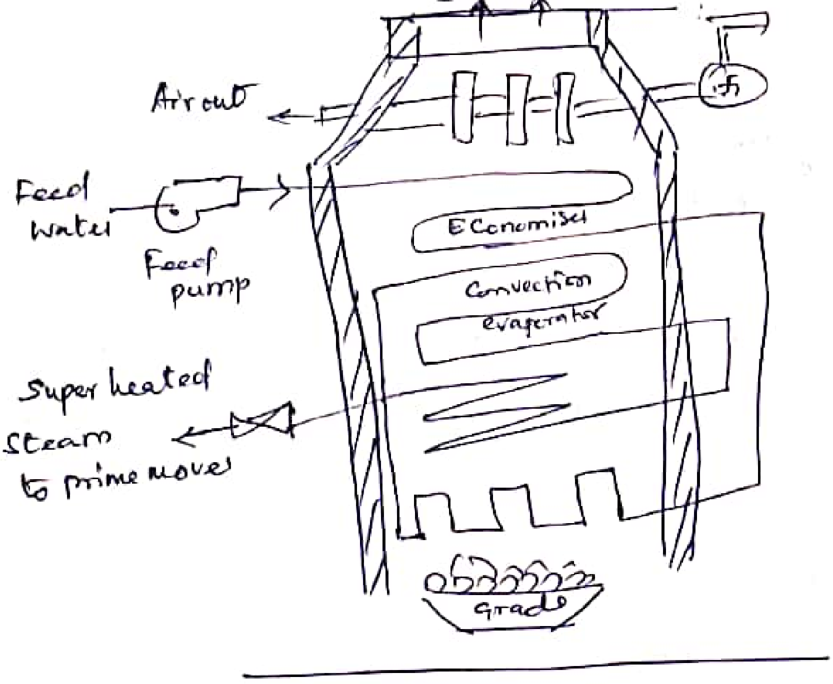
④ Evaporator

⑤ Convection super heater.

⑥ Economiser.

⑦ Air pre heater.

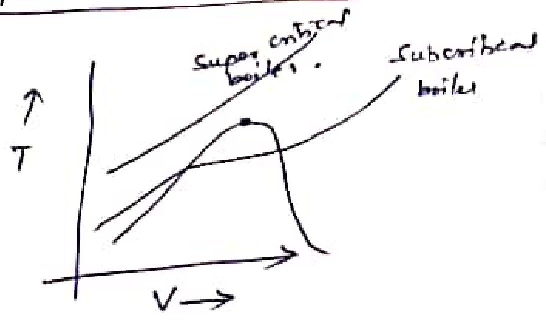
Benson Boiler



Benson Boiler

① Economiser.
② Radiant evaporator
③ Convection evaporator
④ Convection Super heater.

Supercritical Boiler



Condition of Super Critical boiler

(1) Economiser
(2) Evaporator
(3) superheater.

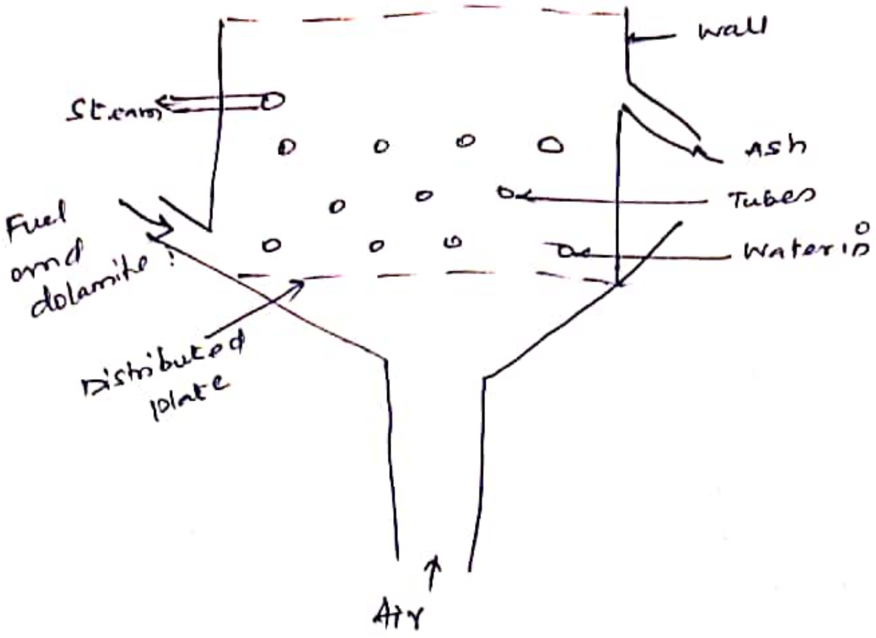
Boiler Mountings

(1) pressure gauge
(2) stop valve
(3) feed check valve
(4) safety valve
(5) Fusible plug
(6) Blow-off cock.
(7) water level indicator
(8) Man hole.

Boiler Accessories:-

(a) Economiser.
(b) Steam super heater.
(c) Air pree heater
(d) Deaerators.
(e) steam injector
(f) steam separator
(g) stream trap.

Fluidized Bed Combustion (FBC)



→ fuel and dolomite it FBC

→ Bed – 800 – 900°C

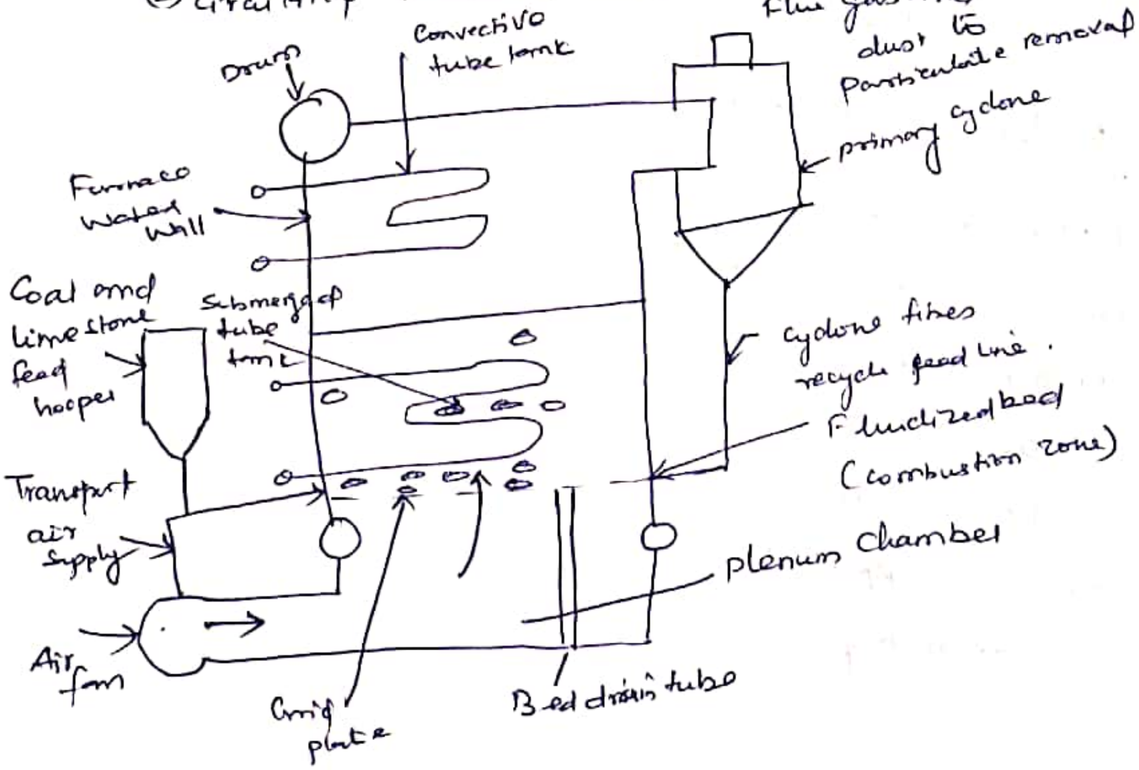
→ SO_2 Controlled by limestone (or) dolomite

→ NO_x reduced · low excess air .

FBC Boiler

(1) Bubbling fluidized boiler

(2) Circulating fluidized boiler



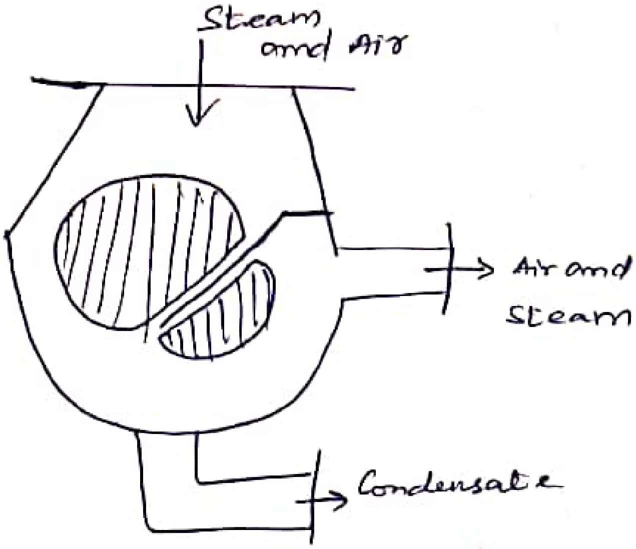
Condenser :-

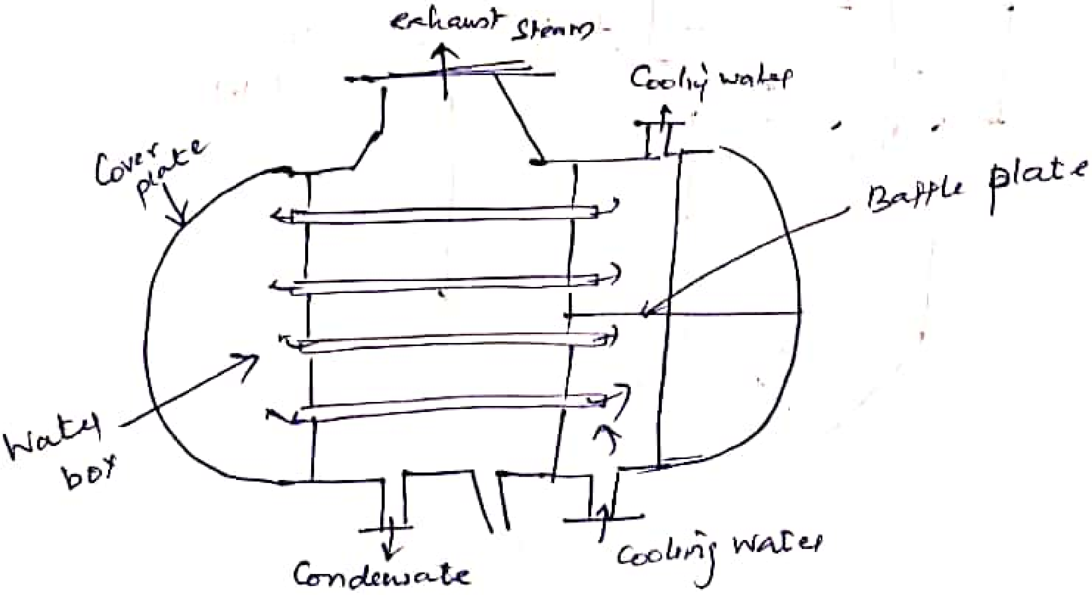
Down flow Condenser.

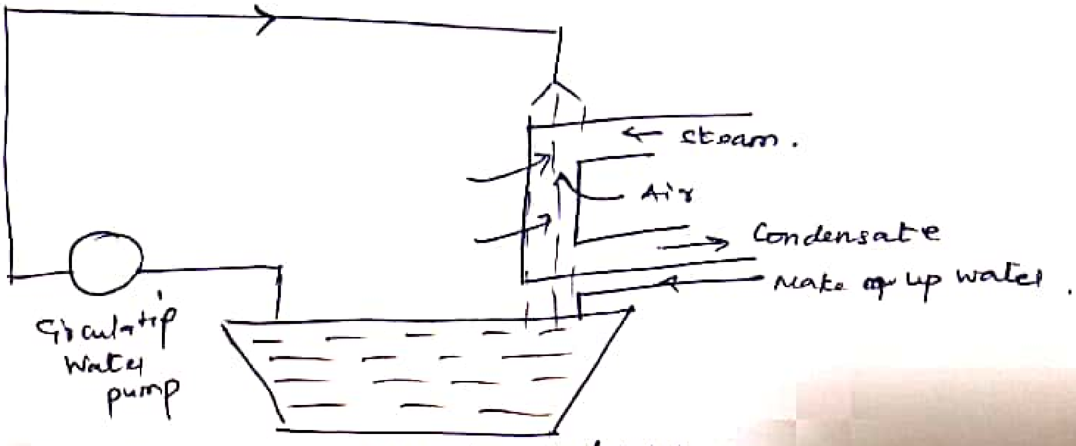
Central flow Condenser.

two pass down-flow Condenser.

Evaprator Condenser.







Evaporator Condenser.

Steam rate:-

$$SSC \rightarrow \frac{\text{Mass of steam}}{\text{Work output}} .$$

$$\rightarrow \frac{3600 \times m_s}{W_T}$$

Heat Rate.

$$\text{Heat rate} = \frac{\text{Heat supplied}}{\text{Work output}} .$$

$$\text{Heat rate} = \frac{3600 \times Q_1}{W_T} \quad kJ/kWh.$$

Subsystems of thermal power plants:-

① Fuel handling system
② Ash handling system
③ Cooling system
④ Draught system
⑤ Feed system.

Fuel handling system:-

(1) Coal handling system:-

(a) coal delivery
(b) Unloading
(c) preporation
(d) Transfer
(e) coal storage { Dead storage
site selection of coal dead storage.
(f) Inplant handling
(g) Weighing and Measuring
(h) furnace

(2) oil fuel handling

(3) Gaseous fuel handling.

Coal preparation process:-

crushers, sizers, dryers, & Magnetic Separators.

Coal cleaning equipment;

(1) Removal of dirt

(2) Coal drying

(3) coal sizing

(4) Sulphur removal

(5) washing &
- water jigs
- Concentrating table
- hydro-cyclone
- Heavy medium

Coal Blending (or) Mixing

(1) Bed blending
(2) Belt blending
(3) Automatic blending

Coal Desulphurization

(1) First the coal is crushed and its sent to a mixing tank

(2) It is mixed with the $Fe_2(SO_4)_3$

(3) The resulting slurry is heated to 100-130°C

(4) The coal solution is pumped to a filter.

(5) It is neutralized by addition of Coal.

(6) In the extractor, Coal is mixed with warm acetone and water which dissolve the elemental sulphur left in the coal.

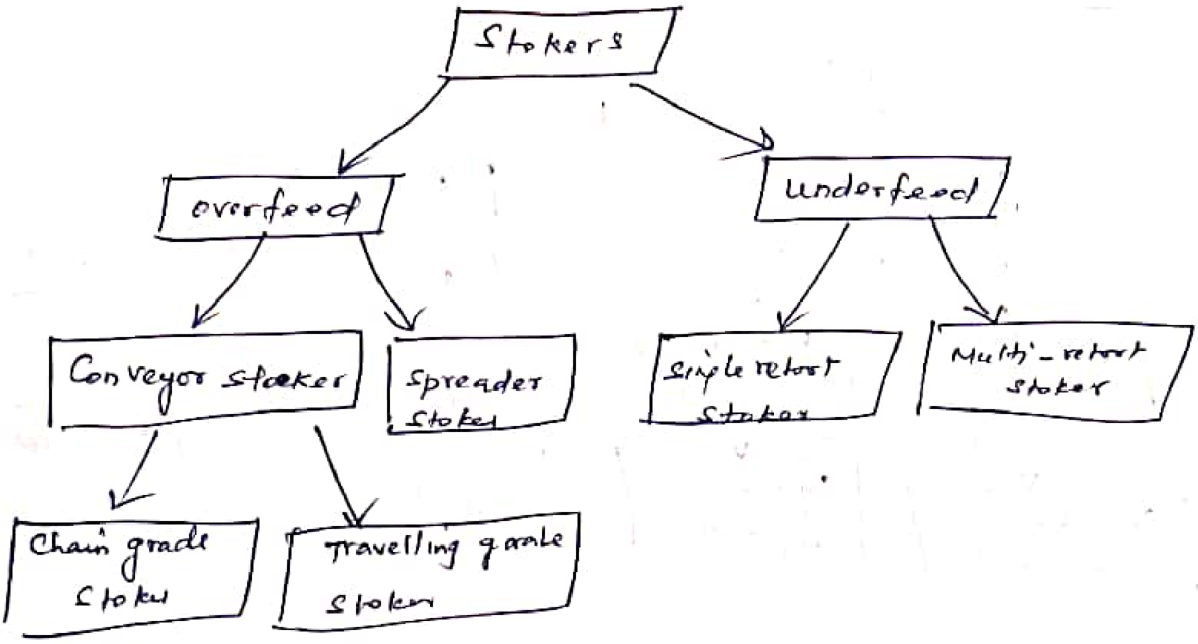
Coal transfer equipement

(1) Belt Conveyer
(2) Screw Conveyor
(3) Bucket Conveyor
(4) Grab bucket Conveyor
(5) Grab bucket elevator
(6) Skip hoists
(7) Flight Conveyer.

Combustion equipement for Burning Coal.

(1) fuel bed furnace.
(2) fluidized bed furnace
(3) cyclone furnace
(4) pulverized coal furnace.

Mechanical Stockers :-



Types of pulverising mill :-

(1) Ball mill
(2) Hammer mill
(3) Ball and race mill
(4) Bowl mill

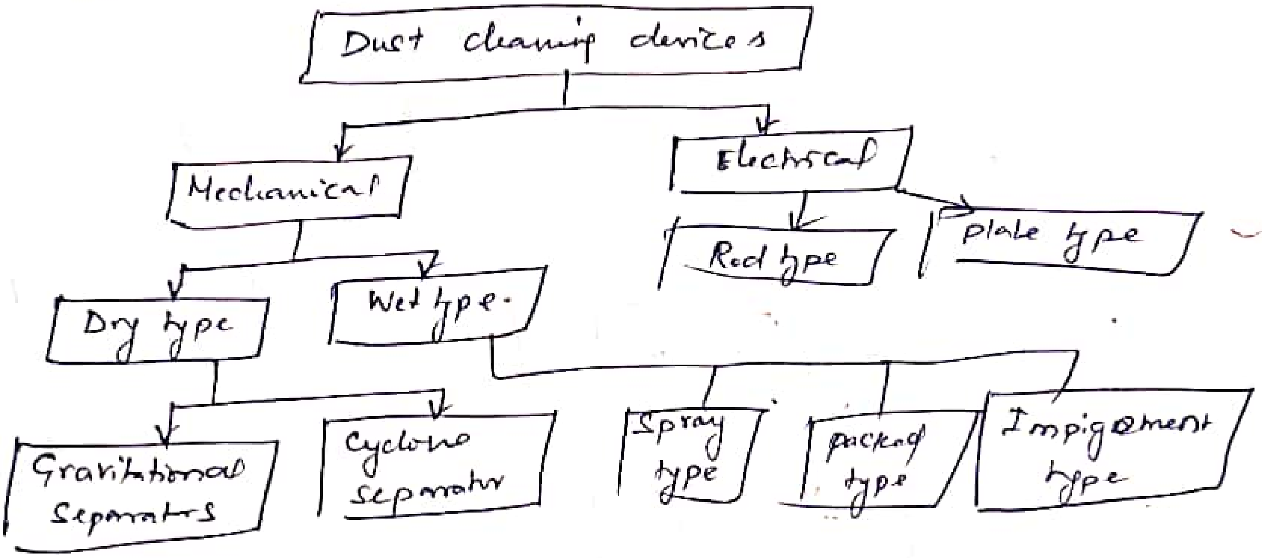
Pulverised fuel burner

(1) U flame burner
(2) Turbulent burner
(3) Tangential flow burner
(4) cyclone burner

Hash Handling

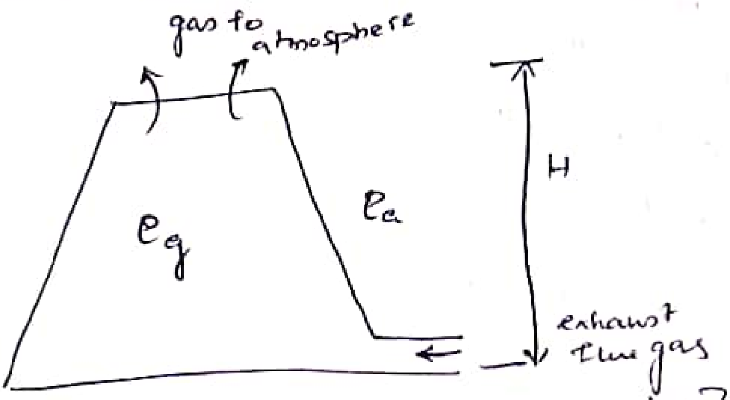
(1) Vaccum Extraction plant
(2) Hydraulic system.
(3) Mechanical system.
(4) Steam jet system.
(5) pneumatic system

Dust Collector:-



Draught System:-

Natural Draft



$$\Delta p = \frac{gHP_a}{R_a}\left[\frac{1}{T_a} - \frac{1}{T_g}\right]$$

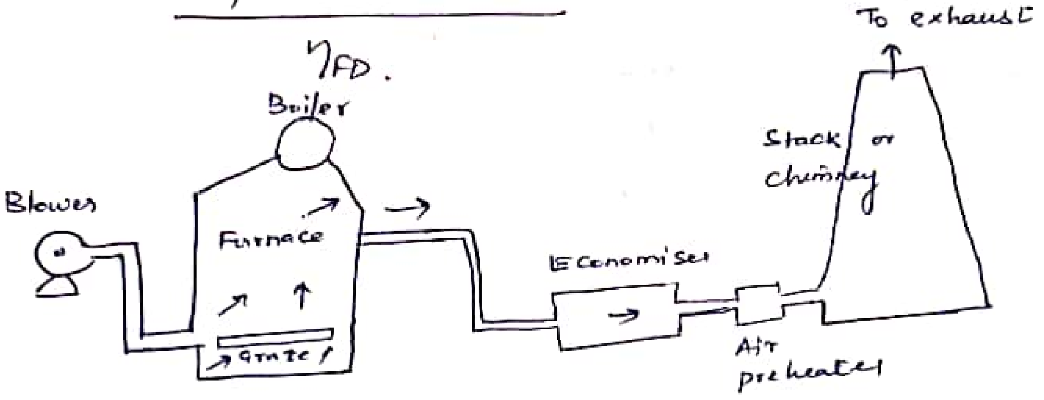
$$\boxed{\Delta p = gH(\rho_a - \rho_g)}$$

Mechanical Draught :-

(1) Forced draught System

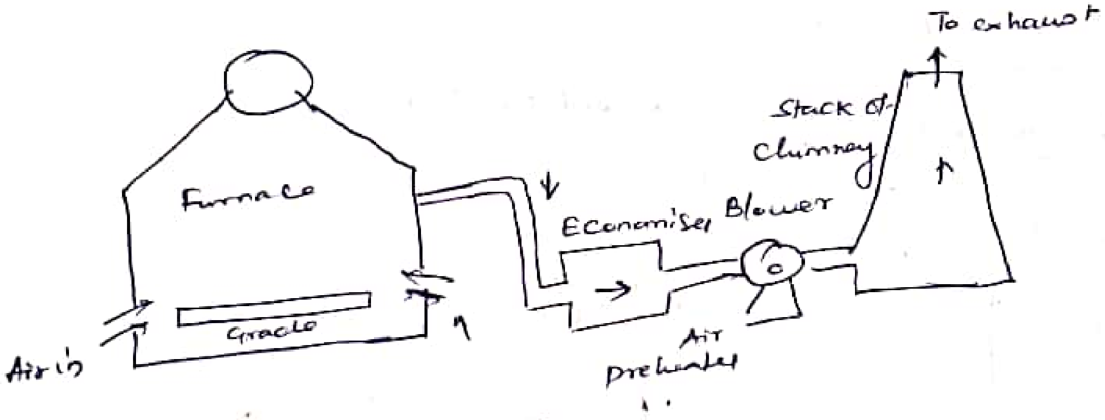
(2) Induced draught system.

$$P = \frac{N_f \times A/F \times U \times \Delta p}{\eta_{FD}}$$



Forced draft

Induced draft :-



Cooling tower :-

(1) Wet type

(2) dry type

Design parameter :-

(1) The exposing time

(2) Amount of water Surface exposed

(3) Relative humidity of Air

(4) velocity of air

(5) Accessibility of air to various part of cooling tower.

Wet type :-

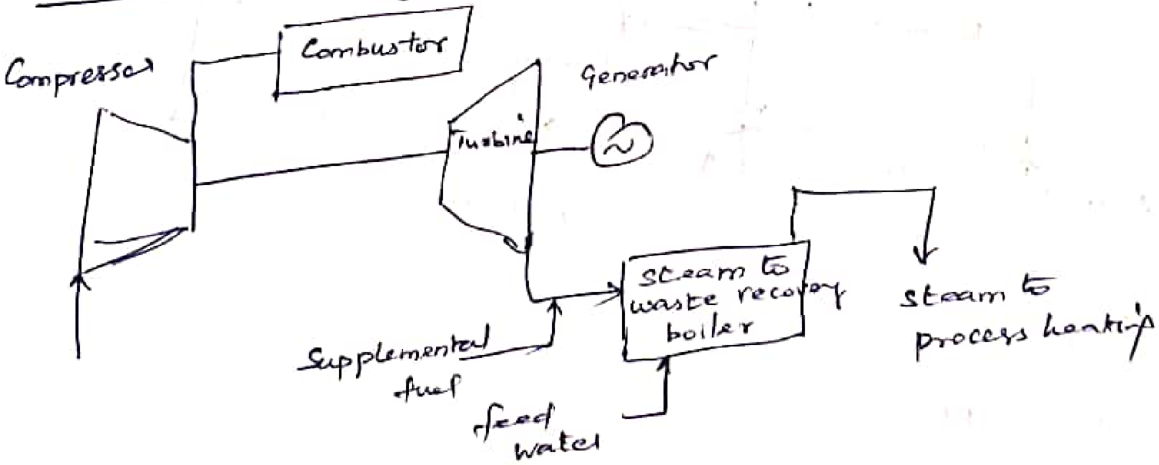
(1) Atmospheric (or) Natural draft cooling tower.
  (a) Natural draft spray filled tower.
  (b) Natural draft packed type tower.
  (c) hyperbolic cooling tower.
(2) Mechanical draft cooling tower.
  (a) Forced draft cooling tower
  (b) Induced draft cooling tower

Dry type cooling tower

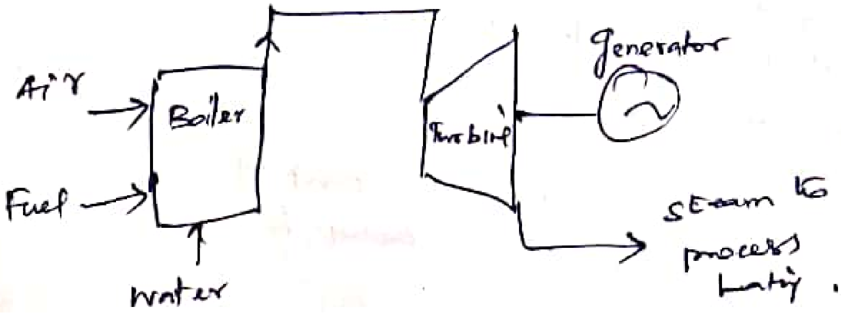
(1) Direct type
(2) Indirect type
  (a) cooling tower using conventional surface condenser.
  (b) Direct contact spray condenser.
  (c) Cooling tower using Ammonia as the coolant.

Co generation :-

Gas turbine topping Combined Heat power plant

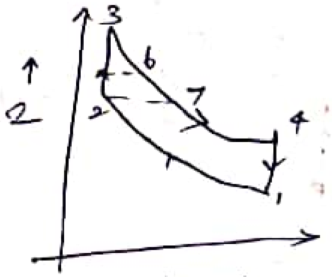


Steam turbine topping CHP plant

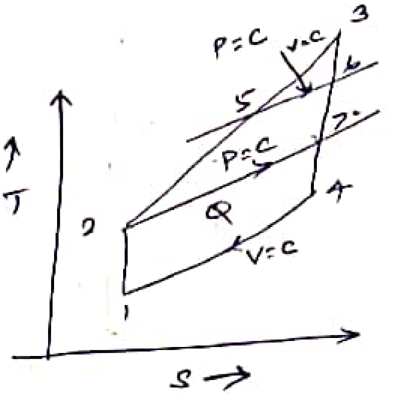


Diesel, gas turbine & Combined cycle power plants:-

Comparison of otto, Diesel and Dual cycles for the same Compression ratio:-



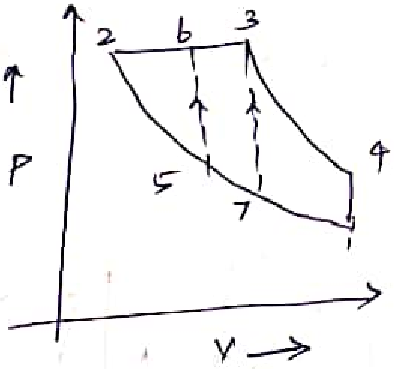
P-V diagram.

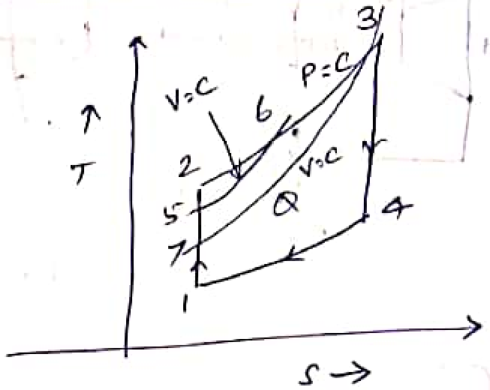


T-S diagram

$\eta_{otto} > \eta_{Dual} > \eta_{Diesel}$.

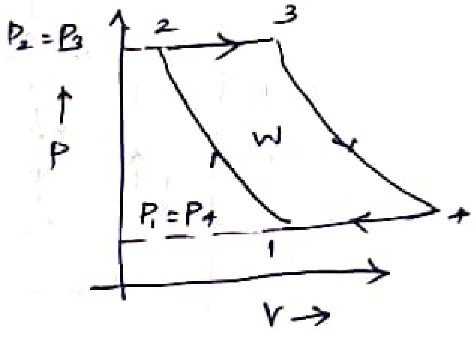
For the same Maximum pressure and temp:



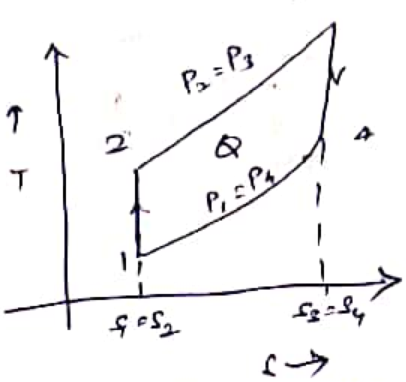


$\eta_{Diesel} > \eta_{Dual} > \eta_{otto}$.

Brayton cycle (or) Joule cycle



P-V diagram.



T-S diagram

Improvisation of Brayton cycle in power plants:-

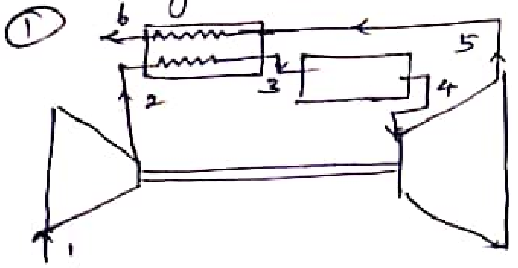
(1) Brayton cycle with regeneration.

(2) Brayton cycle with intercooling

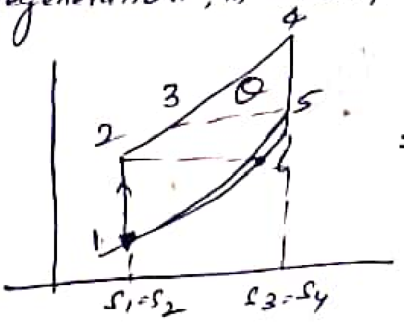
(3) Brayton cycle with Reheating

(4) Brayton cycle with Combined regeneration, intercooling & reheating.

