BASIC CIVIL AND MECHANICAL ENGINEERING

UNIT III

(POWER PLANT ENGINEERING)

1. What are the various classifications of power plants?

The power plants are mainly classified into conventional and non conventional power plants.

Conventional power plants are further classified into
(i) Steam power plant
(ii) Diesel power plant
(iii) Hydroelectric power plant
(iv) Nuclear power plant

Non conventional power plants are classified into
(i) Solar power plant
(ii) Wind power plant
(iii) Tidal and wave power plant
(iv) Geothermal power plant

2. What is a prime mover?

Prime mover is a device used for converting different forms of energy into mechanical energy in the form of rotation. *Example: Steam turbine*

3. What is the function of a condenser?

Condenser is a device which cools the steam and converts it back to water. The condensed water can be used as feed (*input*) water to the boiler (*steam generator*).

4. Write short notes on steam power plant.

Steam power plant is also known as thermal power plant. It is used to generate electricity and it is working based on *Rankine cycle*. It is widely operated around the world, because it can be operated round the clock with coal as the fuel.

5. What are the various factors to be considered in selecting site for a thermal power plant?

(a) Availability of coal
(b) Availability of water

(c) Transportation facilities
(d) Type of land
(e) Distance from residential area

6. List the various merits of steam (thermal) power plant.

(a) The cost of fuel is cheap
(b) Plant can be located near the fuel and water source
(c) Less construction space is required
(d) Installation cost is lesser when compared to hydroelectric power plant
(e) The construction, erection and commissioning of thermal power plant requires less period of time than a hydel (**hyd**ro**el**ectric) power plant.

7. State the demerits of a steam (thermal) power plant.

(a) Steam power plant produces smoke, which affects environment.
(b) Cost of power generation is more compared to other power plants
(c) If the plant is located far away from distribution area, then cost of transmission is more.
(d) The power plant cannot be used during peak load
(e) Stand by losses is more, because the boiler continues to work even after the turbine is switched off.

8. State the working principle of hydroelectric (hydel) power plant.

Hydroelectric power plant utilizes the potential energy of water when it is stored in a dam built across the river. The potential energy of stored water is converted into kinetic energy by passing it through a pipe called penstock. The kinetic energy of water is then converted into mechanical energy in a water turbine.

9. What are the various classifications of hydroelectric power plant?

High head power plant – When the water is exceeds 70 m the hydroelectric power plant is said to be high head power plant. The ***Pelton wheel turbine*** is used as the prime mover.

Medium head power plant – When the head water ranges between 15 m to 70 m, then the hydroelectric power plant is said to be medium head power plant. The plant uses ***Francis turbine*** as the prime mover.

Low head power plant – When the head of water is less than 15 m, then the hydro electric power plant is said to be low head power plant. The plant uses ***Kaplan turbine*** as the prime mover.

10. State the merits of hydroelectric power plant.

(a) Water is a renewable source of energy and cheapest.
(b) There is no ash disposal problem
(c) Hydroelectric power plant does not pose problem of air pollution
(d) Life of hydroelectric power plant is more, when compared with thermal power plant (e) The stored water from hydroelectric water can be used for domestic purpose also.
(f) Less supervising staff is required during operation.
(e) Less maintenance cost.

11. State the disadvantages of hydroelectric power plant.

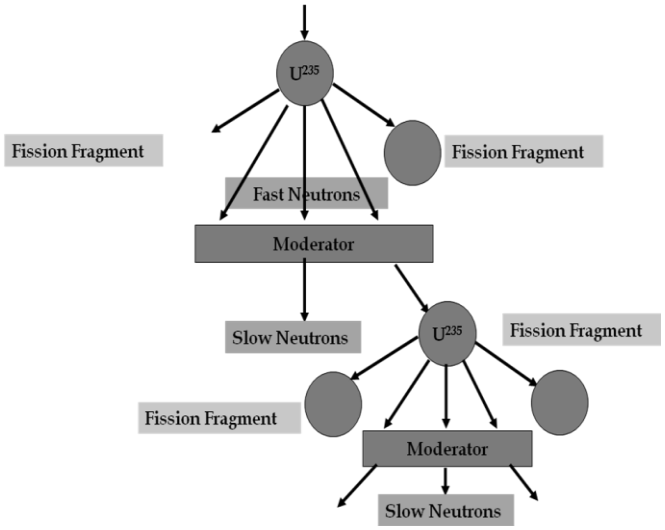
(a) Initial cost of plant is high.
(b) Erection of the hydroelectric plant usually takes long period of time
(c) The power produced by hydroelectric power plant depends upon the quantity of water, which in turn depends on rain fall.
(d) Hydroelectric plants are situated near water source and away from residential area. Hence transmission lines are required for power transportation and distribution. Cost of transmission lines and transmission lines are other demerits.

12. State the working principle of nuclear power plant.

A nuclear power plant differs from a thermal power plant only in the steam generating part. In thermal (steam) power plant, the source is coal but in a nuclear power plant the source is a nuclear fuel (Uranium). The heat produced by the nuclear fission reaction of the nuclear fuel is used to convert water into steam. The steam with high energy content is used to drive the prime mover which is coupled which generator.

As per the statement of scientists, "***One kg of U^{235} can produce as much as energy can be produced by burning of 4500 tonnes of high grade coal***".

13. Write short notes on chain reaction.



A chain reaction produces enormous amount of heat which is used to produce steam. (***The uncontrolled chain reaction under release extremely conditions can energy causing large amount of atomic explosion***).

- It is a process of splitting up of nucleus of fissionable material like uranium into two or more fragments with release of enormous amount of energy.
- The nucleus of U^{235} is bombarded with high energy neutrons
- The neutrons produced are very fast and can be made to fission other nuclei of U^{235}, thus setting up a chain reaction.
- Out of 2.5 neutrons released one neutron is used to sustain the chain reaction.
- $\mathbf{U_{235}+{}_0n_1 \longrightarrow Ba_{141}+Kr_{92}+2.5{}_0n_1+200\ MeV\ energy}$ 1 eV = $1.6X10^{-19}$ joule.

  1 MeV = 10^6 eV

14. List the advantages of a nuclear power plant.

(a) Large amount of heat is liberated by a very small quantity of fuel
(b) It is suitable for large power generation
(c) Cost of fuel transportation and storage is less

15. List the demerits of a nuclear power plant.

(a)Installation cost is very high
(b) Availability of nuclear fuel is scarce and cost is high
(c) Maintenance cost is high
(d) Problems are involved in waste disposal and there is also a risk of radiation hazards.

16. What are the various disposal methods for solid, liquid and gaseous waste from power plants?

Gaseous wastes are discharged to the atmosphere through high stacks. Moderate liquid wastes, after a preliminary treatment is discharged to deep pits. Active liquids are kept in concrete tanks. These tanks are buried in the ground till their radioactivity decays up to a safe level for disposal.

Solid wastes are classified into combustible wastes and non combustible wastes. Combustible wastes can be reduced to ashes by putting them into fire.

Land burial is the best method employed for solid waste disposal.

17. What are gas turbines?

Gas turbines are mainly used for electric power generation and also in jet engines of air craft. It is also used in turbochargers of internal combustion (IC) engines. They have limited application in marine engines.

Gas turbines have a unique advantage of using any type of fuel. i.e., Solid, liquid or gas. Gas turbine operates either on an open cycle or closed cycle.

18. List the advantages of gas turbines.

(a) Gas turbines have a flexibility of using any type of fuel
(b) Compact size, less weight and low space requirement
(c) Simple foundation and low installation cost
(d) Less vibration

19. List the demerits of gas turbines

(a) Operating temperature is high in the combustion chamber; hence special high temperature alloys should be used.
(b) Thermal efficiency is very low.
(c) Not suitable for low capacity.
(d) Large size exhaust duct due to increased requirement for air for cooling and combustion.

20. What is the method can be adopted to improve the thermal efficiency of gas turbine power plant.

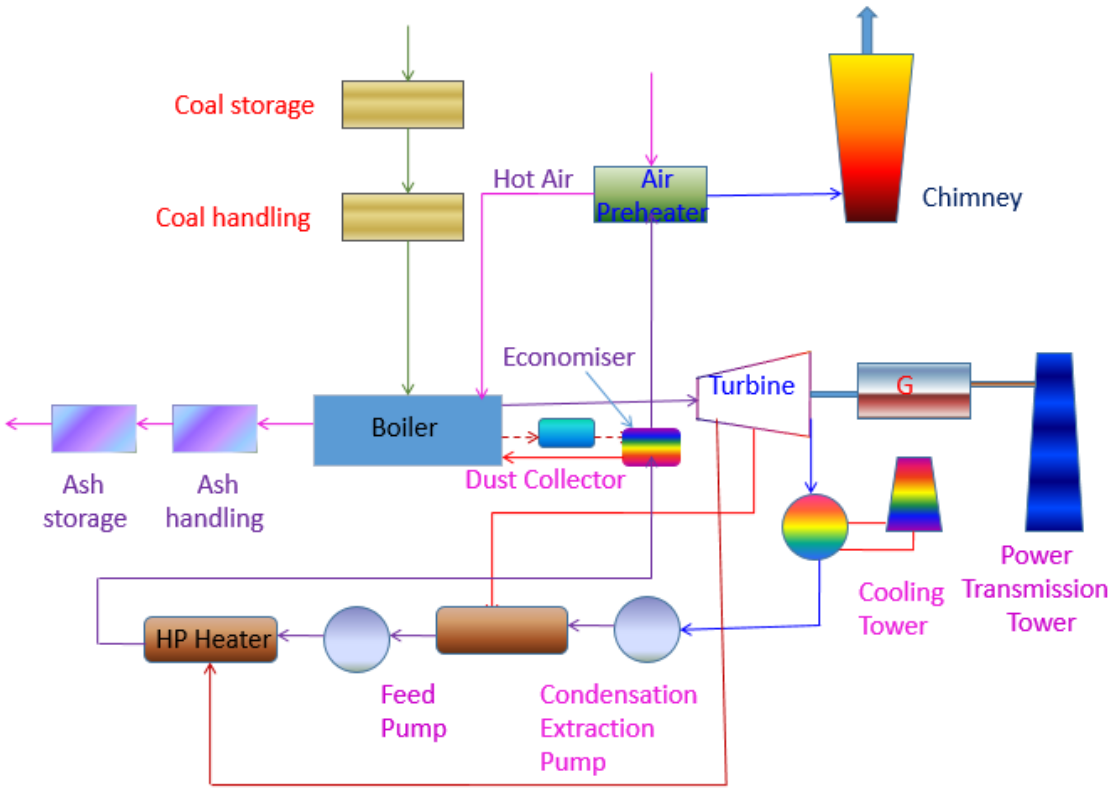
(a) By using a multistage compressor and inter-cooling to reduce the work of compression. (b) By using a multistage turbine to reduce the temperature of the exhaust gases before leaving the turbine
(c) By using a generator, to further reduce the temperature waste gases.

21. What are the advantages of a diesel power plant?

(a) Plant layout is simple
(b) Installation and commissioning is easy
(c) Quick starting and easy of pickup of loads

Part B (Questions and Answers)

1. **With a neat layout of thermal (steam) power plant, explain its construction and working principle. What are the major circuits in a thermal power plant. Explain briefly about them. List the advantages and disadvantages.**



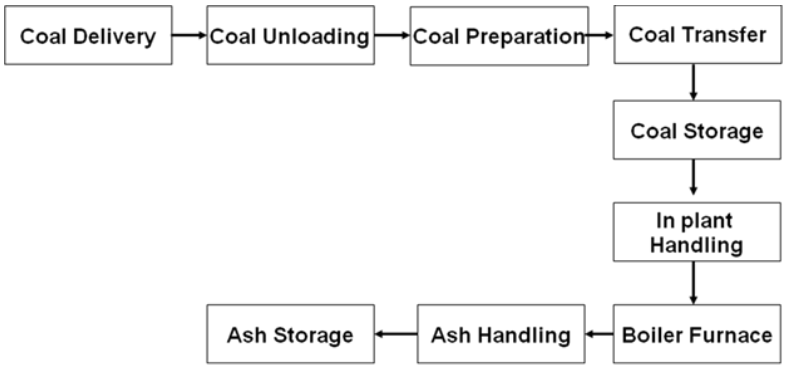
Working Principle: In a steam power plant, the water is converted into steam in a boiler. The stored energy in the steam is used to drive the turbine. The turbine is coupled with generator, hence power is produced.

Steam power plant is also known as "*Thermal power plant*". There are four major circuits in the steam power plant. They are

(i) Coal and ash circuit
(ii) Water and steam circuit
(iii) Air and flue gas circuit

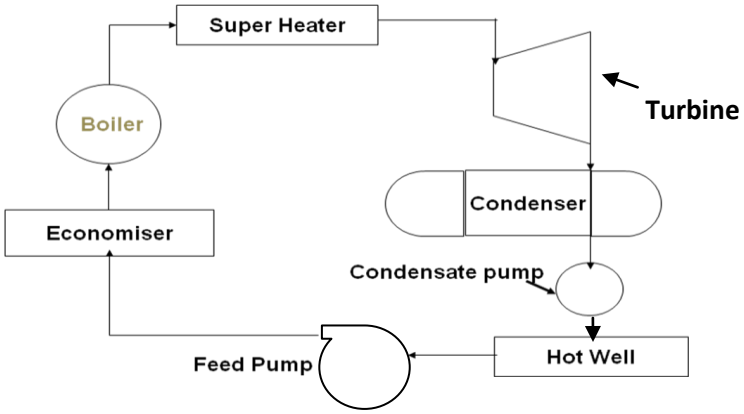
(iv) Cooling water circuit

Coal and Ash circuit



- Coal from mines is delivered by ships, rails or trucks to the power station.
- Coal is sized by crushers, breakers etc., which is called coal sizing.
- The sized coal is stored in coal storage.
- From stock yard, the coal is transferred to the boiler furnace by means of conveyors, elevators etc.,
- The coal is burnt in the boiler and ash is produced.
- Ash coming out of the furnace will be too hot, dusty and accompanied by poisonous gases.
- The ash is transferred to the ash storage.
- Generally the ash will be quenched to reduce the temperature and the dust content.

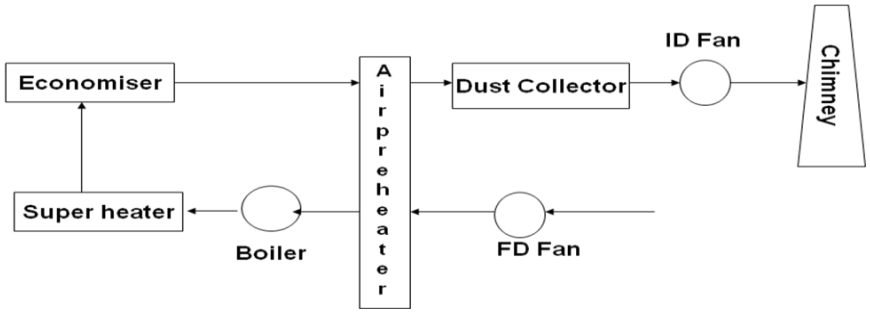
Water and Steam circuit



- The water is preheated by the flue gases in the economizer.

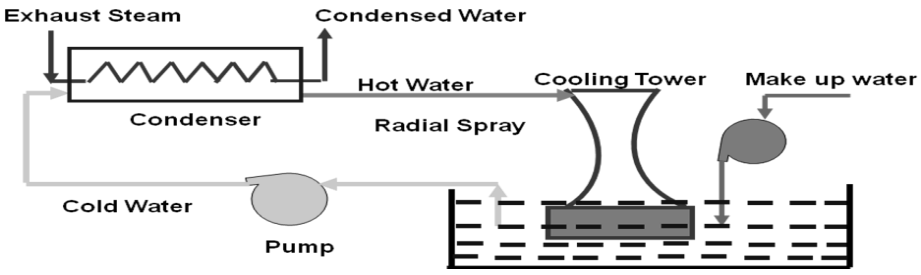
- This preheated water is then supplied to the boiler drum.
- Heat is transferred to the water by the burning of the coal.
- Due to this, water is converted into the steam.
- The steam raised in boiler is passed through a super heater.
- It is superheated by the flue gases.
- The turbine drives generator to produce electric power.
- The expanded steam is then passed through the condenser.
- In the condenser, steam is condensed into water the re-circulated.

Air and Flue gas circuit



- Air is taken from the atmosphere by the action of Forced draught (F.D) fan at atmospheric pressure and temperature.
- It is passed through an air pre heater
- The air is preheated by the flue gases in the pre heater.
- This preheated air is supplied to the furnace to aid the combustion of fuel and to enhance the combustion.
- Due to the combustion of fuel the flue gases are formed.
- The flue gases from the furnace pass over the boiler tubes and super heater tubes.
- Then the flue gases pass through economizer to heat the feed water.
- After that it passes through a dust collector.
- It is then exhausted to atmosphere through chimney.

Cooling Water circuit



- The exhaust steam from the turbine is circulated through the tubes in the condenser.

- In the condenser, the cold water is circulated to condense the steam into water.
- The steam is condensed by losing its latent heat to the circulating the cold water.
- Hence the cold water gets heated.
- This hot water is then taken to a cooling tower.
- In cooling tower the water is sprayed in the form of droplets through nozzles.
- The atmospheric air enters the cooling tower from the openings provided at the bottom of the tower.
- This cold water is again circulated through the pump, condenser and the cooling tower.
- Some amount of water may be lost due to evaporation, during this process.
- Hence make up water is added to the pond by means of a pump

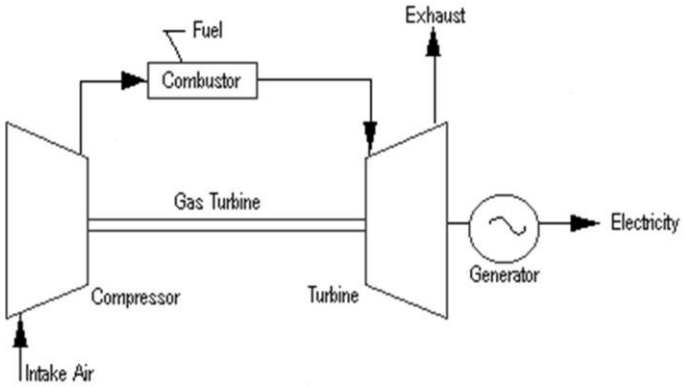
Advantages of a thermal power plant

- Life of plant is more (25-30 years) compared to Diesel plant (2-5 years)
- Repair and maintenance cost is low when compared to diesel plant.
- Initial cost is less compared to nuclear plant.
- Suitable for varying load conditions.
- No radioactive harmful wastes are produced
- Unskilled operators can operate the plant.
- The power generation does not depend on the water storage.
- There are no transmission losses, as they are located near load centers.

Disadvantages of a thermal power plant

- Less efficient than diesel plants.
- Starting up and bringing into service takes more time.
- Water required for cooling purpose is more.
- More space is required.
- Storage required for the fuel is more.
- Ash handling is a big problem.
- Not economical when the plant is located far from coal fields.
- Manpower required is more.
- For large units, the capital cost is more.

2. Explain the construction and working principle of Gas turbine power plant and list the merits and demerits.



Layout of a gas turbine power plant

Working principle: In a gas turbine power plant, high pressure produced by combustion is used to drive a gas turbine. The gas turbine shaft is coupled with generator. When the turbine rotates generator is driven and thus the power is produced.

Working of a simple gas turbine power plant

A simple open cycle gas turbine power plant consists of a compressor, a combustion chamber and a turbine. The compressor and turbine are connected by a common shaft with a flange. Air from the atmosphere is taken and compressed to a high pressure. The high pressure is supplied to the combustion chamber, where the fuel is injected. The fuel burns and the temperature is raised at constant pressure. The hot gases with high energy content passes through the turbine, where it expands to its initial pressure before being exhausted to atmosphere.

