THERMAL ENGG.-I

PREPARED BY

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UNIT-I
SOURCES OF ENERGY

ENERGY & ITE RESOURCES

Energy is defined as the capacity to do work. It may be available in a thermodynamic system (fixed mass) or in a control volume (fixed volume), using which work may be done. The energy is of various forms; kinetic and potential energy (mechanical form), internal energy (molecular level), chemical energy (as stored in fuel or battery), electrical energy, nuclear energy (atomic level), and so on. Internal energy, a microscopic form of energy, is normally evaluated using basic properties such as temperature and pressure. This is used in the conservation of energy, defined by the first law of thermodynamics.

ENERGY & ITE RESOURCES

EXAMPLE OF HARNESSING THE ENERGY:

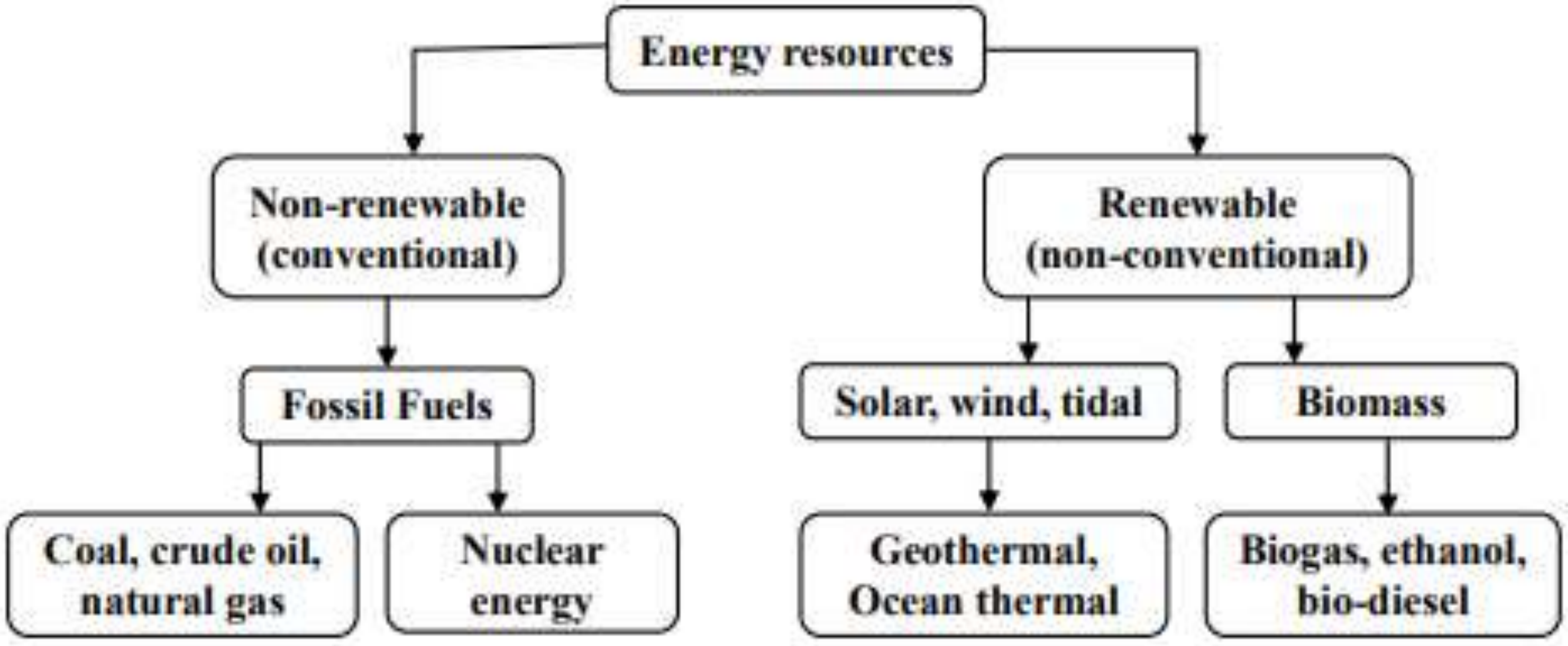
- The potential energy of stored water can be used to produce electricity by using it to run a Pelton wheel turbine.
- Chemical energy in a fuel can be brought out by burning it with an oxidizer such as air in a furnace. During this process, which is called combustion, heat is released that can be used to produce steam and run a steam turbine or produce hot gas, which can be used to run a gas turbine which in turn rotates the generator coupled with it for generating electricity.
- Chemical energy is also available in a battery or fuel cell, which can be used as electrical energy directly. Nuclear energy produces electrical power through nuclear fission reaction.

CLASSIFICATION OF ENERGY SOURCES

Energy sources are classified in different ways :

- Non-renewable or renewable, based on whether they deplete on usage or they are available for usage within a time period or in a cyclic manner.
- Conventional or Non-conventional. Energy sources such as fossil fuels (coal, crude oil, natural gas and so on), nuclear energy, and hydro energy, are being used for several decades. These are called conventional energy sources. Renewable counterparts such as solar, wind, and tidal energy, have been used in the past in a large scale, especially when conventional energy sources had scarcity. Therefore, these sources are often called non-conventional energy sources.

CLASSIFICATION OF ENERGY SOURCES



CLASSIFICATION OF ENERGY SOURCES

Natural gas & CNG

Natural gas is a colourless and odourless gas, consisting primarily of methane (CH_4) by around 95% on a volume basis. Traces of higher order hydrocarbons (C_2H_2, C_2H_4, etc.), carbon dioxide, water vapor and nitrogen are also usually present in natural gas. Some amount of sulfur may also be present. It is available underground over crude oil deposits. It is extracted, compressed and stored in huge storage tanks. When the natural gas is compressed to pressure in the range of 200 bar and 250 bar, a good energy density is obtained. This is called Compressed Natural Gas (CNG). It is lighter than air, having a molecular mass of around 16 kg/kmol, and it has a calorific value between 50000 kJ/kg to 55000 kJ/kg.

CLASSIFICATION OF ENERGY SOURCES

Liquid Petroleum Gas(LPG)

Liquid Petroleum Gas (LPG) is a mixture of various hydrocarbons, with butane and propane as its primary constituents. This evolves during the refining of petroleum. When the gas mixture is pressurized to over six times the atmospheric pressure, it liquefies. The liquid is stored in steel cylinders and distributed to homes and industries. Once released through a pressure regulator into the atmosphere, the liquid instantly vaporizes into its gaseous components. LPG has a molecular mass of over 50 kg/kmol and is heavier than air. Commercial LPG has a synthetic odorant added for easy leak detection. It has a calorific value between 45000 kJ/kg to 50000 kJ/kg.

CLASSIFICATION OF ENERGY SOURCES

Applications of Solar Energy

- Solar energy can be used in cooking. The solar radiation is reflected into a metal vessel, which is coated in the black color inside, to absorb the heat effectively. The lid, when open, can reflect the sun ray into the box, where food to be cooked is kept.
- Further, solar energy is also used in the desalination of seawater. In one of the methods, solar energy is directly used to heat water, evaporate it and allow it to condense over an inclined surface to collect fresh water. Such devices are called solar stills. In the indirect method, first solar energy is used to produce power and that is used to desalinate using membranes.

Solar Energy

Solar energy, obtained as the radiation from the Sun can be utilized in several applications. Most of the solar radiation reaching the earth consists of wavelengths in the range of 315 nm to 1400 nm, 45% of this radiation is in the visible region (400 nm to 700 nm). The earth absorbs radiation mainly in the visible region and emits radiation in the infrared region. Solar energy is an almost limitless source of energy available with negligible pollution.

However, the limitations are:

(1) At present, it is expensive to produce Sources of Energy power at a large scale using solar energy,

(2) It is possible to harness this only when the sun shines; the output varies with a change in irradiation and

(3) It needs energy storage devices to store and supply the energy when the sun is not available, making it complex and expensive. Research works are still going on to improve the utilization of solar energy effectively. Solar energy is used in several applications. It is used to produce heat or electricity directly.

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CLASSIFICATION OF ENERGY SOURCES

Flat Plate Collector (FPC)

Definition: A flat plate collector is a solar thermal device that absorbs solar radiation using a flat absorbing surface and converts it into heat.

Construction:

•Absorber plate (usually copper/aluminum coated with black paint)

•Transparent glass cover

•Insulated casing

•Tubes for water or fluid

Working:

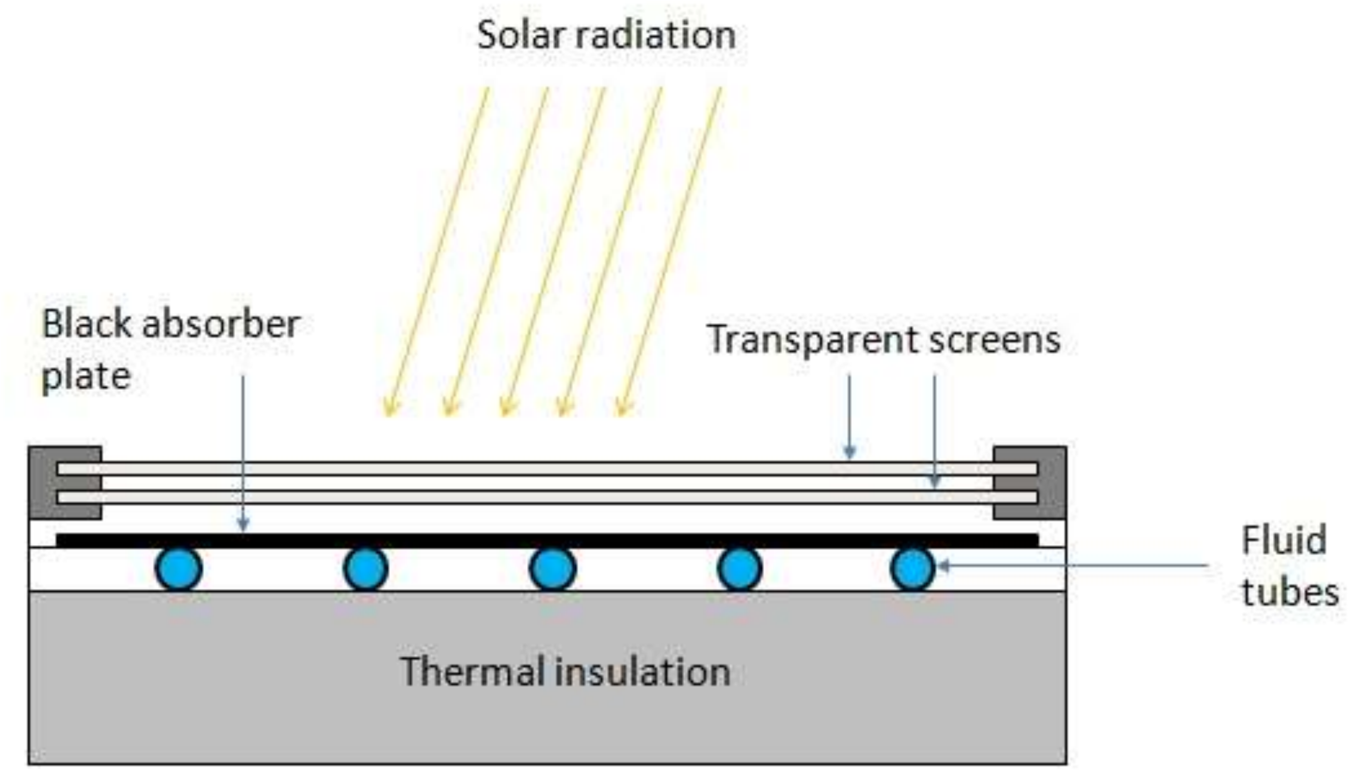
- Sunlight passes through the glass and heats the absorber.
- Heat is transferred to the fluid flowing in tubes.

Applications:

- Solar water heating
- Space heating

CLASSIFICATION OF ENERGY SOURCES

Flat Plate Collector (FPC)



CLASSIFICATION OF ENERGY SOURCES

Concentrating Collectors (CC)

Definition: These focus solar radiation onto a small area using mirrors or lenses to achieve higher temperatures.

Types:

•Parabolic Trough

•Parabolic Dish

•Heliostat Field with Central Receiver

Working:

•Mirrors focus sunlight onto a receiver tube.

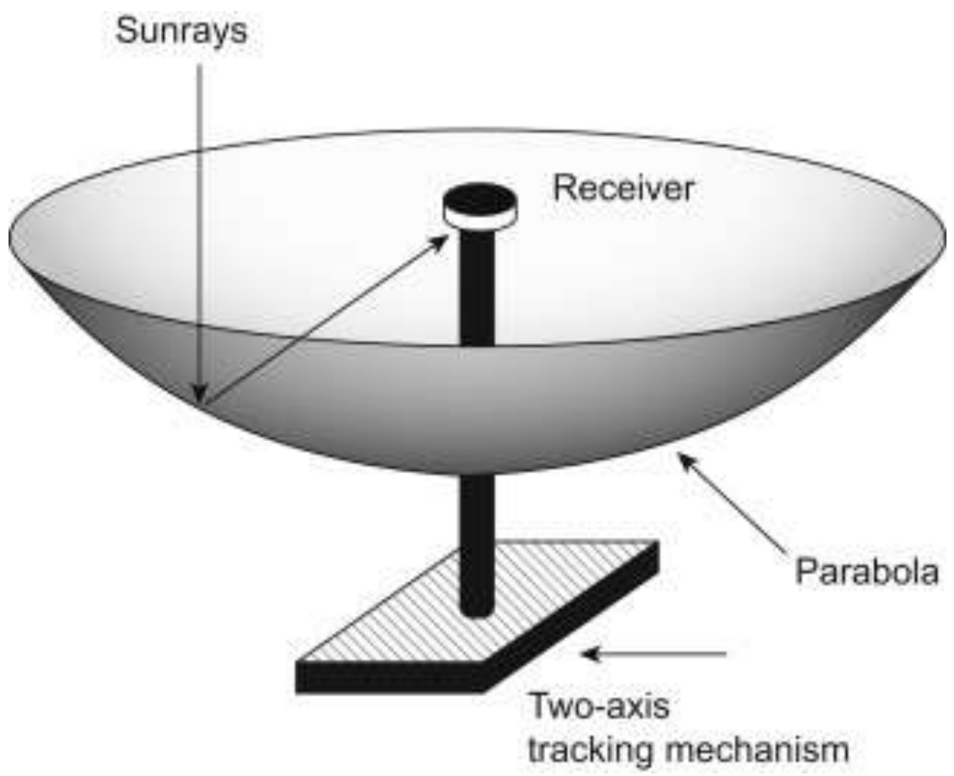
•High-temperature fluid (oil, salt) flows and carries heat.

Applications:

•Power generation (CSP - Concentrated Solar Power), Industrial process heat, Solar cooking

CLASSIFICATION OF ENERGY SOURCES

Concentrating Collectors (CC)



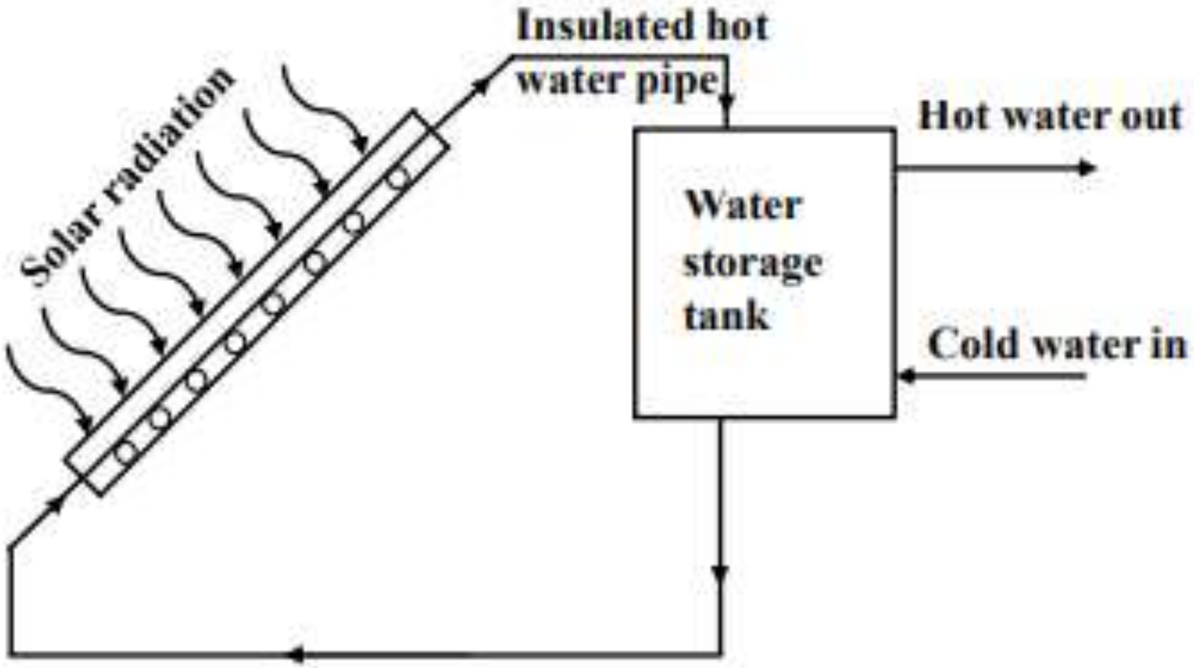
Solar Heater

Solar Heating

In cold regions, solar energy is used to heat buildings. Sunspaces, which act as heat absorbers, are used for this purpose. These are tiles or some form of bricks, which can absorb energy incident on that during the daytime and release the heat during the night. Solar energy can be used to heat water in a roof tank. The collector heats the water, which then flows to a well insulated pipe into a well-insulated storage tank. The flow of water is due to natural circulation for small-scale applications. In larger-scale applications, pumps are used to circulate the water. A schematic of a typical solar water heater with natural circulation of water

Solar Heater

Schematic Diagram of Solar Heater



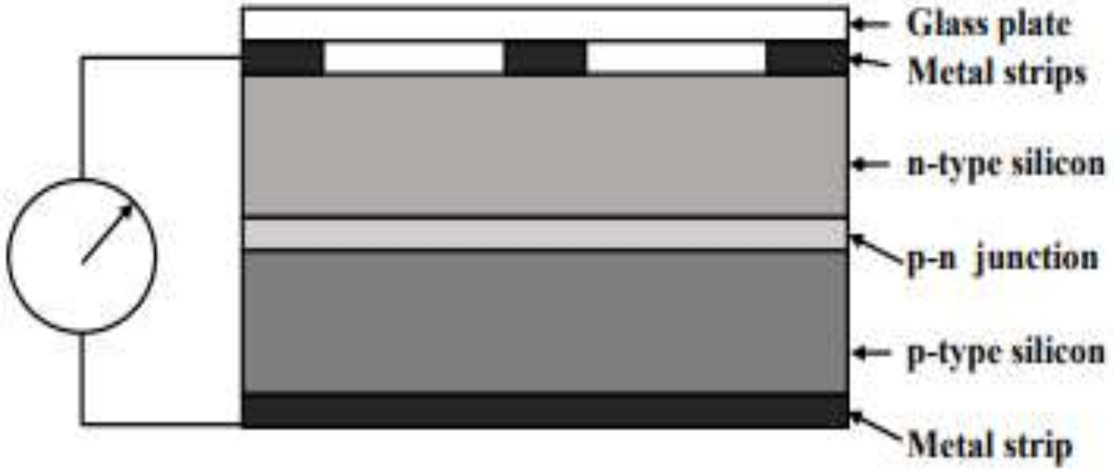
Solar Photo Voltaic Cell

Solar photovoltaic cell: Photon is the smallest unit of radiant energy, which is invisible. Its energy is equal to the frequency of radiation multiplied by Planck's constant. Photons can be viewed as particles, which carry solar radiation at a speed of 3 × 105 km/s. When photons of sufficient energy are incident on special semiconductor materials made of silicon, the photons are absorbed and electrons are generated. **This is called the photoelectric effect**.

- When an electron leaves an atom, a vacant space (positively charged, termed a hole) is created and the electrons randomly move toward another vacant space. Electrons can be made to flow in one direction, completing a loop, two types of silicon layers are used. One layer of silicon is doped with phosphorus that has one more electron than silicon. This is called n-type.
- The other layer is doped with boron that has one electron less than silicon. **This is called p-type.** A p-n junction is formed using these two layers formed as a sandwich. Above this sandwich layer, a glass plate with an anti-reflective coating is provided. Metal strips are also provided beneath the glass plate to provide electrical contact. At the bottom of the sandwich layer, another metal layer is provided to provide electrical contact. When photons are incident on an n-type layer, electrons are excited and they move to the n-side by an electric field. Similarly, the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in

Solar Photo Voltaic Cell

the form of electrical energy. This produces a direct current. The efficiency of a solar PV is around 15% and the materials are costly. Research works are going on to reduce the price and improve efficiency. A schematic of a photovoltaic (PV) cell is shown in Fig. Many PV cells are used to construct a PV module. In a PV system producing solar electricity, many PV modules are used.



Solar Distillations

Solar distillation is the process of using solar energy to purify water by evaporation and condensation. It mimics the natural water cycle using a simple, low-cost setup.

Principle: When impure/salty water is heated by solar radiation:

- **Water evaporates**, leaving behind impurities.
- **Vapors condense** on a cool surface, forming pure water droplets.

Components:

- **Black basin**: Absorbs heat (filled with impure water)
- **Transparent cover**: Glass/plastic, sloped for condensation
- **Condensate channel**: Collects and directs pure water
- **Insulation**: Retains heat below basin

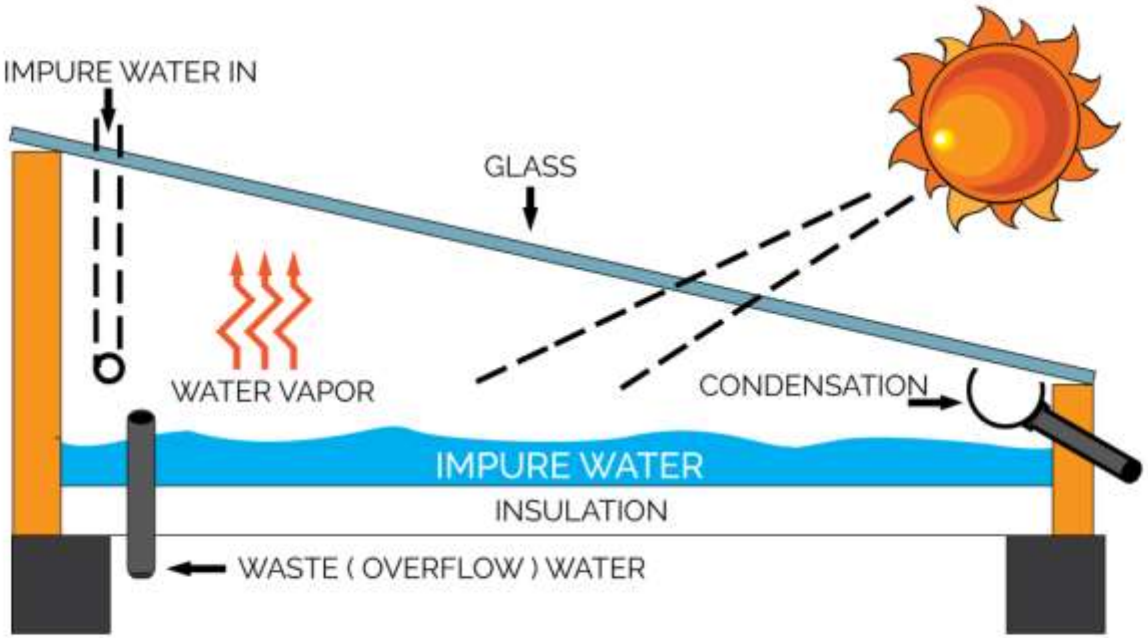
Applications: Purification of brackish or seawater, Water purification for labs and batteries, Drinking water production in remote areas.