①



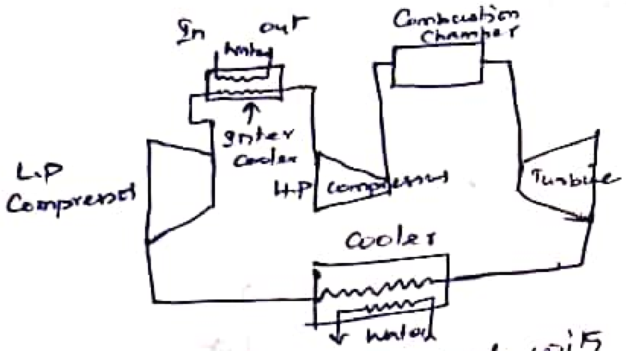
Brayton cycle with regenerator



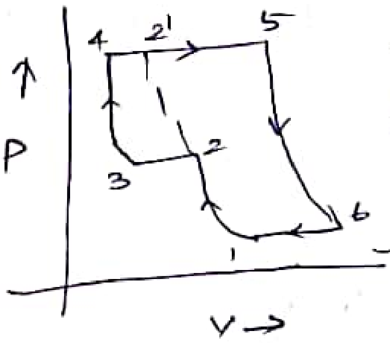
T-s diagram.

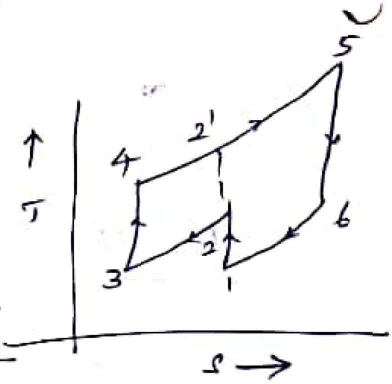
$= 1 - \frac{T_1}{T_4}(R_p)^{\frac{\gamma-1}{\gamma}}$

②

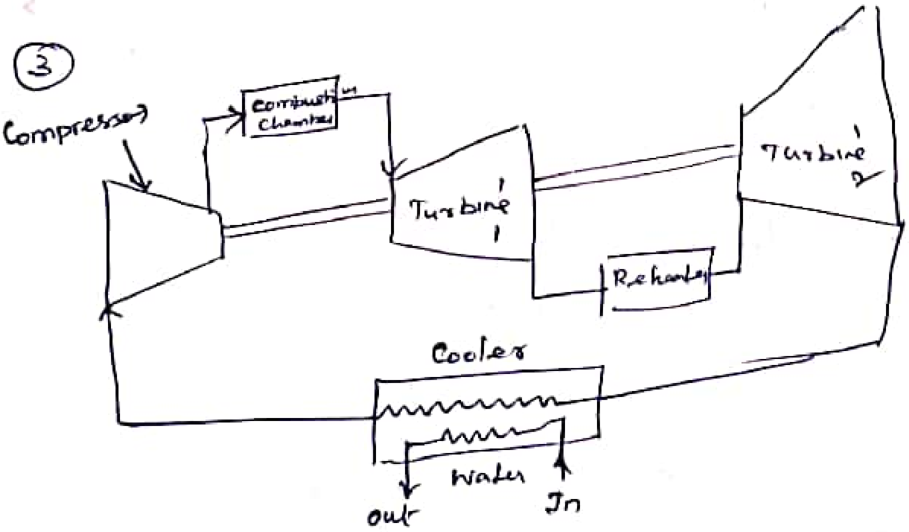


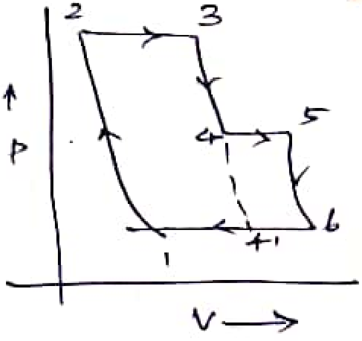
Brayton cycle with Intercooler

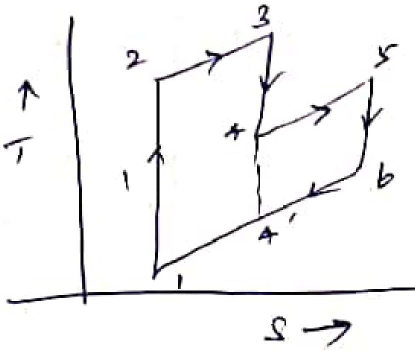




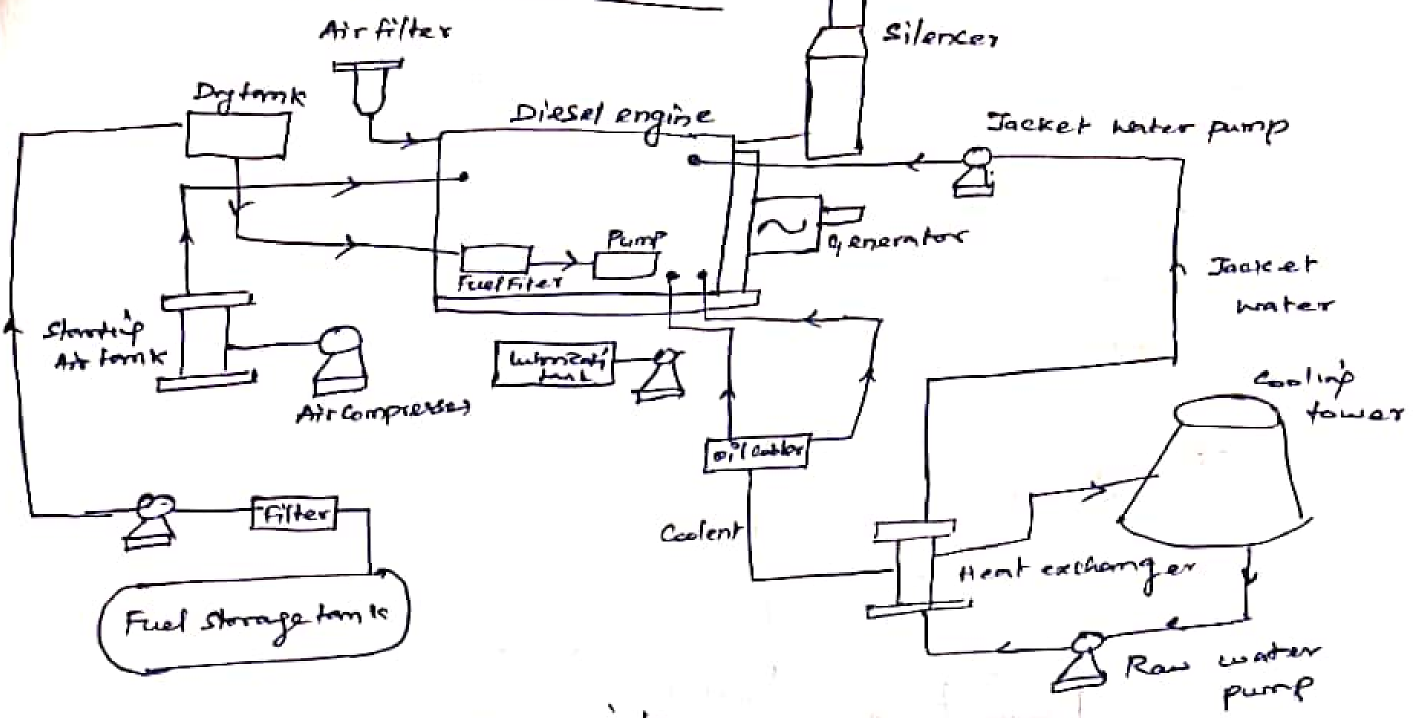
③







Diesel cycle power plant:-



Selection of Diesel engine:-

(1) Amount of fuel burned per minute
② Brake mean effective pressure
③ Fuel Injection system
④ Combustion process
⑤ Type of engine.
⑥ Fuel-air ratio
⑦ Cooling method
⑧ Size of cylinder
⑨ volumetric efficiency
⑩ specific weight.

Site Selection of Diesel power plant:-

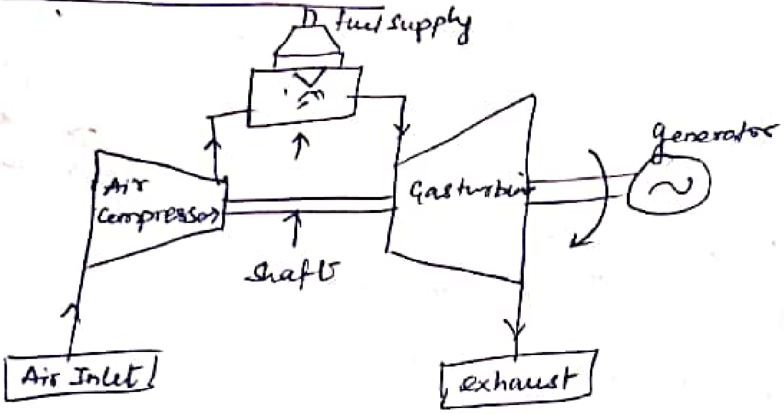
1. Foundation for sub-soil system
2. Distance from load centre
3. Access to the site
4. Availability of water
5. Fuel transportation.

Gas turbine power plant :-

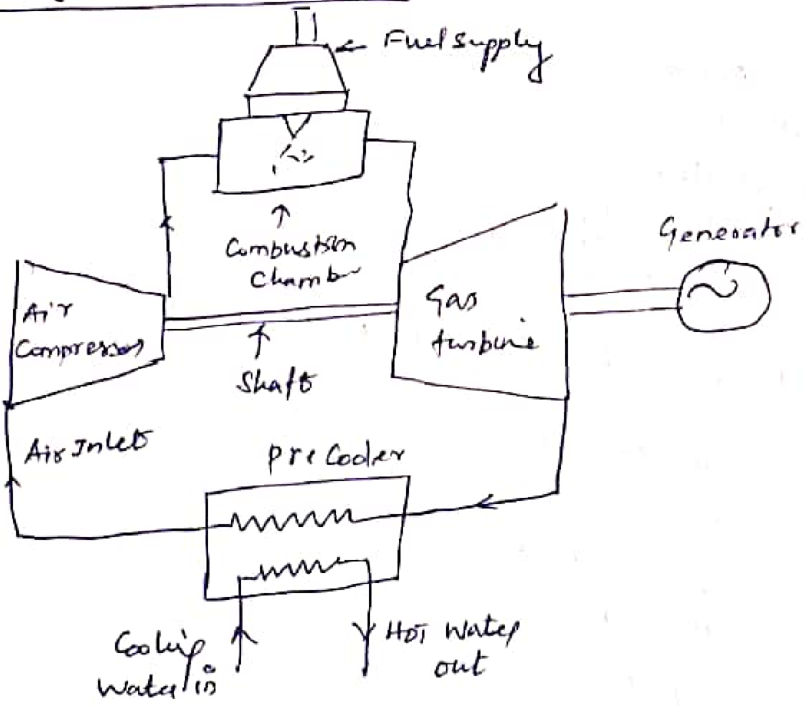
Main Component of gas turbine power plant :-

1. Compressor.
2. Combustion chamber.
3. turbine.

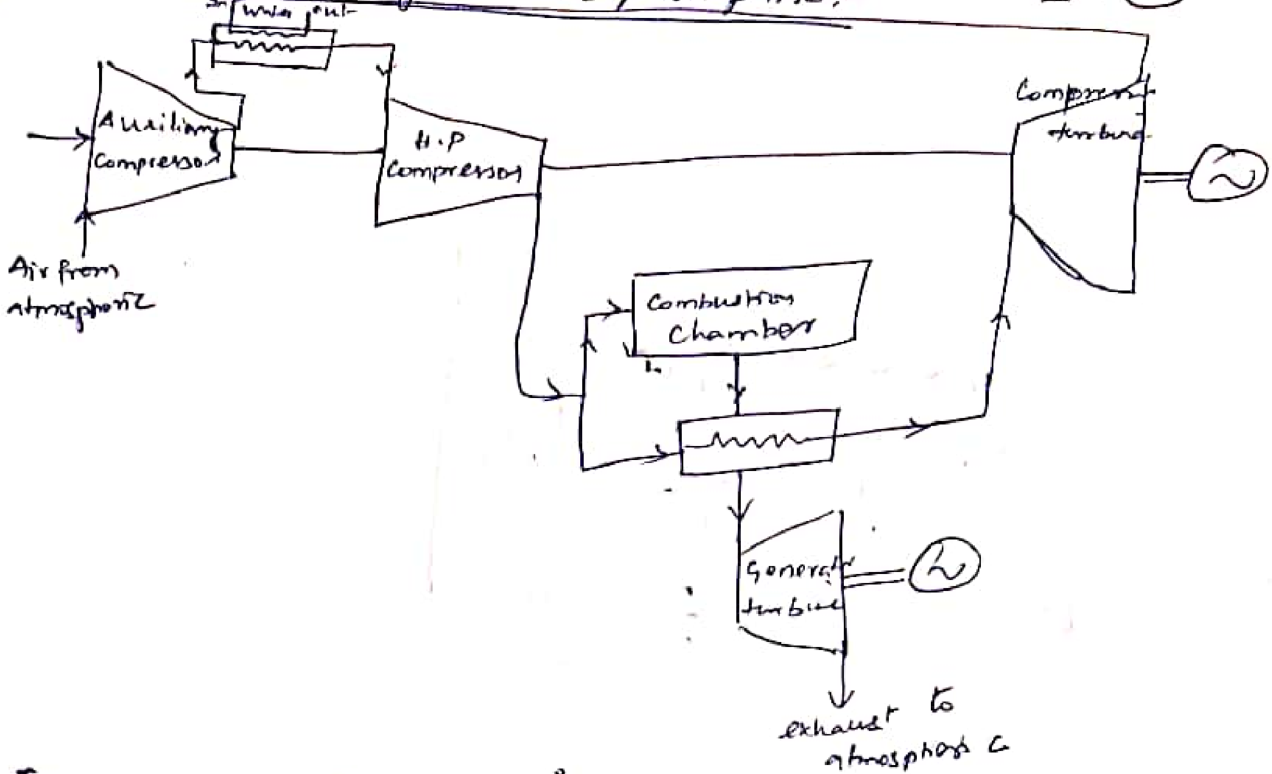
open cycle gas turbine :-



Closed cycle gas turbine :-



Semi-closed cycle gas turbine power plant :-

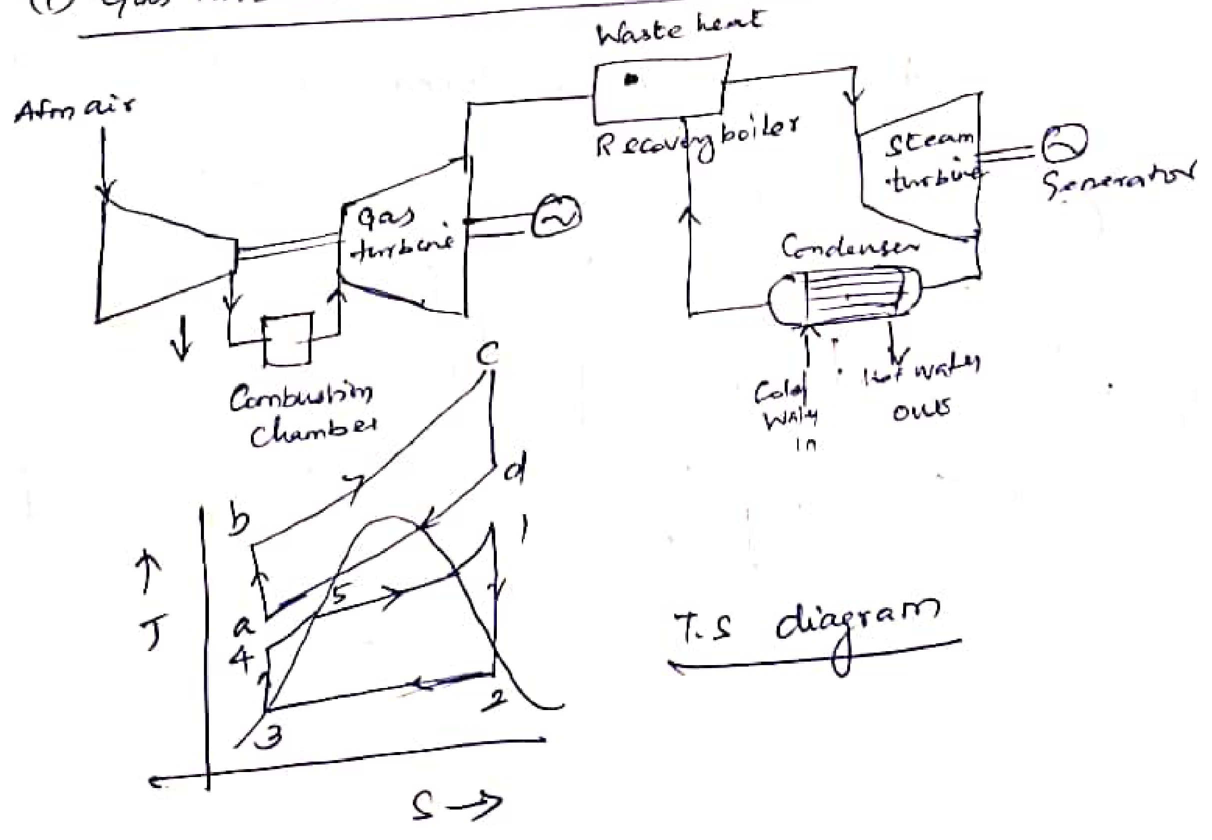


Improvisations of gas turbine power plants :-

(1) Inter Cooler
(2) Regenerator
(3) Reheater .

Combined power plants

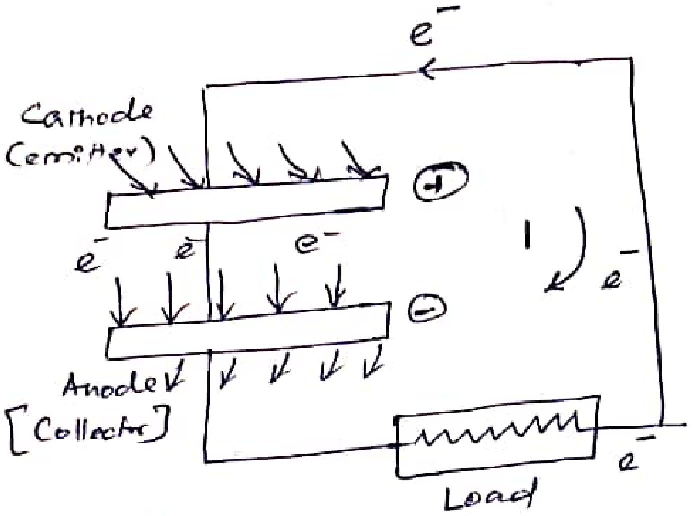
(1) Gas turbine - steam turbine plant :-

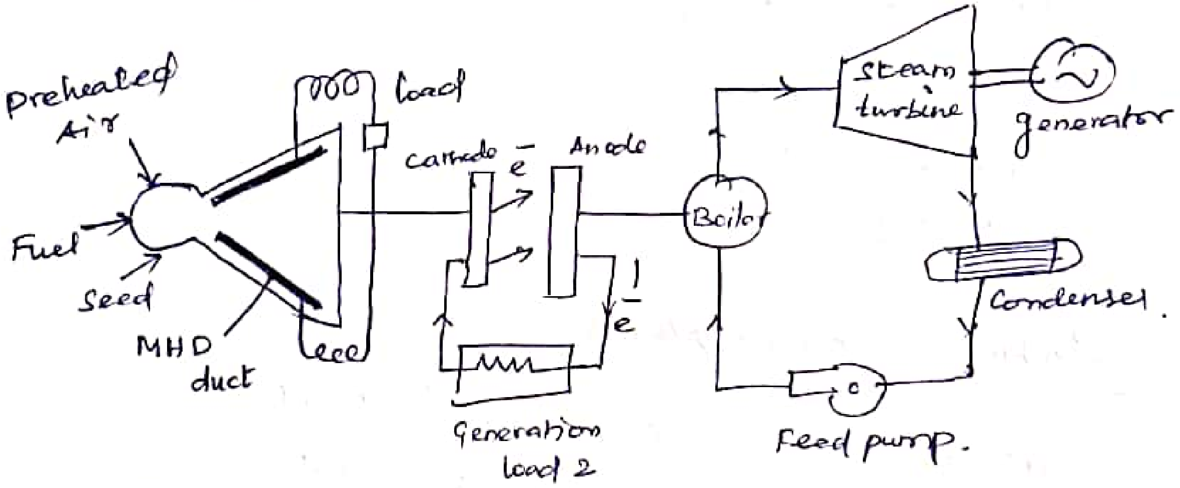


T.S diagram

MHD - Thermo ionic power plant :-

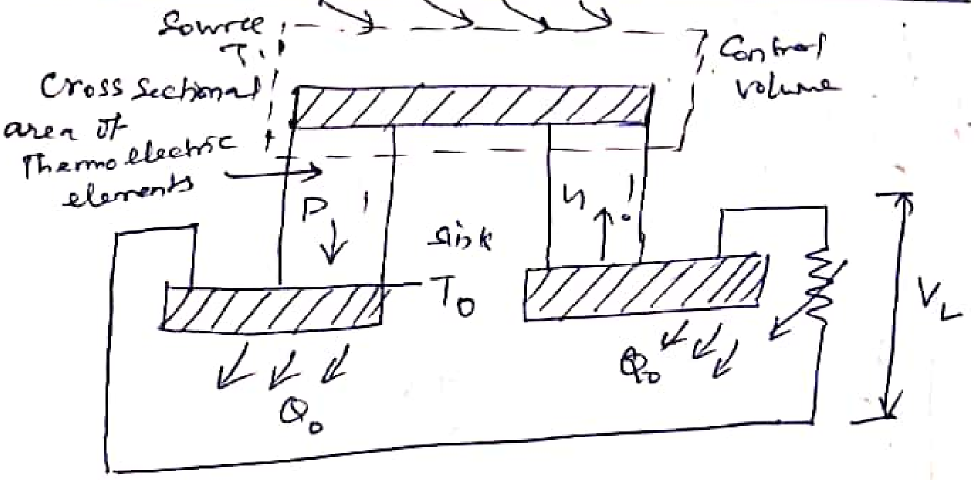
principles of thermionic power generation :-

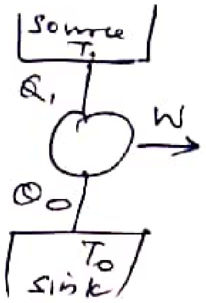




A Combined MHD - thermionic steam power plant.

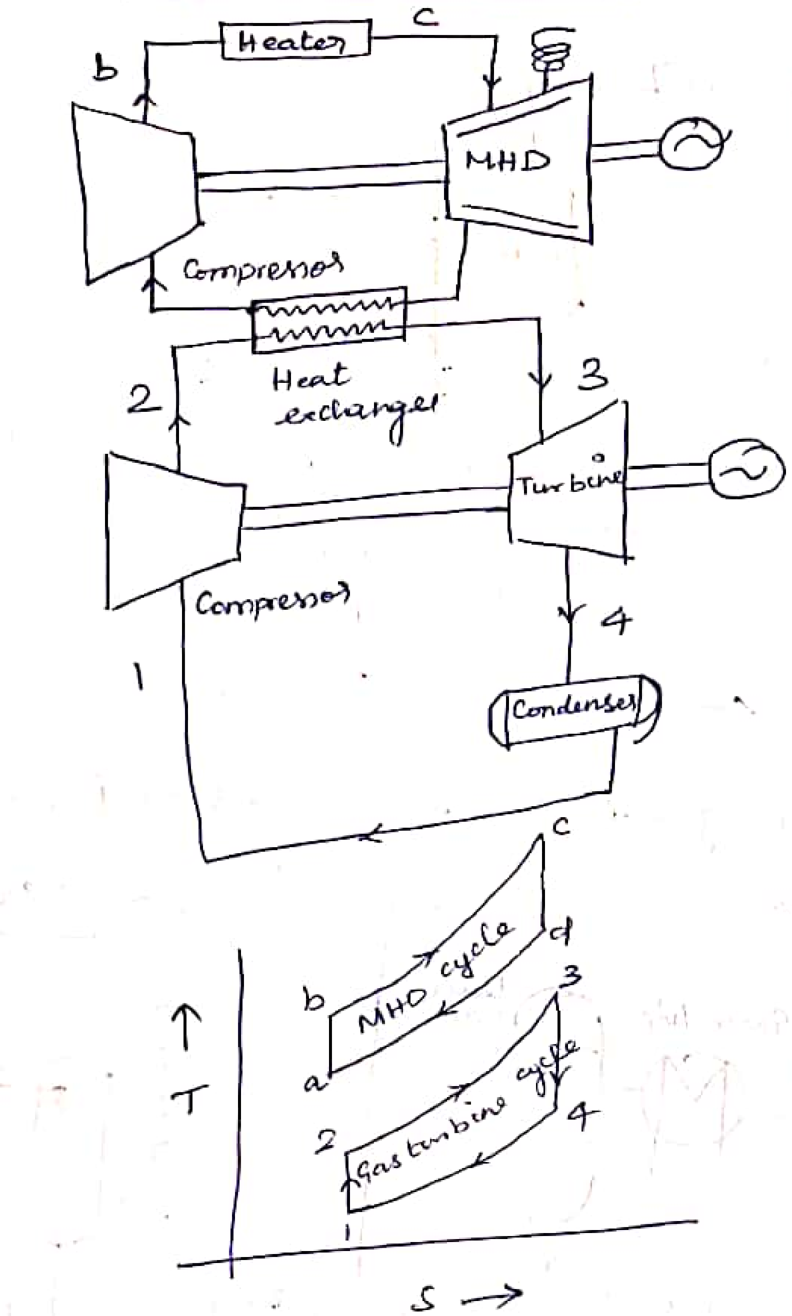
③ Thermo Electric steam power plant :-



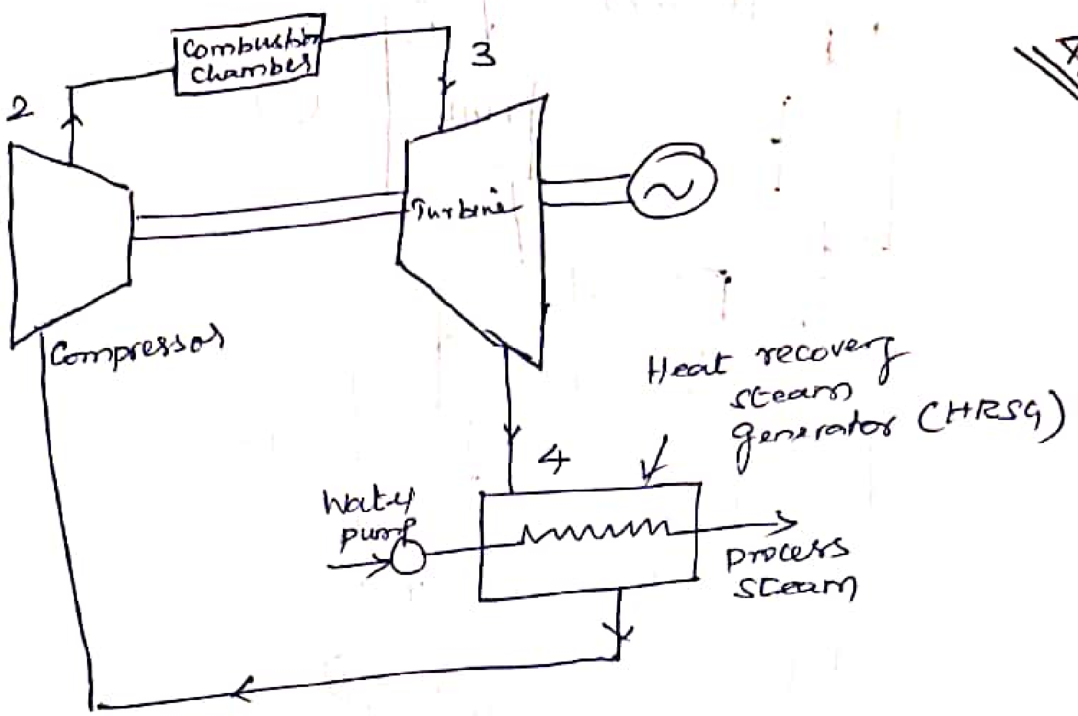


Combined MHD - Gas turbine power plant:-

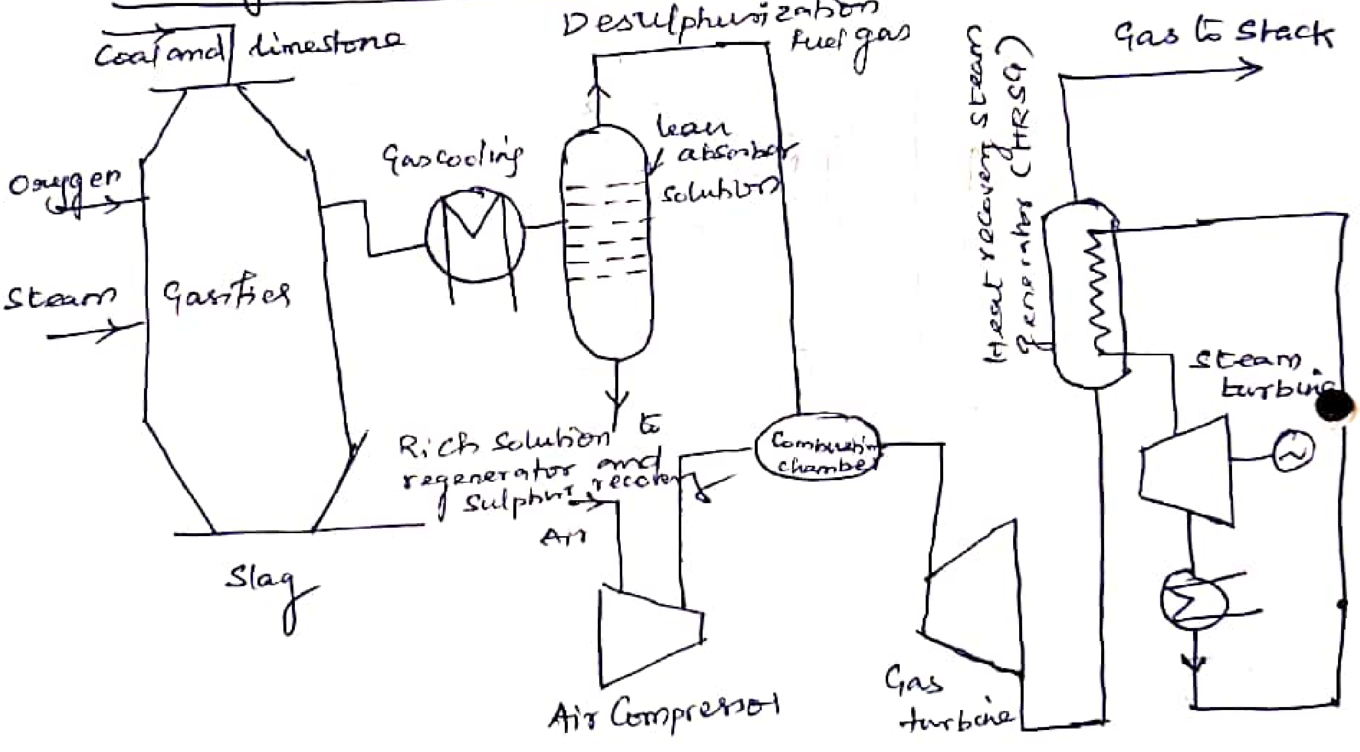
II - (4)



Combined gas turbine and cogeneration power plant:-



Integrated gasifier combined plant:- (IGC cycle)



→ gasification, gas clean up and gas turbines unit.

→ generation of electricity More efficient

→ More efficient environment.

→ reduce cost.

→ fuel flexibility

→ greater η.

→ low pollutant.

→ solid, liquid as well as. Natural gas.

UNIT - III

NUCLEAR POWER PLANT

Elementry Theory of Nuclear Engineering :-

(a) Atomic structure.

(b) Atomic Number & Mass Number.

(c) Isotopes

(d) Atomic mass unit

(e) Nuclear binding energy

(f) Radioactivity

(i) Radioactive dating

(j) Half-life.

