2.1 NUCLEAR POWER PLANT

2.1 GENERAL LAYOUT OF NUCLEAR POWER PLANT:

2.1.1 NUCLEAR REACTOR: Reactor is the part of nuclear power plant where nuclear reaction (controlled chain reaction) takes place and the energy is released which will further utilize to generate electrical power. The nuclear reactor mainly consists of fuel, core, moderator, control rods, reflectors and coolant.

(1) FUEL:

- Generally used fuels are: ${}^{235}_{92}U, {}^{239}_{94}Pu, {}^{233}_{92}U$.
- ${}^{235}_{92}U$ is naturally available up to 0.7% in the Uranium ore and the remaining is ${}^{238}_{92}U$.

(2) REACTOR CORE: This contains a number of fuel rods made of fissile material.

(3) MODERATOR:

- Used to reduce the speed of high speed neutrons to control their operation.
- Generally used moderators are: Heavy water/Graphite/ Beryllium (with natural uranium), Ordinary water (used only with enriched uranium).

(4) SHIELDING: Used to provide protection against deadly radioactive radiation.

(5) CONTROL RODS: Used to control the operation of nuclear reaction and can stop the operation under critical conditions. For this purpose Cadmium, Boron or Hafnium are used because they are very good absorber of neutrons.

(6) COOLANT: A coolant transfers heat produced inside the reactor to a heat exchanger for further utilization in power generation. Generally used coolants are: Gas (Carbon Dioxide/Air/Hydrogen/Helium), Water, Heavy water, liquid metals (Sodium or Sodium-potassium) etc.

(7) COOLING SYSTEM:

Direct: The liquid fuel circulated from the reactor to heat exchanger where steam is generated.

Indirect: Coolant passed through the reactor and then through the heat exchanger for steam generation.

2.1.2 CLASSIFICATION OF REACTORS:

(1) BOILING WATER REACTOR:

- In this reactor fuel used is enriched uranium and has a steel pressure vessel surrounded by concrete shield.
- Water is used as both moderator and coolant and steam is generated in the reactor itself.
- Feed water enters in the reactor tank at the bottom and gets converted into steam which after passing through the turbine and condenser, returns to the reactor.
- Fuel elements are arranged in a particular lattice from inside the pressure vessel containing water.
- The reactors at **Tarapur Atomic Power Station** are of this type.

Advantages:

- These reactors having high thermal efficiency and low cost due to the absence of heat exchanger circuit.
- More efficient.
- These reactors are more stable. Commonly known as a self-controlled reactor.
- The metal surface temperature is lower.

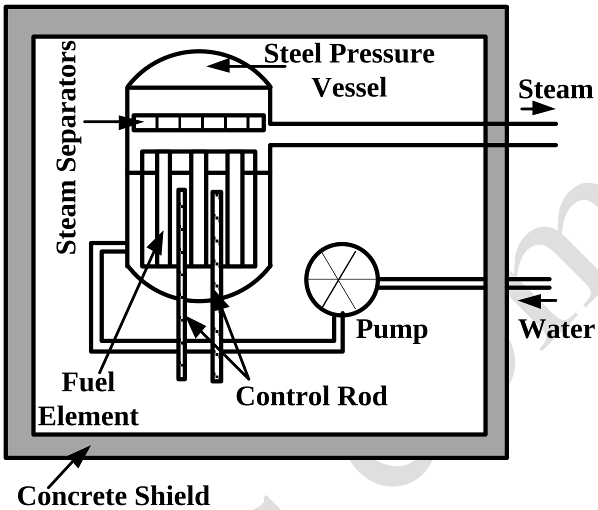


FIG.2.1 BOILING WATER REACTOR

Disadvantages:

- If any failure occurs, there is a possibility of passing of radioactive material through turbine mechanism.
- No one should go within 3 meters of the turbine when it is operating.
- They cannot meet a sudden increase in load.