A major portion of power developed in the turbine is used to drive the compressor and only the remaining power is available as the net power output. Hence open cycle simple gas turbine power plant is not economical to be operated as a single unit.

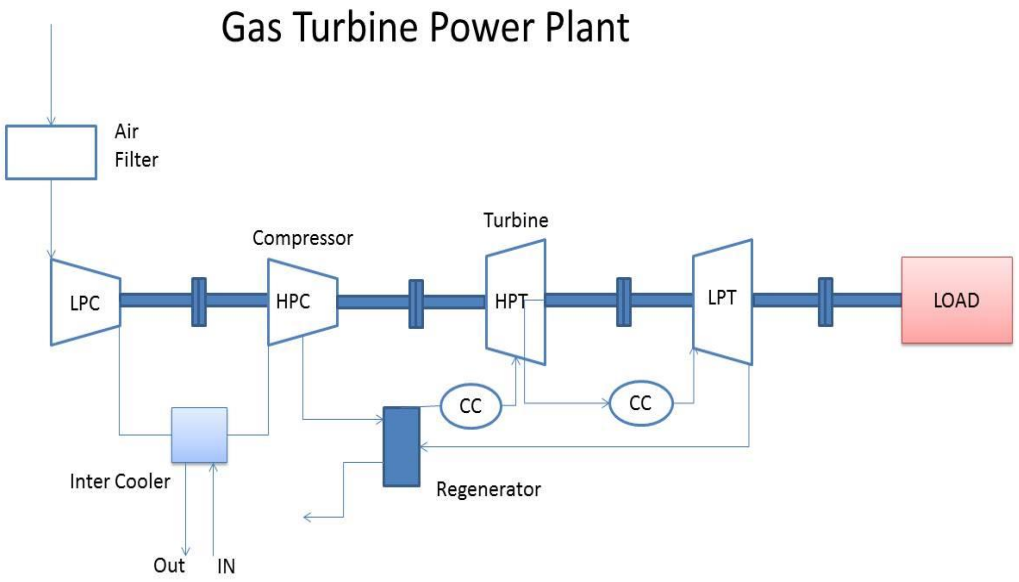
Advantages of gas turbine power plant (Open cycle):

- Flexible to use any type of fuel
- Very compact in its size
- Simple foundation, therefore installation cost is less.
- Lubricating oil requirement is less.
- Vibration is less during operation.

Disadvantages of gas turbine power plant (Open cycle):

- High temperature alloys are required, because of high operating temperature at combustion chamber and turbine.
- Thermal efficiency is lesser due to high operating temperature (450^{o}C) and exhaust waste gases.
- Not economical as the power required to drive the compressor is taken from the power produced.

Gas turbine with cogeneration of power (Combined gas turbine and steam turbine plant)



Layout of gas turbine power plant with cogeneration

Need for a combined cycle gas turbine power plant

A major portion of power developed in the turbine is used to drive the compressor and only the remaining power is available as the net power output. Hence, gas turbine power plant is very expensive to operate. Therefore it is usually steam power plant in a closed combined cycle.

Working of a combined cycle gas turbine power plant:

- Gas turbine draws clean air into through air filter from atmosphere, with the help of a compressor.
- During the compression pressure of the air is increased.

- Compressed air is passed through to a combustion chamber along with fuel (Natural gas).
- The air fuel mixture is ignited at high pressure in the combustion chamber.
- Combustion takes place.
- The generated hot gas of compression is passed through the gas turbine.
- Hot gases expand, and the turbines blades are connected to the turbine shaft are rotated.
- The turbine shaft which is coupled to the shaft of the electrical generator at the other end also rotates and drives the electrical generator.
- A portion of the energy developed by the hot gases through the gas turbine is used to run the compressor.
- The residual hot gases from gas turbine are passed through a heat exchanger (heat recovery steam generator)
- The heat exchanger produces steam with high pressure with the help of a steam boiler.
- The steam is allowed to expand in the steam turbine.
- When it passes through the turbine blades, the turbine shaft is rotated. The shaft is coupled to the generator, which generates electricity.
- Gas turbine and steam turbine combination enables increased power generation.

Advantages

- Natural gas is readily available.
- Setting up cost can be reduced if the plant is installed near the source of natural gas.
- Less gas storage cost
- Less space occupation.
- Compared to steam power plant, smaller in size.
- Low operating cost.
- Low maintenance cost.
- No standby losses.
- Cheaper fuels like natural gas.

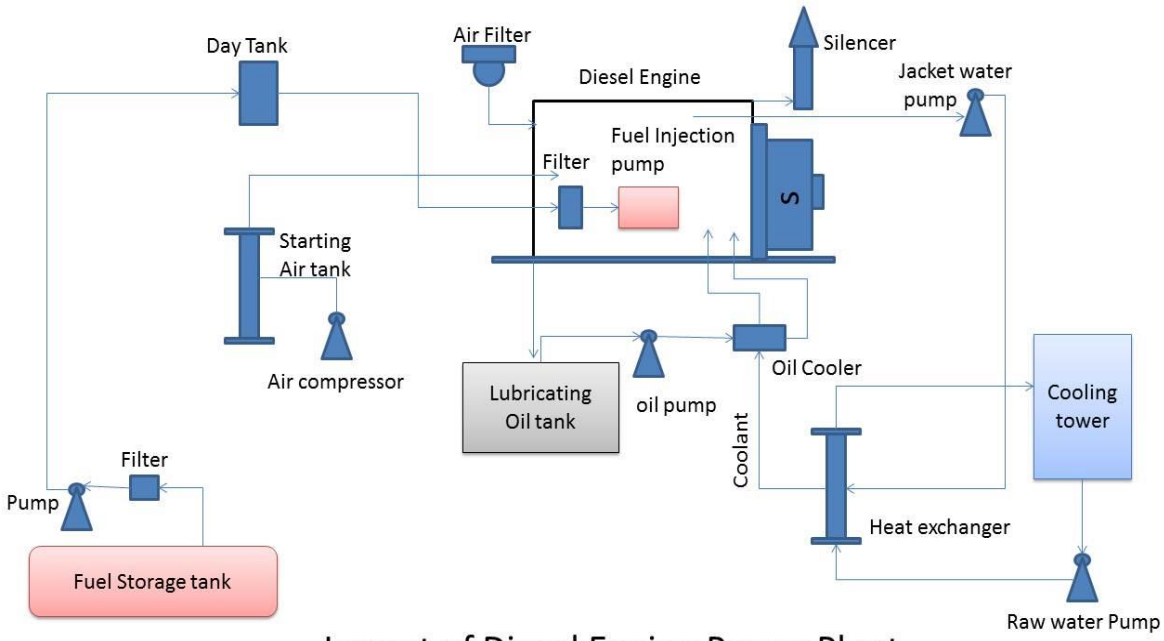
Disadvantages

- 2/3 rd of generated power is used for driving the compressor.
- Gas turbine has low thermal efficiency.
- Has starting problem.
- Efficient only in combined cycle configuration.
- Temperature of combustion chamber is too high, which results in shorter life time.

3. Draw the layout of a diesel power plant, explain its working principle. List the merits and demerits.

Working

- Air from atmosphere is drawn into the compressor and is compressed.
- The compressed air is sent to diesel engine through filter.
- In the filter, dust, dirt from air is filtered and only clean air is sent to diesel engine.
- Fuel oil from tank is passed through filter where it gets filtered and clean oil is injected into the diesel engine through fuel pump and fuel injector
- Mixture of compressed air and spray of fuel oil are ignited into the engine and combustion takes place.
- The heat energy is utilized for driving the generator, which produces power.



Layout of Diesel Engine Power Plant

Advantages of diesel power plant :

- Simple in design and occupies less floor area
- Requires less water for cooling
- Overall cost is cheaper than steam power plant Less man power is required No stand by losses.

Disadvantages of diesel power plant

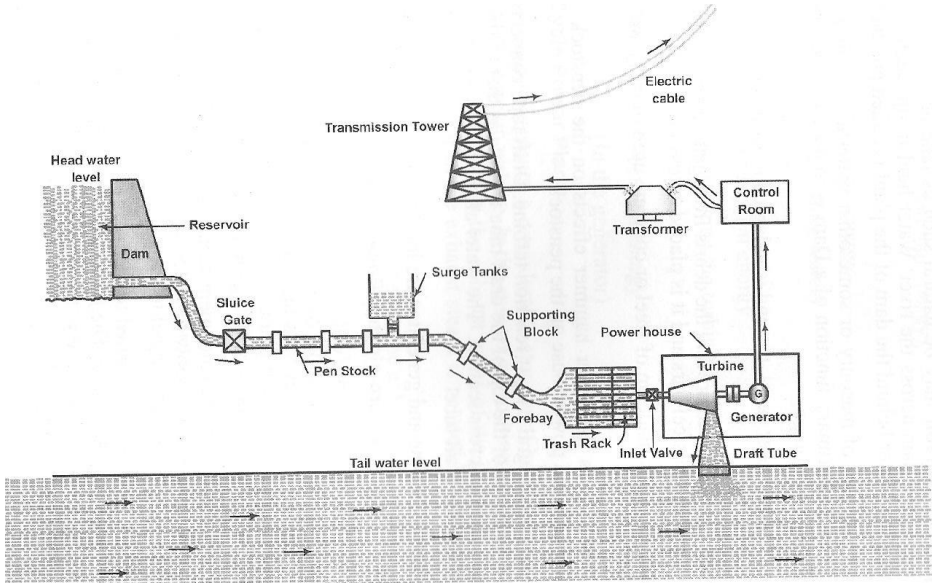
- Exhaust gas from diesel engine pollutes the environment
- Noisy
- Oil consumption is more
- During overload condition the efficiency is less.

- Lubricating cost is high
- Small quantity of power is produced.

4. Draw the neat layout of a hydroelectric power plant. List the merits and demerits.

Working

- It uses the potential energy of water of water stored in a reservoir.
- The water from the reservoir through a penstock and then forced through nozzle or nozzles before reaching the turbine.
- The hydraulic turbine converts the kinetic energy of water under pressure into mechanical energy.
- The shaft of the turbine is coupled to a generator that generates electricity



- The electricity generated is fed to the step-up transformer to increase its voltage.
- Power is fed to the transmission lines for distribution.
- The output power of Hydel power plant depends on the head of water stored in the reservoir and the quantity of water discharged

Advantages of hydroelectric power plant

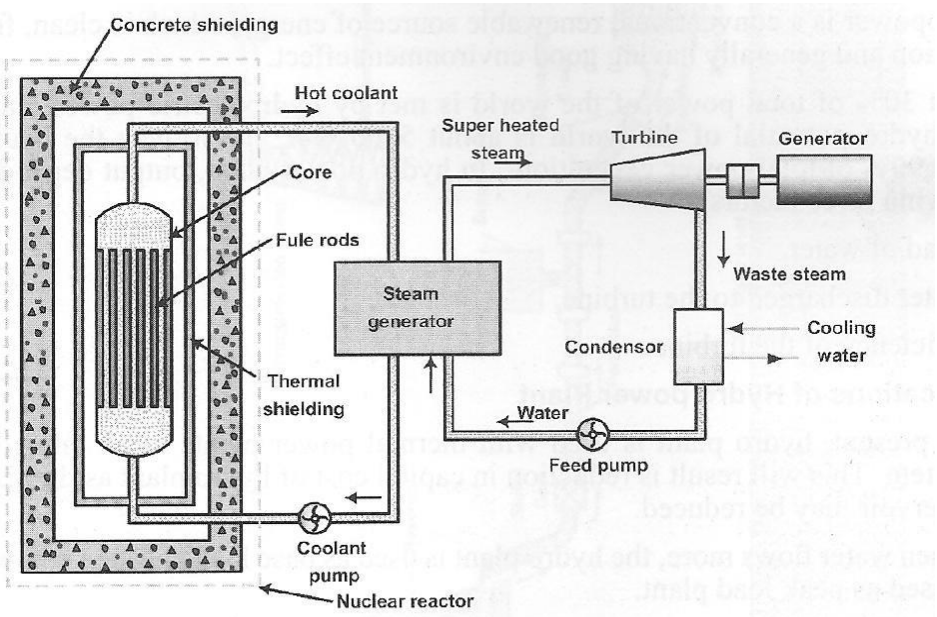
- Plant doesn't require any fuel, it uses naturally available source water and hence no pollution.
- Operating cost is less and skilled operator is not needed.
- Simple in construction and less maintenance cost
- Very robust and durable
- The reservoir and dam used for power generation, can also used for irrigation.

Disadvantages of hydroelectric power plant

- High capital cost as it involves dam construction For construction, skilled person is required.
- Period of construction, delays commissioning of the plant.
- Uncertainty about availability of huge quantity of water.
- Constructing a new hydroelectric power plant requires rehabilitation of people and compensation for land acquisition.

5. With a neat sketch explain the construction and working principle of Nuclear power plant. State its advantages and disadvantages.

- Nuclear power plant uses nuclear energy from radio active element for generating electrical energy.
- More than 15% of the world's electricity is generated from Nuclear power plants.
- It is generally located far away from populated areas.
- In future generation of electricity will be depending on Nuclear Power Plant, as it is economical.
- 1 kg of uranium U -235 can produce electrical power electrical that can be produced by using 3000 -4500 tonnes of high grade coal or 2000 tonnes of oil.



Working

- The heat generated in the reactor due to the fission of the fuel is taken up by the coolant.
- The hot coolant then leaves the reactor and flows through the steam generator.
- In the steam generator the hot coolant transfers its heat to the feed water which gets converted into steam.
- The steam produced is passed through the turbine, which is coupled with generator.
- Hence the power is produced during the running of turbine.
- The exhaust steam from the turbine is condensed in the condenser.

- The condensate then flows to the steam generator through the feed pump.
- The cycle is thus repeated.

Advantages :

- Requires less space compared to steam power plant.
- Fuel required is negligible compared to coal requirement.
- Fuel transport cost is less.
- Reliable in operation.
- Cost of erection is less.
- Water required is very less.

Disadvantages

- Initial Cost is higher than other power plants.
- Not suitable for varying load condition.
- Radioactive wastes are hazardous. Hence these are to be handled with much care.
- Maintenance cost is higher.
- Trained workers are required to operate the plant.

6. What are the various components of a nuclear power plant? Explain.

Nuclear Fuel:

Normally used nuclear fuel is uranium (U^{235})

Fuel Rods: The fuel rods hold nuclear fuel in a nuclear power plant.

Neutron Source: A source of neutron is required to initiate the fission for the first time. A mixture of beryllium with plutonium is commonly used as a source of neutron.

Reactor:

- Nuclear fission takes place in the reactor only.
- Nuclear fission produces large quantity of heat.
- The heat generated in the reactor is carried by coolant circulated through the reactor.

Control Rods:

- They are used to control the chain reaction.
- They are absorbers of neutrons.
- The commonly used control rods are made up of cadmium or boron.

Moderator:

- Moderators are used to slow down the fast neutrons.
- It reduces 2 MeV to an average velocity of 0.025 eV.
- Ordinary or heavy water are used as moderators. **Fuel Rods:**

The fuel rods hold nuclear fuel in a nuclear power plant.

Neutron Reflectors:

- To prevent the leakage of neutrons to large extent.
- In PHWR (Pressurized Heavy Water Reactor), the moderator itself acts as reflectors. **Shielding:**

- To protect from harmful radiations the reactor is surrounded b a concrete wall of thickness about 2 to 2.5 m.

7. What are the various factors to be considered in selecting the site for constructing a hydroelectric power plant?

Availability of Water:

Adequate water must be available with good head**.**

Cost and type of Land:

Bearing capacity of the land should be good to withstand huge structures and equipments.

Storage of Water :

A dam must be constructed to store the large quantity of water in order to cope with variations of water availability throughout the year.

Transportation Facilities :

The site should be accessible by rail and road for easy transportation of equipments and machinery.

Pumped storage facilities :

The pumping facilities to reuse the water should be possible.

8. What are the various components of a hydroelectric power plant?

Reservoir :

- Water is collected during rainy season It is stored in the reservoir.
- A dam is built across the river adequate water head.

Penstock :

- It is a passage through which water flows from reservoir to turbine.

Surge Tank :

- It is installed along the penstock (between turbine and reservoir)
- To control or regulate the sudden water over flow and to protect the penstock from bursting.
- It reduces the pressure and avoids damage to the penstock due to the water hammer effect.
- When the load on the turbine is decreased there will be a back flow, which causes increase or decrease in pressure. It is known as water hammer.

Power House:

- It is building that houses that water turbine, generator, transformer and control room.

Water Turbine:

- Water turbines such as Pelton, Kaplan and Francis are used to convert pressure and kinetic energy of flowing water into mechanical energy.

Draft Tube:

- It is connected to the outlet of the turbine.

Tailrace:

- It refers to the downstream level of water discharged from turbine.

Generator:

- It is a machine used to convert mechanical energy into electrical energy.

Step up transformer:

- It converts the Alternating Current (AC) into high voltage current suitable for transmission.

9. What are the various pollutions caused by a thermal power plant?

- Main pollutants from thermal plants are SO_2, CO_2, CO as minute particles such as fly ash.
- SO_2 causes suffocation, irritation to throat and eyes and respiratory for people. It destroys crop.

- CO is a poisonous gas.
- Dust particles cause respiratory troubles like cough, cold, sneezing etc., **Thermal Pollution**:

- Thermal plants produce 40 millions kJ of heat to the environment through condenser water and exhaust gases.
- Thermal pollution of atmosphere can be reduced using the low grade energy exhausted steam.

Noise Pollution:

- The sources of noise in a power plant are turbo alternators, fans and power transformers.
- Sound proofing can be done to reduce the noise.

10. What are the various factors to be considered in selecting the site for a thermal power plant?

Availability of coal:

- A thermal plant of 400M, capacity requires nearly 6000 tons of coal every day.
- Power plant should be located near coal mines.

Ash Disposal Facilities:

- Ash comes out in hot condition and handling is difficult.
- The ash can be disposed into sea or river.

Water Availability :

- Water consumption is more as feed water into boiler, condenser and for ash disposal.
- Water is required for drinking purpose.
- Hence plant should be located near water source.

Transport Facility :

- Railway lines or other mode of transport for bringing heavy machineries for installation also for bringing coal.

Public Problems:

- The plant should be far away from residential area to avoid nuisance from smoke, fly ash and noise.

Nature of Land:

- Many power plants have failed due to weak foundations.
- Land (soil) should have good bearing capacity to withstand dead load of plant.