Advantages: Uses free solar energy, Low maintenance and eco-friendly, Simple design — suitable for rural use

Limitations: Low output (2–5 liters/day per m^2), Requires sunlight; not suitable in cloudy regions, Slower than mechanical distillation.

Solar Distillations

Schematic Diagram of Solar Distillation of Water



Wind Energy

Wind (airflow) is generated globally due to the rotation of the earth and differential solar heating of the earth and its atmosphere. It is also generated locally due to differential heating of ground and water surfaces. The kinetic energy of the wind is used to rotate a single blade or set of blades. This in turn rotates a generator, through a set of gears, and produces electricity. The wind speed should be in a given range (2 m/s to 15 m/s) for convenient operation of a windmill. A set of anemometers is used to estimate the speed and direction of the wind, and the blades are oriented in windward direction suitably, to enable optimized operation of the windmill. Thus, a feedback control loop is used. Based on a detailed survey, regions are identified to set up windmills. The wind movement may be seasonal and therefore, the windmill may not operate throughout the year. Wind turbines are classified mainly with respect to their axis of rotation - as wind axis (horizontal axis) and crosswind (vertical axis) turbines. There are several configurations in each of these. The orientation of blades (called steering) is done by active (feedback-based) or passive (using tail) methods. Windmills are available in capacities in the ranges of 0.5 kW to 15 kW (small), 15 kW to 150 kW (medium) and 250 kW to 1000 kW (large). There are installations of more than 1 MW in some countries including the USA. Even though wind energy is relatively inexpensive to generate and it produces no pollutants, windmills may be set up only in certain areas, where sufficient wind speed is available and the power generation may also be seasonal.

Tidal Energy

Tidal energy is obtained from tides, which are formed by gravitational forces between the moon and the earth. The ocean water level changes during the rise or fall of the tide and this is a form of kinetic energy. The resulting movement of water can be used to run a turbine and generate power. The turbine is designed such that it is rotated in one direction both during increasing or decreasing water levels. This is renewable energy with no pollution. It is also reliable. However, it has high construction and maintenance costs and has an environmental impact. Further, it is not available at all locations.

Ocean Thermal Energy

Ocean thermal energy utilizes the natural temperature difference between the ocean surface and the deep ocean. The hot surface temperature is used to heat and vaporize a liquid and run a turbine. The heat is rejected to the cold temperature of the deep sea. For example, Hawaii in the USA has much warmer surface water and very cold water in the deep ocean. The U.S. National Science Foundation has funded an ocean thermal energy conversion facility in this area. This source is fuel free, has no significant pollution, produces pure water during the cycle, has low maintenance, is reliable and so on. However, it can be used only in a few locations. It has a high initial cost, moderate efficiency and can be harmful to marine life.

Geo Thermal Energy

Geothermal energy is obtained from the underground, sub-surface of the earth. Geothermal energy is a renewable energy source as heat is continuously produced inside the earth. This can be used for heating purposes as well as for power generation. It is available in a few countries such as New Zealand, the Philippines, Kenya and so on, where a good contribution to power production by geothermal energy is obtained. However, on the disadvantages side, the cost is much high, it can contaminate the water, reservoirs should be properly maintained and so on. Further, it is not available in all places and is location-specific. Researchers mention that natural calamities such as an earthquake can result due to the harnessing of geothermal energy in some places.

Bio Gas, Bio Mass & Bio Diesel

Biomass is a renewable energy source. It is also called a carbon-neutral energy source. It is an organic matter obtained from plants (wood, rice straw, wheat straw), plants derived materials (vegetable seeds, rice husk, wheat hush, sugarcane bagasse) and animal wastes such as cow dung. It primarily consists of hemicellulose, cellulose, and lignin. Biomass fuels can be directly burnt in furnaces to generate heat. Wood is currently used for heating and cooking purposes in several countries. In rural places in India, wood stoves are primarily used for cooking. There are several types of biomass fuels, which can be burnt directly to produce power. Presently, biomass is used as a fuel blend along with coal in several power plants. Biomass can also be used in several processes to produce various types of fuels. Biomass can be subjected to processes such as pyrolysis, anaerobic digestion and gasification, to convert biomass into gaseous fuels such as producer gas, synthetic gas and biogas.

Bio Gas, Bio Mass & Bio Diesel

Synthetic gas is primarily a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. Biogas mainly consists of methane (50% to 60%) and the rest of carbon dioxide. These gaseous fuels can be used in furnaces for heating purposes as well as for power generation. Vegetable seeds are used to produce vegetable oils. When the vegetable oil is processed in the transesterification process, its glycerine content is removed, and bio-diesel is got.

Bio Gas, Bio Mass & Bio Diesel

Bio-diesel has features closer to fossil diesel. It can be used in diesel engines by blending some proportion of it with diesel. Sugarcane bagasse can be processed to get ethanol, a cleaner alcohol fuel. The advantages of bio-diesel and ethanol are that they are oxygenated fuels and their combustion performance is better. Also, several other chemical processes are available to convert biomass into useful chemicals. The main advantage of biomass is that it is renewable and closes the carbon cycle within a few years. However, it is available only in certain locations and the whole energy demand cannot be met by biomass as per the present scenario. Further, the variations in the properties of biomass are extensive and it is not easy to design a reactor for biomass for optimal operating conditions and performance. Research works are ongoing to address these issues.

HYDRAULIC (HYDROPOWER) ENERGY

Hydraulic or hydropower is the energy obtained from flowing water. Water in rivers is stored in dams and is let out at required rates for various purposes. The water level behind a dam is generally several meters and this acts as a huge reservoir. This stored water has a good amount of potential energy. When the water is allowed to flow through a given opening in the dam, the potential energy of water is converted to kinetic energy. The flowing water can be made to pass through a rotating device such as a Pelton wheel turbine so that it rotates and in turn rotate a generator to develop electrical power. In some possible cases, the flowing water in a river can be diverted to another passage, where it is made to pass through a special turbine to generate power. Hydropower has advantages such as it is a very clean, renewable source, quick starting and so on. However, it has disadvantages such as it needs a large area to construct the dam, high initial and maintenance costs, problems with fisheries and so on. Further, in some areas, the construction of huge dams can create seismic problems.

NUCLEAR ENERGY

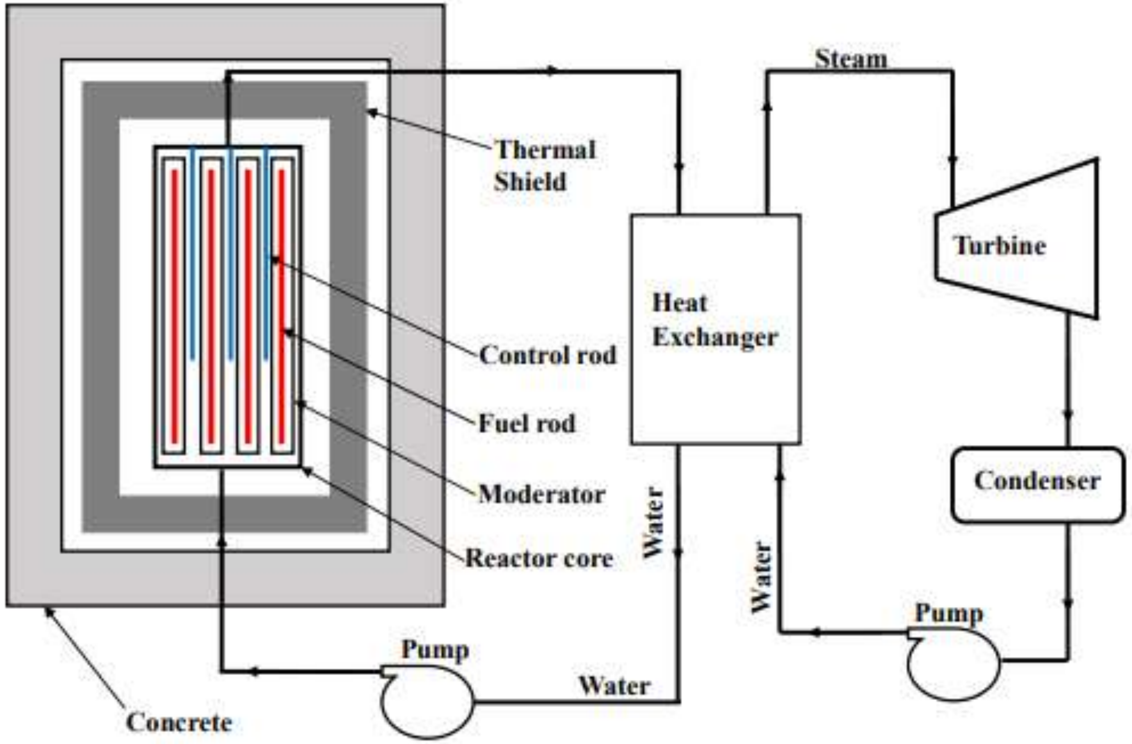
Nuclear energy is got from the nucleus of an atom. When the nucleus of relatively unstable heavy atoms such as uranium 235 (92U235), for example, is split into two smaller nuclei using neutrons, heat is released. The reaction is written as follows:

$$_{92}U^{235} + {_0}n^1 \rightarrow {_{92}}U^{236} \rightarrow {_{56}}Ba^{141} + {_{36}}Kr^{92} + 3\ {_0}n^1 + 177\ \text{MeV (energy)}$$

This reaction yields Barium, Krypton, three neutrons and 177 Mega electric volts of energy. When the neutrons produced react further with uranium atoms, more energy is produced. This reaction proceeds as a chain reaction and if not controlled would lead to excessive energy liberation and disaster, as in the case of an atom bomb. However, in nuclear reactors, the reaction is carried out in a controlled manner, by allowing only one neutron to react further and by absorbing other neutrons. Control rods, made of hafnium or boron, in a nuclear reactor serve the purpose of absorbing neutrons, thereby reducing the rate of the chain reaction. The products are radioactive. Disposal of these wastes has not been planned yet. They are kept underground. Uranium reserves are not very high. Thus, the usage of nuclear energy will also deplete. Thus, this cannot be considered as renewable energy. These are the few disadvantages of nuclear energy. However, one kg of uranium can produce energy generated by burning approximately 200 kg of oil or 4000 kg of coal. The energy from the nuclear fission reaction can be used to heat water, produce steam and run a steam turbine to produce power. A schematic of a nuclear reactor is shown in Fig.

NUCLEAR ENERGY

Schematic Diagram of Nuclear Power Plant



NUCLEAR ENERGY

The reactor core has fuel rods, a moderator surrounding it and control rods to control the chain reaction rate. The core is enclosed in a thermal shield. A concrete structure is used to barricade the nuclear reactor core along with a thermal shield. The heat from the nuclear reaction is transferred to water or sodium, which in turn heats water to produce steam in a heat exchanger. The steam runs a turbine and produces electricity.

On the other hand, nuclear fusion reaction, written as,

$$_{1}H^{2} + {}_{1}H^{3} \rightarrow {}_{2}He^{4} + {}_{0}n^{1} + 17.6\ \text{MeV}$$

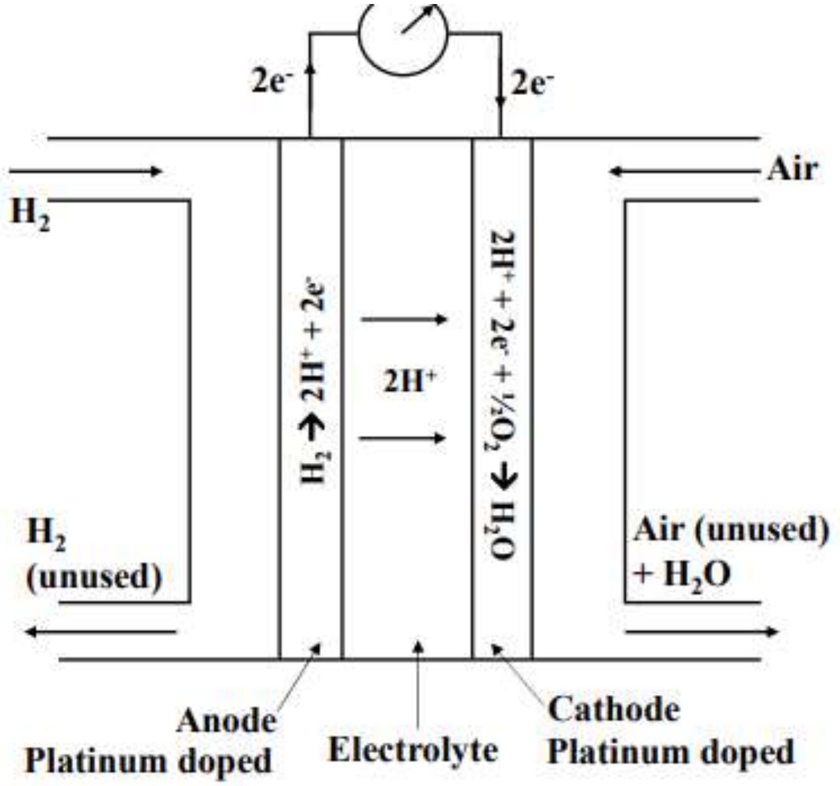
can also be used to produce a significant amount of energy. This process will not produce radioactive products. However, the technology for this process has not yet been available.

Fuel Cells

A **fuel cell** is a device used to produce electricity by converting the chemical energy of a fuel directly to electrical energy. Here, a fuel and oxidizer undergo a series of reactions. If hydrogen is used as fuel, products are only water and electrons (electricity), with some amount of heat release. If a hydrocarbon fuel is used, then carbon dioxide will also be present in the products. A fuel cell consists of two electrodes, which are an anode (negative electrode) and a cathode (positive electrode), kept in an electrolyte. There are layers of catalysts attached to both anode and cathode. A fuel, for example, hydrogen, is fed into the anode chamber. The oxidizer, air, is fed into the cathode chamber. Fuel gas is continuously fed and a part of it diffuses into the catalyst layer of the anode, and the rest of it is recycled back. The catalyst at the anode separates hydrogen molecules into protons (for example, $H+$) and electrons ($e-$). Electrons flow through an external circuit connecting anode and cathode, producing electricity. The protons flow through the electrolyte to the layer of catalyst at the cathode, where it reacts with electrons and oxygen to produce water vapor (and carbon dioxide, in the case of a hydrocarbon fuel) and heat. A schematic of a fuel cell is shown in Fig.

Fuel Cells

Schematic Diagram of Fuel Cell



Fuel Cells

There are various types of electrolytes used depending upon the type of fuel cell. Aqueous alkaline solution, acids and polymer membranes are used in several fuel cells. For example, in hydrogen– oxygen fuel cell, KOH (potassium hydroxide) or NaOH (sodium hydroxide) is used. This is typically an alkaline fuel cell. Here, the water vapor is produced on the anode side and left along with recycling hydrogen. The other types of fuel cells are acid fuel cells (example, phosphoric acid fuel cell), solid acid fuel cell (uses H^+ conducting oxyanion salt, solid acid), solid oxide fuel cell (uses a special ceramic material as electrolyte), direct ethanol fuel cell (uses polymer membrane) and so on. Catalysts are made from materials such as platinum and platinum alloys, supported on carbon. Research is going on for finding cheaper materials to be used as catalysts.

The advantages of a fuel cell are that it directly produces electricity, has high energy density and lower pollution (especially when hydrogen is used as fuel). The disadvantages are its cost, efficiency and less durability.

Introduction to Thermodynamics

Thermodynamics – Definition

Thermodynamics is the branch of science that deals with the **relationships between heat, work, and energy**, and how they affect matter.

Thermodynamic Systems

A **system** is the part of the universe under study, separated by a boundary from its surroundings.

❖ **Types of Systems:**

•**Closed System**: Mass remains constant; only energy crosses the boundary.

Example: A piston-cylinder with no mass entering or leaving.

•**Open System**: Both mass and energy can cross the boundary. *Example: Boiler, Turbine, IC Engine.*

•**Isolated System**: Neither mass nor energy crosses the boundary. *Example: Thermos flask.*

Introduction to Thermodynamics

Thermodynamic Properties of a System

Properties are measurable characteristics of a system that define its state.

◈ **Important Properties:**

- **Pressure (P)** – Force per unit area (Unit: Pa or bar)
- **Volume (V)** – Space occupied by the system (Unit: m^3)
- **Temperature (T)** – Measure of thermal state (Unit: K or °C)
- **Entropy (S)** – Degree of disorder or randomness (Unit: J/K)
- **Enthalpy (H)** – Total heat content, $H = U + PV$ (Unit: J)
- **Internal Energy (U)** – Energy stored within the system (Unit: J)

Introduction to Thermodynamics

Units of Measurement:

Property	SI Unit
Pressure	Pascal (Pa)
Temperature	Kelvin (K)
Volume	m^3
Energy/Heat	Joule (J)

Introduction to Thermodynamics

Intensive and Extensive Properties

•**Intensive Properties**: Do **not** depend on the mass.

Examples: Temperature, Pressure, Density.

•**Extensive Properties**: Depend on the **mass or size** of the system.

Examples: Volume, Internal Energy, Enthalpy.

Introduction to Thermodynamics

Thermodynamic Processes and Terms

- **Thermodynamic Process:** A change of state of the system involving energy interaction.
- **Path:** The **series of states** through which the system passes during a process.
- **Cycle:** A **process or series of processes** in which the system returns to its **original state**.
- **State:** Condition of a system at an instant of time, described by its properties.
- **Path Function:** Value depends on the **path followed**, e.g., Work, Heat.
- **Point Function:** Value depends only on the **state** of the system, not the path.*Examples:*

  Pressure, Volume, Internal Energy.

Introduction to Thermodynamics

Thermodynamic Equilibrium

A system is said to be in **thermodynamic equilibrium** if it is in:

•**Mechanical equilibrium** (no pressure differences)

•**Thermal equilibrium** (uniform temperature)

•**Chemical equilibrium** (no chemical reactions or changes)

Quasi-static Process

A **very slow process** that allows the system to remain in **internal equilibrium** at every stage.

Idealized process used for analysis.

Introduction to Thermodynamics

Laws of Thermodynamics (Statements Only)

- **Zeroth Law:** If two systems are each in thermal equilibrium with a third system, they are in thermal equilibrium with each other.
- **First Law:** Energy can neither be created nor destroyed, only converted from one form to another. (Mathematical form: $\Delta Q = \Delta U + \Delta W$)
- **Second Law:** Heat cannot spontaneously flow from a colder body to a hotter body without external work.
- **Third Law:** As the temperature of a system approaches absolute zero, the entropy of the system approaches a minimum value.

UNIT-II
INTERNAL COMBUSTION ENGINES

Internal Combustion Engines (IC Engines)

Air Standard Cycle Analysis – Assumptions

To simplify IC engine cycle analysis, certain assumptions are made:

•Working fluid is **pure air**, which behaves as an **ideal gas**.

•Cycle is **closed**.

•All processes are **internally reversible**.

•Heat is added and rejected externally.

•No friction or heat losses.

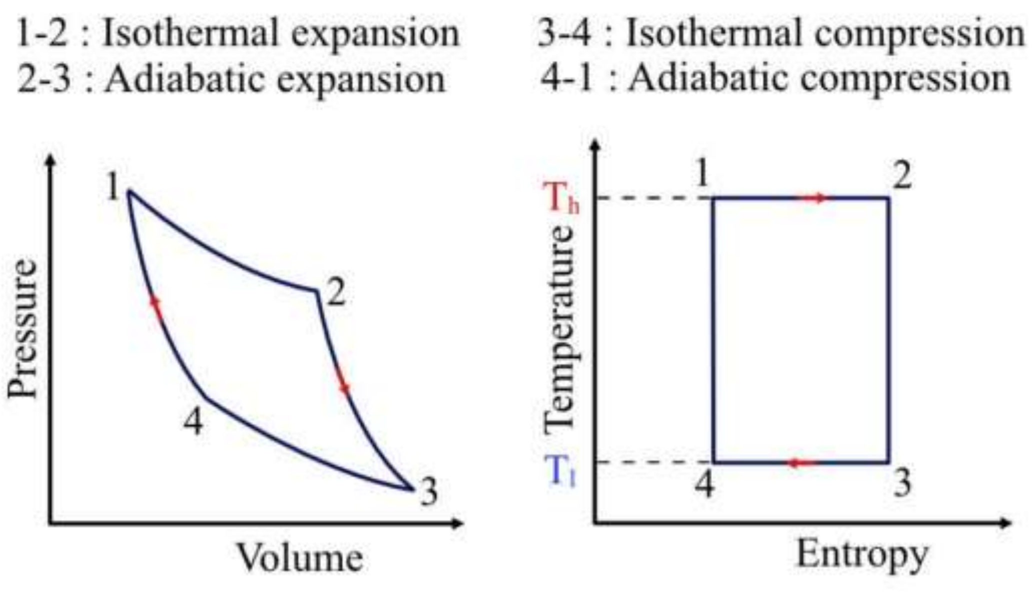
•Combustion is replaced with **heat addition**.