(2) PRESSURIZED WATER REACTOR:

- The fuel used is enriched uranium clad with stainless steel or zirconium alloy.
- Pressurized water is used as both moderator and coolant.
- Water at high pressure (140kg/cm^2 and 190^{0}C) passed into reactor through a pump. This water rounds the core and absorbs heat from uranium and transfers it to the secondary loop-the boiler and discharged from reactor at 270^{0}C.
- The boiler has a heat exchanger and a steam drum.
- To maintain the pressure in the water system throughout the load range, a pressurizer and surge tank are used.
- To condense the steam when pressure is desired to be reduced, water spray is used.
- The pressure vessel is of steel and both pressure vessel and heat exchanger are surrounded by a concrete shield.
- The reactors at **Rajasthan Atomic Power Station, Madras Atomic Power Station** and **Narora Atomic Power Project** are of pressurized heavy water reactors.

Advantages:

- Compact in size as compare to others.
- Has high power density.
- Cheap substance (light water) can be used as moderator or coolant or reflector.
- The reactor responds to supply more power when the load increases.

Disadvantages:

- A strong vessel is required to withstand its high pressure.
- Expensive cladding material is required to prevent corrosion.
- High heat loss due to heat exchanger.
- More safety devices required.
- Low thermal efficiency as 20%.

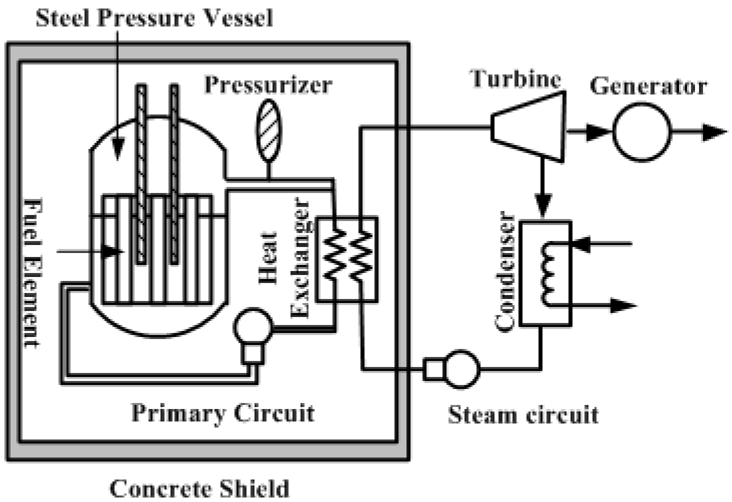


FIG.2.2 PRESSURIZED WATER REACTOR

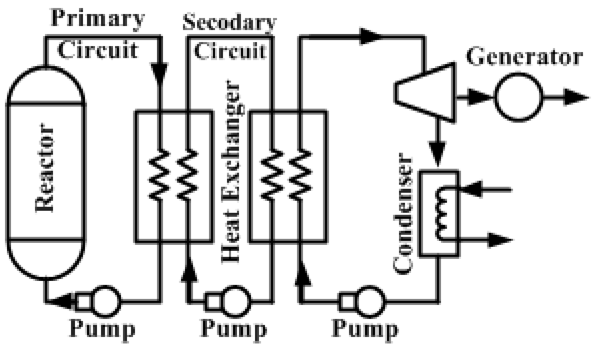


FIG.2.4 LIQUID METAL COOLED REACTOR

(3) GAS COOLED REACTOR:

- A gas cooled reactor employs a gas (usually CO_2) as coolant instead of water.
- Uranium dioxide is used as fuel.
- The pressure vessel is made of prestressed concrete and it contains both the reactor core and heat exchanger.
- Graphite is used as moderator.
- The steam pressure is around 150 atmospheres and temperature around 550^{0}C.
- The rate of flow of CO_2 can be controlled to maintain the gas, fuel elements and core temperature constant as load varies.
- Its overall efficiency is about 40%.
- There are two basic classifications of gas cooled reactors:
  (1) Gas cooled graphite moderated (GCGM) reactor;
  (2) High temperature gas cooled (HTGC) reactor.
- The coolant pressure and temperature in GCGM is about 7bars & 336^{0}C respectively and in HTGC these are about 15-20 bars and 700-800^{0}C.