(h) Mass defect of Nuclei.

Nuclear fuels

(1) $_{92}U^{238} = 99.28\%$

(2) $_{92}U^{235} = 0.714\%$

(3) $_{92}U^{234} = 6.006\%$

Secondary fuel

U^{233}

PU^{239}

Artifically produced

Th^{232}

U^{238}

Uranium situated :-

USA - 33%.

Africa - 20%.

Australia - 20%.

Canada - 20%.

Fuel

(1) Fissible fuels

(2) Fertile fuels.

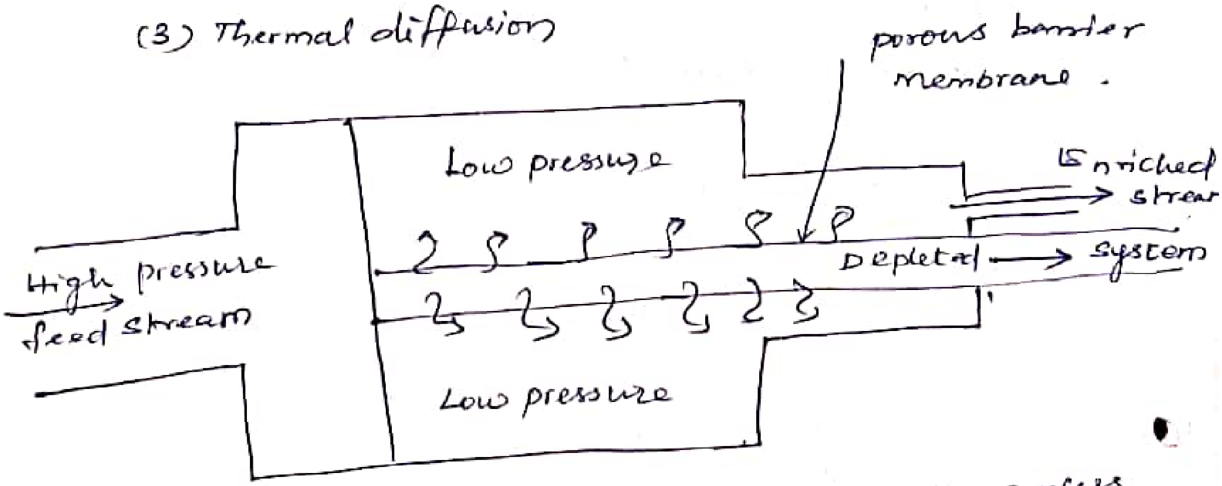
Uranium enrichment :-

Methods :-

(1) Gas Centrifuge

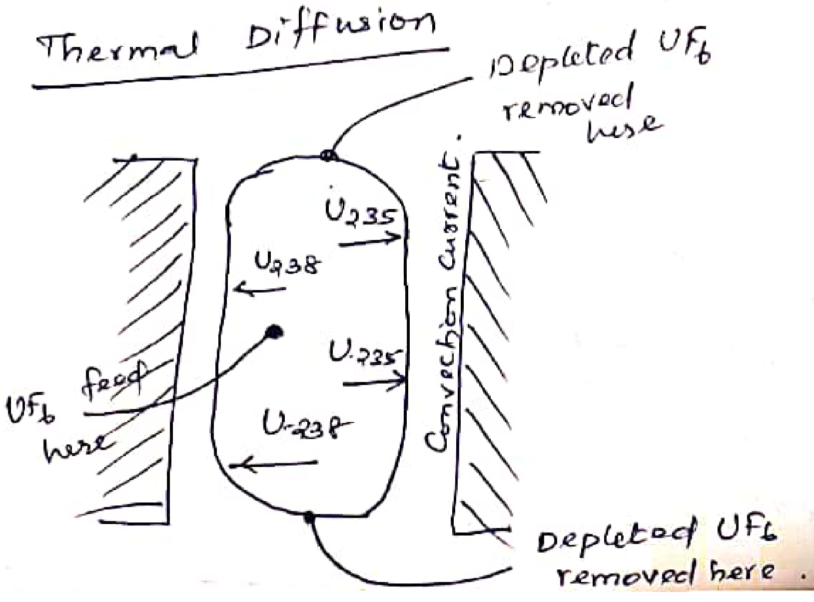
(2) Gaseous diffusion

(3) Thermal diffusion

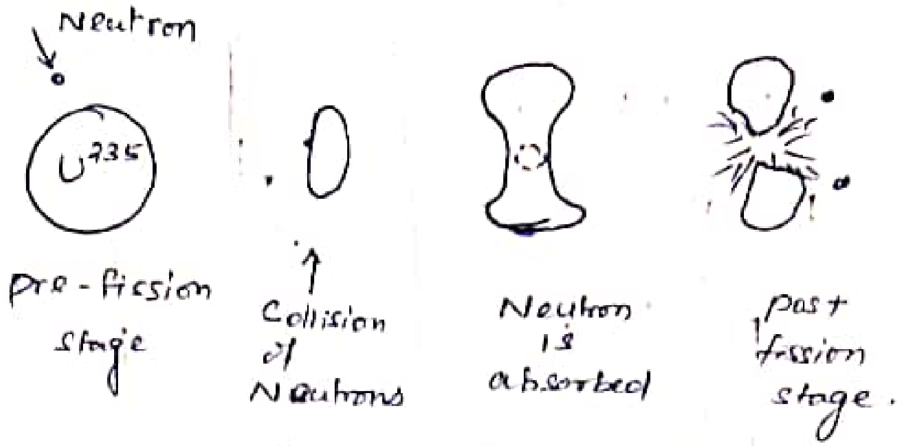


Gas diffusion uranium enrichment process.

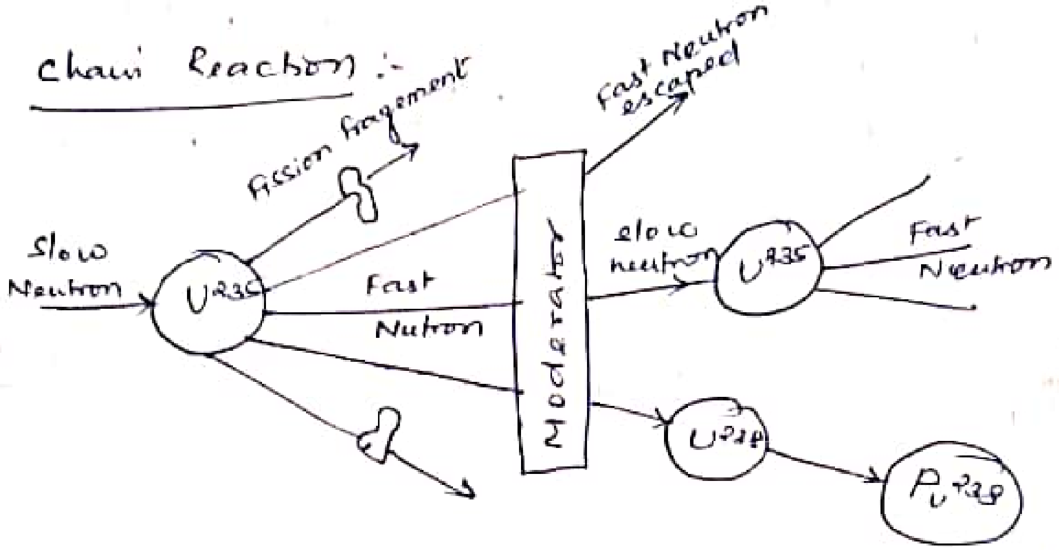
Thermal Diffusion



Nuclear fission:- Splitting of Nucleus.



Chain Reaction:-



$$K = \frac{\text{Number of Neutrons in any particular generation}}{\text{Number of Neutrons in the preceding generation}}.$$

Main Compenements of Nuclear power plant:-

→ Nuclear reactor

→ Heat exchanger or steam generation

→ Steam turbine

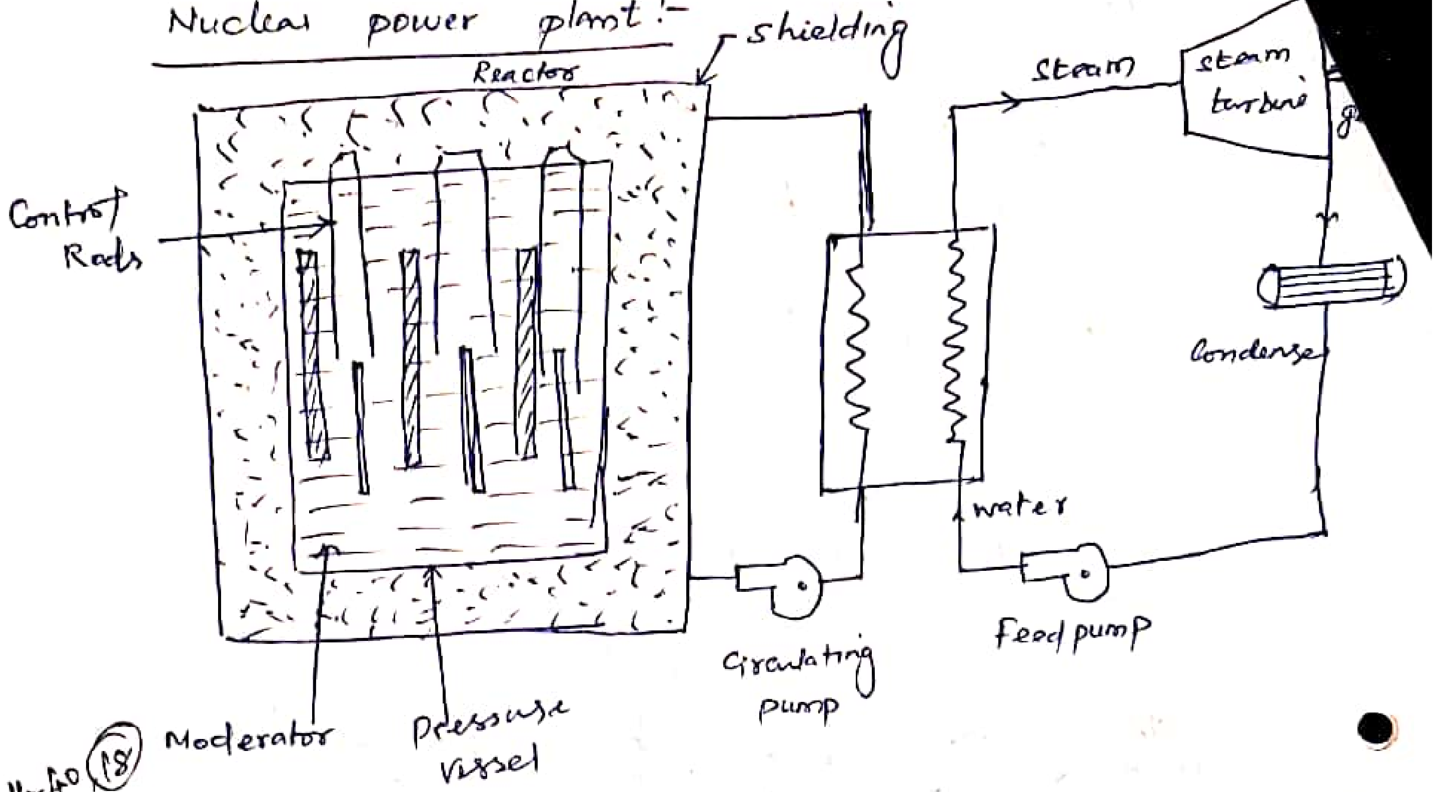
→ Condenser.

→ Electric generator.

Main Components of a Nuclear reactor:-

(1) Reactor core
(2) Moderator
(3) Control rods
(4) Reflector
(5) Cooling system
(6) Reactor vessel.
(7) Bio logical shielding.

Nuclear power plant :-



20, 14, 40, ⑱
4, 24, 28, 16
36, 30, 17, 12
21, 32,

Factors Controlling the selection of a particular type of a Reactor :-

(1) Neutrons energy

(2) Type of fuel.

(3) Type of coolant

(4) Type of moderators.

(5) Construction of core

Classification of Nuclear Reactors :-

(1) According to the Neutrons energy

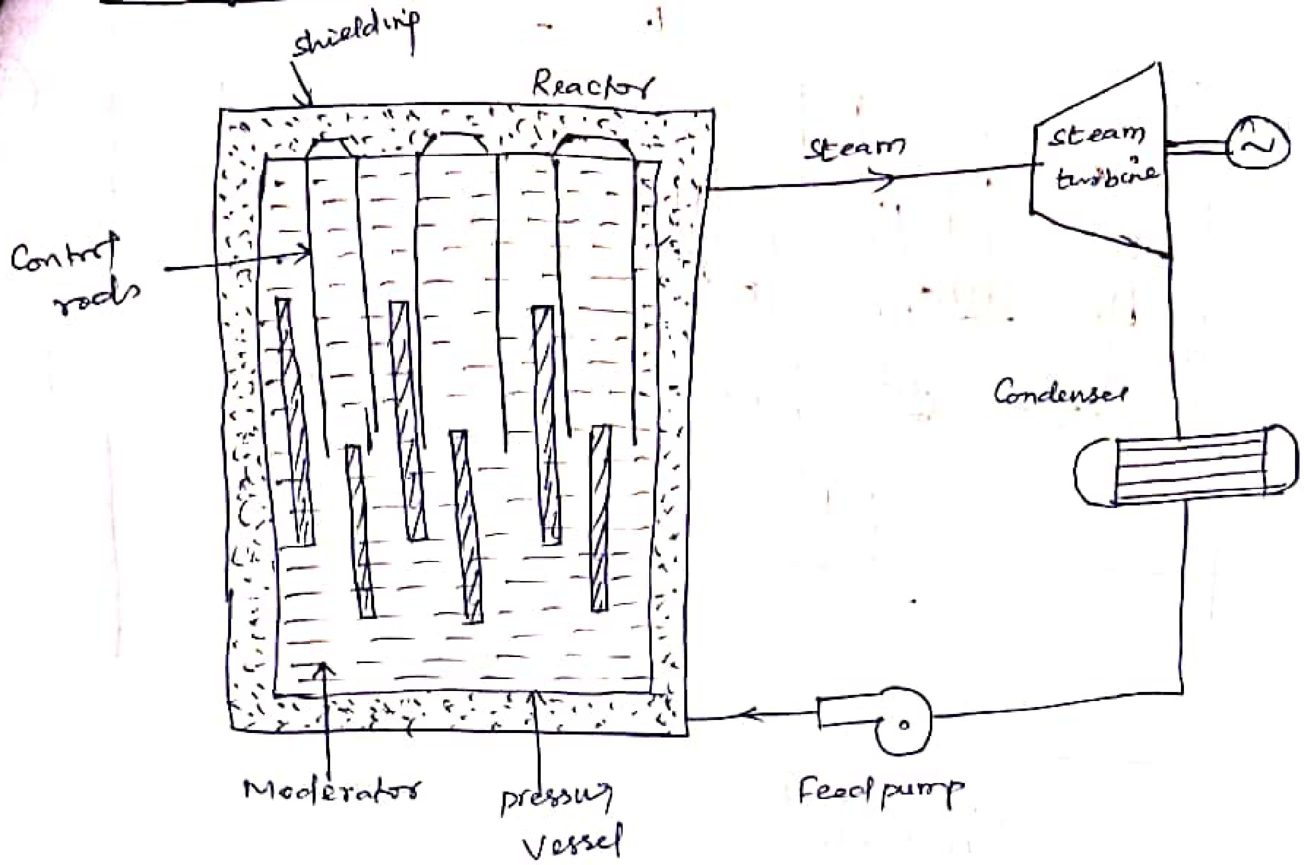
(2) According to the fuel used.

(3) According to the type of Coolant used.

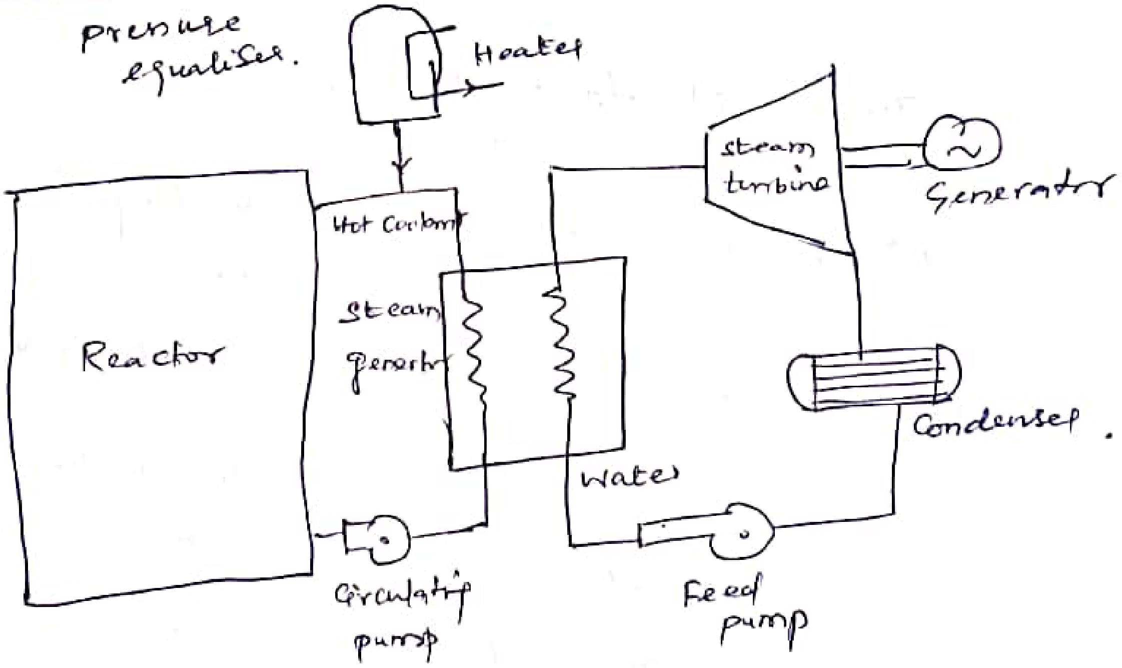
(4) According to the type moderators used

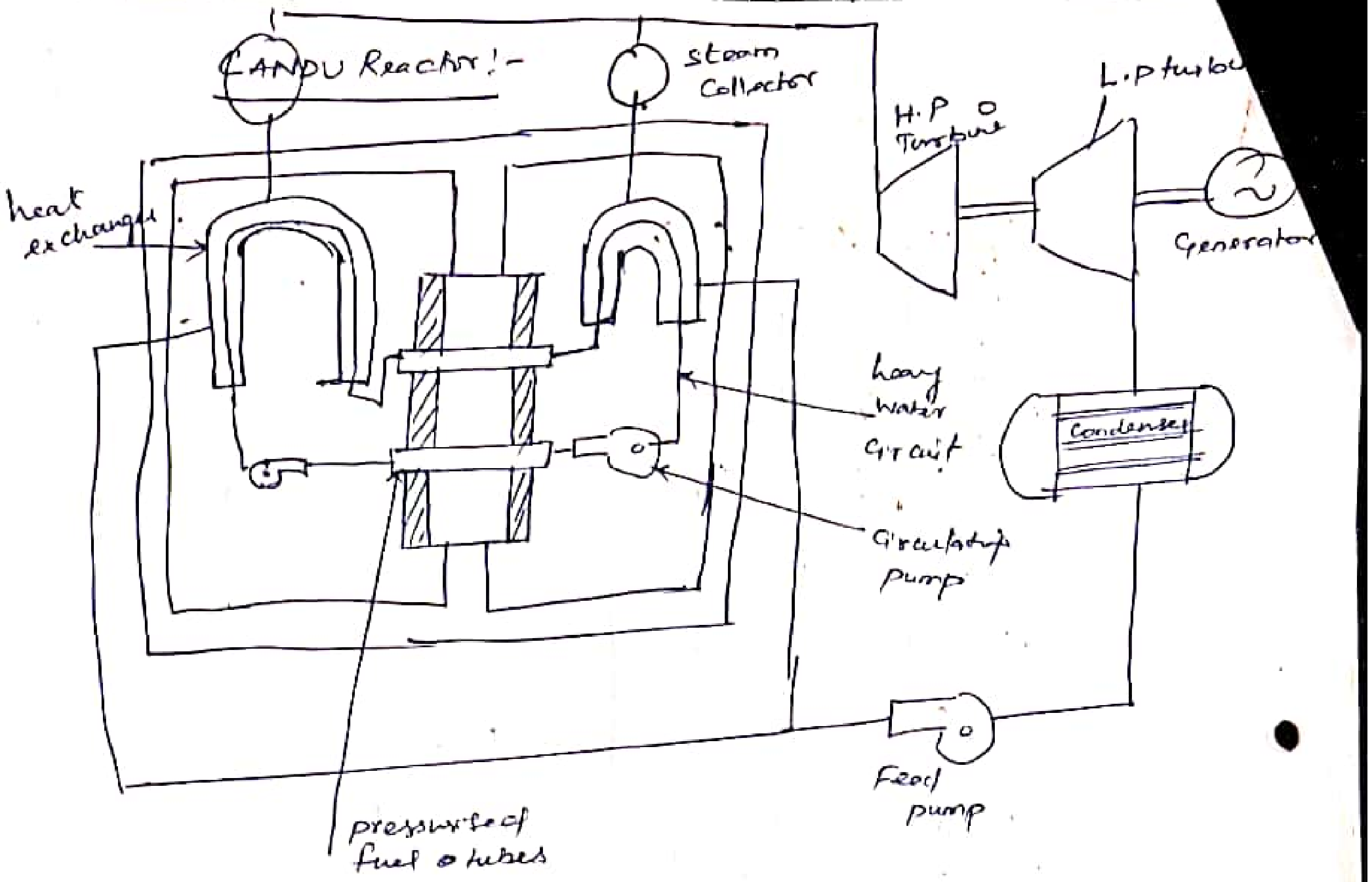
(5) According to the construction of core.

Boiling Water reactor



pressurised Water reactor:- (PWR)





CANDU reactor

Types of fast breeding Reactors :-

(1) GFBR :- gas cooled fast Breeding Reactor system cooled with helium.

(2) LMFBR :- liquid metal cooled Fast Breeding Reactor

(a) SFBR : Sodium Fast Breeding Reactor

(b) LFR :- Lead Fast Reactor cooled with lead.

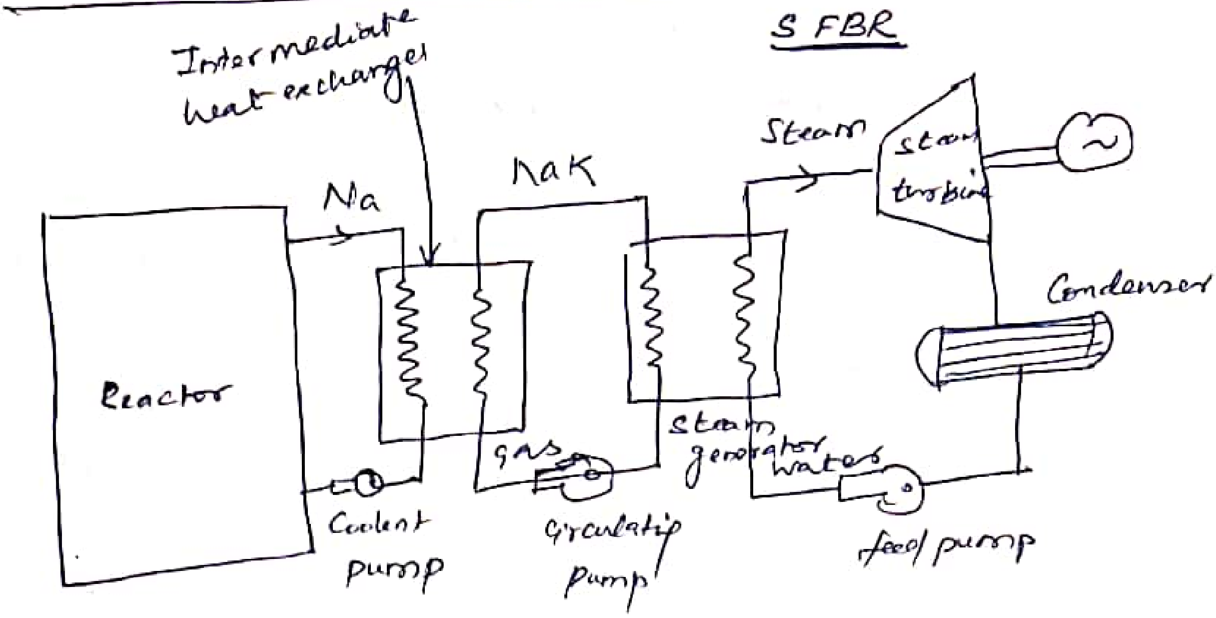
(c) MSR :- Molten salt Reactor fuelled with molten salts.

(d) SCWR :- Super. critical water cooled reactor.

(3) VHTR - Very high Temp. reactor cooled with helium at 1000°C.

Sodium cooled fast Breeder Reactor

SFBR



Selection of the site for Nuclear power station :-

1. Proximity to load centre.
2. Population distribution
3. Land use
4. Metrology
5. Geology
6. Hydrology
7. Seismology.

Safety in Design of Nuclear power plant :-

→ Control of fission reaction

→ Cooling of the reactor core

→ Containment of the radioactive fussion products.

(i) Control of Reactor

(ii) Maintenance of core cooling

(iii) Containment of radioactivity

Criteria for safety of Nuclear power plant:-

(1) There is no unreasonable risk

(2) Adequate protection of public health and safety are achieved.

(3) The risk is reasonably low

(4) Safety is as high as reasonably achievable

(5) It limits the risk by use of best technology at acceptable economic costs.

Safety of modern Nuclear power plant:-

1. First layer of defence is the inert, ceramic quality of the Uranium oxide itself.

2. second ~~year~~ layer is the air tight zirconium alloy of the fuel rod.

3. Third layer is the reactor pressure vessel made of steel more than a dozen centimeters thick.

4. Fourth layer is the pressure resistant and air tight ~~champer~~ containment building.

5. fifth layer is the reactor building (or) newer power plants is the second outer containment building.

Engineered Nuclear power plant safety III - ⑤

Features :-

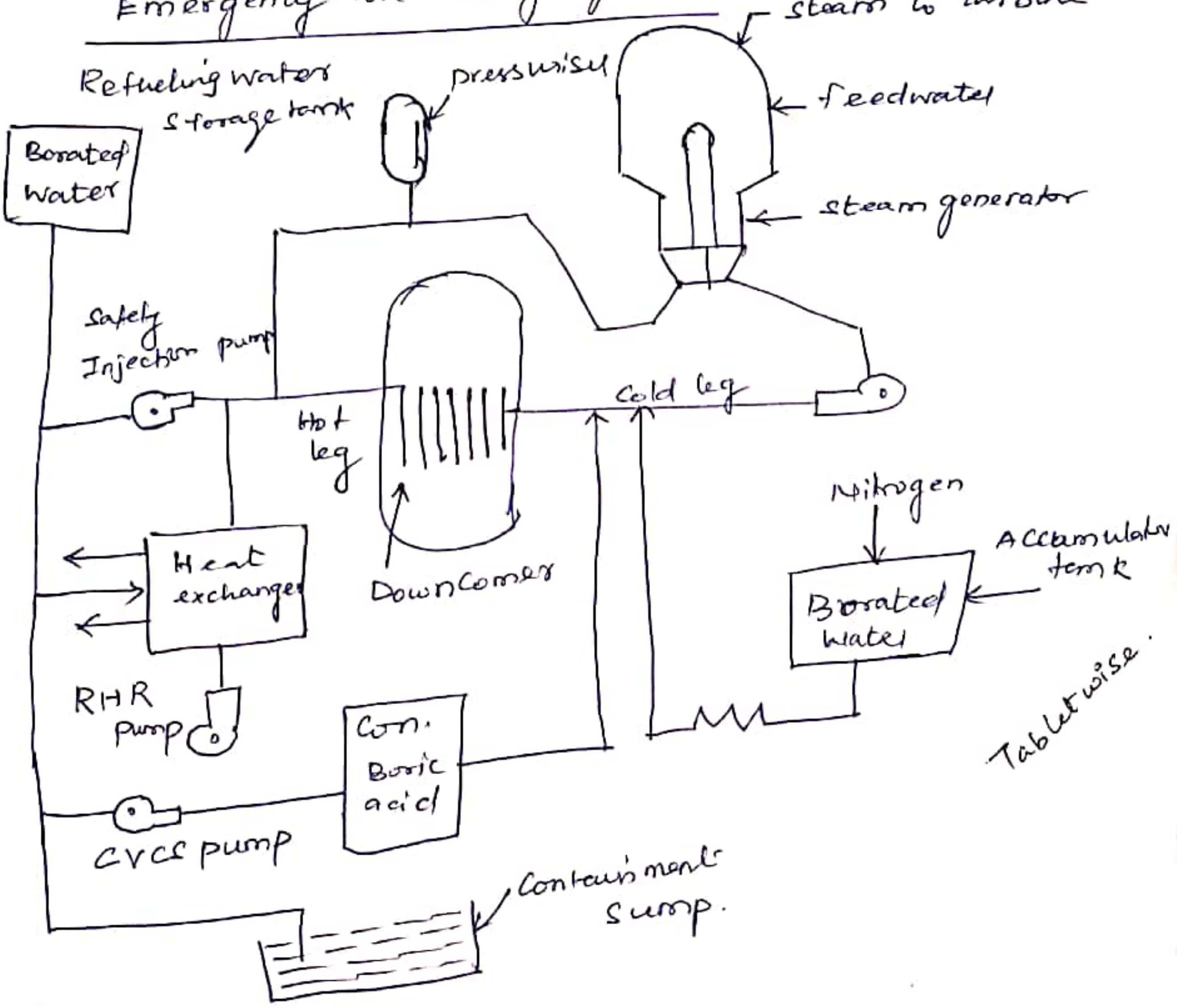
(1) Emergency cooling system is to supply water to the reactor core in the event of a loss of coolant accident.

(2) The containment vessel is to provide a barrier to the escape to the environment of radioactivity.

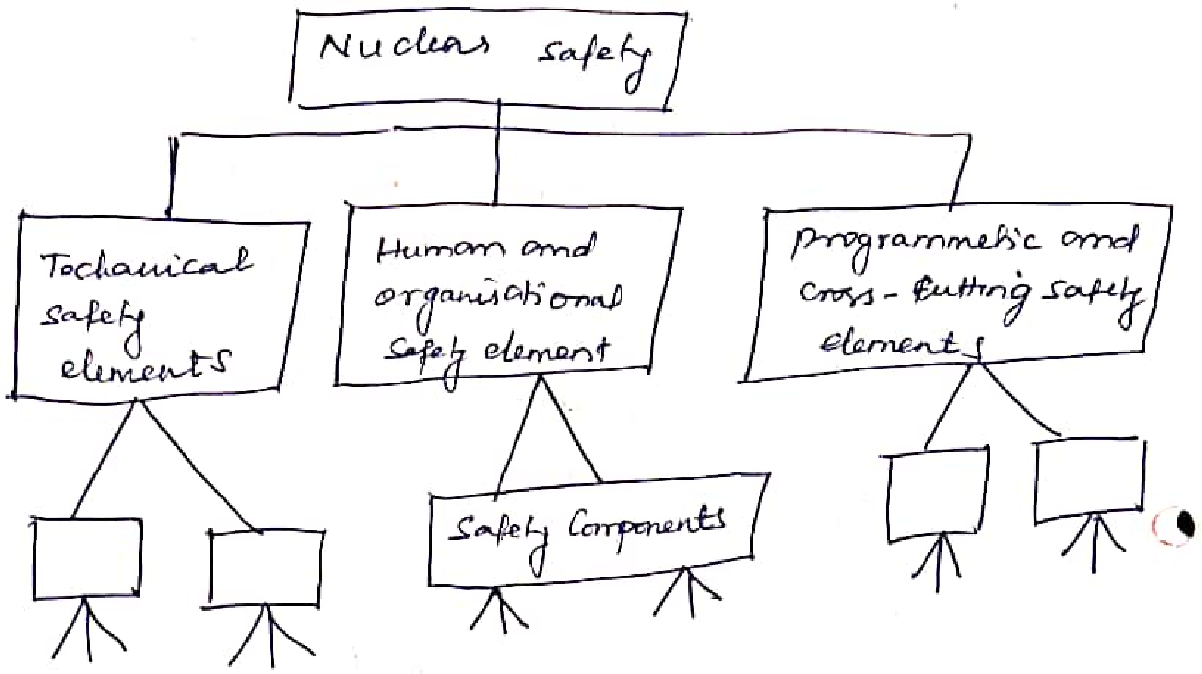
(3) It has a cleanup system for removing the part of the radioactivity and heat which may be present in the contamination atmosphere

(4) hydrogen control is to prevent the formation of explosive hydrogen - oxygen mixture in the containment.

