MECHANICAL ENGINEERING SCIENCE (UE23ME131A)

Srinivasa Prasad K S

Department of Mechanical Engineering

MECHANICAL ENGINEERING SCIENCE

Unit1

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MECHANICAL ENGINEERING SCIENCE

Chapter 1 – IC Engines and Turbines

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The distinctive feature of our civilization today, one that makes it different from all others, is the wide use of mechanical power. At one time, the primary source of power for the work of peace or war was chiefly man's muscles. Later, animals were trained to help and afterwards the wind and the running stream were harnessed. But, the great step was taken in this direction when man learned the art of energy conversion from one form to another. The machine which does this job of energy conversion is called an ENGINE.

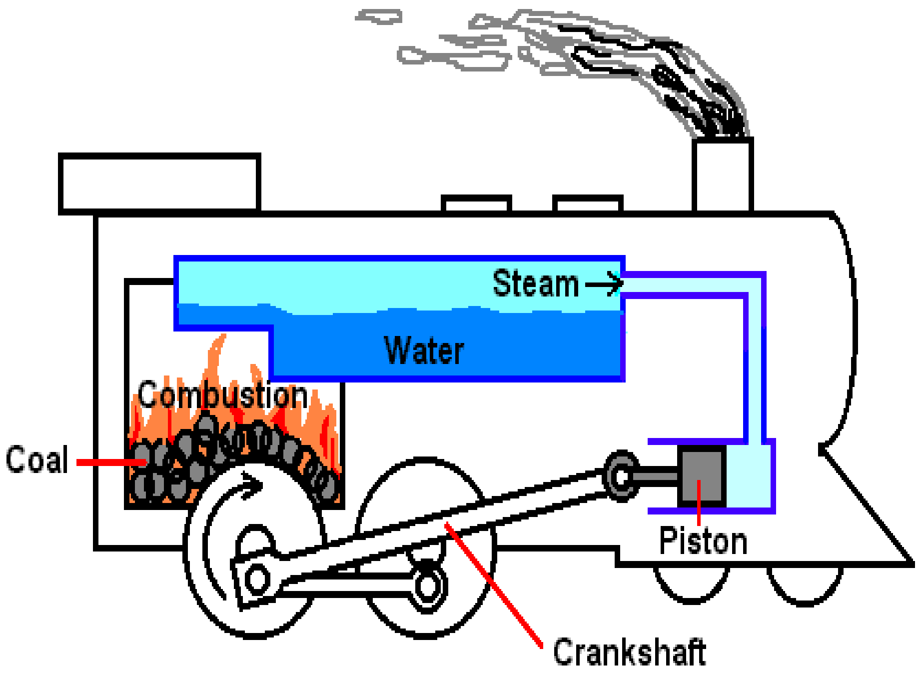
- **ENGINE –** An engine is a device which transforms one form of energy into another form.

- **HEAT ENGINE -** Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine.

- Heat engines can be broadly classified into two categories:
  (i) Internal Combustion Engines (IC Engines)
  (ii) External Combustion Engines (EC Engines)

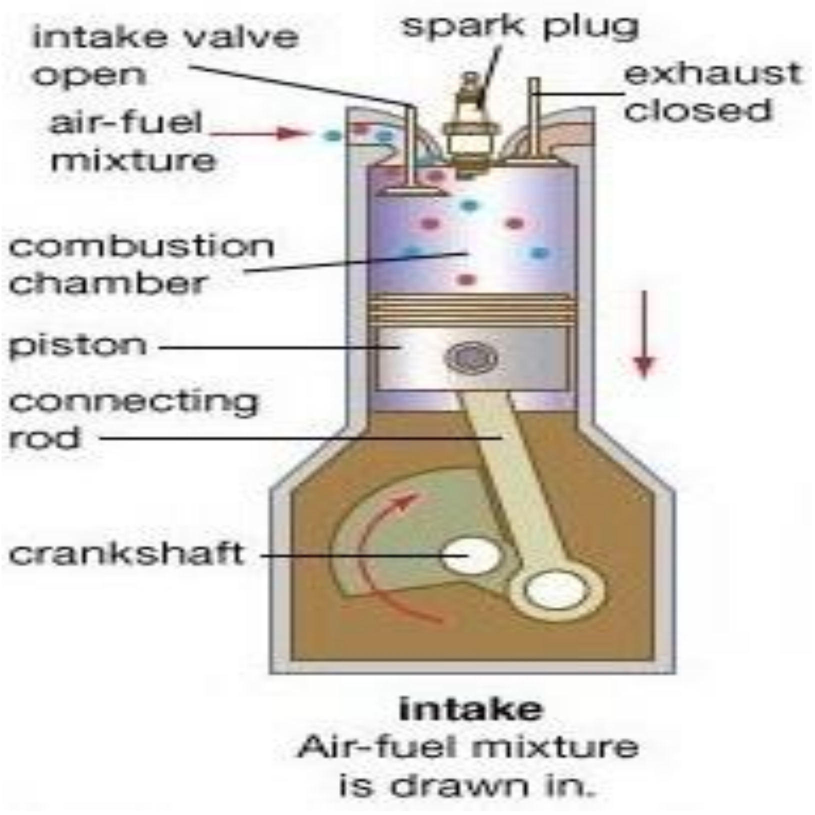
- External combustion engines are those in which combustion takes place outside the engine.

- For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine.



- Internal combustion engines are those in which combustion takes place within the engine.

- For example, in case of petrol or diesel engines, the products of combustion generated by the combustion of fuel and air within the cylinder form the working fluid.



- **CLASSIFICATION OF IC ENGINES -** There are several criteria for classification of I.C. engines. Some of the important criteria can be explained as:
  - Number of strokes per cycle
  - Nature of thermodynamic cycle
  - Ignition systems
  - Fuel used
  - Arrangement of cylinders
  - Cooling systems
  - Fuel supply systems

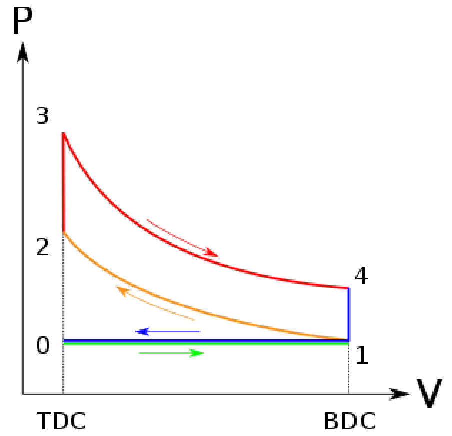
<u>Number of Strokes Per Cycle</u>:

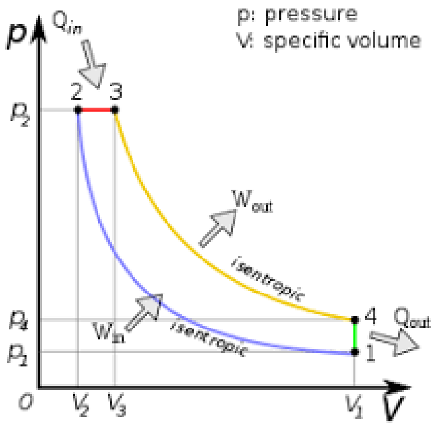
- I.C. engines can be classified as **four-stroke engines (4S)** and **two-stroke engines (2S).**

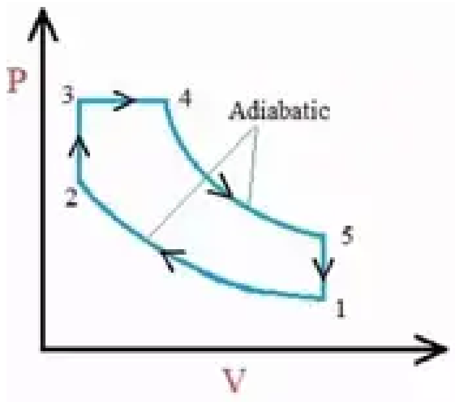
- In four-stroke engines, the thermodynamic cycle is completed in four strokes of the piston or two revolutions of the crankshaft whereas, in two-stroke engines, the thermodynamic cycle is completed in two strokes of the piston or one revolution of the crankshaft.

<u>Nature of Thermodynamic Cycle:</u>

- I.C. engines can be classified as **Otto cycle, Diesel cycle, and Dual cycle engines**.







Ignition Systems:

- There are two modes of ignition of fuel inside the cylinder — **spark ignition** and **compression ignition**.

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

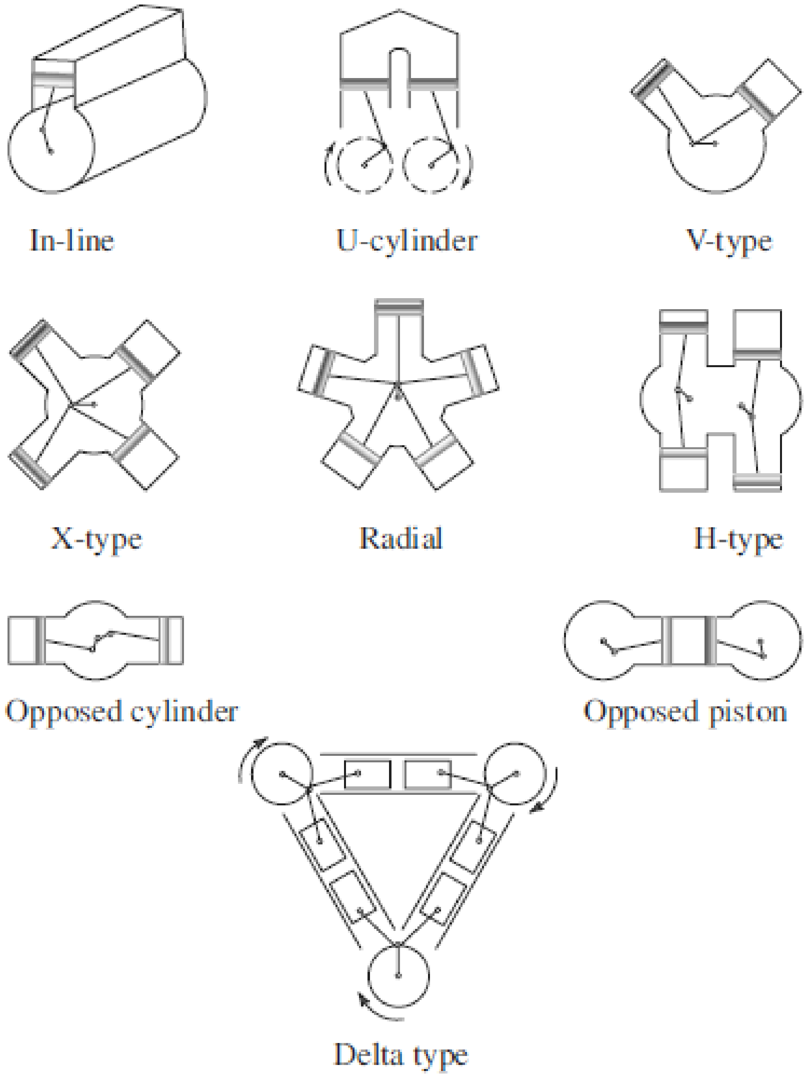
Fuel Used:

- On the basis of fuel used, I.C. Engines can be classified as (a) **Gas engines** like CNG, LPG, etc. (b) **Petrol engine**, (c) **Diesel engine**, and (d) **Bi-fuel engine**. In a bi-fuel engine, two types of fuels are used like gaseous fuel and liquid fuel.

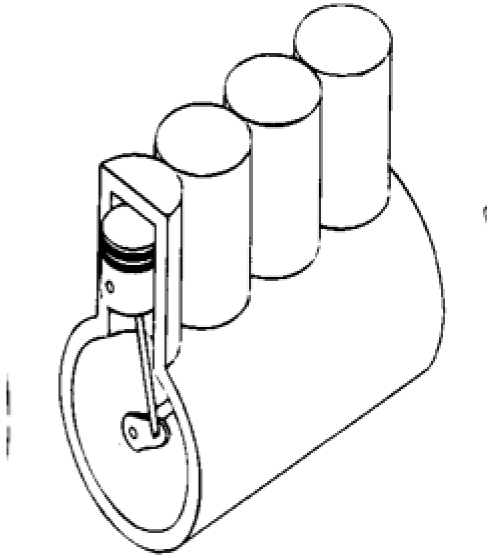
Arrangement of Cylinders:

- Another common method of classifying IC engines is by the cylinder arrangement. The cylinder arrangement is only applicable to multi cylinder engines.

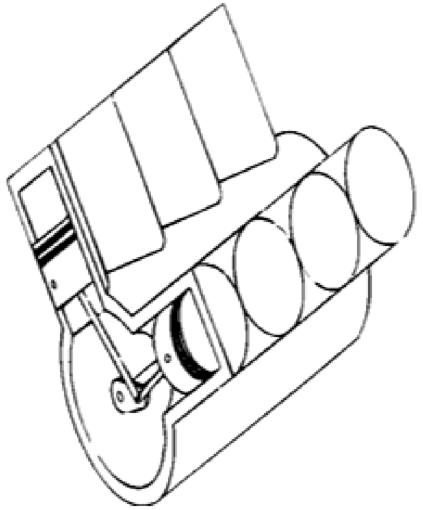
- A number of cylinder arrangements are popular with designers. The details of various cylinder arrangements are shown.



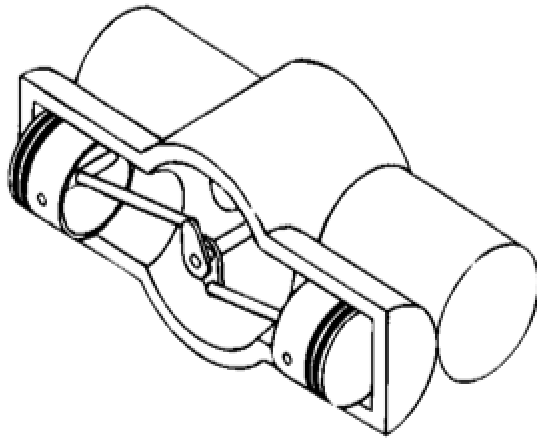
In-line Engine : The in-line engine is an engine with one cylinder bank, i.e. all cylinders are arranged linearly, and transmit power to a single crankshaft. This type is quite common with automobile engines. Four and six cylinder in-line engines are popular in automotive applications.



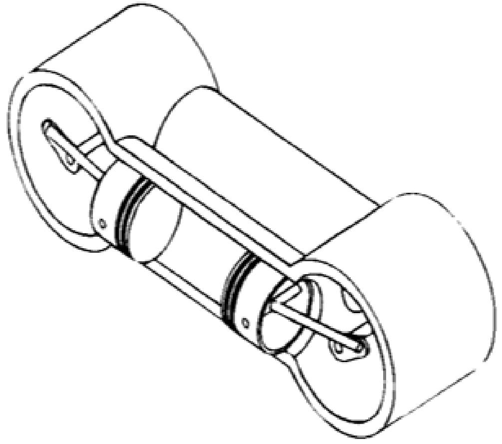
'V' Engine : In this engine there are two banks of cylinders (i.e., two in line engines) inclined at an angle to each other and with one crankshaft. Most of the high powered automobiles use the 8 cylinder 'V' engine, four in-line on each side of the 'V'. Engines with more than six cylinders generally employ this configuration.



Opposed Cylinder Engine : This engine has two cylinder banks located in the same plane on opposite sides of the crankshaft. It can be visualized as two 'in-line' arrangements 180 degrees apart. It is inherently a well balanced engine and has the advantages of a single crankshaft. This design is used in small aircrafts.



Opposed Piston Engine : When a single cylinder houses two pistons, each of which driving a separate crankshaft, it is called an opposed piston engine. The movement of the pistons is synchronized by coupling the two crankshafts. Opposed piston arrangement, like opposed cylinder arrangement is inherently well balanced.



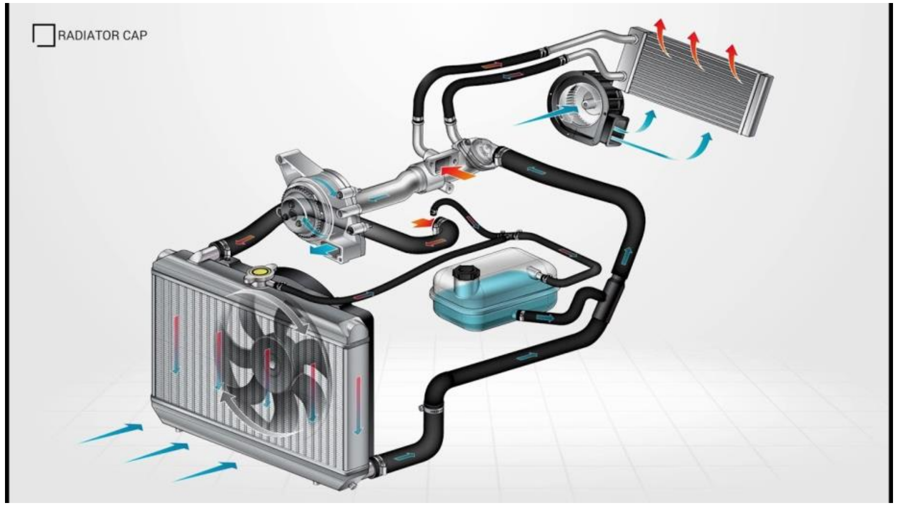
Radial Engine :

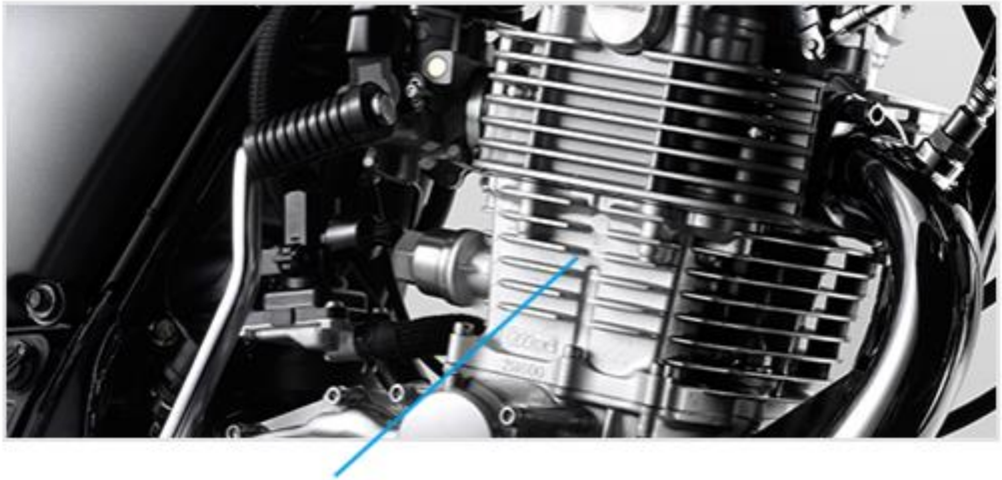
Radial engine is one where more than two cylinders in each row are equally spaced around the crankshaft. The radial arrangement of cylinders is most commonly used in conventional air-cooled aircraft engines. Pistons of all the cylinders are coupled to the same crankshaft.

Cooling Systems:

- There are two types of cooling systems in I.C. Engines—**water cooling** and **air cooling**.

- In water cooling, coolant and radiators are provided to cool the cylinder. In air cooling, fins are provided on the surface of the cylinder to radiate the heat into the atmosphere. Low power engines like motorbikes are equipped with air cooling systems, whereas large power producing engines like a car, bus, truck, etc. are equipped with water cooling systems.





Fins on an air-cooled engine

Fuel Supply Systems:

- On the basis of fuel supply systems, I.C. Engines can be classified as:
  (a) Carburetor engine,
  (b) Air injection engine, and
  (c) Airless or solid or Mechanical injection engines.

- In a carburetor engine, air and fuel are properly mixed into the carburetor and then fed into the cylinder. In air injection engines, fuel is supplied to the cylinder with the help of compressed air. In mechanical injection engines, the fuel is injected into the cylinder with the help of mechanical pump and nozzle.

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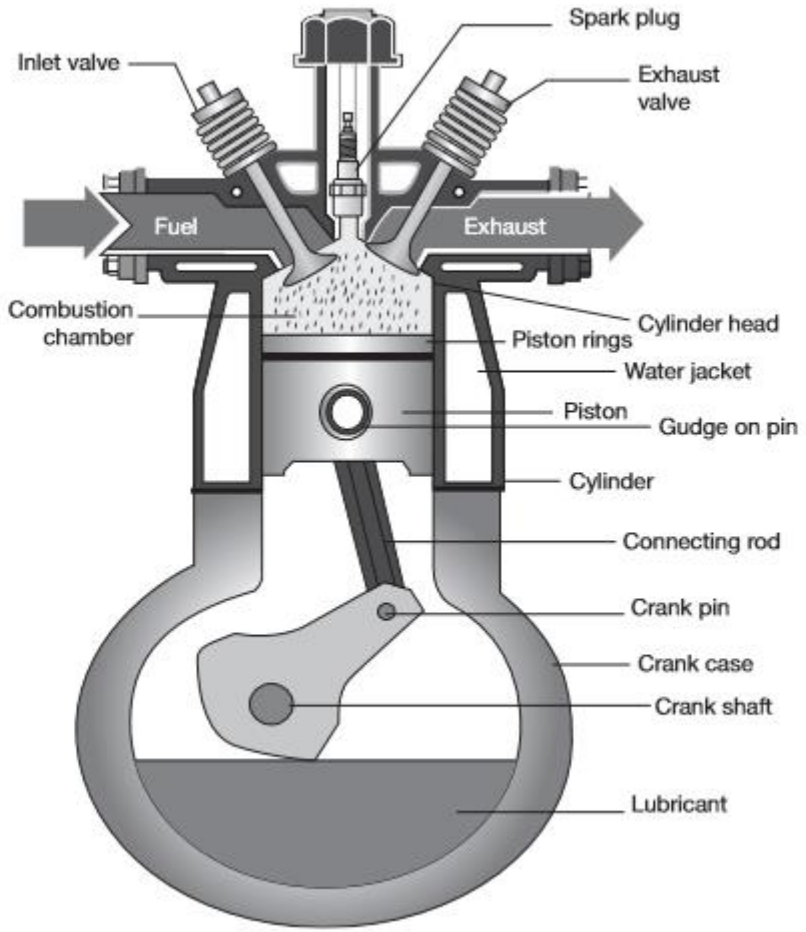
BASIC STRUCTURE OF AN IC ENGINE:

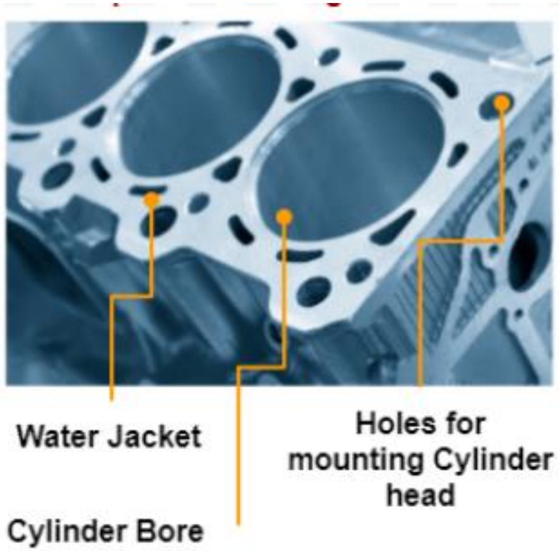


Cylinder:

- It is a hollow cylindrical structure closed at one end with the cylinder head.

- The combustion of the fuel takes place inside the cylinder. This is known as the heart of the engine. It is made of hard and high thermal conductivity materials by casting. A piston reciprocates inside the cylinder and produces power.

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



Piston:

- It is a cylindrical component which is fitted perfectly inside the cylinder providing a gas-tight space with the piston rings and the lubricant.

- The piston is connected to connecting rod by gudgeon pin. The main function of the piston is to transfer the power produced by combustion of the fuel to the crankshaft.

Piston Rings:

- The outer periphery of the piston is provided with several grooves into which piston rings are fitted. The piston is fitted with these rings. The upper ring is known as **compression ring** and the lower rings are known as **oil rings**.

- The function of the compression ring is to compress the air or air-fuel mixture and the function of the oil rings is to collect the surplus lubricating oil on the liner surface.

Connecting Rod:

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

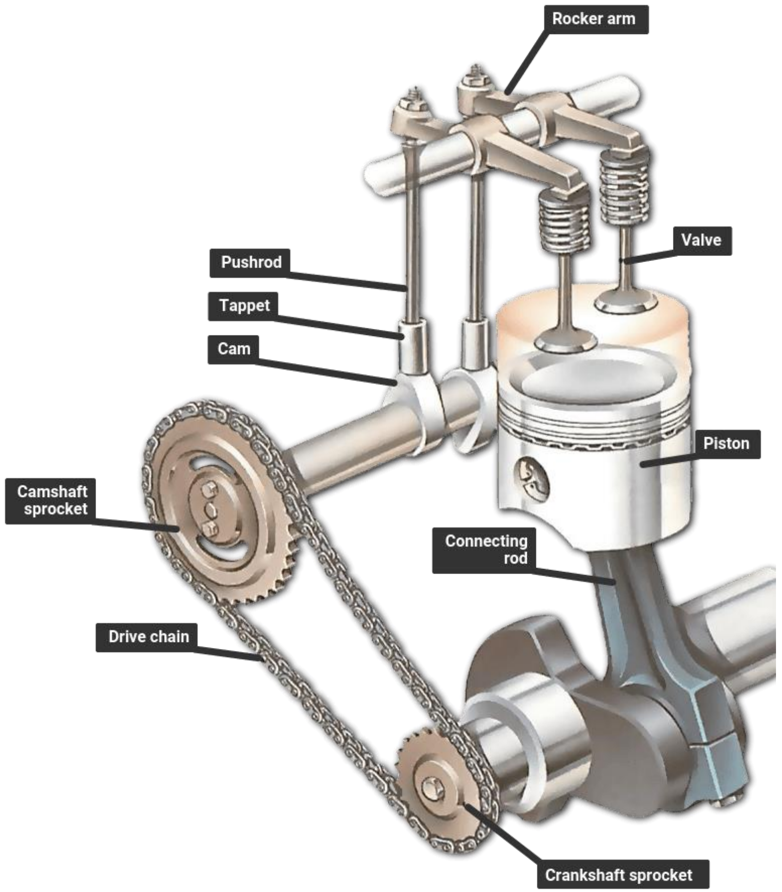
Crankshaft:

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

Valves:

- Normally, the two valves are used for each cylinder, which may be of mushroom shaped poppet type.