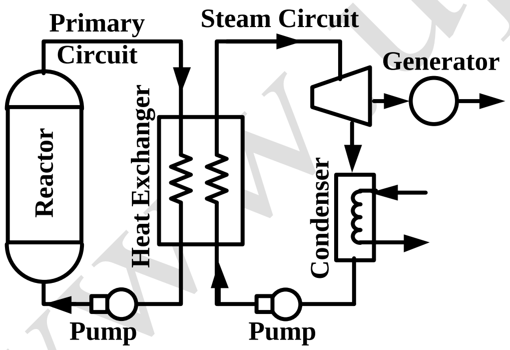


FIG.2.3 GAS COOLED REACTOR

Advantages:

- Simple fuel processing.
- No corrosion problem.
- Less chances of radiation.

Disadvantages:

- More power required for circulation of coolant.
- Large vessel is required due to low power density.
- Costly fuel loading.

(4) LIQUID METAL COOLED REACTOR:

- In this reactor, liquid metal is used as coolant which provides an excellent heat transfer properties permit high operating temperatures and ratings.
- Designing of pressure vessel is simple due to low vapour pressure of liquid metals.
- The reactor core with graphite moderator has the liquid metal fuel passing through it and through a heat exchanger.
- The core is surrounded by a blanket of fertile material through which a separator coolant passes to a separate heat exchanger.
- It is necessary to have two heat exchanger circuits because of handling of activated sodium in reactor core.
- The primary heat exchanger is sodium-sodium heat exchanger while the secondary is a sodium-water heat exchanger in which, sodium gives up heat to water which gets converted into steam and is fed to the steam turbine.

(5) HEAVY WATER COOLED AND MODRATED (CANDU Type) REACTOR:

- The word CANDU stands for CANadian Deuterium Uranium. As the name suggested this type of reactor was first developed and designed in Canada.
- These types of reactors are used in countries which don't produces enriched uranium.
- These reactor uses natural uranium (0.7% U^{235}) as fuel and heavy water as moderator.
- The coolant heavy water is passed through the pressurized fuel tubes and heat exchanger.
- Heavy water is circulated in primary circuit in the same way as with a pressurized water reactor and the steam is raised in the secondary circuit transferring the heat in the heat exchanger.
- The control of the reactor is achieved by varying moderator levels and therefore control rods are not required.
- For sudden purposes the moderator can be dumped through a very large area into a tank provided below the reactor.

Advantages:

- The fuel need not be enriched.
- No control rods are required, therefore much easier control than others.
- The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.

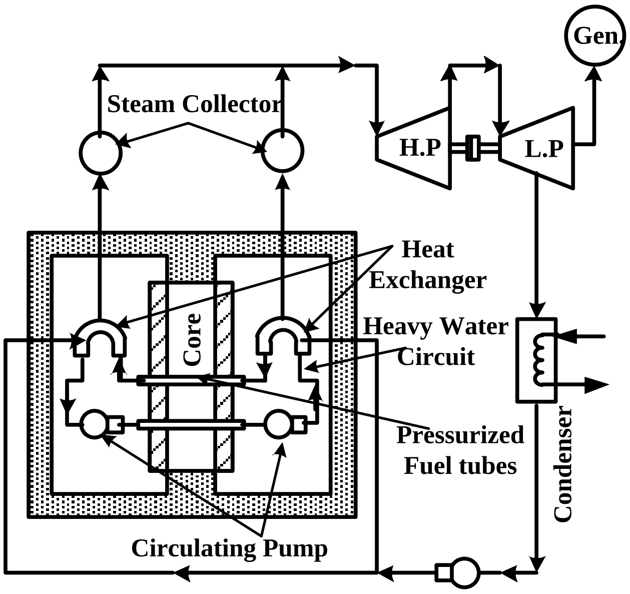


FIG.2.5 CANDU TYPE REACTOR

Disadvantages:
- Extremely high cost of heavy water.
- Very high standard of design, manufacture inception and maintenance are required.
- Low power density as compare to PWR and BWR, therefore reactor size is extremely large.