Emergency Core Cooling system :-



Relationship between safety elements, components ... and aircrafts:-



UNIT - IV

Power from Renewable energy:-

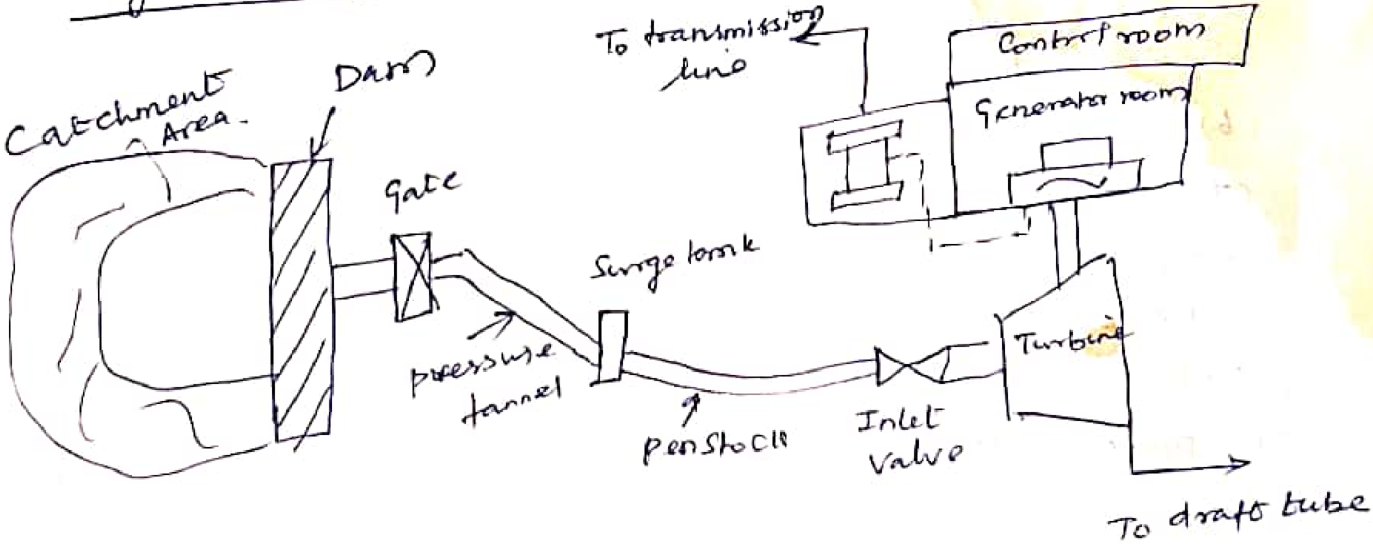
1. classification of hydro electric power plant:-

(1) ~~low~~ classification according to the avilability of head.
- (a) low heat power plant.
- (b) Medium heat power plant
- (c) high head power plant.

(2) classification according to the Nature of load
- (a) Base load plant
- (b) peak load plant

(3) classification according to the quantity of water aviability
- 1. Run-off River plant without pondage
- 2. Run-off River plant with pondage
- 3. pumped storage plant.

Layout out hydro electric power plant:-



Component of Hydro-electric power plant

(1) water Reservior.

(2) Dam
  (a) Based on functional served
  (b) Based on hydraulic design
  (c) Based on materials of construction
  (d) Based on rigidity
  (e) Based on the structural action.

(3) spil way
  (a) Controlled spillway
  (2) chute spillway
  (3) cascade or stepped fillway
  (4) Side Channel spillway
  (5) Shaft spillway.
  Uncontrolled spillway
  (1) Bell Mouth spillway
  (2) straight drop spillway
  (3) overflow spillway

(4) Trash Rack

(5) Forebay

(6) Water Tunnel

(7) Cannals

(8) penstock

(9) surge Tank

(10) Water turbine .

(11) Draft tube

(12) Tail rice

(13) power house

(14)

selection of a site hydro electric power plant :-

(1) water availability

(2) water storage

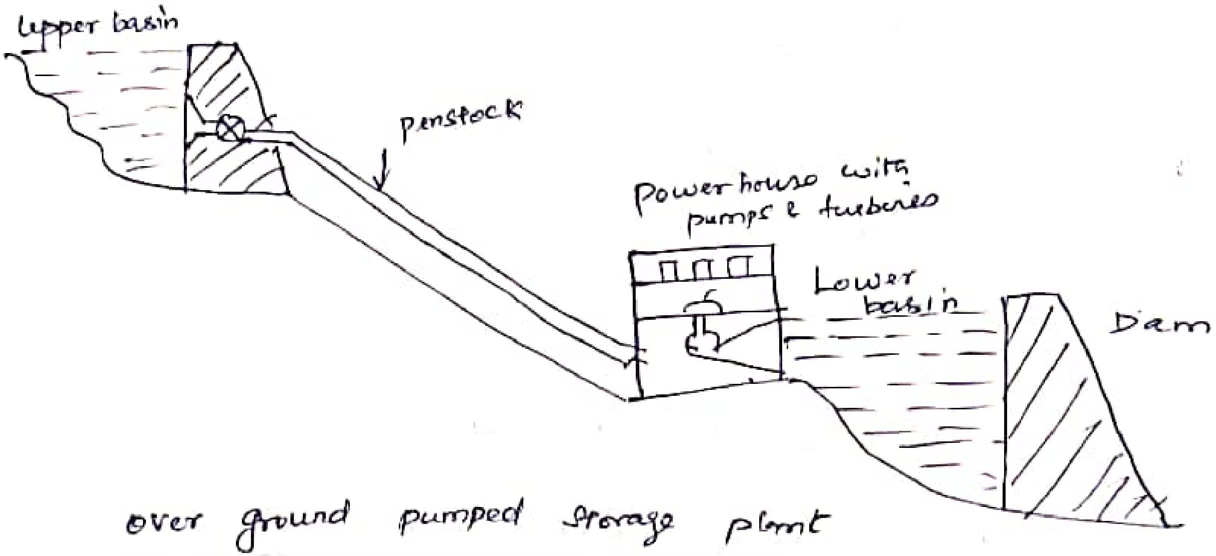
(3) water head

(4) various geological investigation.

(5) Environmental aspects.

(6) consideration of water pollution effects.

pumped storage plant :-



over ground pumped storage plant

1. operating ~~pum~~ . modes of a pumped storage hydel plant.

1.	off peak hours	Motor-pump	Electrical 4 Hydro
2.	peak-load hours	Turbine-generator	Hydro to electrical.

2. Types of pumped storage
   1. over ground
   2. under ground

3. Over ground storage plant.
   1. upper basin
   2. Dam
   3.

Factors to be Considered to select the right ty of turbine :-

1. Rotational speed of the turbine.
2. specific speed
3. Maximum efficiency
4. part load efficiency.
5. Head
6. Type of water
7. Runway speed
8. cavitation
9. Number of turbine units
10. overall cost.

Wind energy Resources:-

Characteristics of wind energy :-

1. Wind-power system do not pollute the atmosphere.
2. Fuel provision and transport are not required in wind-power systems.
3. Wind energy is a renewable source of energy
4. Wind energy when produced on small scale is Cheap but it is Competitive with Conventional power generating system when produced on a large scale.

Advantage & Disadvantage of energy Conversion

Advantage :-

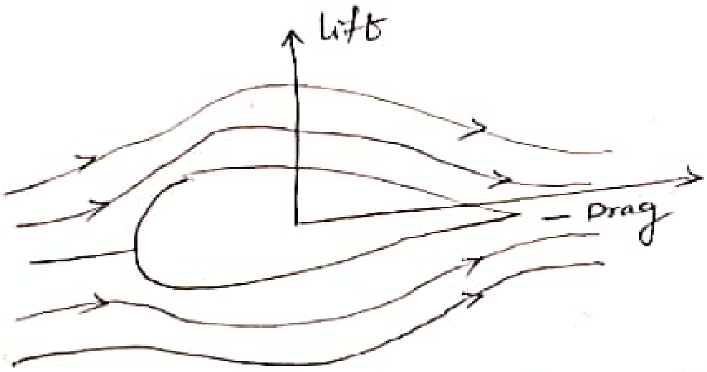
1. clean
2. free
3. place-ability

4. De centralized
5. Domestic
6. Remote area supply

Disadvantage :-

1. Reliability
2. Expenses
3. National security
4. Noise
5. Wildlife
6. Aesthetics.

principle of wind energy conversion:-

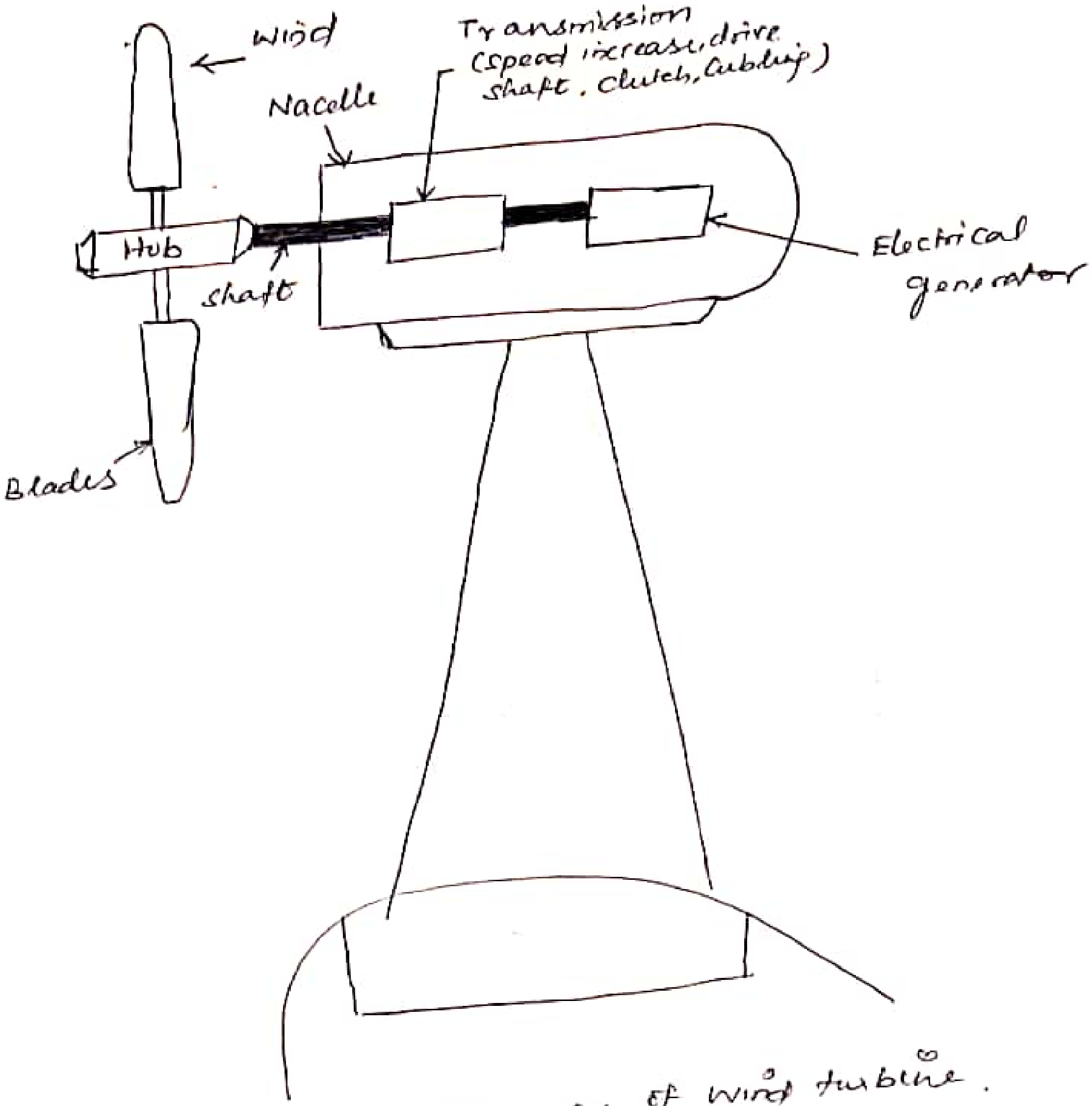


Lift and drag force on areafoil

Basic features which characterize lift and drag are as follows.

(1) Drag is in the direction of airflow.
(2) lift is perpendicular to the direction of airflow.
(3) Generation of lift always causes a certain amount of drag to be developed.
(4) with a good areofoil as shown in fig. the lift produced can be thirty times greater than the drag.
(5) lift devices are generally more efficient than drag devices.

Wind Electric power plant:-



Components of wind turbine.

The main components of wind energy conversion system are as follows:-

- wind turbine
    - Nacelle
    - Rotor the assembly of blades.
    - Hub and shaft.
- Transmission system
- Electrical generator
- Yaw Control system
- Storage
- Energy Converters

IV - ④

18, 52, 14, 45, 51

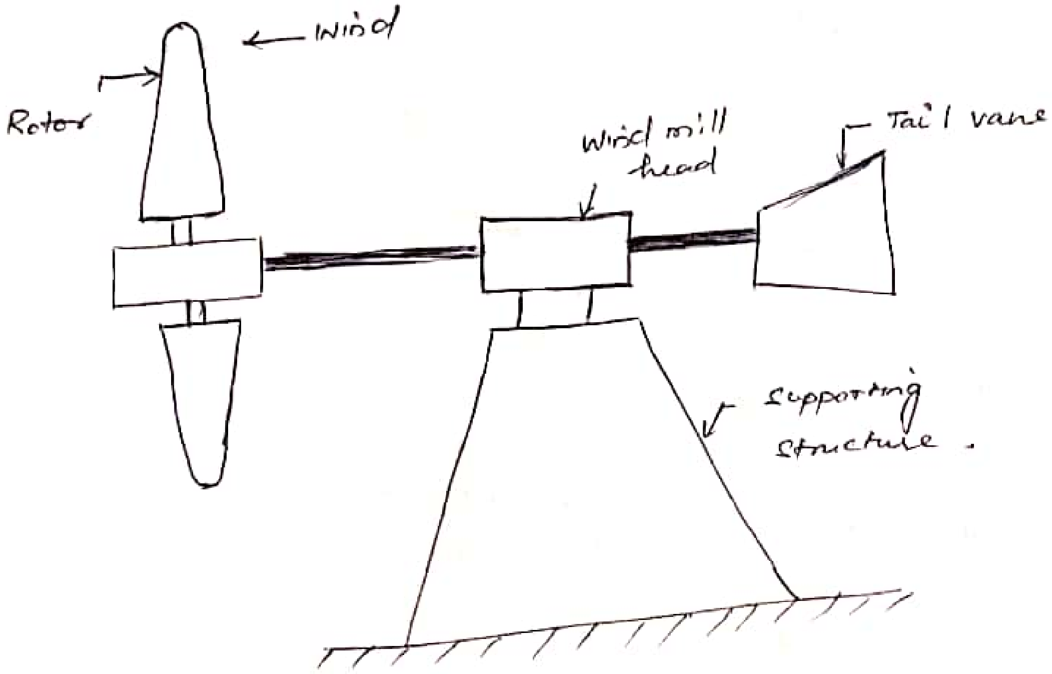
- Energy Converters
- Tower to support the rotor system.

Type of wind energy system :-

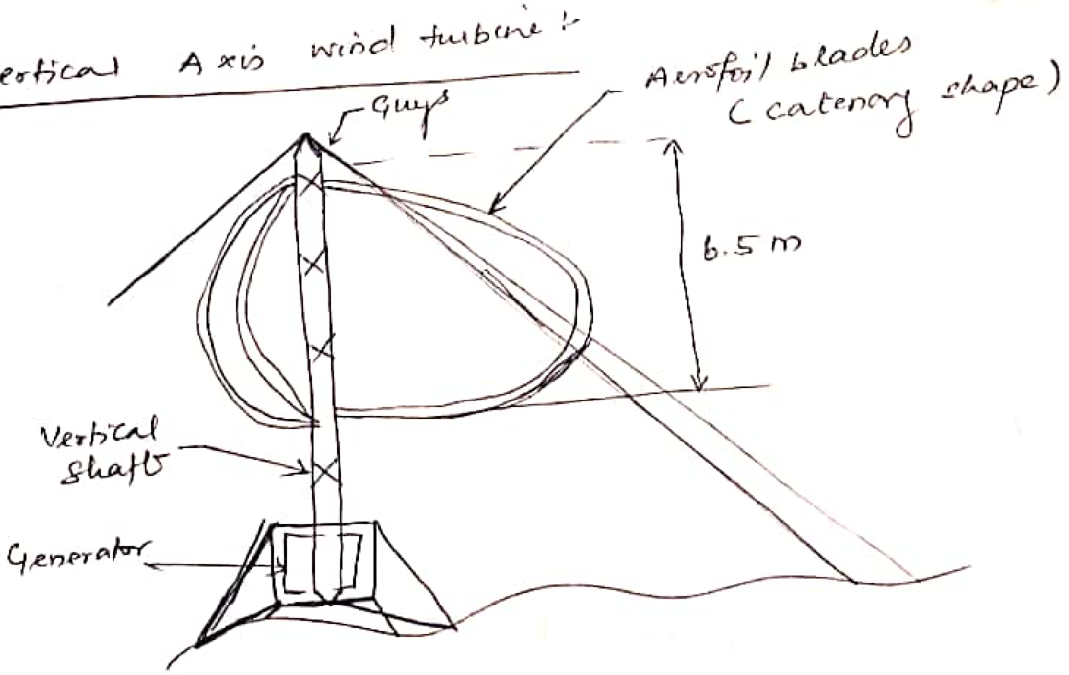
(i) Left type wind turbine

(2) Drag type wind turbine

Horizontal axis wind turbine :-



Vertical Axis wind turbine :-



Various types of Vertical axis wind turbine are as fol

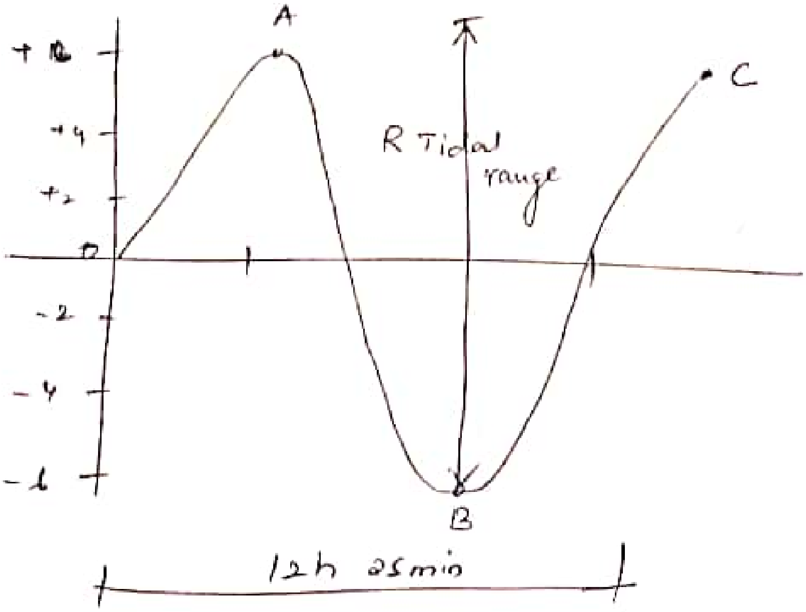
(1) Darrieus rotor
(2) Savonius rotor (turbo Machine)
(3) Multiple blade rotor
(4) Musgrove rotor
(5) Evans rotor

Site selection for wind mill power system:-

(1) plain site
(2) Hill top site
(3) Sea-shore site
(4) off-shore shallow type

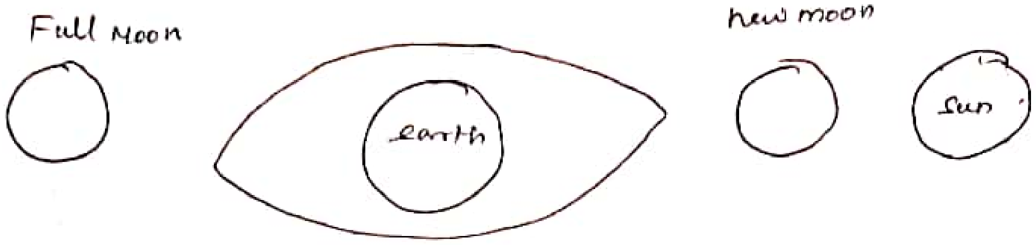
TIDAL Energy

principle of Tide generation:-

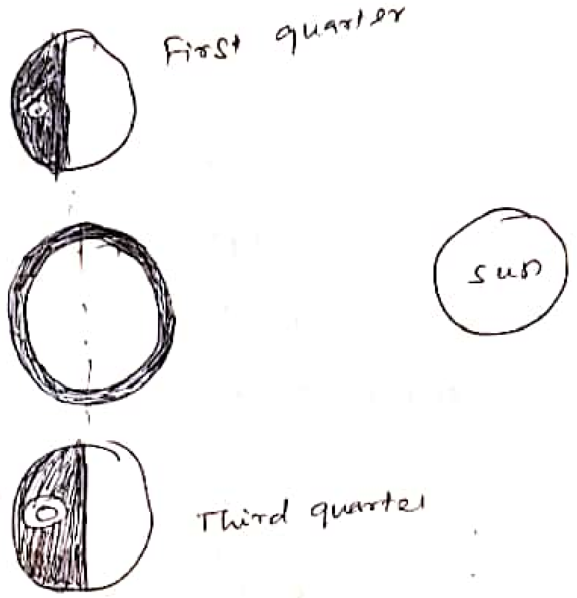


Formation of a tide.

Spring tide



Neap tides:-

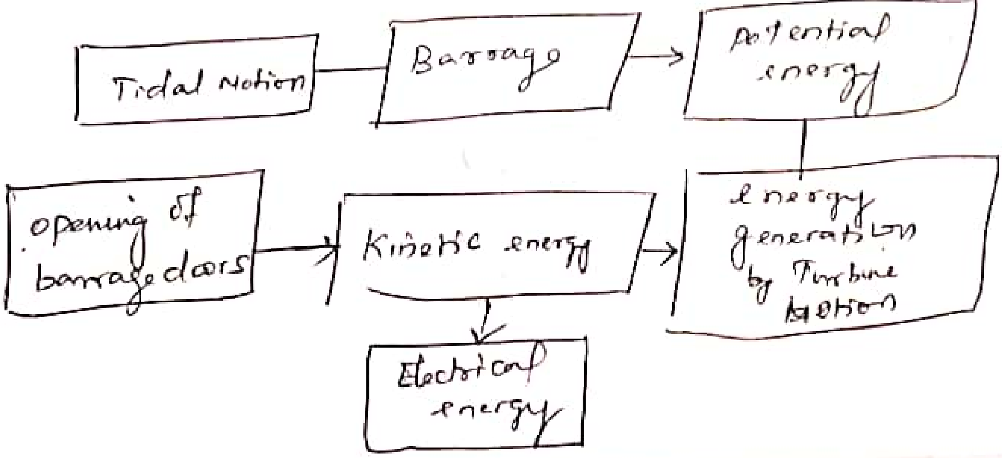


Energy of tide

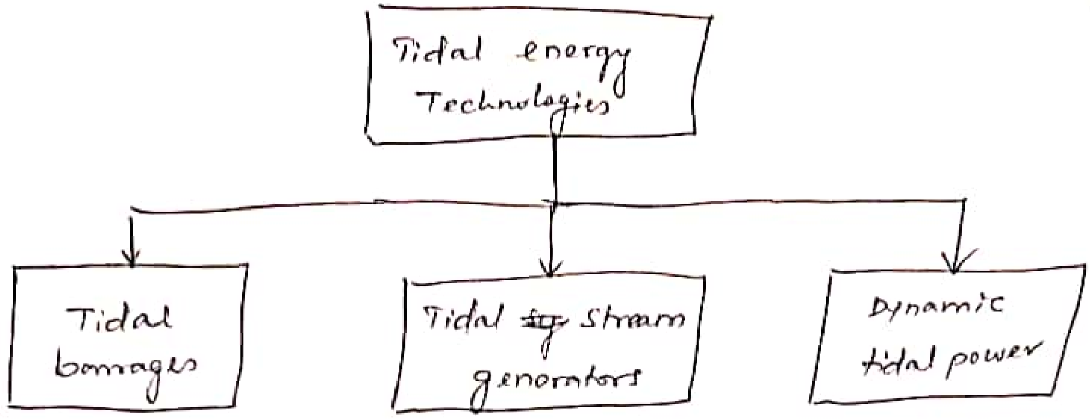
$$E = g\rho A \int z\,dz = 0.5\,g\rho A h^2$$

$$\boxed{E = 5.04\,h^2\ kJ}$$

Transformation of tidal energy to electrical energy



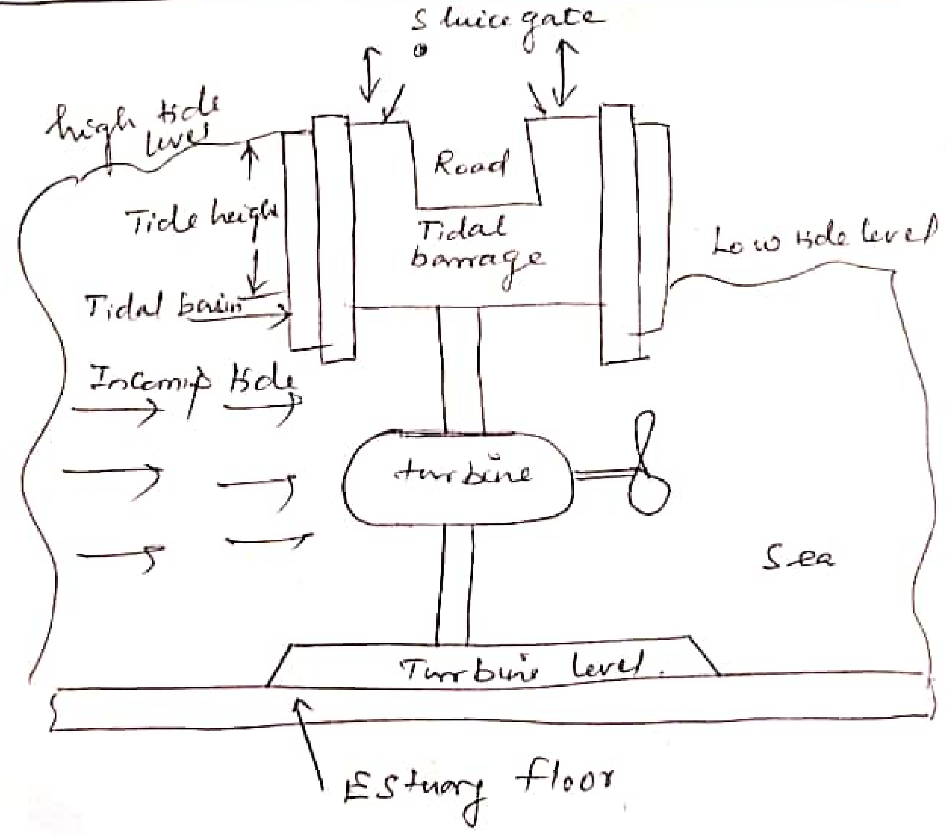
Types of tidal technology



Components of Tidal Barrage power plants :-

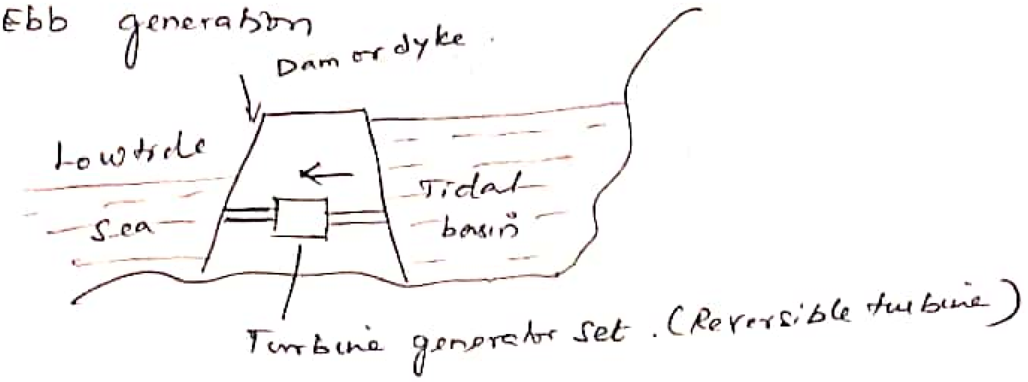
(1) Barrage (or) Dyke or Dam
(2) Sluice ways
(3) Embankments
(4) power house.

Cross section of a typical tidal barrage

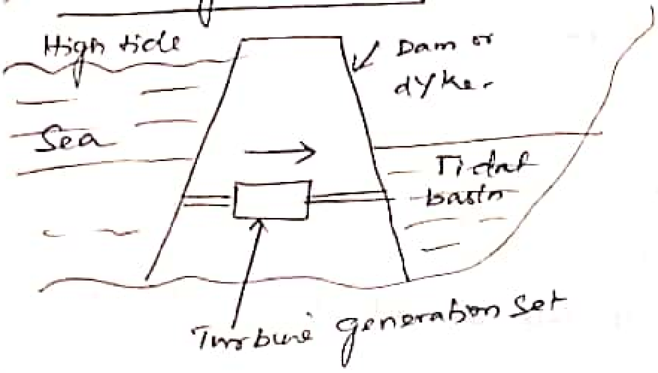


Modes of opeartion of Tidal Barrage power plants

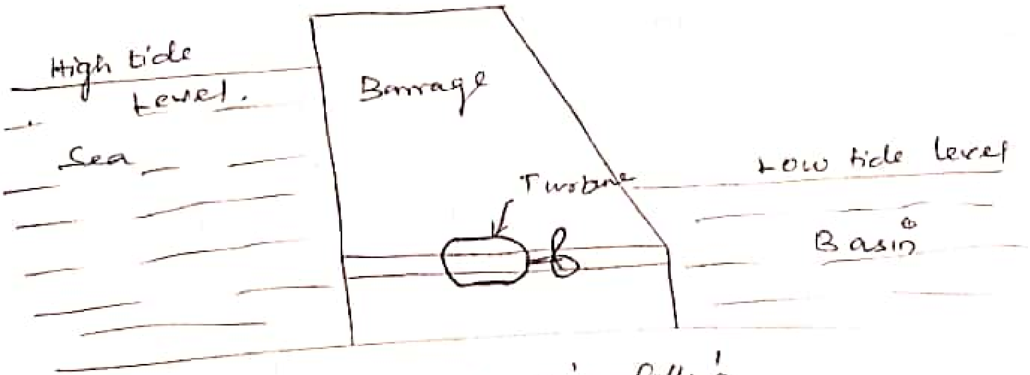
(1) Ebb generation



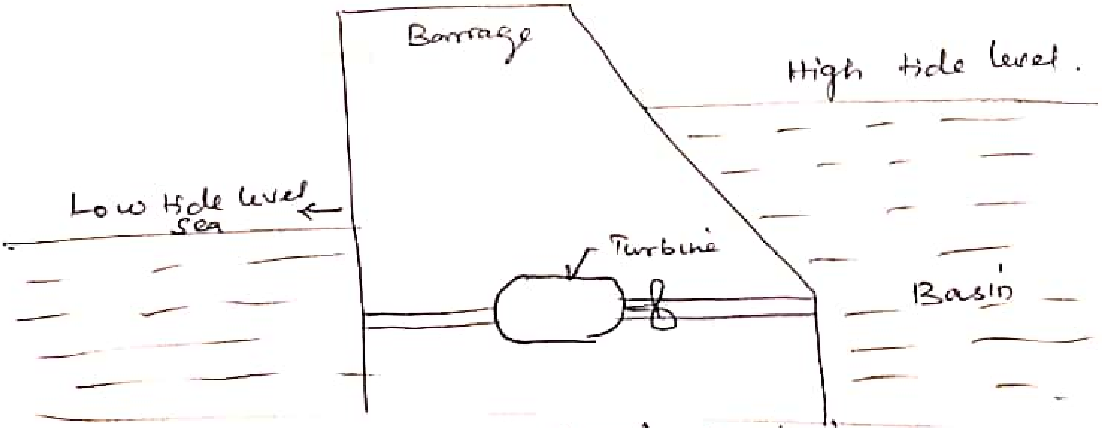
(ii) Flood generation



Two - way generation :-



During filling



During emptying.