- They are provided on the cylinder head for regulating the charge coming into the cylinder and for discharging the products of combustion from the cylinder. The valve mechanism consists of cams, cam follower, push rod, rocker arms, and spring.

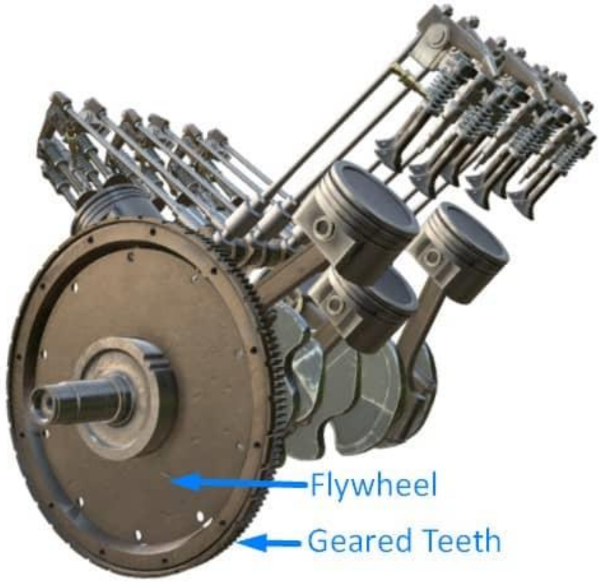


Crankcase:

➢ The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the cylinder block.

Flywheel:

➢ It is a heavy wheel mounted on the crankshaft to minimize the cyclic variations in speed. It absorbs the energy during the power stroke and releases it during the non-power stroke.



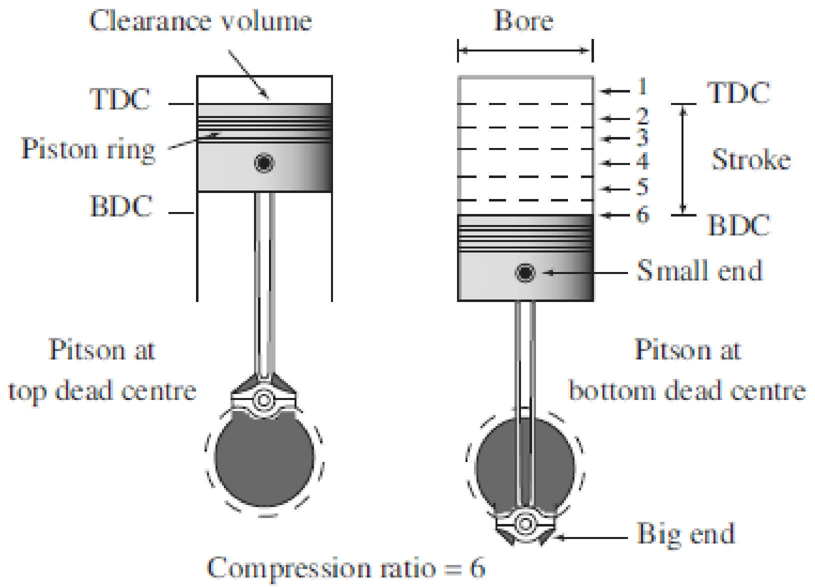
NOMENCLATURE:

Cylinder Bore (d) : The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d.

Piston Area (A) : The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A.

Stroke (L) : The nominal distance through which a working piston moves between two successive reversals of its direction of motion is called the stroke and is designated by the letter L.

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 of the stroke is called the dead centre.



NOMENCLATURE:

There are two dead centres in the engine as indicated in Fig. They are:

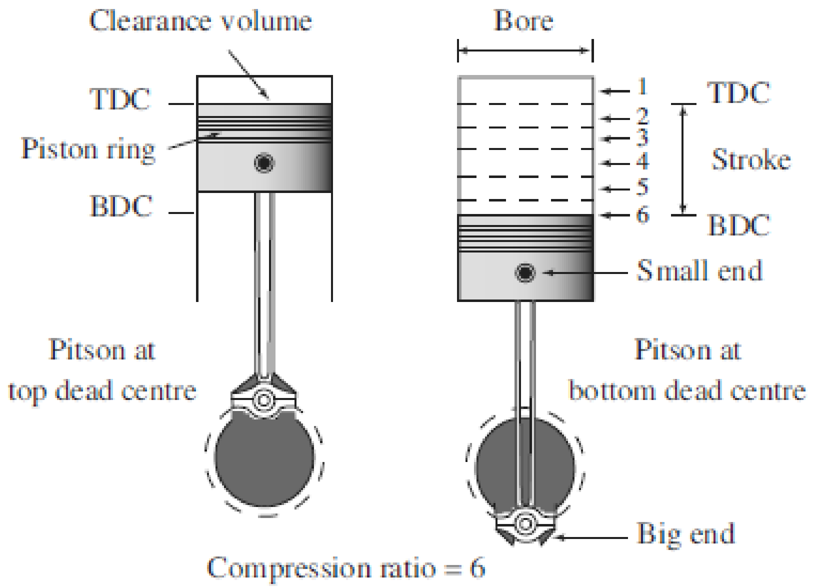
(i) Top Dead Centre (ii) Bottom Dead Centre

(i) Top Dead Centre (TDC) : It is the dead centre when the piston is farthest from the crankshaft.

(ii) Bottom Dead Centre (BDC) : It is the dead centre when the piston is nearest to the crankshaft.

Displacement or Swept Volume (Vs) : The nominal volume swept by the working piston when travelling from one dead centre to the other is called the displacement volume. It is usually expressed in terms of cubic centimeter (cc).

$$V_s = A \times L = \frac{\pi}{4} d^2 L$$

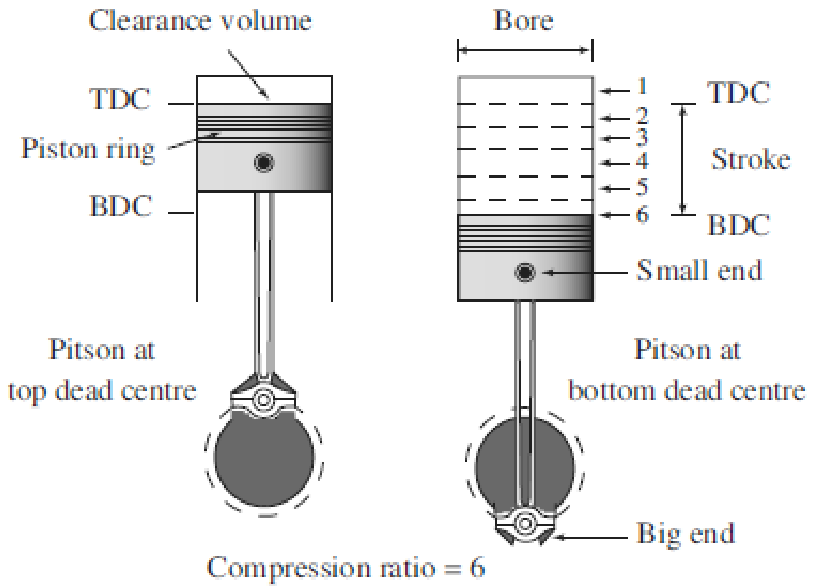


NOMENCLATURE:

Clearance Volume (Vc): The nominal volume of the combustion chamber above the piston when it is at the top dead centre is the clearance volume.

Compression Ratio (r) : It is the ratio of the total cylinder volume when the piston is at the bottom dead centre, Vt , to the clearance volume, Vc.

$$r = \frac{V_T}{V_C} = \frac{V_C + V_s}{V_C} = 1 + \frac{V_s}{V_C}$$



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Chapter 1 – IC Engines and Turbines

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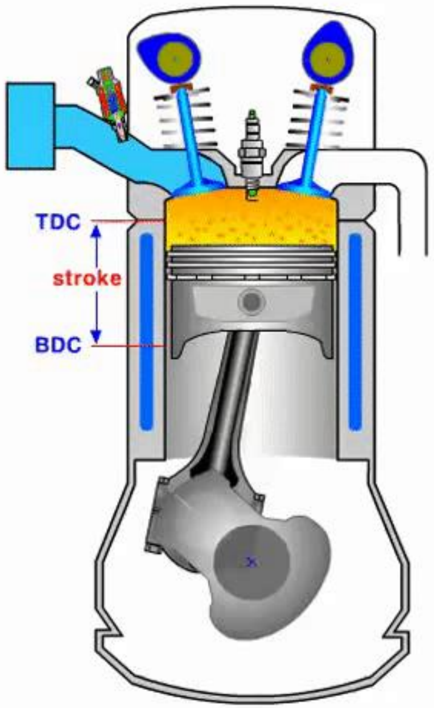
WORKING PRINCIPLE OF 4S PETROL ENGINE (SPARK IGNITION ENGINE)



- In a four-stroke engine, the cycle of operations is completed in **four strokes** of the piston or **two revolutions** of the crankshaft.

- During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation and hence a four-stroke cycle is completed through 720° of crank rotation.

- The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes :
  (i) suction or intake stroke;
  (ii) compression stroke;
  (iii) expansion or power stroke and
  (iv) exhaust stroke.

WORKING PRINCIPLE OF 4S PETROL ENGINE

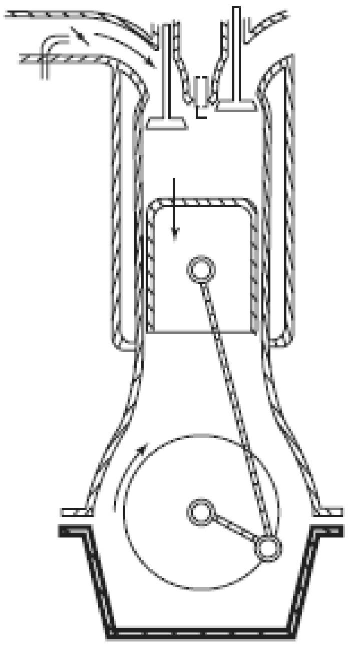
Suction Stroke:

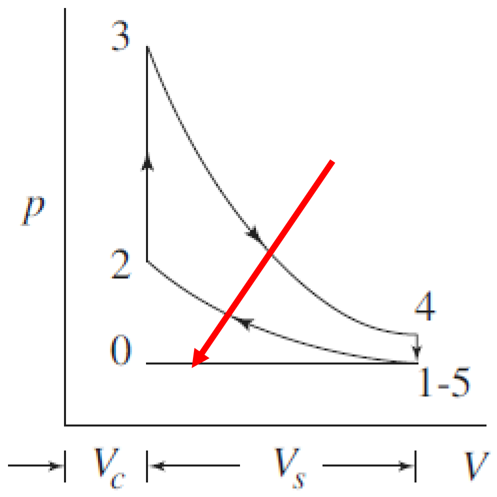
- Suction stroke 0→1 starts when the piston is at the top dead centre and about to move downwards.

- The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position.

- Due to the suction created by the motion of the piston towards the bottom dead centre, the charge consisting of fuel-air mixture is drawn into the cylinder.

- When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.

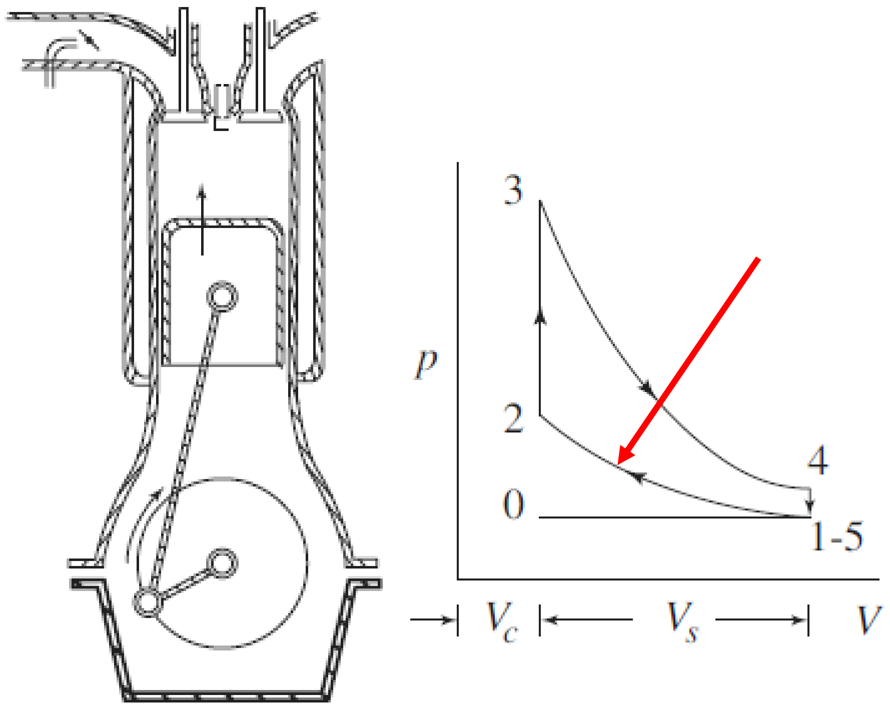




WORKING PRINCIPLE OF 4S PETROL ENGINE

Compression Stroke:

- The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston 1→2.
- During this stroke both inlet and exhaust valves are in closed position.
- The mixture which fills the entire cylinder volume is now compressed into the clearance volume.



WORKING PRINCIPLE OF 4S PETROL ENGINE

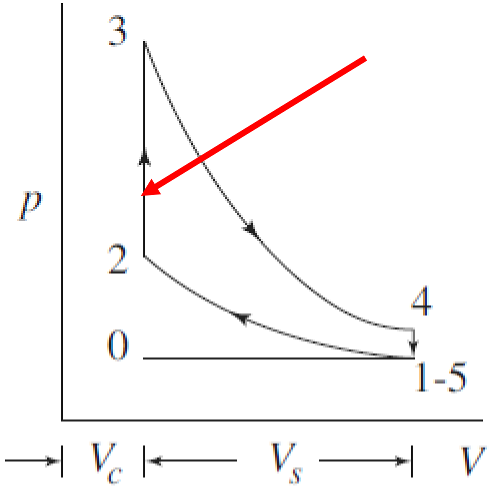
Compression Stroke:

- At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head.

- In ideal engines it is assumed that burning takes place instantaneously when the piston is at the top dead centre and hence the burning process can be approximated as **heat addition at constant volume**.

- During the burning process the chemical energy of the fuel is converted into heat energy producing a temperature rise of about 2000°C (process 2→3).

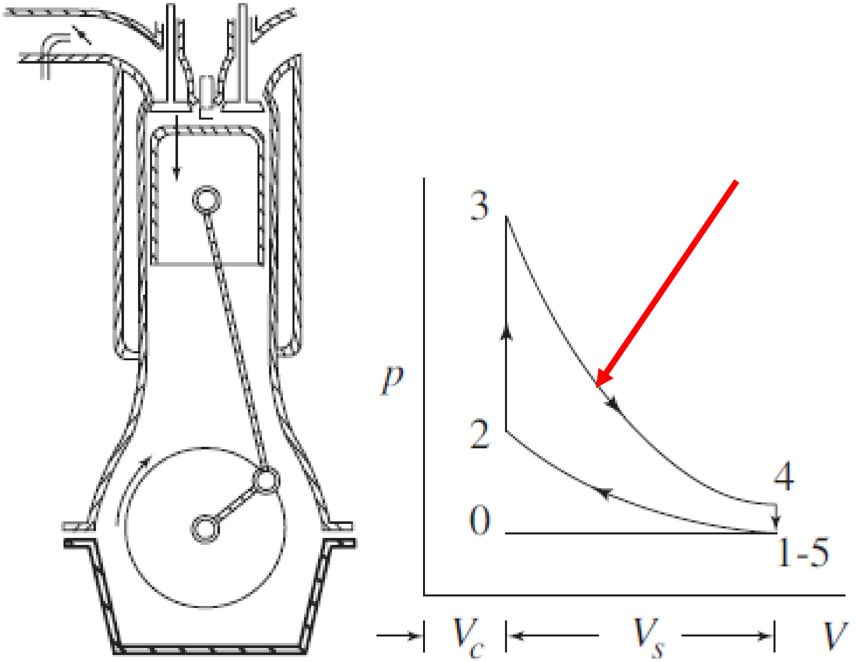
- The pressure at the end of the combustion process is considerably increased due to the heat release from the fuel.



WORKING PRINCIPLE OF 4S PETROL ENGINE

Expansion or Power Stroke :

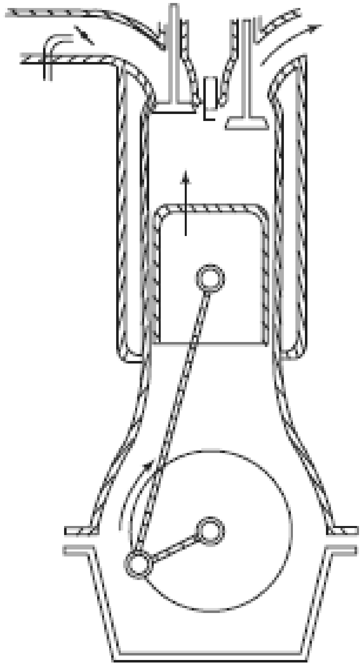
- The high pressure of the burnt gases forces the piston towards the BDC, (stroke 3→4).
- Both the valves are in closed position.
- Of the four-strokes only during this stroke power is produced. Both pressure and temperature decrease during expansion.

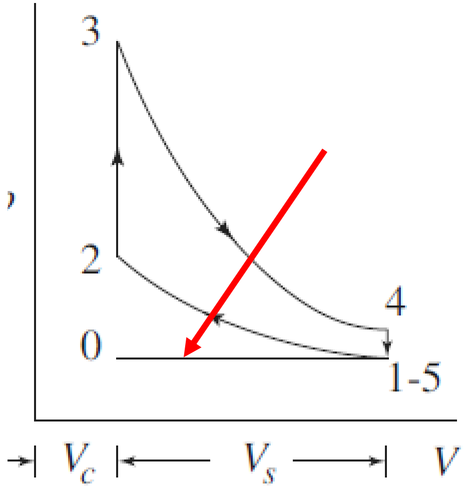


WORKING PRINCIPLE OF 4S PETROL ENGINE

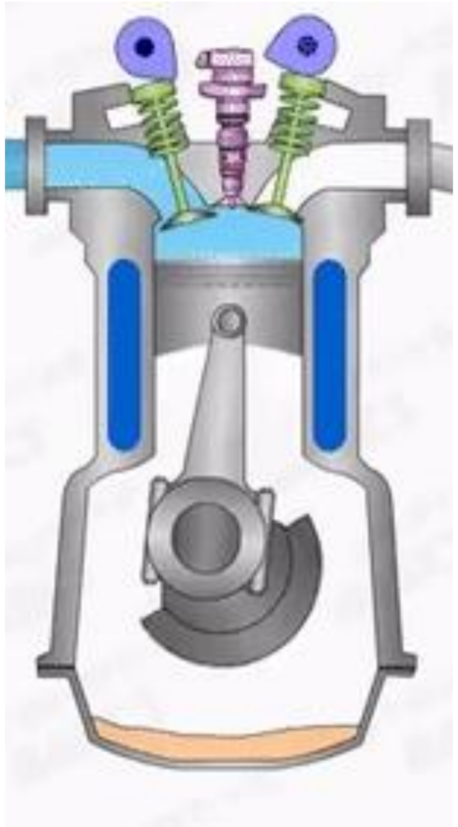
Exhaust Stroke:

- At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed.
- The pressure falls to atmospheric level a part of the burnt gases escape.
- The piston starts moving from the bottom dead centre to top dead centre (stroke 5→0) and sweeps the burnt gases out from the cylinder almost at atmospheric pressure.
- The exhaust valve closes when the piston reaches TDC.





WORKING PRINCIPLE OF 4S DIESEL ENGINE (COMPRESSION IGNITION ENGINE)

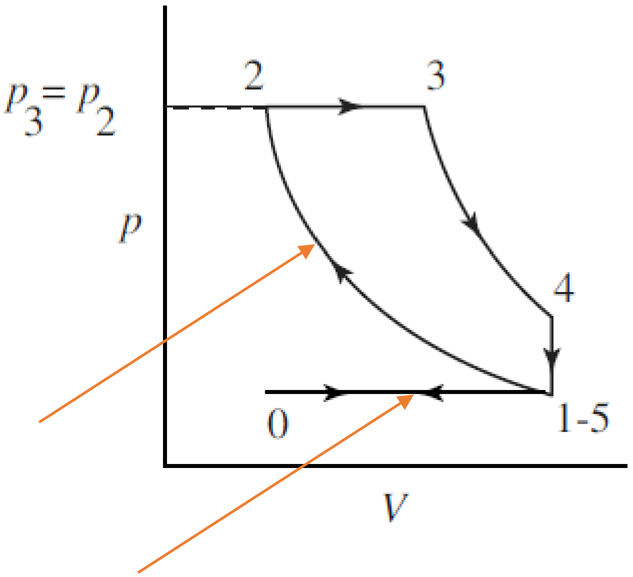


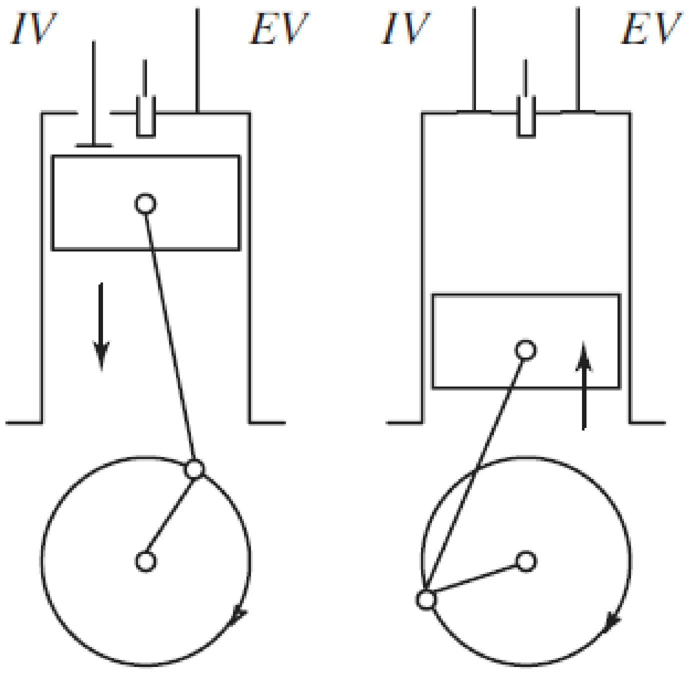
- The four-stroke CI engine is similar to the four-stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a CI engine it is from 16 to 20.
- In the CI engine during suction stroke, air, instead of a fuel-air mixture, is inducted.
- Due to higher compression ratios employed, the temperature at the end of the compression stroke is sufficiently high to self ignite the fuel which is injected into the combustion chamber.
- In CI engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburettor and ignition system necessary in the SI engine are not required in the CI engine.

WORKING PRINCIPLE OF 4S DIESEL ENGINE

Suction Stroke: Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed.

Compression Stroke: Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke.





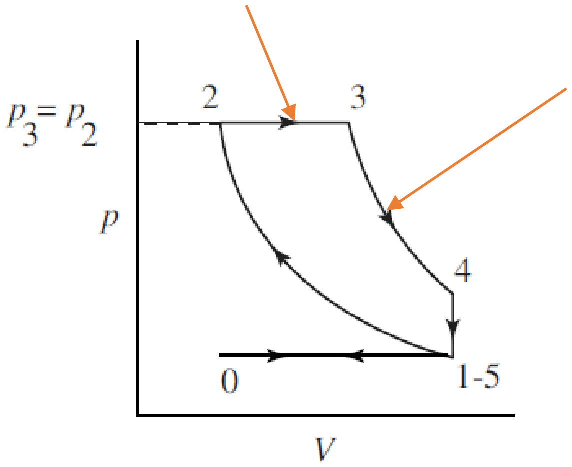
(a) Suction (b) Compression

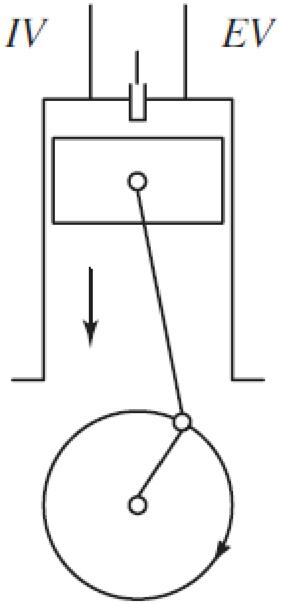
WORKING PRINCIPLE OF 4S DIESEL ENGINE

Expansion Stroke : Fuel injection starts nearly at the end of the compression stroke.

The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at **constant pressure**.

After the injection of fuel is completed (i.e. after cut-off) the products of combustion expand. Both the valves remain closed during the expansion stroke.