(6) FAST BREEDER REACTOR:
- A fast breeder reactor is a small vessel in which the necessary quantity of enriched uranium or plutonium is kept without moderator.
- This vessel surrounded by a fairly thick blanket of depleted fertile uranium.
- A fast breeder reactor produces heat and at the same time converts fertile material into fissile material.
- The reactor is cooled by liquid metal.
- In fast breeder reactors neutron shielding is provided by the use of boron, light water, oil or graphite.
- Additional shielding is provided for gamma-rays, by lead, concrete with added magnetite or boron.

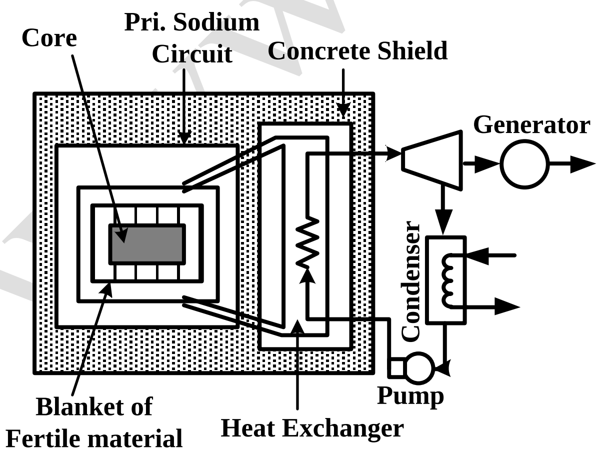


FIG.2.6 FAST FEEDER REACTOR

Advantages:
- The moderator is not required.
- High breeding is possible.
- Small core is sufficient.
- Absorption of neutron is low.

Disadvantages:
- Requires highly enriched fuel.
- It is necessary to provide sufficient protection against meltdown.
- Neutron flux is high at the centre of the core.
- The specific power of the neutron is low.

2.1.3 NUCLEAR POWER PLANT:

The main components of nuclear power plant are:

i. Nuclear Reactor;
ii. Heat Exchanger;
iii. Steam Turbine;
iv. Condenser;
v. Electric Generator.

In a nuclear power plant, the reactor produces heat by nuclear fission reaction. The heat is liberated in the reactor as a result of nuclear fission of the fuel is taken up by the coolant circulating through the reactor core. Hot coolant leaves the reactor at the top and then flows through the tubes of the steam generator and pass on it next to the feed water. The steam so produced expands in the steam turbine producing work and therefore is condensed in the condenser. Then steam turbine runs an electrical generator which generates electrical energy.

2.1.4 SITE SELECTION:

a) **AVAILABILITY OF COOLING WATER:** The plant required huge quantity of water; therefore it must be located near a river, lake or sea so the ample quantity of water will be available.

b) **TRANSPORT FACILITY:** There should be good transport facilities as heavy equipments are to be transported to the site.

c) **DISTANCE FROM THE LOAD CENTRE:** It should be located near the load centre. This will reduce the power loss as well as cost of long transmission line.

d) **SAFETY:** The power plant should be located at a reasonable distance from the populated area to avoid the radiation hazards.

e) **RADIATION WASTE DISPOSAL FACILITY:** It is a well known fact that waste of nuclear power plant is highly radioactive and therefore sufficient should be available near the plant for short time storage as well as for long time burial of the radioactive waste.

2.1.5 NUCLEAR POWER PLANTS IN INDIA: As per NPCIL, the list of Nuclear power plants in India is as given below:

1. Tarapur Atomic Power Station (TAPS), Maharashtra;
2. Rajasthan Atomic Power Station (RAPS), Rajasthan;
3. Madras Atomic Power Station (MAPS), Tamilnadu;
4. Narora Atomic Power Station (NAPS), Uttarpradesh;
5. Kakrapar Atomic Power Station (KAPS), Gujrat;
6. Kaiga Generating Station (KGS), Karnataka;
7. Kundankulam Nuclear Power Station (KKNPS), Tamilnadu.