Site Selection for tital power plant:-

(a) Short length of dam is to create a basin of reasonable storage. It is possible to a narrow inlet to an estuary to bay.

(b) It should be nearer to local location or nearer to the ocean.

(c) It should be protected from high waves.

(d) It should not hamper shipping traffic

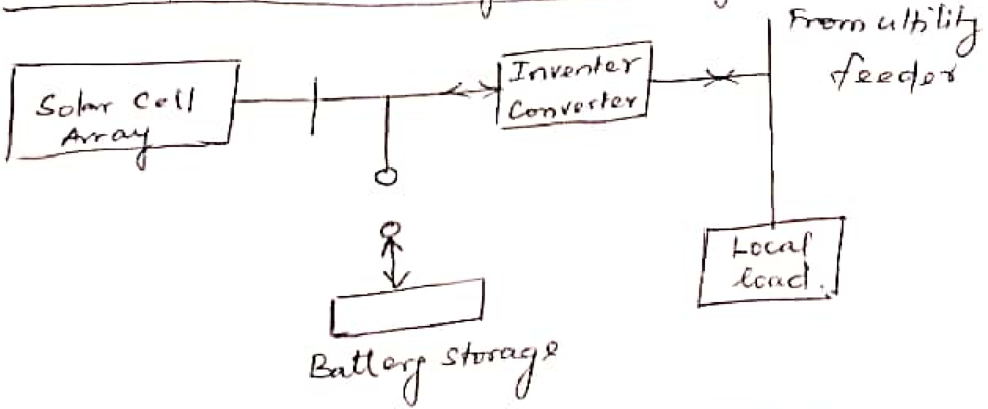
(e) The tidal range of ocean is large

(f) The geographical features of the plant must enclose the large areas with short dams.

(g) The sluice gate of dam should allow water to or from basins.

SOLAR PHOTO VOLTAIC (SPV) power systems:-

Basic photovoltaic system integrated with power grid.



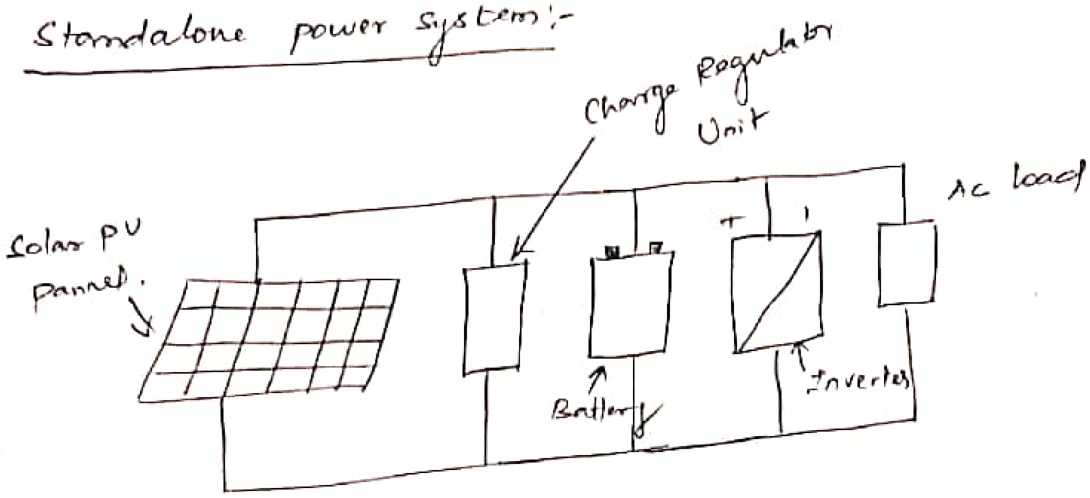
Solar PV power generation system:-

1. Solar array
2. Blocking diode
3. Battery storage
4. Inverter / Converter
5. Switches and circuits.

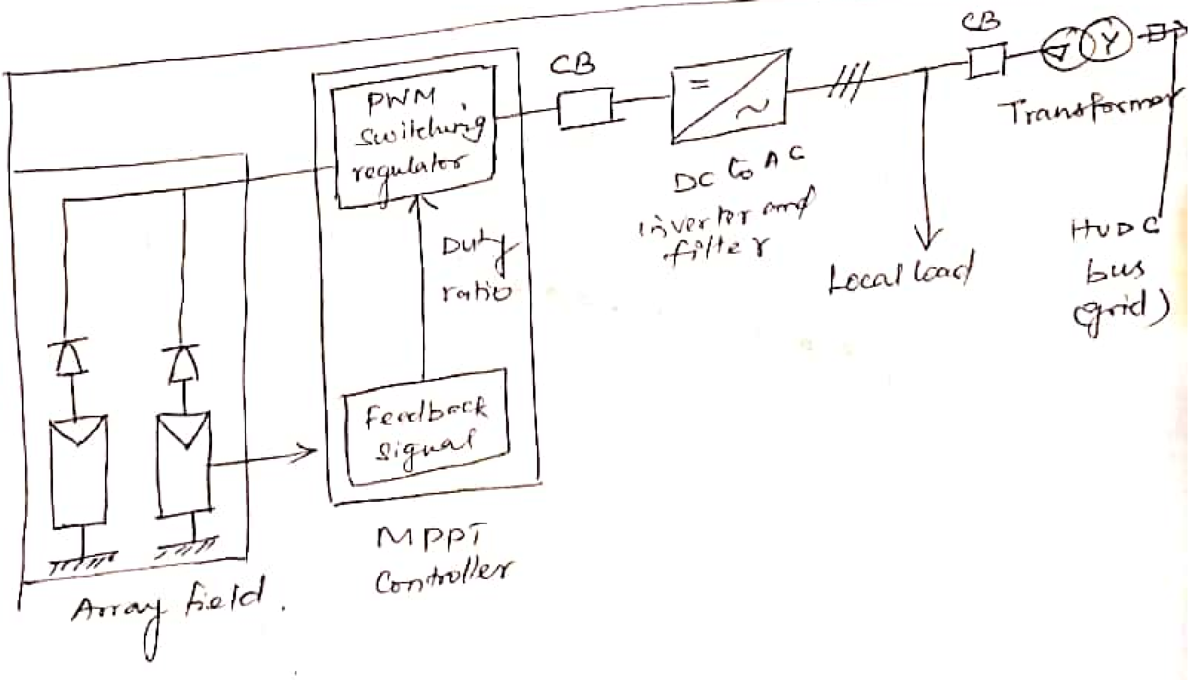
Types of PV power generation systems:-

1. Standalone power system.
2. Central power system or Grid connected system.
3. Hybrid system.

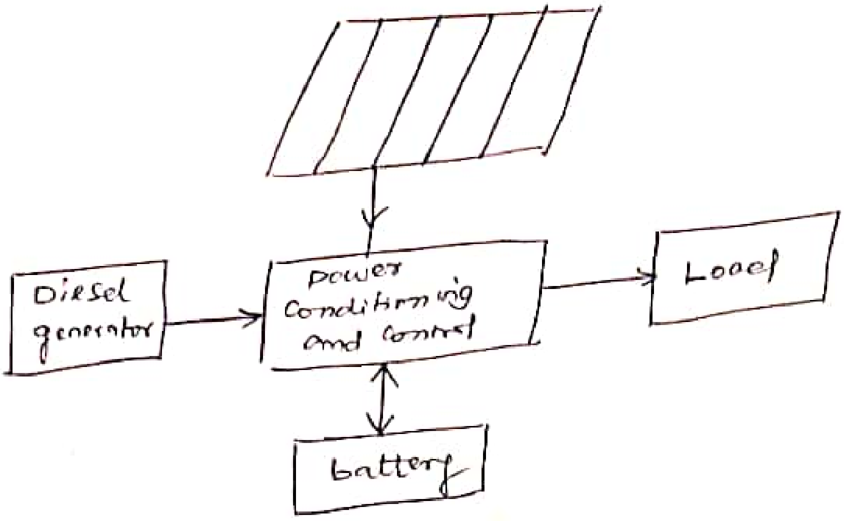
Standalone power system:-



Grid Connection power system:-



PV - diesel hybrid system :-



Solar thermal power system

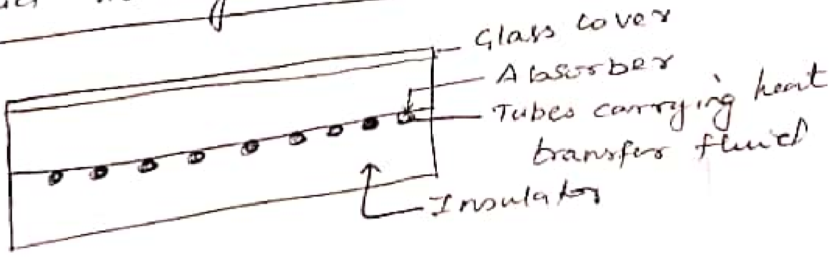
Factor affecting solar collectors system efficiency :-

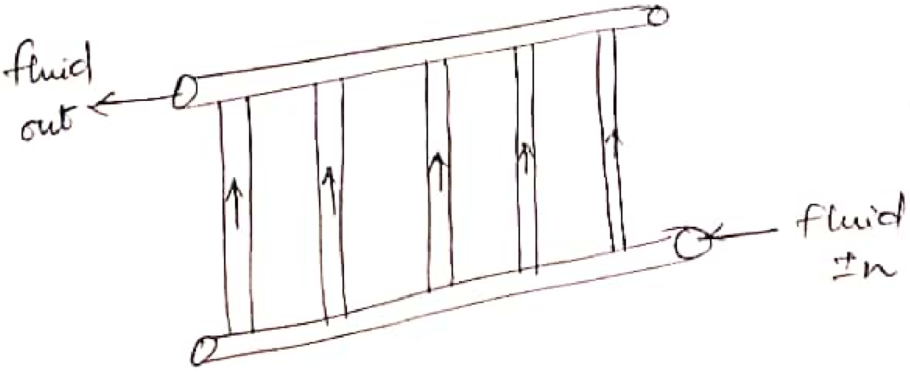
(a) Shadow effect

(b) cosine loss factor

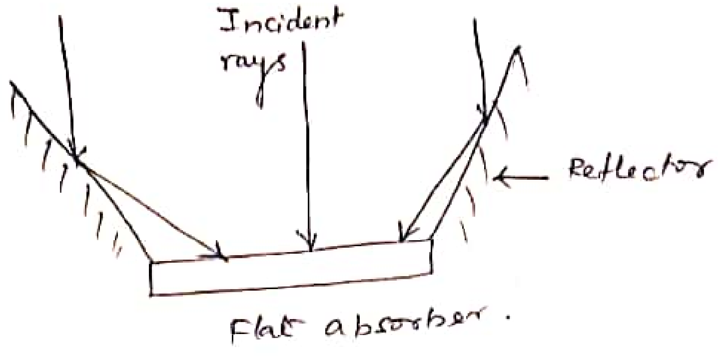
(c) Reflective loss factor

liquid heating Collectors :-

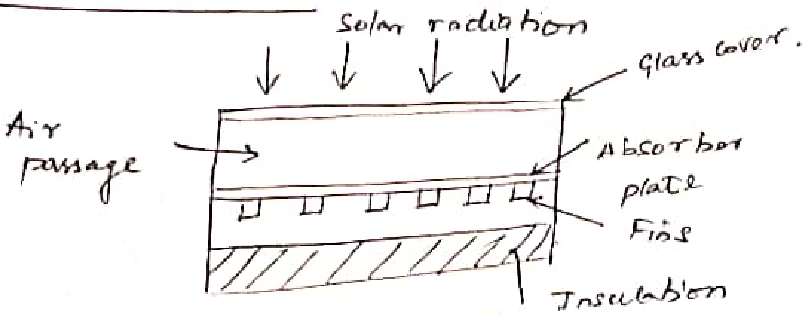




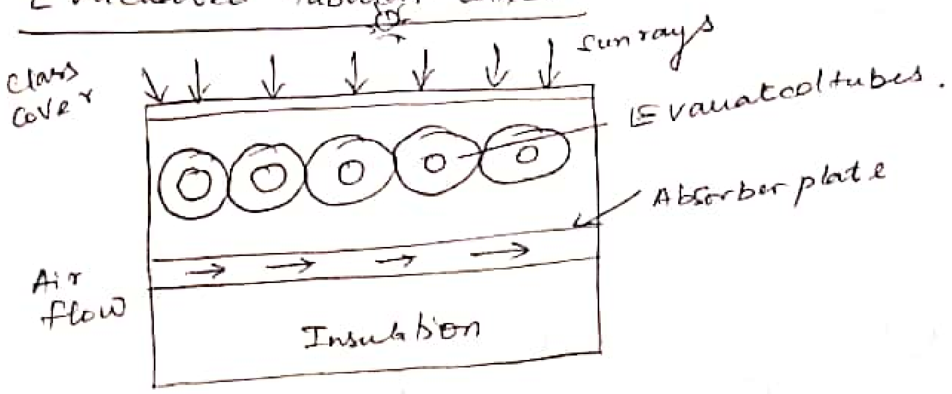
Modified Flat plate Collector



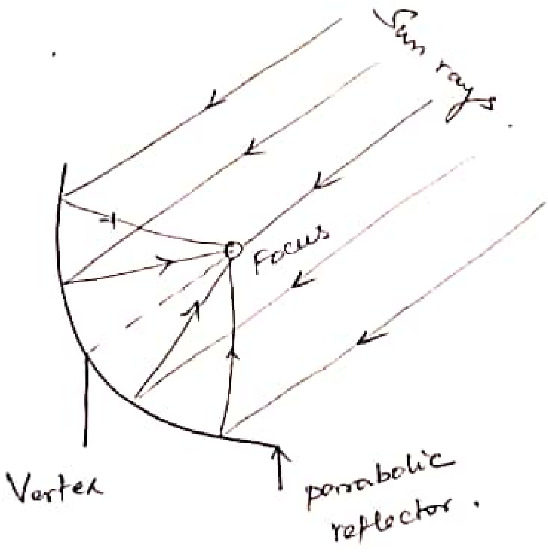
Solar Air heaters:-



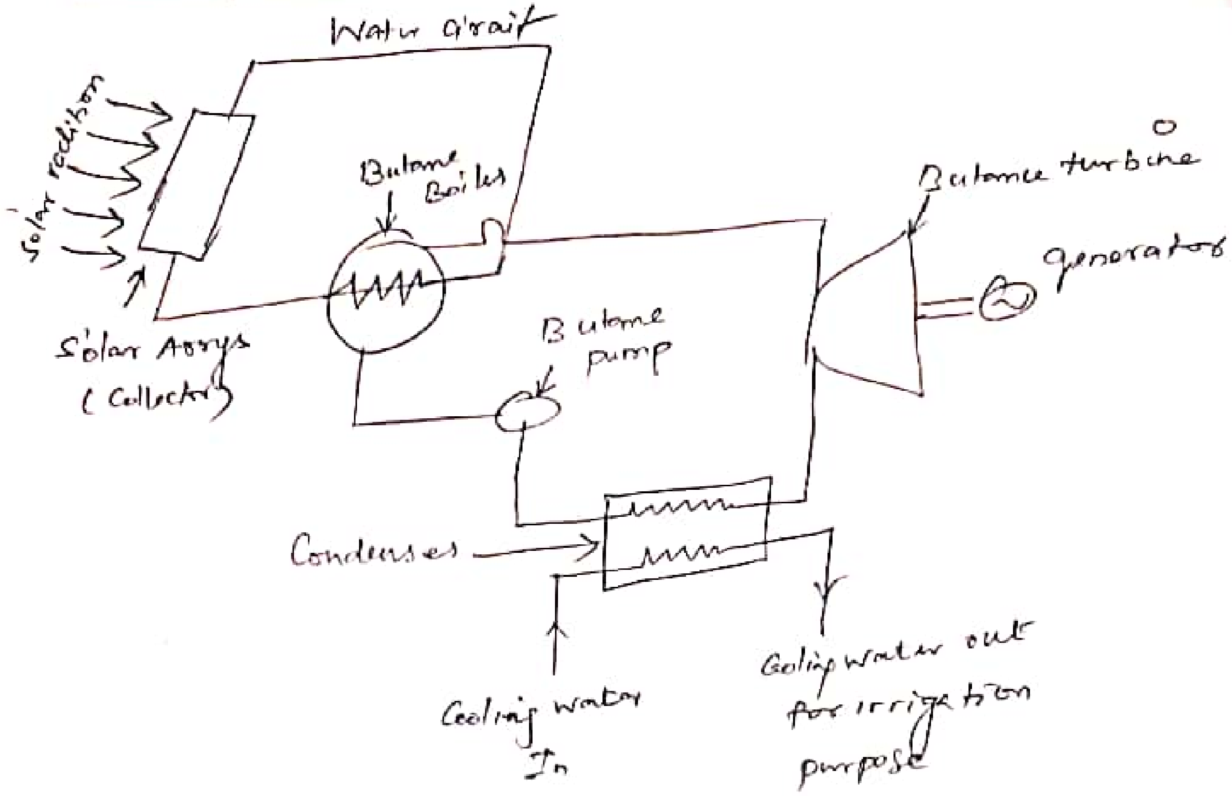
Evacuated tubular Collector



parabolic trough Collectors:-



power generation using Flat plate collector



low Temp. flat plate solar collector.

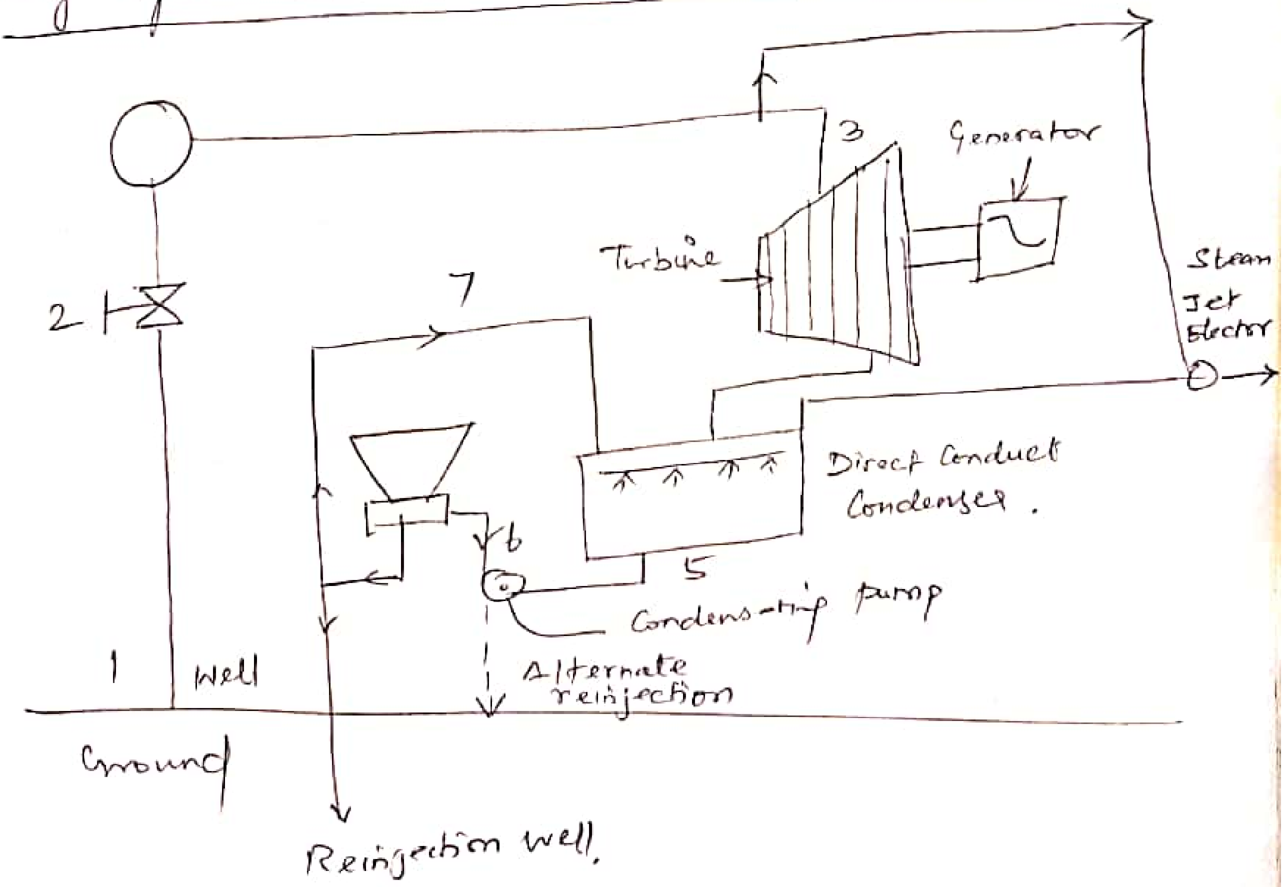
Geothermal energy sources

1. Hydrothermal.
   (a) vapour dominated or dry steam fields.
   (b) liquid dominated system
   (c) Hot-water fields
2. Geopressured
3. Hot dry rock (or) Petrothermal
4. Magma resources
5. Volcanoes.

Direct use of thermal energy :-

(1) Space heating
(2) Air Conditioning
(3) Industrial processes
(4) Drying
(5) green house
(6) Aquaculture
(7) Hot water
(8) Resorts and pools
(9) Melting snow.

Dry system (or) Vapour-dominated geothermal power plant



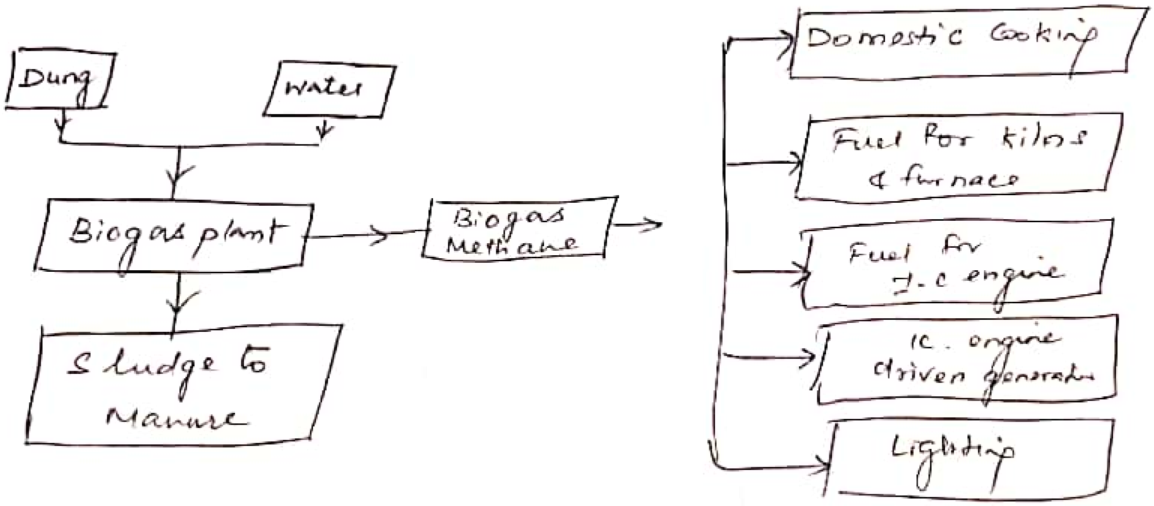
Introduction to Bio Energy:-

(i) photosynthesis process

(2) Biomass Resources

- (a) Forests
- (b) Agriculture residues
- (c) energy crops
- (d) surgar cane
- (e) oil producing plants
- (f) Aquatic plants
- (g) Urban waste.

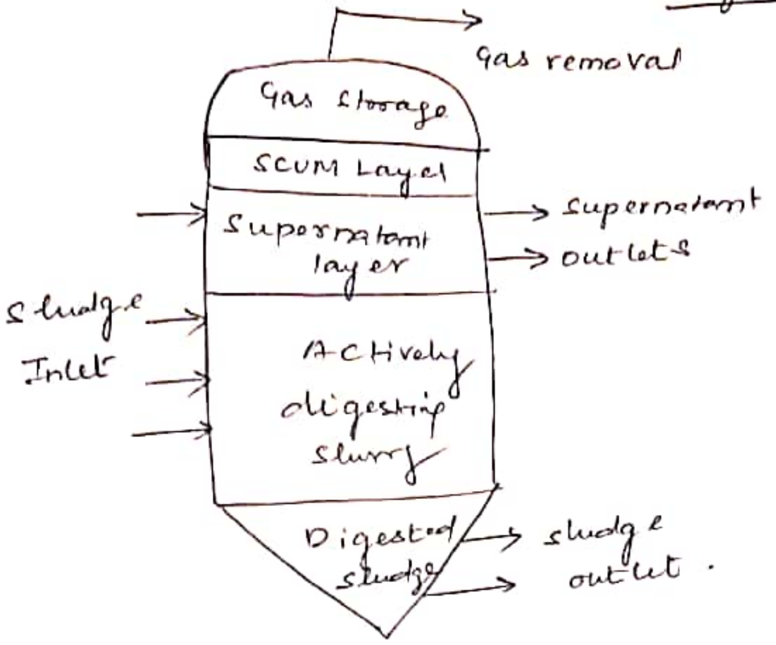
Energy route of Biogas plant:-



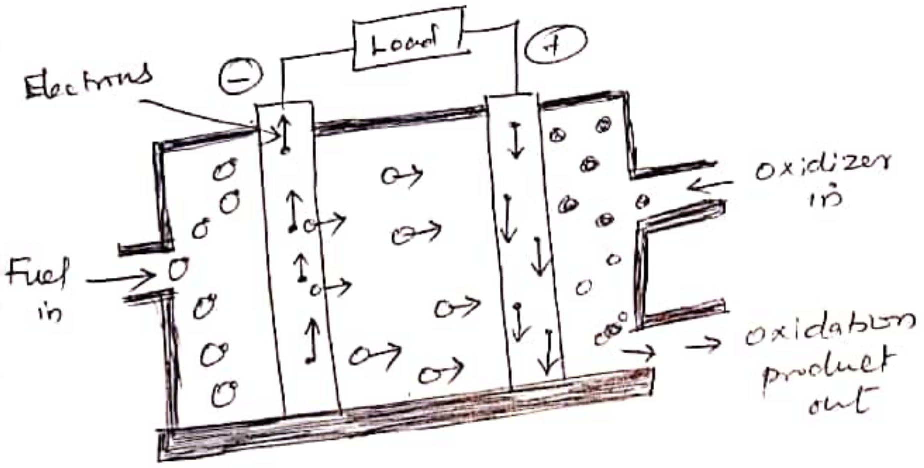
Factor affecting Dignestion process:

- (i) pH Concentration
- (ii) Total Solid content
- (iii) Seeding
- (iv) temp.
- (v) loading rate
- (vi) Type of feed
- (vii) pressure
- (viii) Nutrients
- (ix) Diameter depth ratio
- (x) Mixing of the Content
- (xi) Retention time.
- (xii) carbon to nitrogen ratio
- (xiii) Uniform feeding

schematic of single process conventional digester



Fuel cell power system:-



schematic of a fuel cell.

Fuel cell power plants:-

(1) Fuel processing section

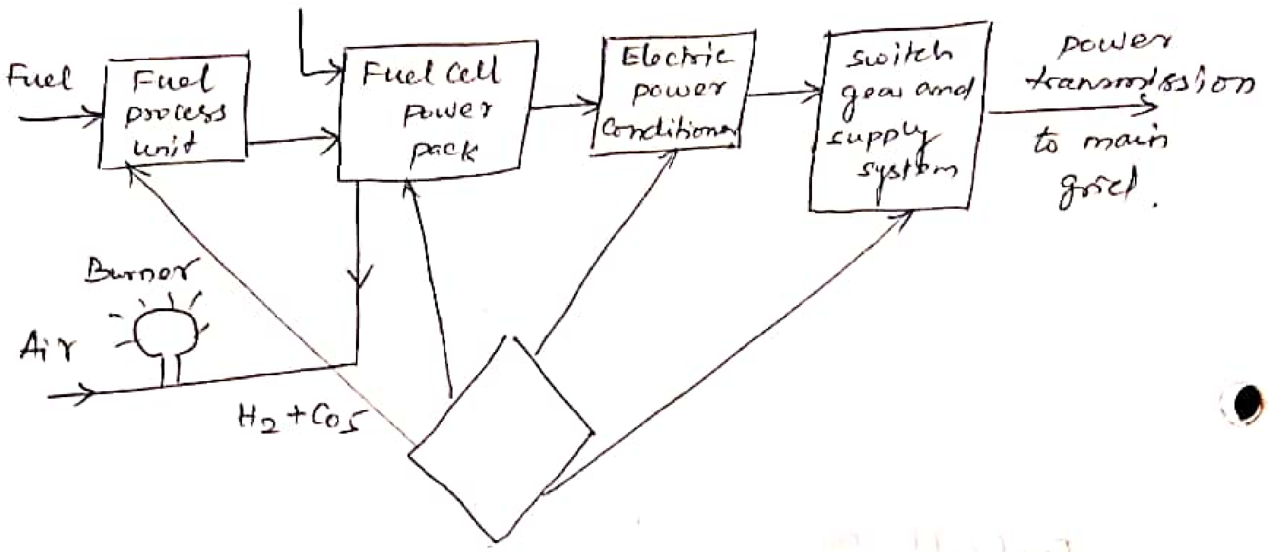
(2) Fuel cell power pack

(3) power conditioning section

(4) switchgear and supply system.

(4) Control subsystem Section

(5) Heating Section.



fuel cell plant

UNIT - III

PART - B.

Flow in Constant Area ducts with friction and without heat transfer. [Fanno flow]

→ flow in a Constant area duct with friction and without heat transfer and work transfer is known as Fanno flow.

→ Fanno line (or) curve:-

* Flow in a Constant area duct with friction and without heat transfer is described by a curve is known as Fanno line (or) Fanno curve.

* mass flow rate, $m = \rho A C$

$$\Rightarrow \frac{m}{A} = \rho C$$

$$\Rightarrow G = \frac{m}{A} = \rho C$$

G - mass flow density

$$\boxed{G = \rho C}$$

$$\boxed{C = \frac{G}{\rho}} \quad \text{———} ①$$

Stagnation enthalpy, $h_0 = h + \frac{1}{2}C^2$

Substitute $C = \frac{G}{\rho}$

$$\Rightarrow h_0 = h + \frac{1}{2}\frac{G^2}{\rho^2}$$

$$h = h_0 - \frac{1}{2}\frac{G^2}{\rho^2} \quad \text{———} ②$$

Density (ρ) is a function of entropy and enthalpy.

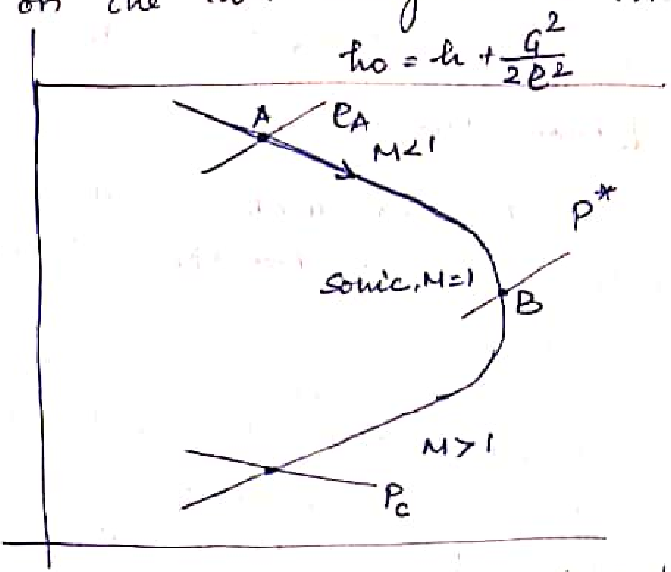
$$\Rightarrow \rho = f(s, h)$$

Substitute ρ value in equation no ——②

$$h = h_0 - \frac{1}{2}\frac{G^2}{[f(s,h)]^2}$$

$$h = h_0 - \frac{1}{2}\frac{G^2}{[f(s,h)]^2} \quad \text{———} ③$$

Equation ③ and ④ may be used for representing fanno line on the h-s diagram as shown in fig.