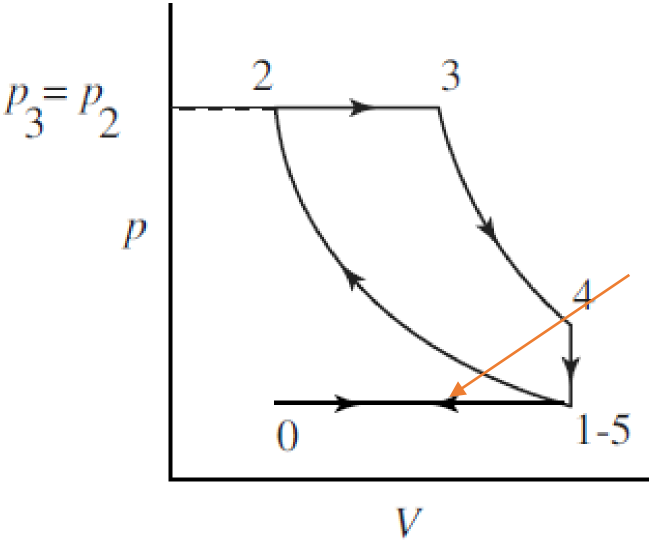
(c) Expansion

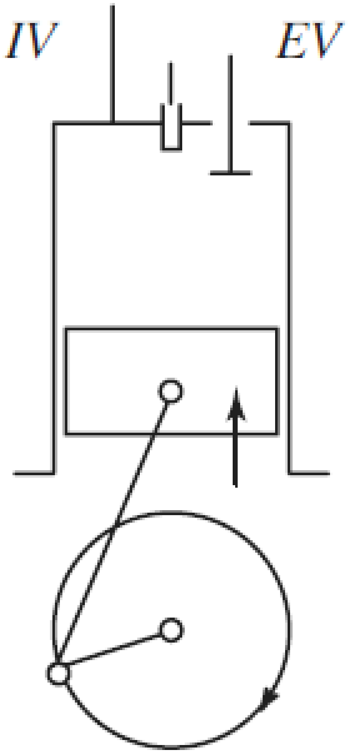
WORKING PRINCIPLE OF 4S DIESEL ENGINE

Exhaust Stroke :

The piston travelling from BDC to TDC pushes out the products of combustion.

The exhaust valve is open and the intake valve is closed during this stroke.





(d) Exhaust

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COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel 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	Petrol, 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 petrol 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.

COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
Ignition	Requires an ignition system with spark plug in the combustion chamber.	Self-ignition occurs due to high temperature of air because of the high compression.
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 they are high speed engines.	Due to heavy weight 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.

COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
Weight	Lighter due to comparatively lower peak pressures.	Heavier due to comparatively higher peak pressures.

APPLICATIONS OF IC ENGINES

- The most important application of IC engines is in transport on land, sea and air. Other applications include industrial power plants and as prime movers for electric generators.

4S Petrol Engines:

- The most important application of small four-stroke petrol engines is in automobiles. A typical automobile is powered by a four-stroke four cylinder engine developing an output in the range of 30-60 kW at a speed of about 4500 rpm.

- Another application of four-stroke petrol engine is in small pumping sets and mobile electric generating sets.

- Smaller aircrafts normally employ four-stroke gasoline (SI) radial engines.

APPLICATIONS OF IC ENGINES

4S Diesel Engines:

- The four-stroke diesel engine is one of the most efficient and versatile prime movers. It is manufactured in sizes from 50 mm to more than 1000 mm of cylinder diameter and with engine speeds ranging from 100 to 4500 rpm while delivering outputs from 1 to 35000 kW.

- Small diesel engines are used in pump sets, construction machinery, air compressors, drilling rigs and many miscellaneous applications.

- Tractors for agricultural application use about 30 kW diesel engines whereas jeeps, buses and trucks use 40 to 100 kW diesel engines.

- Diesel engines are used both for mobile and stationary electric generating plants of varying capacities.

PERFORMANCE PARAMETERS OF IC ENGINES

- The following factors are to be considered in evaluating the performance of an engine:

  (i) **Maximum power or torque** available at each speed within the useful range of speed.

  (ii) **Specific fuel consumption** at each operating condition within the useful range of operation.

  (iii) **Reliability and durability** of the engine for the given range of operation.

- Engine performance characteristics can be determined by the following two methods.

  (i) By using **experimental results** obtained from engine tests.

  (ii) By **analytical calculation** based on theoretical data.

PERFORMANCE PARAMETERS OF IC ENGINES

Engine Power

- The energy flow through the engine is expressed in three distinct terms. They are indicated power, IP, friction power FP and brake power, BP.

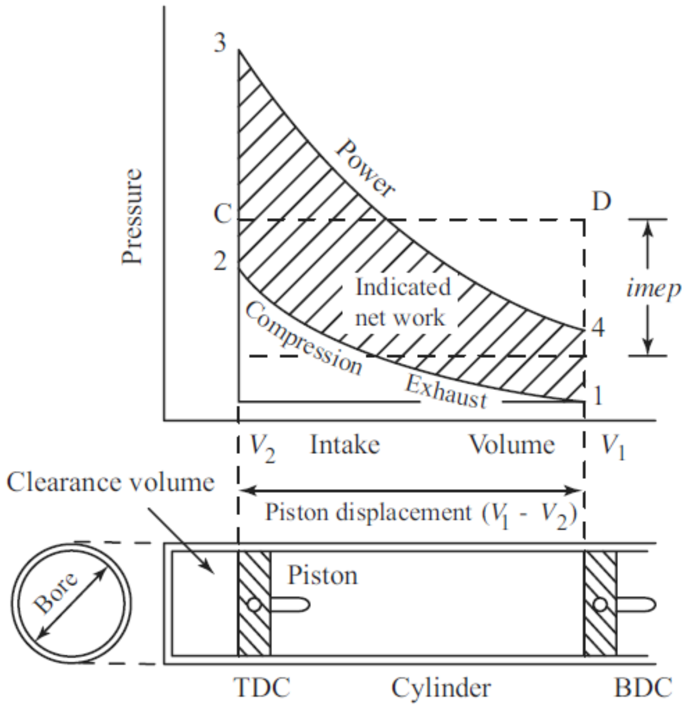
- Indicated power can be computed from the measurement of forces in the cylinder and brake power may be computed from the measurement of forces at the crankshaft of the engine. Friction power can be calculated with the above two values.

i) **Mean Effective Pressure** - It is the average pressure inside the cylinder of an IC engine in one cycle.

PERFORMANCE PARAMETERS OF IC ENGINES

- The net work of the cycle is represented by the area 1234 enclosed by the process lines for that cycle.

- If the area of rectangle ABCD equals area 1234, the vertical distance between the horizontal lines AB and CD represents the mean effective pressure. It is a mean value expressed which, when multiplied by the displacement volume, Vs, gives the same net work as is actually produced with the varying pressures.

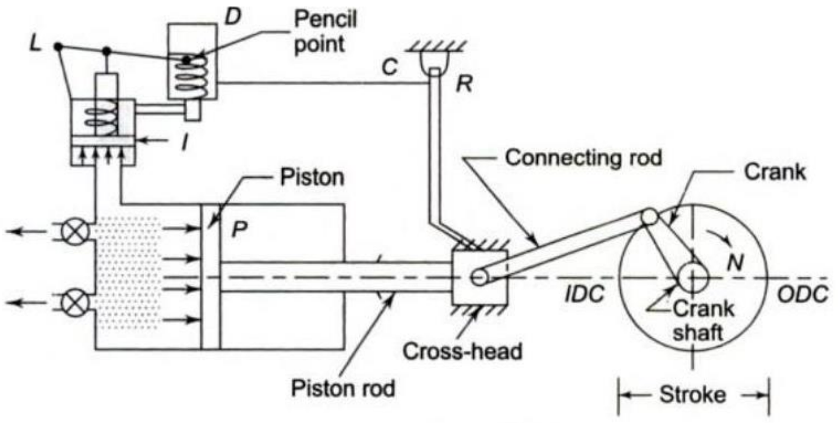


$$p_{im} \times (V_1 - V_2) = \text{Net work of cycle}$$

$$p_{im} = \frac{\text{Net work of cycle}}{V_1 - V_2}$$

PERFORMANCE PARAMETERS OF IC ENGINES

- On an actual engine, the p-V diagram called the indicator diagram is obtained by a mechanical or electrical instrument attached to the cylinder taking into consideration the spring constant.

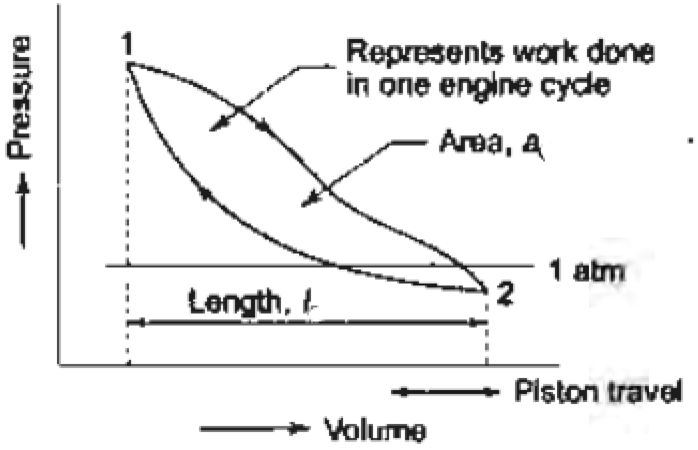


- The area enclosed by the actual cycle on the indicator card may be measured by a planimeter.

- With reference to an indicator diagram, the mean effective pressure can be calculated as,

$$p_m = \frac{sa}{l} \text{ bar}$$

where
s = Spring value of the spring
a = Area of the indicator diagram
l = Length of the indicator diagram



MECHANICAL ENGINEERING SCIENCE (UE23ME131A)

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MECHANICAL ENGINEERING SCIENCE

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Chapter 1 – IC Engines and Turbines

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PERFORMANCE PARAMETERS OF IC ENGINES

ii) Indicated Power - The power developed inside the cylinder of the engine is called the indicated power (IP).

$$IP = \frac{np_m LANK}{60 \times 1000} \qquad (expressed\ in\ kW)$$

where n = number of cylinders
p_m = indicated mean effective pressure in N/m^2
L = Length of stroke in m
A = Cross sectional area of the cylinder in m^2
N = Engine speed in rpm
K = ½ for 4 stroke engine

PERFORMANCE PARAMETERS OF IC ENGINES

iii) Brake Power – It is the net power available at the crank shaft of the engine for performing useful work (BP).

- It is always less than indicated power since a part of the power developed in the engine cylinder is used to overcome the frictional losses at different moving parts of the engine.

- Brake power of an engine can be determined by a brake of some kind applied to the brake pulley of the engine. The arrangement used for determination of BP of the engine is known as dynamometer. Usually, **rope brake dynamometer** is used for this purpose.

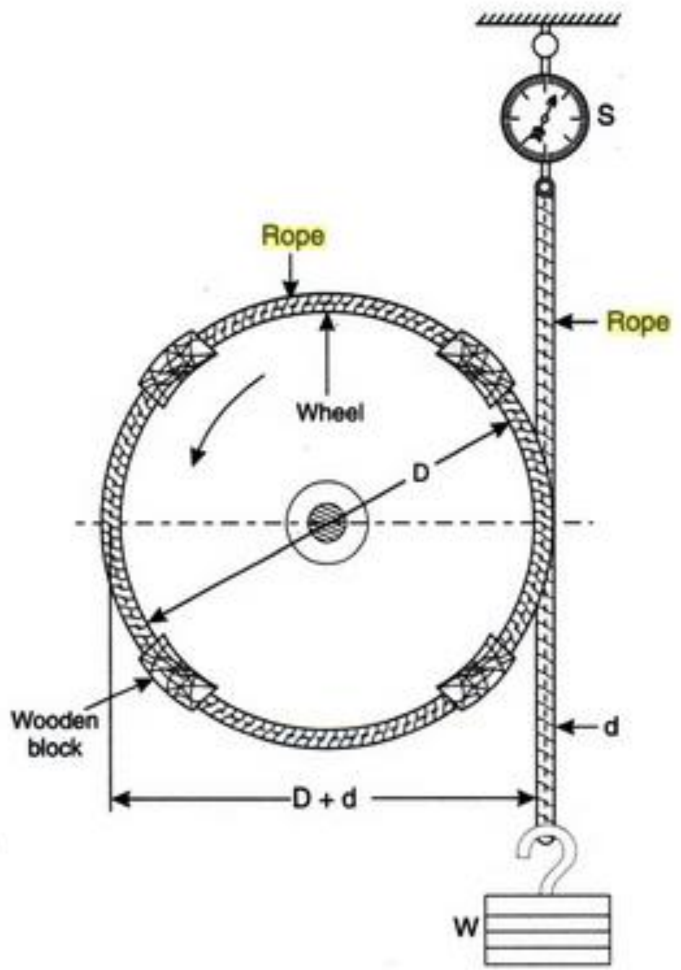
- BP is given by,

$$BP = \frac{2\pi NT}{60\times 1000} \qquad (expressed\ in\ kW)$$

where
N = Crank speed in rpm; T = Torque in N-m

PERFORMANCE PARAMETERS OF IC ENGINES

- The rope brake dynamometer consists of rope wrapped round the brake drum or flywheel keyed to crankshaft of an engine whose BP is to be determined.
- One end of the rope is connected to the spring balance (with reading ‘S’) while at the other end is hung a weight W.
- Wooden blocks are incorporated to check the rope slipping off the brake drum/flywheel.
- It is evident from the figure that the net brake load which opposes the rotation is (W-S) and the effective radius at which the net load acts = (D+d)/2, where D is the diameter of the brake drum and d is the diameter of the rope.



PERFORMANCE PARAMETERS OF IC ENGINES

- Therefore,

∴ Braking torque,

$$T = \text{Frictional force} \times \text{radius} = (W - S)\left(\frac{D+d}{2}\right) \text{ Nm.}$$

$$\therefore \quad \text{Brake power, B.P.} = \frac{(W-S)\pi(D+d)N}{60 \times 10^3} \text{ kW}$$

PERFORMANCE PARAMETERS OF IC ENGINES

iv) Friction Power – It is the difference between the indicated power and brake power.

$$FP = IP - BP$$

- Apart from expressing engine performance in terms of power, it is also essential to express in terms of efficiencies.

v) Mechanical efficiency - Mechanical efficiency takes into account the mechanical losses in an engine like friction losses in case of pistons, bearings, gears, valve mechanisms, losses due to absorption of power by fuel pump, oil pump, radiator etc. In general, mechanical efficiency of engines varies from 65 to 85%.

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

$$\eta_{mech} = \frac{Brake\ power\ (BP)}{Indicated\ power\ (IP)}$$

PERFORMANCE PARAMETERS OF IC ENGINES

vi) Thermal efficiency – It gives an idea of the output generated by the engine with respect to heat supplied in the form of fuel.

- Thermal efficiency is expressed in two ways, viz., **indicated thermal efficiency** and **brake thermal efficiency.**

- **Indicated thermal efficiency =** $\eta_{ith} = \dfrac{IP}{CV \times m_f}$

- **Brake thermal efficiency** = $\eta_{bth} = \dfrac{BP}{CV \times m_f} \times 100$

CV is the calorific value of the fuel in KJ/kg and m_f is mass flow rate of the fuel in kg/s. IP and BP are in kW.

PERFORMANCE PARAMETERS OF IC ENGINES

vii) Specific fuel consumption – It is the mass of fuel consumed per kW of power developed per hour and is a criterion of economical power production.

- Specific fuel consumption is expressed in two ways, viz., **indicated specific fuel consumption (ISFC)** and **brake specific fuel consumption (BSFC).**

- **ISFC** = $\frac{Mass\ of\ fuel\ consumed\ in\ kg/hr}{Indicated\ Power\ in\ kW}$

- **BSFC** = $\frac{Mass\ of\ fuel\ consumed\ in\ kg/hr}{Brake\ Power\ in\ kW}$

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PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

1) The following data refers to a test on a single cylinder engine working on four stroke cycle:

Diameter of brake drum = 60 cm
Rope diameter = 3 cm
Load on brake drum = 25 kg
Spring balance reading = 5 kg
Speed of engine = 400 rpm
Area of indicator diagram = 4 cm^2
Length of indicator diagram = 6 cm
Spring stiffness = 12 bar/cm
Bore = 10 cm
Stroke = 15 cm

Calculate (i) Indicated Power (ii) Brake Power (iii) Mechanical Efficiency

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution: Data: d = 10 cm = 0.1 m; L = 15 cm = 0.15 m, s = 12 bar/cm, a = 4 cm^2, l = 6 cm, N = 400 rpm, Diameter of brake drum = D_b = 60 cm = 0.6 m, Diameter of rope = d_r = 3 cm = 0.03 m

1) Indicated Power (IP)

Mean effective pressure = $p_m = \frac{sa}{l} = \frac{12\times4}{6} = 8\ bar$

Indicated Power = $IP = \frac{np_mLANK}{60\times1000} = \frac{1\times8\times10^5\times0.15\times\frac{\pi}{4}\times(0.1^2)\times400\times(\frac{1}{2})}{60\times1000} = 3.141\ kW$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

2) Brake Power (BP)

$$\text{Torque} = T = (W - S) \times \left(\frac{D_b + d_r}{2}\right) = (25 - 5) \times 9.81 \times \left(\frac{0.6+0.03}{2}\right) = 61.803\ Nm$$

$$\text{Brake Power} = BP = \frac{2\pi NT}{60\times1000} = \frac{2\times\pi\times400\times61.803}{60\times1000} = 2.589\ kW$$

3) Mechanical Efficiency

$$\eta_{mech} = \frac{BP}{IP} = \frac{2.589}{3.141} = 0.8241\ or\ 82.41\%$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

2) The following observations are taken during a trial on four stroke diesel engine.

Cylinder diameter = 25 cm
Stroke = 40 cm
Speed = 250 rpm
Brake load = 70 kg
Brake drum diameter = 2m
Mean effective pressure = 6 bar
Diesel oil consumption = 0.1 litres/min
Specific gravity of fuel = 0.78
Calorific value of fuel = 43900 kJ/kg

Determine (i) Indicated Power (ii) Brake Power (iii) Mechanical efficiency (iv) Brake thermal efficiency (v) Indicated thermal efficiency.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

1) Indicated Power (IP)

We know that Indicated Power is given by,

$$IP = \frac{nP_mLANK}{60000} = \frac{1\times6\times10^5\times40\times10^{-2}\times\frac{\pi}{4}\times(25\times10^{-2})^2\times250\times1/2}{60000} = 24.54kW$$

2) Brake Power

We know that brake power is given by

$$BP = \frac{2\pi NT}{60000} = \frac{2\times\pi\times250\times70\times9.81\times1}{60000} = 17.98\ kW$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

3) Mechanical efficiency

We know that mechanical efficiency is given by,

$$\eta_{mech} = \frac{BP}{IP} = 73.3\%$$

4) Brake Thermal Efficiency

We know that brake thermal efficiency is given by,

$$\eta_{Bth} = \frac{BP}{m_f \times CV} = \frac{17.98}{\frac{0.1\times0.78\times1000}{1000\times60}\times43900} = 31.5\%$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

5) Indicated Thermal Efficiency

We know that indicated thermal efficiency is given by,

$$\eta_{Ith} = \frac{IP}{m_f \times CV} = \frac{24.54}{\frac{0.1\times0.78\times1000}{1000\times60}\times 43900} = 43\%$$

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PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

3) A four cylinder four stroke petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on each piston is 8 bar and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We know that,

$$\eta_{mech} = \frac{BP}{IP}$$

Therefore,

$$IP = \frac{BP}{\eta_{mech}} = \frac{30}{0.8} = 37.5\ kW$$

Also, $IP = \frac{n p_m L A N K}{60 \times 1000}$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

$$37.5 = \frac{4 \times 8 \times 10^5 \times L \times (\frac{\pi}{4} d^2) \times 2500 \times (\frac{1}{2})}{60 \times 1000}$$

$$7.16 \times 10^{-4} = Ld^2$$

From data, L/d = 1.5 or L = 1.5d

Therefore,

$$7.16 \times 10^{-4} = (1.5d)d^2$$

This gives, d = 0.078 m = 78 mm; L = 1.5d = 117 mm

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

4) A diesel engine develops 5 kW. Its indicated thermal efficiency is 30% and mechanical efficiency is 75%. Estimate the fuel consumption of the engine in a) kg/hr and b) litres/hr. Also find ISFC and BSFC. Take CV of fuel = 42000 kJ/kg and specific gravity of fuel = 0.87.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We have,

$$\eta_{mech} = \frac{BP}{IP}$$

$$Therefore, IP = \frac{BP}{\eta_{mech}} = \frac{5}{0.75} = 6.67kW$$

We know that,

$$\eta_{ITH} = \frac{IP}{m_f \times CV}$$

$$Therefore, m_f = \frac{IP}{\eta_{ITH} \times CV}$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We have,

$$\eta_{mech} = \frac{BP}{IP}$$

$$Therefore, IP = \frac{BP}{\eta_{mech}} = \frac{5}{0.75} = 6.67 kW$$

We know that,

$$\eta_{ITH} = \frac{IP}{m_f \times CV}$$

$$Therefore, m_f = \frac{IP}{\eta_{ITH} \times CV}$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

So,

$$m_f = \frac{6.67}{0.3 \times 42000} = 5.293 \times 10^{-4}\, kg/s = 1.9057\, kg/hr$$

To get fuel consumption in litres/hr,

$$m_f = \frac{1.9057}{0.87 \times 1000} = 2.1905 \times 10^{-3}\, m^3/hr$$

$$= 2.1905 \times 10^{-3} \times 1000 = 2.1905\ litres/hr$$

$$ISFC = \frac{m_f}{IP} = \frac{1.9057}{6.67} = 0.2857\, kg/kWhr$$

$$BSFC = \frac{m_f}{BP} = \frac{1.9057}{5} = 0.3811\, kg/kWhr$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

5) A six cylinder 4 stroke IC engine develops 50 kW of indicated power at MEP of 700 kPa. The bore and stroke length are 70 mm and 100 mm respectively. If the engine speed is 3700 rpm. Determine the average misfires per unit time.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

Misfire means that one or more of the cylinders are not igniting the fuel mixture at the right time like it should. This occurs due to the malfunctioning of the fuel injector/spark plug or due to insufficient compression in the cylinder.

We know that,

$$IP = \frac{np_m LANK}{60 \times 1000}$$

Therefore,

Theoretical engine speed = $N = \frac{IP\times60\times1000}{np_m LAK} = \frac{50\times60\times1000}{6\times700\times10^3\times0.1\times\frac{\pi}{4}\times(0.07^2)\times(\frac{1}{2})} = 3712\ rpm$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

For a 4S engine, number of cycles/min or number of explosions/min = N/2 = 3712.07/2 = 1856

Actual explosions/min = N'/2 = 3700/2 = 1850

Therefore, number of misfires = 1856 – 1850 = 6

Approximately number of misfires/min = 6

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Chapter 1 – IC Engines and Turbines

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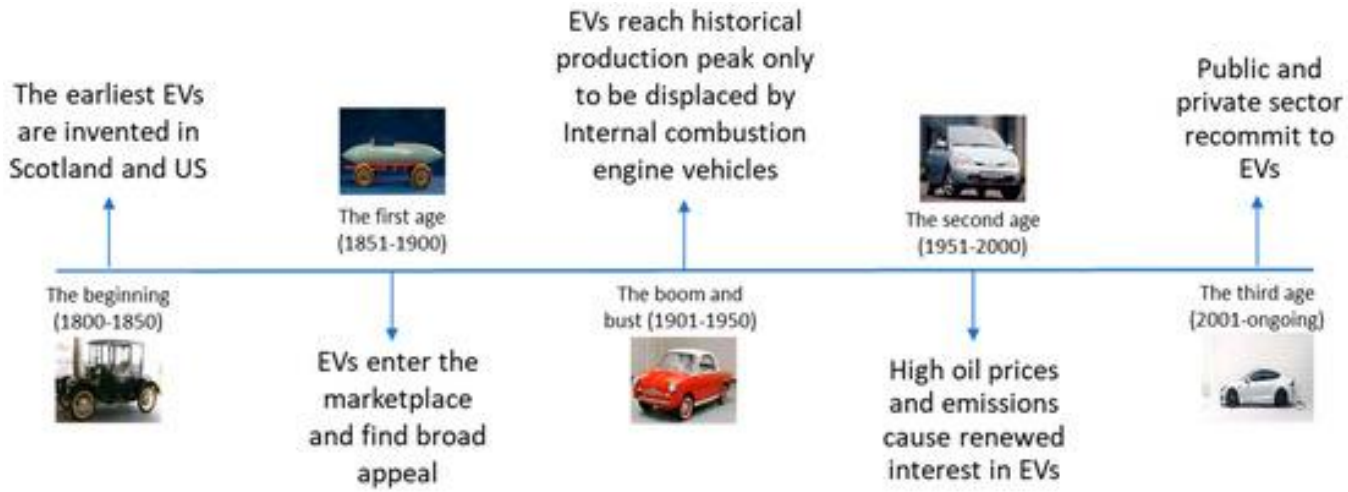
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

- The issues like global warming, depleting fossil fuel reserves, and greenhouse gas (GHG) emissions need dire attention for ensuring a sustainable future.

- Because the transportation sector is one of the largest contributors to the rising harmful emissions, the electrification of transportation is seen as a promising solution for this problem.