2.2 GAS TURBINE POWER PLANT

2.2 GAS TURBINE POWER PLANT: These power plants are similar to steam power plant. In these plants gas is used instead of hot steam. These are cheaper in capital cost compared to steam stations.

2.2.1 PRINCIPLE OF OPERATION OF GAS TURBINE PLANTS: A gas turbine plant consists of a compressor, combustion chamber, gas turbine and alternator. Apart from these main components there may be auxiliaries such as starting device, fuel system, the duct system, auxiliary lubrication system etc.

- Fuel is injected into the combustion chamber and burnt in the stream of air supplied by the compressor.
- The burned high temperature gases are passed through the turbine where they expand and develop mechanical power to rotate it.
- In this scheme both the compressor and the alternator are coupled to the turbine shaft.
- The turbine drives the compressor and the surplus power drives the alternator.
- After expansion the gases leaves the turbine at atmospheric pressure.
- The temperature range of the exhaust gases is about 475 to 550^{0}C.
- Such plants are the example of open cycle gas turbine plants in which gas turbine has to drive the compressor as well as alternator.
- Sometimes two turbines are used for the two purposes, high pressure turbine to drive the compressor while a low pressure type turbine to drive alternator.
- In such arrangement about 65% of the generated power is employed to drive the compressor itself so its efficiency is about 20% of the energy input in the form of fuel.

2.2.2 REGENERATION, INTERCOOLING & REHEATING: These three methods are used to improve the thermal efficiency of a gas turbine plant.

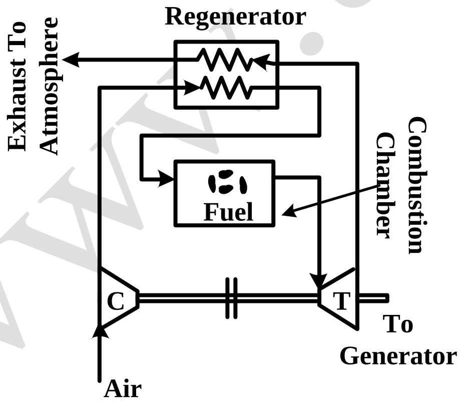


FIG.2.7 GAS TURBINE PLANT USING REGENERATOR

a) **REGENERATION:** In regeneration, heat from the exhaust gases is transferred to the compressed air which is flowing between the compressor and the combustion chamber. This process reduces the amount of heat loss through the exhaust gases. A perfect regenerator could cool the exhaust gases to the incoming air temperature and would have 100% efficiency. In actual practice the efficiency may vary between 70-80%.

b) **INTERCOOLING:** In this process the heat is removed from compressed air between the stages of compression i.e. low pressure and high pressure. Intercooling reduces the internal consumption of power by the plant and results in improvement of thermal efficiency, air rate and work ratio. When the pressure ratio for each stage is the same and is high, then the maximum advantage of intercooling is achieved.

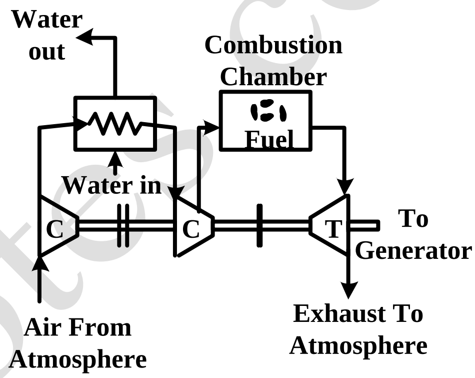


FIG.2.8 GAS TURBINE PLANT WITH INTERCOOLER

c) **REHEATING:** It is the process to increase the temperature of partially expanded gas by burning more fuel in it and necessitates a compounding of the turbine. Reheating improves the output from the turbine due to multiple heating. A reheater may have an additional combustor.