Internal Combustion Engines (IC Engines)

Thermodynamic Cycles

❖ **Carnot Cycle (Theoretical maximum efficiency)**

- 2 isothermal + 2 adiabatic processes.
- **Used for theoretical comparison only.**
- **Diagrams:**
  - **P-V Diagram** –Isothermal and adiabatic curves
  - **T-S Diagram** – Rectangular shape



Carnot Cycle

Internal Combustion Engines (IC Engines)

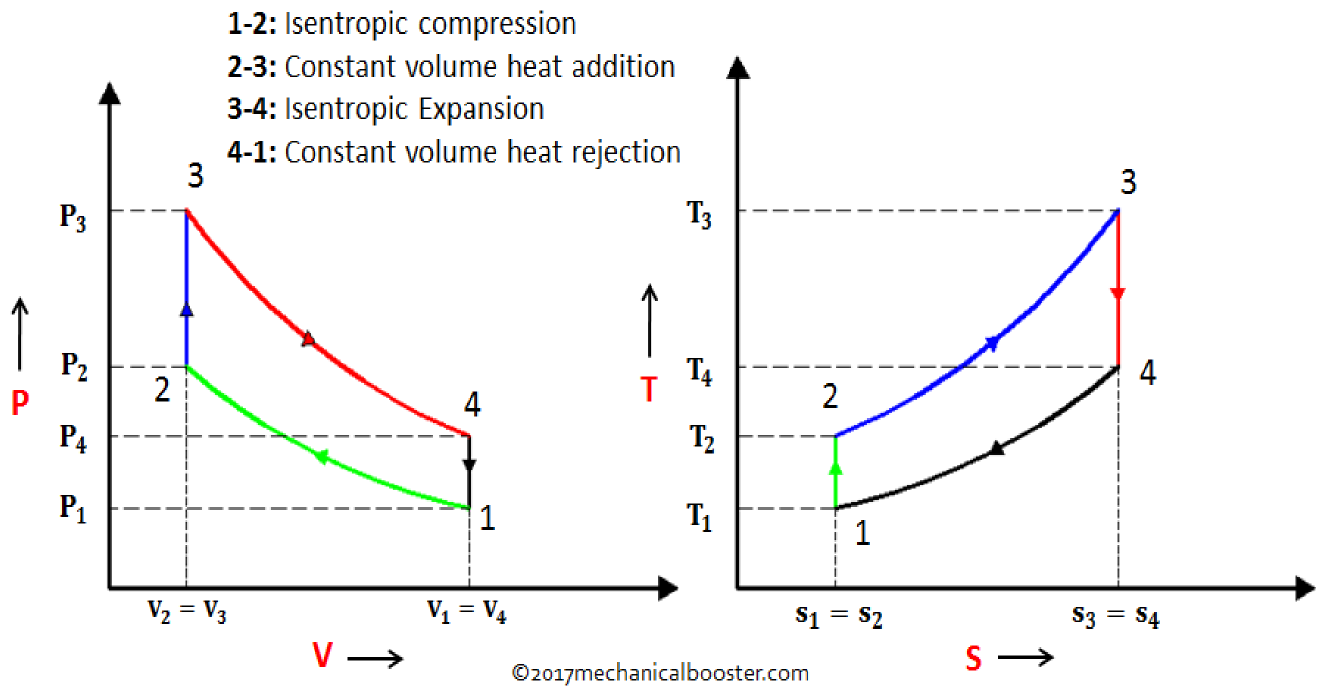
Otto Cycle (Petrol Engine)

•Ideal cycle for spark-ignition (S.I.) engines.

•2 isentropic + 2 constant volume processes.

•**Used in petrol engines**.

•**Diagrams:** P-V and T-S (dome-shaped)



P-V and T-S Diagram of Otto Cycle

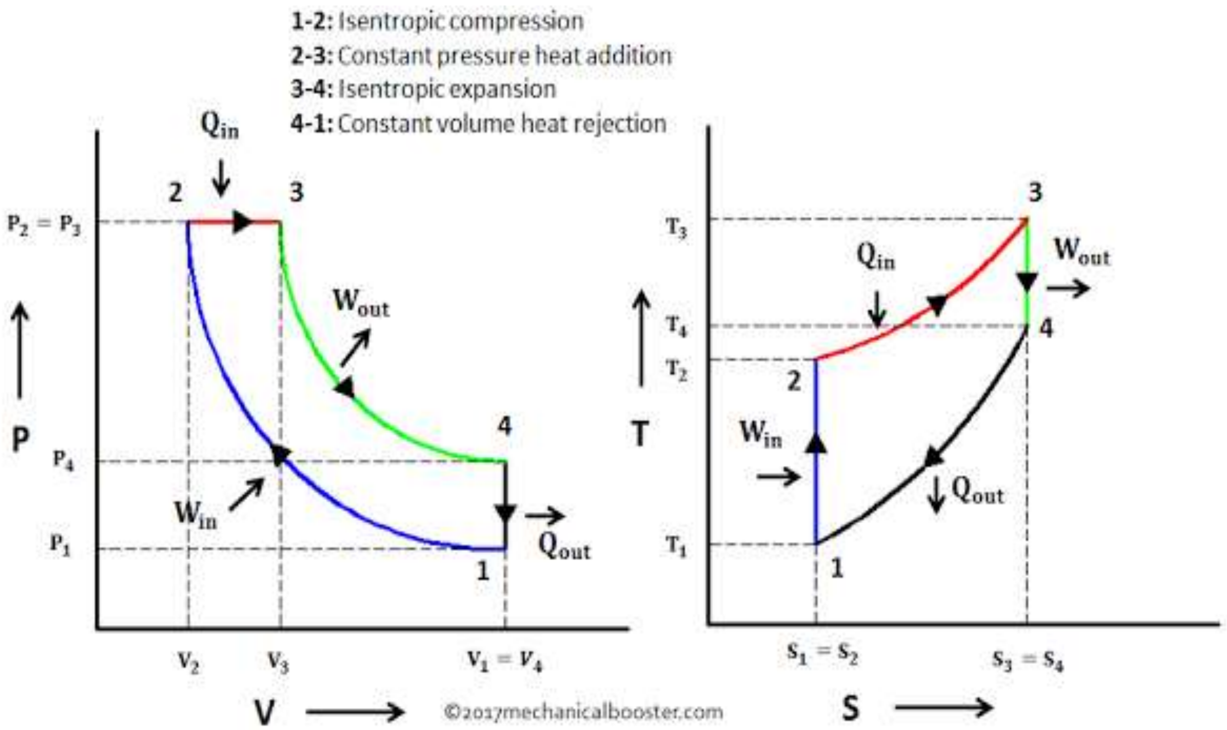
Internal Combustion Engines (IC Engines)

Diesel Cycle (Compression Ignition)

•2 isentropic, 1 constant pressure, 1 constant volume.

•**Used in diesel engines**.

•**Diagrams:** P-V and T-S (shifted dome with pressure constant during part of expansion)



P-V and T-S Diagram of Diesel Cycle

Internal Combustion Engines (IC Engines)

Internal vs. External Combustion Engines

Criteria	Internal Combustion Engine (IC)	External Combustion Engine (EC)
Combustion location	Inside the engine	Outside the engine
Size	Compact	Large
Starting	Quick	Slow
Efficiency	Higher	Lower
Examples	Petrol, Diesel engines	Steam engines, boilers

Internal Combustion Engines (IC Engines)

Advantages of IC Engines over EC Engines

•High thermal efficiency

•Compact size and lightweight

•Quick start and stop

•Less warm-up time

•Economical and portable

Internal Combustion Engines (IC Engines)

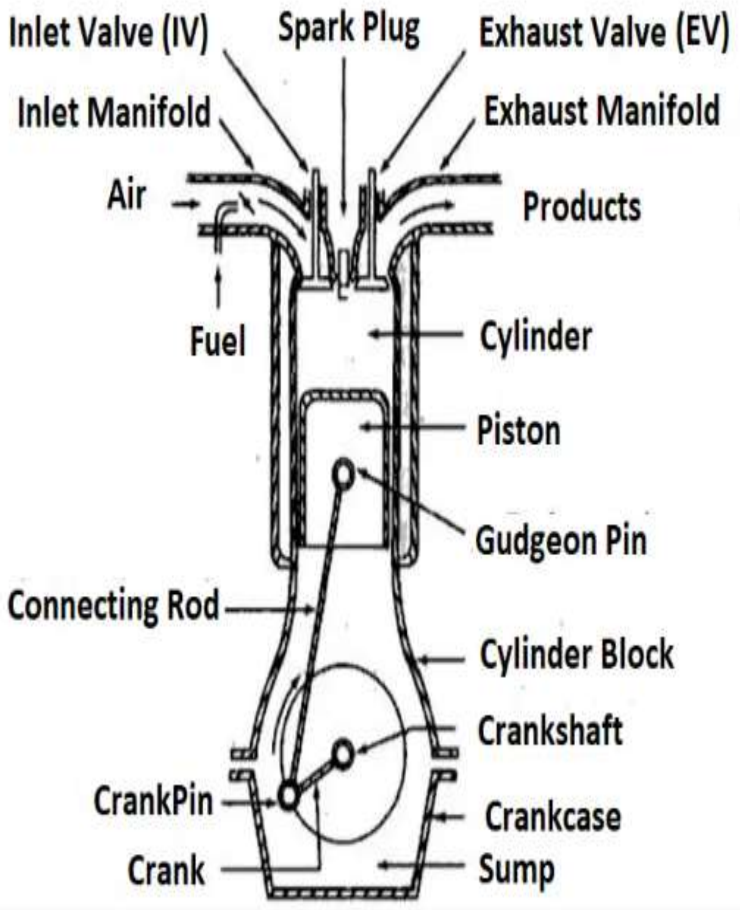
Classification of IC Engines

Basis	Type
Fuel used	Petrol, Diesel, Gas, etc.
Number of strokes	2-stroke, 4-stroke
Ignition method	Spark Ignition (SI), Compression Ignition (CI)
Cooling method	Air cooled, Water cooled
Arrangement of cylinders	Inline, V-type, Opposed

Internal Combustion Engines (IC Engines)

Functions and Materials of Engine Components

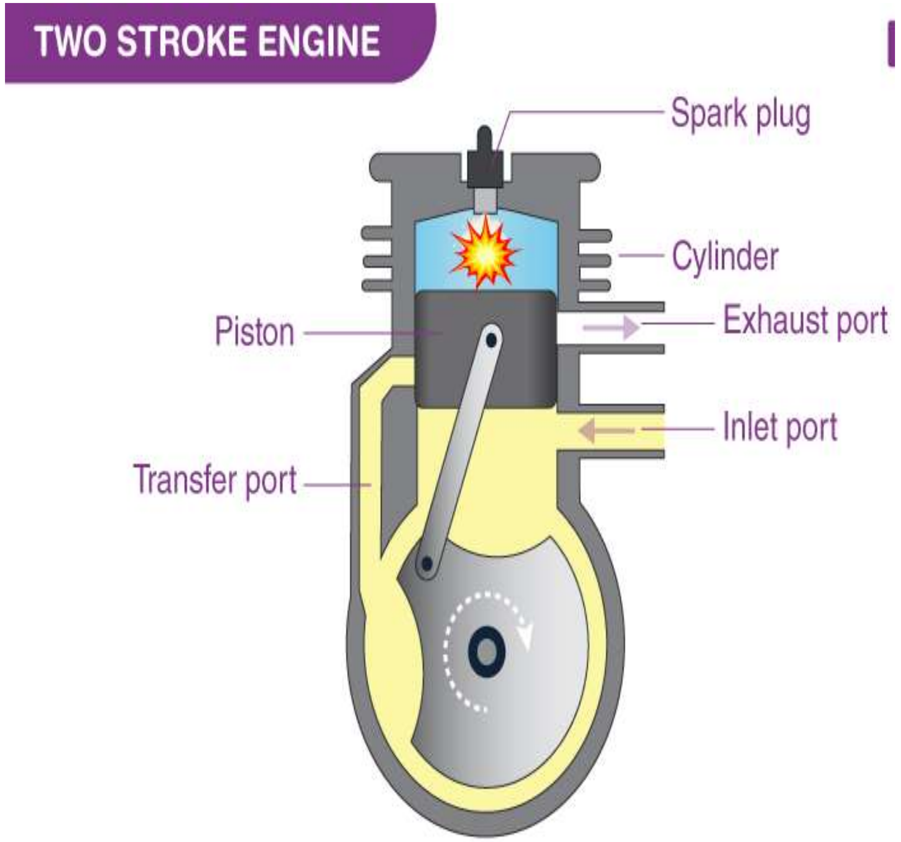
Component	Function	Material Used
Cylinder	Forms combustion chamber	Cast iron/Steel alloy
Crankcase	Houses the crankshaft & supports engine block	Aluminium alloy
Crankshaft	Converts reciprocating to rotary motion	Forged steel
Connecting rod	Connects piston to crankshaft	Forged steel
Wrist/Gudgeon Pin	Links piston to connecting rod	Case-hardened steel
Piston	Moves up and down to compress and expand gases	Aluminium alloy
Crank pin	Pivot point for connecting rod on crankshaft	Hardened steel
Cooling fins	Increase surface area for heat dissipation	Aluminium
Cylinder head	Closes cylinder and holds valves, spark plug	Cast iron/Aluminium
Inlet valve	Allows fresh charge into cylinder	Heat-resistant steel
Exhaust valve	Releases burnt gases from cylinder	Inconel / Nickel alloy



Internal Combustion Engines (IC Engines)

Petrol Engines (2 Stroke)

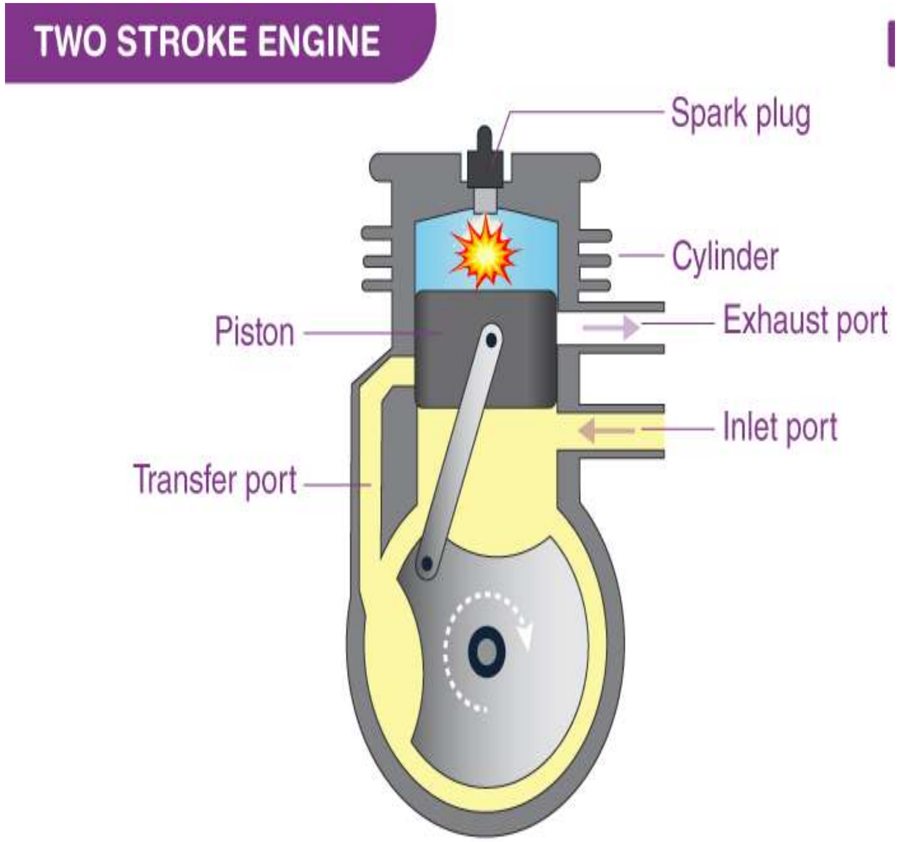
- In a 2-Stroke engine, the filling process is accompanied by the change compressed in a crank case or by a blower. The induction of compressed charge moves out the product of combustion through exhaust ports. Therefore, no piston stroke is required.
- For these 2- strokes one for compression of fresh charge and second for power stroke. The charge conducted into the crank case through the spring loaded valve when the pressure in the crank case is reduced due to upward motion of piston during the compression stroke. After the compression & ignition expansion takes place in usual way.
- During the expansion stroke the charge in crankcase is compressed. Near the end of the expansion stroke, the piston uncovers the exhaust ports and the cylinder pressure drops to atmosphere pressure as combustion produced leave the cylinder.



Internal Combustion Engines (IC Engines)

Various Parts of Petrol Engines (2 Stroke)

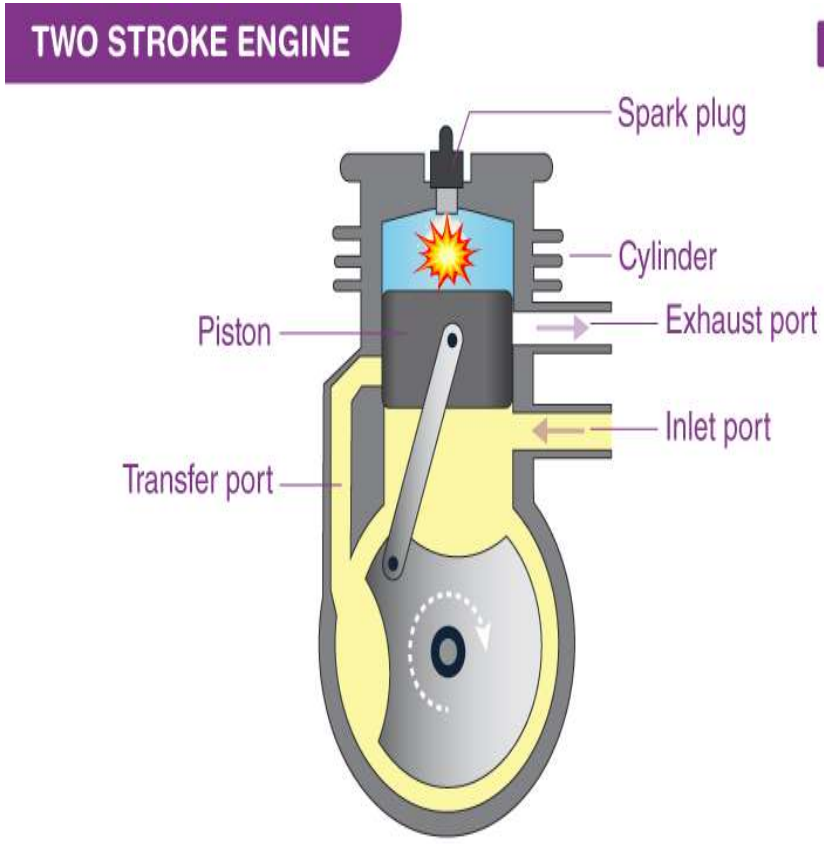
1. Cylinder: - In it the piston makes a reciprocating process motion.
2. Piston: - It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits into cylinder.
3. Combustion Chamber: - The space enclosed in the upper part of the cylinder, by the head and the piston top during the combustion process.
4. Inlet/ Outlet ports: - They are provided on the side of cylinder to regulate the charge coming in and out of cylinder.
5. Fuel Injector: - It injects the fuel in combustion chamber to initiate combustion process for power stroke.
6. Connecting Rod: - It interconnects crank shaft and the piston.
Fly Wheel: - The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates cow sing change in angular velocity of shaft. In order to achiever uniform torque an internal mass is attached to the output shaft & this is called as fly wheel.



Internal Combustion Engines (IC Engines)

Working of Petrol Engines (2 Stroke)

- In two stroke engines, the cycle is completed in one revolution of the crankshaft.
- In 2-stroke engine, the filling process is accomplished by the charge compressed in crankcase or by a blower.
- The induction of compressed charge moves out of the exhaust ports. Therefore, no piston strokes are required for these 2 operations.
- Two strokes are sufficient to complete the cycle one for compressing the fresh charge and other for expansion or power stroke.
- **1. Compression: -** The air or charge is inducted into the crankcase through the spring loaded inlet valve when the pressure in crankcase is reduced due to upward motion of piston.
- **2. Expansion: -** During this, the charge in the crankcase is compressed. At the end the piston uncovers the exhaust ports and cylinder pressure drops to the atmospheric pressure. Further movement of piston opens the transfer ports, permitting the slightest compressed charge in the crankcase to enter the engine cylinder.



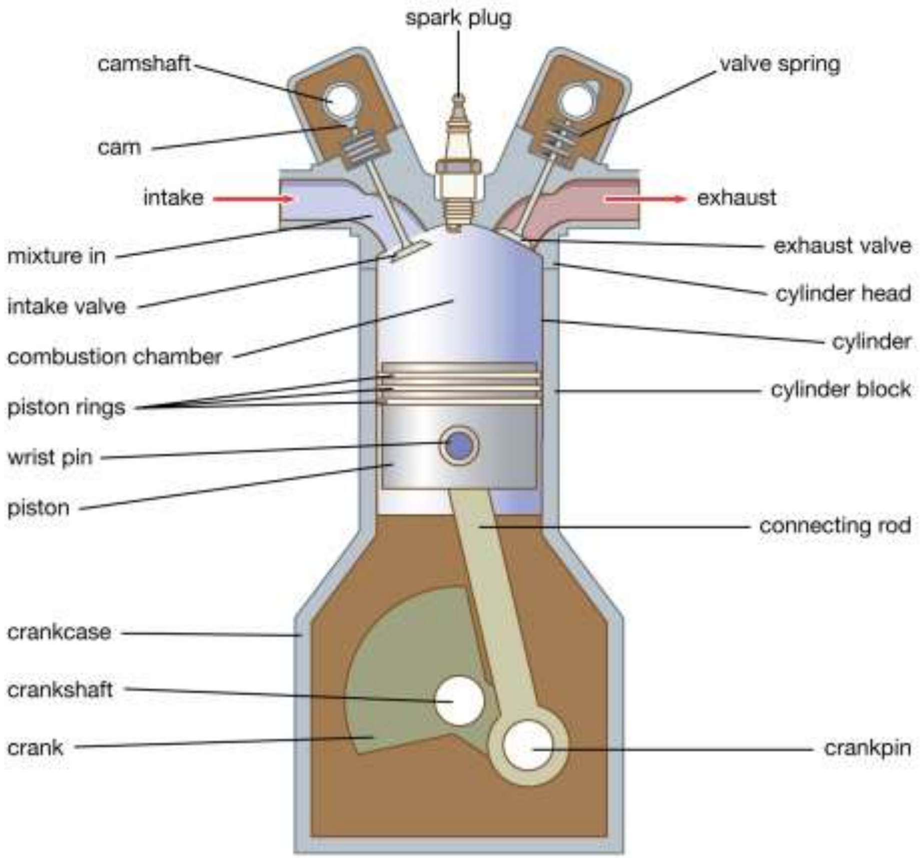
Internal Combustion Engines (IC Engines)

Components of a Petrol Engines (4 Stroke)

- **Cylinder: -** It is a cylindrical vessel or space in which the piston makes a reciprocating produces.
- **Piston: -** It is a cylindrical component fitted into the cylinder forming the moving boundary of combustion system. It fits in cylinder perfectly.
- **Combustion Chamber: -** It is the space enclosed in the upper part of cylinder, by the cylinder head & the piston top during combustion process.
- **Inlet Manifold: -** The pipe which connects the intake system to the inlet valve of engine.
- **Exhaust Manifold: -** The pipe which connects the exhaust system to the exhaust valve of engine.
- **Inlet / Exhaust Valves: -** They are provided on the cylinder head to head to regulate the charge coming into or going out of the chamber.
- **Spark Plug: -** It is used to initiate the combustion process in S.I engines.
- **Connected Rod: -** It connects piston & the crank shaft.
- **Crank shaft: -** It converts the reciprocating motion of the piston into useful rotary motion of output shaft.
- **Gudgeon pins: -** It forms a link between connection rod and the piston.
- **Cam shaft: -** It controls the opening & closing of the valves. □ Cam: - They open the valves at the correct tunes.
- **Carburetor: -** Used in S.I engine for atomizing & vaporizing and mixture it with air in varying proportion.