CONVENTIONAL & NON-CONVENTIONAL ENERGY SOURCES:

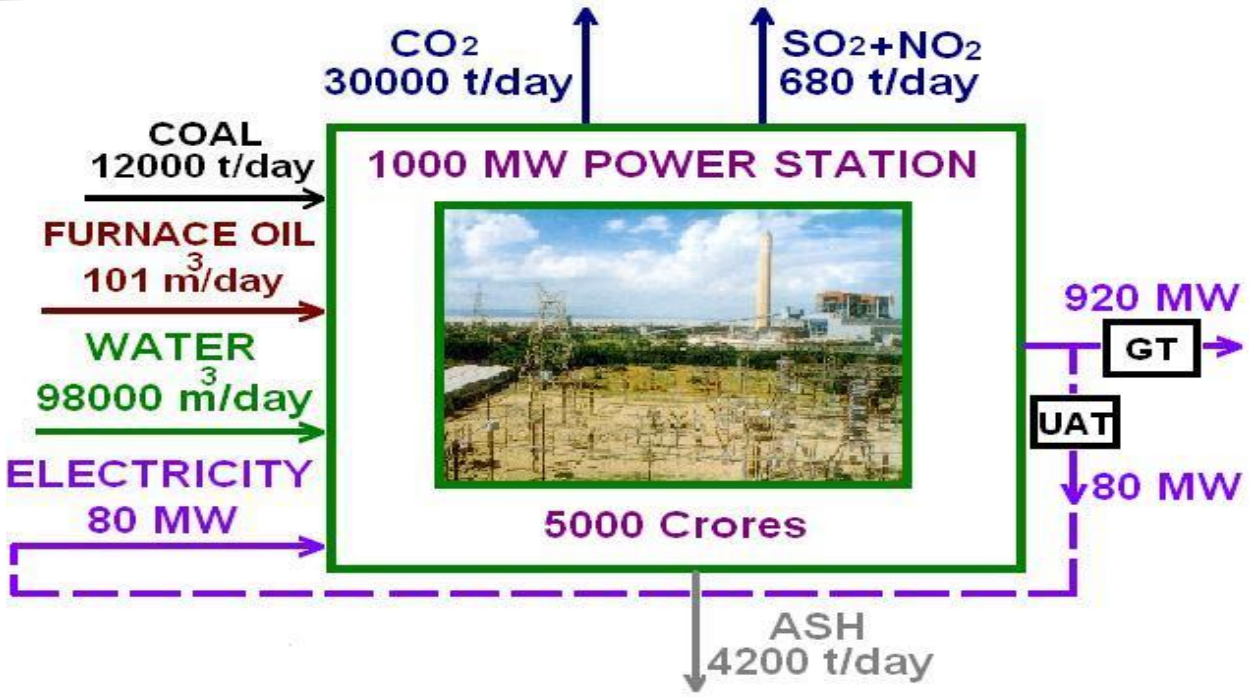
(A) Conventional Energy Sources:

The energy sources which cannot be compensated, **once these are used** (after their exploitation) **are termed as conventional energy sources.**

- **Coal:**
- **Petroleum and natural gases:**
- **Fuel woods:**
- **Hydropower:**
- **Nuclear energy:**

(B) Non conventional energy sources:

- **Renewable and provide a pollution free environment.**
- **1. Solar energy: (Sun Rays)**
- **2. Wind energy: (Air-Motion)**
- **3. Tidal energy: (Tides of ocean)**
- **4. Geothermal energy:** (heat energy obtainable from hot rocks present inside the earth crust)
- **5. Bio-mass based energy:**



IC ENGINE

Heat engine:

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work.

It is classified into two types-

(a) External combustion engine
(b) Internal combustion engine

History of IC engines:

1700s - Steam engines (external combustion engines)

1860 - Lenoir engine ($\eta = 5\%$)

1867 - Otto-Langen engine ($\eta = 11\%$, 90 RPM max.)

1876 - Otto four stroke "spark ignition" engine
($\eta = 14\%$, 160 RPM max.)

1880s - Two stroke engine

1892 - Diesel four stroke "compression ignition" engine

1957 - Wankel "rotary" engine

External combustion engine:

In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle.

Examples:

*In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work.

*In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.

Internal combustion engine:

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force. It can be classified into the following types:

1. **According to the basic engine design-**

(a) Reciprocating engine (Use of cylinder piston arrangement),
(b) Rotary engine (Use of turbine)

2. According to the type of fuel used-
(a) Petrol engine,
(b) diesel engine,
(c) gas engine (CNG, LPG),
(d) Alcohol engine (ethanol, methanol etc)

3. According to the number of strokes per cycle-
(a) Four stroke and
(b) Two stroke engine

4. According to the method of igniting the fuel-
(a) Spark ignition engine,
(b) compression ignition engine and
(c) hot spot ignition engine

5. According to the working cycle-
(a) Otto cycle (constant volume cycle) engine,
(b) diesel cycle (constant pressure cycle) engine,
(c) dual combustion cycle (semi diesel cycle) engine.

6. According to the fuel supply and mixture preparation-

(a) Carburetted type (fuel supplied through the carburettor),

(b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition).

7. According to the number of cylinder-
(a) Single cylinder and
(b) multi-cylinder engine

8. Method of cooling- water cooled or air cooled

9. Speed of the engine- Slow speed, medium speed and high speed engine

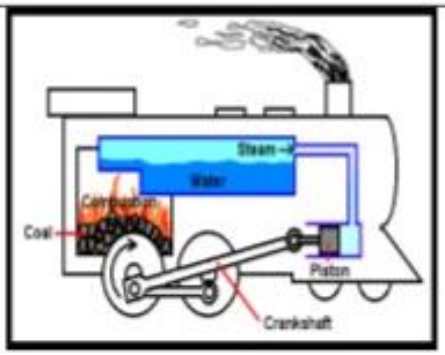
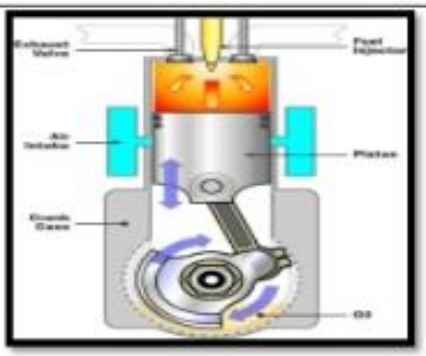
10. Cylinder arrangement-Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines.

11. Valve or port design and location- Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging.

12. Method governing- Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine

13. Application- Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators.

Comparison between external and internal combustion engine

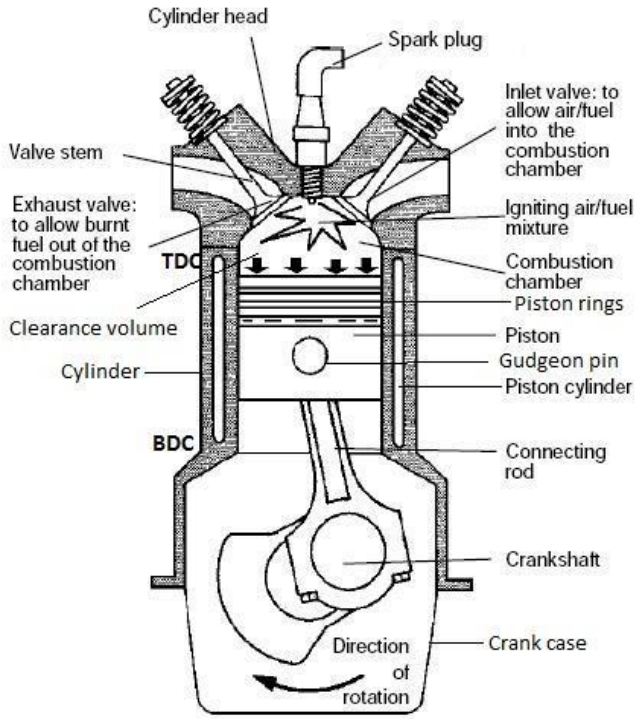
External combustion engine	Internal combustion engine
	
Combustion of air-fuel is outside the engine cylinder (in a boiler)	Combustion of air-fuel is inside the engine cylinder (in a boiler)
The engines are running smoothly and silently due to outside combustion	Very noisy operated engine
Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome.	It is light and compact due to lower ratio of weight and bulk to output.
Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts.	Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used
It can use cheaper fuels including solid fuels	High grade fuels are used with proper filtration
Lower efficiency about 15-20%	Higher efficiency about 35-40%
Higher requirement of water for dissipation of energy through cooling system	Lesser requirement of water
High starting torque	IC engines are not self-starting

Main components of reciprocating IC engines:

Cylinder: It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above 2000 ^{o}C. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Cylinder head: The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint.

Piston: Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminium alloy which has good heat conducting property and greater strength at higher temperature.



Piston rings: These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature. 2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

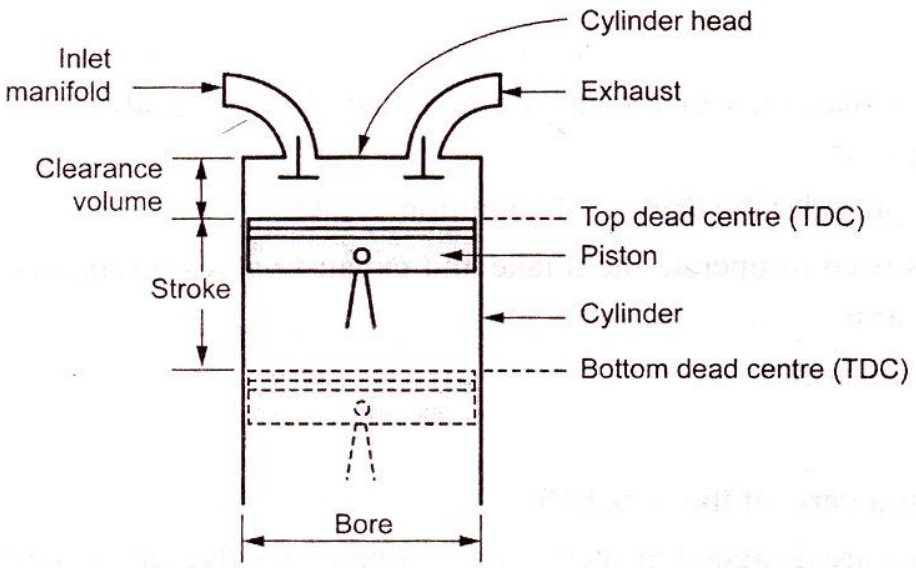
Connecting rod: It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank with crank pin. The special steel alloys or aluminium alloys are used for the manufacture of connecting rod.

Crankshaft: It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Crank case: It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.

Flywheel: It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant. It is done by storing excess energy during the power stroke, which is returned during other stroke.

Terminology used in IC engine:



1. **Cylinder bore (D):** The nominal inner diameter of the working cylinder.

2. **Piston area (A)**: The area of circle of diameter equal to the cylinder bore.

3. **Stroke (L)**: The nominal distance through which a working piston moves between two successive reversals of its direction of motion.

4. **Dead centre**: The position of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).

(a) **Bottom dead centre (BDC):** Dead centre when the piston is nearest to the crankshaft.

(b) **Top dead centre (TDC):** Dead centre when the position is farthest from the

crankshaft.

5. **Displacement volume or swept volume (V_s):** The nominal volume generated by the working piston when travelling from the one dead centre to next one and given as,

$$V_s = A \times L$$

6. **Clearance volume (V_c):** the nominal volume of the space on the combustion side of

the piston at the top dead centre.

7. **Cylinder volume (V):** Total volume of the cylinder.

$$V = V_s + V_c$$

8.Compression ratio(r):

$$\text{Compression ratio} = \frac{Maximum Cylinder Volume}{Minimum Cylinder Volume}$$

$$= \frac{Swept Volume + Clearence Volume}{Clearence Volume}$$

The compression ratio varies from 5 : 1 to 10 : I for petrol engines and from 12:1 to 22 : I for diesel engines.

FOUR STROKE PETROL ENGINES

- ✓ Petrol engine is also known as Spark Ignition (SI) engine.
- ✓ Invented by Nicolaus A. Otto in 1876 that is why petrol engine is also known as Otto engine.
- ✓ Since ignition occurs due to a spark petrol engines are called spark ignition (SI) engines.
- ✓ A four stroke engine gives a power stroke in every set of four strokes of the piston or two revolution of the crankshaft.
- ✓ The petrol engine operates on theoretical Otto cycle.
- ✓ It is also called as constant volume combustion cycle as the combustion takes place at constant volume with increase of pressure.

The cycle of operation of a four stroke petrol engine consists of the following strokes:
1. Suction or intake stroke,
2. Compression stroke,
3. Expansion or power stroke, and
4. Exhaust stroke.

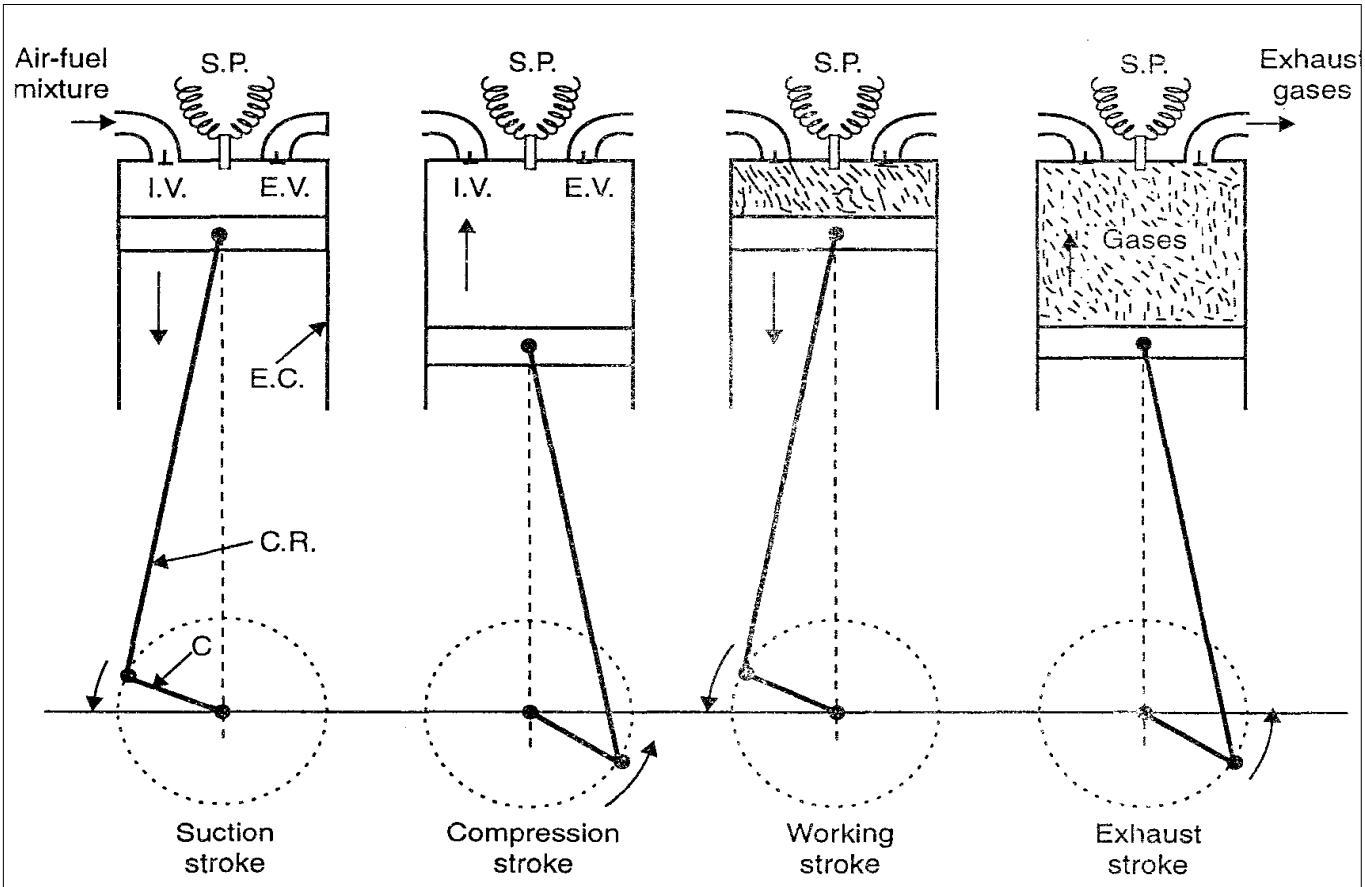
1. Suction Stroke:

- ✓ During this stroke, the piston moves from Top Dead Centre (TDC) to Bottom Dead Centre (BDC) creating a vaccum inside the cylinder.
- ✓ During this stroke, the inlet valve is kept opened and the exhaust valve is kept closed.
- ✓ The vacuum created inside the cylinder draws the air petrol mixture (which is also known as charge) into the cylinder through the inlet valve. It is performed till the piston reaches BDC.
- ✓ The above process is known as suction and this stroke is called the suction stroke.

2. Compression Stroke:

- ✓ During this stroke, both the inlet and exhaust valves are closed.
- ✓ The air petrol mixture is compressed as the piston moves upwards from BDC to TDC.
- ✓ As a result of this compression, pressure and temperature of the air fuel mixture or charge is increased.
- ✓ Just before the piston reaches the TDC, the air petrol mixture (charge) is ignited by a spark plug; suddenly burning of the air fuel mixture takes place almost instantaneously.
- ✓ It increases the pressure and temperature inside the cylinder. Volume remains constant during combustion.

- ✓ These two strokes (i.e., suction and compression stroke) complete one revolution of the crankshaft.



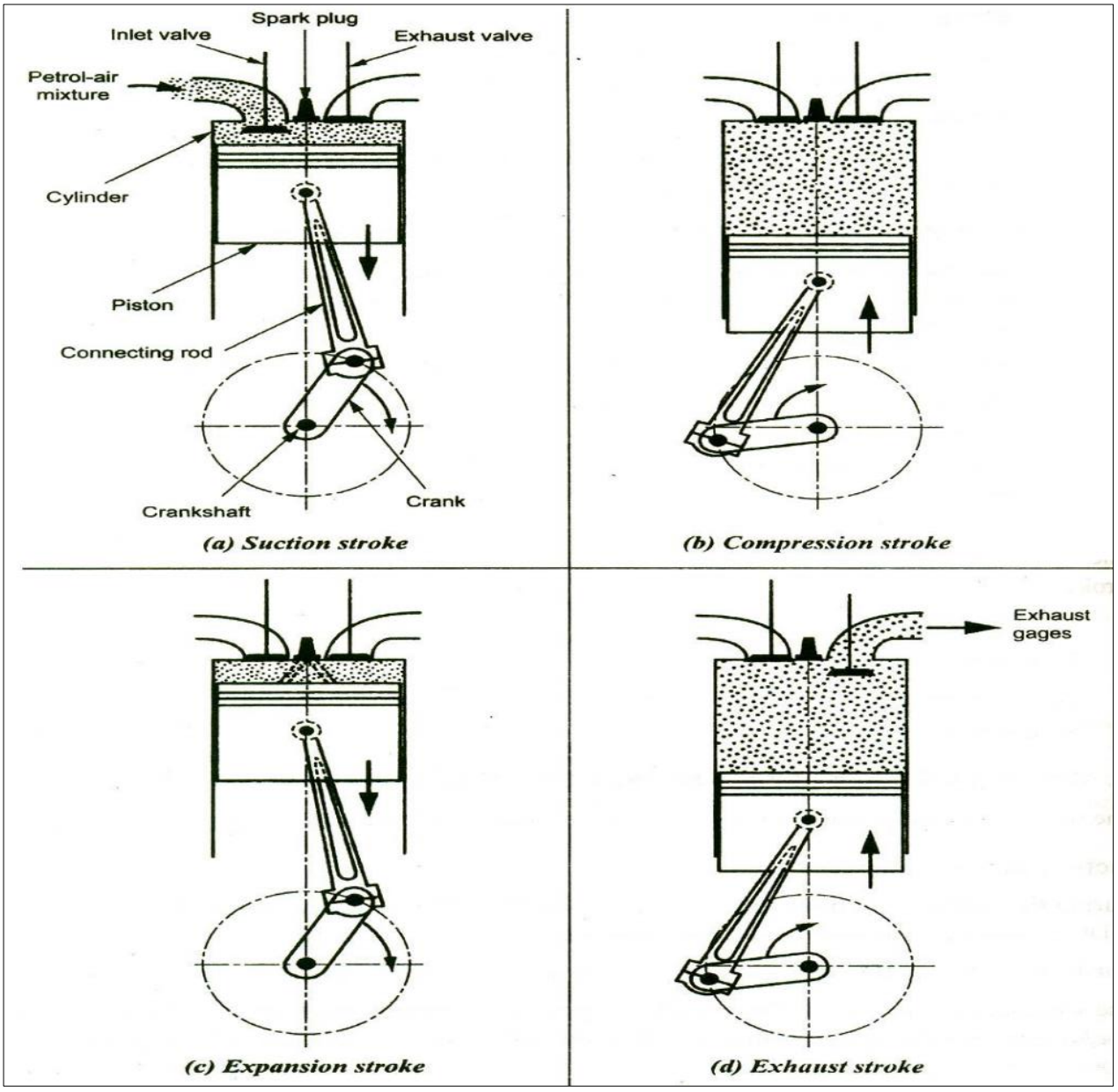
3. Expansion or Power Stroke or Working Stroke:

- ✓ During this stroke, both the inlet and exhaust valves remain closed.
- ✓ The high pressure of the products of combustion (due to expansion of charge) pushes tile piston from TDC to BDC.
- ✓ It is also called as working stroke as work is done by the expansion of hot gases.
- ✓ The force above the piston is transmitted to the crankshaft through the connecting rod and crank mechanism.
- ✓ Excess energy due to the combustion is stored in the flywheel which helps for the operation of three idle strokes.