History of Electric Vehicles –

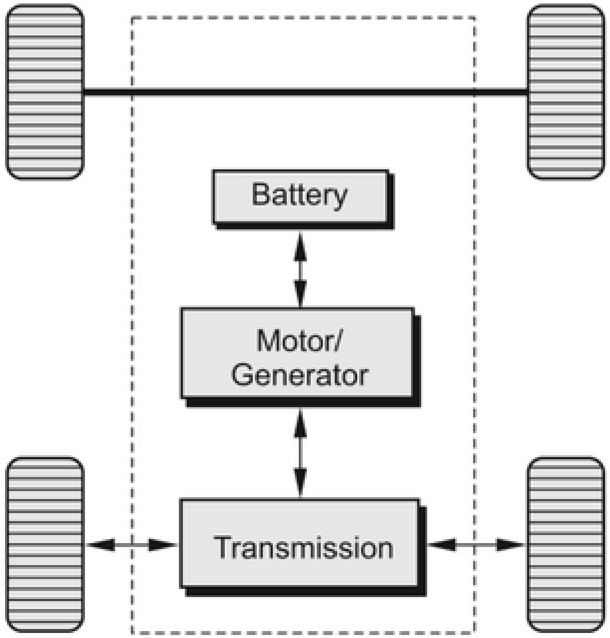


INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

- Electric vehicles are defined as vehicles which use an electric motor for propulsion.

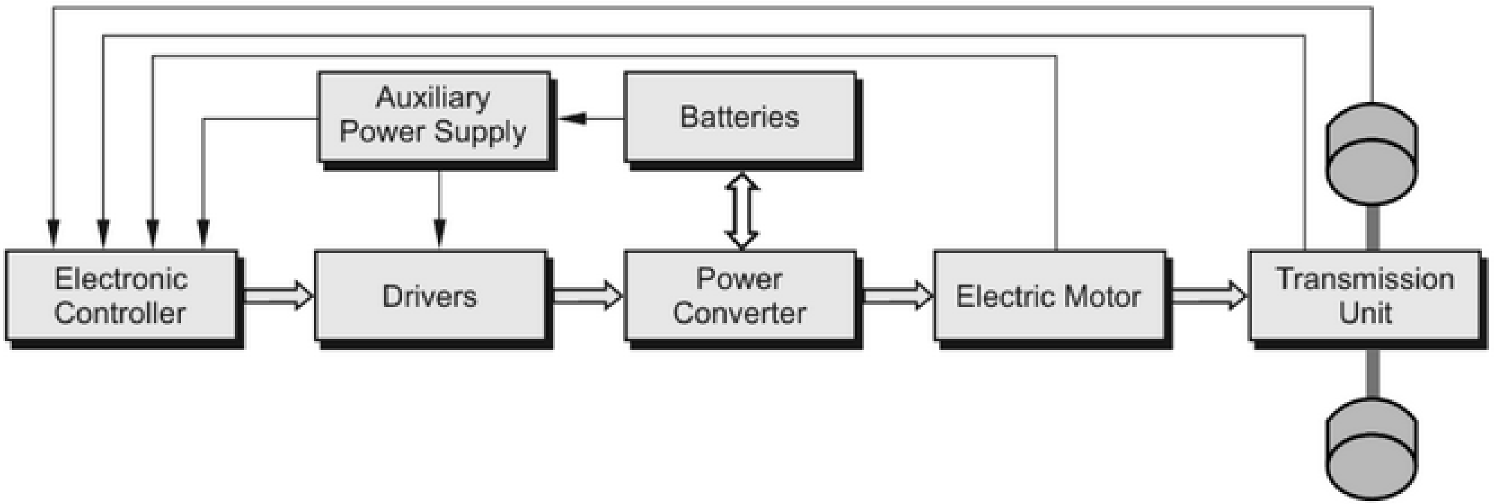
- They are propelled by one or more electric motors, receiving power from an onboard source of electricity such as batteries, fuel cells, ultra capacitor, flywheel etc.

- EVs include a large range of vehicles from electric two wheelers, three wheelers (rickshaws), cars and electric buses and trucks.



INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:



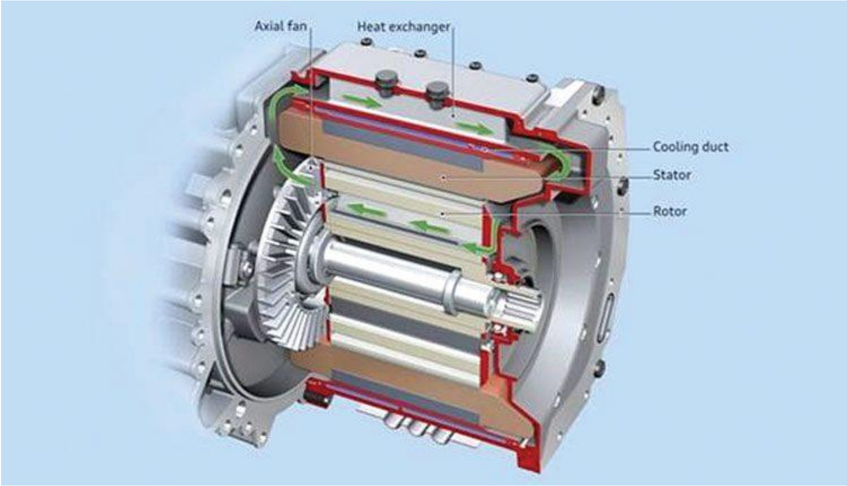
- An electric vehicle consists of a battery that provides energy, an electric motor that drives the wheels and a controller that regulates the energy flow to the motor. There are no gear box and clutch in these vehicles.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

Motor –

- The prime mover in electric vehicle is the high torque electric motor.
- It converts the energy stored in the power pack into mechanical motion. The power is directly delivered to the wheels or through the transaxle that propels the vehicle.
- While braking, it acts like a generator (regenerative braking) and recharges the batteries.

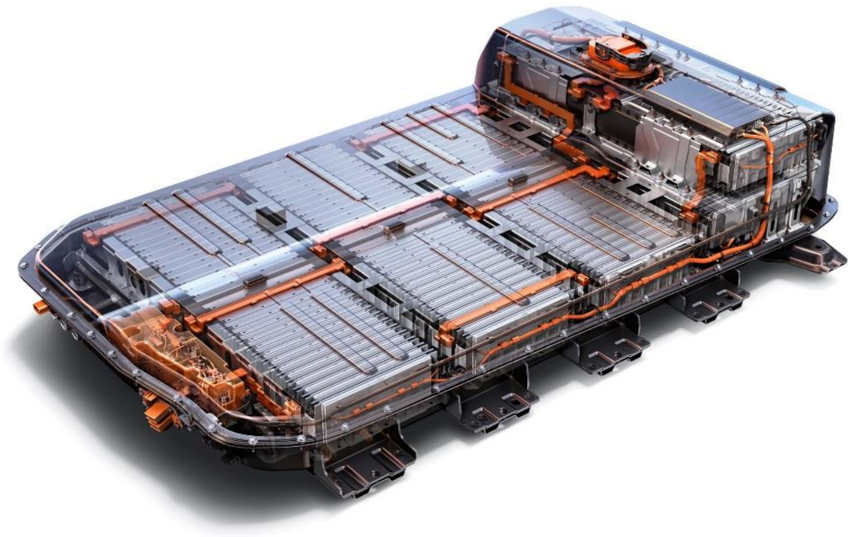


INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

Power pack (Battery) –

- Automobile manufacturers use three types of rechargeable batteries. Those are lead acid batteries, nickel metal hydride (NiMH) batteries and lithium ion (Li – ion) batteries.



Charger –

- EVs have an on – board charger, which converts AC into DC power to charge the power pack.

Controller -

- EVs also have a computerized motor controller. This regulates the flow of energy from the power pack to the motor in direct relation to the pressure applied on the accelerator.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

DC/DC converter –

- A 12V auxiliary battery is normally used in an electric car to power all 12V accessories such as lights, horn etc. EVs use a DC/DC converter which taps the full battery pack voltage and cuts it down to a regulated 13.5 V output similar to an alternator.

Energy Management System –

- The brain of EVs is the energy management system that monitors and controls all required functions.

- It is a computer based system that optimizes charging and energy output of batteries to maximize operating range and improve performance.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Classification of EVs –

- There are 3 types of electric vehicle:

i) Battery Electric Vehicle (BEV)

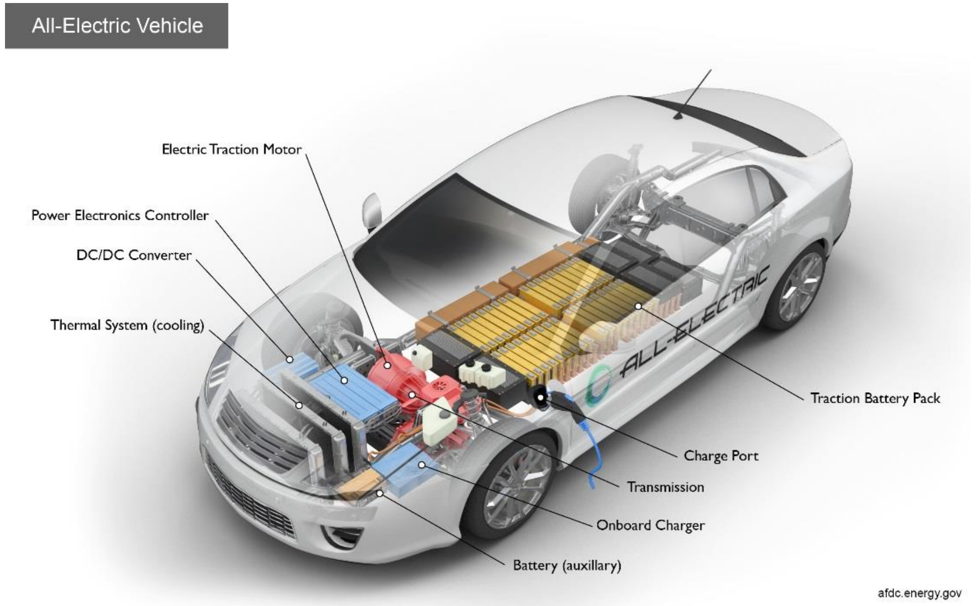
ii) Hybrid Electric Vehicle (HEV)

iii) Plug in Hybrid Electric Vehicle (PHEV)

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Battery Electric Vehicle (BEV) –

- A battery electric vehicle (BEV) runs entirely using an electric motor and battery, without the support of a traditional internal combustion engine and must be plugged into an external source of electricity to recharge its battery.
- BEVs can also recharge their batteries through a process known as regenerative braking, which uses the vehicle's electric motor to assist in slowing the vehicle and to recover some of the energy normally converted to heat by the brakes.
- Examples – Tesla Model S Nissan Leaf, BMW i3, Mitsubishi iMi etc.



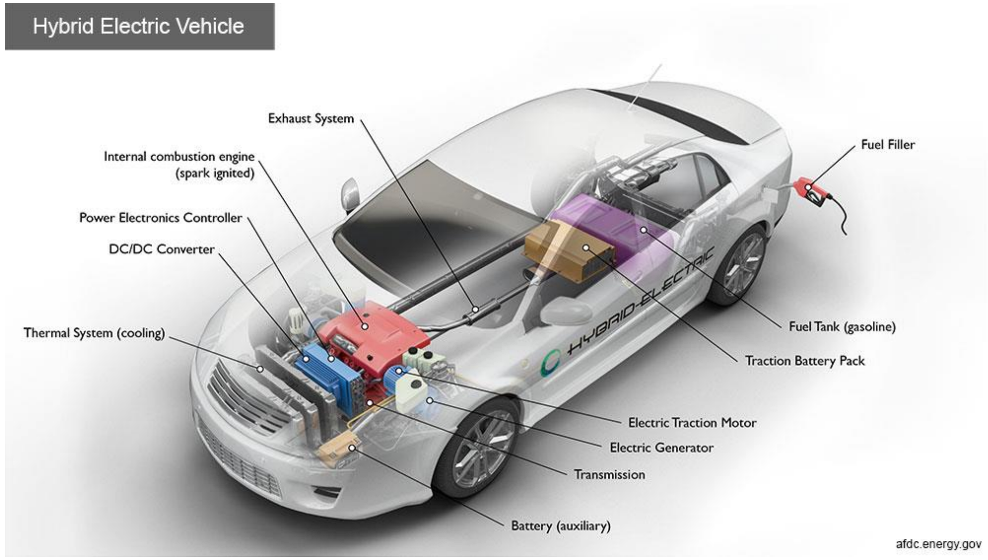
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Hybrid Electric Vehicle (HEV) –

- Hybrid electric vehicles have a supplemental fuel source to produce electricity on – board. They have two complementary drive systems: an IC engine with a fuel tank and an electric motor with a battery.

- Both the drive systems can be used to turn the transmission and the transmission then turns the wheels.

- HEVs cannot be recharged from the electricity grid – all their energy comes from fuel and from regenerative braking.

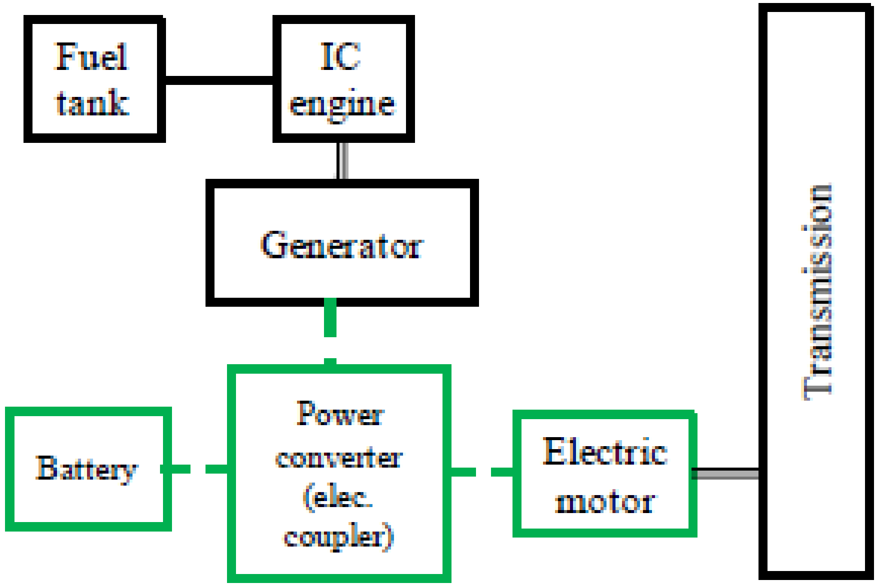


INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Hybrid Electric Vehicle (HEV) – Architectures

i) Series Architecture

- In case of series hybrid system, the mechanical output is first converted into electricity using a generator.
- The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission.
- Conceptually, it is an ICE assisted Electric Vehicle (EV).



INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

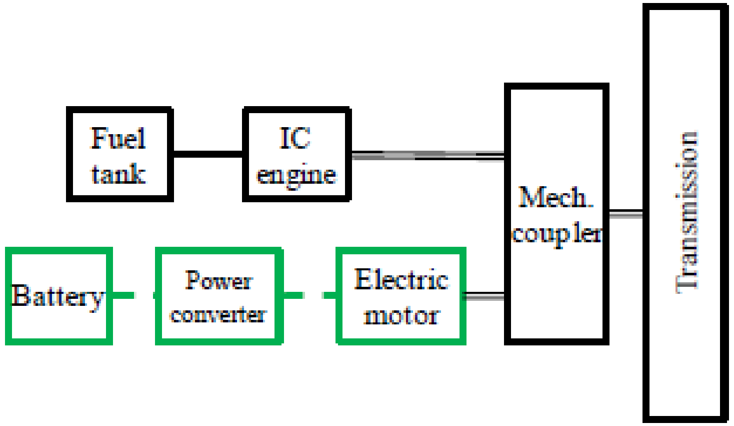
Hybrid Electric Vehicle (HEV) – Architectures

ii) Parallel Architecture

- The parallel HEV allows both ICE and electric motor (EM) to deliver power to drive the wheels.

- Since both the ICE and EM are coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by ICE alone, by EM only or by both ICE and EM.

- The EM can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels.



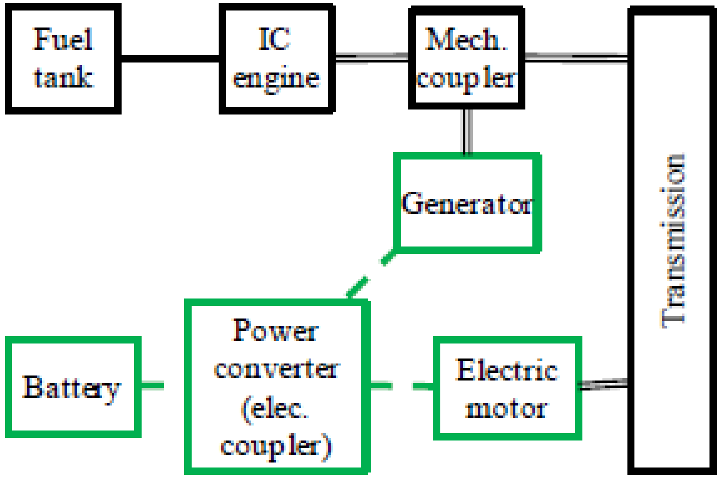
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Hybrid Electric Vehicle (HEV) – Architectures

iii) Series - Parallel Architecture

- In the series-parallel hybrid, the configuration incorporates the features of both the series and parallel HEVs.

- However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.



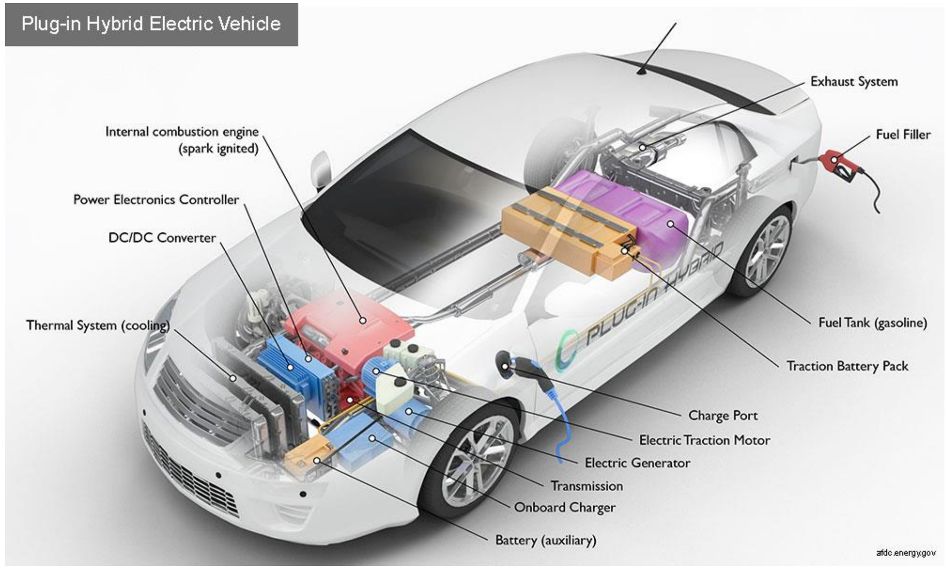
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Plug in Hybrid Electric Vehicle (PHEV) –

- Plug in hybrids use an electric motor and battery that can be plugged into the power grid to charge the battery, but also have the support of an internal combustion engine that may be used to recharge the vehicle's battery and/or to replace the electric motor when the battery is low.

- Because Plug in hybrids use electricity from the power grid, they often realize more savings in fuel costs than tradition hybrid electric vehicles (HEV).

- Examples – Cadillac ELR, GM Chevy Volt, Toyota Prius Plugin etc.



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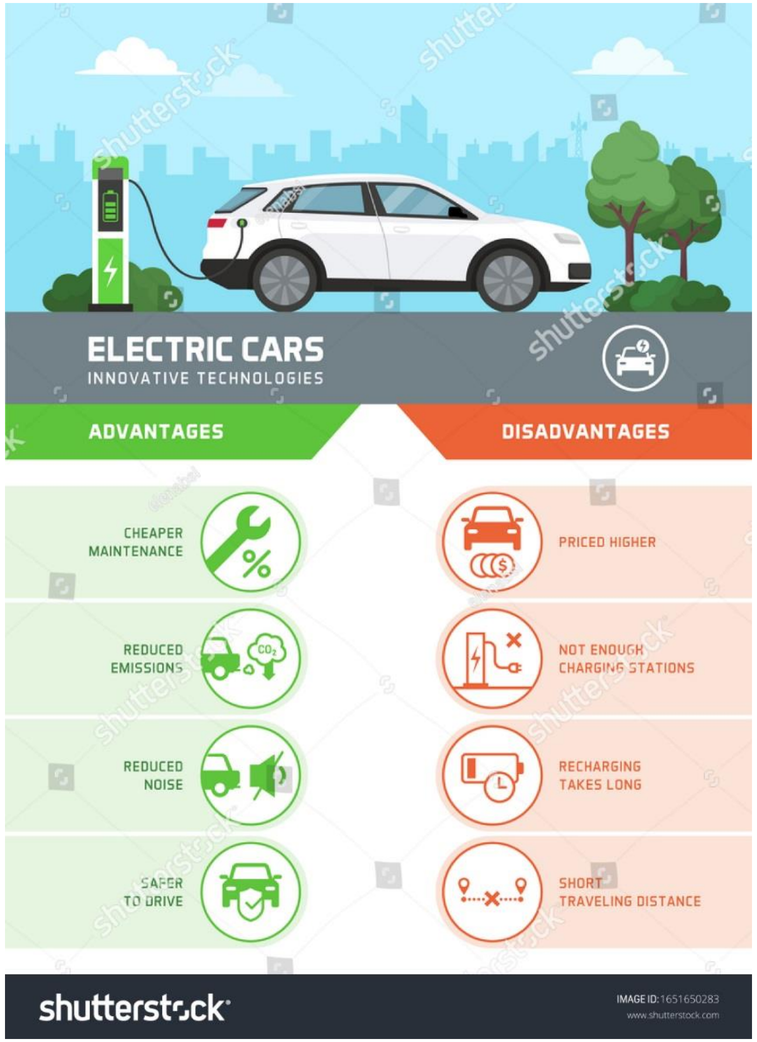

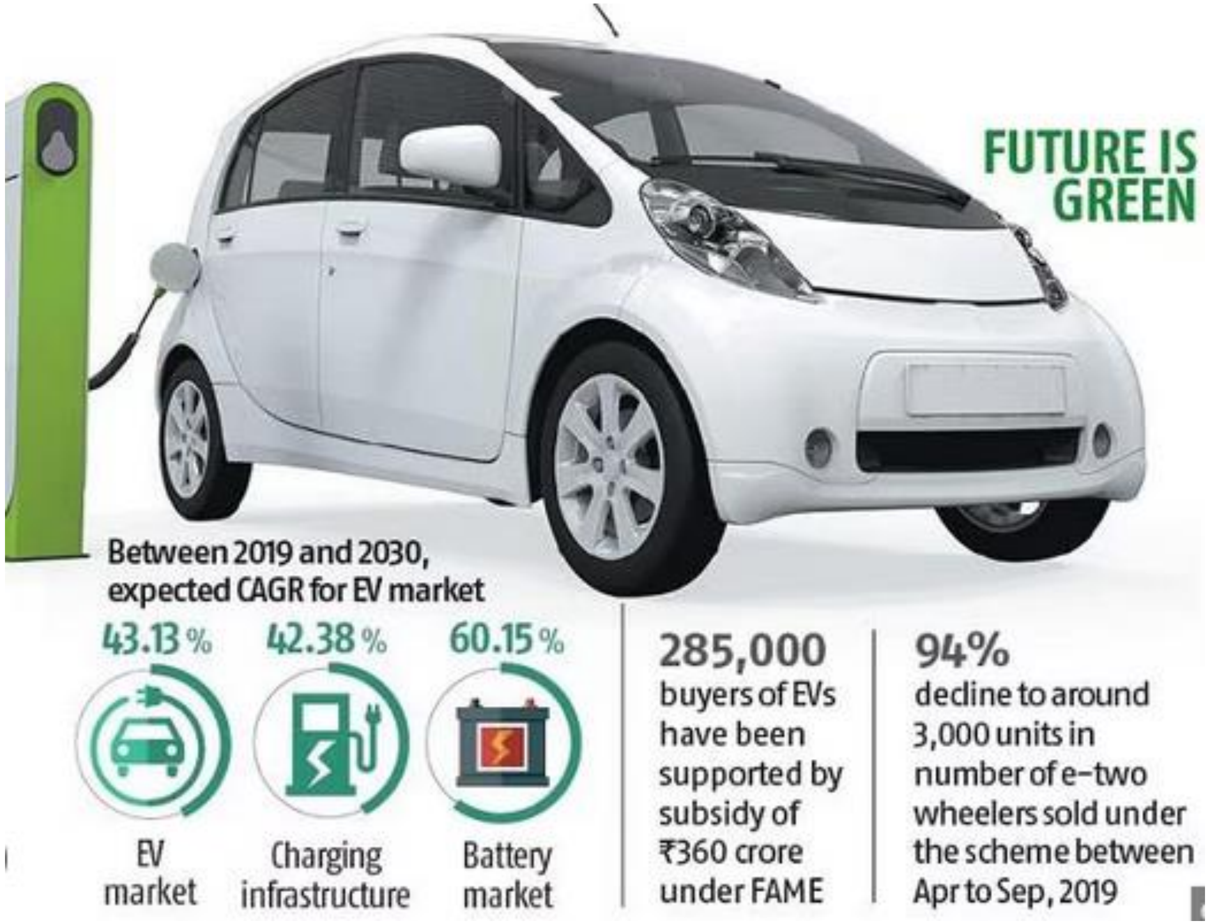

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Chapter 1 – IC Engines and Turbines

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POWER PLANT ENGINEERING

- Power plant engineering is a branch of engineering which deals with the conversion of various forms of energy into electrical energy.

- Some of the important power plants are –

  i) **Thermal power plant** - Thermal power plants may be coal based or gas based. In coal based power plant coal is used as burning fuel and the heat energy is transferred to water to convert it into super-heated steam. The heat energy of the steam is converted into shaft power through the expansion of steam in a **steam turbine**. The shaft of the steam turbine is coupled to a generator where electricity is generated. A gas based power plant uses a **gas turbine** in a similar way for the production of electricity.

  ii) **Hydroelectric power plant** - The principle of electricity generation in the case of hydroelectric power plant is same as in thermal power plant only difference is that the shaft power to the turbine is provided by pressure and kinetic energy of water.