Internal Combustion Engines (IC Engines)

Components of a Petrol Engines (4 Stroke)



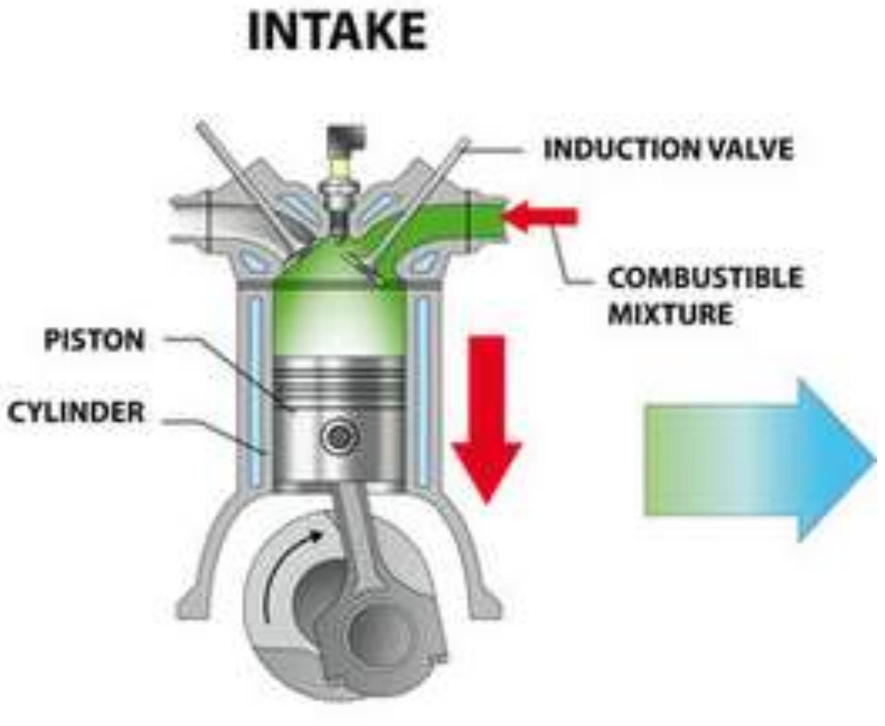
Internal Combustion Engines (IC Engines)

Working of Petrol Engines (4 Stroke)

Four Stroke (S.I) Engine. In a four stroke engine, the cycles of operations is completed in 4 strokes of piston or 2 revolution of crank shaft. Each stroke consists of 180 degree & hence the fuel cycle consists of 720 degree of crank rotation.

The 4-Strokes are: -

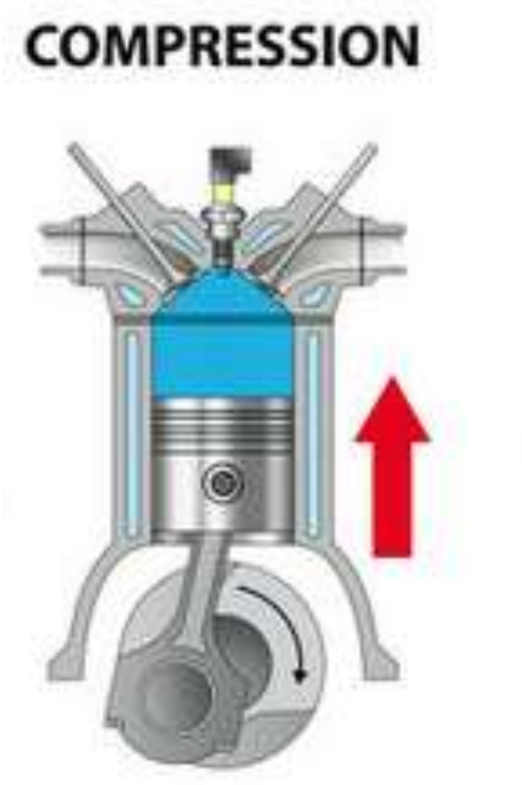
Suction or Intake Stroke: - In starts at, when the piston is at top dead centre & about to move downwards. The inlet valve is open at that time and exhaust valve is closed due to suction created by the motion of the piston towards the bottom dead centre, the charge containing air fuel mixture is drawn into the cylinder. When the piston reaches BDC the suction stroke ends and inlet valve is closed.



Internal Combustion Engines (IC Engines)

Working of Petrol Engines (4 Stroke)

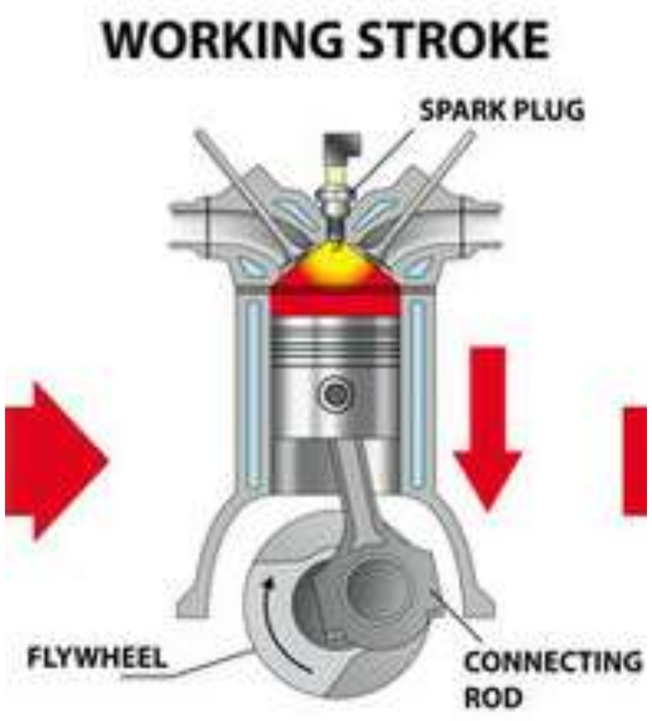
Compression Stroke: - The charge taken into the cylinder during suction stroke is compressed by return stroke of piston. During this stroke both the valves are closed. The mixture which fills the entire cylinder volume is now compressed into the clearance volume. At the end, the mixture is ignited with the help of electrode of spark plug. During the burning process the chemical energy of fuel is converted to heat energy. The pressure is increased in the end due to heat release.



Internal Combustion Engines (IC Engines)

Working of Petrol Engines (4 Stroke)

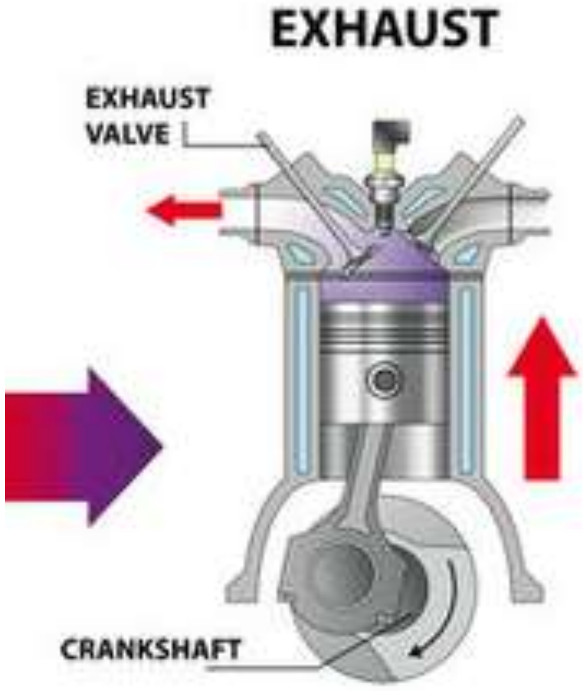
Expansion Stroke: - The burnt gases escape out and the exhaust valve opens but inlet valve remaining closed the piston moves from BDC to TDC and sweeps the burnt gases out at almost atmospheric pressure. The exhaust valve gets closed at the end of this stroke. Thus, for one complete cycle of engine, there is only one power stroke while crank shaft makes 2 revolutions.



Internal Combustion Engines (IC Engines)

Working of Petrol Engines (4 Stroke)

Exhaust Stroke: - During the upward motion of the piston, the exhaust valve is open and inlet valve is closed. The piston moves up in cylinder pushing out the burnt gases through the exhaust valve. As the piston reaches the TDC, again the inlet valve opens and fresh charge is taken in during next downward movement of the piston and the cycle is repeated.



Internal Combustion Engines (IC Engines)

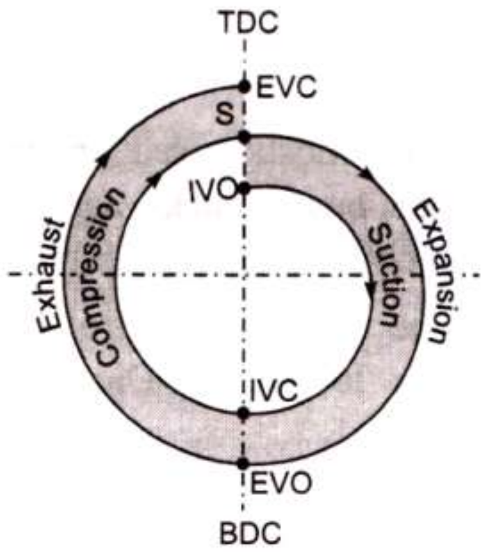
VALVE TIMING DIAGRAM

Valve timing is the regulation of the time instants when intake and exhaust valves open and close. Theoretically, it is assumed that the valves open or close instantly. However, there is a finite time required for the opening or closing of a valve. Cams provided on camshafts are designed carefully to achieve smooth operation of the valves, starting at a given time instant (or crank angle) and completing within a given time period.

Internal Combustion Engines (IC Engines)

THEORETICAL & ACTUAL VALVE TIMING DIAGRAM (4 Stroke SI Engine)

Theoretically, the intake valve is expected to open instantly at the TDC, at the end of the exhaust stroke. In practice, to accommodate the time required for valve operation, the intake valve is made to open a few degrees **(20 degrees)** of the crank angle before TDC on the exhaust stroke. This will facilitate the complete opening of the intake valve as soon as the piston reaches the TDC and fresh charge flows into the cylinder during the suction stroke.

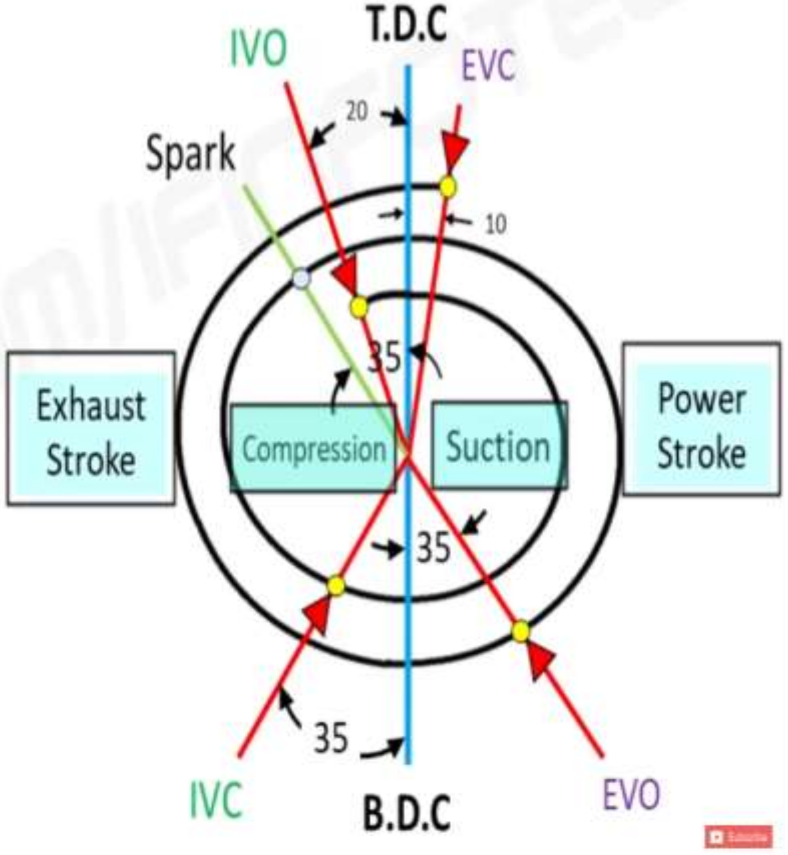


IVO = Inlet valve opens when piston at TDC
IVC = Inlet valve closes, when piston reaches BDC
S = Spark produces, when piston reaches TDC
EVO = Exhaust valve opens when piston at BDC
EVC = Exhaust valve closes, when piston at TDC

Internal Combustion Engines (IC Engines)

THEORETICAL & ACTUAL VALVE TIMING DIAGRAM
(4 Stroke SI Engine)

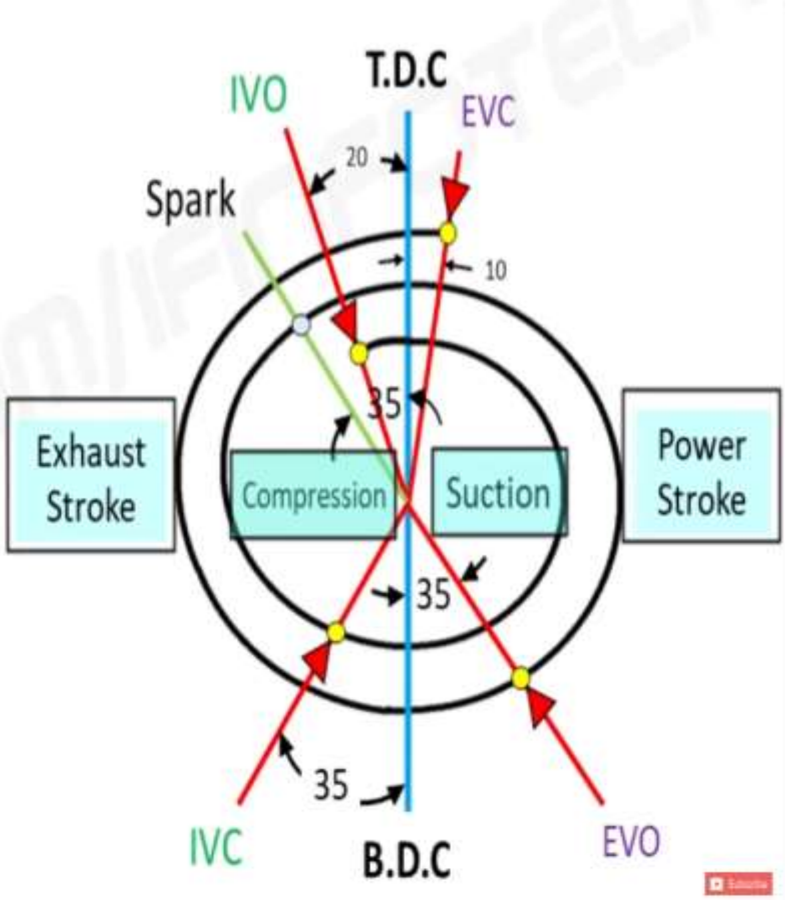
Similarly, theoretically, the inlet valve is expected to close exactly at BDC and the compression stroke should start. In practice, the charge coming into the cylinder has some inertia (momentum) due to pressure difference and this is dependent on the engine speed. Therefore, the rapidly moving piston may run away from the incoming charge. As a result of this, when the piston reaches the BDC, enough time will not be available for the required charge to come into the cylinder. This will reduce the volumetric efficiency of the engine. Therefore, the inlet valve is closed a few degrees **(35 degrees)** after BDC, depending on the engine speed. The intake valve setting is done considering the low to high speed range of the engine.



Internal Combustion Engines (IC Engines)

THEORETICAL & ACTUAL VALVE TIMING DIAGRAM
(4 Stroke SI Engine)

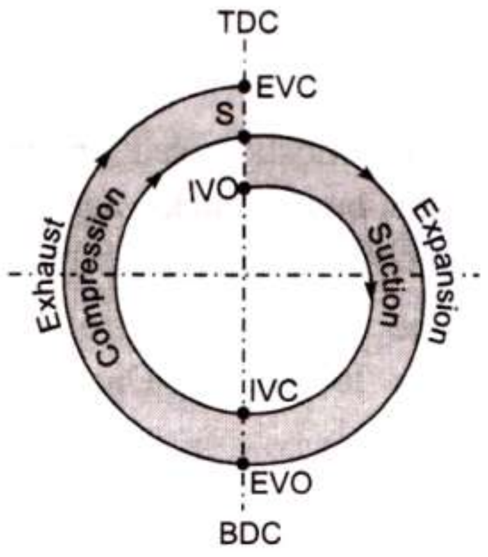
Similarly, the exhaust valve opening and closing are not done exactly at the BDC and the TDC, respectively, as shown in the theoretical valve timing diagram. The timing of exhaust valve operation also affects the volumetric efficiency. The exhaust valve is opened a few degrees **(35 Degrees)** before the BDC on the power stroke. This may slightly decrease the work done during the expansion process. However, it reduces the flow work required to expel the exhaust gases during the subsequent exhaust stroke. Similarly, the exhaust valve is closed a few degrees **(10 Degrees)** after the TDC on the exhaust stroke. This will facilitate better scavenging of the exhaust gases remaining in the clearance volume.



Internal Combustion Engines (IC Engines)

ACTUAL & THEORETICAL VALVE TIMING DIAGRAMS
(4 Stroke CI Engine)

Theoretically, the intake valve is expected to open instantly at the TDC, at the end of the exhaust stroke. In practice, to accommodate the time required for valve operation, the intake valve is made to open a few degrees **(25 degrees)** of the crank angle before TDC on the exhaust stroke. This will facilitate the complete opening of the intake valve as soon as the piston reaches the TDC and fresh charge flows into the cylinder during the suction stroke.

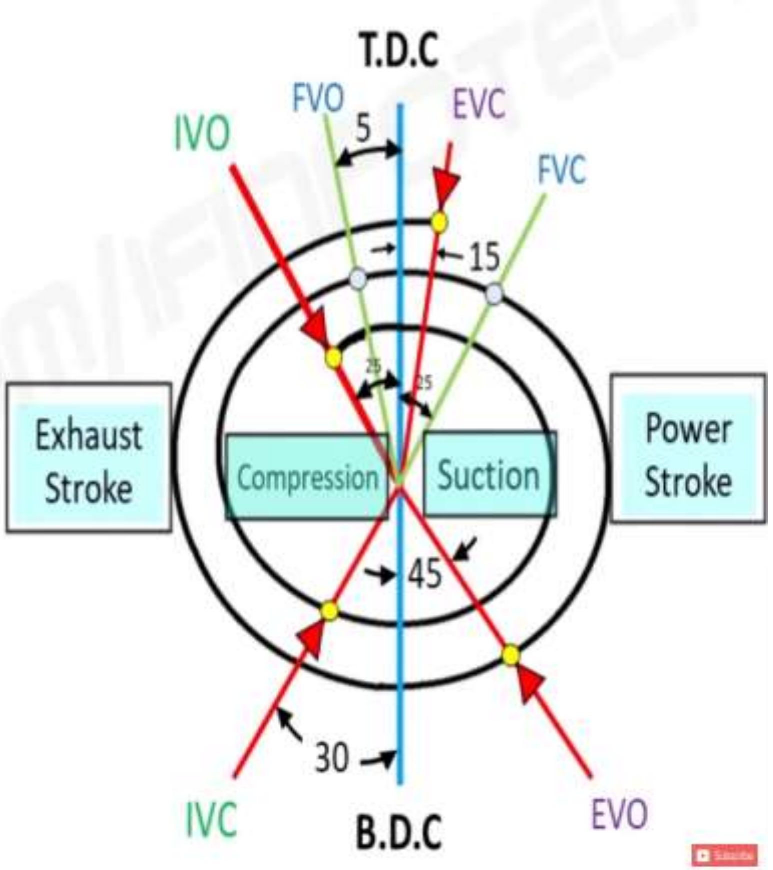


IVO = Inlet valve opens when piston at TDC
IVC = Inlet valve closes, when piston reaches BDC
S = Spark produces, when piston reaches TDC
EVO = Exhaust valve opens when piston at BDC
EVC = Exhaust valve closes, when piston at TDC

Internal Combustion Engines (IC Engines)

ACTUAL & THEORETICAL VALVE TIMING DIAGRAMS
(4 Stroke CI Engine)

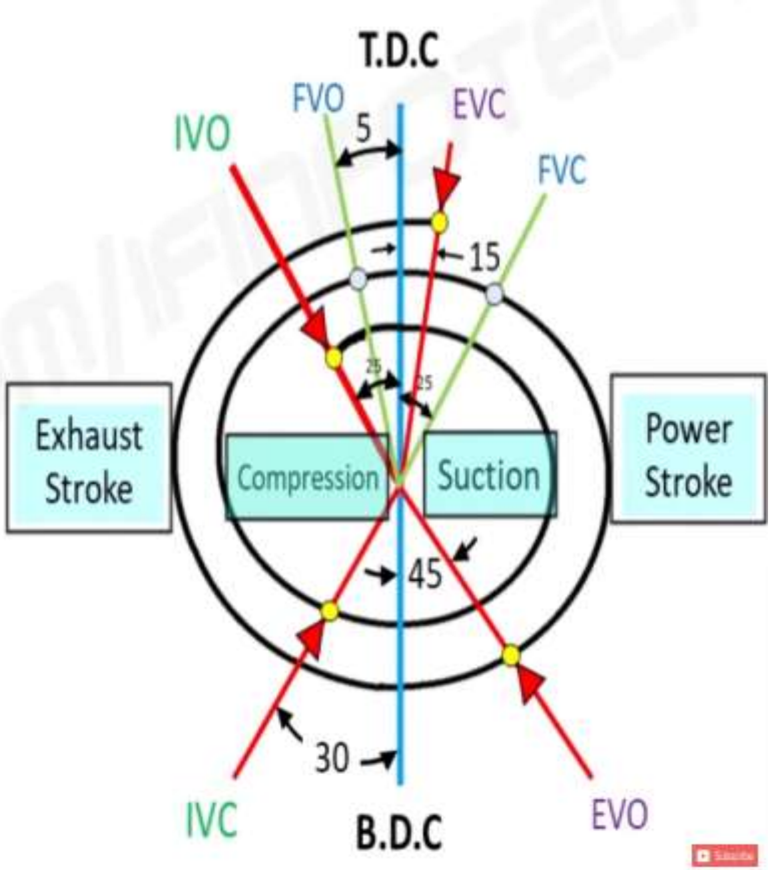
Similarly, theoretically, the inlet valve is expected to close exactly at BDC and the compression stroke should start. In practice, the charge coming into the cylinder has some inertia (momentum) due to pressure difference and this is dependent on the engine speed. Therefore, the rapidly moving piston may run away from the incoming charge. As a result of this, when the piston reaches the BDC, enough time will not be available for the required charge to come into the cylinder. This will reduce the volumetric efficiency of the engine. Therefore, the inlet valve is closed a few degrees **(30 degrees)** after BDC, depending on the engine speed. The intake valve setting is done considering the low to high speed range of the engine.