4. Exhaust Stroke:

- ✓ At the end of the expansion stroke, the exhaust valve opens and the pressure inside falls suddenly.
- ✓ Thus during this stroke, the inlet valve is closed and the exhaust valve is kept opened.
- ✓ The upward movement of the piston from BDC to TDC, pushes out the products of combustion from the engine cylinder through the exhaust valve into the atmosphere. The cycle of operation is then repeated.

- ✓ These two strokes (i.e., expansion and exhaust strokes) complete one revolution of the crankshaft.

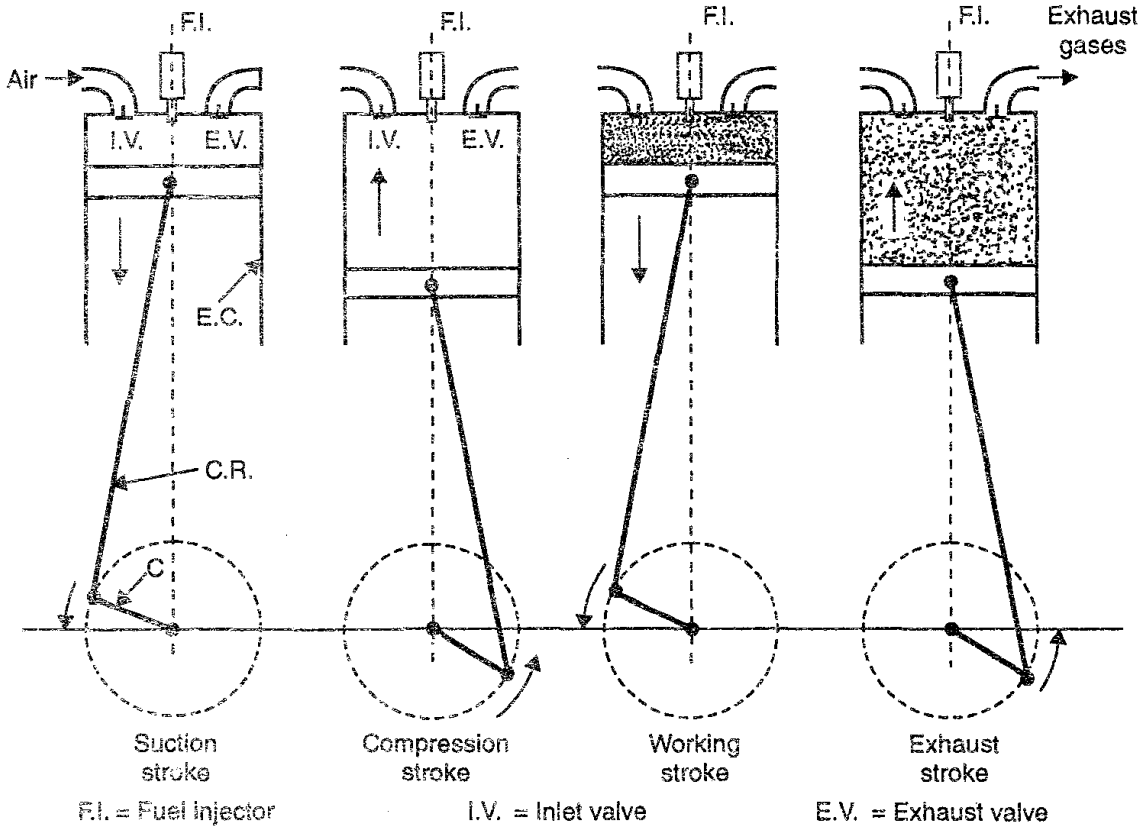


FOUR STROKE DIESEL ENGINES

- ✓ Diesel engine is also known as **compression ignition (CI) Engine.**
- ✓ It is invented by **Rudolf Diesel (1892)**
- ✓ The four stroke diesel engine is similar to four stroke petrol engine except that it operates at a **higher compression ratio (14 to 22).**
- ✓ In a diesel engine, only **air is sucked from the atmosphere** instead of air fuel mixture during the suction stroke.
- ✓ In diesel engines, spark plug is not required for igniting the air fuel mixture. Because **the fuel is injected and forms an explosive mixture, which ignites spontaneously under pressure.**
- ✓ Diesel engine works on the principle of **diesel cycle**.
- ✓ It is also called as **constant pressure combustion cycle** as the combustion of fuel takes place at constant pressure with increase of temperature.
- ✓ Since ignition results due to high temperature of compressed air, these are called compression ignition (CI) engines.

The cycle of operation of a four stroke diesel engine consists of the following strokes:

1. Suction or intake stroke,
2. Compression stroke,
3. Expansion or power stroke, and
4. Exhaust stroke.



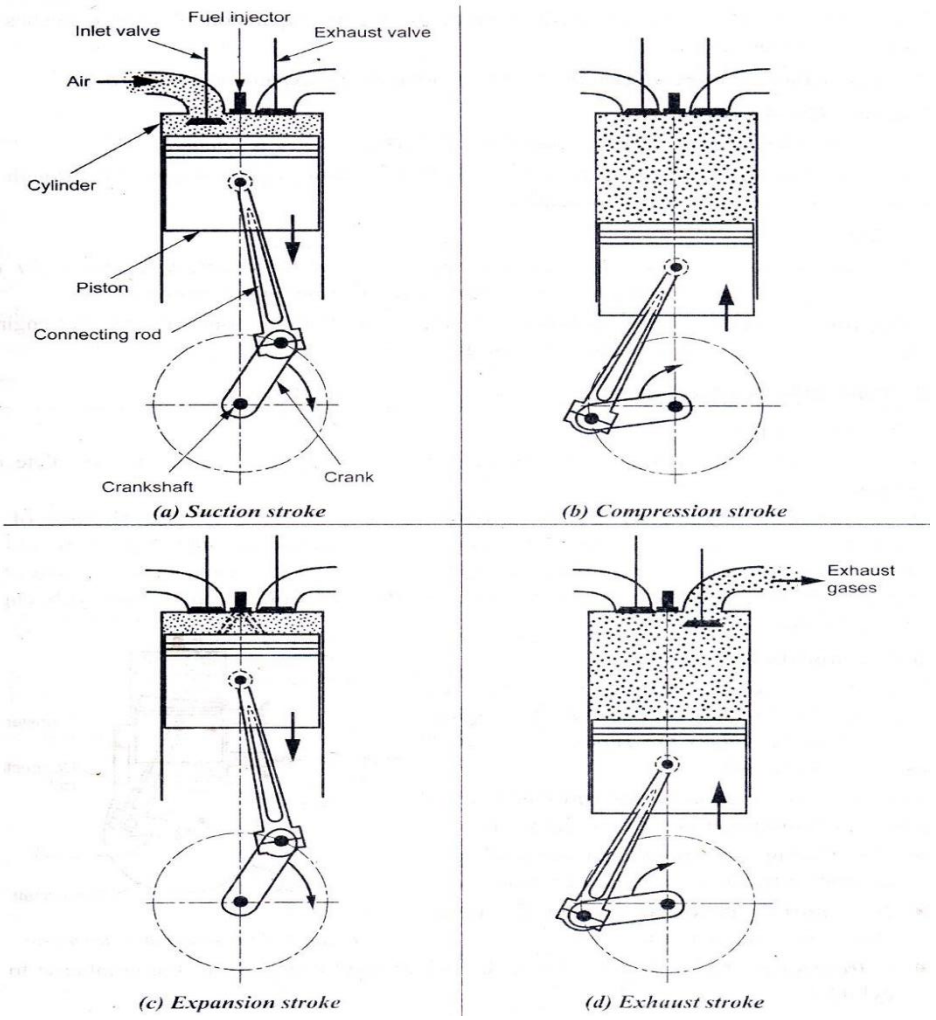
1. Suction Stroke:

- ✓ During suction stroke, the inlet valve opens and the exhaust valve closes. The piston moves from TDC to BDC.
- ✓ This piston movement reduces the pressure inside the cylinder below the atmospheric pressure.
- ✓ Due to the pressure difference, the fresh air is sucked into the cylinder through

the inlet valve.

2. Compression Stroke:

- ✓ During this stroke, both the inlet and exhaust valves are closed.
- ✓ The air in the cylinder is compressed as the piston moves upwards from BDC to TDC.
- ✓ As a result of this compression, pressure and temperature of the air is increased.
- ✓ Just before the piston reaches the TDC, the diesel is injected into the cylinder in the form of a fine spray.
- ✓ The fuel gets vaporized and self-ignited due to the heat of compressed air. The fuel burns instantaneously at constant pressure.



3. Expansion or Power Stroke:

- ✓ During this stroke, both inlet and exhaust valves are closed.
- ✓ The combustion of fresh fuel injected into the cylinder is due to the high pressure and temperature developed during compression stroke.
- ✓ The fuel is continuously injected for 20% of the expansion stroke.
- ✓ The high pressure of the combustion products due to expansion of charge pushes piston from TDC to BDC. It is also called as working stroke as work is done by the expansion of hot gases.

4. Exhaust Stroke:

- ✓ During this stroke, inlet valve is closed and the exhaust valve is opened
- ✓ The piston moves from BDC to TDC. The burnt waste gases are sent out through exhaust valve and the cycle is repeated.

Valve timing diagram:

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Fig.

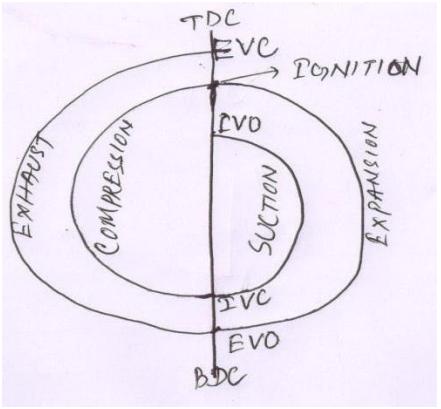


Fig. Theoretical valve timing diagram

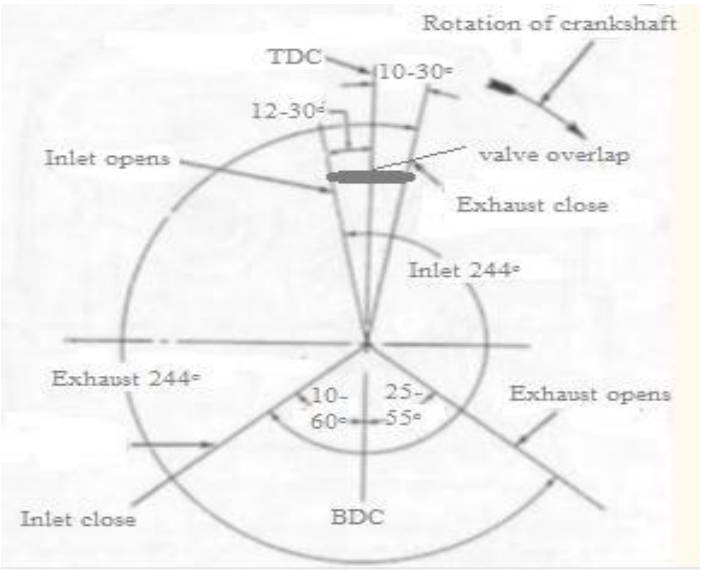
But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

Opening and closing of inlet valve

-Inlet valve opens 12 to 30^{o} CA before TDC to facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

-Inlet valve closes 10-60^{o} CA after TDC due to inertia movement of fresh charge into cylinder i.e. ram effect.

Figure represents the actual valve timing diagram for low and high speed engine.



Actual valve timing diagram for low and high speed engine

Opening and closing of exhaust valve

Exhaust valve opens 25 to 55^{o} CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30^{o} CA after TDC to avoid the compression of burnt gases in next cycle. Kinetic energy of the burnt gas can assist maximum exhausting of the gas. It also increases the volumetric efficiency.

Note: For low and high speed engine, the lower and upper values are used respectively

Valve overlap

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.

Table 1.1 Comparison of SI and CI Engines

Description	SI Engine	CI Engine
Basic cycle	Works on Otto cycle or constant volume heat addition cycle.	Works on Diesel cycle or constant pressure heat addition cycle.
Fuel	Gasoline, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low.
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburettor and an ignition system are necessary. Modern engines have gasoline injection.	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.
Load control	Throttle controls the quantity of fuel-air mixture introduced.	The quantity of fuel is regulated. Air quantity is not controlled.

Ignition	Requires an ignition system with spark plug in the combustion chamber. Primary voltage is provided by either a battery or a magneto.	Self-ignition occurs due to high temperature of air because of the high compression. Ignition system and spark plug are not necessary.
Compression ratio	6 to 10. Upper limit is fixed by antiknock quality of the fuel.	16 to 20. Upper limit is limited by weight increase of the engine.
Speed	Due to light weight and also due to homogeneous combustion, they are high speed engines.	Due to heavy weight and also due to heterogeneous combustion, they are low speed engines.
Thermal efficiency	Because of the lower CR, the maximum value of thermal efficiency that can be obtained is lower.	Because of higher CR, the maximum value of thermal efficiency that can be obtained is higher.
Weight	Lighter due to lower peak pressures.	Heavier due to higher peak pressures.

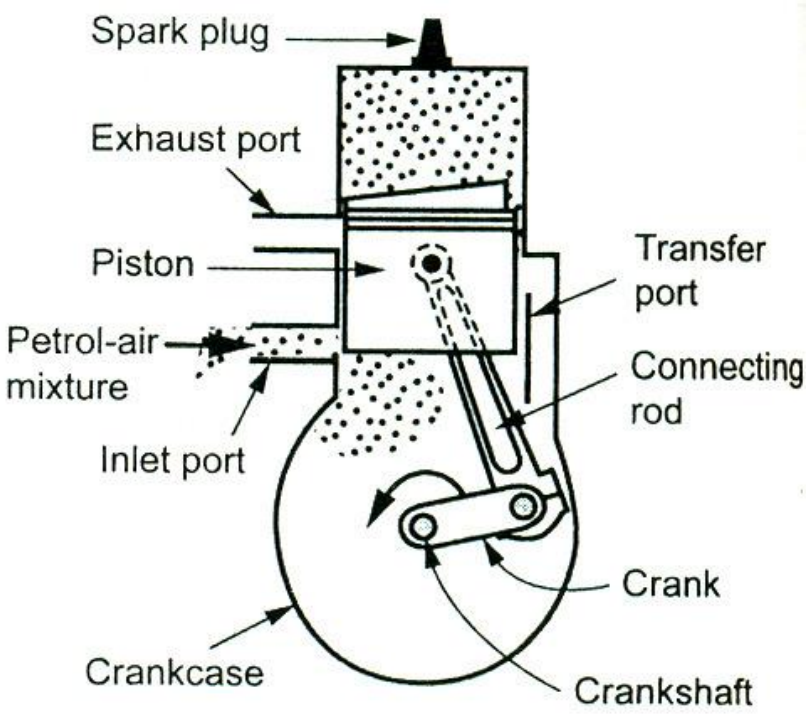
Characteristics of Four Stroke Compression Ignition & Spark Ignition Engines

Characteristics	Compression-Ignition Engine	Spark- Ignition Engine
Compression Ratio	14-22 : 1	5-8 : 1
Ignition	Compression	Electric Spark
Thermal Efficiency	30-60%	25-30%
Fuel induction	Injector	Carburettor (Fuel Injection)
Fuel System	Fuel Oil / Diesel	Gasoline (LP gas)
Fire Hazard	Less	Greater
Power Variation	Increase in Fuel	Increase in Air/Fuel Mixture
Air Induction	Constant	Variable
Air-Fuel Ratio	15-100 : 1	10-20 : 1
Relative Fuel Consumption	Lower	Higher
Energy per litre of fuel	Higher	Lower
Manifold Throttle	Absent	Present
Exhaust Gas Temperature	482° C / 900 F	704° C / 1300 F
Starting	Harder	Easier
Lubricants	Heavy duty oils	Regular and Premium Oils
Speed Range	Limited (600-3200 rpm)	Wide range (400-6000 rpm)
Engine Mass per Horsepower	8 kg (17.5 lb)	Average 4 kg (9 lb)
Initial Cost	High	Much Lower
Lugging ability (Torque)	Excellent	Less
Time Before Maintenance	Good	Fair
Continuous Duty	Good	Fair

TWO STROKE ENGINES

Two stroke engines perform only two strokes to complete one cycle.

In a four stroke cycle, the power is obtained only once in two revolutions of the crankshaft. Therefore, much attention was paid to obtain power once in every revolution of the crankshaft and this lead to the development of a two stroke cycle. Two stroke Cycle engines will theoretically give twice the power obtained from a four stroke cycle engine of similar size.