POWER PLANT ENGINEERING

- Apart from the above mentioned important types, the following power plants are also used to generate energy.

iii) Nuclear power plant

iv) Diesel power plant

v) Tidal power plant

vi) Geothermal power plant

vii) Windmill

STEAM TURBINES

- Steam turbine is a power generating machine in which the heat energy of the steam is converted into mechanical energy.

- It converts thermal energy into mechanical work by expanding high pressure and high temperature steam.

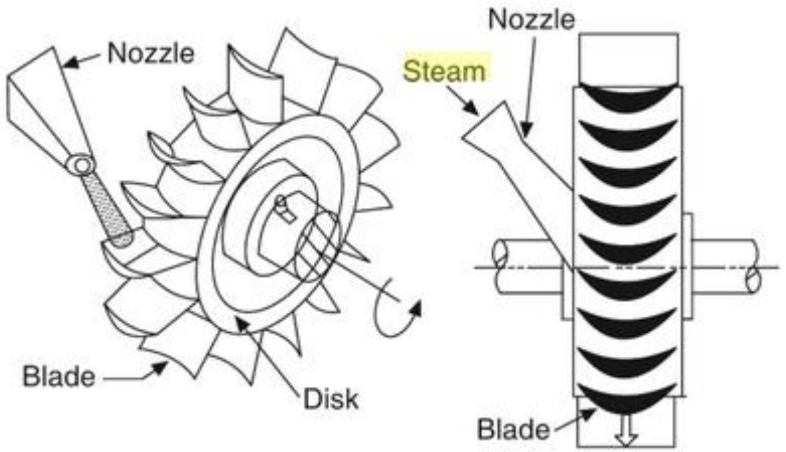
- Steam turbine stands as one of the most important prime movers for power generation. The thermal efficiency of steam turbine is fairly high and the uniform speed of steam turbine at wide loads makes it suitable for coupling it with generators, centrifugal pumps, centrifugal gas compressors etc.

- Broadly, steam turbine can be classified into two categories as follows:
  1. **Impulse Turbine**
  2. **Impulse-Reaction Turbine**. Pure reaction turbine cannot be used for practical purposes; therefore, the impulse-reaction turbine is referred as reaction turbine.

STEAM TURBINES

Impulse Steam Turbine

- A single stage impulse turbine consists of a set of nozzles and moving blades.
- High pressure steam at boiler pressure enters the convergent – divergent nozzle and expands to low back pressure in the nozzle.
- Thus, the pressure energy is converted into kinetic energy increasing the velocity of steam.
- The high velocity steam is then directed on to a series of blades where the kinetic energy is partly absorbed and converted into an **impulse** force by changing the direction of flow of steam, which gives rise to a change in momentum and therefore to a force.



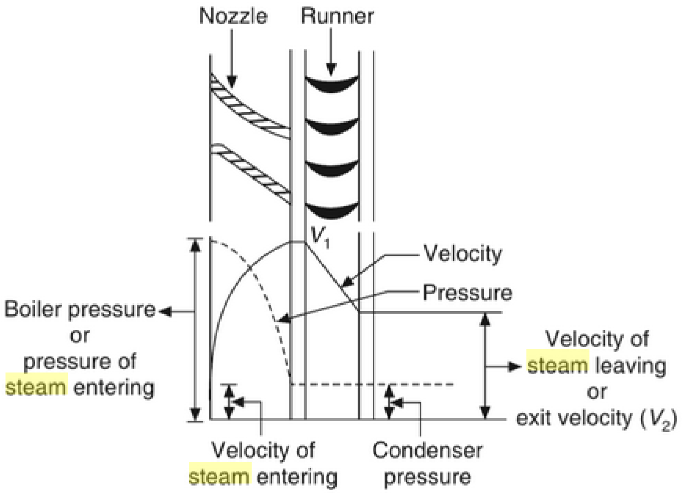
STEAM TURBINES

Impulse Steam Turbine

- This force sets the blades in motion. These blades are attached to a rotor, which finally rotates. The rotation of the shaft of the rotor is used for generation of electricity.

- The velocity of the steam decreases as it flows over the blades but the pressure remains constant.

- The final velocity is much higher than the inlet velocity to the nozzles in case of the single stage turbine. Hence there is considerable loss in kinetic energy.



MECHANICAL ENGINEERING SCIENCE (UE23ME131A)

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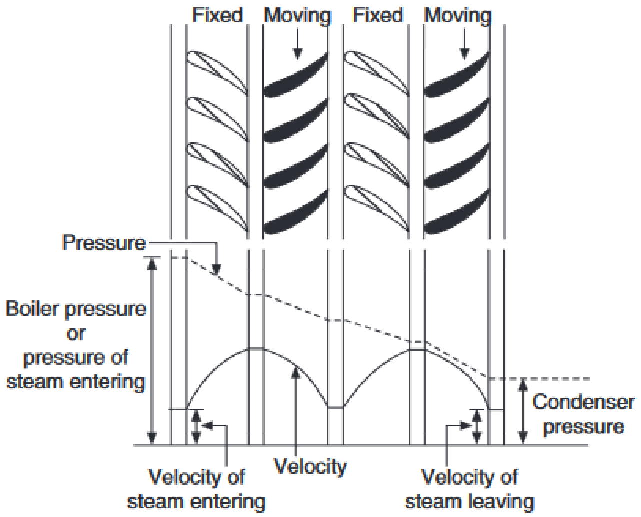
STEAM TURBINES

Impulse - reaction Steam Turbine

- In the impulse – reaction turbine, power is generated by the combination of impulse action and reaction by expanding the steam in both fixed blades and moving blades.

- The pressure of the steam drops partially in fixed blades and partially and continuously in moving blades.

- The fixed blades are attached to the casing and the moving blades are attached to the rotor containing the shaft. Steam is admitted throughout the circumference unlike impulse turbine where it is admitted through a set of nozzles.



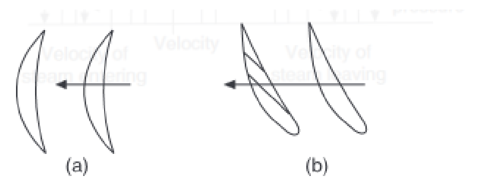
STEAM TURBINES

Impulse - reaction Steam Turbine

- Steam enters the fixed row of blades, undergoes a small drop in pressure and increases in velocity.

- Then similar to an impulse turbine, steam enters the row of moving blades. It undergoes a change in direction and momentum, this sets up an impulse to the blades.

- There is a small drop in pressure too due to the nozzle effect created by the asymmetric profile of blades, giving rise to increase in kinetic energy. The pressure drop gives rise to reaction. Hence the name impulse reaction turbine.



Cross section of blades of steam turbine: (a) Impulse blade. (b) Reaction blade.

STEAM TURBINES

Impulse turbine	*Reaction turbine*
• Complete expansion of the steam takes place in the nozzle, hence steam is ejected with very high kinetic energy.	• Partial expansion of the steam takes place in the nozzle (fixed blade) and further expansion takes place in the rotor blades.
• Blades are symmetrical in shape.	• Blades are non-symmetrical in shape, i.e. aerofoil section.
• No change in pressure between the ends of the moving blade, i.e. the pressure remains constant between the ends of the blade.	• Pressure drops from inlet to outlet of the blade, i.e. difference in pressure exists between the ends of the moving blade.
• Low efficiency, i.e. part load efficiency is poor.	• More flattened efficiency curve, hence part load efficiency is good.
• High speed	• Relativity low speed
• Less floor area for the same power generation, hence compact	• More floor area for the same power generation, hence bulky.
• Used for small power generation	• Used for medium and large power generation.
• Less stages for the same power generation	• More stages for the same power generation.

GAS TURBINES

- The gas turbine is a rotating type prime mover which converts the heat energy of gas/air (at high pressure and temperature) into mechanical work.

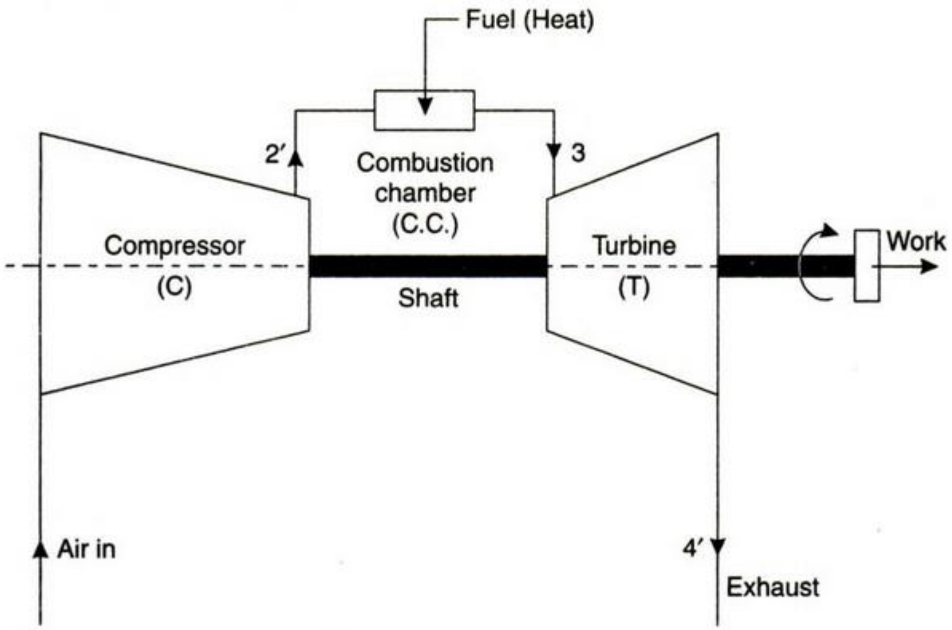
- On the basis of the path of the working fluid, gas turbine can be classified as:
  (i) **Open cycle gas turbine**-Working fluid enters from the atmosphere and exhausts to the atmosphere
  (ii) **Closed cycle gas turbine**- Working fluid is confined within the plant and recirculated.

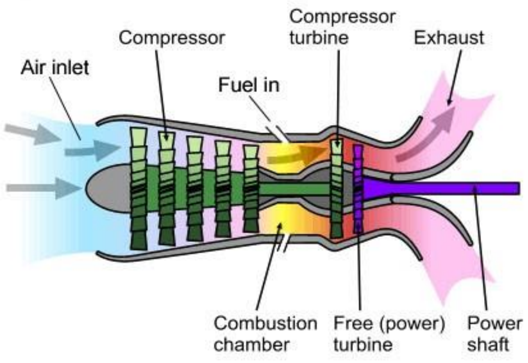
- Gas turbines are used for the following purposes:
  Central power stations
  Stand-by power plants
  Locomotive power plants
  Jet engine, Marine propulsion etc.,

GAS TURBINES

Open cycle gas turbine

- Air is drawn into the compressor and after compression passes to a combustion chamber.
- Energy is supplied in the combustion chamber by spraying fuel into the air stream, and the resulting hot gases expand through the turbine to the atmosphere.
- The rotary compressor and the turbine are mounted on a common shaft. Therefore, the turbine must develop more gross work output than is required to drive the compressor and overcome the mechanical losses.
- The products of combustion coming out of the turbine are exhausted to the atmosphere. Therefore, the working fluid (air and fuel) must be replaced continuously.

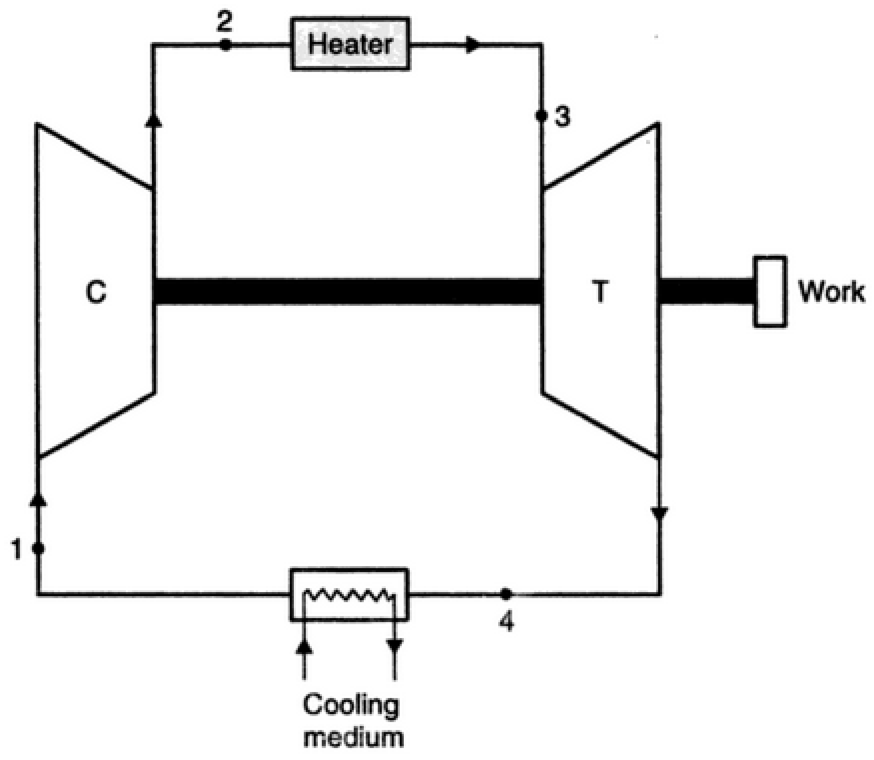




GAS TURBINES

Closed cycle gas turbine

- Atmospheric air or some other stable gases like argon, helium etc. may be used as the working fluid.
- In operation, the working fluid is compressed to a high pressure in a compressor and then passed to a heater where it is heated with the help of some external source.
- The working fluid will not come in contact with the products of combustion as in case of open cycle gas turbine. Instead, heat is transferred using a heat exchanger.
- The high pressure and high temperature fluid is made to flow through the turbine blades, wherein the heat energy is converted into mechanical work.



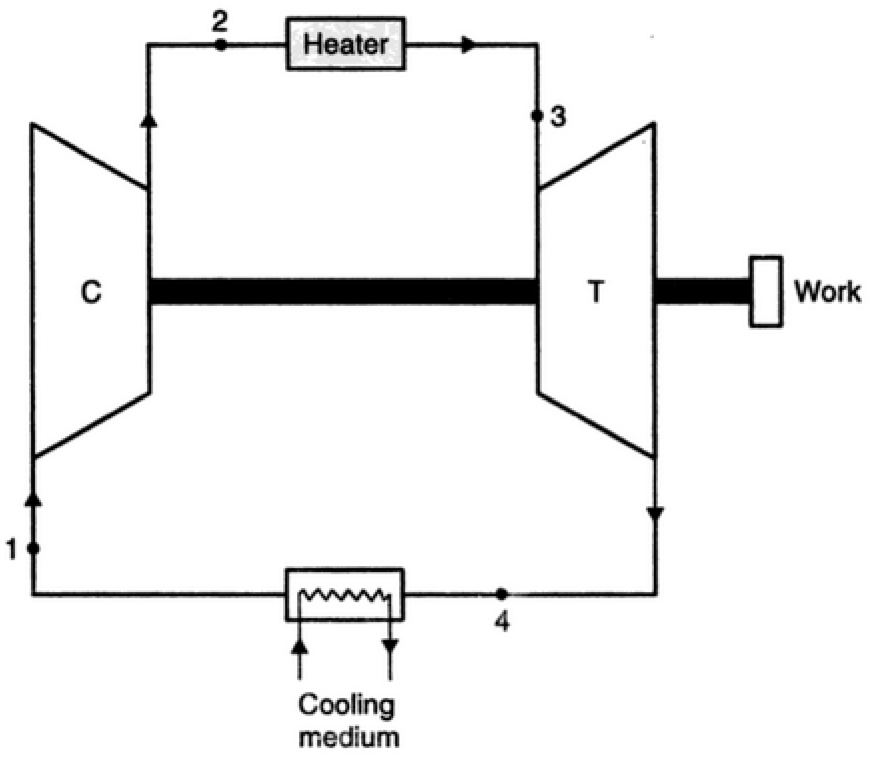
GAS TURBINES

Closed cycle gas turbine

- From the turbine, the fluid is passed to a cooler, where it is cooled to its original temperature from external cooling source.

- The low temperature and low pressure fluid from the cooler is then passed to the compressor for the next cycle to take place.

- Since the working fluid is circulated again and again, this type of turbine is called closed cycle gas turbine.



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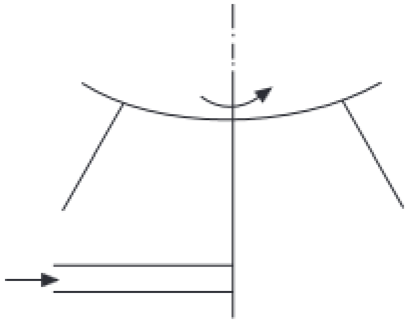
HYDRAULIC (WATER) TURBINES

- A hydraulic turbine is a machine, which converts hydraulic energy into mechanical energy. It uses the potential and kinetic energy of water and sets the rotor in motion by the dynamic action of water flowing from a high level.

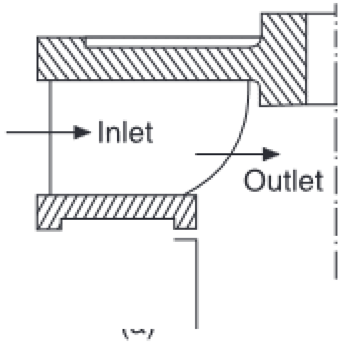


- Hydraulic turbines may be classified as follows

  1. Based on the type of energy at inlet to the turbine

  (a) **Impulse turbine** - The energy is in the kinetic form. Example: Pelton wheel.

  (b) **Reaction turbine** - The energy is in both kinetic and pressure form. Example: Francis turbine.

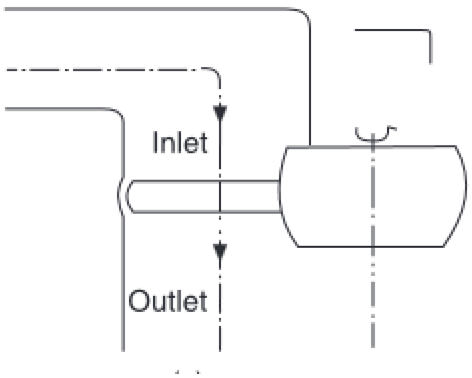


  2. Based on the direction of flow of water through the runner

  (a) **Tangential flow** - Water flows in a direction tangential to the path of rotation, i.e perpendicular to both axial and radial directions. Example: Pelton wheel

  (b) **Radial flow –** Water flows in a radial direction through the runner. Example: Francis turbine

  (c) **Axial flow** - Water flows parallel to the axis of the turbine. Example: Kaplan turbine



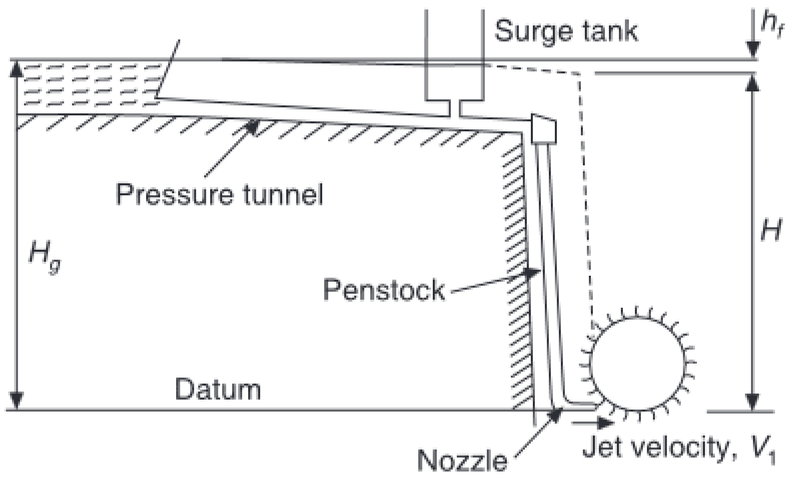
HYDRAULIC (WATER) TURBINES

3. Based on the head under which turbine works

(a) **High head turbine –** Head of water available at the inlet of the turbine ranges from several hundred meters to few thousand meters. Example: Pelton wheel

(b) **Medium head turbine** – Head of water available at the inlet of the turbine ranges fro 50m to 400m. Example: Francis turbine

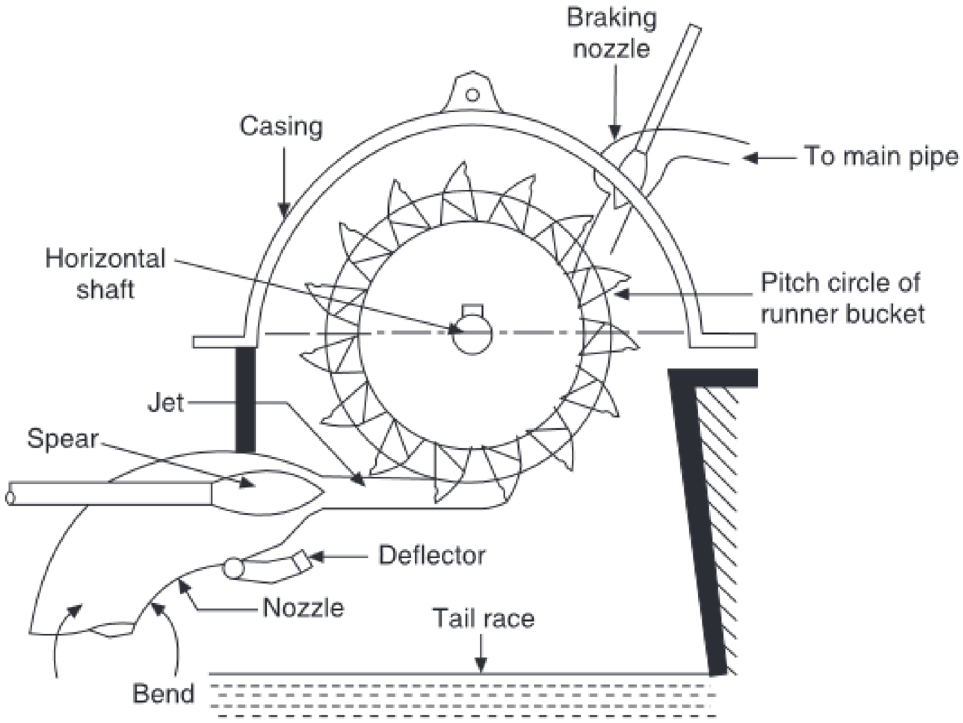
(c) **Low head turbine** – Head of water available at the inlet of the turbine will be less than 50m. Example: Kaplan turbine



HYDRAULIC (WATER) TURBINES

PELTON WHEEL

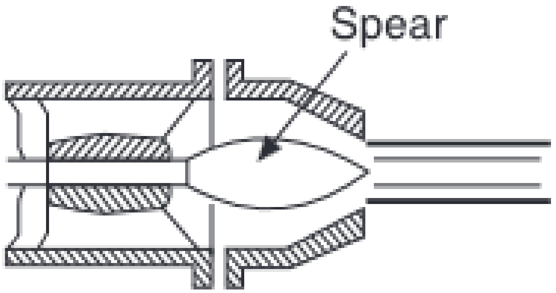
- It is an impulse turbine working under a high head (above 300 m).



HYDRAULIC (WATER) TURBINES

PELTON WHEEL

- The main components of the Pelton wheel are:
  (a) Nozzle and flow regulating mechanism
  (b) Jet deflector
  (c) Runner and bucket
  (d) Casing
  (e) Braking jet

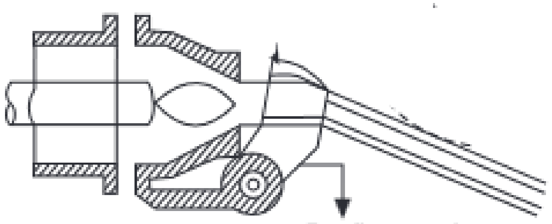


- **Nozzle and Flow Regulating Mechanism** - **Nozzle** is a device which converts pressure energy into kinetic energy, resulting in water leaving with a high velocity. There is an arrangement to vary the quantity of water called **spear**. Spear is a conical needle inside the nozzle which operates in the axial direction to control the quantity of water. When the power demand is less the spear is moved towards the bucket, so that the annular space between the nozzle and the spear decreases and the quantity of water coming from the nozzle decreases. When the power demand is more, the spear is moved away from the bucket, so that more quantity of water flows through nozzle.

HYDRAULIC (WATER) TURBINES

PELTON WHEEL

- **Jet Deflector** - If there is a sudden decrease in available head, immediate closure of the nozzle is required. However, such a sudden closure or reduction in flow may damage the pipe line and penstock, etc. due to strong pressure waves generated in the pipe line. A deflector is used along with the spear to deflect the jet and only a small amount of water jet strikes the bucket.

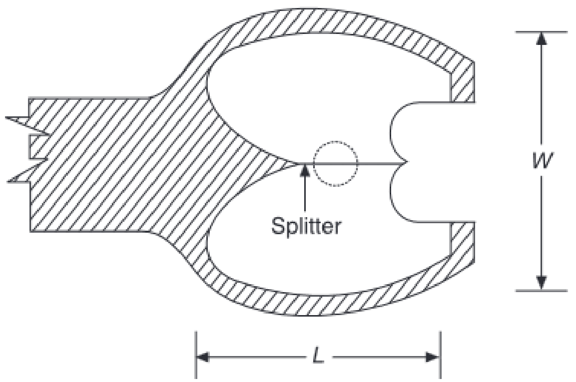


- **Braking Jet** - Even after the complete closure of nozzle the runner goes on revolving for a considerable period of time due to its inertia before it comes to rest. In order to bring the runner to rest in a short period, a nozzle is provided such that it will direct a jet of water on the back of the bucket. It acts as a brake for reducing the speed of the runner. The jet, which is coming from this nozzle is called the braking jet.