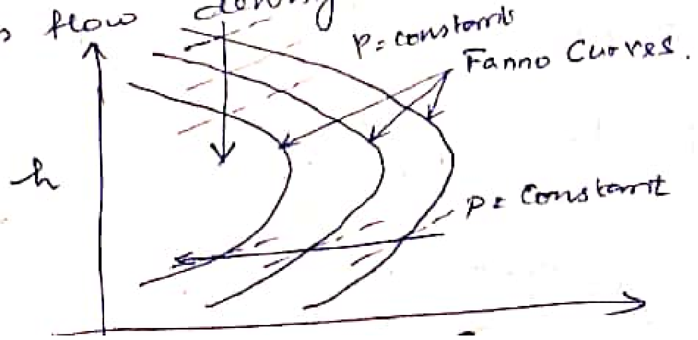
→ The curve Consists of two branches AB and BC. At point B the flow is sonic i.e, M=1. The flow A to B is subsonic (M<1) and C to B is supersonic (M>1)

→ In subsonic flow region (A to B), the effect of friction will increase the velocity and Mach Number and to decrease the enthalpy and pressure of the gas.

→ In super sonic region (C to B), The effect friction will decrease the velocity and Mach Number and to increase the enthalpy and pressure of the gas.

→ The Second law of thermodynamics for an adiabatic flow, the entropy may increase but cannot decrease. So the processes in the direction B to A and B to C are not possible because they lead to decrease in the entropy.

→ The three fanno curves for different values of the mass flow density (G) is shown in fig.



Fanno Curves for Various of the mass flow density.

Fanno flow Equations:-

→ Mass flow density $G = \rho c$

$$\ln(G) = \ln[\rho c]$$

$$\ln(G) = \ln(\rho) + \ln[c]$$

→ Differentiating, [∵ mass flow density G = Constant]

$$0 = \frac{d\rho}{\rho} + \frac{dc}{c}$$

$$\frac{d\rho}{\rho} = \frac{-dc}{c}$$

$$\boxed{\frac{d\rho}{\rho} = \frac{-d[c^2]}{2c^2}} \quad \text{—①}$$

$$\therefore d[c^2] = 2.c\,dc$$

$$dc = \frac{d[c^2]}{2c}.$$

$$\frac{dc}{c} = \frac{d[c^2]}{2c^2}.$$

Gas equation:-

$$PV = RT$$

$$P = \frac{1}{V}RT$$

$$P = \rho RT$$

$$\ln[P] = \ln[\rho RT]$$

$$\ln[P] = \ln[\rho] + \ln[R] + \ln[T]$$

Differentating. [R = Constant]

$$\boxed{\frac{dP}{P} = \frac{d\rho}{\rho} + \frac{dT}{T}} \quad \text{—②}$$

Mach number, $M = \frac{c}{a} = \frac{c}{\sqrt{\gamma RT}}$

$$M^2 = \frac{c^2}{\gamma RT}$$

$$\ln[M^2] = \ln\left[\frac{c^2}{\gamma RT}\right]$$

$$\ln[M^2] = \ln[c^2] - \ln[\gamma RT]$$

$$= \ln[c^2] - [\ln\gamma + \ln R + \ln T]$$

$$\ln[M^2] = \ln[c^2] - \ln[T]$$

Differentiating :

$$\boxed{\frac{dM^2}{M^2} = \frac{dc^2}{c^2} - \frac{dT}{T}} \quad — ③$$

[γ, R = constant]

Stagnation enthalpy $h_0 = h + \frac{1}{2}c^2$

$h + \frac{1}{2}c^2 = h_0 = \text{constant}$

Differentiating.

$$dh + \frac{2c\,dc}{2} = 0$$

$$c_p dT + c\,dc = 0$$

$$c_p dT + d\left[\frac{c^2}{2}\right] = 0$$

$$\frac{\gamma R}{\gamma - 1} dT + \frac{1}{2} dc^2 = 0$$

$$\frac{\gamma R T}{\gamma - 1} \times \frac{1}{T} dT + \frac{1}{2} dc^2 = 0$$

$$\frac{a^2}{\gamma - 1} \times \frac{dT}{T} + \frac{1}{2} dc^2 = 0$$

Multiplying throughout by $(\gamma - 1)$

$M = \frac{c}{a}$

$$a^2 \frac{dT}{T} + \frac{(\gamma-1)}{2} dc^2 = 0$$

$$\frac{c^2}{M^2} \frac{dT}{T} + \frac{(\gamma-1)}{2} dc^2 = 0$$

$$\Rightarrow \frac{dT}{T} + \frac{(\gamma-1)}{2} dc^2 \times \frac{M^2}{c^2} = 0$$

$$\Rightarrow \boxed{\frac{dT}{T} + \frac{\gamma-1}{2} M^2 \times \frac{dc^2}{c^2} = 0} \quad — ④$$

Fanning's Co-efficient of skin friction (f)

$$= \frac{\text{Wall shear stress}}{\text{Dynamic head}}$$

$$= \frac{\tau_w}{\frac{1}{2}\rho c^2}$$

$$f = \tau_w \Big/ \tfrac{1}{2}\rho c^2$$

$$\boxed{\tau_w = f \times \tfrac{1}{2}\rho c^2} \quad — ⑤$$

The area of the duct is given by

$$dA_w = \text{perimeter} \times \text{length}$$

$$\boxed{dA_w = p \times dx} \quad — ⑥$$

The hydraulic mean diameter of the duct is given by

$$D = \frac{4A}{P}$$

$$\boxed{P = \frac{4A}{D}}$$

Substituting perimeter value in equation ⑥

$$\boxed{dA_w = \frac{4A}{D} \times dx} \quad — ⑦$$

The momentum equation between state ① and state ②

is given by.

$$PA + mc = (p+dp)A + m(c+dc)$$

Considering shear stress.

$$PA + mc = (p+dp)A + m(c+dc) + \tau_w dA_w$$

$$PA + mc = PA + Adp + mc + mdc + \tau_w dA_w$$

$$Adp + mdc + \tau_w dA_w = 0$$

$$\boxed{mdc = -[Adp + \tau_w dA_w]} \quad — ⑧$$

Substituting τ_w and dA_w value in equation ⑧

$$m\,dc = -\left[A\,dp + f \times \tfrac{1}{2}\rho c^2 \times \frac{4A}{D}dx\right]$$

$$m\,dc = -A\left[dp + \frac{\rho c^2}{2} \times 4f\,\frac{dx}{D}\right]$$

$$\frac{m}{A}dc = -\left[dp + \frac{\gamma P M^2}{2} \times 4f\,\frac{dx}{D}\right] \quad ⑨$$

$$\rho c^2 = \frac{P}{RT}c^2 = \frac{P}{RT}M^2a^2 = \frac{P}{\cancel{RT}}M^2\gamma\cancel{RT} = \underline{\underline{\gamma P M^2}}.$$

We know that

$$\frac{m}{A}dc = \frac{\rho \cancel{A} c}{\cancel{A}}dc$$

$$= \rho c\,dc$$

$$= \frac{\rho c^2\, d[c^2]}{2c^2}$$

$$d[c^2] = 2c\,dc$$

$$[\rho c^2 = \gamma P M^2]$$

$$\boxed{\frac{m}{A}dc = \frac{\gamma P M^2\, d[c^2]}{2c^2}}$$

Substituting $\frac{m}{A}dc$ value in equation ⑨

$$\frac{\gamma P M^2\, d[c^2]}{2c^2} = -\left[dp + \frac{\gamma P M^2}{2} \times 4f\,\frac{dx}{D}\right]$$

$$\frac{\gamma P M^2\, d[c^2]}{2c^2} + dp + \frac{\gamma P M^2}{2} \times 4f\,\frac{dx}{D} = 0$$

Dividing by P

$$\Rightarrow \frac{\gamma M^2\, dc^2}{2c^2} + \frac{dp}{P} + \frac{\gamma M^2}{2} \times 4f\,\frac{dx}{D} = 0$$

$$\Rightarrow \frac{dp}{P} + \frac{\gamma M^2}{2} \times \frac{dc^2}{c^2} + \frac{\gamma M^2}{2} \times 4f\,\frac{dx}{D} = 0$$

$$\boxed{\frac{dp}{P} + \frac{\gamma M^2}{2} \times \frac{dc^2}{c^2} + \frac{\gamma M^2}{2} \times \left[4f\,\frac{dx}{D}\right] = 0} = 0.$$

Stagnation pressure - Mach number Relation.

$$\frac{P_0}{P} = \left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{\gamma}{\gamma-1}}$$

$$\ln\left[\frac{P_0}{P}\right] = \ln\left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{\gamma}{\gamma-1}}$$

$$\ln p_0 - \ln p = \frac{\gamma}{\gamma-1} \times \ln\left[1 + \frac{\gamma-1}{2} M^2\right]$$

Differentating

$$\frac{dp_0}{p_0} - \frac{dp}{p} = \frac{\gamma}{\gamma-1} \times \frac{d\left[1 + \frac{\gamma-1}{2} M^2\right]}{1 + \frac{\gamma-1}{2} M^2}$$

$$\frac{dp_0}{P_0} - \frac{dp}{P} = \frac{\gamma}{\gamma-1} \times \frac{\left[0 + \frac{\gamma-1}{2} dM^2\right]}{1 + \frac{\gamma-1}{2} M^2}$$

$$\frac{dp_0}{P_0} - \frac{dp}{P} = \frac{\frac{\gamma}{2} dM^2}{1 + \frac{\gamma-1}{2} M^2}$$

$$\Rightarrow \frac{dp_0}{P_0} - \frac{dp}{P} = \frac{\gamma dM^2}{2\left[1 + \frac{\gamma-1}{2} M^2\right]}$$

$$\Rightarrow \frac{dp_0}{P_0} - \frac{dp}{P} = \frac{\gamma M^2}{2\left[1 + \frac{\gamma-1}{2} M^2\right]} \times \frac{dM^2}{M^2}$$

$$\boxed{\frac{dp_0}{P_0} = \frac{dp}{P} + \frac{\gamma M^2}{2\left[1 + \frac{\gamma-1}{2} M^2\right]} \times \frac{dM^2}{M^2}} \quad -⑤$$

Impluse Function $F = PA(1 + \gamma M^2)$

$$\ln[F] = \ln\left[PA(1 + \gamma M^2)\right]$$

$$\ln[F] = \ln[P] + \ln[A] + \ln\left[1 + \gamma M^2\right]$$

Differentiating.

$$\frac{dF}{F} = \frac{dp}{p} + 0 + \frac{d(1+\gamma M^2)}{1+\gamma M^2}$$

$$\frac{dF}{F} = \frac{dp}{p} + \frac{\gamma dM^2}{1+\gamma M^2}$$

$$\frac{dF}{F} = \frac{dp}{p} + \frac{\gamma}{1+\gamma M^2} \times dM^2$$

$$\boxed{\frac{dF}{F} = \frac{\gamma M^2}{1+\gamma M^2} \frac{dM^2}{M^2} + \frac{dp}{p}} \quad -10$$

Solution of Fanno flow equations:-

In this section, the differential flow parameters $\frac{dc^2}{c^2}$, $\frac{d\rho}{\rho}$, $\frac{dp}{p}$, $\frac{dT}{T}$, $\frac{dp_0}{p_0}$, $\frac{dF}{F}$ and $4f\frac{dx}{D}$ are expressed as a functions of γ and M^2 only.

From equation ③

$$\frac{dM^2}{M^2} = \frac{dc^2}{c^2} - \frac{dT}{T}$$

From equation ④

$$\frac{dT}{T} + \frac{\gamma-1}{2} M^2 \frac{dc^2}{c^2} = 0$$

$$\frac{dT}{T} = -\left[\frac{\gamma-1}{2} M^2 \frac{dc^2}{c^2}\right]$$

Substitute $\frac{dT}{T}$ value in $\frac{dM^2}{M^2}$ equation.

$$\frac{dM^2}{M^2} = \frac{dc^2}{c^2} + \frac{\gamma-1}{2} M^2 \frac{dc^2}{c^2}$$

$$\frac{dM^2}{M^2} = \frac{dc^2}{c^2}\left[1 + \frac{\gamma-1}{2} M^2\right]$$

$$\boxed{\frac{dc^2}{c^2} = \frac{dM^2}{M^2} \times \frac{1}{1+\frac{\gamma-1}{2} M^2}}$$

—⑪

From equation ⑥

$$\frac{d\rho}{\rho} = \frac{-d[c^2]}{2c^2}$$

$$= -\frac{1}{2} \times \frac{dc^2}{c^2}$$

$$\boxed{\frac{d\rho}{\rho} = \frac{-dM^2}{2M^2} \times \frac{1}{1+\frac{\gamma-1}{2}M^2}} \quad — ⑫$$

From equation ⑪, we know that

$$\frac{dT}{T} + \frac{\gamma-1}{2} M^2 \frac{dc^2}{c^2} = 0$$

$$\frac{dT}{T} = -\left[\frac{\gamma-1}{2} M^2 \frac{dc^2}{c^2}\right]$$

$$= -\left[\frac{\gamma-1}{2} M^2 \times \frac{dM^2}{M^2} \frac{1}{1+\frac{\gamma-1}{2}M^2}\right]$$

$$= \frac{\gamma-1}{2} dM^2 \times \frac{1}{1+\frac{\gamma-1}{2}M^2}$$

$$\boxed{\frac{dT}{T} = -\left[\frac{\gamma-1}{2\left[1+\frac{\gamma-1}{2}M^2\right]} dM^2\right]} \quad — ⑬$$

From equation ③

$$\frac{dp}{p} = \frac{d\rho}{\rho} + \frac{dT}{T}$$

substitute $\frac{d\rho}{\rho}$ and $\frac{dT}{T}$ values

$$\Rightarrow \frac{dp}{p} = -\left[\frac{dM^2}{2M^2} \times \frac{1}{1+\frac{\gamma-1}{2}M^2}\right] - \left[\frac{\gamma-1}{2\left[1+\frac{\gamma-1}{2}M^2\right]} dM^2\right]$$

$$= -\left[\frac{dM^2}{2M^2} \times \frac{1}{1+\frac{\gamma-1}{2}M^2} + \frac{\gamma-1}{2\left(1+\frac{\gamma-1}{2}M^2\right)} dM^2\right]$$

$$= -\left[\frac{dM^2}{M^2} \times \frac{1}{2\left[1+\frac{\gamma-1}{2}M^2\right]} + \frac{\gamma-1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\, dM^2\right]$$

$$= -\frac{1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\,\frac{dM^2}{M^2}\left[1+(\gamma-1)M^2\right]$$

$$\boxed{\frac{dp}{p} = -\left[\frac{1+(\gamma-1)M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]} \times \frac{dM^2}{M^2}\right]}$$ — ⑭

From equation ⑨, we know that.

$$\frac{dp_0}{p_0} = \frac{dp}{p} + \frac{\gamma M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]} \times \frac{dM^2}{M^2}$$

substitute $\frac{dp}{p}$ value

$$\frac{dp_0}{p_0} = -\left[\frac{1+(\gamma-1)M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]} \times \frac{dM^2}{M^2}\right] + \left[\frac{\gamma M^2}{2\left(1+\frac{\gamma-1}{2}M^2\right)} \times \frac{dM^2}{M^2}\right]$$

$$= \frac{-1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\,\frac{dM^2}{M^2}\left[1+(\gamma-1)M^2-\gamma M^2\right]$$

$$= \frac{-1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\,\frac{dM^2}{M^2}\left[1+\gamma M^2-M^2-\gamma M^2\right]$$

$$\boxed{\frac{dp_0}{p_0} = \frac{-1\left(1-M^2\right)}{2\left[1+\frac{\gamma-1}{2}M^2\right]} \times \frac{dM^2}{M^2}}$$ — ⑮

From equation ⑩, we known that.

$$\frac{dF}{F} = \frac{\gamma M^2}{1+\gamma M^2}\,\frac{dM^2}{M^2} + \frac{dp}{p}$$

substitute $\frac{dp}{p}$ value

$$\frac{dP}{P} = \frac{\gamma M^2}{1+\gamma M^2}\,\frac{dM^2}{M^2} - \left[\frac{1+(\gamma-1)M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\times\frac{dM^2}{M^2}\right]$$

from equation ①

$$\frac{dp}{p}+\frac{\gamma M^2}{2}\times\frac{dc^2}{c^2}+\frac{\gamma M^2}{2}\times 4f\,\frac{dx}{D}=0$$

substitute $\frac{dp}{p}$, $\frac{dc^2}{c^2}$ value

$$= -\left[\frac{1+(\gamma-1)M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\times\frac{dM^2}{M^2}\right]+\frac{\gamma M^2}{2}\left[\frac{dM^2}{M^2}\times\frac{1}{1+\frac{\gamma-1}{2}M^2}\right]$$

$$+\frac{\gamma M^2}{2}\times\left[4f\,\frac{dx}{D}\right]=0$$

$$= \frac{\gamma M^2}{2}\times 4f\,\frac{dx}{D} = \left[\frac{1+(\gamma-1)M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]} - \frac{\gamma M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\right]\times\frac{dM^2}{M^2}$$

$$= \frac{\left[1+(\gamma-1)M^2-\gamma M^2\right]}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\times\frac{dM^2}{M^2}$$

$$= \frac{1-M^2}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\times\frac{dM^2}{M^2}$$

$$\boxed{4f\,\frac{dx}{D} = \frac{1-M^2}{\gamma M^2\left[1+\frac{\gamma-1}{2}M^2\right]}\,\frac{dM^2}{M^2}} \quad —⑮$$

Variation of flow properties:

$$\frac{T_0}{T} = 1 + \frac{\gamma-1}{2}M^2 \quad \Big| \quad \frac{T_0^*}{T^*} = \frac{\gamma+1}{2}$$

$$\frac{T}{T^*} = \frac{\gamma+1}{2\left[1+\frac{\gamma-1}{2}M^2\right]} \quad \Big| \quad \frac{T_2}{T_1} = \frac{1+\frac{\gamma-1}{2}M_1^2}{1+\frac{\gamma-1}{2}M_2^2}$$

Velocity:

$$c = M \times \sqrt{\gamma RT} \quad \Big| \quad \frac{c}{c^*} = M\left[\frac{\gamma+1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\right]^{1/2}$$

$$\frac{c_2}{c_1} = \frac{M_2}{M_1}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{1+\frac{\gamma-1}{2}M_2^2}\right]^{1/2}$$

Density:

$$\rho = \frac{1}{c} \quad \Big| \quad \rho/\rho^* = \frac{1}{c/c^*} \quad \Big| \quad \frac{\rho_2}{\rho_1} = \frac{M_1}{M_2}\left[\frac{1+\frac{\gamma-1}{2}M_2^2}{1+\frac{\gamma-1}{2}M_1^2}\right]^{1/2}$$

Pressure :- $p = \rho RT$

$$\frac{p}{p^*} = \frac{1}{M}\left[\frac{\gamma+1}{2\left[1+\frac{\gamma-1}{2}M^2\right]}\right]^{1/2} \quad \Big| \quad \frac{p_2}{p_1} = \frac{M_1}{M_2}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{1+\frac{\gamma-1}{2}M_2^2}\right]^{1/2}$$

Stagnation pressure

$$\frac{p_0}{p_0^*} = \frac{1}{M}\left[\frac{2\left(1+\frac{\gamma-1}{2}M^2\right)}{\gamma+1}\right]^{\frac{\gamma+1}{2(\gamma-1)}} \quad \Big| \quad \frac{p_0}{p} = \left[\frac{T_0}{T}\right]^{\frac{\gamma}{\gamma-1}}$$

$$p_0 = p\left[T_0/T\right]^{\frac{\gamma}{\gamma-1}}$$

$$p_0^* = p^*\left[\frac{T_0^*}{T^*}\right]^{\frac{\gamma}{\gamma-1}} \quad \Big| \quad \frac{p_{0_2}}{p_{0_1}} = \frac{M_1}{M_2}\left[\frac{1+\frac{\gamma-1}{2}M_2^2}{1+\frac{\gamma-1}{2}M_1^2}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

Impluse function $F = pA(1+\gamma M^2)$

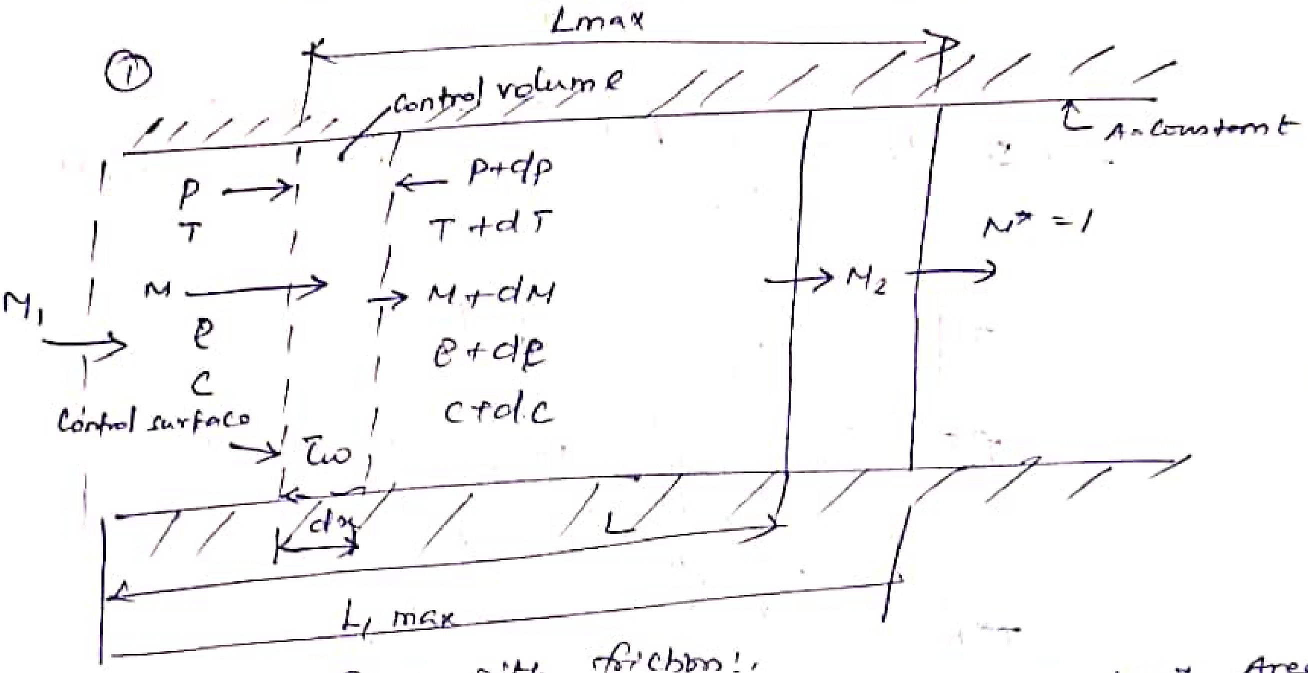
$$\frac{F_2}{} = \frac{M_1}{}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{}\right]^{1/2}\left[\frac{1+\gamma M_2^2}{}\right]$$

entropy :-

$$\frac{S_2-S_1}{R} = \ln\frac{M_2}{M_1}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{1+\frac{\gamma-1}{2}M_2^2}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

Variation of Mach Number with duct length:-

$$4\bar{f}\frac{L}{D} = \left[4\bar{f}\frac{L_{max}}{D}\right]_{M_1} - \left[4\bar{f}\frac{L_{max}}{D}\right]_{M_2}.$$



Isothermal flow with friction:-

→ In this Section, Isothermal flow is Constant Area with friction is considered.

→ Isothermal flow is achived at low velocities in long pipes which are not thermally Insulated.

→ Due to low velocity. mach number is low, so the pressure change are significant and therefore does not remains Constant.

→ In this flow there is considerable surface area and time variable for heat transfer to take place.

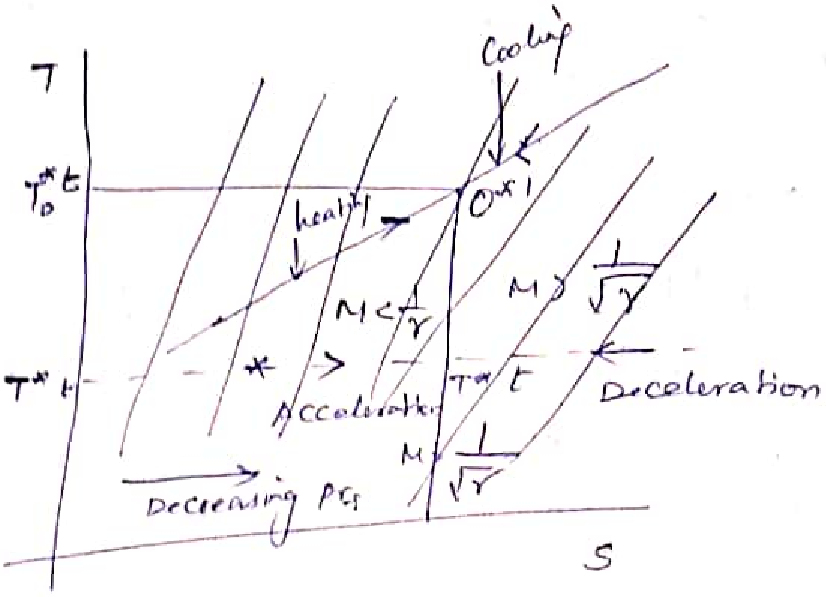
→ Therefore, the flow is closer to Isothermal than adiabatic.

→ The following asumption are made for Isothermal flow ① one dimensional friction flow ② flow takes place in Constant sectional area ③ The gas is perfect with Constant specific heats ④ Temp: remains

→ Isothermal flow processes are ~~pre~~ represented by straight horizontal lines on the temp-entropy diagram as shown in fig.

→ In accelerating process (heating process), the pressure of the gas decrease up to limiting state, where $M = 1/\sqrt{\gamma}$ and entropy Increase.

→ In deceleration process (cooling process), the pressure of the gas increase and entropy decrease.



Isothermal flow friction

Problem on fanno flow.

① Air at $P_1 = 3.4$ bar, $T_1 = 35°c$ enters a circular duct at a Mach number of 0.14. The exit mach number is 0.6 and co-efficient of friction is 0.004. If the mass flow rate is 8.2 kg/s, determine. (1) pressure, temp: at the exit ② Determine of the duct ③ Length of the duct ④ Stagnation pr: loss. ⑤ verify the exit mach number through exit velocity and Temp.

Given Data :- $P_1 = 3.4 \times 10^5 N/m^2$ $T_1 = 308K$ $M_1 = 0.11$, $M_2 = 0.6$

$\bar{f} = 0.004$, $\dot{m} = 8.2 kg/s$.

To find :- (1) P_2, T_2 (2) D (3) L (4) $P_{01} - P_{02}$ ⑤ verify exit mach Number.

Solution :-

Refer Isentropic flow table for $\gamma = 1.4$ and $M_1 = 0.14$.

$$\frac{T_1}{T_{01}} = 0.996$$

$$\frac{P_1}{P_{01}} = 0.986$$

From gas tables page no: 28

$$T_{01} = \frac{T_1}{0.996} = \frac{308}{0.996} = 308.93K \qquad \boxed{T_{01} = 308.93K}$$

$$P_{01} = \frac{P_1}{0.986} = \frac{3.4 \times 10^5}{0.986} = 3.44 \times 10^5 N/m^2 \qquad \boxed{P_{01} = 3.44 \times 10^5 N/m^2}$$

Fanno flow table for $\gamma = 1.4$ and $M_1 = 0.14$

$$\frac{P_1}{P_1^*} = 7.809$$

$$\frac{C_1}{C_1^*} = 0.153$$

$$\frac{T_1}{T_1^*} = 1.195$$

$$\frac{P_{01}}{P_{01}^*} = 4.183$$

$$\frac{4\bar{f}L_{max}}{\;} = 32.511$$

From gas table page No: 81

$\Rightarrow P_1^* = \frac{P_1}{7.809} = \frac{3.4\times10^5}{7.809}$

For Fanno flow

$P_1^* = P_2^*$

$$\boxed{P_1^* = 0.435\times10^5\ N/m^2 = P_2^*}$$

$\Rightarrow C_1^* = \frac{C_1}{0.153} = \frac{M_1\times a_1}{0.153} = \frac{M_1\times\sqrt{\gamma R T_1}}{0.153}$

$a = \sqrt{\gamma R T}$

$= \frac{0.14\times\sqrt{1.4\times287\times308}}{0.153}$

$$\boxed{C_1^* = 321.89\ m/s = C_2^*}$$

$\Rightarrow T_1^* = \frac{T_1}{1.195} = \frac{308}{1.195} = \boxed{T_1^* = 257.74\ K = T_2^*}$

$\Rightarrow P_{01}^* = \frac{P_{01}}{4.183} = \frac{3.44\times10^5}{4.183} = \boxed{P_{01}^* = 0.822\times10^5\ N/m^2 = P_{02}^*}$

Refer Fanno flow table for $\gamma = 1.4$ and $M_2 = 0.6$

$\frac{P_2}{P_2^*} = 1.763$

$\frac{C_2}{C_2^*} = 0.635$

$\frac{T_2}{T_2^*} = 1.119$

$\frac{P_{02}}{P_{02}^*} = 1.188$

$\frac{4\bar{f}L_{max}}{D} = 0.491$

From gas table page no: 81

$\Rightarrow P_2 = P_2^*\times1.763$; $0.435\times10^5\times1.763 = \boxed{P_2 = 0.766\times10^5\ N/m^2}$

$\Rightarrow T_2 = T_2^*\times1.119$; $257.74\times1.119 = \boxed{T_2 = 288.41\ K}$

$\Rightarrow C_2 = C_2^*\times0.635$; $321.89\times0.635 = \boxed{C_2 = 204.40\ m/s}$

$\Rightarrow P_{02} = P_{02}^*\times1.188$; $0.822\times10^5\times1.188 = P_{02} = 0.976\times10^5\times1.188$

$$\boxed{P_{02} = 0.976\times10^5\ N/m^2}$$

Diameter of the duct (D)

mass flow rate $\dot{m} = \rho_1 A_1 C_1$

$$= \frac{P_1}{RT_1} \times \frac{\pi}{4} \times (D_1^2) \times C_1 \qquad M = \frac{c}{a}$$

$$8.2 = \frac{3.4\times10^5}{287\times308} \times \frac{\pi}{4}(D_1^2)\times M_1 \times a_1$$

$$8.2 = \frac{3.4\times10^5}{287\times308} \times \frac{\pi}{4} \times (D_1^2) \times M_1 \times \sqrt{\gamma RT}$$

$$8.2 = \frac{3.4\times10^5}{287\times308} \times \frac{\pi}{4} \times (D_1^2) \times 0.14 \times \sqrt{1.4\times287\times308}$$

$$D_1^2 = 0.0551$$

$$\boxed{D_1 = 0.234\ m}$$

Area is constant so, $\boxed{D_1 = D_2 = D = 0.234\ m}$

Length of the duct:-

$$\frac{4fL}{D} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

$$= 32.511 - 0.491$$

$$\frac{4\bar{f}L}{D} = 32.02$$

$$L = \frac{32.02 \times D}{4 \times \bar{f}}$$

$$= \frac{32.02 \times 0.238}{4 \times 0.004}$$

$$\boxed{L = 468.29\ m}$$

Stagnation pressure loss:-

$$\Delta P = P_{01} - P_{02}$$

$$= 3.44\times10^5 - 0.976\times10^5$$

$$\boxed{\Delta P = 2.464\times10^5\ N/m^2}$$

To Verify exit Mach Number :

$$\text{Exit Mach Number } M_2 = \frac{C_2}{a_2}$$

$$= \frac{204.40}{\sqrt{\gamma R T_2}}$$

$$= \frac{204.40}{\sqrt{1.4 \times 287 \times 288.41}}$$

$$\boxed{M_2 = 0.60}$$ Verified.

H.W

② Air enters a pipe of 25mm diameter, at a Mach Number of 2.4 stagnation temp. of 300K and static pressure of 0.5bar. If the Co-efficient of friction is 0.003, determine the following for a Section at which the Mach Number reaches 1.2. ① static Pr & temp. ② stagnation Pr & Temp. ③ velocity of air ④ Distance of the section from the Inlet ⑤ mass flow rate.