Internal Combustion Engines (IC Engines)

ACTUAL & THEORETICAL VALVE TIMING DIAGRAMS
(4 Stroke CI Engine)

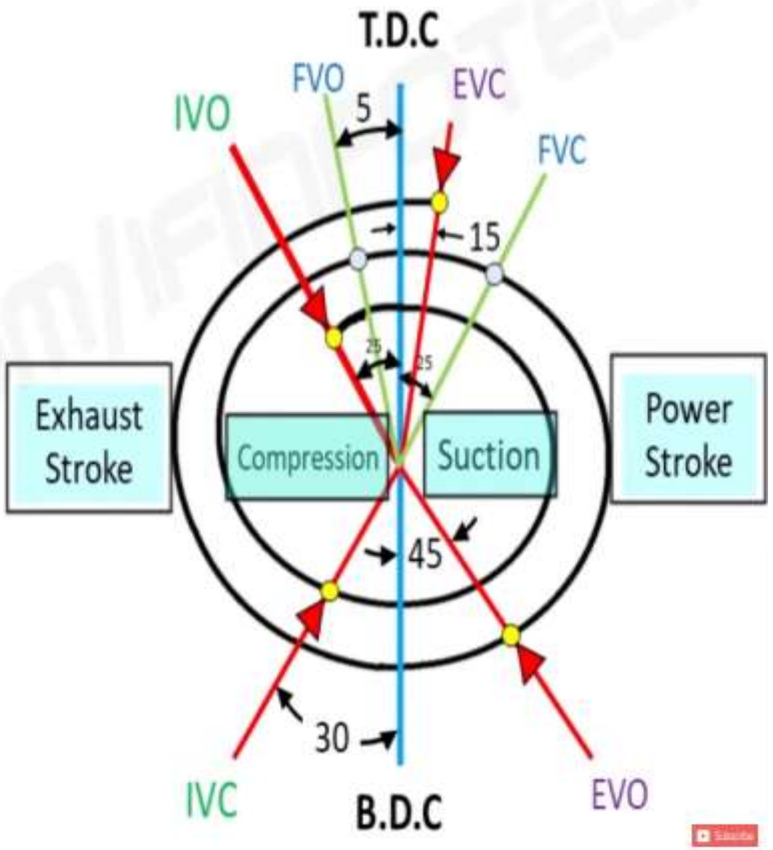
Similarly, the exhaust valve opening and closing are not done exactly at the BDC and the TDC, respectively, as shown in the theoretical valve timing diagram. The timing of exhaust valve operation also affects the volumetric efficiency. The exhaust valve is opened a few degrees **(45 Degrees)** before the BDC on the power stroke. This may slightly decrease the work done during the expansion process. However, it reduces the flow work required to expel the exhaust gases during the subsequent exhaust stroke. Similarly, the exhaust valve is closed a few degrees **(15 Degrees)** after the TDC on the exhaust stroke. This will facilitate better scavenging of the exhaust gases remaining in the clearance volume.



Internal Combustion Engines (IC Engines)

ACTUAL & THEORETICAL VALVE TIMING DIAGRAMS
(4 Stroke CI Engine)

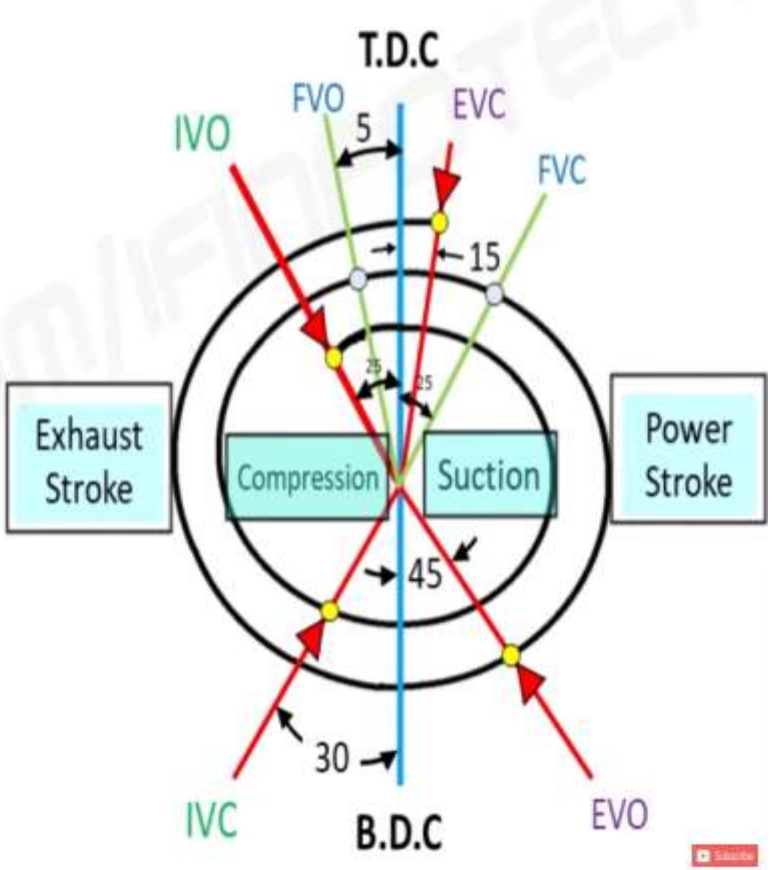
Similarly, the exhaust valve opening and closing are not done exactly at the BDC and the TDC, respectively, as shown in the theoretical valve timing diagram. The timing of exhaust valve operation also affects the volumetric efficiency. The exhaust valve is opened a few degrees **(45 Degrees)** before the BDC on the power stroke. This may slightly decrease the work done during the expansion process. However, it reduces the flow work required to expel the exhaust gases during the subsequent exhaust stroke. Similarly, the exhaust valve is closed a few degrees **(15 Degrees)** after the TDC on the exhaust stroke. This will facilitate better scavenging of the exhaust gases remaining in the clearance volume.



Internal Combustion Engines (IC Engines)

ACTUAL & THEORETICAL VALVE TIMING DIAGRAMS
(4 Stroke CI Engine)

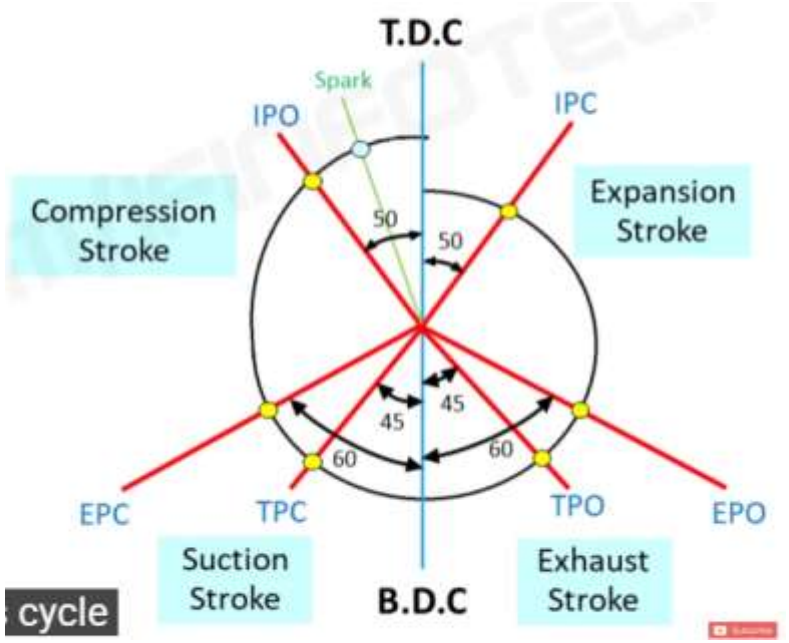
Similarly, the exhaust valve opening and closing are not done exactly at the BDC and the TDC, respectively, as shown in the theoretical valve timing diagram. The timing of exhaust valve operation also affects the volumetric efficiency. The exhaust valve is opened a few degrees **(45 Degrees)** before the BDC on the power stroke. This may slightly decrease the work done during the expansion process. However, it reduces the flow work required to expel the exhaust gases during the subsequent exhaust stroke. Similarly, the exhaust valve is closed a few degrees **(15 Degrees)** after the TDC on the exhaust stroke. This will facilitate better scavenging of the exhaust gases remaining in the clearance volume.



Internal Combustion Engines (IC Engines)

PORT TIMING DIAGRAMS
(2 Stroke SI Engine)

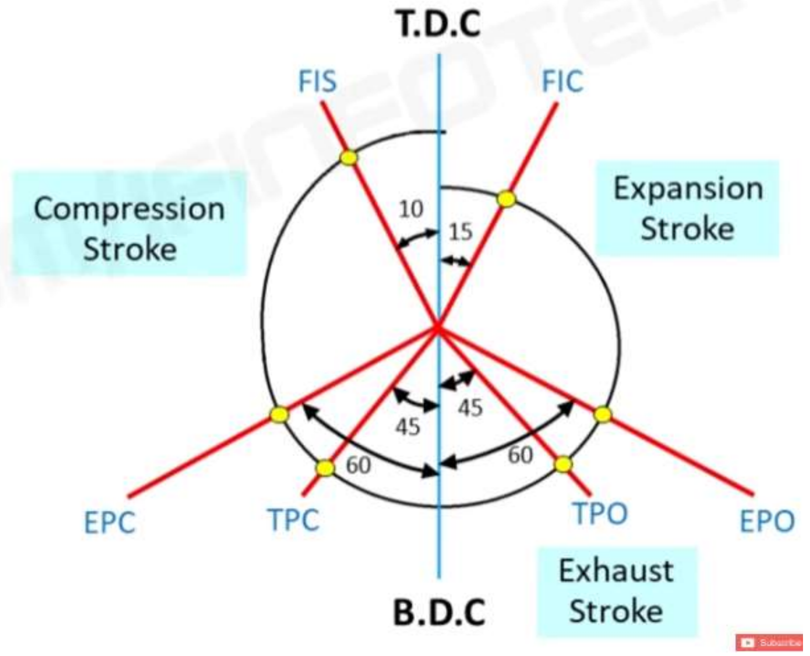
Here the inlet port opens few degrees **(50 Degrees)** before TDC i.e before expansion stroke & inlet port closes few degrees **(50 Degrees)** after TDC. The exhaust port opens few degrees **(60 Degrees)** before BDC i.e near the end of expansion stroke & Transfer Port Opens few degrees **(45 Degrees)** before BDC for initiation of scavenging process & closes few degrees **(45 Degrees)** after BDC. The exhaust port then closes few degrees **(60 Degrees)** after BDC. This will done to suck fresh air through transfer port & to exhaust burnt gases through exhaust port. Then compression process starts.



Internal Combustion Engines (IC Engines)

PORT TIMING DIAGRAMS
(2 Stroke CI Engine)

Here the inlet port opens few degrees **(10 Degrees)** before TDC i.e before expansion stroke & inlet valve closes few degrees **(15 Degrees)** after TDC. The exhaust port opens few degrees **(60 Degrees)** before BDC i.e near the end of expansion stroke & Transfer Port Opens few degrees **(45 Degrees)** before BDC for initiation of scavenging process & closes few degrees **(45 Degrees)** after BDC. The exhaust port then closes few degrees **(60 Degrees)** after BDC. This will done to suck fresh air through transfer port & to exhaust burnt gases through exhaust port. Then compression process starts.



IC Engines Systems

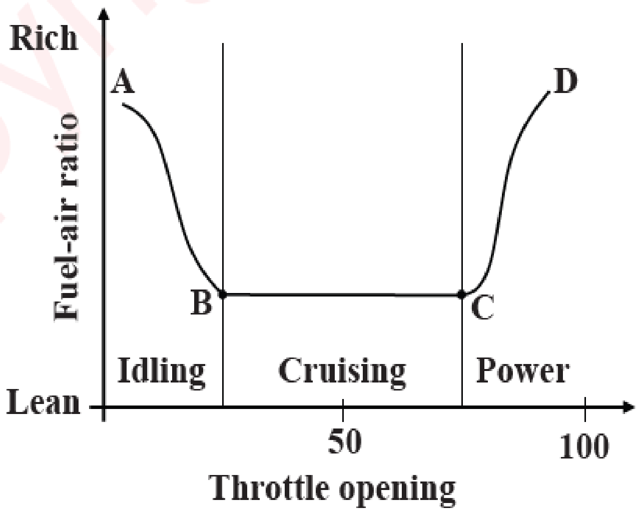
1. Fuel System of Petrol Engines

In petrol engines, a device called carburettor is used to mix petrol and air in the required proportions. A carburettor should be able to deliver a mixture of air and petrol vapor in required proportions based on the engine speed. Figure shows the typical fuel-air ratio as a function of throttle opening. A throttle valve is a device used to control the intake of the mixture. When it is fully closed, engine runs with a minimum speed and is said to be idling. When the throttle is fully open, engine runs at its maximum speed. There is a regime of operation called cruising, where engine operates with an almost constant value of fuel-air ratio. The actual fuel-air ratio may be quite different from the theoretical fuel-air ratio. The theoretical fuel-air ratio is the ratio of the amount of fuel (mass or volume) to the amount of air that is just sufficient to burn the given amount of fuel. The actual fuel-air ratio may be lean (having lesser fuel in the mixture than the theoretical)
or rich (having more fuel in the mixture than the theoretical).

IC Engines Systems

1. Fuel System of Petrol Engines

Idling range is indicated by the curve A-B in Fig. When the engine has started and the throttle valve is almost fully closed, the engine requires a fuel-rich mixture, as indicated by point A in Fig. As the throttle is opened from A to B, more air is added to the mixture getting into the engine and thus, the fuel-air ratio decreases. Generally, at point B, the mixture will be leaner. This condition provides a good fuel-economy. Further opening of the throttle valve from B to C provides cruising range. Carburettor should be able to provide a leaner mixture in this range at approximately same fuel-air ratio to provide a good fuel-economy. Further opening of the throttle beyond C, creates a condition that the engine operates at an almost fully opened throttle. Higher power is achieved with more fuel burnt. Fuel-air ratio increases to the rich condition at the maximum power condition, indicated by point D in Fig. It is clear that the fuel system of the petrol engine should be capable of delivering a fuel-air mixture varying with engine operating condition that depends on the throttle opening.

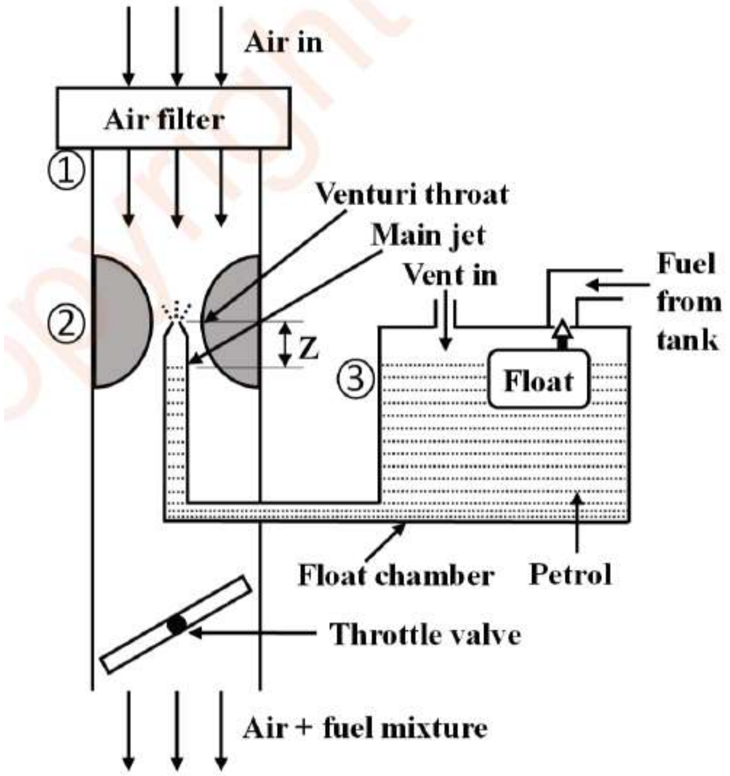


IC Engines Systems

1. Fuel System of Petrol Engines

Carburettor:

If a fluid flows through a pipe with a constriction, such as a choke or an orifice or a venturi, the fluid accelerates and the pressure decreases. At the minimum area for the flow, usually called vena contracta, the velocity reaches a maximum value and the pressure reaches a minimum value. This pressure drop between the upstream section of the pipe and at vena contracta can be used to deliver another fluid into the pipe at the location where the area is minimum. This is called venturi effect. A simple carburettor works on the principle of the venturi effect. Figure presents a schematic of a simple carburettor.

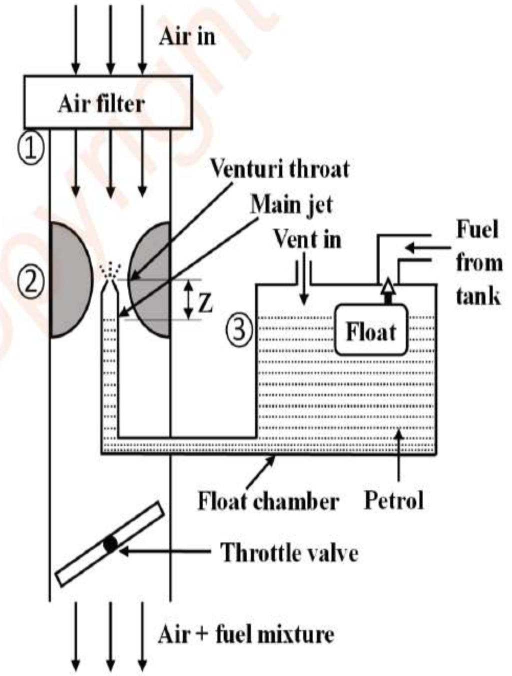


IC Engines Systems

1. Fuel System of Petrol Engines

Simple carburettor:

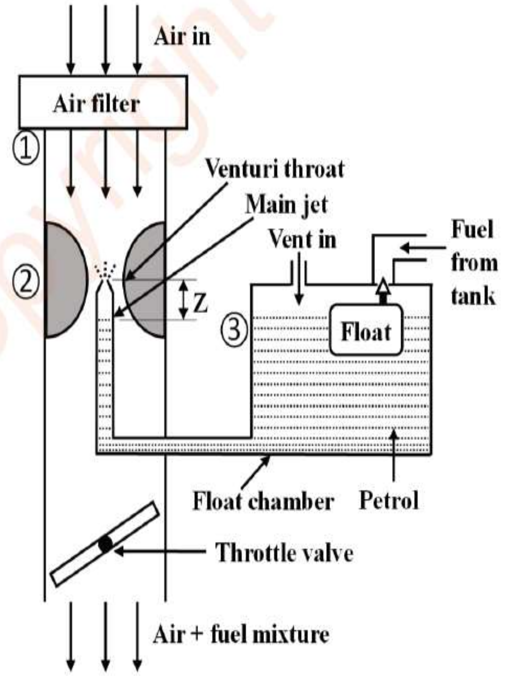
Simple carburettor consists of a vertical carburettor pipe with a venturi and one end attached to an air filter, as shown in Fig. It has a float chamber into which petrol is taken in from the main fuel tank. The float chamber has a float that maintains the level of the petrol inside it. When the level falls, the float drops down along with the needle valve, opening the fuel inlet port connected to the fuel tank and fuel flows in. When the fuel flows in, the liquid level increases in the chamber and the float gradually moves up due to buoyancy. When the required fuel level is reached, the port is closed by the needle valve. The float chamber has a small pipe projecting into the carburettor pipe, with a nozzle or an orifice fitted at its end. This is called the main jet. The exit of the main jet is located inside the venturi, where the cross-sectional area of the venturi is the minimum, called the throat. The liquid level in the small pipe is maintained just below the nozzle or orifice, at a small distance Z, as indicated in Fig., such that the overflow of fuel is avoided.



IC Engines Systems

1. Fuel System of Petrol Engines

Simple carburettor:

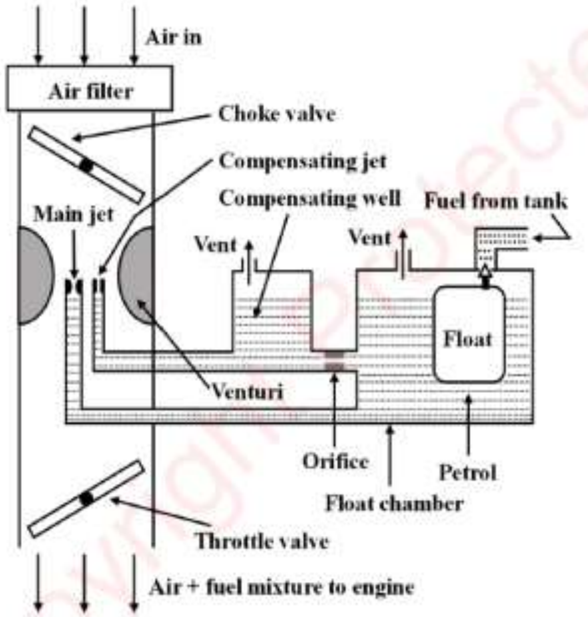


The float chamber has a vent hole that is exposed to a pressure (usually equal to the atmospheric pressure) that is higher than the pressure at the venturi throat section. The fuel surface in the float chamber is thus maintained at this vent pressure. The pressure at the throat of the venturi is lower and its value is dependent on the air flow rate through the carburettor tube. Based on the pressure difference between the float chamber fuel surface and venturi throat, petrol from the float tank flows into the carburettor pipe at a certain rate. The petrol vaporizes as it flows along with the air. Homogeneous air and fuel mixture exits the carburettor through a throttle valve, which is like a butterfly valve. Based on the engine speed, the throttle valve provides a certain opening area. Based on this, a certain amount of air flows into the carburettor. Pressure drop between the float chamber fuel surface and venturi throat varies with the air flow rate. Depending on this pressure drop, a given quantity of petrol is injected into the carburettor for the given throttle valve opening. When the throttle is fully open, the pressure drop is in the range of 35 mm to 50 mm of the mercury column.