HYDRAULIC (WATER) TURBINES

PELTON WHEEL

- **Runner and Bucket -** The runner of Pelton wheel consists of a circular disc mounted on a horizontal shaft. On the periphery of the runner, a number of buckets are fitted uniformly. Each bucket is divided vertically into two halves by a splitter with a sharp edge and the buckets look like a double hemispherical cup. The jet of water from the nozzle strikes the splitter and is equally distributed to the two halves of the hemispherical bucket.



- Theoretically if the bucket were hemispherical, it would deflect the jet by 180°, then the relative velocity of the jet leaving the bucket will be exactly in opposite direction to that of the relative velocity of the entering jet. This is not good in practice, since the jet leaving the bucket would strike the back of the next bucket. This would affect the overall efficiency of the turbine. Hence, the angle of deflection is limited to between 165° and 170°.

HYDRAULIC (WATER) TURBINES

PELTON WHEEL

- Casing - The casing to the Pelton wheel does not perform any hydraulic function but it is necessary to avoid accidents and to prevent splashing of water. The casing leads the water to the tail race.

Working Principle -

- The water flows from the reservoir to the turbine through the penstock. The end of the penstock is fitted with one or more nozzles.

- The entire pressure energy of water is converted into kinetic energy in the nozzle. The high velocity water jet emerging from the nozzle strikes the bucket (blades) attached to the periphery of the rotor and sets the bucket into rotary motion.

- Here, water flows in the tangential direction, doing work. The buckets change the direction of the jet, resulting in change in momentum that sets the wheel into rotary motion.

HYDRAULIC (WATER) TURBINES

PELTON WHEEL

- The kinetic energy of the jet is completely transferred to the rotating wheel, i.e. the velocity of water at the exit of the runner is just sufficient to enable it to move out the runner.

- The static pressure of water at the entrance and exit of the bucket is same and it is equal to atmospheric pressure. Water is discharged at the tail race after doing work on the runner.

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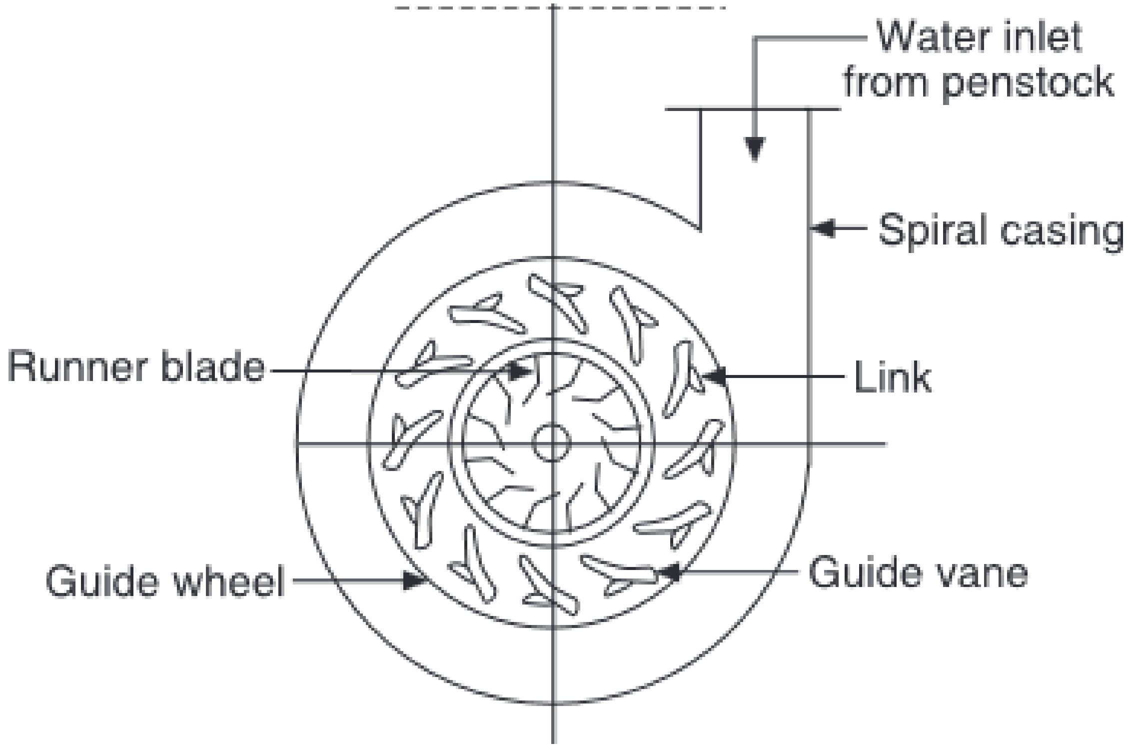
HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE

- It is a reaction turbine working under medium head (50 m to 300 m).



HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE

- The main components of Francis turbine are:
  (a) Casing
  (b) Guide mechanism
  (c) Runner
  (d) Draft tube

- **Spiral Casing** - Water from the head race enters the spiral casing (scroll casing) of Francis turbine through the penstock. The area of the casing decreases gradually around the circumference of the wheel (maximum at the entrance and minimum at the tip). This is done in order to distribute water uniformly around the entire perimeter of the runner.

HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE

- **Guide vanes** - Water from the spiral casing enters the runner through the stationary guide vanes. The guide vanes are fixed on the guide mechanism as well as on the periphery of a circle. The amount of water striking the runner and the speed can be varied by varying the angle of guide vane. Here, a number of guide vanes are fixed around the circumference of the runner. Each guide vane is made to rotate about its pivot centre with the help of an individual link.

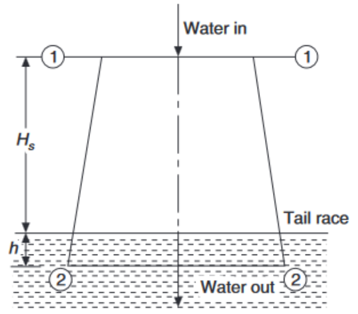
- **Runner** - The runner is a circular wheel on which a series of radial curved vanes are fixed. The runner may by either cast or fabricated.

HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE

- **Draft tube** - It is a pipe of gradually increasing cross-sectional area, which converts kinetic energy of water into pressure energy.

- A reaction turbine is required to be installed above the tail race level for ease of maintenance (repair) work. Hence, some head is lost. The draft tube recovers this head. by reducing the pressure head at the outlet to below the atmospheric level.



- Exit kinetic energy of water is a necessary loss in the case of turbine. A draft tube recovers part of this exit K.E. (enables to recover the K.E.)

HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE

Working Principle –

- The water flows from the reservoir to the turbine through the penstock and feeds water to a row of fixed blades through casing.

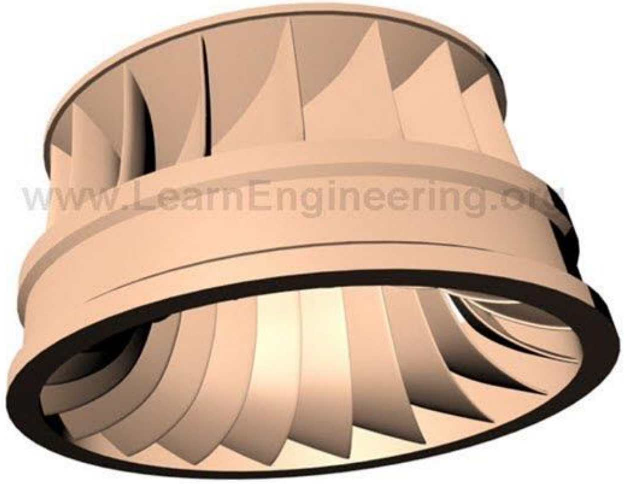
- These fixed blades convert a part of the pressure energy into kinetic energy before the water enters the runner. Thus, water possessing pressure and kinetic energy enters the runner vanes (blades) in the **radial** direction and leaves in the **axial** direction. Thus, it is a mixed flow.

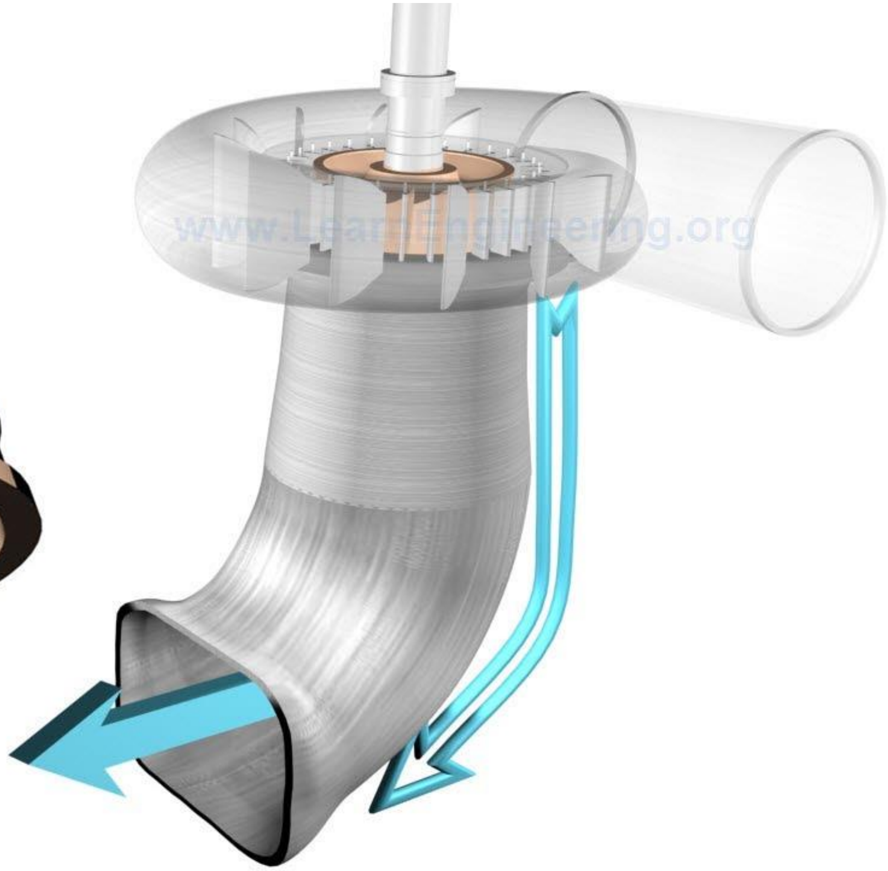
- The pressure energy of water is gradually changed into kinetic energy as water flows over the vanes. Therefore, the rotor is set in motion by the reaction of the leaving water.

- The rotation of the runner is partly due to impulse action and partly due to change in pressure over the runner blades (leads to reaction) and hence the turbine is called reaction turbine.

HYDRAULIC (WATER) TURBINES

FRANCIS TURBINE





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MECHANICAL ENGINEERING SCIENCE

Chapter 2 – Heat Transfer and Refrigeration

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INTRODUCTION TO HEAT TRANSFER

- Heat is defined as energy in transit. Heat itself cannot be seen, but its effect can be felt and measured as a property called temperature.

- Heat transfer occurs whenever two bodies at different temperatures are brought in contact with each other or, whenever there is a temperature gradient within a body.

- Science of heat transfer involves the study of principles that govern and the methods that determine the rate of heat transfer.

- Often, we are also interested in the spatial temperature distribution within a body causing that heat transfer.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

- Generally, for convenience of analysis, we consider heat transfer in three different modes: **conduction**, **convection** and **radiation**.

Conduction:

- Conduction is a microscopic phenomenon. Here, more energetic particles of a substance transfer their energy to their less energetic neighbours.

- Conduction can occur in a solid, liquid or gas. In a solid, transfer of energy occurs by lattice vibrations and/or free electrons. In a liquid or gas, the transfer of energy occurs by collisions and diffusion of molecules.

- It should be noted that in solids energy transfer occurs only by conduction whereas in liquids and gases other modes of energy transfer are also possible.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Conduction:

- Consider, for example, a copper rod, well insulated on its surface, held with its one end inside a furnace at a high temperature; its other end is open to atmosphere at room temperature.

- It can easily be observed that after some time, the end open to atmosphere will get warmer and reach a temperature higher than ambient. We say that heat is transferred along the rod by conduction.

- Governing rate equation for conduction is given by **Fourier's law**. This is an empirical law based on experimental observations of Biot, but formulated by the French mathematical physicist, Fourier in 1822.

- It states that ***the rate of heat flow by conduction in a given direction is proportional to the area normal to the direction of heat flow and to the gradient of temperature in that direction.***

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Conduction:

- Referring to Fig., for heat flow in the X-direction, Fourier's law states

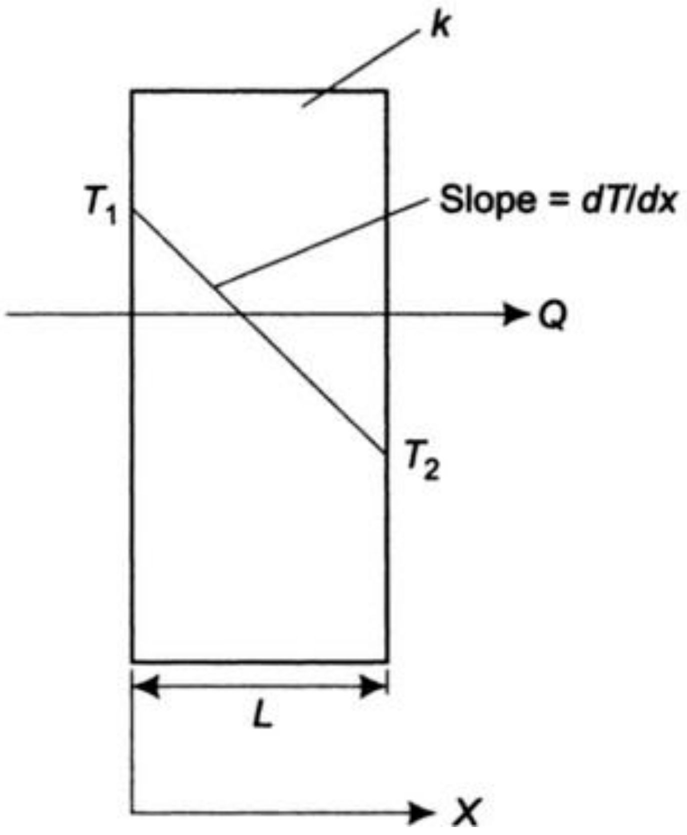
$$Q_x = -kA\frac{dT}{dx}, \mathrm{W} \qquad ...(1.1)$$

i.e. $$Q_x = -kA\ (T_2 - T_1)/L$$ *(For a plane slab, in steady state)*

$$= kA\ (T_1 - T_2)/L$$

or, $$q_x = -k\frac{dT}{dx}, \mathrm{W/m^2} \qquad ...(1.2)$$

i.e. $$q_x = k\ (T_1 - T_2)/L$$



INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Conduction:

- Here, Qx is the rate of heat transfer in the positive X-direction, A is the area normal to direction of heat flow, dT/dx is the temperature gradient in the X-direction and k is a proportionality constant.

- Note that if the heat flow has to be in the positive X-direction, the temperature must go on decreasing in the X direction, i.e. the temperature will decrease as X increases which means that the temperature gradient is negative; therefore, we insert a negative sign in Eqs. 1.1 and 1.2 to make the heat flow positive in the positive X-direction.

- q_x in Eq. 1.2 is known as heat flux, which is nothing but the heat flow rate per unit area.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Conduction:

- The proportionality constant k in Eqs. 1.1 and 1.2 is known as "**thermal conductivity**", a property dependent on the material.

- Thermal conductivity of materials varies over a wide range, by about 4 to 5 orders of magnitude. For example, at 20°C, thermal conductivity of air is 0.022 W/(mC), of water 0.51 W/(mC), that of asbestos 0.095 W/(mC), that of stainless steel 19.3 W/(mC) and that of pure silver, about 407 W/(mC).

- Thermal conductivity, essentially depends upon the material structure (i.e. crystalline or amorphous), density of material, moisture content, pressure and temperature of operation.

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INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Convection:

- Convection is a macroscopic phenomenon. It occurs only in fluids.

- When a fluid flows over a body that is at different temperature than itself, heat transfer occurs by convection; the direction of heat transfer, of course, depends on the relative magnitude of the temperatures of the fluid and the surface.

- In addition, if two fluids at different temperatures are mixed together, heat transfer occurs by convection. Boiling and condensation also involve convective heat transfer, but with phase change.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Convection:

- In convection, the fluid particles themselves move and thus carry energy from a high temperature level to a low temperature level.

- As an example, consider a hot copper plate held hanging in air. The air layer in the immediate vicinity of the plate gets heated up, its density decreases (since the room air pressure is constant) and therefore rises up, thus carrying away heat with it; the cooler air takes the place of the displaced hot air, gets heated, rises up and this process continues till the plate attains equilibrium with room temperature.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Convection:

- In case of convection, fluid motion may occur by density differences caused by temperature differences, as mentioned in the above example. Such a case is known as **natural (or free)** convection.

- When fluid motion is caused by an external agency such as a pump, fan or atmospheric winds, that case is known as **forced** convection. One can intuitively feel that heat transfer in the case of forced convection is higher as compared to free convection.

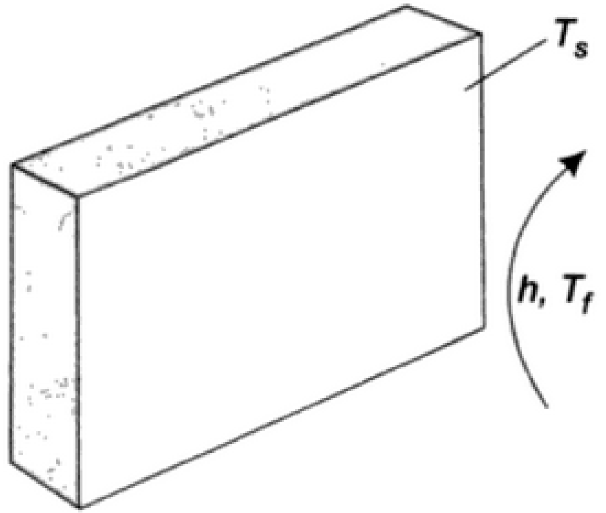
INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Convection:

- Governing rate equation for convection is given by **Newton's Law of Cooling**.

- Fig. shows a situation of natural convection. Here, a flat plate at a surface temperature of Ts is held vertically; the ambient is at a temperature T_f . Then, the rate of heat transfer is given by Newton's law as follows,



$$Q = hA(T_s - T_f), \text{ W} \qquad \ldots(1.3)$$

or,

$$q = h(T_s - T_f), \text{ W/m}^2 \qquad \ldots(1.4)$$

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Convection:

- Ts is the surface temperature (°C) ,T_f is the fluid temperature (°C), A is the surface area (m^2) exposed to the fluid, Q is the rate of heat transfer (W) from the surface to the fluid, q is the heat flux (W/m^2) and h is coefficient of heat transfer for convection.

- The convective heat transfer coefficient, h, is not a property of the surface material nor that of the fluid. Instead, h is a complicated function of the type of flow (i.e. whether the flow is laminar or turbulent), geometry and orientation of the body, fluid properties (such as specific heat, thermal conductivity, viscosity), average temperature and the position along the surface of the body.

- In normal practice, even though h varies along the length of the body, it is customary to take an average (or mean) value of h over the entire body, and use it in Eq. 1.3 to calculate the total heat transfer rate.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Radiation:

- All bodies above the temperature of 0 K emit radiation.
- According to Maxwell's wave theory, the radiation is emitted as electromagnetic waves.
- Electromagnetic waves travel at the speed of light and generally obey all laws of light.
- Radiation is emitted over all the wavelengths. However, the radiation emitted over the wavelength range of 0.1µm to 100 µm is known as thermal radiation since radiation in this particular range gets converted to heat when absorbed by a body.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Radiation:

- Thermal radiation is a volume phenomenon, i.e. the radiation is the result of excitation of all the particles of a body. However, the radiation travels to the surface and is then emitted from the surface.

- When radiation falls on a body, it may be attenuated within a short distance from the surface (of the order of a few angstroms), or get reflected from the surface or just pass through the body.

- One or more of these phenomena may occur simultaneously. In vacuum, radiation propagates without any attenuation. For practical purposes, atmospheric air is considered to be transparent to thermal radiation.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Radiation:

- Governing rate equation for emission of radiation flux from a body is given by the Stefan–Boltzmann law:

$$E_b = \sigma T^4, \mathrm{W/m^2}$$

- where, σ = Stefan–Boltzmann constant = 5.6697×10^{-8} W/(m^2K^4)
  T = temperature in Kelvin
  E_b = black body emissive power.

- Note that Eq. above defines the emissive power of a black body, i.e. an ideal emitter.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Radiation:

- Radiation flux emitted by a real body is less than that of the black body and is given by,

$$E = \varepsilon E_b = \varepsilon \sigma T^4 \text{ W/m}^2$$

where, ε is known as Emissivity, lies between zero and unity.

- Emissivity depends on the surface material, surface finish, temperature and the wavelength of radiation.

- By definition, a black body is also an ideal absorber, i.e. it absorbs all the radiation falling on it. However, a real body absorbs only a part of the radiation falling on it.

INTRODUCTION TO HEAT TRANSFER

MODES OF HEAT TRANSFER

Radiation:

- Hence, we can write

$$q_{abs} = \alpha q_{inc} \, \mathrm{W/m^2}$$

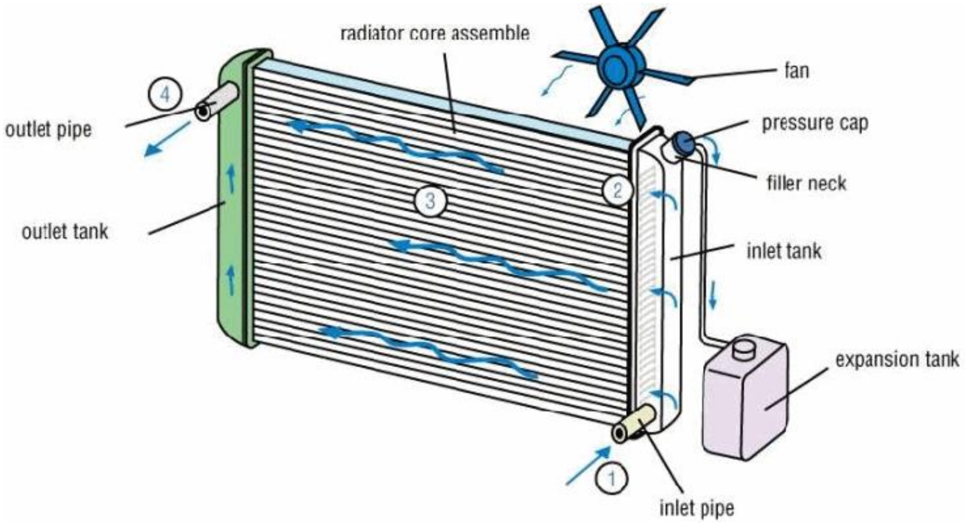
- where, α is absorptivity and lies between zero and unity.

- In general, α and ε are different, but for practical purposes, we assume them to be equal to each other.

INTRODUCTION TO HEAT TRANSFER

APPLICATIONS OF HEAT TRANSFER

- Heat transfer is an important branch of thermal science which has applications in diverse fields of engineering.
- a) Mechanical Engineering - Boilers, Heat exchangers, Turbine Systems, IC Engines etc.



INTRODUCTION TO HEAT TRANSFER

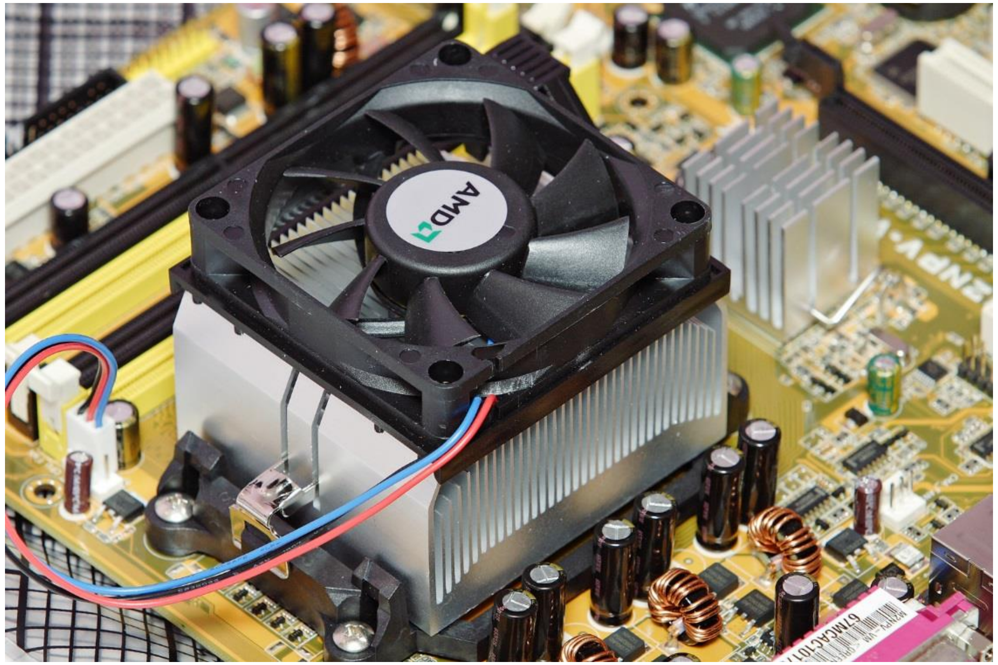
APPLICATIONS OF HEAT TRANSFER

b) Metallurgical Engineering - Furnaces, heat treatment of components etc.