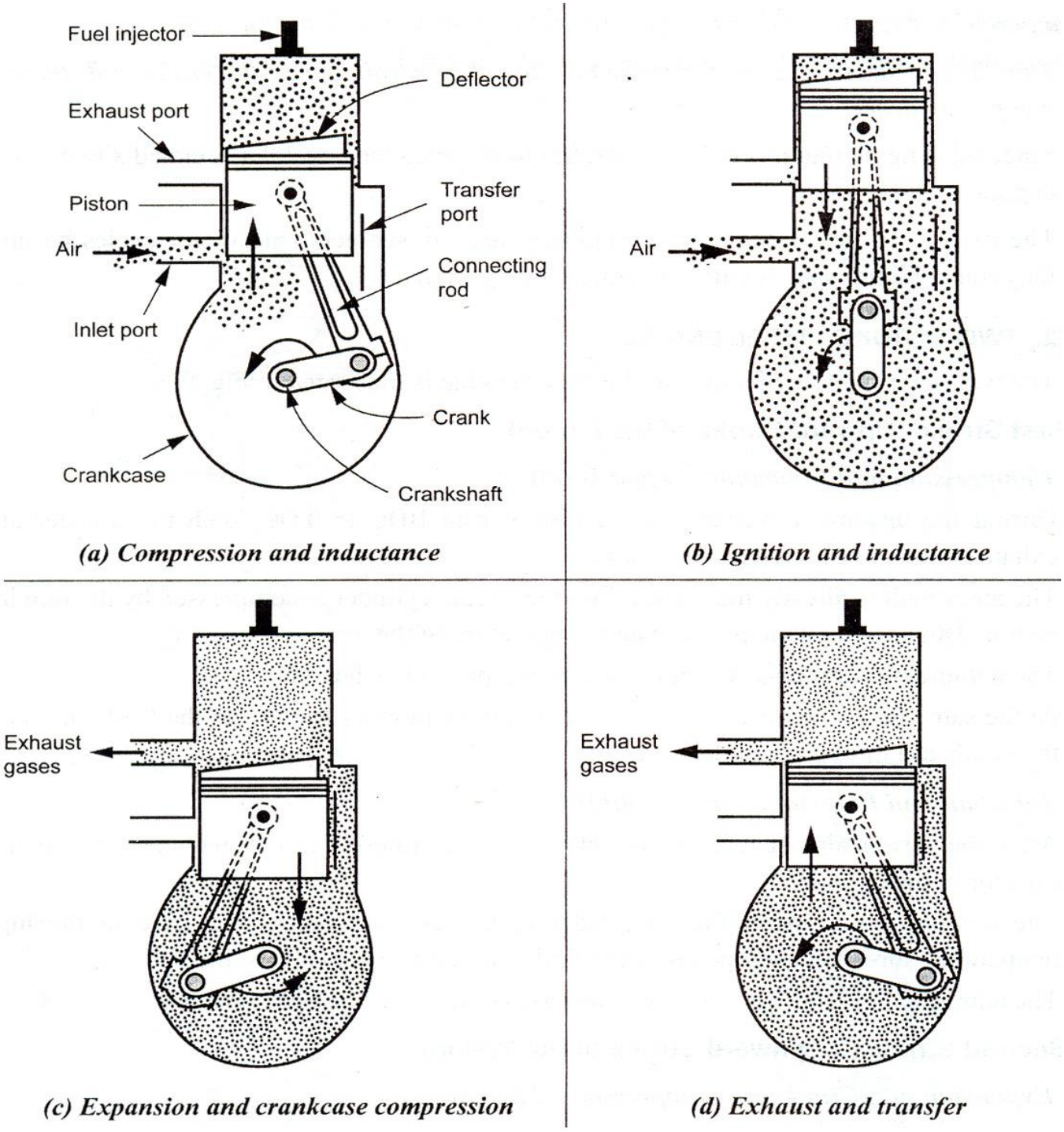
Construction:

- ✓ The two stroke IC engine is similar in construction to the four stroke IC engine except that the valves are replaced by ports, the two stroke engines are provided with Inlet port ports or openings cut in the cylinder walls.
- ✓ The closing and opening of the ports are controlled by the movement of piston.
- ✓ Inlet port is provided to feed the fresh charge into the crankcase.
- ✓ A transfer port is provided to take the compressed charge from the crankcase to the cylinder.
- ✓ The burnt waste gases are discharged into the atmosphere through a exhaust port.
- ✓ The crown of the piston (i.e., top of the piston) is shaped in such a way to assist in deflecting the fresh charge upwards in the cylinder and help scavenging.

Scavenging: Scavenging is the process of forcing out the burnt exhaust gases from the cylinder by admitting the fresh charge into the cylinder.

TWO STROKE DIESEL ENGINE

The working principle of a two stroke diesel engine is shown in the Fig. For every one revolution of Crankshaft there is One Power Stroke



(a) Compression and inductance

(b) Ignition and inductance

(c) Expansion and crankcase compression

(d) Exhaust and transfer

1. First Stroke (Upward Stroke of the Piston)

(a) Compression and Inductance:

- ✓ During the upward movement of the piston from BDC to TDC, both the transfer and exhaust ports are covered by the piston.
- ✓ The air which is already transferred into the engine cylinder is compressed by the moving piston. This increases the pressure and temperature of the air.
- ✓ The compression process is continued until the piston reaches TDC.
- ✓ At the same time, the inlet port is uncovered by the moving piston and the fresh air enters the crankcase through the inlet port.

(b) Injection and Inductance:

- ✓ After the piston almost reaches the TDC, the fuel (diesel) is injected through the fuel injector in the cylinder.
- ✓ The combustion of fresh fuel injected into the cylinder takes place due to the high temperature already developed in the cylinder during compression of the air.
- ✓ The admission of fresh air into the crankcase continues till the piston reaches the TDC

2. Second Stroke (Downward Stroke of the Piston)

(c) Expansion and Crankcase Compression:

- ✓ The burnt gases expand and forces the piston to move down, thus useful work is obtained.
- ✓ When the piston moves down, the air is partially compressed in the crankcase. This compression is known as crankcase compression.

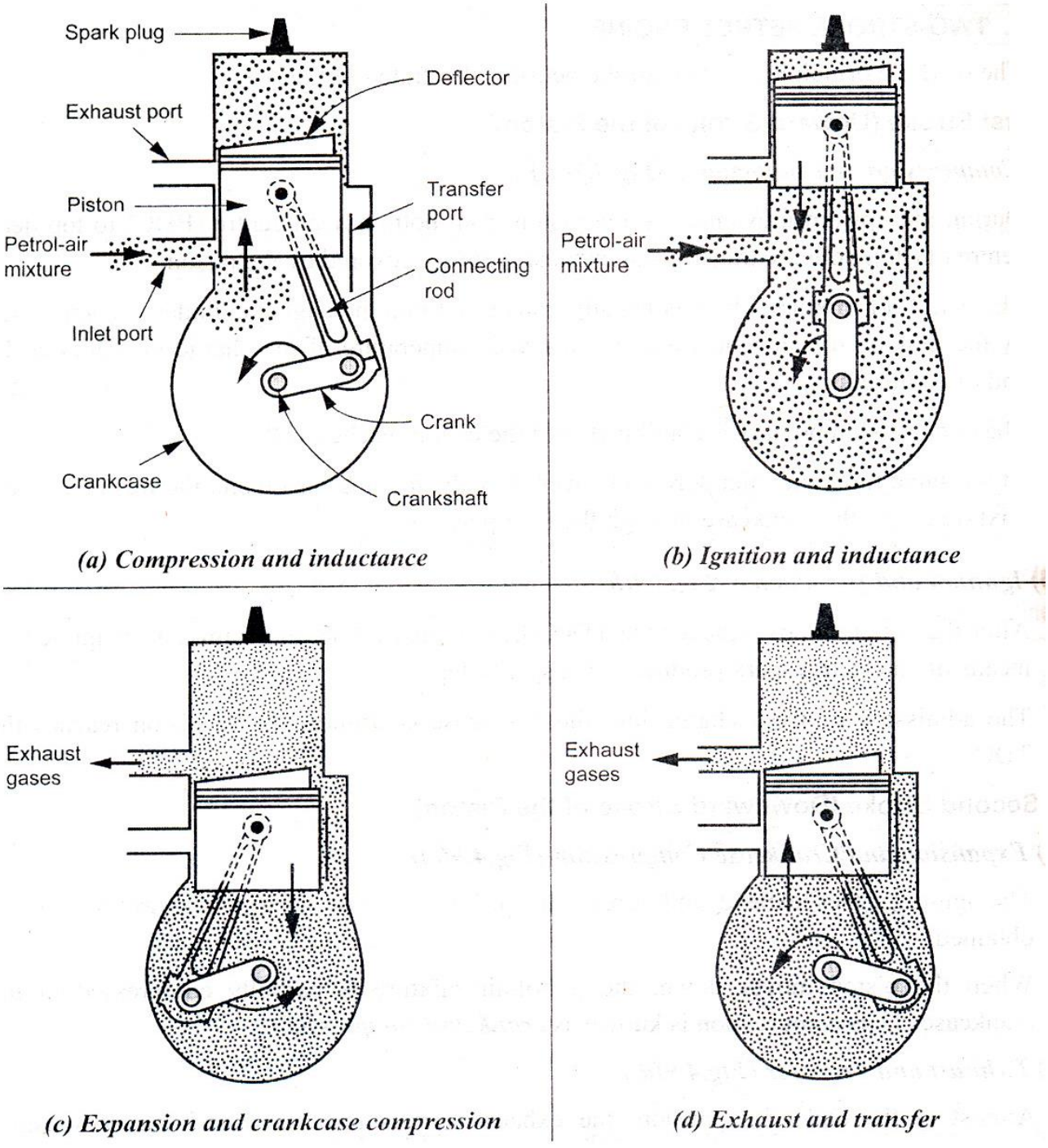
(d) Exhaust and Transfer:

- ✓ Nearly at the end of expansion, the exhaust port is uncovered and the combustion products escape to the atmosphere.
- ✓ Immediately the transfer port is also uncovered and the partially compressed air from the crankcase enters the cylinder through the transfer port.

The cycle of the operations are then repeated.

TWO STROKE PETROL ENGINES

The working principle of two stroke petrol engine is shown in the Fig.



1. First Stroke (Upward Stroke of the Piston)

(a) Compression and Inductance:

- ✓ During the upward movement of the piston from BDC to TDC, both the transfer and exhaust ports are covered by the piston.
- ✓ The petrol air mixture which is already transferred into the engine cylinder is compressed by the moving piston. Thus, the pressure and temperature of the charge increases at the end of compression.
- ✓ The compression process is continued until the piston reaches TDC.
- ✓ At the same time, the inlet port is uncovered by the moving piston and the fresh petrol air mixture enters the crankcase through the inlet port.

(b) Ignition and Inductance:

- ✓ After the piston almost reaches the TDC, the compressed petrol air mixture is ignited by means of an electric spark produced by a spark plug.
- ✓ The admission of fresh charge into the crankcase continues till the piston reaches the TDC.

2. Second Stroke (Downward Stroke of the Piston)

(c) Expansion and Crankcase Compression:

- ✓ The ignited gases expand and forces the piston to move down, thus useful work is obtained.
- ✓ When the piston moves down, the petrol air mixture is partially compressed in the crankcase. Thus compression is known as crankcase compression.

(d) Exhaust and Transfer:

- ✓ Almost at the end of expansion, the exhaust port is uncovered and the combustion products escape to the atmosphere. Immediately, the transfer port is also uncovered and the partially compressed air fuel mixture from the crankcase enters the cylinder through transfer port.
- ✓ The crown of the piston is made of a deflected shape, so the fresh air – petrol mixture entering the cylinder is deflected upward in the cylinder. Thus the escape of fresh charge along with the exhaust gases is reduced.

The cycle of operations are then repeated.

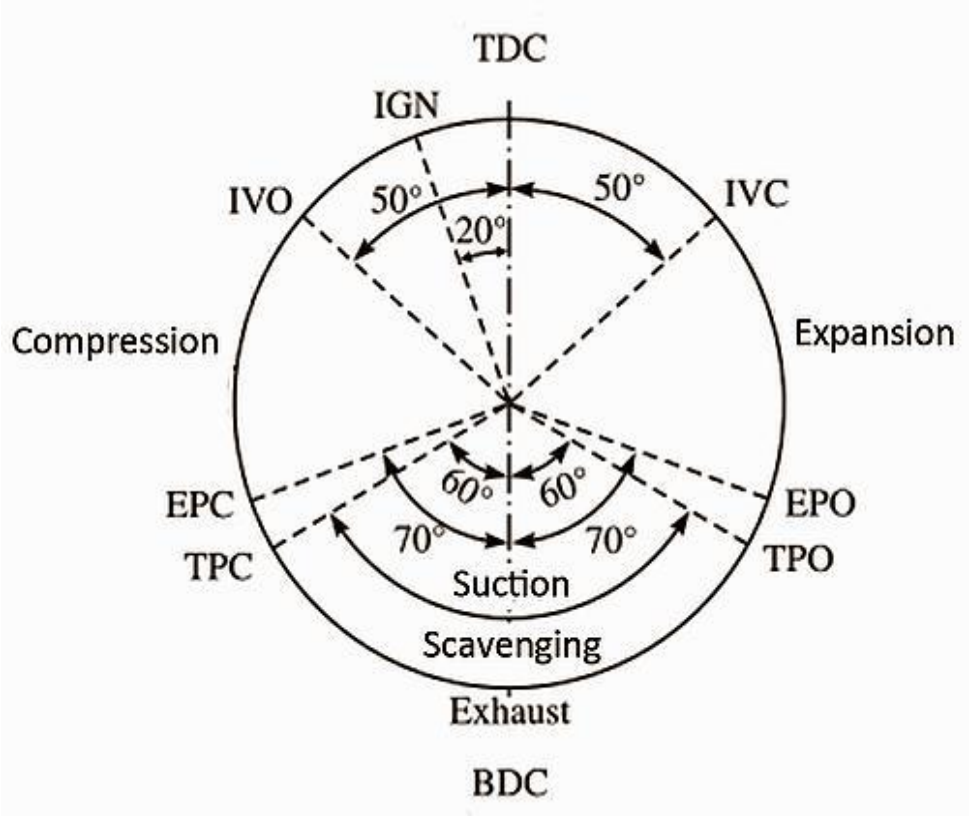
Port timing diagram:

-For 2-stroke engine

-No valve arrangement

-3 ports- inlet, transfer and exhaust

Figure shows port timing diagram for 2-stroke engine



Port timing diagram for 2-stroke engine

Table 1.2 Comparison of Four and Two-Stroke Cycle Engines

Four-Stroke Engine	Two-Stroke Engine
The thermodynamic cycle is completed in four strokes of the piston or in two revolutions of the crankshaft. Thus, one power stroke is obtained in every two revolutions of the crankshaft.	The thermodynamic cycle is completed in two strokes of the piston or in one revolution of the crankshaft. Thus one power stroke is obtained in each revolution of the crankshaft.
Because of the above, turning moment is not so uniform and hence a heavier flywheel is needed.	Because of the above, turning moment is more uniform and hence a lighter flywheel can be used.
Again, because of one power stroke for two revolutions, power produced for same size of engine is less, or for the same power the engine is heavier and bulkier.	Because of one power stroke for every revolution, power produced for same size of engine is twice, or for the same power the engine is lighter and more compact.

Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lower rate of wear and tear.	Because of one power stroke in one revolution greater cooling and lubrication requirements. Higher rate of wear and tear.
Four-stroke engines have valves and valve actuating mechanisms for opening and closing of the intake and exhaust valves.	Two-stroke engines have no valves but only ports (some two-stroke engines are fitted with conventional exhaust valve or reed valve).
Because of comparatively higher weight and complicated valve mechanism, the initial cost of the engine is more.	Because of light weight and simplicity due to the absence of valve actuating mechanism, initial cost of the engine is less.
Volumetric efficiency is more due to more time for induction.	Volumetric efficiency is low due to lesser time for induction.

Hybrid Vehicles:

A hybrid electric vehicle (HEV) has two types of energy storage units, electricity and fuel. Electricity means that a battery (sometimes assisted by ultracaps) is used to store the energy, and that an electromotor (from now on called *motor*) will be used as traction motor. Fuel means that a tank is required, and that an Internal Combustion Engine (ICE, from now on called *engine*) is used to generate mechanical power, *or* that a fuel cell will be used to convert fuel to electrical energy. In the latter case, traction will be performed by the electromotor only. In the first case, the vehicle will have both an engine and a motor.

Motors are the "work horses" of Hybrid Electric Vehicle drive systems. The electric traction motor drives the wheels of the vehicle. Unlike a traditional vehicle, where the engine must "ramp up" before full torque can be provided, an electric motor provides full torque at low speeds. The motor also has low noise and high efficiency. Other characteristics include excellent "off the line" acceleration, good drive control, good fault tolerance and flexibility in relation to

voltage fluctuations.

The front-running motor technologies for HEV applications include PMSM (permanent magnet synchronous motor), BLDC (brushless DC motor), SRM (switched reluctance motor) and AC induction motor. A main advantage of an electromotor is the possibility to function as generator. In all HEV systems, mechanical braking energy is regenerated. The max. operational braking torque is less than the maximum traction torque; there is always a mechanical braking system integrated in a car.

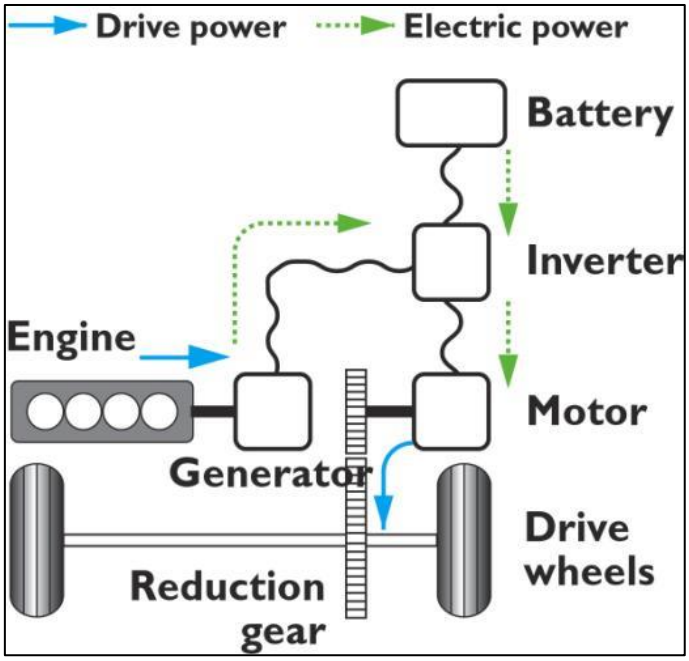
The battery pack in a HEV has a much higher voltage than the SIL automotive 12 Volts battery, in order to reduce the currents and the I^2R losses.

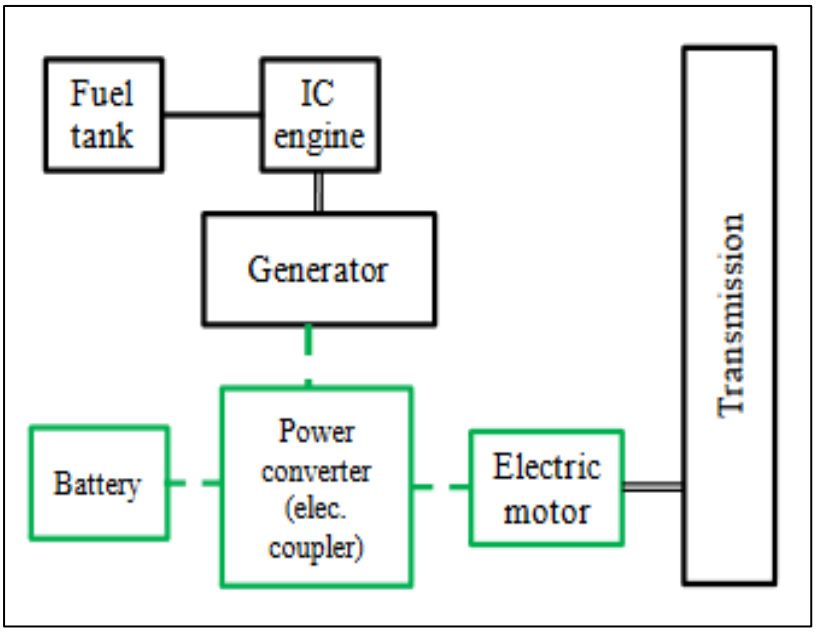
Accessories such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at a constant speed or can be switched off, regardless of how fast the combustion engine is running. Especially in long haul trucks, electrical power steering saves a lot of energy.

Series hybrid:

In a series hybrid system, the combustion engine drives an electric generator (usually a three-phase alternator plus rectifier) instead of directly driving the wheels. The electric motor is the only means of providing power to the wheels. The generator both charges a battery and powers an electric motor that moves the vehicle. When large amounts of power are required, the motor draws electricity from both the batteries and the generator.

Series hybrid configurations already exist a long time: diesel-electric locomotives, hydraulic earth moving machines, diesel-electric power groups, loaders.