IC Engines Systems

1. Fuel System of Petrol Engines

Zenith Carburettor : The simple carburettor depicted in previous Fig. has been improved in several ways for several reasons. One such improved carburettor is called Zenith carburettor. It has a choke valve, secondary fuel supply pipe called the compensating jet, an additional (compensating) float chamber and an additional orifice connecting the two float chambers, apart from the components in the simple carburettor. Figure shows a schematic of an improved Zenith carburettor. The choke valve is a butterfly type of valve useful for cold start conditions. When a cold engine starts, especially at low atmospheric temperatures, the engine speed is quite low (~150 rpm). The manifold vacuum produced at this condition may not be enough to induct enough fuel into the carburettor. Thus, the resulting mixture will be very lean and it will be tough to ignite the mixture. Therefore, in cold start conditions, choke valve is kept partially closed to intake lesser amount of air, so that the resultant mixture is fuel rich and ignitable. When the engine warms up, the choke valve is fully opened and a proper lean and flammable mixture is formed. The compensating jet is attached to the additional float chamber called the compensating well. The compensating well is also vented to the atmosphere as the float chamber. The compensating jet is supplied with the fuel from the compensating well through an orifice. When the air flow rate increases, fuel supply through the main jet increases and through the compensating jet decreases. The total fuel supply rate from the main and compensating jets keeps the fuel-air ratio almost constant.



IC Engines Systems

2. Fuel System of Diesel Engines

An important system responsible for proper working of a CI engine is the fuel injection system. A fuel injection system should meet the following requirements:

- (1) Injection of the required quantity of fuel per cycle into the cylinder. Since this quantity is small, proper metering of the quantity is vital.
- (2) Start and end of the injection should be accurate as per the set timing.
- (3) The rate at which injection is done is also important.
- (4) Injector should be able to atomize the fuel into small droplets for rapid vaporization.
- (5) Proper injection over a given volume within the cylinder to ensure proper mixing.
- (6) Ensure uniform distribution of fuel droplets.
- (7) In the case of multiple cylinders, an equal quantity of fuel should be injected into each cylinder at appropriate timing.

IC Engines Systems

2. Fuel System of Diesel Engines

The fuel injection systems are classified as air injection and solid (airless) injection.

AIR INJECTION SYSTEM :

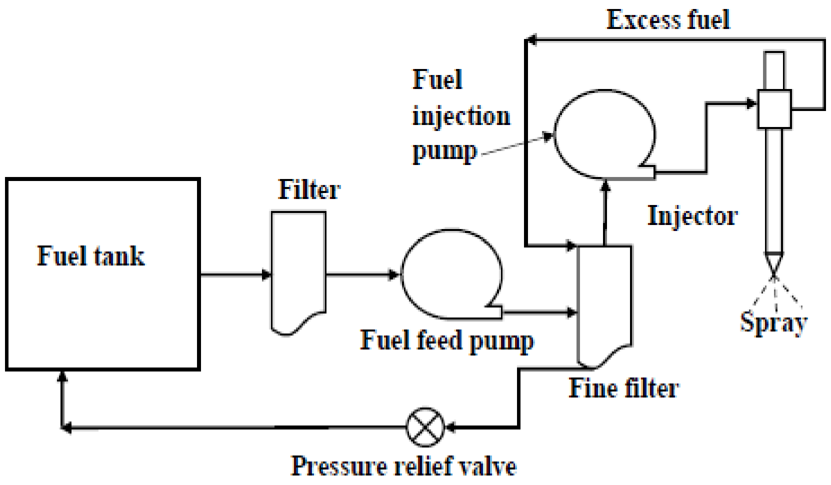
In the air injection system, an air compressor is used. Fuel is injected into the cylinder using compressed air. The advantage of an air injection system is that it provides better mixing of fuel and air and higher mean effective pressure. It can be used for injecting fuels with higher viscosity. Due to the requirement of compressed air, air injection systems are not used presently. Solid injection systems are also called airless mechanical injection systems. Here, a liquid fuel is directly injected into the cylinder.

IC Engines Systems

2. Fuel System of Diesel Engines

SOLID INJECTION SYSTEM :

Solid injection system comprises of a fuel tank, fuel feed pump to feed fuel from the main tank to the injection system, fuel filters, an injection pump to feed the fuel into the injector at high pressure, governor to control the amount of fuel injected based on the engine load and injector to inject the fuel at high pressure and atomize it. Fuel from the main fuel tank passes through a filter and a fuel feed pump and leaves at a slightly higher pressure. It passes through another filter, where fine impurities are removed. Subsequently, fuel enters the fuel injection pump, where it is pressurized in the range of around 200 - 1700 bar, based on the engine type and load. The fuel is then injected into the cylinder through an injector. There is an arrangement to take back the excess fuel supplied to the injector along with a pressure relief valve. A block diagram of a solid injection system is shown in Figure.



IC Engines Systems

1. Fuel System of Diesel Engines

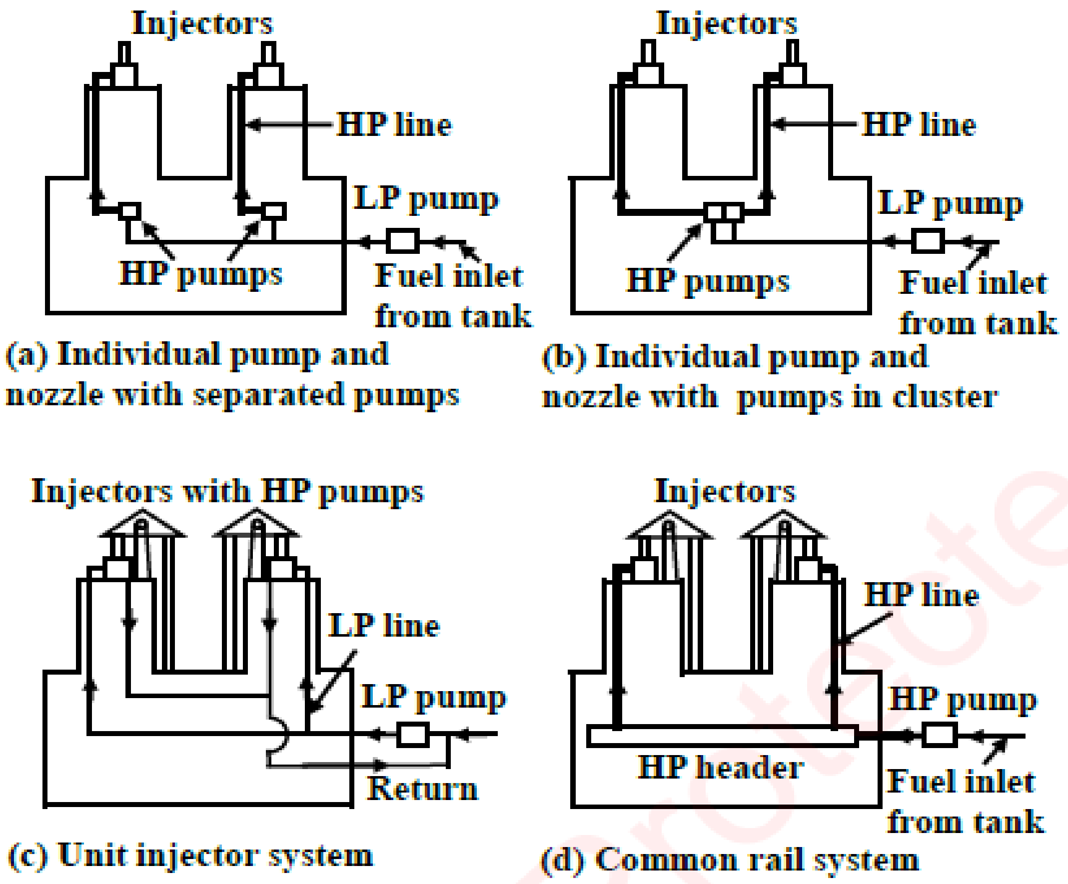
CLASSIFICATION OF SOLID INJECTION SYSTEM :

(a) INDIVIDUAL PUMP AND NOZZLE SYSTEM,

(b) UNIT INJECTOR SYSTEM,

(c) COMMON RAIL SYSTEM AND

(d) DISTRIBUTOR SYSTEM



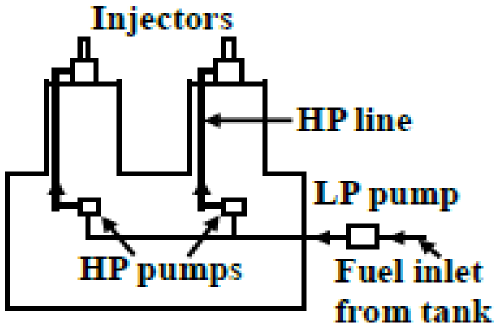
IC Engines Systems

2. Fuel System of Diesel Engines

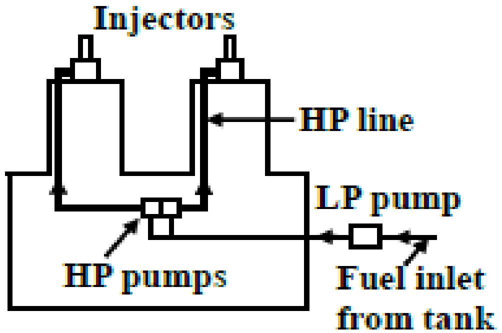
CLASSIFICATION OF SOLID INJECTION SYSTEM :

(a) INDIVIDUAL PUMP AND NOZZLE SYSTEM,

As the name suggests, each cylinder is provided with one pump and one injector in an individual pump and nozzle system. The pumps can be kept separated as shown in Fig. (a) or they can be in a cluster as shown in Fig. (b). Fuel is supplied to the high pressure (HP) pumps through a low pressure (LP) pump. The plunger of the high pressure pump is actuated by a cam, so that it produces the required fuel pressure at the correct time instant. The amount of fuel injected is controlled by the stroke of the plunger.



(a) Individual pump and nozzle with separated pumps



(b) Individual pump and nozzle with pumps in cluster

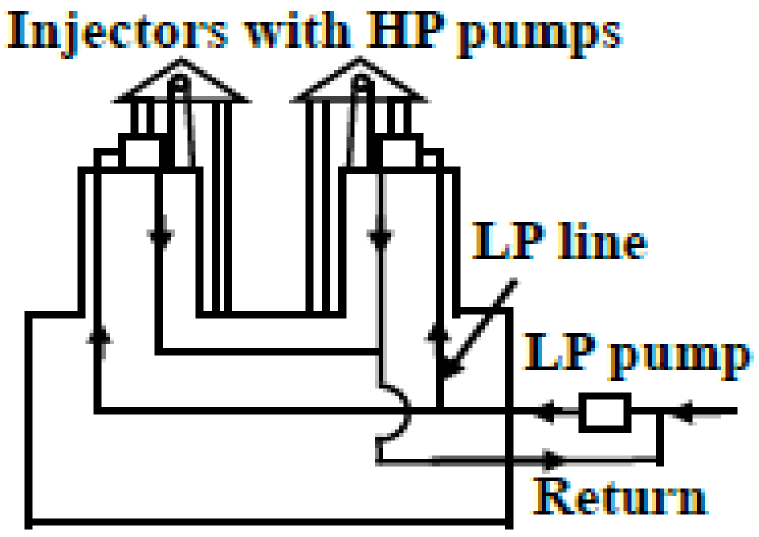
IC Engines Systems

2. Fuel System of Diesel Engines

CLASSIFICATION OF SOLID INJECTION SYSTEM :

(b) UNIT INJECTOR SYSTEM,

In the unit injector system, the fuel pump and injector are combinedly kept in a single housing, called the unit, as shown in Fig. (c). Each cylinder has one such injector unit. Fuel is supplied up to the unit using a low pressure pump. At an appropriate instant of time, the plunger of the HP pump is activated and the injector sprays the fuel into the cylinder. The amount of fuel injected is controlled by the stroke of the plunger.



(c) Unit injector system

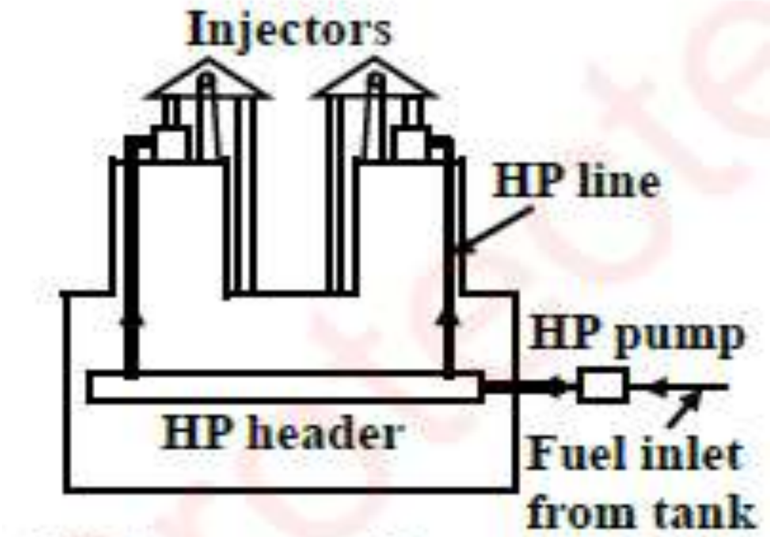
IC Engines Systems

2. Fuel System of Diesel Engines

CLASSIFICATION OF SOLID INJECTION SYSTEM :

(c) COMMON RAIL SYSTEM

The common rail system is shown in Fig. (d). Here, a HP pump supplies fuel under high pressure to a common high pressure header. From this, fuel is supplied to individual injectors through the high pressure lines. A mechanical system consisting of a push rod and rocker arm operates the appropriate valve to supply the fuel to a given cylinder through the dedicated injector. Here, the amount of fuel supplied to each cylinder is controlled by the push rod stroke.



(d) Common rail system

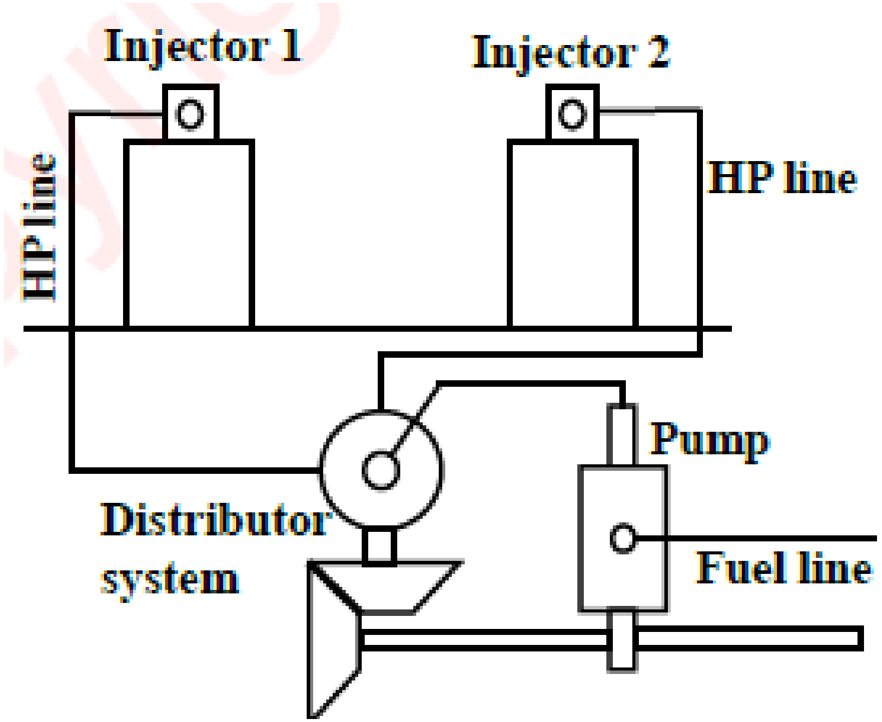
IC Engines Systems

2. Fuel System of Diesel Engines

CLASSIFICATION OF SOLID INJECTION SYSTEM :

(d) DISTRIBUTER SYSTEM

Schematic of the distributor fuel injection system is shown in Fig. In the distributor system, there is a rotating distributor, connected to multiple cylinders. At a given time instant, fuel pump supplies the required quantity of fuel to the distributor, which then supplies it to a given cylinder. At the next appropriate time instant, the distributor receives the fuel from the fuel pump and supplies it to the next cylinder and so on. There is a metering system connected to the fuel pump that supplies the required amount of fuel to the rotating distributor. This aspect decreases the overall cost of the fuel system.



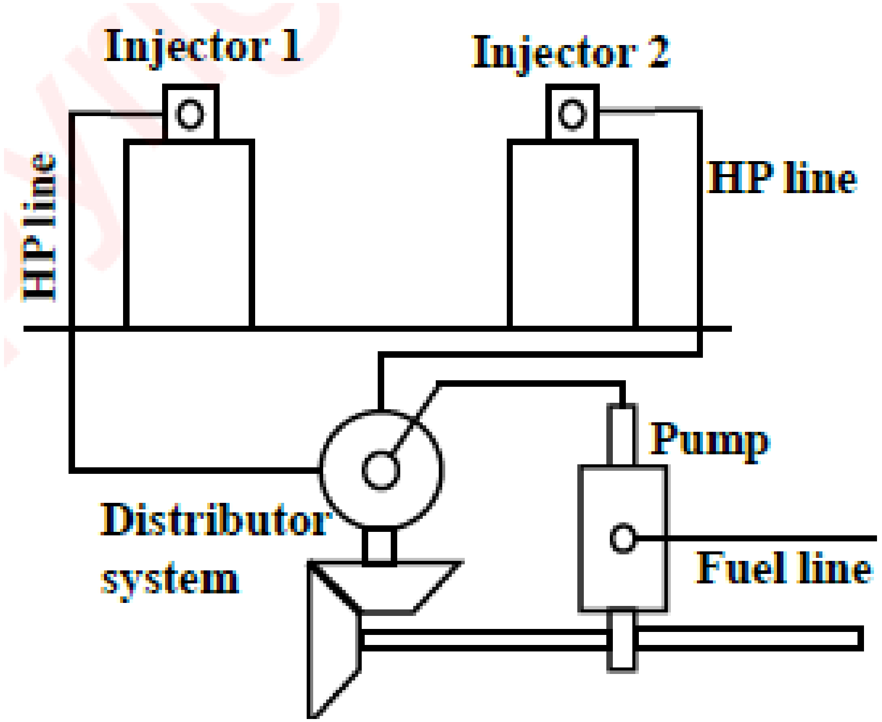
IC Engines Systems

2. Fuel System of Diesel Engines

CLASSIFICATION OF SOLID INJECTION SYSTEM :

(d) DISTRIBUTER SYSTEM

Schematic of the distributor fuel injection system is shown in Fig. In the distributor system, there is a rotating distributor, connected to multiple cylinders. At a given time instant, fuel pump supplies the required quantity of fuel to the distributor, which then supplies it to a given cylinder. At the next appropriate time instant, the distributor receives the fuel from the fuel pump and supplies it to the next cylinder and so on. There is a metering system connected to the fuel pump that supplies the required amount of fuel to the rotating distributor. This aspect decreases the overall cost of the fuel system.

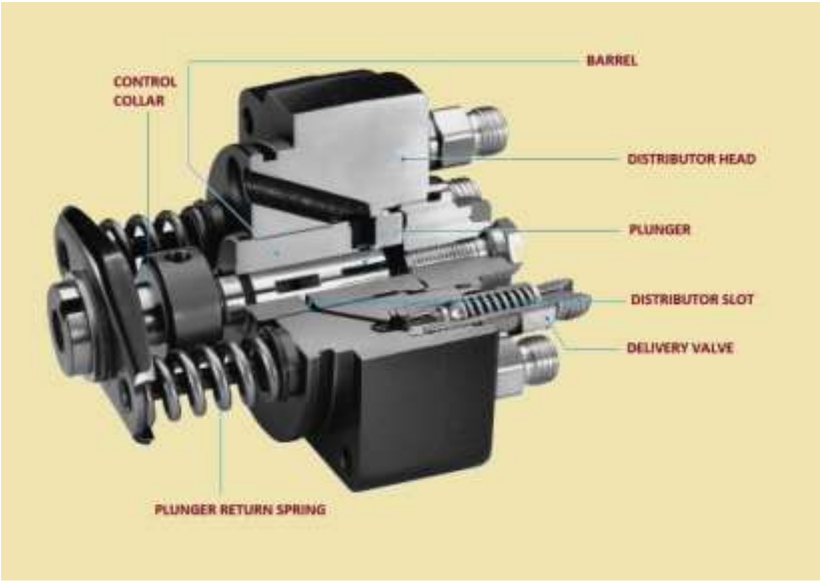


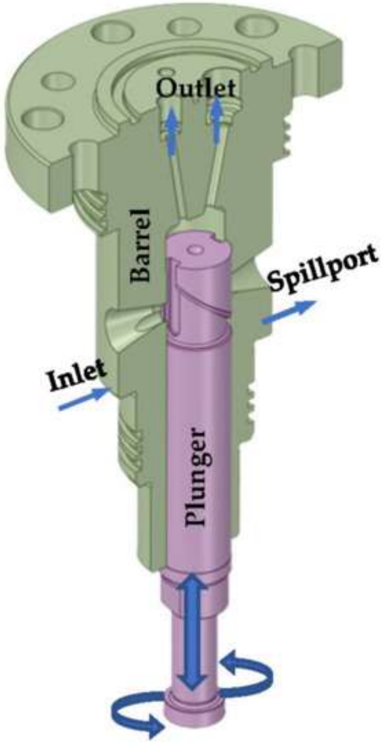
IC Engines Systems

2. Fuel System of Diesel Engines

Fuel Pump :

The fuel feed pump that supplies fuel from the main tank to the fuel injector pump is generally of spring loaded plunger type. The plunger is activated through a pushrod attached to a cam. When the cam is at its minimum height position, suction is created in the fuel feed pump and fuel is fed from the main fuel tank. When the cam reaches its maximum height, the fuel is pushed out of the feed pump to the fuel injector pump. Fuel injection pumps are designed to accurately measure and deliver the given quantity of fuel to the injector at high pressure (150 bar to 200 bar) at a given time instant. There are two types of fuel injection pumps. They are **Plunger/jerk type** and **Distributor type.**



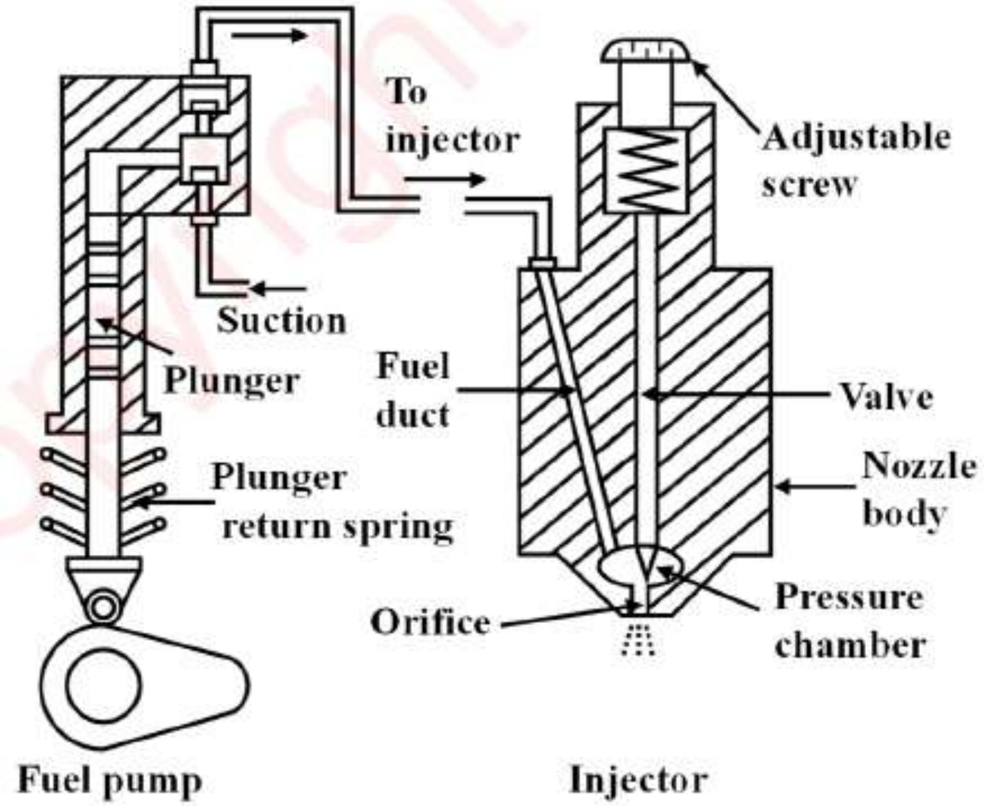


IC Engines Systems

2. Fuel System of Diesel Engines

INJECTOR :

An injector assembly comprises of needle valve, compression spring, a nozzle and an injector body. Fuel supplied from the fuel injection pump at high pressure works against the spring and lifts the nozzle valve and opens the injector orifice. As a result, the fuel is sprayed into the cylinder. When the required quantity of fuel is injected, the spring force acts on the nozzle valve and it moves down and closes the injector orifice. A small quantity of fuel leaks through the clearance between the nozzle valve and its guide path and drains back into the fuel tank. There is an adjustable screw that can be used to vary the spring tension and valve opening. A schematic of the fuel feed pump and injector is shown in Fig.