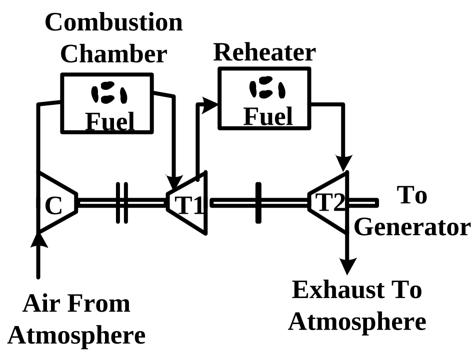


FIG.2.9 GAS TURBINE PLANT WITH REHEATER

2.2.3 OPEN CYCLE & CLOSED CYCLE PLANTS: In an open cycle plant, heat was given to the air by mixing and burning of fuel in it and the gases coming out of the turbine were exhausted to the atmosphere while in the case of closed cycle plants, the heat of the working medium was given without directly burning the fuel in that medium and the same working fluid were used again and again.

(a) OPEN CYCLE GAS TURBINE PLANT: In open cycle plant, fresh atmospheric air is drawn in the compressor where its pressure is raised and heat is added to it in combustor by burning the fuel. These heated gases coming out from the combustor is then fed to the turbine where they expand to do mechanical work. Some part of the power developed by the turbine is used in driving the compressor and other accessories and the remaining is used for generation of electrical energy. A sufficient amount of air enters the compressor and gases coming out of turbine are exhausted into the atmosphere, so the working medium has to replace continuously.

(b) CLOSED CYCLE GAS TURBINE PLANT: In closed cycle plant the air is compressed in the compressor and is fed into the heater where it is heated upto the temperature of of turbine inlet. The fluid after expansion in the turbine is cooled to the original temperature in the recooler. In further process it re-enters the compressor to begin next cycle. In this way the same working fluid circulates through the working parts of the system.

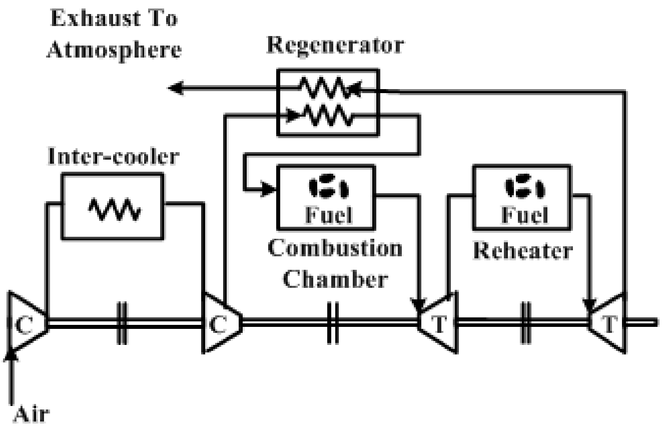


FIG.2.10 OPEN CYCLE GAS TURBINE PLANT WITH REGENERATOR, INTER-COOLER & REHEATER

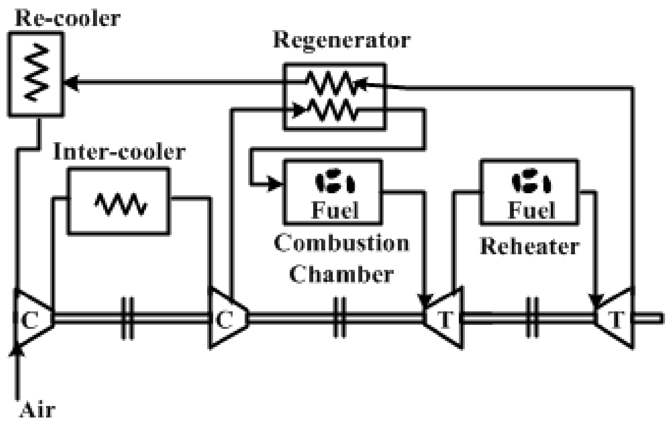


FIG.2.11 CLOSED CYCLE GAS TURBINE PLANT WITH REGENERATOR, INTER-COOLER & REHEATER

2.2.4 APPLICATIONS OF GAS TURBINE PLANT:

- To derive generators and supply peak loads in thermal/diesel or hydro plants.
- To work as combination plants with conventional boilers.
- They can work for auxiliary power plant for thermal stations.