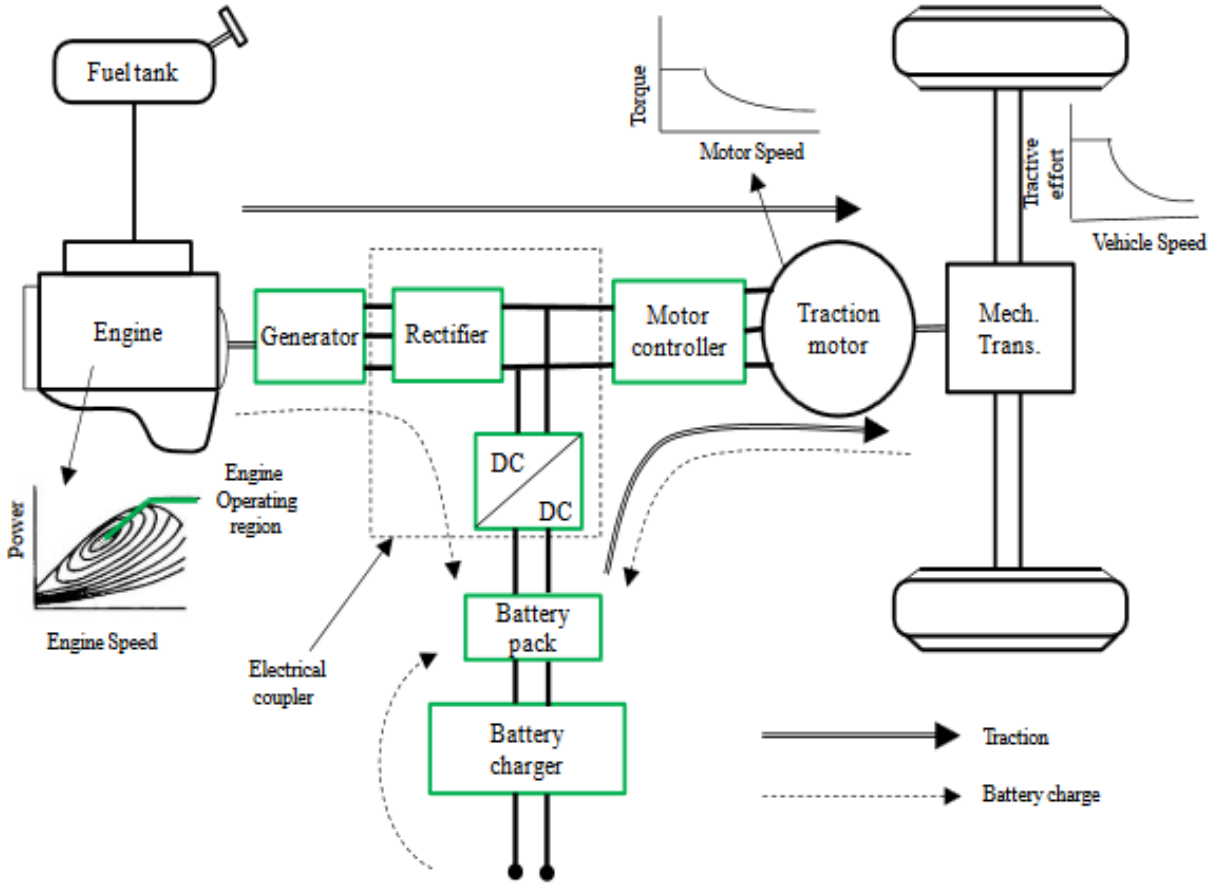


Disadvantages of series hybrid vehicles:

- The ICE, the generator and the electric motor are dimensioned to handle the full power of the vehicle. Therefore, the total weight, cost and size of the powertrain can be excessive.
- The power from the combustion engine has to run through both the generator and electric motor. During long-distance highway driving, the total efficiency is inferior to a conventional transmission, due to the several energy conversions.

Advantages of series hybrid vehicles:

- There is no mechanical link between the combustion engine and the wheels. The engine-generator group can be located everywhere.
- There are no conventional mechanical transmission elements (gearbox, transmission shafts). Separate electric wheel motors can be implemented easily.
- The combustion engine can operate in a narrow rpm range (its most efficient range), even as the car changes speed.
- Series hybrids are relatively the most efficient during stop-and-go city driving.



Series Hybrid Vehicle

Parallel hybrid

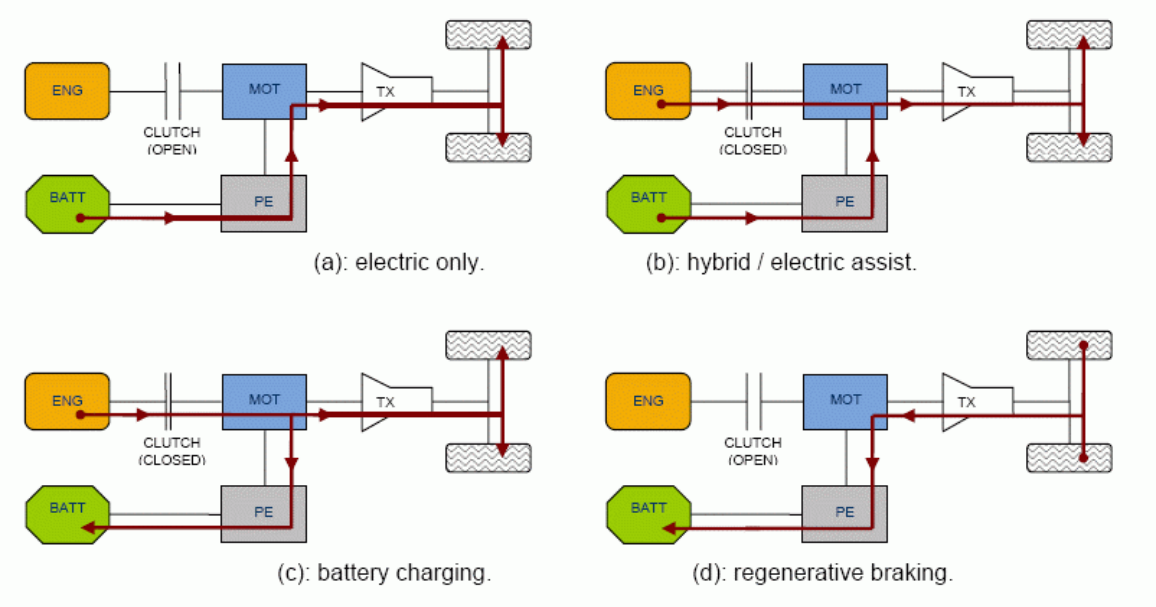
Parallel hybrid systems have both an internal combustion engine (ICE) and an electric motor in parallel connected to a mechanical transmission.

Most designs combine a large electrical generator and a motor into one unit, often located between the combustion engine and the transmission, replacing both the conventional starter motor and the alternator (see figures above). The battery can be recharged during regenerative breaking, and during cruising (when the ICE power is higher than the required power for propulsion). As there is a fixed mechanical link between the wheels and the motor (no clutch), the battery cannot be charged when the car isn't moving.

When the vehicle is using electrical traction power only, or during brake while regenerating energy,

the ICE is not running (it is disconnected by a clutch) or is not powered (it rotates in an idling manner).

Operation modes:



(a) electric power only: Up to speeds of usually 40 km/h, the electric motor works with only the energy of the batteries, which are not recharged by the ICE. This is the usual way of operating around the city, as well as in reverse gear, since during reverse gear the speed is limited.

(b) ICE power only: At speeds superior to 40 km/h, only the heat engine operates. This is the normal operating way at the road.

(b) ICE + electric power: if more energy is needed (during acceleration or at high speed), the electric motor starts working in parallel to the heat engine, achieving greater power

(c) ICE + battery charging: if less power is required, excess of energy is used to charge the batteries. Operating the engine at higher torque than necessary, it runs at a higher efficiency.

(d) regenerative breaking: While braking or decelerating, the electric motor takes profit of the kinetic energy of the he moving vehicle to act as a generator.

Sometimes, an extra generator is used: then the batteries can be recharged when the vehicle is not driving, the ICE operates disconnected from the transmission. But this system gives an increased weight and price to the HEV.

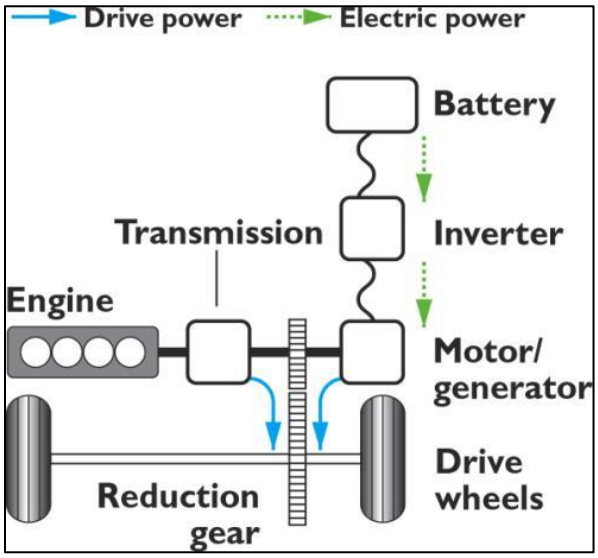
Disadvantages of parallel hybrid Vehicles:

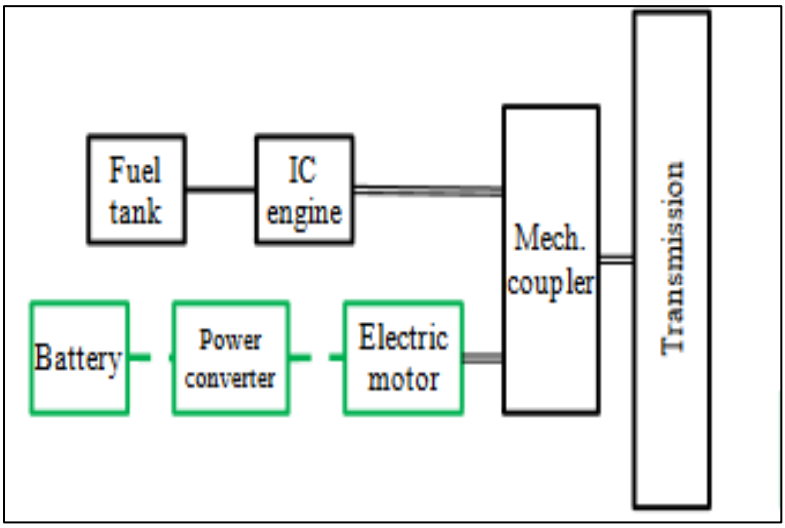
- Rather complicated system.
- The ICE doesn't operate in a narrow or constant RPM range, thus efficiency drops at low rotation speed.
- As the ICE is not decoupled from the wheels, the battery cannot be charged at standstill.

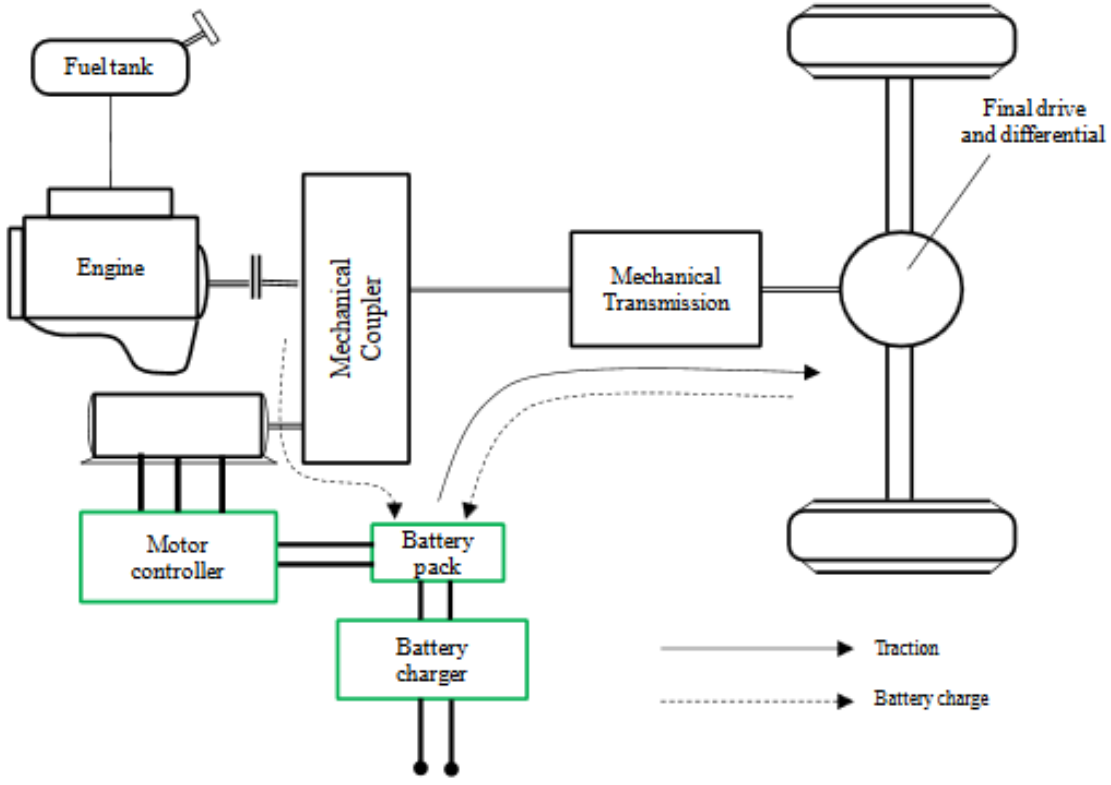
Advantages of parallel hybrid vehicles:

- Total efficiency is higher during cruising and long-distance highway driving.
- Large flexibility to switch between electric and ICE power

- Compared to series hybrids, the electromotor can be designed less powerful than the ICE, as it is assisting traction. Only one electrical motor/generator is required







Parallel Hybrid Vehicle

Combined hybrid

Combined hybrid systems have features of both series and parallel hybrids. There is a *double connection between the engine and the drive axle: mechanical and electrical*. This split power path allows interconnecting mechanical and electrical power, at some cost in complexity.

Power-split devices are incorporated in the powertrain. The power to the wheels can be either mechanical or electrical or both. This is also the case in parallel hybrids. But the main principle behind the combined system is the *decoupling of the power supplied by the engine from the power demanded by the driver*.

In a conventional vehicle, a larger engine is used to provide acceleration from standstill than one needed for steady speed cruising. This is because a combustion engine's torque is minimal at lower RPMs, as the engine is its own air pump. On the other hand, an electric motor exhibits maximum torque at stall and is well suited to complement the engine's torque deficiency at low RPMs. In a combined hybrid, a smaller, less flexible, and highly efficient engine can be used. It is often a variation of the conventional Otto cycle, such as the Miller or Atkinson cycle. This contributes significantly to the higher overall efficiency of the vehicle, with regenerative braking playing a much smaller role.

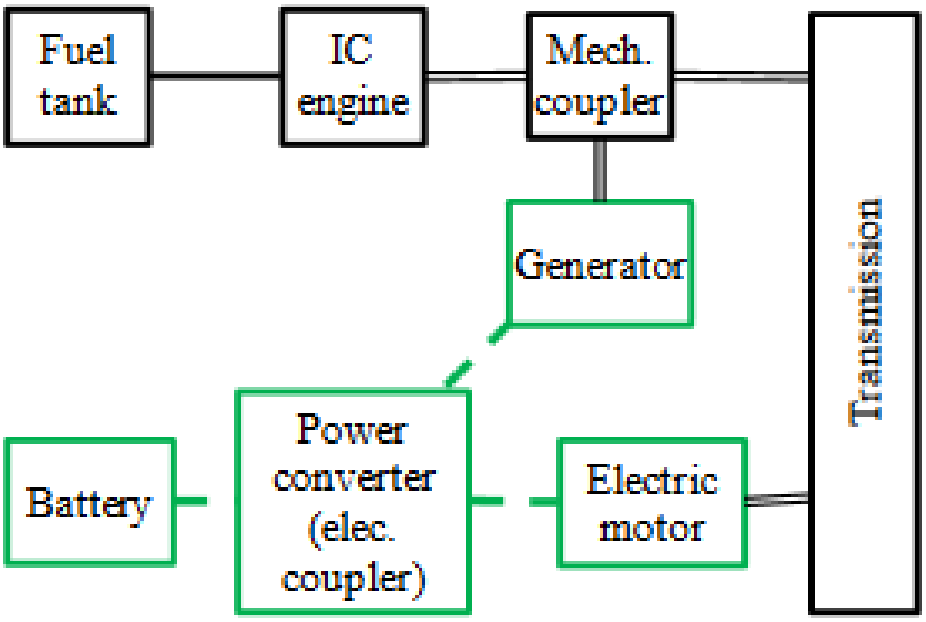
At lower speeds, this system operates as a series HEV, while at high speeds, where the series powertrain is less efficient, the engine takes over. This system is more expensive than a pure parallel system as it needs an extra generator, a mechanical split power system and more computing power to control the dual system.

Disadvantages of combined hybrid vehicles:

- Very complicated system, more expensive than parallel hybrid.
- The efficiency of the power train transmission is dependent on the amount of power being transmitted over the electrical path, as multiple conversions, each with their own efficiency, lead to a lower efficiency of that path (~70%) compared with the purely mechanical path (98%).

Advantages of combined hybrid vehicles:

- Maximum flexibility to switch between electric and ICE power
- Decoupling of the power supplied by the engine from the power demanded by the driver allows for a smaller, lighter, and more efficient ICE design.


Fuel tank
IC engine
Mech. coupler
Transmission
Generator
Battery
Power converter (elec. coupler)
Electric motor

INTRODUCTION

*The term „*refrigeration'* may be defined as the process of removing heat from a substance under controlled conditions.

*It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings.

*In other words, the refrigeration means a continued extraction of heat from a body whose temperature is already below temperature of its surroundings.

*In a refrigerator, heat is virtually pumped from a lower temperature to a higher temperature.

*According to Second Law of Thermodynamics, this process can only be performed with the aid of some external work.

*It is thus obvious that supply of power is regularly required to drive a refrigerator.

*Theoretically, a refrigerator is a reversed heat engine or a heat pump which pumps heat from a cold body and delivers it to a hot body.

*The substance which works in a pump to extract heat from a cold body and to deliver it to a hot body is known as refrigerant.

VAPOUR COMPRESSION CYCLE

* Vapour compression cycle is an improved type of air refrigeration cycle in which a suitable working substance, termed as refrigerant, is used.

* The refrigerants generally used for this purpose are ammonia (NH_3), carbon dioxide (CO_2) and sulphur-dioxide (SO_2).

* The refrigerant used, does not leave the system, but is circulated throughout the system alternately condensing and evaporating.

* In evaporating, the refrigerant absorbs its latent heat from the solution which is used for circulating it around the cold chamber and in condensing; it gives out its latent heat to the circulating water of the cooler.