Given

$D = 0.025 m$ $\quad M_1 = 2.4$ $\quad T_{01} = 300K$ $\quad P_1 = 0.5 \times 10^5 N/m^2$

$\bar{f} = 0.003$ $\quad M_2 = 1.2.$

To find :- (1) P_2, T_2 (2) P_{02}, T_{02} (3) C_2 (4) L ⑤ m

Solution :-

Refer Isentropic flow table for $\gamma = 1.4$ and $M_1 = 2.4$ page no : 34.

$$\left.\begin{aligned} \frac{T_1}{T_{01}} &= 0.464 \\ \frac{P_0}{P_{01}} &= 0.0684 \end{aligned}\right\} \text{From gas table}$$

$$T_1 = T_{01} \times 0.464 = 300 \times 0.464 \quad \therefore \boxed{T_1 = 139.2K}$$

$$P_{01} = \frac{P_1}{0.0684} = \frac{0.5 \times 10^5}{0.0684} = \boxed{P_{01} = 7.309 \times 10^5 N/m^2}$$

Refer. Fanno flow table for $\gamma = 1.4$ & $M_1 = 2.4$

$\frac{P_1}{P_1^*} = 0.311$ $\frac{P_{01}}{P_{01}^*} = 2.403$

$\frac{T_1}{T_1^*} = 0.557$ $\frac{4\bar{f}L_{max}}{D} = 0.409$

} From gas tables page No: 84.

$$\Rightarrow P_1^* = \frac{P_1}{0.311} = \frac{0.5\times10^5}{0.311} = \boxed{P_1^* = 1.607\times10^5\ N/m^2 = P_2^*}$$

$$\Rightarrow T_1^* = \frac{T_1}{0.557} = \frac{139.2}{0.557} = \boxed{T_1^* = 249.91k = T_2^*}$$

$$\Rightarrow P_{01}^* = \frac{P_{01}}{2.403} = \frac{7.309\times10^5}{2.403} = \boxed{P_{01}^* = 3.042\times10^5\ N/m^2 = P_{02}^*}$$

Refer fanno flow table for $\gamma = 1.4$ and $M_2 = 1.2$

$\frac{P_2}{P_2^*} = 0.804$ $\frac{P_{02}}{P_{02}^*} = 1.030$

$\frac{T_2}{T_2^*} = 0.932$ $\frac{4\bar{f}L_{max}}{D} = 0.034$

} From gas tables page no: 82

$$\Rightarrow P_2 = P_2^* \times 0.804 = 1.607\times10^5 \times 0.804 \quad \boxed{P_2 = 1.292\times10^5\ N/m^2}$$

$$\Rightarrow T_2 = T_2^* \times 0.932 = \boxed{T_2 = 239.92k}$$

$$\Rightarrow P_{02} = P_{02}^* \times 1.030 = 3.042\times10^5 \times 1.030 = \boxed{P_{02} = 3.133\times10^5\ N/m^2}$$

We know that

Stagnation temp. remains constant.

$$\boxed{T_0 = T_{01} = T_{02} = 300k}$$

velocity of air at exit, $C_2 = M_2 \times a_2$

$$C_2 = M_2 \times \sqrt{\gamma R T_2}$$

$$= 1.2 \times \sqrt{1.4 \times 287 \times 232.92}$$

$$\boxed{C_2 = 367.10\ m/s}$$

We know

$$\frac{4\bar{f}L}{D} = \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

$$= 0.409 - 0.034$$

$$\frac{4\bar{f}L}{D} = 0.375$$

$$L = \frac{32.02\times D}{4\times\bar{f}} = \frac{0.375\times 0.025}{4\times 0.003}$$

$$\boxed{L = 0.781\,m}$$

mass flow rate, $m = \rho_1 A_1 C_1$

$$= \frac{P_1}{RT_1}\times\frac{\pi}{4}\times(D_1)^2\times C_1$$

$$= \frac{P_1}{RT_1}\times\frac{\pi}{4}\times(D_1)^2\times M_1\times a_1$$

$$= \frac{P_1}{R\times T_1}\times\frac{\pi}{4}\times(D_1)^2\times M_1\times\sqrt{\gamma RT_1}$$

$$= \frac{0.5\times10^5}{287\times139.2}\times\frac{\pi}{4}\times(0.025)^2\times 2.4 \times\sqrt{1.4\times287\times139.2}$$

$$\boxed{m = 0.348\,kg/s}$$

H.W

③ Air at $120\ kN/m^2$ and $40°C$ flows through a 200 mm diameter pipe adiabatically. If the upstream Mach Number is 2.5, determine the Max. length of pipe and the properties of air at exit. Also estimate the length of the pipe if the exit Mach Number is 1.8.

Take $f = 0.01$

Given:- $P_1 = 120\times10^3\ N/m^2$ $T_1 = 40°C + 273 = 313K$

$D_1 = 200mm = 0.2m$ $M_1 = 2.5$

$M_2 = 1.8$ $\bar{f} = 0.01$

To find

1) L_{max}

2) P_2, T_2, C_2

3) L

Solution :-

Refer Fanno table for $\gamma = 1.4$ and $M_1 = 2.5$

$$\frac{P_1}{P_1^*} = 0.292$$

$$\frac{C_1}{C_1^*} = 1.826$$

$$\frac{T_1}{T_1^*} = 0.533$$

$$\frac{P_{01}}{P_{01}^*} = 2.637$$

$$\frac{4\bar{f}L_{max}}{D} = 0.432$$

From gas table page No: 84.

$$\Rightarrow P_1^* = \frac{P_1}{0.292} = \frac{120 \times 10^3}{0.292} = \boxed{P_1^* = 4.10 \times 10^5 \ N/m^2 = P_2^*}$$

$$\Rightarrow C_1^* = \frac{C_1}{1.826} = \frac{M_1 \times a_1}{1.826} = \frac{M_1 \times \sqrt{\gamma R T_1}}{1.826} = \frac{2.5 \times \sqrt{1.4 \times 287 \times 313}}{1.826}$$

$$\boxed{C_1^* = 485.53 \ m/s = C_2^*}$$

$$\Rightarrow T_1^* = \frac{T_1}{0.533} = \frac{313}{0.533} = \boxed{T_1^* = 587.24 = T_2^*}$$

$$\Rightarrow \frac{4\bar{f}L_{max}}{D} = 0.432 = L_{max} = \frac{0.432 \times D}{4 \times \bar{f}}$$

$$= \frac{0.432 \times 0.2}{4 \times 0.01} = \boxed{L_{max} = 2.16 \ m}$$

$\boxed{\text{Maximum length of the pipe, } L_{max} = 2.16 \ m}$

Refer Fanno flow table $\gamma = 1.4$ and $M_2 = 1.8$

$$\frac{P_2}{P_2^*} = 0.474 \qquad \frac{T_2}{T_2^*} = 0.728 \qquad \frac{4\bar{f}L_{max}}{D} = 0.242$$

$$\frac{C_2}{C_2^*} = 1.536 \qquad \frac{P_{02}}{P_{02}^*} = 1.439$$

From gas tables page No: 83

$\Rightarrow P_2 = P_2^* \times 0.474 = 4.10\times10^5 \times 0.474$

$$\boxed{P_2 = 1.94 \times 10^5 \ N/m^2}$$

$\Rightarrow c_2 = c_2^* \times 1.536 = 485.53 \times 1.536$ $\boxed{c_2 = 745.77 \ m/s}$

$\Rightarrow T_2 = T_2^* \times 0.728 = 587.24 \times 0.728$ $\boxed{T_2 = 427.51 K}$

We know that

$$\frac{4fL}{D} = \left[\frac{4\bar{f} L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f} L_{max}}{D}\right]_{M2}$$

$$= 0.432 - 0.242$$

$\frac{4fL}{D} = 0.19$; $L = \frac{0.19 \times D}{4 \times \bar{f}}$; $\frac{0.19 \times 0.2}{4 \times 0.01}$

$$\boxed{\text{Length of pipe, } L = 0.95m}$$

④ Air at an inlet temp. of 60°c flows with subsonic velocity through an insulated pipe having inside diameter of 50mm and a length of 5m. The pressure at the exit of the pipe is 101 kPa and the flow chocked at the end of the pipe. If the friction factor 4f = 0.005, determine the Inlet Mach member, the mass flow rate and the exit temp.

D = 50mm = 0.050 m L = 5m

Given $T_1 = 333K$ $4\bar{f} = 0.005$

$P_2 = 101$ kPa $= 101 \times 10^3$ N/m². It means at the Flow is Chocked at the end of the pipe. Mach number value is One end of the pipe

$M_2 = 1$.

To find:-

(1) M_1

(2) $\dot{m}$

(3) T_2.

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Solution:-

Refer Fanno flow table for $\gamma = 1.4$ and $M_2 = 1$.

$$\frac{P_2}{P_2^*} = 1 \qquad \frac{T_2}{T_2^*} = 1 \qquad \frac{4\bar{f}L_{max}}{D} = 0 \quad \Bigg\} \text{From gas table page no: 82.}$$

$$\boxed{P_2 = P_2^* = 101 \times 10^3 \, N/m^2 = P_1^*}$$

We know that

$$\frac{4fL}{D} = \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

$$= \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - 0$$

$$\frac{0.005 \times 5}{0.050} = \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1}$$

$$\left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} = 0.5$$

Refer Fanno flow table for $\left[\frac{4\bar{f}L_{max}}{D}\right] = 0.5 \approx 0.4914$

$\gamma = 1.4$

$$\left.\begin{aligned} M_1 &= 0.60 \\ \frac{P_1}{P_1^*} &= 1.763 \\ \frac{T_1}{T_1^*} &= 1.119 \end{aligned}\right\} \text{From gas tables page No: 81}$$

Note: For $\left[\frac{4\bar{f}L_{max}}{D}\right] = 0.5$, we can refer gas table page no. 81 and page no: 85. But we have to make $M < 1$ corresponding value since the flow is subsonic.

$$\Rightarrow P_1 = P_1^* \times 1.763$$
$$= 101 \times 10^3 \times 1.763$$

$$\boxed{P_1 = 1.78 \times 10^5 \, N/m^2}$$

$$\Rightarrow T_1^* = \frac{T_1}{1.119} = \frac{333}{1.119} = \boxed{T_1^* = 297.58\,K = T_2^*}$$

$$\boxed{T_1^* = 297.58 = T_2^* = T_2}$$

mass flow rate, $\dot{m} = \rho A C = \rho_1 A_1 C_1 = \rho_2 A_2 C_2$

$$\dot{m} = \rho_1 A_1 C_1$$

$$= \frac{P_1}{RT_1} \times \frac{\pi}{4} \times (D_1^2) \times M_1 \times a_1$$

$$= \frac{P_1}{R \times T_1} \times \frac{\pi}{4} \times (D_1^2) \times M_1 \times \sqrt{\gamma R T_1}$$

$$= \frac{1.78 \times 10^5}{287 \times 333} \times \frac{\pi}{4} [0.050]^2 \times 0.60 \times \sqrt{1.4 \times 287 \times 333}$$

$$\boxed{\dot{m} = 0.802 \text{ kg/s}}$$

⑤ H.W Air is following into an insulated duct with a velocity of 150 m/s. The temp. and Pr. at the Inlet are 280°c and [illegible] bar respectively. Find the temp. at a section in the duct where the pressure is 15.7 bar. If the duct diameter is 15cm and friction factor is 0.005, find the distance between the two sections.

Given

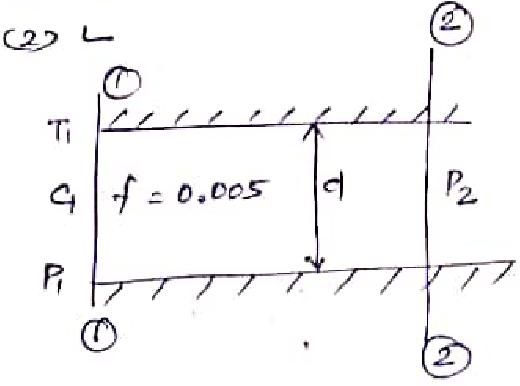
$C_1 = 150$ m/s $\quad T_1 = 280 + 273 = 553$k $\quad P_1 = 28$ bar $= 28 \times 10^5$ N/m² $\quad \bar{f} = 0.005$.

$P_2 = 15.7$ bar $= 15.7 \times 10^5$ N/m² $\quad D = 15$cm $= 0.15$m

To find:- (1) T_2

(2) L

Solution:-



At Inlet, $M_1 = \frac{C_1}{a_1} = \frac{150}{\sqrt{\gamma R T_1}}$

$$= \frac{150}{\sqrt{1.4 \times 287 \times 553}}$$

$$\boxed{M_1 = 0.3182}$$

Refer Isentropic flow table for $\gamma = 1.4$ and $M_1 = 0.318 \simeq 0.32$

$\frac{T_1}{T_{01}} = 0.979$

$\frac{P_1}{P_{01}} = 0.932$

} From gas tables page No:29

$$T_{01} = \frac{T_1}{0.979} = \frac{553}{0.979}$$

$$\boxed{T_{01} = 564.86 \text{ K}}$$

$$P_{01} = \frac{P_1}{0.932} \; ; \; \frac{28 \times 10^5}{0.932}$$

$$\boxed{P_{01} = 30.04 \times 10^5 \text{ N/m}^2}$$

Refer Fanno flow table for $\gamma = 1.4$ & $M_1 = 0.318$
$\simeq 0.32$

$$\left.\begin{aligned}\frac{P_1}{P_1^*} &= 3.388\\ \frac{T_1}{T_1^*} &= 1.176\end{aligned}\right\}$$ From gas tables Page No: 81

$$\left[\frac{4\bar{f}L}{D}\right]_{M_1} = 4.447$$

$$\Rightarrow P_1^* = \frac{P_1}{3.388} = \frac{28\times10^5}{3.388} = \boxed{P_1^* = 8.26\times10^5\ N/m^2 = P_2^*}$$

$$\Rightarrow T_1^* = \frac{T_1}{1.176} = \frac{553}{1.176} = \boxed{T_1^* = 470.23 = T_2^*}$$

$$\Rightarrow \frac{P_2}{P_2^*} = \frac{15.7\times10^5}{8.26\times10^5} = 1.90$$

Refer Fanno flow table for $\gamma = 1.4$ & $\frac{P_2}{P_2^*} = 1.90$
$\simeq 1.897$

$$\left.\begin{aligned}M_2 &= 0.56\\ \frac{T_2}{T_2^*} &= 1.129\\ \left[\frac{4\bar{f}L}{D}\right]_{M_2} &= 0.674\end{aligned}\right\}$$ From gas table page No: 81

$$T_2 = T_2^* \times 1.129 = 470.23 \times 1.129 \quad \boxed{T_2 = 530.88K}$$

We know that

$$\frac{4\bar{f}L}{D} = \left[\frac{4\bar{f}\,L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

$$= 4.447 - 0.674$$

$$\frac{4\bar{f}L}{D} = 3.773$$

$$L = \frac{3.773\times D}{4\times\bar{f}} = \frac{3.773\times0.15}{4\times0.005}$$

$$\boxed{L = 28.29m}$$

⑥ A Circular duct passes 8.25 kg/s of air at an exit Mach Number of 0.5. The entry Pr. and Temp. are 3.5 bar and 38°c respectively and co-efficient of friction is 0.005. If the Mach Number at entry is 0.15, determine ① Diameter of the duct ② length of the duct ③ Pr. and temp. at the exit ④ stagnation Pr. loss.

Given:- $m = 8.25$ kg/s $\quad M_2 = 0.5 \quad P_1 = 3.5 \times 10^5 \; N/m^2$

$T_1 = 38°c + 273 = 311 k \quad \bar{f} = 0.005 \quad M_1 = 0.15.$

To find :- (1) D (2) L (3) P_2, T_2 (4) ΔP_0.

Solution:- Refer Isentropic flow table for $\gamma = 1.4$ and $M_1 = 0.15$

$$\left.\begin{aligned} \frac{T_1}{T_{01}} &= 0.995 \\ \frac{P_1}{P_{01}} &= 0.984 \end{aligned}\right\}$$

From gas table page No: 28

$$T_{01} = \frac{T_1}{0.995} = \frac{311}{0.995}$$

$$\boxed{T_{01} = 312.56 \; k}$$

$$P_{01} = \frac{P_1}{0.984} = \frac{3.5 \times 10^5}{0.984} = \boxed{P_{01} = 3.55 \times 10^5 \; N/m^2}$$

Refer fanno flow table for $\gamma = 1.4$ & $M_1 = 0.15$

$$\frac{P_1}{P_1^*} = 7.319 \; ; \; \frac{c_1}{c_1^*} = 0.164 \; ; \; \frac{T_1}{T_1^*} = 1.1945 \; ; \; \frac{P_1}{P_{01}^*} = 3.928$$

$$\frac{4\bar{f}L_{max}}{D} = 28.354.$$

$$P_1^* = \frac{P_1}{7.319} = \frac{3.5 \times 10^5}{7.319} = \boxed{P_1^* = 0.478 \times 10^5 \; N/m^2 = P_2^*}$$

$$c_1^* = \frac{c_1}{0.164} = \frac{M_1 \times a_1}{0.164} = \frac{0.15 \times \sqrt{1.4 \times 287 \times 311}}{0.164}$$

$$\boxed{c_1^* = 323.32 \; m/s = c_2^*}$$

$$T_1^* = \frac{T_1}{1.1945} = \frac{313}{1.1945} \quad \boxed{T_1^* = 260.35 \; k = T_2^*}$$

$$P_{01}^* = \frac{P_{01}}{3.928} = \frac{3.55 \times 10^5}{3.928} = \boxed{P_{01}^* = 0.9037 \times 10^5 \; N/m^2 = P_{02}^*}$$

Refer Fanno flow table for $\gamma = 1.4$ and $M_2 = 0.5$

$\frac{P_2}{P_2^*} = 2.138$; $\frac{C_2}{C_2^*} = 0.534$ $\frac{T_2}{T_2^*} = 1.143$; $\frac{P_{02}}{P_{02}^*} = 1.340$

$\frac{4\bar{f}L_{max}}{D} = 1.069$.

$P_2 = P_2^* \times 2.138 = 0.478 \times 10^5 \times 2.138 = \boxed{P_2 = 1.021 \times 10^5 \ N/m^2}$

$T_2 = T_2^* \times 1.143 = 260.35 \times 1.143$ $\boxed{T_2 = 297.58 K}$

$P_{02} = P_{02}^* \times 1.340 = 0.9037 \times 10^5 \times 1.340$

$\boxed{P_{02} = 1.210 \times 10^5 \ N/m^2}$

Diameter of the duct (D)

mass flow rate, $\dot{m} = \rho A C = \rho_1 A_1 C_1 = \rho_2 A_2 C_2$

$m = \rho_1 A_1 C_1$

$= \frac{P_1}{RT_1} \times \frac{\pi}{4}(D_1^2) \times M_1 \times a_1$

$8.25 = \frac{3.5 \times 10^5}{287 \times 311} \times \frac{\pi}{4} \times (D_1^2) \times 0.15 \times \sqrt{\gamma R T_1}$

$8.25 = \frac{3.5 \times 10^5}{287 \times 311} \times \frac{\pi}{4} \times (D_1^2) \times 0.15 \times \sqrt{1.4 \times 287 \times 311}$

$D_1^2 = 0.0505$ Area is Constant, so

$\boxed{D_1 = 0.224 m}$ $\boxed{D_1 = D_2 = D = 0.224 m}$

Length of the duct :-

$\frac{4\bar{f}L}{D} = \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$

$= 28.354 - 1.069$

$\frac{4fL}{D} = 27.285$

$L = \frac{27.285 \times D}{4 \times \bar{f}} = \frac{27.285 \times 0.224}{4 \times 0.005}$

$\boxed{L = 305.59 m}$

Stagnation pressure loss

$\Delta P_0 = P_{01} - P_{02}$

$= (3.55 - 1.210) \times 10^5$

$\boxed{\Delta P_0 = 2.34 \times 10^5 \ N/m^2}$

⑦ The friction factor for a 50mm diameter steel pipe is 0.005. At the inlet to the pipe the velocity is 70m/s. temp is 80°C and the pressure is 10 bar. Find the temp, Pr and Mach Number at exit if the pipe is 25m long. Also determine the maximum possible length.

Given:-

$D = 0.050\,m$

$\bar{f} = 0.005$

$C_1 = 70\,m/s$

$T_1 = 353K$

$P_1 = 10\times10^5\,N/m^2$

$L = 25m$

To find:-

(1) T_2, P_2, M_2

(2) L_{max}.

Solution:-

Mach Number, $M_1 = \frac{C_1}{a_1} = \frac{C_1}{\sqrt{\gamma R T_0}} = \frac{70}{\sqrt{1.4\times287\times353}}$

$$\boxed{M_1 = 0.185}$$

Refer Fanno flow table for $\gamma = 1.4$ and $M_1 = 0.185$

$\frac{P_1}{P_1^*} = 6.067$ From gas table page No: 81

$P_1^* = \frac{P_1}{6.067} = \frac{10\times10^5}{6.067}$

$\boxed{P_1^* = 1.648\times10^5\,N/m^2} = P_2^*$

$\frac{T_1}{T_1^*} = 1.192$

$\frac{4\bar{f}L_{max}}{D} = 18.543$

$T_1^* = \frac{T_1}{1.192} = \frac{353}{1.192} = \boxed{T_1^* = 296.14 = T_2^*}$

$\frac{4\bar{f}L_{max}}{D} = 18.543$ $\quad L_{max} = \frac{18.543\times D}{4\times0.005}$ $\quad \boxed{L_{max} = 46.357m}$

We know that

$$\frac{4\bar{f}L}{D} = \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_1} - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

$$= \frac{4\times0.005\times25}{0.050} = 18.543 - \left[\frac{4\bar{f}L_{max}}{D}\right]_{M_2}$$

UNIT – IV

Jet propulsion

→ The principle of Jet propulsion is obtained from the application of Newton's third law.

→ **Classification of Jet propulsion.**

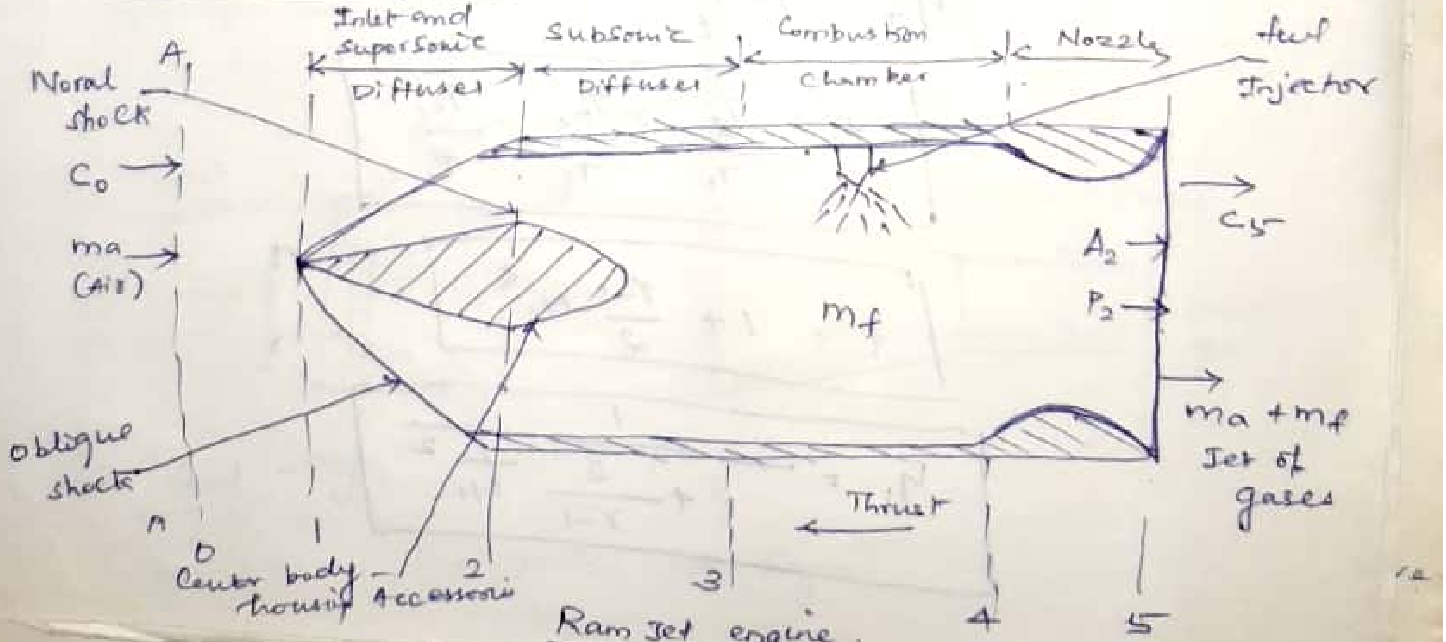
(a) Air breathing engines – Combustion takes place by using atmospheric air.

(b) Rocket engines – Combustion takes place by using its own oxygen supply.

Classification of Air breathing Engines:-

1. Ram Jet engine
2. pulse Jet engine.
3. Turbojet engine.
4. Turbo prop engine.
5. Turbo fan engine.

Ram Jet engine



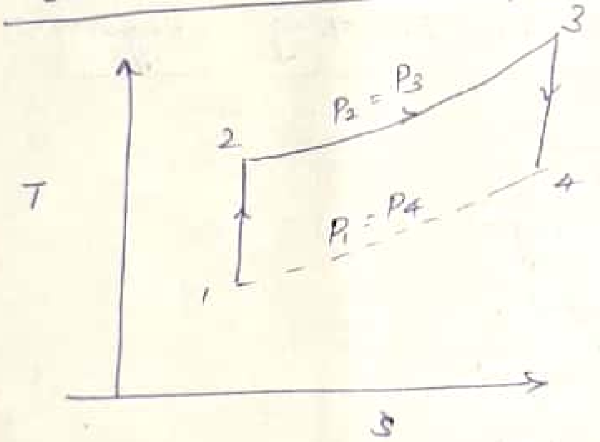
Ram Jet engine.

Construction

1. Super Sonic diffuser
2. subsonic diffuser
3. Combustion Chamber
4. Discharge Nozzle section.

→ The function of supersonic and subsonic diffuser are convert the K.E of the entering air pr. energy. The energy transformation is called "ram effect" and the pressure rise is called the "Ram pressure"

→ Ideal Ram Jet engine η



$\Delta s = 0$

$\Delta P_0 = 0$

$P_2 = P_3$

$P_2 = P_{02} = P_{03}$

$T_2 = T_{02} = T_{01}$

Ideal Brayton cycle for Ram Jet engine.

$$\eta_I = 1 - \frac{1}{t}$$ t = temp. ratio

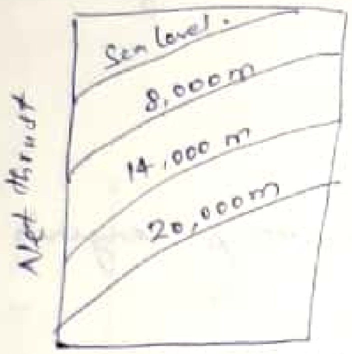
$$\boxed{t = \frac{T_2}{T_1} = \frac{T_{02}}{T_1} = \frac{T_{01}}{T_1}}$$

$$\boxed{t = 1 + \frac{\gamma-1}{2} M_1^2}$$

$$\boxed{\eta_1 = \frac{1}{1 + \frac{2}{\gamma-1} {\frac{1}{M_1}}^2}}$$

Performance:-

Thrust Vs Mach Number is shown in fig. It can be seen at low flight speeds the thrust is quite high. While at the high speeds it reduces considerably. This is because at low speeds of the compression is poor.

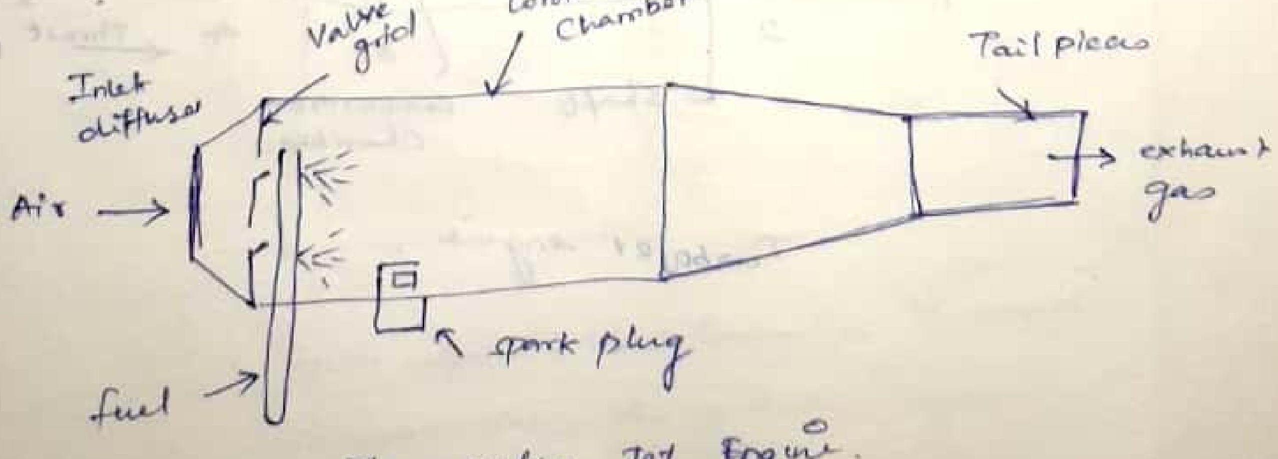


performance of RamJet engine.

Application:-

→ widely used in high speed Air crafts
→ Missiles due to high thrust
→ high operating speed.
→ Subsonic ramjets are used in target weapons.

pluse Jet engine (or) FLYING BOMB:-



The pulse Jet Engine.

Applications.

→ It is used in subsonic flights, German V-I missiles, Target aircraft Missiles, pilotless air craft.

→ A factor practically restricting the use of the pulse jet engine to pilotless air craft is its servere vibrations and high intensity of Noise.

Turbojet Engine :-

~~Two~~ air breathing engines ~~described~~ ~~so~~

→ It Consists of

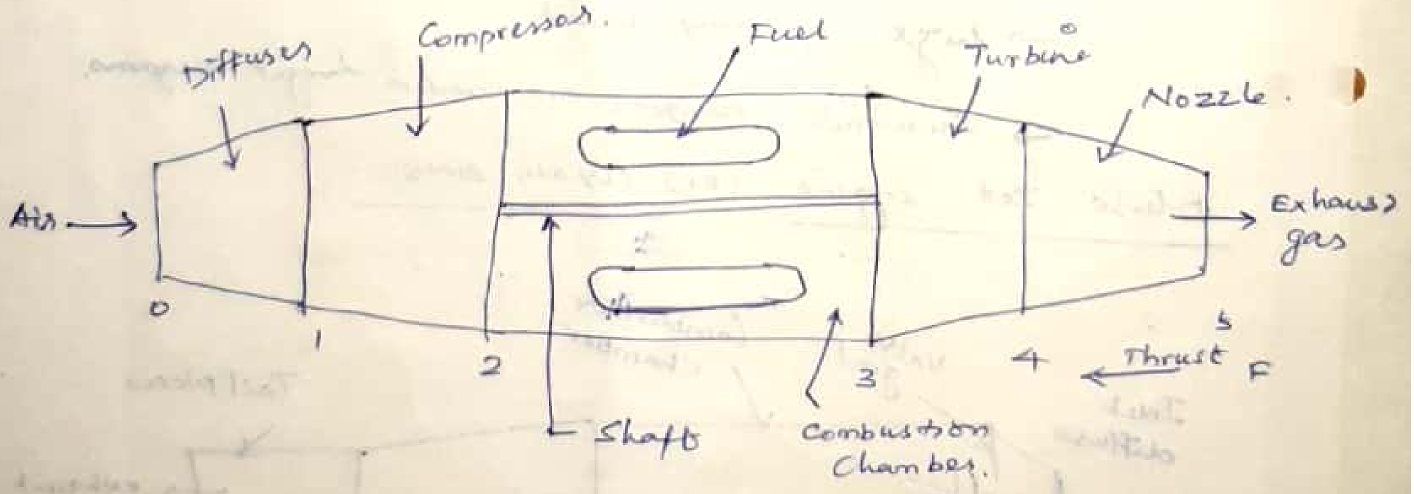
(1) Diffuser

(2) Rotary Compressor.