2.2.5 COMPARISION OF GAS TURBINE PLANTS &STEAM PLANTS:

- The capital cost of gas turbine plant is lower than that of steam plant of same rating.
- A gas turbine plant has no standby losses.
- Lesser area required as in the case of gas turbine plant.
- Less water requirement.
- Easy to handle facility i.e easy start and stop.
- They can be locate very near to the load.
- The operating costs of a gas turbine plant are very high as compared to steam plants.
- Gas turbine plants can be used only in small sizes about 50MW or so.

2.3 DIESEL PLANTS

2.3.1 DIESEL PLANTS: Diesel plants are more efficient than any other heat engine of comparable size. A diesel plant needs the following equipment for their operation:

Diesel Engine: may be of two-stroke or four-stroke type.

Fuel system: Storage tank, pumps, strainers, oil filters, meters, heaters, piping.

Air-Intake system: air, ducts, super charger.

Engine cooling system: pumps, spray-pond, heat exchanger, water treatment, piping.

Lubricating system: oil tanks, oil pumps, valves, filters, purifier, coolers, piping.

Exhaust system: silencers, mufflers, water-heaters.

Starting system: air compressor, motor, battery.

(1) ENGINE: This is the main component of diesel power plant which generates electrical power. IC engines are used for such purpose, which may be of two-stroke or four-stroke type depends on (i) kind of fuel used, (ii) how fuel is introduced in the engine, (iii) type of ignition used.

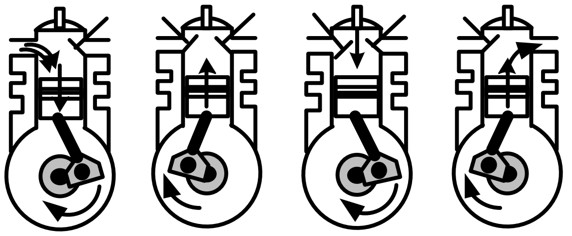
(a) FOUR STROKE ENGINE: In this type of engines, the complete cycle of operation is performed in four revolution of the engine and each revolution is named as a stroke. These strokes are:

(i) Suction Stroke: In this stroke the air is sucked into the cylinder through the manifold and inlet valve, the piston receding towards the crank end of the cylinder. The exhaust valve is kept closed during the process.

(ii) Compression Stroke: In this stroke, the piston moved towards the cover end of the cylinder. At the end of the stroke, piston has reached the extreme position at cover end. During this stroke, inlet and exhaust valves both are kept closed.

(iii) Expansion/Power Stroke: This stroke starts at the end of compression stroke when the fuel is injected in atomized form resulting in its ignition and an increase in pressure of gases in the cylinder which causes the piston to move back furnishing the power stroke.

(iv) Exhaust Stroke: In exhaust stroke, the piston again moves forward and exhausts valves being opened and the gaseous products due to combustion being exhausted from the cylinder.



(a) Suction (b)Compression (c) Power (d) Exhaust

FIG.2.12 CYCLE OPERATION OF A 4-STROKE ENGINE

(b) **TWO STROKE ENGINE:** In the case of two stroke engine, the complete cycle of operation is completed within two strokes of the piston or during one revolution of the crank-shaft. In the backward direction, the power and exhaust operations are completed while intake and compression operations are completed during the forward direction of the piston.

(2) FUEL SYSTEM:

- The fuel is stored in a bulk storage tanks which are situated outside.
- Oil is drawn by pump in day tanks which is used to feed engine.
- There is a fuel admission system which is use to measure the correct amount of fuel for engines.