The vapour compression cycle which is used in vapour compression refrigeration system is now-a-days used for all purpose refrigeration. It is used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

Simple Vapour Compression Refrigeration System

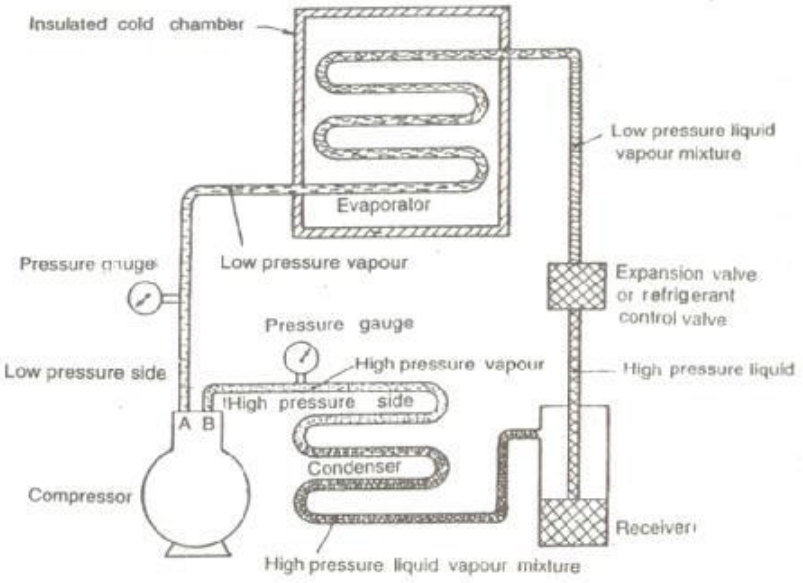
It consists of the following essential parts:

Compressor

The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery or discharge valve B.

Condenser

The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed.



Simple Vapour Compression Refrigeration System

The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

Receiver

The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

Expansion Valve

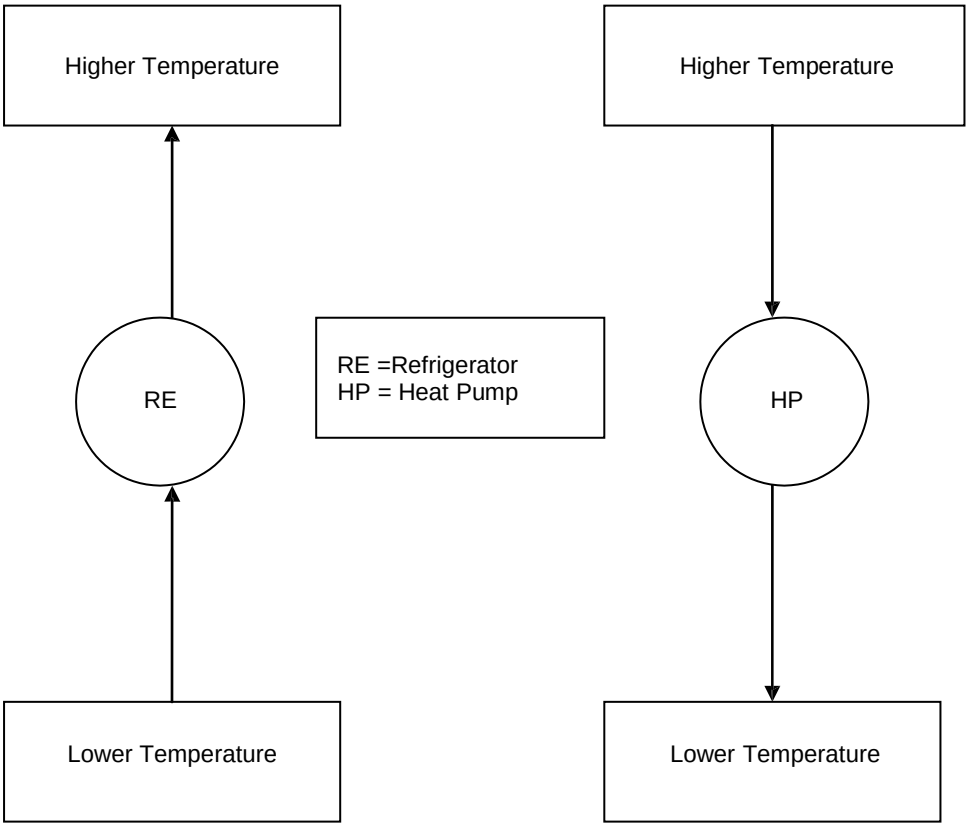
It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature

Evaporator

An evaporator consists of coils of pipe in which the liquid-vapour. refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

Difference between Refrigeration and Heat Pump System

The major difference between the refrigeration and heat pump system is that refrigerator delivers heat from lower temperature to a higher temperature, whereas heat pump delivers heat from higher temperature to lower temperature body. The difference between refrigerator and heat pump is shown in the Figure 2.10 schematically.



Schematic Representation of Refrigerator and Heat Pump

VAPOUR ABSORPTION SYSTEM

The vapour absorption refrigeration is heat operated system. It is quite similar to the vapour compression system. In both the systems, there are evaporator and condenser. The process of evaporation and condensation of the refrigerant takes place at two different pressure levels to achieve refrigeration in both the cases. The method employed to create the two pressure levels in the system for evaporation and condensation of the refrigeration makes the two processes different. Circulation of refrigerant in both the cases is also different.

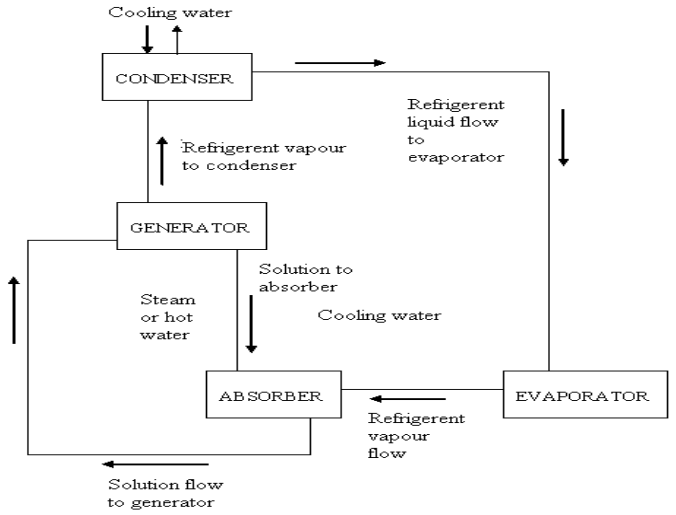
In the absorption system the compressor of the vapour compression system is replaced by the combination of „absorber" and „generator". A solution known as the absorbent, which has an affinity for the refrigerant used, is circulated between the absorber and the generator by a pump (solution pump). The absorbent in the absorber draws (or sucks) the refrigerant vapour formed in the evaporator thus maintaining a low pressure in the evaporator to enable the refrigerant to evaporate at low temperature. In the generator the absorbent is heated. There by releasing the refrigerant vapour (absorbed in the absorber) as high pressure vapour, to be condensed in the condenser. Thus the suction function is performed by absorbent in the absorber and the generator performs the function of the compression and discharge. The absorbent solution carries the refrigerant vapour from the low side (evaporator–absorber) to the high side (generator-condenser). The liquefied refrigerant flows from the condenser to the evaporator due to the pressure difference between the two vessels; thus establishing circulation of the refrigerant through the system.

As can be seen from the figure, the refrigerant and absorbent have separate flow paths. The refrigerant path is:

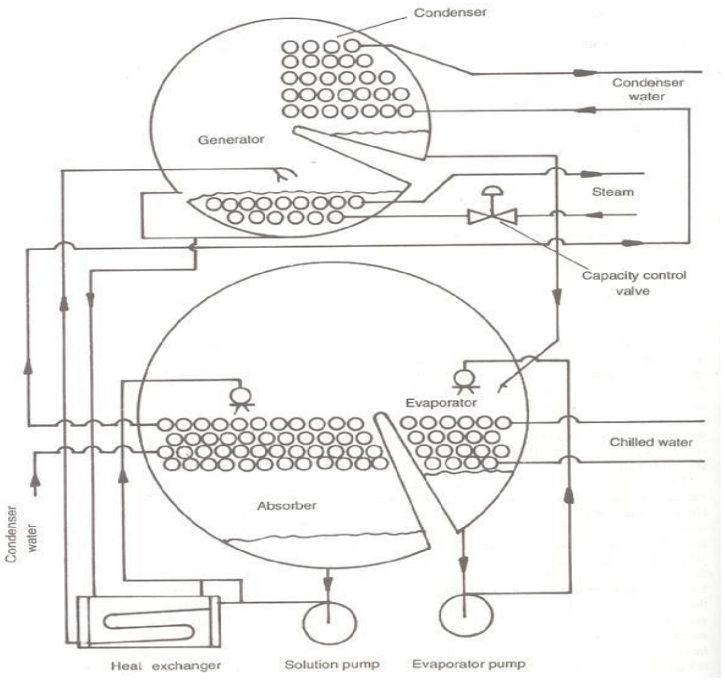
Evaporator ↓ Absorber ↓ Generator ↓ Condenser ↓ Evaporator and for the absorbent it is,

Absorber ↓ Generator ↓ Absorber

The absorbent solution passing from the generator to the absorber is hot and ha to be cooled. On the other hand the absorbent solution sent to the generator is cooled and has to be heated in the generator for the regeneration of the refrigerant. A shell and tube heat exchanger is introduced between the generator and the absorber.



Schematic Diagram of Absorption System of Refrigeration



Schematic Sketch of a Lithium-Bromide Absorption Machine – Single Stage

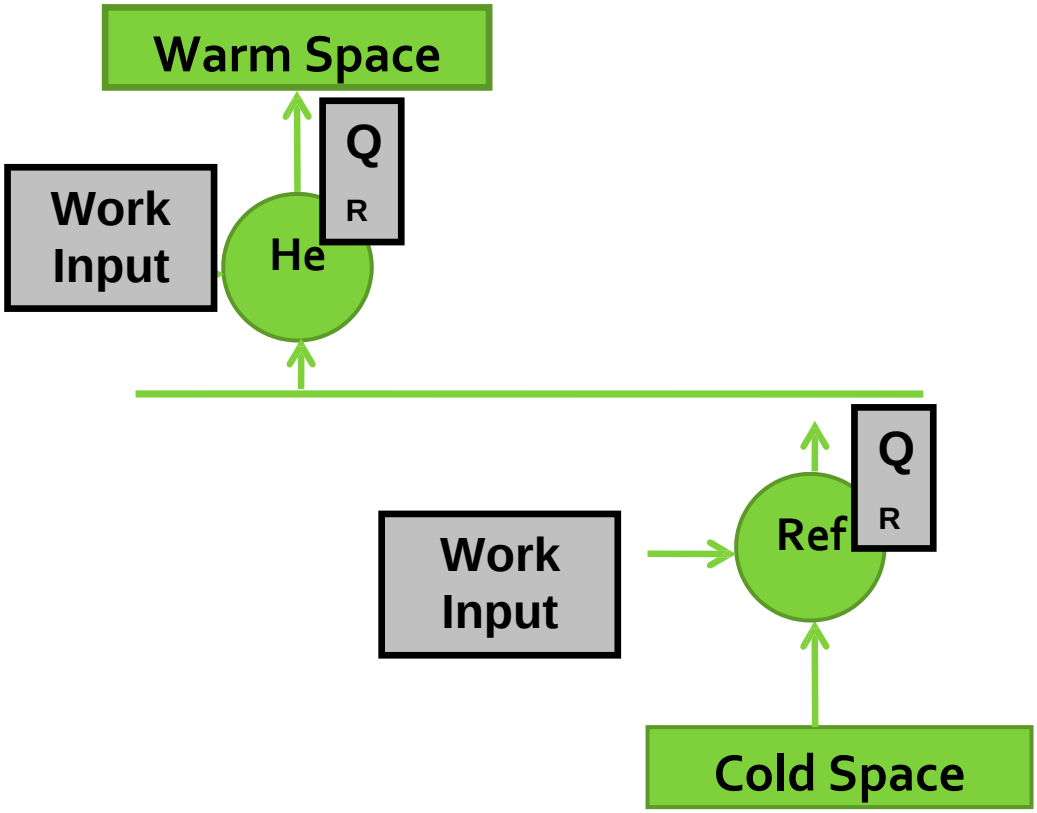
There is number of vapour absorption system depending on the absorbent e.g. ammonia absorbent system, lithium bromide absorption system etc. Ammonia absorbent systems were used in the early stages of refrigeration. This system uses ammonia as the refrigerant and water as absorbent. In lithium bromide absorption system lithium bromide salt solution is used as the absorbent and water as the refrigerant. A concentrated solution of lithium bromide has a great affinity for water. Since water is the refrigerant, the refrigerant operating temperature in the evaporator has to be above the freezing point of water (0^oC) of water.

(Refrigeration and Air-conditioning)

Refrigeration : It is defined as the process of providing and maintaining a temperature well below that of surrounding atmosphere. In other words refrigeration is the process of cooling substance.

Refrigerator and Heat Pump:

If the main purpose of the machine is to cool some object, the machine is named as refrigerator
If the main purpose of machine is to heat a medium warmer than the surroundings, the machine is termed as heat pump



Terminologies of Refrigeration :

Refrigerating Effect (N): It is defined as the quantity of heat extracted from a cold body or space to be cooled in a given time.

N= Heat extracted from the cold space / Time taken

Specific Heat of water and ice : It is the quantity of heat required to raise or lower the temperature of one kg of water (or ice), through one kelvin or (10 c) in one second.

Specific heat of water, Cpw = 4.19 kJ/kg K
Specific heat of ice, Cpice = 2.1 kJ/kg K.

Co efficient of Performance: It is defined as the ratio of heat extracted in a given time (refrigerating effect) to the work input.

The COP is always greater than 1 and known as theoretical coefficient of performance

Classification of Refrigerants

Refrigerants are classified as,

(a) Primary Refrigerants: It is a working medium which is used for cooling the substance by absorption of latent heat.

Examples : Ammonia (NH3), Carbon dioxide (CO2), Sulphur dioxide (SO2), Freon 12, etc.,

(b) Secondary Refrigerants: Secondary refrigerant is a substance already cooled by primary refrigerant and then employed for cooling purposes.

Examples : Ice, solid carbon dioxide.

These refrigerants cool the substance by absorption of their sensible heat

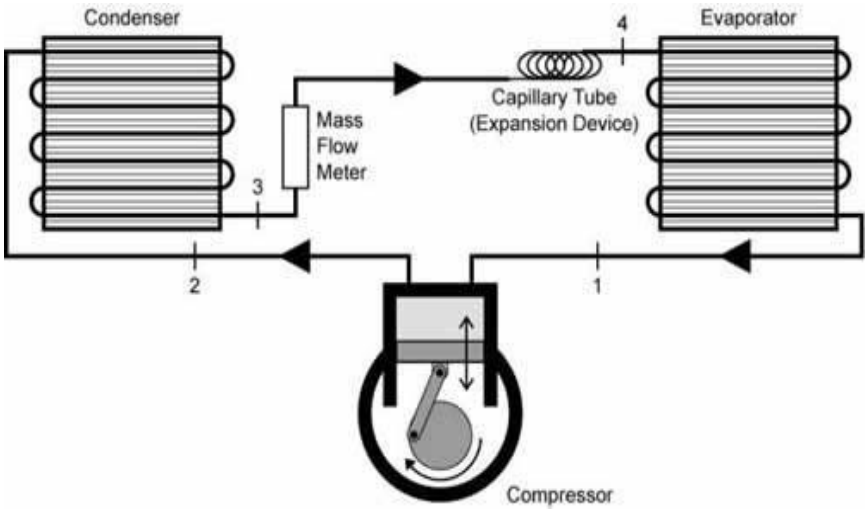
Properties of Refrigerants :

- A good refrigerant should have high latent heat of vapourisation.
- It should have low boiling and low freezing point.
- It should be non toxic and should non corrosiveness
- It should be non flammable and non explosive.
- It should have high thermal conductivity
- It should be easy to handle
- It should have low specific volume of vapour.
- It should have high co efficient of performance

Applications of Refrigeration :

- In chemical industries, for separating and liquefying the gases.
- In manufacturing and storing ice.
- For the preservation of perishable food items in cold storages.
- For cooling water.
- For controlling humidity of air manufacture and heat treatment of steels.
- For chilling the oil to remove wax in oil refineries.
- For the preservation of tablets and medicines in pharmaceutical industries.
- For the preservation of blood tissues etc.,
- For comfort air conditioning the hospitals, theatres, etc.,

Vapour Compression Refrigeration system :

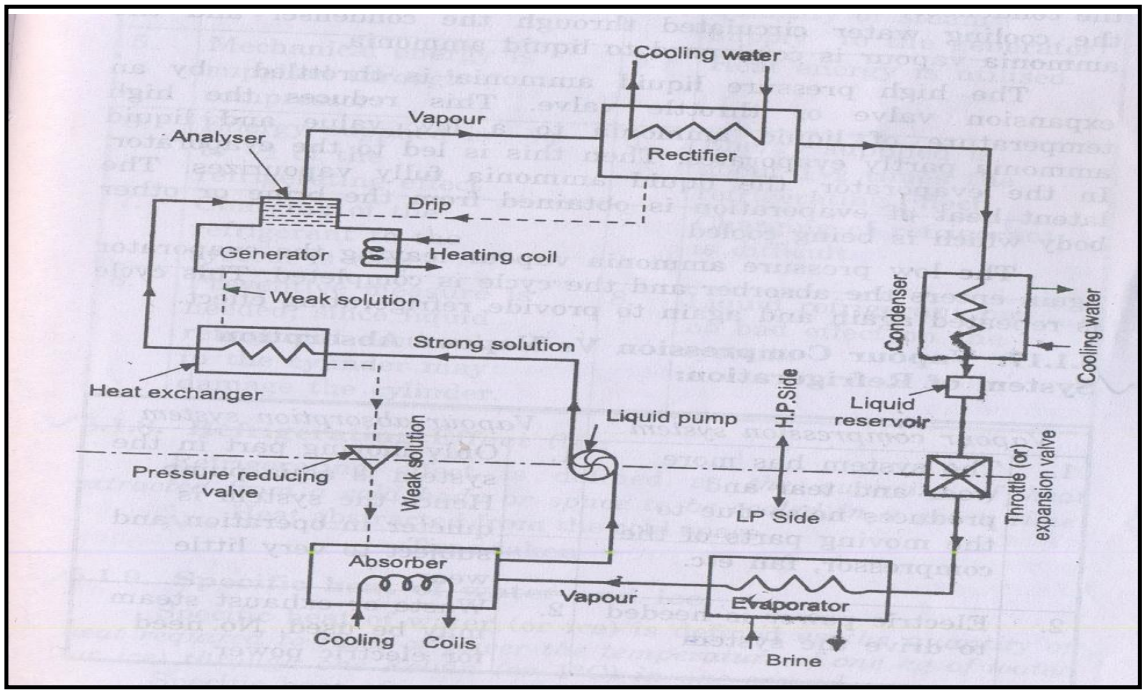


Working :

1. The low pressure refrigerant vapour coming out of the evaporator flows into the compressor.
2. The compressor is driven by a prime mover.
3. In the compressor the refrigerant vapour is compressed.
4. The high pressure refrigerant vapour from the compressor is then passed through the condenser.
5. The refrigerant gives out the heat it had taken in the evaporator (N)
6. The heat equivalent of work done on it (w) on the compressor.
7. This heat is carried by condenser medium which may be air or water.
8. The high pressure liquid refrigerant then enters the expansion valve.
9. This valve allows the high pressure liquid refrigerant to flow at a controlled rate into the evaporator.
10. While passing though this valve the liquid partially evaporates.

11. Most of the refrigerant is vapourised only in the evaporator, at a low pressure.
12. In the evaporator the liquid refrigerant absorbs its latent heat of vapourisation from the material which is to be cooled.
13. Thus the refrigerating effect (N) is obtained.
14. Then the low pressure refrigerant enters the compressor and the cycle is repeated

Vapour Absorption system :



Construction :

- The vapour absorption system consists of a condenser, an expansion valve and an evaporator.
- They perform the same as they do in vapour compression method.
- In addition to these, this system has an absorber, a heat exchanger, an analyser and a rectifier

Working :

1. Dry ammonia vapour at low pressure passes in to the absorber from the evaporator.
2. In the absorber the dry ammonia vapour is dissolved in cold water and strong solution of ammonia is formed.
3. Heat evolved during the absorption of ammonia is removed by circulating cold water through the coils kept in the absorber.
4. The highly concentrated ammonia (known as Aqua Ammonia) is then pumped by a pump to generator through a heat exchanger.
5. In the heat exchanger the strong ammonia solution is heated by the hot weak

solution returning from the generator to the absorber.