INTRODUCTION TO HEAT TRANSFER

APPLICATIONS OF HEAT TRANSFER

c) Electrical Engineering - Cooling systems for electric motors, generators, transformers etc.



INTRODUCTION TO HEAT TRANSFER

APPLICATIONS OF HEAT TRANSFER

d) Cryogenic Engineering - In the production, storage, transportation and utilisation of cryogenic liquids (at very low temperatures ranging from 100 K to 4 K or even lower) for various industrial, research and defence applications.

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MODES OF HEAT TRANSFER - NUMERICALS

1) Asbestos layer of 10 mm thickness (k = 0.116 W/mK) is used as insulation over a boiler wall. Consider an area of 0.5 m^2 and find out the rate of heat flow as well as the heat flux over this area if the temperatures on either side of the insulation are 300°C and 30°C.

MODES OF HEAT TRANSFER - NUMERICALS

Solution:

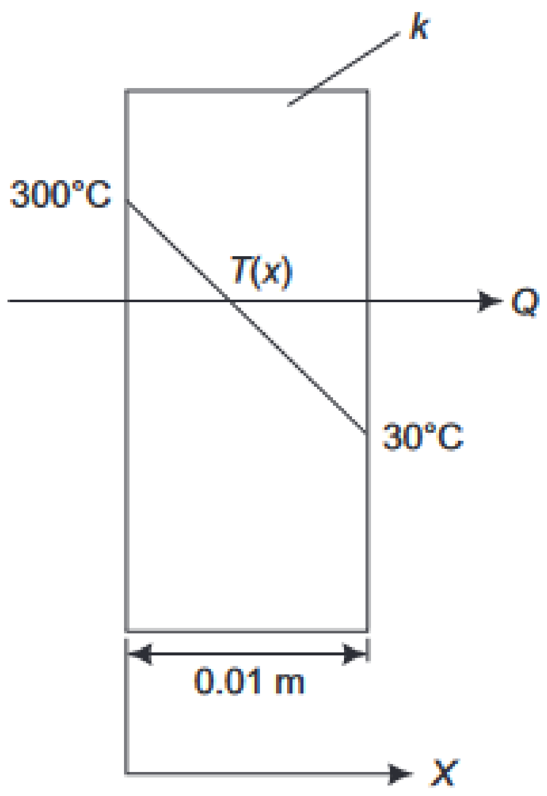
Here, dT/dx is linear i.e. the temperature gradient is linear

Heat flux q

$$q_x = -k\frac{dT}{dx} = -0.116 \times \left[\frac{30-300}{0.01}\right] = 3132\ W/m^2$$

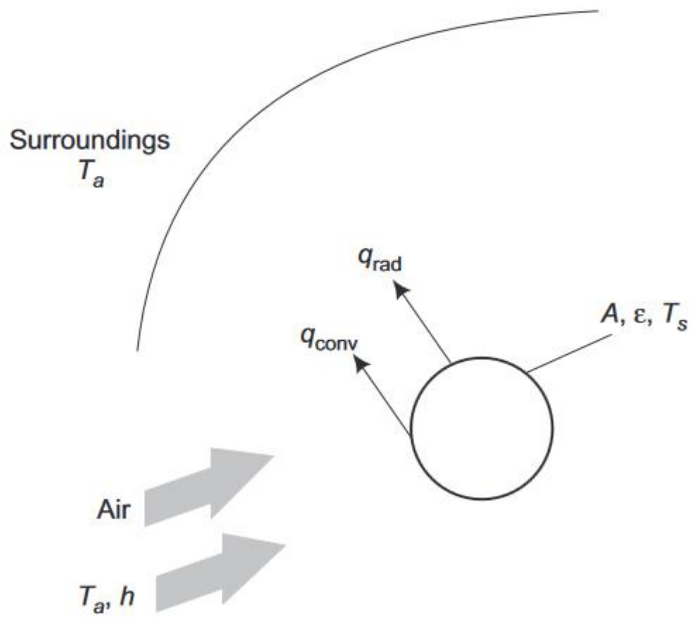
Rate of heat flow Q

$$Q = Heat\ flux\ (q) \times Area = 3132 \times 0.5 = 1566\ W$$



MODES OF HEAT TRANSFER - NUMERICALS

2) A small metallic sphere of emissivity 0.9 loses heat to the surroundings at a rate of 450 W/m^2 by radiation and convection. If the ambient temperature is 300 K and the convective heat transfer coefficient between the sphere and ambient air is 15 W/m^{2}K, find out the surface temperature of the sphere.



MODES OF HEAT TRANSFER - NUMERICALS

Solution:

Let the surface area of the sphere be A and surface temperature, Ts. Ambient temperature, Ta = 300 K.

Writing an energy balance (i.e. applying the First law):

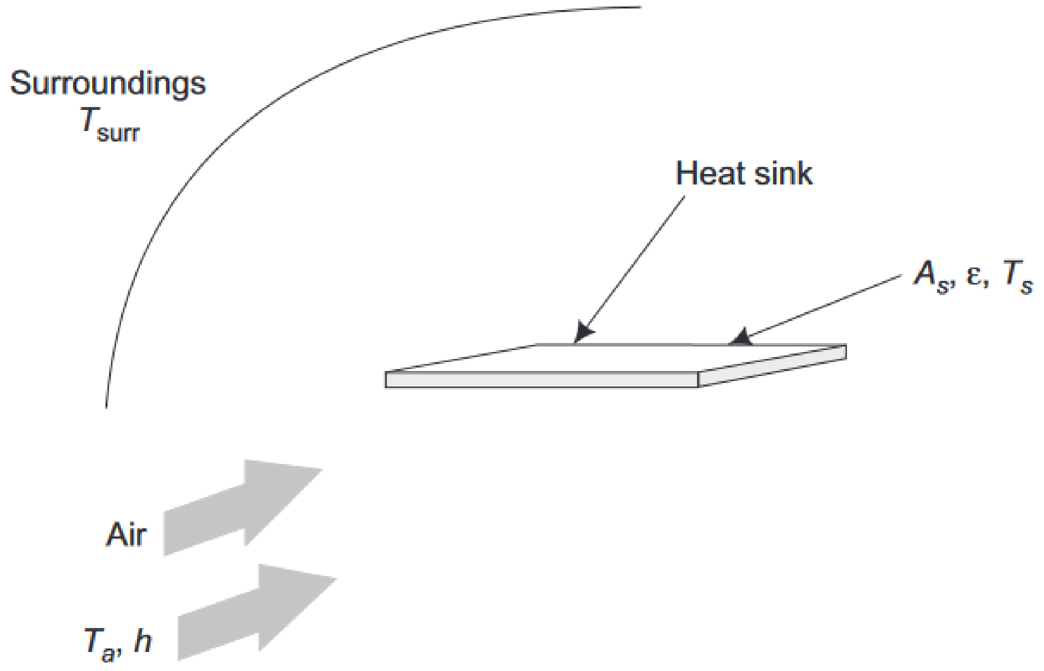
Total heat lost = heat lost by convection + heat lost by radiation

$$450 \times A = hA(T_s - T_a) + A\varepsilon\sigma(T_s^4 - T_a^4)$$
$$450 = 15 \times (T_s - 300) + 0.9 \times 5.67 \times 10^{-8} \times (T_s^4 - 300^4)$$
$$15T_s + 5.103 \times 10^{-8} \times T_s^4 - 5363.343 = 0$$

Solving, we get Ts = 321.3 K

MODES OF HEAT TRANSFER - NUMERICALS

2) Electronic power devices are mounted to a heat sink having an exposed surface area of 0.045 m^2 and an emissivity of 0.8. When the devices dissipate a total power of 20 W and air and surroundings are at 27°C, the average sink temperature is 42°C. What average temperature will the heat sink reach when the devices dissipate 30 W for the same environmental conditions?



MODES OF HEAT TRANSFER - NUMERICALS

Solution:

Let, the surface area of the heat sink be A, and heat dissipated to surroundings, Q. Also, surface temperature is Ts and surrounding temperature and air temperature Ta. Heat transfer coefficient for convection is h. Then, from energy balance,

Heat dissipated by devices = heat lost by sink by convection + heat lost by radiation to surroundings

$$Q = hA(T_s - T_a) + A\varepsilon\sigma(T_s^4 - T_a^4)$$

Case 1: h has to be calculated first using the energy balance; all other quantities are known

$$Q := 20\ \text{W} \qquad A := 0.045\ \text{m}^2 \qquad T_s := 42 + 273\ \text{K} \qquad T_a := 27 + 273\ \text{K} \qquad T_{surr} := 27 + 273\ \text{K}$$

$$\varepsilon := 0.8 \qquad \sigma := 5.67 \times 10^{-8}\ \text{W/m}^2\text{K}^4$$

MODES OF HEAT TRANSFER - NUMERICALS

Solution:

From the energy balance:

$$h = \frac{Q - \sigma \cdot \varepsilon \cdot A \cdot (T_s^4 - T_{surr}^4)}{A \cdot (T_s - T_a)}$$

i.e. $h = 24.351\ \mathrm{W/m^2K}$.

Case 2: If heat dissipated is changed to 30 Watt, what will be the new equilibrium temperature attained by the sink surface? Other conditions remain the same, i.e. now, h value is known, but Ts has to be calculated.

MODES OF HEAT TRANSFER - NUMERICALS

Solution:

$$Q := 30\ \mathrm{W}$$

$$T_s := 450\ \mathrm{K}$$

Given

$$Q = h \cdot A \cdot (T_s - T_a) + \varepsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_{surr}^4)$$

Solving, Ts = 322.353 K
That is, the new equilibrium temperature of the heat sink surface is 322.353 K when the amount of heat dissipated changes to 30 Watt.

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PRINCIPLE OF REFRIGERATION

- ***The process of cooling or reducing the temperature of a substance below that of the surrounding atmosphere and maintaining this lower temperature within the boundary of a given space is called refrigeration.***

- The machine or device employed to produce refrigeration effect is called **refrigerator.**

- In order to keep the substance cold, heat must be continuously removed from the given substance.

- According to the law of thermodynamics, heat naturally flows from a hot substance to a cold substance. But if heat has to flow from a cold substance to a hot substance, some form of work has to be performed.

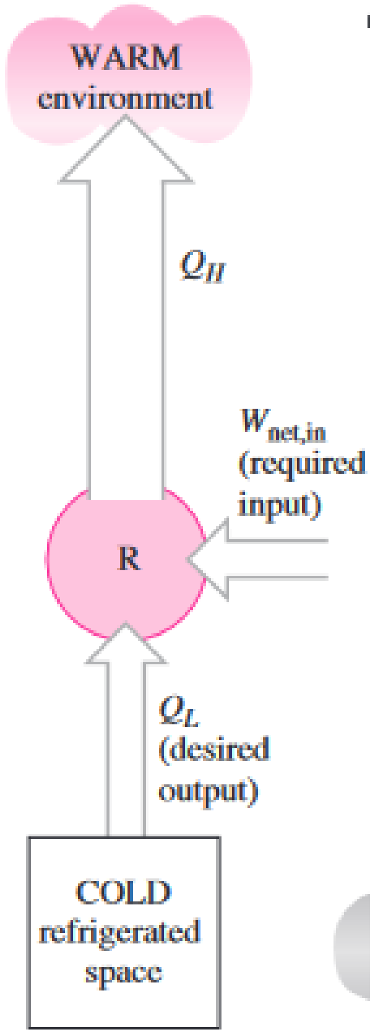
PRINCIPLE OF REFRIGERATION

- Refrigeration works on the principle that heat is continuously extracted from the low temperature substance ***by performing mechanical work***. This heat is then rejected to the surrounding atmosphere (high temperature level).

- A carrier substance is used to extract the heat and this substance is known as ***refrigerant***.

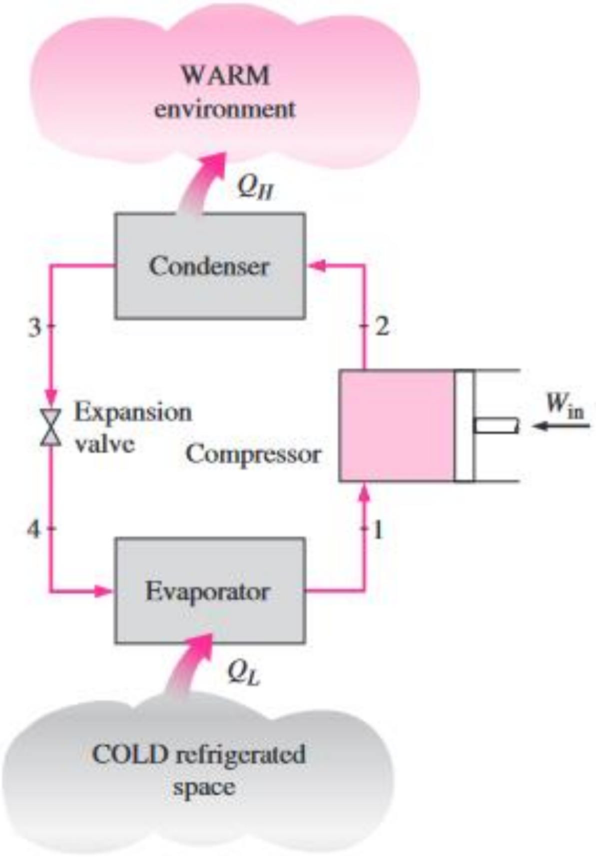
- The refrigerant is a chemical substance like ammonia, carbon di oxide, methyl chloride, Freon etc.

- There are two major types of refrigeration cycles –
  a) Vapour compression refrigeration cycle
  b) Vapour absorption refrigeration cycle



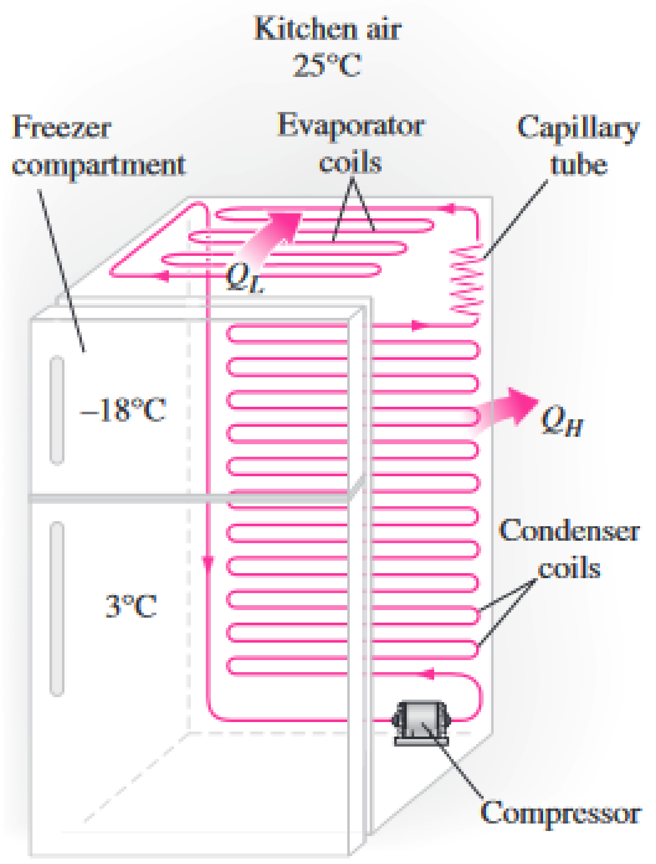
VAPOUR COMPRESSION REFRIGERATION CYCLE

- The vapour compression refrigerator which works on vapour compression cycle, finds use for domestic (household) purposes, as well as in many large commercial and industrial refrigeration.



VAPOUR COMPRESSION REFRIGERATION CYCLE

- The vapour compression refrigerator which works on vapour compression cycle, finds use in domestic (household) purposes, as well as in many large commercial and industrial refrigeration.
- The basic components include evaporator, compressor, condenser and an expansion valve.
- The evaporator is located inside the cabinet in which the substance has to be kept cool.
- The condenser is usually located at the back of the refrigerator, while the compressor at the bottom.
- The compressor is driven by electric motor which takes power from the AC supply.



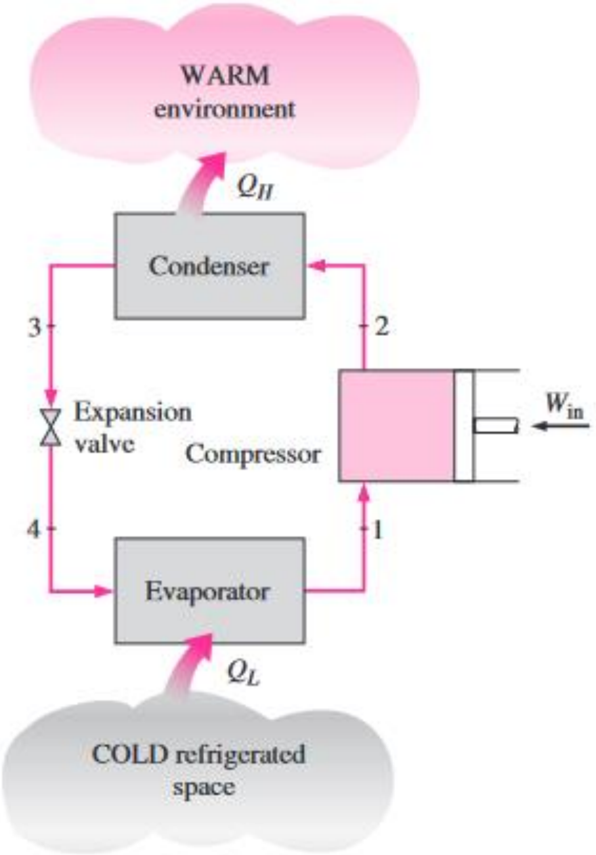
VAPOUR COMPRESSION REFRIGERATION CYCLE - WORKING

- To begin with, let us assume that the **low pressure and low temperature liquid refrigerant** in the evaporator absorbs the heat from the inside of the cabinet and undergoes a change of phase from ***liquid to vapour***.

- This vapour at low temperature and low pressure is drawn into the compressor, where it is compressed to **high pressure and temperature**. The compressor then circulates the refrigerant to the condenser.

- While the high temperature, high pressure refrigerant flows through the condenser, it gives away its latent heat to the cooling medium, either air or water flowing around the condenser coils.

- As a result, the vapour refrigerant gets condensed to ***liquid*** state. The temperature of the refrigerant decreases, but its pressure remains constant.

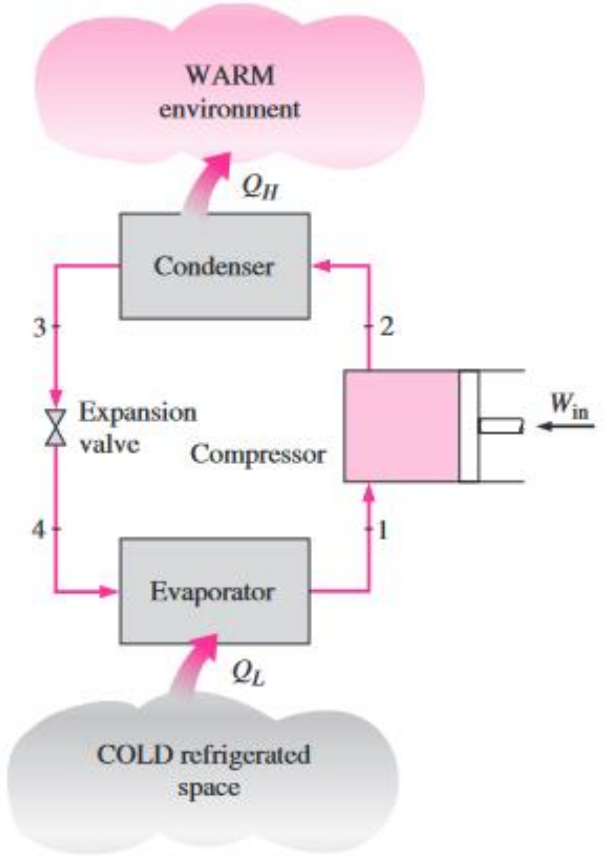


VAPOUR COMPRESSION REFRIGERATION CYCLE - WORKING

- The **high pressure and low temperature** liquid refrigerant coming from the condenser passes through the expansion valve, where it is expanded to **low pressure and temperature.** The temperature of the refrigerant after expansion will be below than the temperature inside the cabinet.

- The low pressure, low temperature liquid refrigerant now enters the evaporator where it absorbs heat from the cabinet and changes into vapour phase. The cycle repeats from here.

- Thus, heat is continuously extracted from the cabinet thereby keeping the substance inside the cabinet at the required lower temperature.



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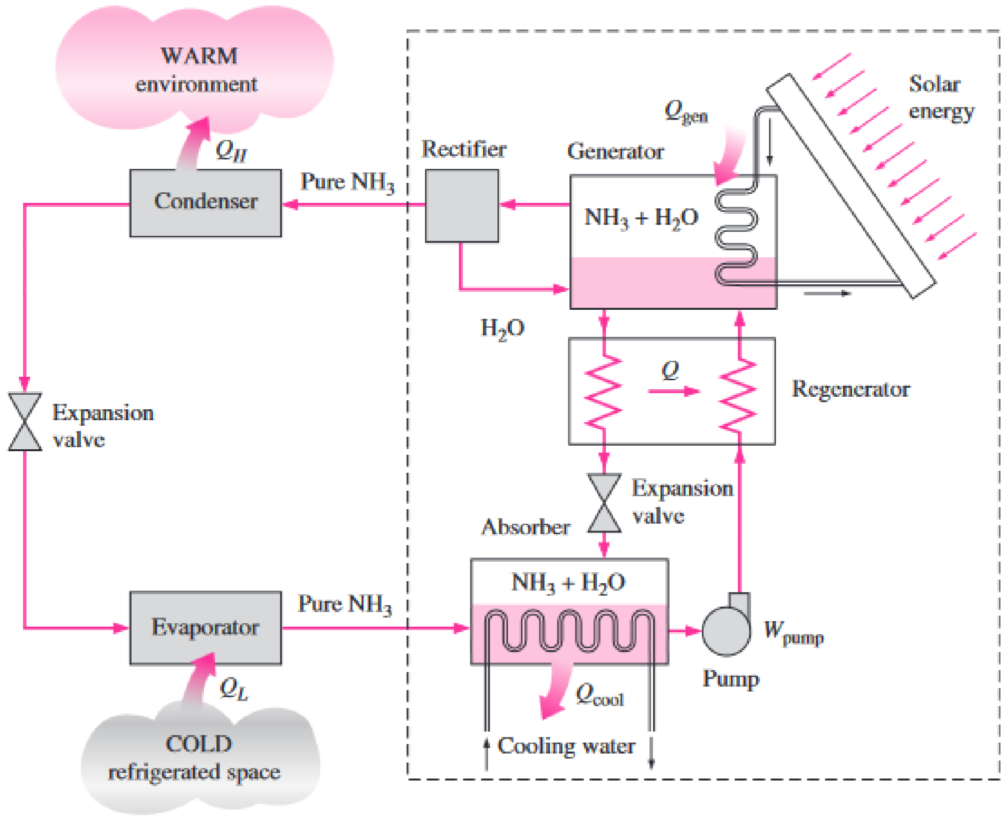
VAPOUR ABSORPTION REFRIGERATION CYCLE

- The vapour absorption refrigeration system is similar in working to the vapour compression system, except for the method of raising the pressure of the refrigerant vapour.



VAPOUR ABSORPTION REFRIGERATION CYCLE

- In the absorption system, the compressor is replaced by an ***absorber, generator and a pump***.
- The system makes use of a heat source such as combustion of LPG, kerosene fuelled flame, solar energy or an electric heating element.
- These heat sources make the system work smoothly and quietly than the compressor – motor used in vapour compression system.
- Further, in an absorption system, the refrigerant used must be highly soluble in a liquid known as ***absorbent***.
- The most common combinations are ***ammonia (refrigerant) and water (absorbent) , water (refrigerant) and lithium bromide (absorbent).***
- VAR is used in **industrial environments** where exhaust waste heat can be used to provide the energy needed to drive the cooling system. It is also used as a **chiller** in office buildings and hospitals.