IC Engines Systems

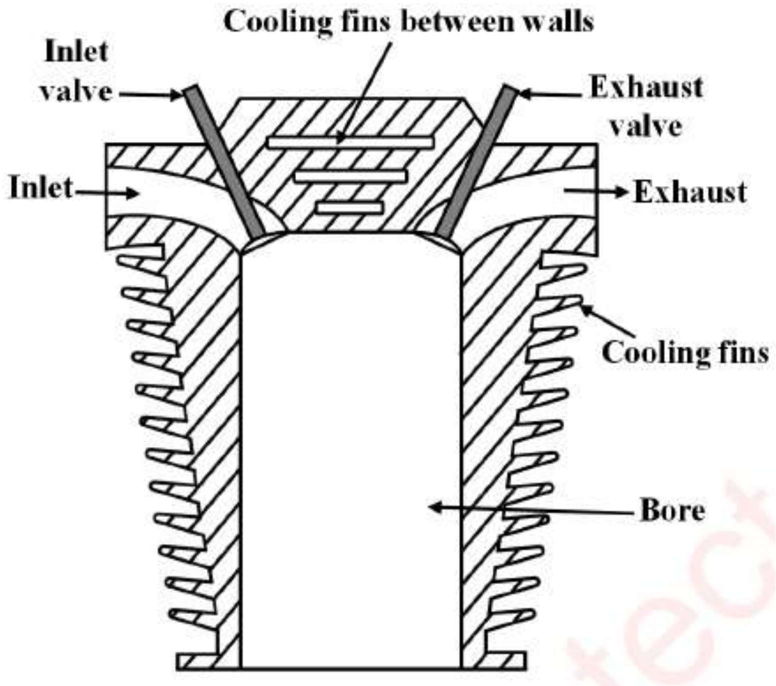
3. COOLING SYSTEMS IN IC ENGINES

An engine requires a properly designed cooling system. Based on the capacity of the engine, air or liquid can be used as the cooling medium. Fundamentally, two types of cooling systems are used. They are **liquid cooling system** and **air cooling system**. **A liquid cooling system is also called an indirect cooling system and the air cooling system is called the direct cooling system**.

IC Engines Systems

3. COOLING SYSTEMS IN IC ENGINES

AIR COOLING SYSTEM : In an **air cooling system**, a stream of air flows around the cylinder periphery. The heat transfer rate is directly proportional to the temperature difference between the cylinder surface and the air. It is also directly proportional to the area of heat transfer. In order to increase the area of heat transfer, extended metallic surfaces or fins are provided to the periphery of the cylinder. The air cooling system is used in small engines such as in two-wheelers and small cars. It is also used in airplanes, where high velocity air is available for cooling the engine. To orient the air stream properly across the engine, baffles are used. A typical cross-section of a single cylinder engine with fins is shown in Fig. Fins of different shapes, such as, triangular, trapezoidal and rectangular, are commonly used. The design of fins is such that more area is provided where hotter surfaces are present. Cylinder, cylinder head, valve ports, space around fuel injector or spark plug and so on are cooled by proper arrangements of fins and orienting the air flow through these fins using baffles.



IC Engines Systems

3. COOLING SYSTEMS IN IC ENGINES

WATER COOLING SYSTEM :

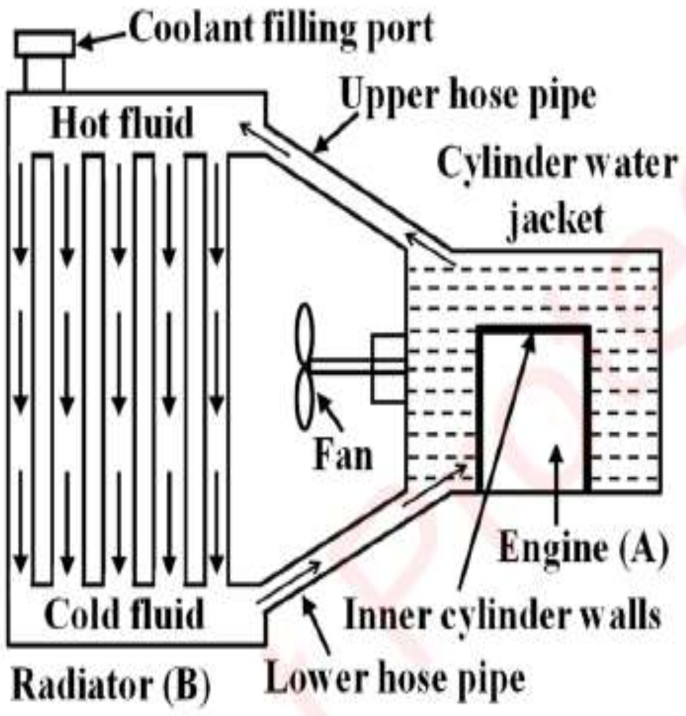
In many liquid cooling systems, mainly water is used for cooling. In several modern vehicles, a mixture of water and anti-freeze chemicals such as ethylene glycol is used. Water or coolant is circulated through the jackets provided surrounding the outer surface of the engine cylinder, cylinder head, valve ports and so on. The water flows through the jacket exchanging heat from the hot parts of the engine. The hot water then flows through a radiator, where it is cooled by air. Radiator is a heat exchanger having several tubes through which the water flows and over the water tubes, air flows through passages having fins. Air is drawn through the radiator with the help of a fan as well as by the movement of the vehicle. The air stream exchanges heat with the hot water and cools the water to the required extent. The cool water is again sent through the jacket and this cycle continues. A thermostat is used to control the temperature of the water. The thermostat controls the flow of water through the radiator based on its temperature and prevents water circulation through the radiator if the water temperature is below a certain value. For example, during cold start-up, water is not circulated through the radiator until the engine warms up. In several automobiles, a water pump is used to circulate the water to the jacket through a tube fitted in the front end of the block.

IC Engines Systems

3. COOLING SYSTEMS IN IC ENGINES

WATER COOLING SYSTEM :

In a few cases, natural circulation of water caused by the **thermosyphon effect** is also used. Figure shows the **thermosyphon based water circulation**. " The water flows through the water jacket surrounding the cylinder of the engine (A) and is heated by the hot engine parts. Hot water has a relatively lower density. Thus, due to buoyancy, the hot water travels up and enters the top of the radiator (B). This hot water slowly cools down by exchanging heat with the air flowing past the radiator by convective heat transfer. Fan is used to increase the cooling rate by inducing forced convection. Relatively colder liquid moves down the radiator tubes causing recirculation in a natural manner. In order to ensure circulation and cooler water reaching back the engine, the water jackets in the engine are located at a lower height than the radiator. Even though this system has advantages in terms of simplicity, no pump requirement and natural water circulation, this system may not be able to take care of higher rate of water flow as required in high capacity engines."



IC Engines Systems

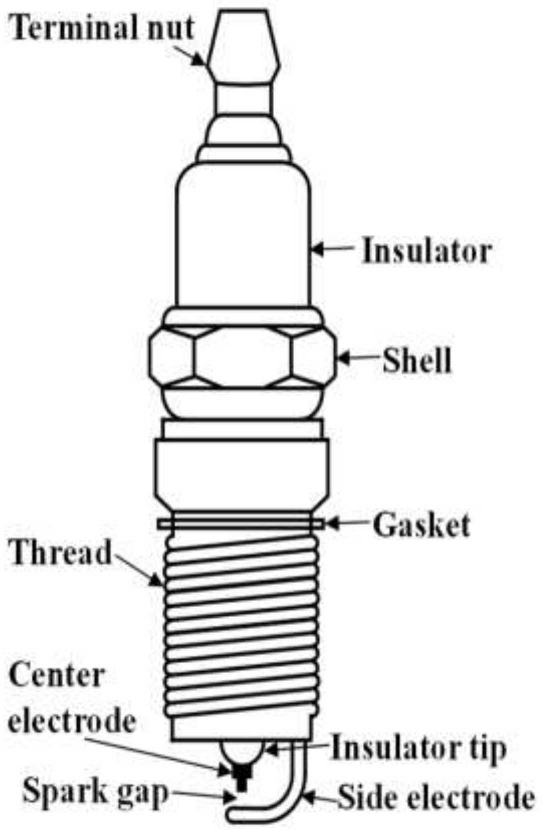
3. COOLING SYSTEMS IN IC ENGINES (COMMPARISON B/W WATER & AIR COOLING SYSTEM)

Water cooling system	Air cooling system
Advantages: (i) Due to higher rate of heat transfer, compact design is possible. (ii) Fuel consumption is relatively lower than that in air cooled engines. (iii) Cooling system can be conveniently located. (iv) More control is available in terms of water flow rate.	Advantages: (i) Design and installation of the engine without water jackets and with fins are simpler. (ii) Maintenance is cheaper, radiator and pumps are absent. (iii) Coolant liquid may freeze. Such a problem is not present here. (iv) Improved power-to-weight ratio.
Limitations: (i) Relatively complex cooling arrangement. (ii) Additional power for cooling affects power output of the engine. (iii) In the event of coolant leakage and failure, engine could be damaged severely. (iv) Cost and maintenance are high.	Limitations: (i) Can be used in small engines only. (ii) Cooling may not be uniform. (iii) High ambient temperature results in poor cooling. (iv) May produce more noise due to air flow through fins. (v) Results in higher operating temperature.

IC Engines Systems

IGNITION SYSTEMS

In spark-ignition engines, an external energy source is required to ignite the fuel-air mixture. As the name suggests, the ignition energy source is provided by means of a spark generated between two electrodes of a spark plug towards the end of the compression stroke. A schematic of a typical spark plug is shown in Fig. In an insulated housing, two electrodes are kept embedded in a shell. One is called the center electrode and another is the side electrode. A specific gap is maintained between these electrodes. The spark plug is connected to the cylinder head of an engine through the threaded portion. When the terminal nut is connected to electrical power, a high voltage exists between the two electrodes and a spark is produced in the spark gap.



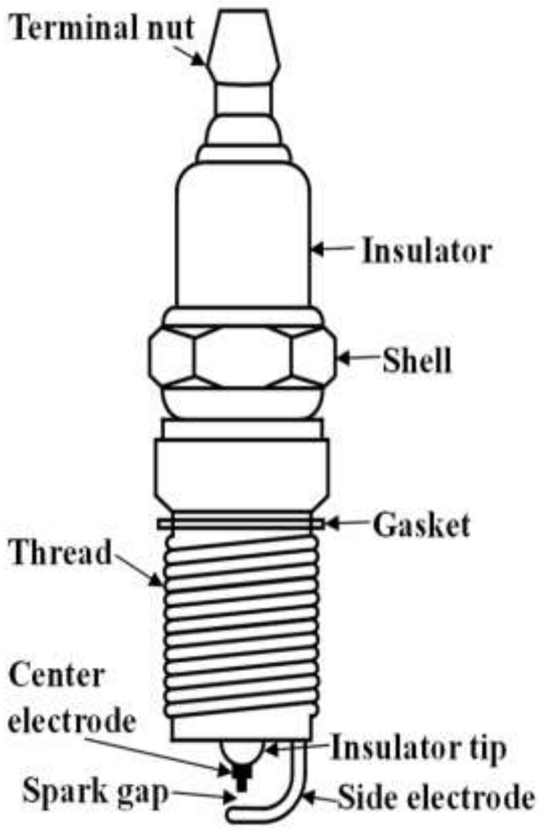
IC Engines Systems

IGNITION SYSTEMS

The ignition system is classified based on the method of supply of the energy as

- Battery ignition system (also called coil ignition system) and
- Magneto ignition system.

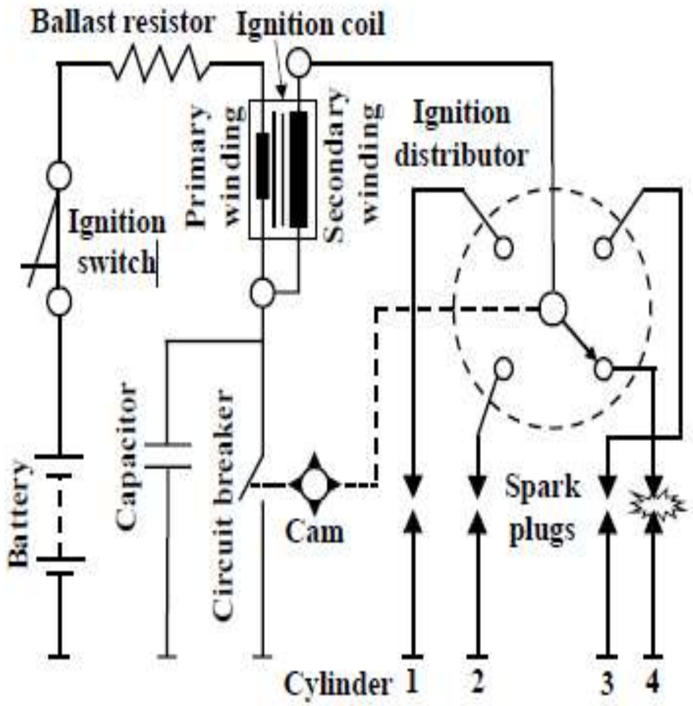
The Voltage required to produce a spark across the gap between the two electrodes of the spark plug is in the range of 10000 to 20000 volts.



IC Engines Systems

BATTERY IGNITION SYSTEMS

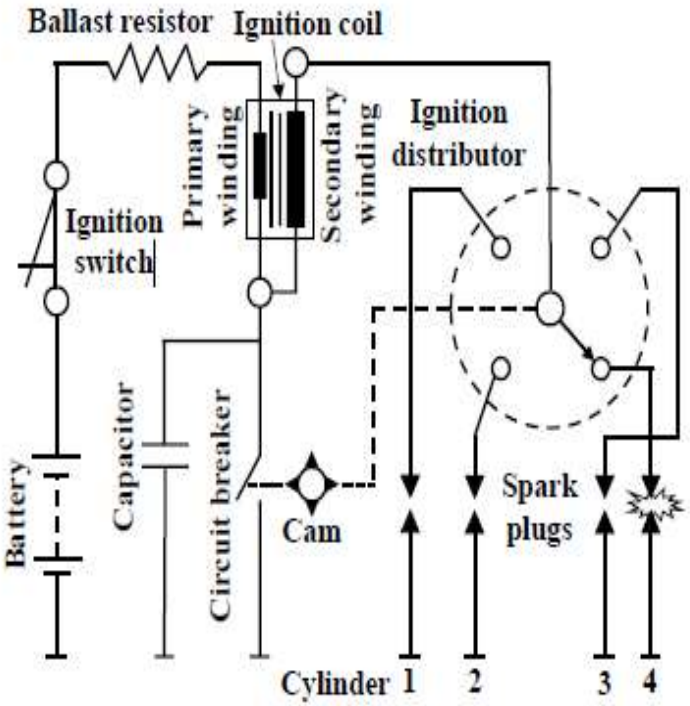
The battery or coil ignition system consists of a battery, an ignition coil, a condenser (or a capacitor), a ballast resistor (optional) a circuit (or contact) breaker, a distributor and spark plugs (one for each cylinder). A schematic of the coil ignition system is shown in Fig. The ignition coil is used to step up the battery output of 6-12 volts to 10000 to 20000 volts required to produce a spark across the electrodes. The ignition coil has a primary winding and a secondary winding. The primary winding is made of 200 to 300 turns of thick wire (20 standard wire gauge) wound over a soft-iron core to produce a resistance of 1.15 ohms.



IC Engines Systems

BATTERY IGNITION SYSTEMS

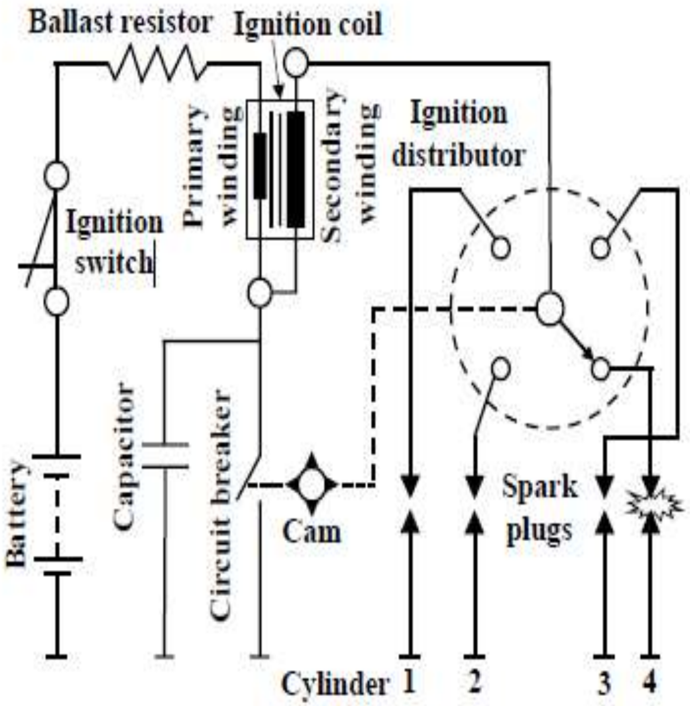
The secondary winding is present inside the primary winding and it is formed by around 21000 turns of fine copper wire (40 standard wire gauge) wound on a soft-iron core. It is sufficiently insulated to withstand high voltage. One end of the primary coil is connected to the ballast resistor, ignition switch, ammeter and battery. The other end of the primary coil is connected to the condenser and the contact breaker. The secondary coil is connected to the distributor with a central terminal of the spark plugs. The outer terminals of the spark plugs are earthed and connected to the body of the engine. The coil ignition system is employed in medium and heavy spark ignition engines.



IC Engines Systems

BATTERY IGNITION SYSTEMS

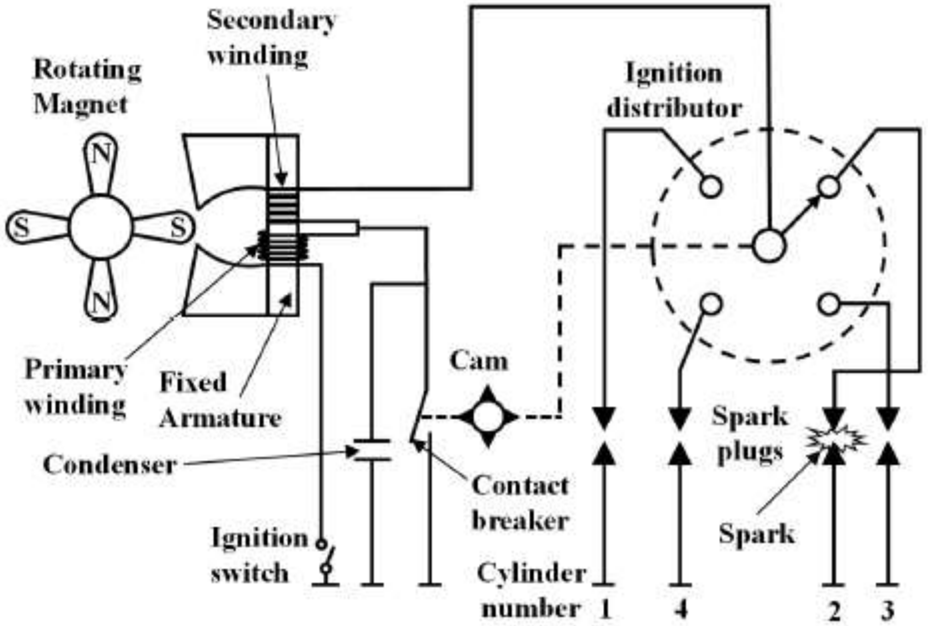
The ballast resistor is provided to regulate the primary current. An ignition switch is used to turn on or off the ignition system. The contact breaker is a mechanical device that is used for forming or breaking the ignition circuit connected through the ignition coil. It is operated by a cam. The ignition capacitor provides the same function as that of an electrical capacitor. The distributor distributes the electrical energy to individual spark plugs at correct time instant. Brush type and gap type distributors are generally used. A spark plug has a shell made up of steel, insulating material and two electrodes. The central electrode is connected to the secondary winding terminal that provides high tension (voltage) supply. The other electrode is attached to the steel shell by welding. The electrodes are well insulated with porcelain or other ceramic materials. The electrodes are usually made of high nickel alloy. Proper cooling is provided to the steel shell to dissipate the heat.