6. In the generator the warm solution is further heated by steam coils, gas or electricity and the ammonia vapour is driven out of solution.
7. The boiling point of ammonia is less than that of water.
8. Hence the vapours leaving the generator are mainly of ammonia.
9. The weak ammonia solution is left in the generator is called weak aqua.
10. This weak solution is returned to the absorber through the heat exchanger.
11. Ammonia vapours leaving the generator may contain some water vapour.
12. If this water vapour is allowed to the condenser and expansion valve, it may freeze resulting in chocked flow.
13. Analyser and rectifiers are incorporated in the system before condenser.
14. The ammonia vapour from the generator passes through a series of trays in the analyser and ammonia is separated from water vapour.
15. The separated water vapour returned to generator.
16. Then the ammonia vapour passes through a rectifier.
17. The rectifier resembles a condenser and water vapour still present in ammonia vapour condenses and the condensate is returned to analyser.
18. The virtually pure ammonia vapour then passes through the condenser.
19. The latent heat of ammonia vapour is rejected to the cooling water circulated through the condenser and the ammonia vapour is condensed to liquid ammonia.
20. The high pressure liquid ammonia is throttled by an expansion valve or throttle valve.
21. This reduces the high temperature of the liquid ammonia to a low value and liquid ammonia partly evaporates.
22. Then this is led to the evaporator.
23. In the evaporator the liquid fully vaporizes
24. The latent heat of evaporation is obtained from the brine or other body which is being cooled.
25. The low pressure ammonia vapour leaving the evaporator again enters the absorber and the cycle is completed.
26. This cycle is repeated again to provide the refrigerating effect.

Application of Refrigeration system :

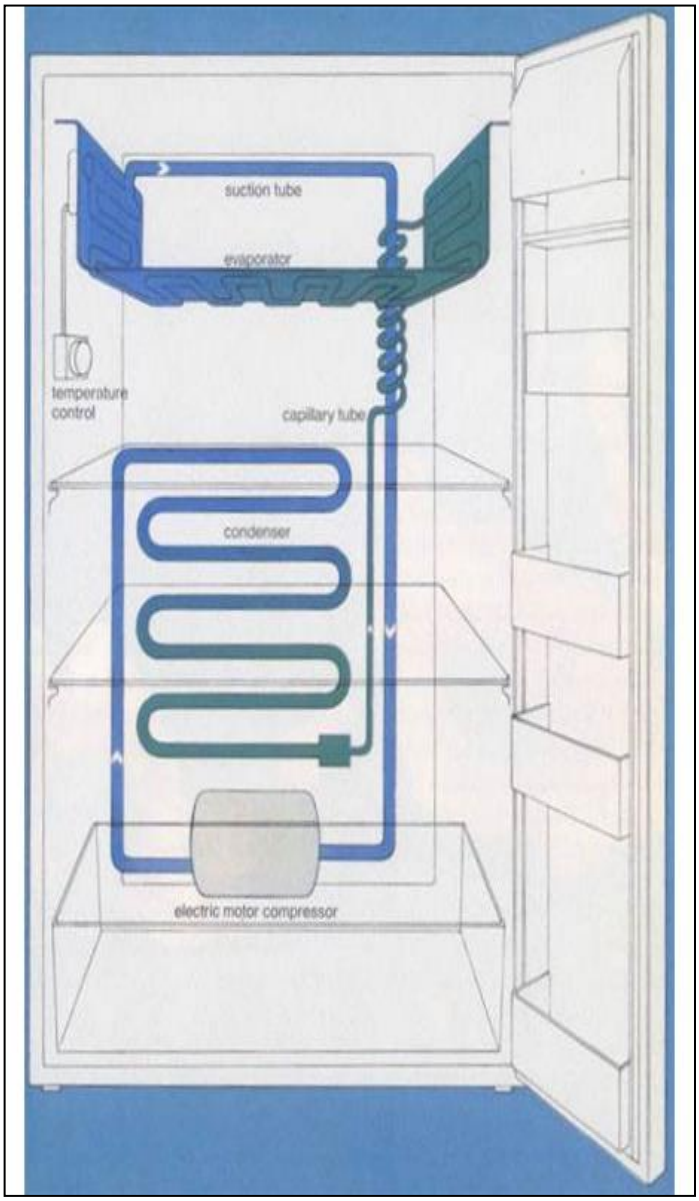
- Preservation of food items like vegetables, milk and eggs.
- Preservation of medicines.
- Preservation of blood, tissues, etc.,
- Preservation and cooling of cool drinks.
- Preservation of chemicals (Chemical industries)
- Cooling of water.
- Industrial and comfort airconditioning.
- Processing of dairy products.

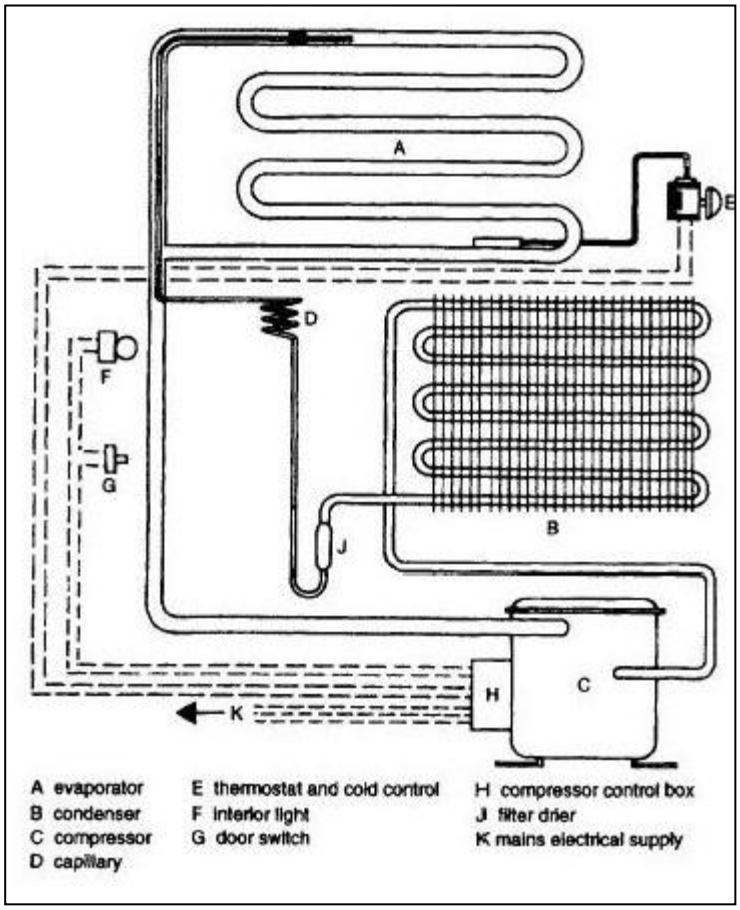
Comparison between Vapour Compression Refrigeration system and Vapour Absorption refrigeration system

S.No.	Vapour Compression System	Vapour Absorption System
1	This system has more wear and tear and produces more noise due to the moving parts of the compressor.	Only moving part in this system is an aqua pump. Hence the quieter in operation and less wear and tear
2.	Electric power is needed to drive the system	Waste of exhaust steam may be used. No need of electric power
3.	Capacity of the system drops rapidly with lowered evaporator pressure	Capacity of the system decreases with the lowered evaporative pressure, by increasing the steam pressure in generator.
4.	At partial loads performance is poor.	At partial loads performance is not affected.
5.	Mechanical energy is supplied through compressor	Heat energy is utilised
6.	Energy supplied is ¼ to ½ of the refrigerating effect	Energy supplied is about one and half times the refrigerating effect
S.No.	Vapour Compression System	Vapour Absorption System
7.	Charging of the refrigerating to the system is easy	Charging of refrigerant is difficult
8.	Preventive measure is needed, since liquid refrigerant accumulated in the cylinder may damage to the cylinder	Liquid refrigerant has no bad effect on the system.

Layout of domestic refrigerator:

The domestic refrigerator is one found in almost all the homes for storing food, vegetables, fruits, beverages, and much more. This article describes the important parts of the domestic refrigerator and also their working. The parts of domestic refrigerator can be categorized into two categories: internal and external.





The internal parts of the refrigerator are ones that carry out actual working of the refrigerator. Some of the internal parts are located at the back of the refrigerator, and some inside the main compartment of the refrigerator. Some internal parts of the domestic refrigerator are

1) **Refrigerant**: The refrigerant flows through all the internal parts of the refrigerator. It is the refrigerant that carries out the cooling effect in the evaporator. It absorbs the heat from the substance to be cooled in the evaporator (chiller or freezer) and throws it to the atmosphere via condenser. The refrigerant keeps on recirculating through all the internal parts of the refrigerator in cycle.

2) Compressor: The compressor is located at the back of the refrigerator and in the bottom area. The compressor sucks the refrigerant from the evaporator and discharges it at high pressure and temperature. The compressor is driven by the electric motor and it is the major power consuming devise of the refrigerator.

3) Condenser: The condenser is the thin coil of copper tubing located at the back of the refrigerator. The refrigerant from the compressor enters the condenser where it is cooled by the atmospheric air thus losing heat absorbed by it in the evaporator and the compressor. To increase the heat transfer rate of the condenser, it is finned externally.

4) Expansive valve or the capillary: The refrigerant leaving the condenser enters the expansion devise, which is the capillary tube in case of the domestic refrigerators. The capillary is the thin copper tubing made up of number of turns of the copper coil. When the refrigerant is passed through the capillary its pressure and temperature drops down suddenly.

5) Evaporator or chiller or freezer: The refrigerant at very low pressure and temperature enters the evaporator or the freezer. The evaporator is the heat exchanger made up of several turns of copper or aluminum tubing. In domestic refrigerators the plate types of evaporator is used as shown in the figure above. The refrigerant absorbs the heat from the substance to be cooled in the evaporator, gets evaporated and it then sucked by the compressor. This cycle keeps on repeating.

6) Temperature control devise or thermostat: To control the temperature inside the refrigerator there is thermostat, whose sensor is connected to the evaporator. The thermostat setting can be done by the round knob inside the refrigerator compartment. When the set temperature is reached inside the refrigerator the thermostat stops the electric supply to the compressor and compressor stops and when the temperature falls below certain level it restarts the supply to the compressor.

7) Defrost system: The defrost system of the refrigerator helps removing the excess ice from the surface of the evaporator. The defrost system can be operated manually by the thermostat button or there is automatic system comprising of the electric heater and the timer.

AIRCONDITIONING

Air-conditioning : Air Conditioning is the process of conditioning the air according to the human comfort, irrespective of external conditions.

Applications of Air Conditioning

- Used in offices, hotels, buses, cars.,etc
- Used in industries having tool room machines.
- Used in textile industries to control moisture.
- Used in printing press.
- Used in Food industries, Chemical plants.

Air conditioning systems are classified as

1) According to the purpose

a) Comfort Air conditioning.
b) Industrial Air conditioning.

2) According to Season of the year

a) Summer Air conditioning.
b) Winter Air conditioning.
c) Year round Air conditioning

Types of Air conditioners

a) Room Air conditioners
b) Winter Air conditioners
c) Central Air conditioners

Functions of Air conditioners

a) Cleaning air.
b) Controlling the temp of air.
c) Controlling the moisture content.
d) Circulating the air.

Important Definitions :

1) Dry air: The atmospheric air which no water vapour is called dry air.

2) Psychrometry: Psychrometry is the study of the properties of atmospheric air**.**

3) Temperature: The degree of hotness (or) Coldness is called the temperature.

4) Moisture: Moisture is the water vapour present in the air

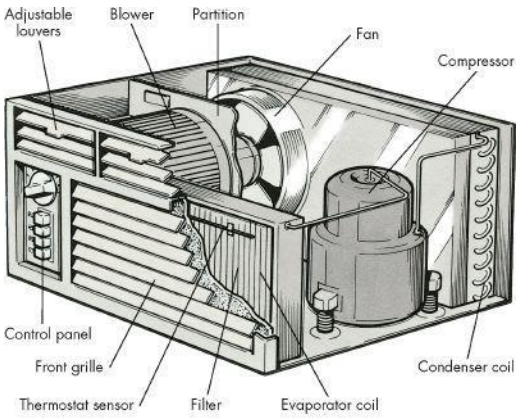
5) Relative humidity: Relative humidity is the ratio of actual mass of water vapour in a given volume to the mass of water vapour.

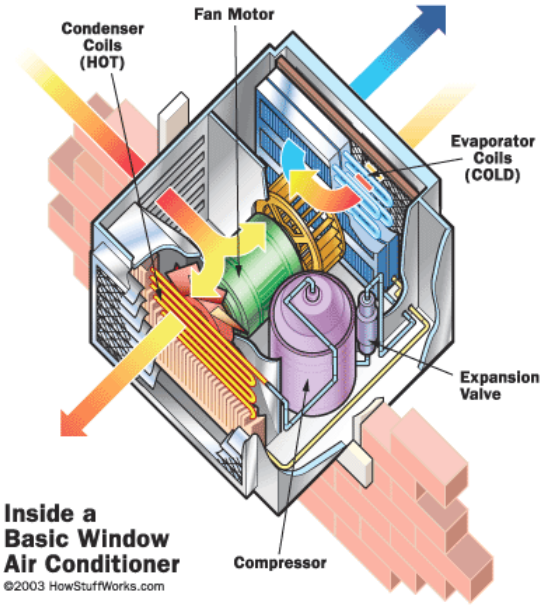
6) Dry bulb temperature: The temperature of air measured by the ordinary thermometer is called dry bulb temperature:

7) Wet bulb Temperature: The temperature of air measured by the thermometer when it is covered by the wet cloth is known as wet bulb Temperature.

8) Dew point Temperature: The temperature at which the water vapour starts condensing is called dew point Temperature:

Window Type air conditioner :





Working :

- The low pressure vapour refigerant from the evaporator is sucked by compressor through the open inlet valve.
- The compressor compresses the vapour refrigerant.
- The high pressure and high temperature vapour refrigerant then flows to the condenser through the open outlet valve.
- In the condenser, the outside atmospheric temperature in summer being around 42o C, air is circulated by fan.
- After condensation, the high pressure liquid refrigerant formed passes through an expansion valve which reduces its pressure
- The low pressure refrigerant then enters the evaporator and evaporates, thus absorbing latent heat of vapourisation from the room air.
- The equipment which is used for evaporating the refrigerant is called evaporator.
- After evaporation, the refrigerant becomes vapour.
- The low pressure vapour is again passed to the compressor. Thus the cycle is repeated.
- A partition separates high temperature side of condenser, compressor and low temperature side of evaporator
- The quantity of air circulated can be controlled by the dampers.
- 10. The moisture in the air passing over the evaporator coil is dehumidified and drips into the trays.
- The unit automatically stops when the required temperature is reached in the room. This is accomplished by the thermostat and control panel.
- Generally, the refrigerant monochloro diluloro mehane (CHCLF2) is used in air conditioner. It is called Freon 22.

Merits and Demerits of Window type air conditioner

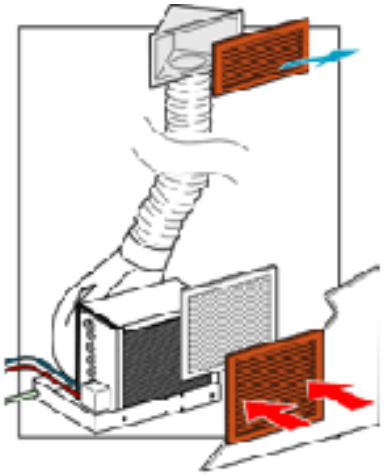
Merits :

- A separate temperature control is provided in each room.
- Ducts are not required for distribution.
- Cost is less.
- Skilled technician is required for installation.

Demerits:

- It makes noise.
- Large hole is made in the external wall or a large opening to be created in the window panel. This leads to insecurity to inmates.
- Air quantity cannot be varied.

Split Type Air conditioner :



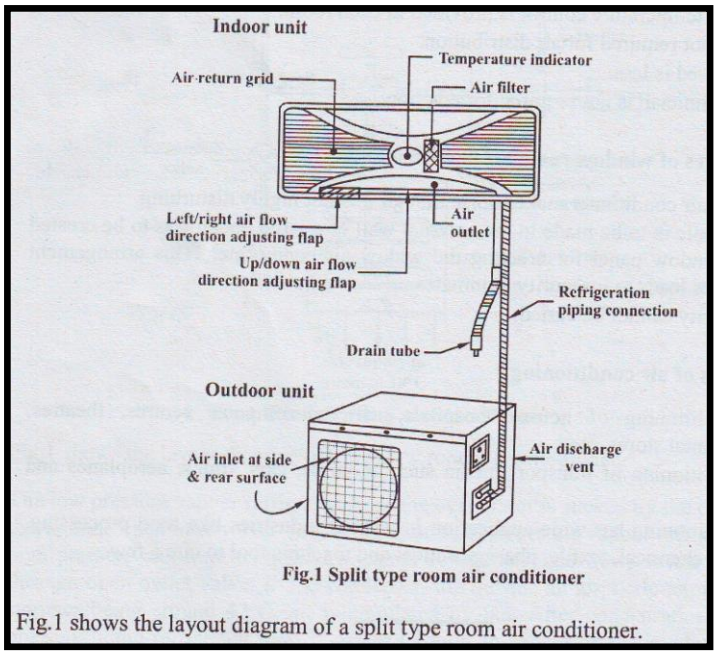


Fig.1 Split type room air conditioner

Fig.1 shows the layout diagram of a split type room air conditioner.

- In split air type air conditioner noise making components like compressor and condenser are mounted outside or away from room.
- Split type air conditioning system has two main components.

(i) Outdoor Unit (ii) Indoor unit.

- The outdoor unit consists of compressor and condenser.
- The indoor unit consists of power cables, refrigerant tube and an evaporator mounted inside the room.
- Compressor is used to compress the refrigerant.
- The refrigerant moves between the evaporator and condenser through the circuit of tubing and fins in the coils.
- The evaporator and condenser are usually made of coil of copper tubes and surrounded by aluminium fins.
- The liquid refrigerant coming from the condenser evaporates in the indoor evaporator coil.
- During this process the heat is removed from the indoor unit air and thus, the room is cooled.
- Air return grid takes in the indoor air.
- Water is dehumidified out of air is drained through the drain pipe.

- The hot refrigerant vapour is passed to the compressor and then to the condenser where it becomes liquid.
- Thus the cycle is repeated.
- A thermostat is used to keep the room at a constant, comfortable temperature avoiding the frequent turning on off.

Merits and Demerits of Split type air conditioner :

Merits :

- It is compact
- Upto four indoor AHU's may be connected to one outdoor unit.
- It is energy and money saving.
- Duct is not used.
- Easier to install.
- It is noiseless, because rotary air compressor used is, kept outside.
- It is more efficient and powerful.
- It has the flexibility for zoning.

Demerits :

- Initial cost is higher than window air conditioner
- Skilled technician is required for installation.
- Each zone or room requires thermostat to control the air cooling

Applications of airconditioning :

- Used in houses, hospitals, offices, computer centres, theatres, departmental stores etc.,
- Air-conditioning of transport media such as buses, cars trains, aeroplanes and ships.
- Wide application in food processing, printing, chemical, pharmaceutical and machine tool, etc.,