(3) AIR-INTAKE SYSTEM:

- Air is drawn from outside the engine room and delivered to the inlet manifold through the air filters which remove the dust other impurities from air.
- In cold climates, heaters are used to heat air before injection.

(4) ENGINE COOLING SYSTEM:

- The extra heat which is not useful to work has to be removed from the engine by a proper arrangement.
- Cold water is pumped –in through a pump which extract heat from the engine.
- This hot water is cooled in a spray pond and re-circulated.

(5) LUBRICATING SYSTEM:

- An effective lubricating system is a necessary requirement for a diesel engine power plant.
- Lubricating system improves the life span and efficiency of the plant.
- In general, forced feed lubrication is used and the equipments for this purpose includes pumps, oil cooler, oil cleaner, sump oil tank etc.

(6) EXHAUST SYSTEM:

- This system is used to discharge the engine exhaust to the atmosphere.
- It should keep the low noise level, to reduce air pollution and should prevent vibrations.

(7) STARTING SYSTEM:

- Generally, compressed air system is used for starting diesel engines.
- In this process, compressed air from air tank is admitted to a few of the engine cylinders making them wok life reciprocating air motors to turn the engine shaft.
- Fuel admission to remaining cylinders causes the engine to start.

2.3.2 ADVANTAGES:

1. Plant layout is simple. Hence it can be quickly installed and commissioned, while the erection and starting of a steam power plant or hydro-plant takes a fairly long time.
2. Quick starting and easy pick-up of loads are possible in a very short time.
3. Location of the plant is near the load center.
4. The load operation is easy and requires minimum labors.
5. Efficiency at part loads does not fall so much as that of a steam plant.
6. Fuel handling is easier and no problem of ash disposal exists.
7. The plant is smaller in size than steam power plant for same capacity.
8. Diesel plants operate at high overall efficiency than steam.

2.3.3 DISADVANTAGES:

1. Plant capacity is limited to about 50 MW of power.
2. Diesel fuel is much more expensive than coal.
3. The maintenance and lubrication costs are high.
4. Diesel engines are not guaranteed for operation under continuous, while steam can work under 25% of overload continuously.

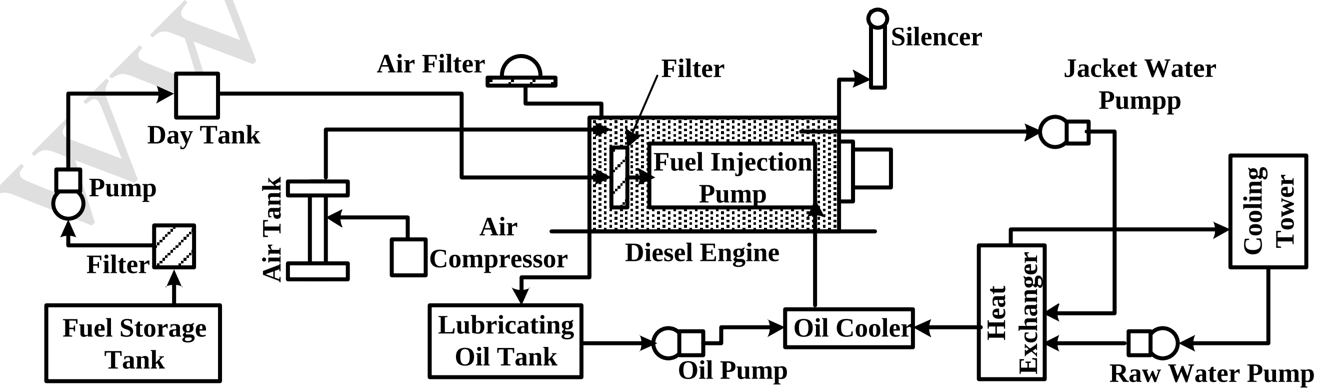


FIG.2.13 LAYOUT OF DIESEL ENGINE POWER PLANT