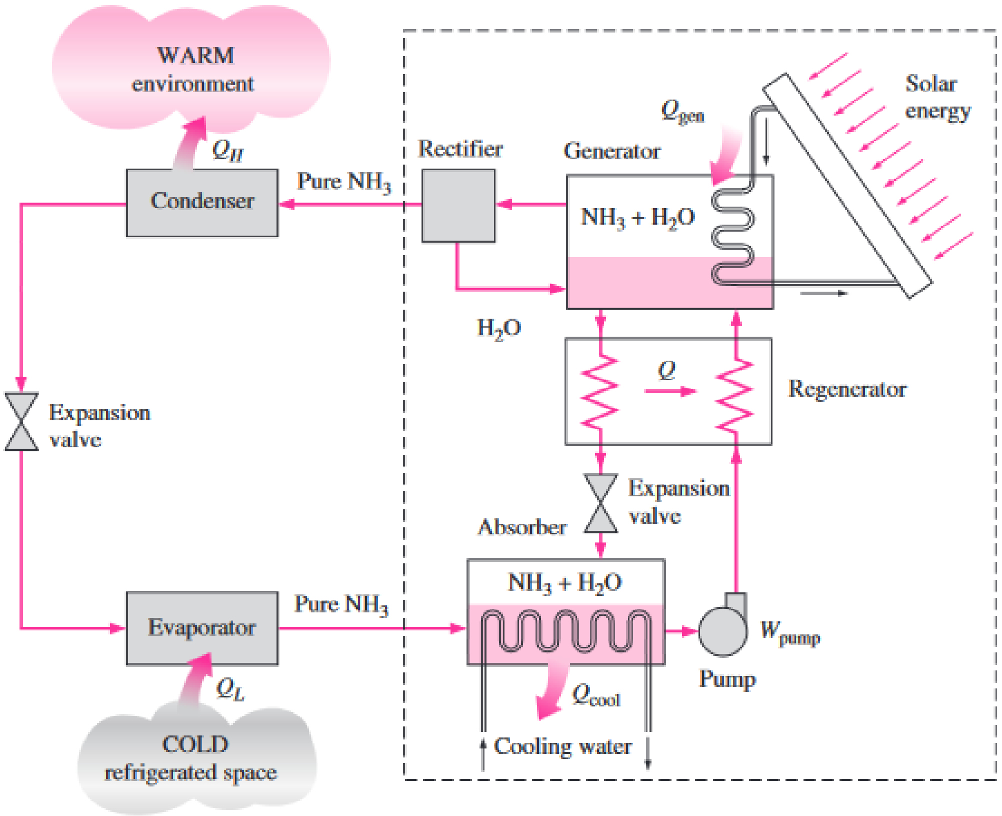
VAPOUR ABSORPTION REFRIGERATION CYCLE – WORKING

- To begin with, let us assume that the ***liquid*** ammonia refrigerant in the evaporator absorbs heat from the inside of the cabinet and undergoes a phase change from ***liquid to vapour.***

- The **low pressure and low temperature** ammonia (NH_3) vapour is passed to the absorber, which contains weak solution of ***ammonia+water***.

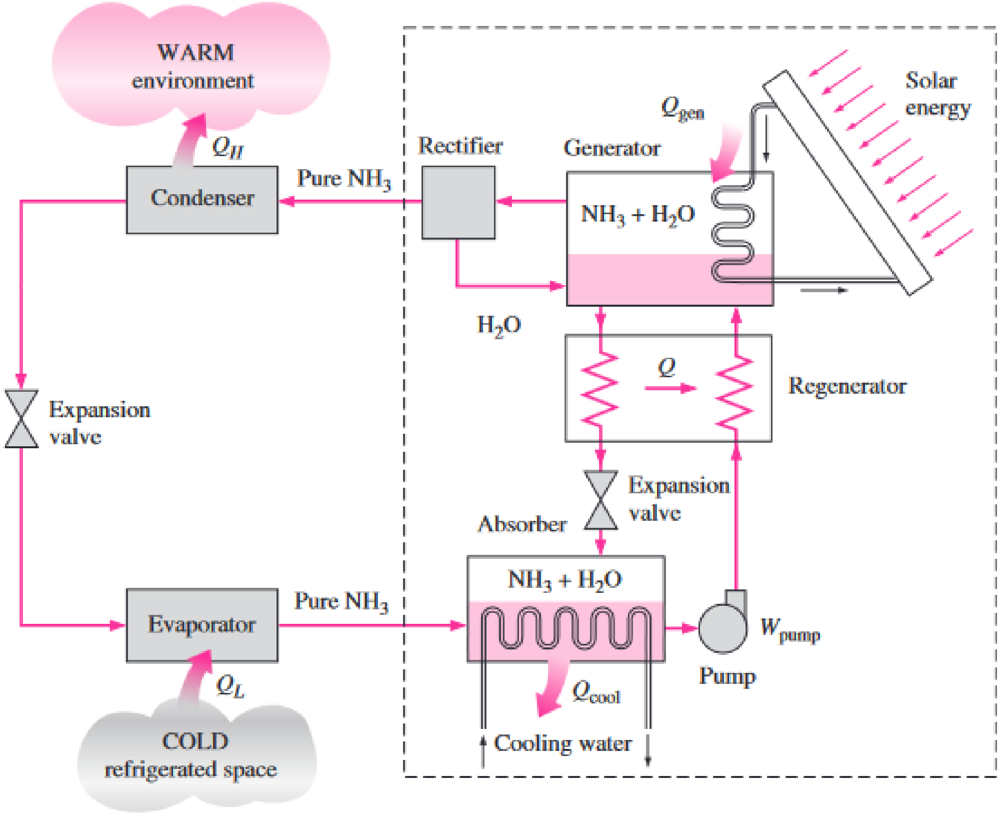
- Since water has the capacity to absorb ammonia vapour, the low pressure ammonia vapour from the evaporator is dissolved in the weak ammonia solution in the absorber resulting in strong ammonia solution.

- This is an exothermic reaction; thus heat is released during this process.



VAPOUR ABSORPTION REFRIGERATION CYCLE – WORKING

- The strong ammonia solution is then pumped to a generator through the heat exchanger at high pressure.
- While passing through the heat exchanger, the strong ammonia solution is warmed up by the hot weak ammonia solution flowing from the generator to the absorber.
- The ammonia solution from the heat exchanger enters the generator, where it is heated by an external source.
- Due to heating, the ***vapour*** gets separated from the ***solution***.
- The ***ammonia solution*** (hot and weak) flows through the heat exchanger to the absorber as shown in the figure.

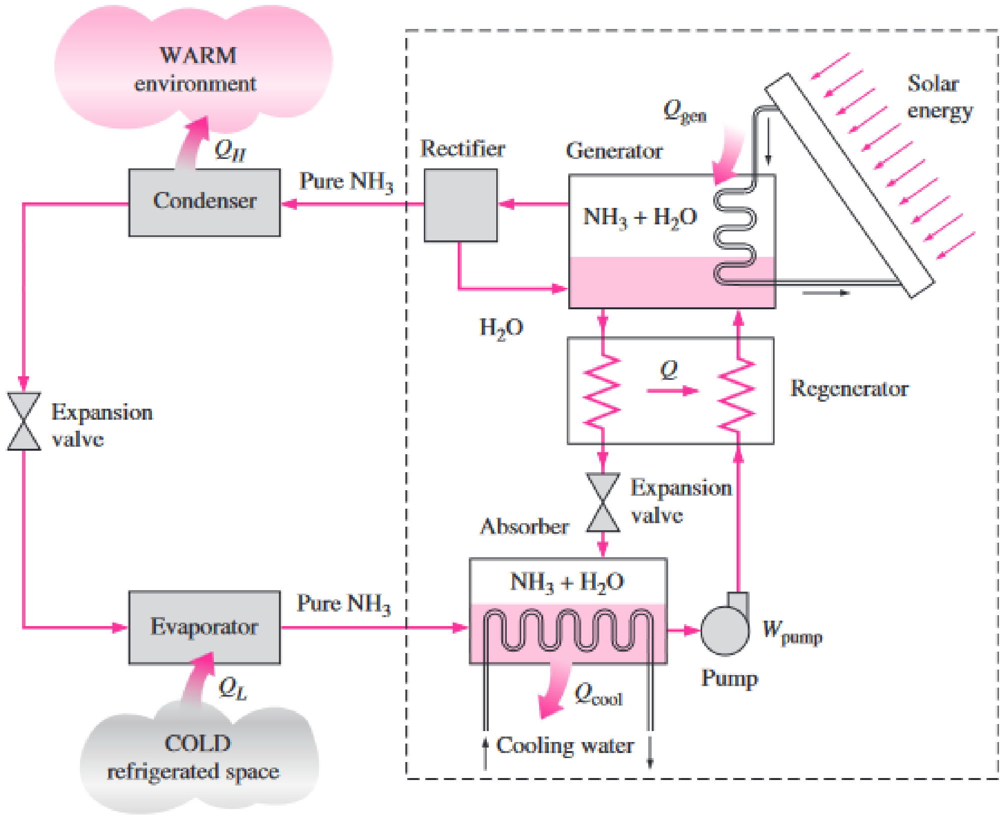


VAPOUR ABSORPTION REFRIGERATION CYCLE – WORKING

- While the **high pressure and high temperature** ammonia vapour from the generator, enters the condenser, where it gives away its heat to the circulating cooling medium (cold water). The vapour refrigerant gets condensed to ***liquid*** state.

- The **high pressure and low temperature** ammonia liquid refrigerant now enters the expansion valve where it is expanded to low pressure and temperature.

- The **low pressure and low temperature** liquid refrigerant enters the evaporator where it absorbs heat from the cabinet and evaporates. The cycle repeats again.



TYPES OF REFRIGERANTS

- Some of the commonly used refrigerants –

1) **Ammonia** – It is one of the oldest and widely used of all the refrigerants. However it is highly toxic, not miscible with lubricating oil, explosive, moderately flammable, irritating and corrosive. These food destroying properties makes it unsuitable for domestic refrigerators. It is widely used in large commercial applications like ice manufacturing plants, packaging plants, cold storage etc.

2) **Freon** – Freon group of refrigerants are highly efficient and overcomes the disadvantages of all other refrigerants like ammonia, sulphur di oxide, carbon di oxide etc.
   R 12 – It has a chemical formula CCl_2F_2 (dichloro difluoromethane). It is used in small capacity equipments such as domestic refrigerators, water coolers, air conditioners etc.
   R 22 – It has a chemical formula $CHCl_2F_2$ (Chloro difluoromethane). It is used in large capacity plants like packaged air conditioning units where size of equipment and economy are important.

TYPES OF REFRIGERANTS

- Freons were found to deplete the ozone layer thereby making us to search for newer refrigerants.

3) **HFC (Hydro Fluoro Carbon) –** HFCs are a family of hydrocarbons containing one or several fluorine atoms, but no chlorine atoms; thus have no ozone depleting potential. Members of this family of compounds possess favourable thermodynamic, healthy and safety properties to be used as an alternative refrigerant to R12 and R22. For example, R134A known as tetrafluoromethane (CH_2FCF_3) is a HFC compound with no chlorine content is identified as a replacement for R12 refrigerant.

APPLICATIONS OF REFRIGERATION –

1) Food processing, preservation and distribution

2) Chemical and Processing Industries

3) Special applications – Ice manufacturing, Cold treatment of metals, Manufacturing and preservation of medicines, chemicals etc.

4) Air conditioning – Indoor cooling for comfort, vehicular air conditioning, laboratories etc.

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AIR CONDITIONING

- ***Air conditioning is defined as the process of simultaneous control of temperature, humidity (moisture content in air), cleanliness and air motion of the confined space.***

- The principle of air conditioning is similar to that of refrigeration, except without an insulated box.

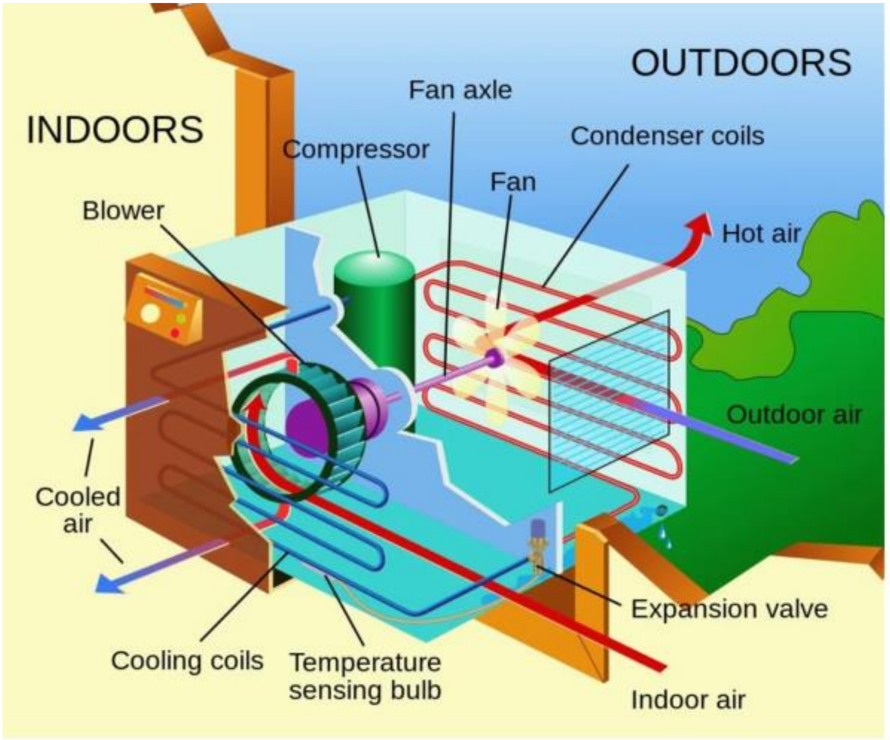
- The cooling is achieved using a vapour compression refrigeration cycle.

- A refrigerant usually Freon 22 or HFC like R134A is made to circulate through various components like evaporator, compressor, condenser and expansion valve to complete the working cycle.

- Room air conditioner, also called window unit is the simplest form of air conditioning designed to cool a single room.

ROOM AIR CONDITIONER

- The air conditioner unit mainly consists of a compressor, condenser, expansion valve and an evaporator working in a vapour compression cycle.
- Other components include an air filter, a control panel, a double shaft motor that drives a fan at one end and a blower at the other end.
- The evaporator and expansion valve are located at the room side (indoor) while the compressor and condenser are located at the outdoor side.
- The room side and the outdoor side of the unit are separated by an insulated partition wall within the casing of the air conditioner.

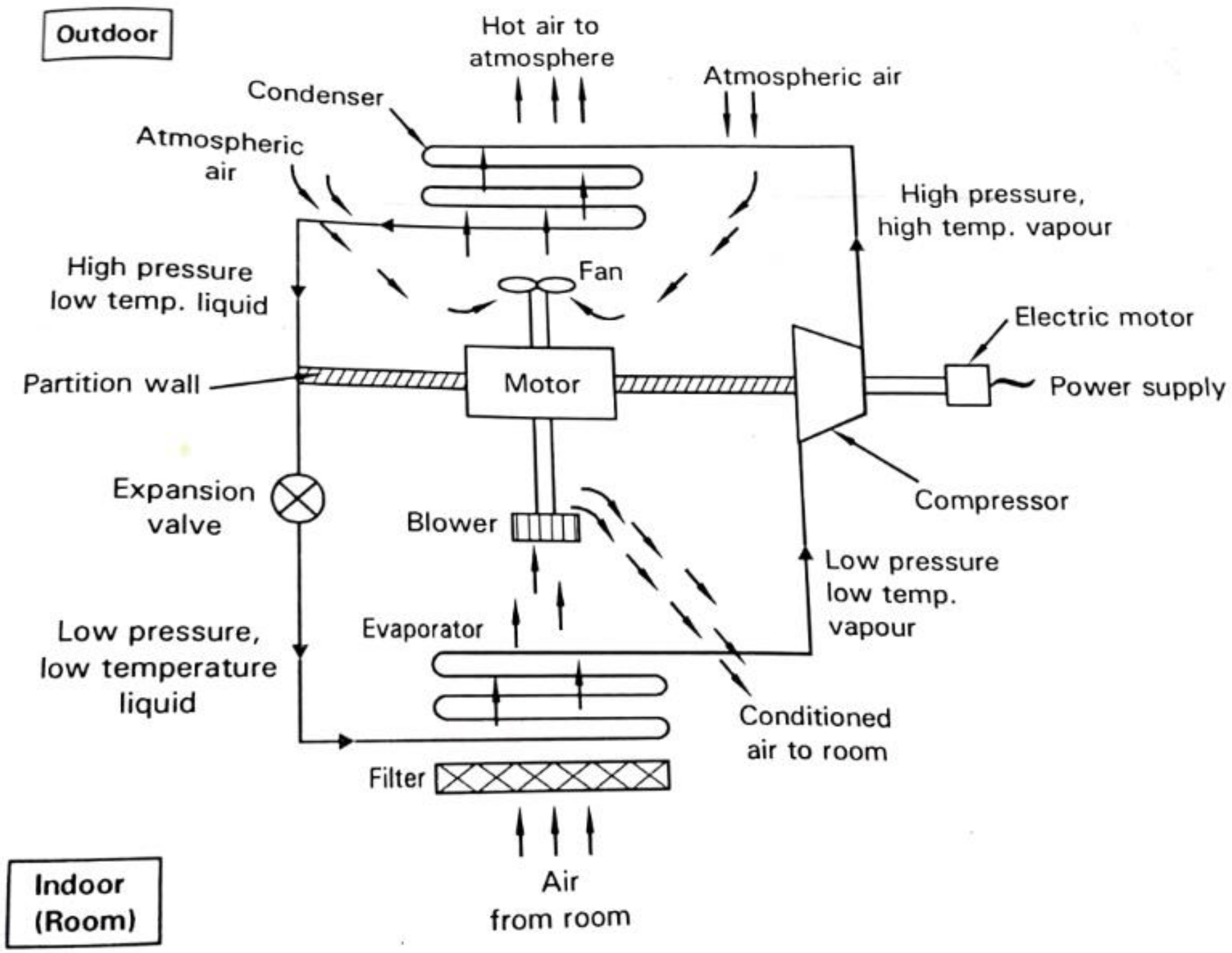


ROOM AIR CONDITIONER - WORKING

- The blower draws the warm air from the room through the air filter and over the evaporator coils.

- The low pressure and low temperature liquid refrigerant flowing through the evaporator coils absorb heat from the warm air and undergoes a change of phase from liquid to vapour.

- The blower then delivers the cool air to the room where it mixes with the room air to bring down the temperature and humidity of the room.



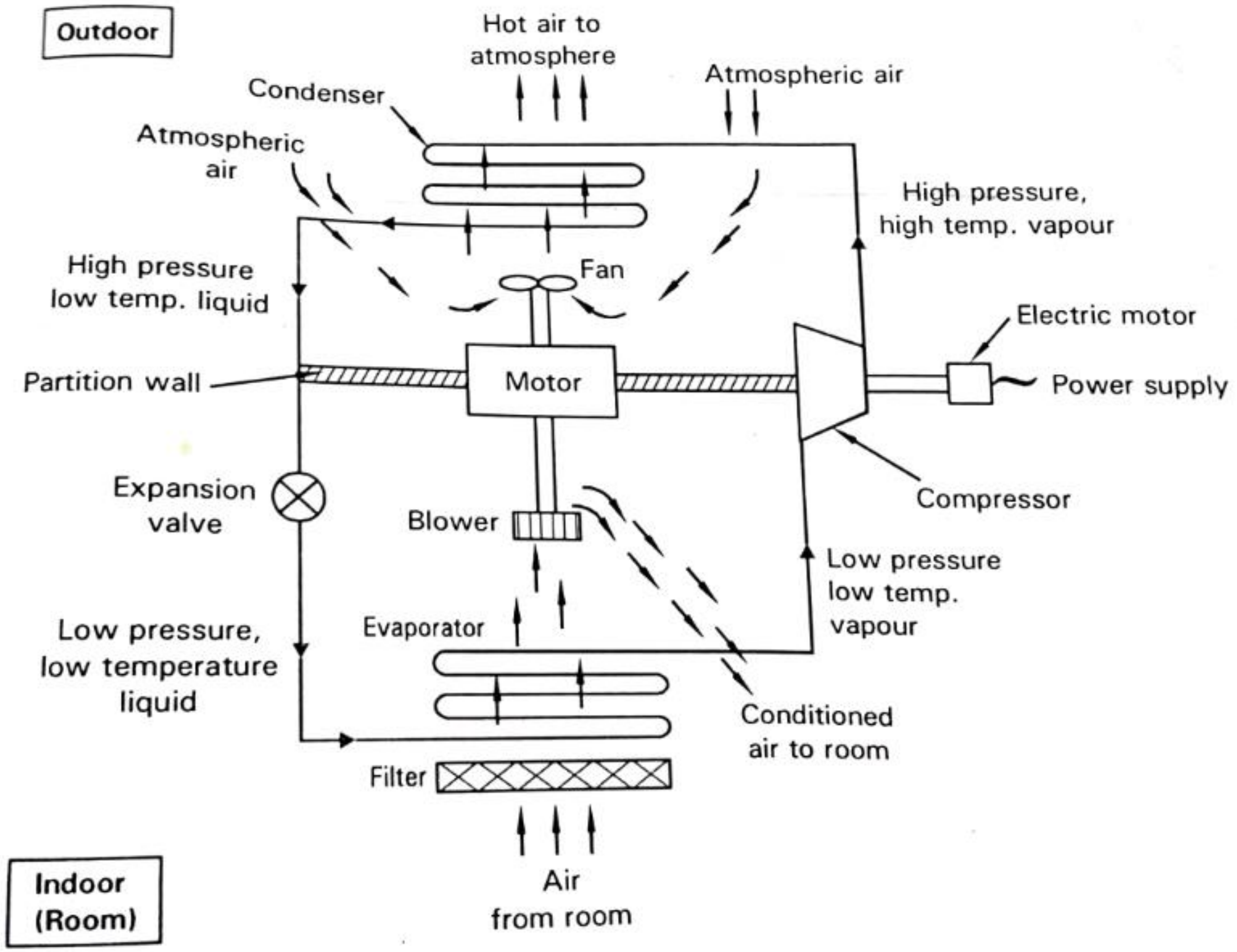
ROOM AIR CONDITIONER - WORKING

- The low temperature and low pressure vapour refrigerant from the evaporator is drawn by the suction of the compressor, which compresses it to high pressure and temperature.

- The high pressure, high temperature vapour refrigerant now flows through the condenser coils.

- The fan located at the outdoor side draws atmospheric air and blows it over the condenser coils.

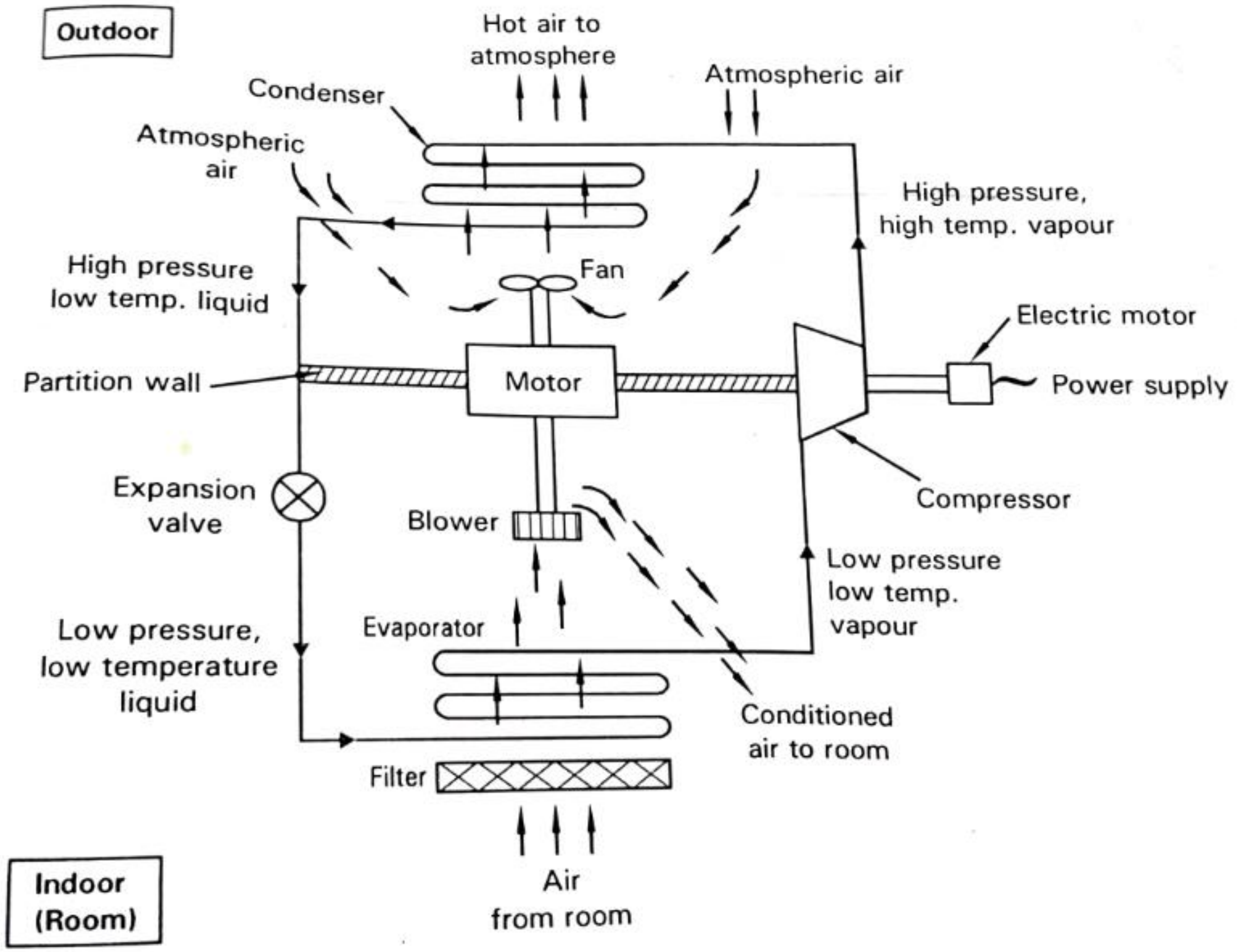
- The heat contained in the refrigerant is dissipated to the atmosphere, and as a result, the vapour refrigerant condenses to liquid state.



ROOM AIR CONDITIONER - WORKING

- The high pressure, low temperature liquid refrigerant now enters the expansion valve, where it is expanded to low pressure and temperature.

- The low pressure and low temperature liquid refrigerant enters the evaporator coils, absorb heat from the warm air, and the cycle repeats until the desired temperature inside the room is achieved.



APPLICATIONS OF REFRIGERATION –

1) **Comfort applications** – Residential buildings, institutional buildings like hospitals, academic computer laboratories etc., commercial buildings like malls, shopping centers etc, transportation like cars, buses etc.

2) **Process applications** – Hospitals, Industrial environment especially in production of Ics, microprocessors, nano material fabrication etc., nuclear power plants, pharmaceutical, chemical and biological laboratories, etc.