(3) Combustion Chamber

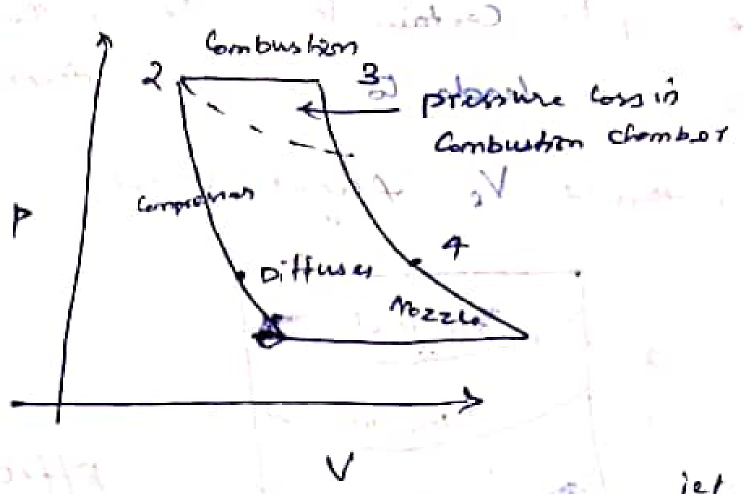
(4) Turbine

(5) Exhaust Nozzle.

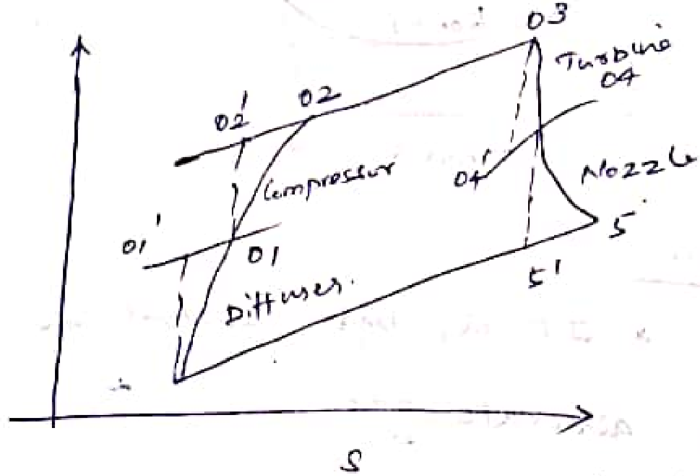


Turbojet engine.

Thermodynamic cycle

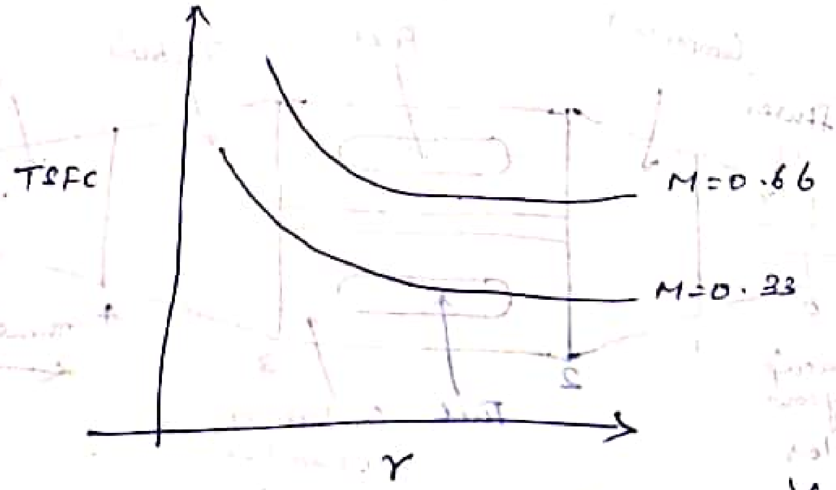


P-V diagram of turbo jet engine.



T-S Diagram of a turbojet engine.

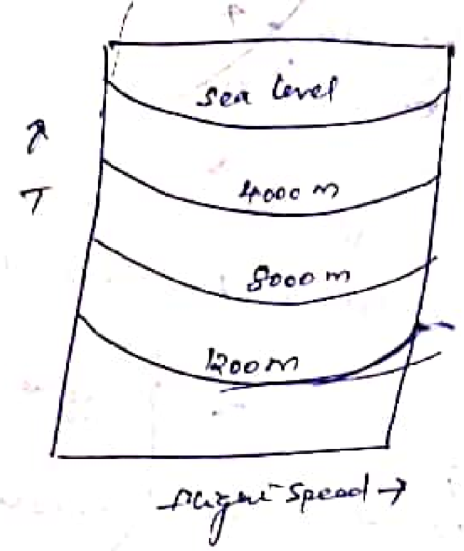
performance of a turbojet engine.



Thrust specific fuel Combustion Vs Compressor pressure ratio for a turbojet engine.

When the pr: ratio increase, the fuel consum decrease up to certain level. After that further increa in pr: ratio leads to increas in fuel consumption.

Turbojet thrust Vs flight speed.



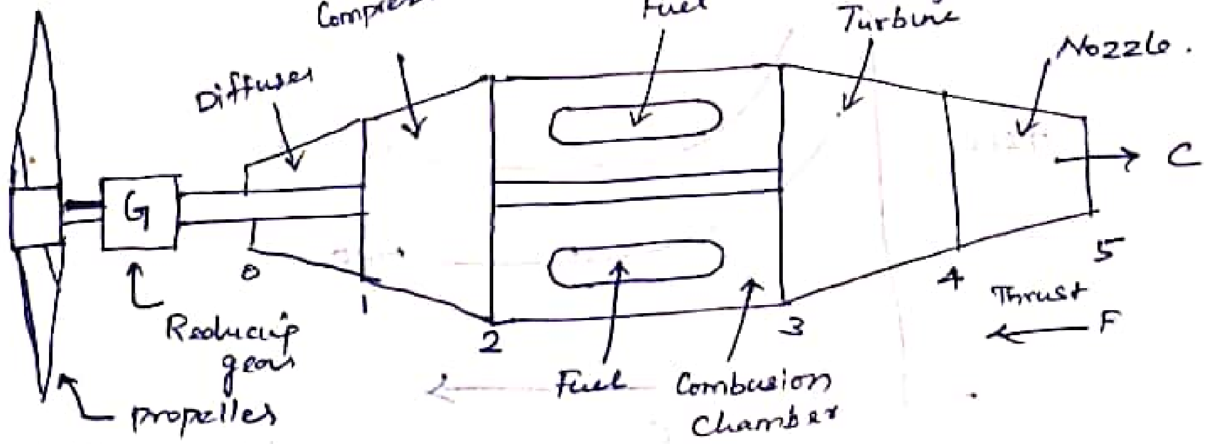
Effect of Altitude on thrust.

Application

* It is best suited for piloted air-crafts

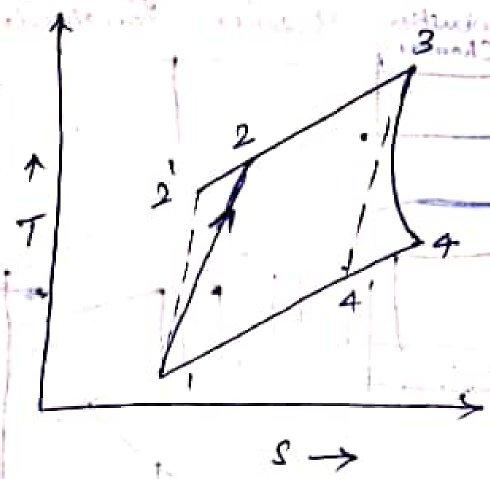
Military aircrafts etc.

Turbo-Prop engine (or) Turbo-Propeller engine



Turboprop engine

Thermodynamics cycle



80 to 90 energy used in turbine

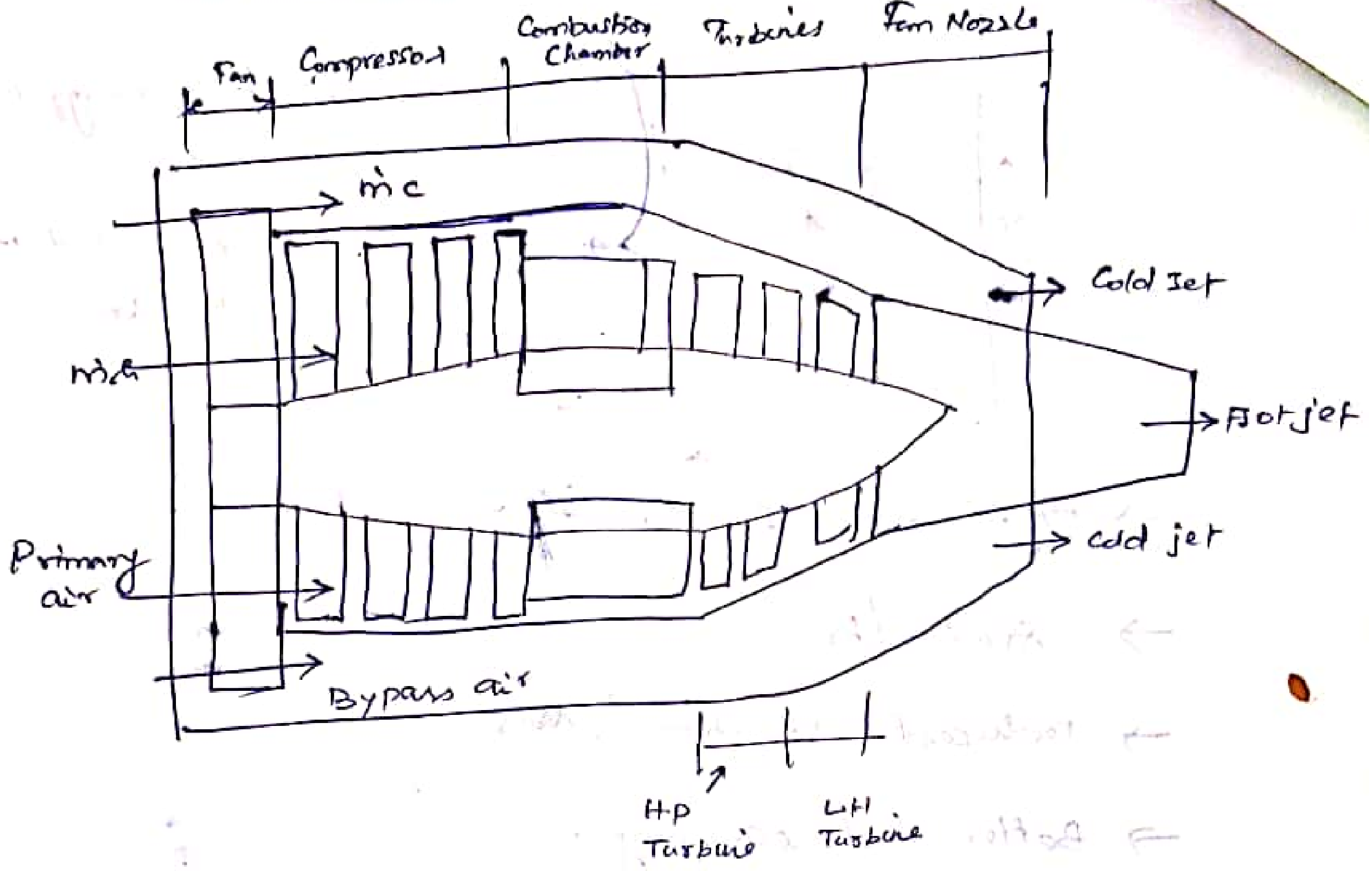
10 to 20% used in Nozzle.

- → High rate of thrust.
- → 800 km/hr.
- → reduced vibration & Noise
- → Better fuel economy.
- → propeller η rapidly decreased at high speeds due to shock and flow separation.

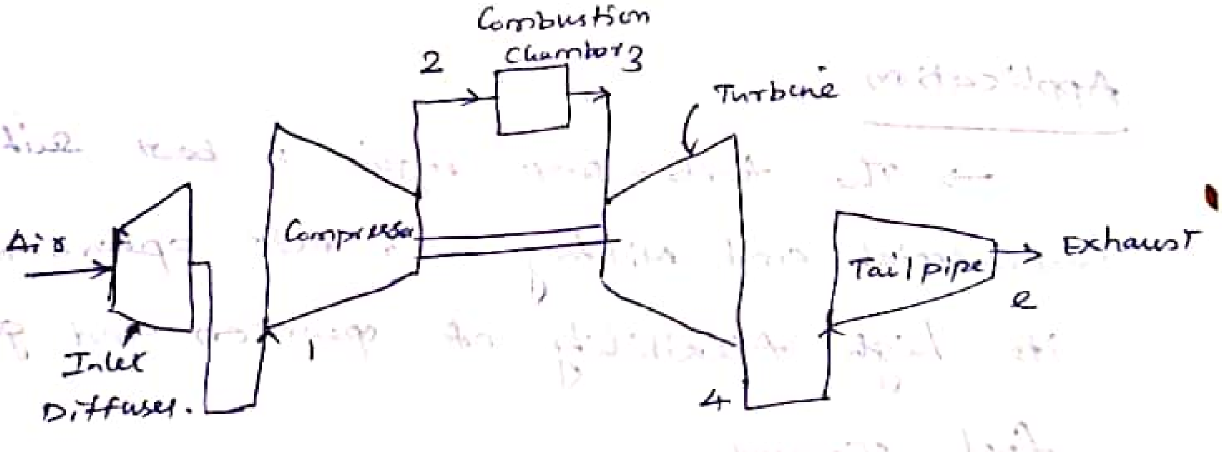
Application

→ The turb-prop engine is best suited for Commercial and Military air craft operation due to its high flexibility of operation and good fuel economy.

Turbo fan engine:



Component efficiency



gas turbine power plant for aircraft propulsion.

Diffuser :

١٢_⑤

$$\eta_0 = \frac{\text{Static pressure rise in The actual process}}{\text{Static pressure rise in the Isentropic process}}$$

$$\eta_0 = \frac{P_1 - P_i}{P_{is} - P_i}$$

$$\boxed{\eta_0 = \frac{P_1 - P_i}{\frac{1}{2}\rho\left[c_i^2 - c_1^2\right]}}$$

$$\boxed{\eta_D = \frac{\text{Enthalpy change in Isentropic diffusion}}{\text{Enthalpy change in actual diffusion for the same exit pressure}}}$$

$$= \frac{h_{is} - h_i}{h_1 - h_i}$$

$$\boxed{\eta_D = \frac{\left(\frac{P_1}{P_i}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{\gamma-1}{2} M_i^2}}$$

Compressor

$$\eta_c = \frac{\text{Isentropic work done}}{\text{Actual work done}}$$

$$\eta_c = \frac{T_{01}\left[\left(R_{0c}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{T_{02} - T_{01}}$$

R_{0c} → Compressor pressure ratio $= \frac{P_{02}}{P_{01}}$

Combustion Chamber:-

$$\dot{m} = \dot{m}_a + \dot{m}_f$$

$$\boxed{\dot{m} = \dot{m}_a (1+f)}$$

$$f = \frac{\dot{m}_f}{\dot{m}_a}$$ = Fuel air ratio

$$\eta_B = \frac{(\dot{m}_a + \dot{m}_f)\, c_p T_{03} - \dot{m}_a c_p T_{02}}{\dot{m}_f \times \text{Calorific value}}$$

$$\boxed{\eta_B = \frac{\frac{\dot{m}_a}{\dot{m}_f}\left[c_p T_{03} - c_p T_{02}\right] + c_p T_{03}}{C_V}}$$

Turbine

$$\eta_T = \frac{\text{Actual Work done}}{\text{Isentropic Work done}}$$

$$\eta_T = \frac{T_{03} - T_{04}}{T_{03}\left[1 - \frac{1}{(R_{0T})^{\frac{\gamma-1}{\gamma}}}\right]}$$

$$R_{0T} = \frac{P_{03}}{P_{04}}$$ = Turbine pressure ratio

Nozzle

$$\eta_N = \frac{\text{Actual enthalpy drop}}{\text{Isentropic enthalpy drop}}$$

$$R_{0N} = \frac{P_{04}}{P_e}$$

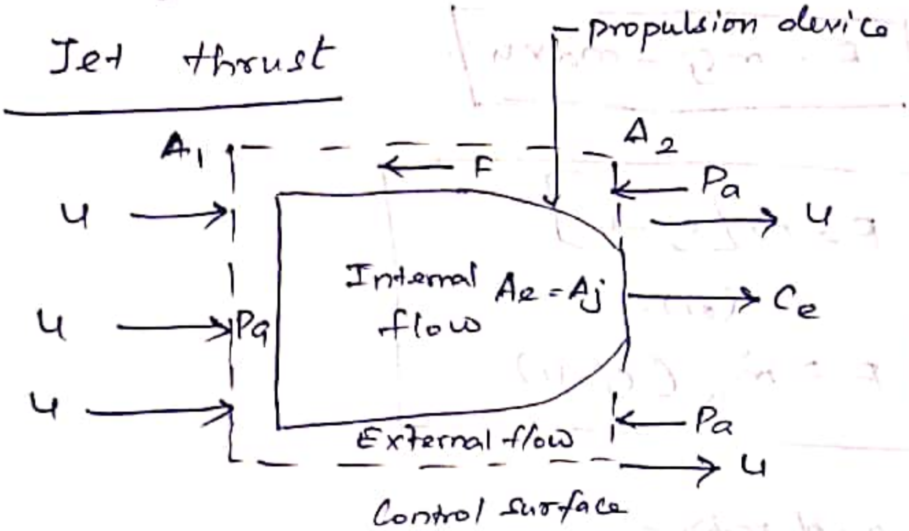
Nozzle pressure ratio.

$$\eta_N = \frac{T_{04} - T_e}{T_{04}\left[1 - \frac{1}{(R_N)^{\gamma-1/\gamma}}\right]}$$

Thrust :-

The force which propels the air craft forward at a given speed is called as thrust or propulsive force. This thrust mainly depends on the velocity of gases at the exits of the Nozzle.

Jet thrust



$$\left.\begin{matrix}\text{Net thrust of}\\ \text{the engine}\end{matrix}\right\} F = \left\{\begin{matrix}\text{Momentum}\\ \text{thrust}\\ F_{mom}\end{matrix}\right\} + \left\{\begin{matrix}\text{pressure}\\ \text{thrust}\\ F_{pre}\end{matrix}\right\}$$

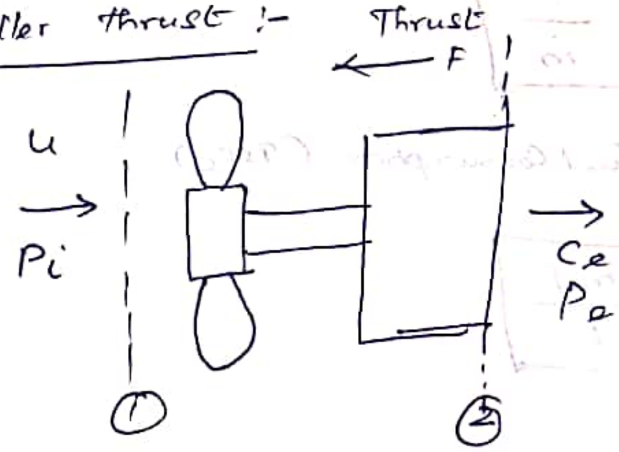
$$\text{momentum thrust } (F_{mom}) = (\dot{m}_a + \dot{m}_f)\, C_e - \dot{m}_a \times u.$$

$$\text{pressure thrust} = (P_e - P_a) \times A_e.$$

$$\text{Net thrust } (F) = (\dot{m}_a + \dot{m}_f)\, C_e - \dot{m}_a \times u + (P_e - P_a) \times A_e$$

$$\boxed{\text{Net thrust } F = (\dot{m}_a + \dot{m}_f)\, C_e - \dot{m}_a \times u}$$

propeller thrust :-



Net thrust
Considering
mass of fuel

$$F = (\dot{m}_a + \dot{m}_f) C_e - \dot{m}_a \times u$$

$$= \dot{m} C_e - \dot{m}_a \times u$$

$$C_j = C_e$$

$$\boxed{F = \dot{m} C_j - \dot{m}_a \times u}$$

$$\boxed{\begin{gathered} F = \dot{m}[C_j - u] \\ \text{(or)} \\ F = \dot{m}_a (C_j - u) \end{gathered}}$$

Efficiency speed ratio:-

$$\sigma = \frac{\text{Flight speed}}{\text{Jet velocity (or) velocity of exhaust gases}}$$

$$F = \dot{m}_a [C_j - u]$$

$$\boxed{F = \dot{m}_a \times C_j [1 - \sigma]}$$

specific thrust:- (F_{sp})

$$\boxed{F_{sp} = \frac{F}{\dot{m}}}$$

Thrust specific fuel Consumption (TSFC)

$$\boxed{TSFC = \frac{\dot{m}_f}{F}}$$

propulsive efficiency :-

The ratio of propulsive power (or) Thrust power to the power output of the engine.

$$\eta_p = \frac{\text{Propulsive power (or) Thrust power}}{\text{power output of the engine}}$$

Thrust power = $\dot{m}\left[C_j - u\right] \times u$

$$\boxed{\text{Power output} = \frac{1}{2}\dot{m}\left[C_j^2 - u^2\right]}.$$

$$\boxed{\eta_p = \frac{2u}{C_j + u}}$$

$$\boxed{\eta_p = \frac{2\sigma}{1+\sigma}}$$

σ - Effective speed ratio = $\frac{u}{C_j}$

Thermal efficiency

$$\eta_t = \frac{\text{power output of the engine}}{\text{power input to the engine through fuel}}$$

$$\boxed{\eta_t = \frac{\frac{1}{2}\dot{m}\left[C_j^2 - u^2\right]}{\eta_B \times \dot{m}_f \times CV}}$$

overall efficiency :-

$$\eta_o = \frac{\text{propulsive power (or) Thrust power}}{\text{power input to the engine}}$$

$$\boxed{\eta_o = \eta_p \times \eta_t}$$

Problem ① A turbojet propels an aircraft a speed of 900 Km/h while taking 300 kg of air p minute. The isentropic enthalpy drop in the Nozzle is 200 kJ/kg. and the Nozzle efficiency is 90%. The air-fuel is 85 and the Combustion efficiency is 95%. The Calorific value of the fuel is 42,000 kJ/kg. Calculate

(i) propulsive power (or) Thrust power

(2) Thermal efficiency

(3) propulsive efficiency.

Given Aircraft speed $u = 900$ km/h

$$= \frac{900\times10^3 \text{ m}}{3600 \text{ s}} = 250 \text{ m/s}.$$

mass of air, $\dot{m}_a = 3000$ kg/min

$$= \frac{3000}{60} \text{ kg/s} = 50 \text{ kg/s}$$

Enthalpy drop $dh = 200$ kJ/kg $= 200\times10^3$ J/kg.

Nozzle efficiency $\eta_N = 90\%$.

Air fuel ratio $= \dfrac{\dot{m}_a}{\dot{m}_f} = 85$

Combustion efficiency, $\eta_B = 95\%$.

Calorific value of $C_V = 42{,}000 \dfrac{\text{kJ}}{\text{kg}} = 42{,}000\times10^3$ J/kg.

To find

(1) P

(2) η_T

(3) η_P

Solution:- mass flow rate of air-fuel mixture $\overline{\underline{\text{IV}}}$ - ⓐ

$$\dot{m} = \dot{m}_a + \dot{m}_f$$

$$= \dot{m}_a \left[1 + \frac{\dot{m}_f}{\dot{m}_a}\right] = \dot{m}_a \left[1 + \frac{1}{85}\right]$$

$$\dot{m} = 50 \left[1 + \frac{1}{85}\right]$$

$$\boxed{\dot{m} = 50.58 \text{ kg/s}}$$

$$\dot{m}_f = \dot{m} - \dot{m}_a$$

$$= 50.58 - 50$$

$$\boxed{\dot{m}_f = 0.58 \text{ kg/s}}$$

Velocity of exhaust gas $c_j = \sqrt{2 \times \eta_N \times \Delta h_0}$

$$= \sqrt{2 \times 0.90 \times 200 \times 10^3}$$

$$\boxed{c_j = 600 \text{ m/s}}$$

$$F = \dot{m} c_j - \dot{m}_a u$$

$$= 50.58 \times 600 - 50 \times 250$$

$$\boxed{F = 17.84 \times 10^3 \times 250}$$

Thrust power (or) propulsive power $P = F \times u$

$$P = 17.84 \times 10^3 \times 250$$

$$\boxed{\text{Propulsive power} = P = 4.46 \times 10^6 \text{ W}}$$

$$\eta_p = \frac{2u}{c_j + u} = \frac{2 \times 250}{600 + 250}$$

$$\boxed{\eta_p = 0.588}$$

$$\text{Thermal efficiency} = \eta_t = \frac{\frac{1}{2}\,\dot{m}\,[C_j^2 - u^2]}{\eta_B \times \dot{m}_f \times C_v}$$

$$= \frac{\frac{1}{2} \times 50.58\,[(600)^2 - (250)^2]}{0.95 \times 0.58 \times 42{,}000 \times 10^3}$$

$$\boxed{\eta_t = 0.325 \text{ (or) } 32.5}$$

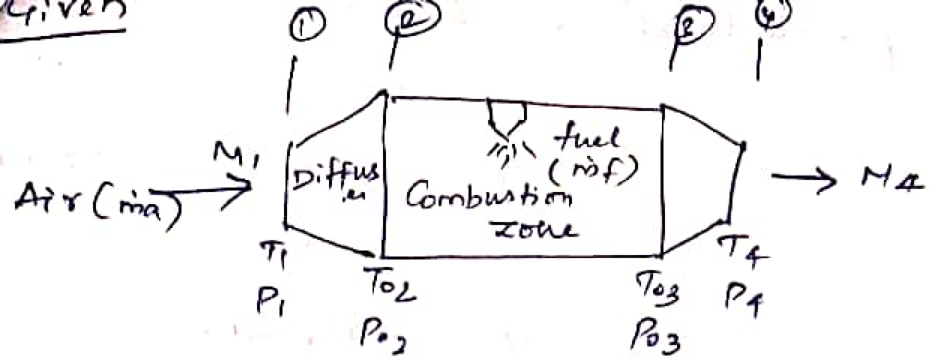
Problem ②

A ram Jet engine operates at M = 1.2 a an altitude of 6500 m. The diameter of Inlet dif at entry is 50cm and the Stagnation temp: at th Nozzle entry is 1500 K. The calorific value of the fuel used is 40 MJ/kg. The properties of the Combustion gases are same those of air [$\gamma = 1.4$ & $R = 287$ J/kg.K]. The velocity of the air at the diffuser exit is negligible, calculate

(i) The efficiency of the ideal cycle
(ii) Air flow rate
(iii) Fuel/air ratio
(iv) Flight speed
(v) Diffuser pressure ratio
(vi) Nozzle Jet Mach Number.

The efficiency of the diffuser = 0.9, Combustor = 0.9 and the Nozzle = 096

Given



$M_1 = 1.2$

$z = 6500\,m$

$d_1 = .50\,m$

T_0. Stagnation temp. at Nozzle entry $\}$ $T_{03} = 1500K$

$CV = 40\,MJ/kg = 40 \times 10^6\,J/kg$.

$\eta_D = 0.9$

$\eta_B = 0.98$

$\eta_j = 0.96$

To find

(1) η_I
(2) u
(3) $\dot{m}a$
(4) R_{OD}
(5) $\dot{m}f/ma$
(6) M_4

Solution :-

Ideal efficiency $\eta_I = \dfrac{1}{1 + \frac{2}{\gamma - 1} \times \frac{1}{M_1}^2}$

$$= \frac{1}{1 + \frac{2}{1.4-1} \times \frac{1}{(1.2)^2}}$$

$$= 0.223$$

$$\boxed{\eta_I = 22.3\%}$$

Refer gas table at $z = 6500\ m$

$T_1 = 245.90\ k$

$P_1 = 0.440\ bar = .444 \times 10^5\ N/m^2$

$\rho_1 = 0.624\ kg/m^3$

$a_1 = 314.5\ m/s$

$$M_1 = \frac{\text{Flight speed}}{\text{velocity of sound}}$$

$$M_1 = \frac{u}{a_1}$$

$u = M_1 \times a_1$

$u = 1.2 \times 314.5$

$$\boxed{u = 377.4\ m/s}$$

Area of cross section of the diffuser.

$$A_1 = \frac{\pi}{4} d_1^2$$

$$= \frac{\pi}{4} \times 0.5^2$$

$$\boxed{A_1 = 0.1963\ m^2}$$

Air flow rate of the diffuser $\dot{m}_a = \rho_1 A_1 u$

$= 0.624 \times 0.1963 \times 377.4$

$$\boxed{\dot{m}_a = 46.228\ kg/s}$$

Diffuser efficiency $$\eta_D = \frac{(R_{OD})^{\frac{\gamma-1}{\gamma}} - 1}{\frac{\gamma-1}{2} M_1^2}$$

$$0.9 = \frac{(R_{OD})^{\frac{1.4-1}{1.4}} - 1}{\frac{1.4-1}{2} (1.2)^2}$$

$1.259 = (R_{OD})^{0.2857}.$

$$\boxed{R_{OD} = 2.239} = \frac{P_{02}}{P_1}$$

Stagnation temp:- Mach Number relation

$$\frac{T_0}{T} = 1 + \frac{\gamma-1}{2} M^2.$$

$$\frac{T_{01}}{T_1} = 1 + \frac{\gamma-1}{2} M_1^2$$

$$\frac{T_{01}}{245.90} = 1 + \frac{1.4-1}{2} (1.2)^2$$

$$\boxed{T_{01} = 316.72 = T_{02}}$$

$T_{01} = T_{02}$ Refer ideal efficiency of ram Jet engine

Combustion efficiency of ram jet engine is given by

$$\eta_B = \frac{\dot{m}_a C_p [T_{03} - T_{02}]}{\dot{m}_f \times C_v}$$

$$0.98 = \frac{46.228 \times 1005 \, [1500 - 316.722]}{\dot{m}_f \times 40 \times 10^6}$$

$$\boxed{\dot{m}_f = 1.402 \text{ kg/s}}$$

$$\text{Fuel air ratio} = \frac{\dot{m}_f}{\dot{m}_a} = \frac{1.402}{46.228}$$

$$\boxed{f = \frac{\dot{m}_f}{\dot{m}_a} = 0.0303}$$

$$\frac{P_4}{P_{03}} = \frac{P_1}{P_{02}} = \frac{1}{2.239} = 0.446$$

Combustion takes place at Constant Pr:- $P_{03} =$

For Complete expansion of Nozzle, $P_4 = P_1$

Refer Isentropic flow table for $\gamma = 1.4$ and $\frac{P_4}{P_{03}} = 0446$

$$M_{4s} = 1.14$$

$$\frac{T_{4s}}{T_{04}} = 0.794$$

$$T_{4s} = 0.794 \times T_{04}$$

$$= 0.794 \times 1500$$

$$\boxed{T_{4s} = 1191K}$$

Nozzle efficieny $\eta_N = \frac{T_{04} - T_4}{T_{04} - T_{4s}}$

$$0.96 = \frac{1500 - T_4}{1500 - 1194}$$

$$0.96(1500 - 1191) = 1500 - T_4$$

$$296.64 = 1500 - T_4$$

$$\boxed{T_4 = 1203.36K}$$

Stagnation temp:- $T_0 = T + \frac{C^2}{2C_p}$

$$T_{04} = T_4 + \frac{C_4^2}{2C_p}$$

$$1500 = 1203.36 + \frac{C_4^2}{2 \times 1005}$$

$$C_4^2 = 596.24 \times 10^3$$

$$\boxed{C_4 = 772.86 \text{ m/s}}$$

velocity of sound at exit, $a_4 = \sqrt{\gamma R T_4}$

$$= \sqrt{1.4 \times 287 \times 1203.36}$$

$$\boxed{a_4 = 695.32 \text{ m/s}}$$

Nozzle jet Mach Number (or) Mach Number at exit $\Bigg\}$ $M_4 = \dfrac{C_4}{a_4}$

$$= \frac{772.16}{695.36}$$

$$\boxed{M_4 = 1.110}$$