IC Engines Systems

MAGNETO IGNITION SYSTEMS

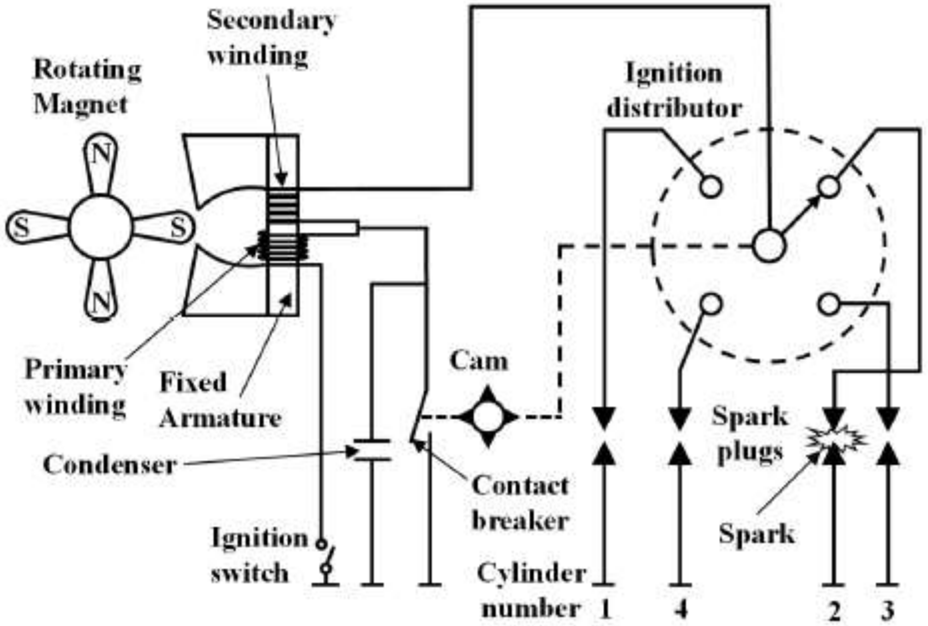
The magneto ignition system is a special type that has its own electric generator to provide the necessary energy for ignition. A magneto operates on the principle of a generator. A magneto can be a rotating armature type or rotating magnet type. In the rotating armature type, an armature consisting of primary and secondary windings rotate between the north and south poles of a stationary magnet. In the rotating magnet type, a permanent magnet revolves inside the primary and secondary windings, which are kept stationary. A third type of magneto is called polar inductor type.



IC Engines Systems

MAGNETO IGNITION SYSTEMS

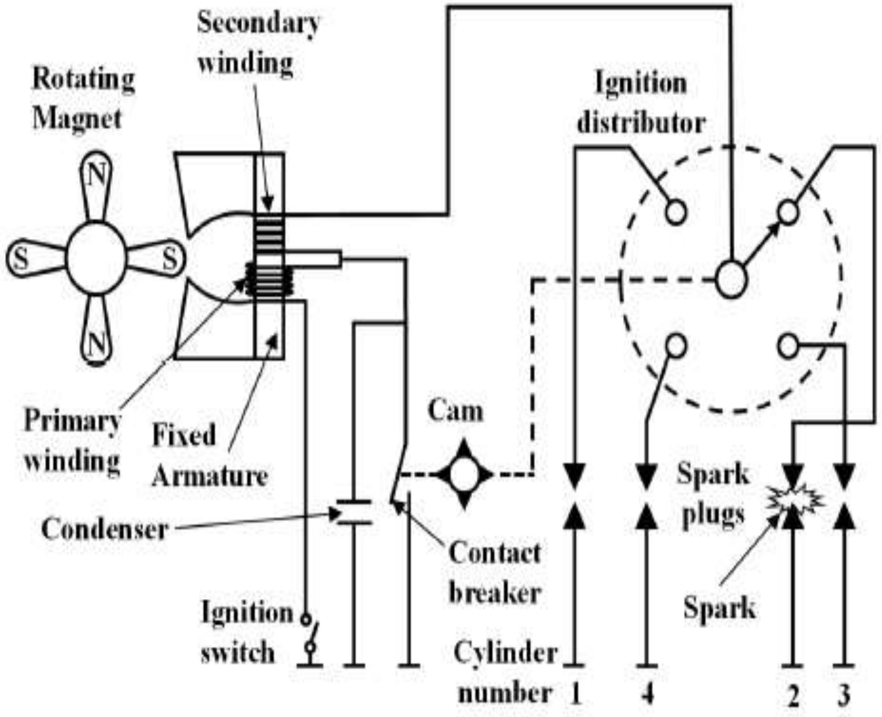
It has an inductor apart from a magnet and an armature. Rotating magnet type magneto with an armature having primary and secondary windings is also called high tension magneto. It is commonly used in two-wheelers, mopeds, racing cars and reciprocating aircraft engines. A schematic of high tension magneto is shown in Fig. It has a fixed armature with primary and secondary windings, rotating system of magnets, contact breaker, capacitor, distributor, high tension cables and spark plugs. When the engine starts, the cam shaft rotates the magnet connected to it.



IC Engines Systems

MAGNETO IGNITION SYSTEMS

As the magnet rotates, the magnetic flux changes and this induces an alternating current (AC) in the primary winding when the contact breaker is closed. This charges a capacitor (or condenser) connected to the circuit. The primary current also creates its own magnetic field around the primary and secondary windings. When the contact breaker is closed, the fully charged capacitor discharges. This creates a rapid change in the magnetic flux and as a result, a very high voltage is induced in the secondary winding. This high voltage is sufficient to trigger a spark in one of the spark plugs connected to the distributor through high tension cables.



IC Engines Systems

COMPARISON

Battery (or Coil) ignition system	Magneto ignition system
Requires a battery	No battery is required
More maintenance cost	Lesser maintenance cost
Primary current is delivered by a battery	Primary current is generated by a magneto
Performance is very good at low speeds	Performance is poor at low speeds
Slight decrease in efficiency with increasing speed	Efficiency improves with increasing speed
Occupies more space	Occupies less space
Used in cars and commercial vehicles	Used in two-wheelers, three-wheelers and racing cars

IC Engines Systems

LUBRICATING SYSTEMS

Lubrication systems are designed to provide sufficient amount of lubricating oil to all the moving parts to impart adequate lubrication and to prevent wear and tear due to friction between the components. There are three classifications of lubricating systems.

They are

(a) Mist lubricating System

(b) Wet sump lubricating system and

(c) Dry sump lubricating system.

IC Engines Systems

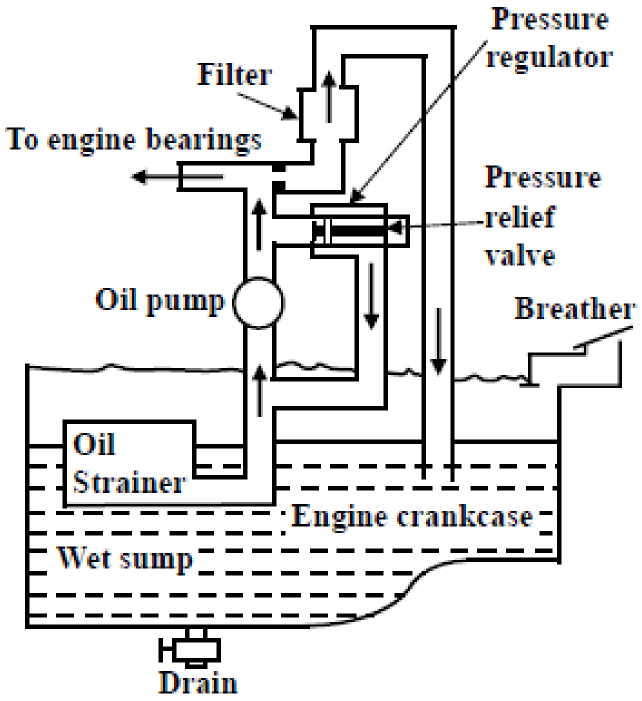
MIST LUBRICATING SYSTEMS

Mist lubricating system is also called the petrol lubricating system. It is used in two-stroke SI engines, where the charge (petrol and air) is taken in and compressed in the crankcase. Here, the lubricating oil is mixed in a given proportion (3% to 6%) with petrol and supplied through the carburettor. Petrol vaporizes and oil remains as tiny droplets (mist). The oil reaches the walls of the crankcase and lubricates the main bearings and the connecting rod bearings. The remaining oil lubricates the piston, piston rings and the cylinder. Even though this system is simple and cheaper, it results in wastage of oil, production of smoke and emissions. Also, the lubrication depends on the supply of fuel.

IC Engines Systems

WET SUMP LUBRICATING SYSTEMS

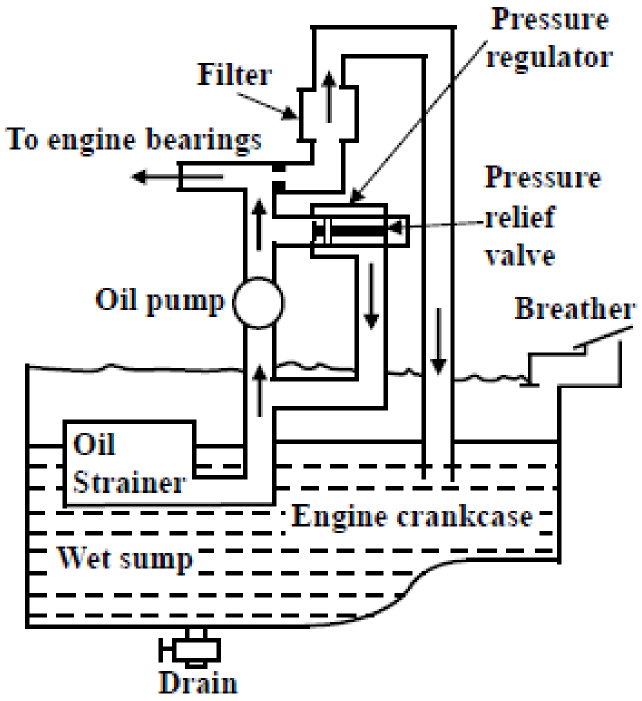
Wet sump lubricating system has an oil pan or sump attached to the bottom of the crankcase that contains the oil. An oil pump is used to supply the oil from this sump to various parts of the engine. After flowing through the required parts of the engine, the oil returns back to the sump assisted by gravity. There are three types of wet sump lubricating systems. They are splash system, splash and pressure system, and pressure feed system. The typical components of wet sump lubricating system are a pump, strainer, filter, pressure regulator and breather. A line diagram of the wet sump lubrication system is shown in Fig.



IC Engines Systems

WET SUMP LUBRICATING SYSTEMS

Oil is pumped using a gear pump or a rotor type pump. It passes through an oil strainer, which has a fine mesh screen to filter out particle impurities from the oil. A pressure relief valve is used to maintain a constant delivery pressure. When a certain set pressure is exceeded, this valve opens and some amount of the oil returns to the sump. A major portion of the oil is supplied to the main engine bearings to lubricate them. Some amount of oil passes through another filter, called cartridge filter, where solid particles in the oil are filtered out. This cartridge filter is also called a by-pass filter. Periodically all the oil will pass through this filter and get cleaned up.

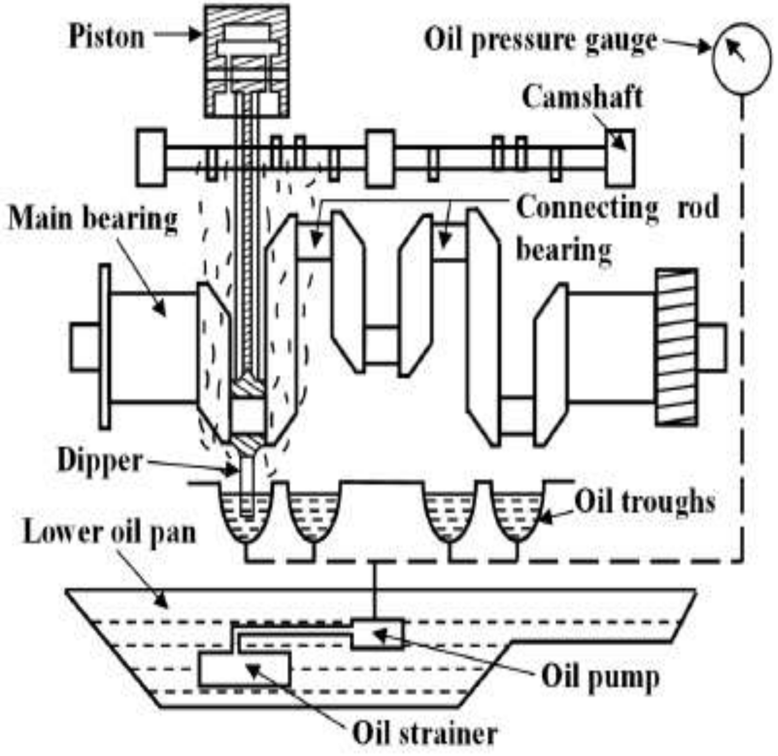


IC Engines Systems

WET SUMP LUBRICATING SYSTEMS

A clogged filter will not restrict the flow of oil to the engine components. Some fresh air enters the crankcase through the breather to cool the oil.

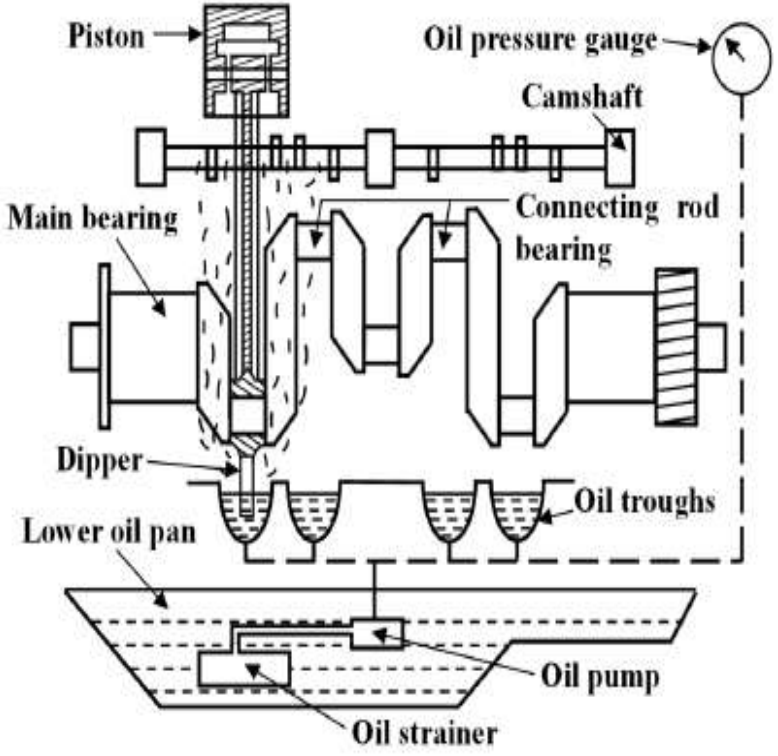
In the splash system, splash oil troughs are provided under the big ends of all the connecting rods as shown in Fig. Oil from the crankcase is pumped from the sump to splash oil troughs through the strainer and a distributing pipe. A splasher, also called a dipper, is provided in each connecting rod.



IC Engines Systems

WET SUMP LUBRICATING SYSTEMS

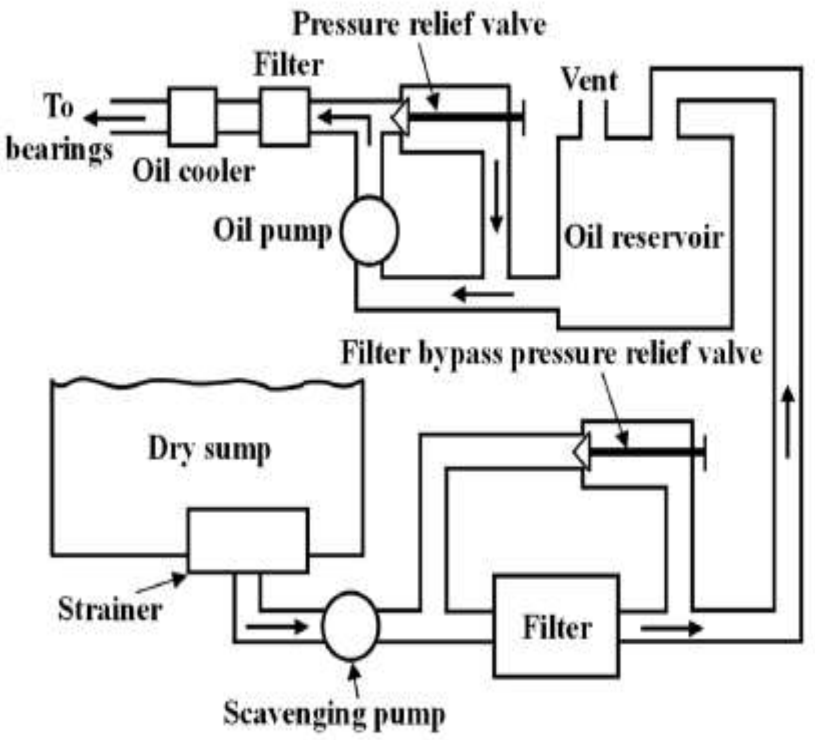
In each crankshaft revolution, the splasher dips into the oil in the trough and splashes it all over the interior of the crankcase, to the piston, cylinder walls and the bearing surface through holes drilled through the connecting rod. Splash system is commonly used in light motor vehicles.



IC Engines Systems

DRY SUMP LUBRICATING SYSTEMS

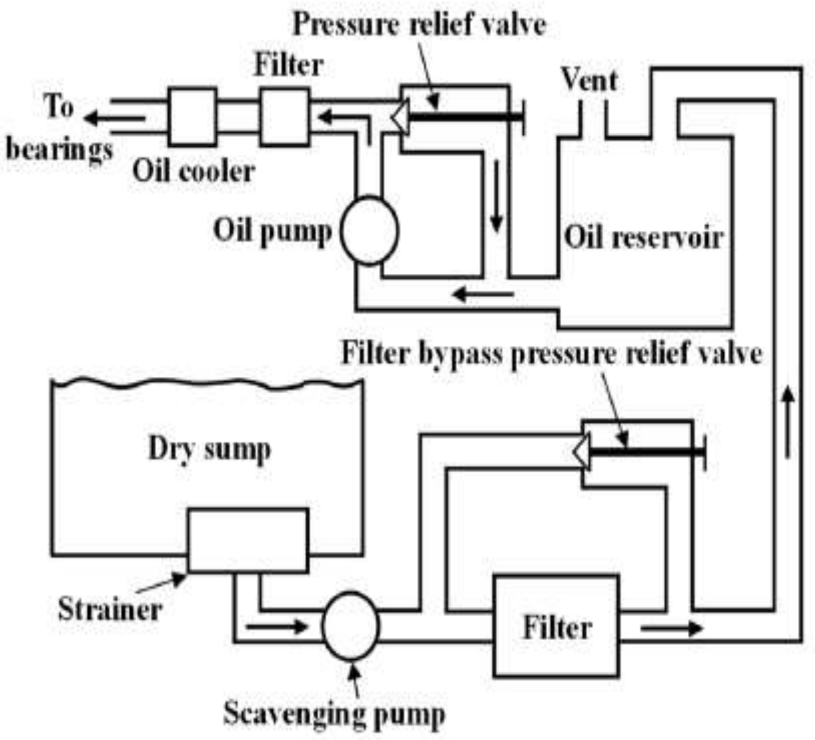
The dry sump lubricating system uses an external tank to store the oil. An oil pump takes the oil from this tank and circulates it to various bearings. In this manner, the dry sump lubricating system uses only the pressure feed method. The oil dripping from the cylinders and bearings into the crankcase passes through a strainer and is removed using a scavenging pump, which has a higher capacity than the oil pump. Oil from the scavenging pump passes through a filter and a bypass valve, and reaches the supply tank. In this manner, there will be no oil accumulated in the base of the engine crankcase.



IC Engines Systems

DRY SUMP LUBRICATING SYSTEMS

A pressure relief valve opens when the filter is clogged and enables the oil to by-pass the filter and reach the supply tank. Oil is cooled by using a dedicated oil cooler, where either water or air is used for cooling.



IC Engines Systems

GOVERNING OF IC ENGINES

A governor is usually a mechanically operated device used to control the speed of the engine and to maintain a constant mean speed in different loads. Basically, the supply of the fuel or the fuel-air mixture is varied to achieve this. When the load on an engine increases, the engine speed decreases below the mean speed value. To increase the engine speed, more diesel (in CI engines) or more petrol-air mixture (in SI engines) is required. This is achieved by using a governor. Similarly, when the load on the engine decreases, the engine speed increases beyond the mean speed. To decrease the engine speed towards the mean value, lesser amount of diesel or petrol-air mixture is to be supplied. A governor is capable of accomplishing this task. There are three commonly used methods of governing. They are **hit and miss method**, **qualitative method** and **quantitative methods.**

IC Engines Systems

GOVERNING OF IC ENGINES (HIT & MISS METHOD)

The hit and miss method is used in small petrol and gas engines. In the hit and miss method, when the engine speed increases, the fuel supply is cut-off by the governor for a few cycles and the engine performs idle cycles in this duration. These are also called missed cycles. As a result, the engine speed decreases. This method is simple and governing is easier. However, this results in an uneven turning moment, abnormal noise and reduced efficiency. Another way followed in this method is to prevent the opening of the exhaust valve such that idle cycles with exhaust gases are performed by the engine in this duration.

IC Engines Systems

GOVERNING OF IC ENGINES (QUANTITATIVE METHOD)

The quantitative governing method is utilized in the SI engines. Here, the governor controls the throttle valve to vary the quantity of petrol-air mixture supplied to the engine, and thus, controls the engine speed. The quality, ratio of petrol to air, remains almost the same. This method is also called the throttle governing. When the engine speed increases above the mean speed, the governor mechanism closes the throttle valve to permit lesser amount of petrol-air mixture supplied to the engine. As a result, the engine speed decreases towards the mean value. Alternatively, the lift of the inlet valve is varied by the governor mechanism to control the amount of the fuel-air mixture taken into the cylinder.

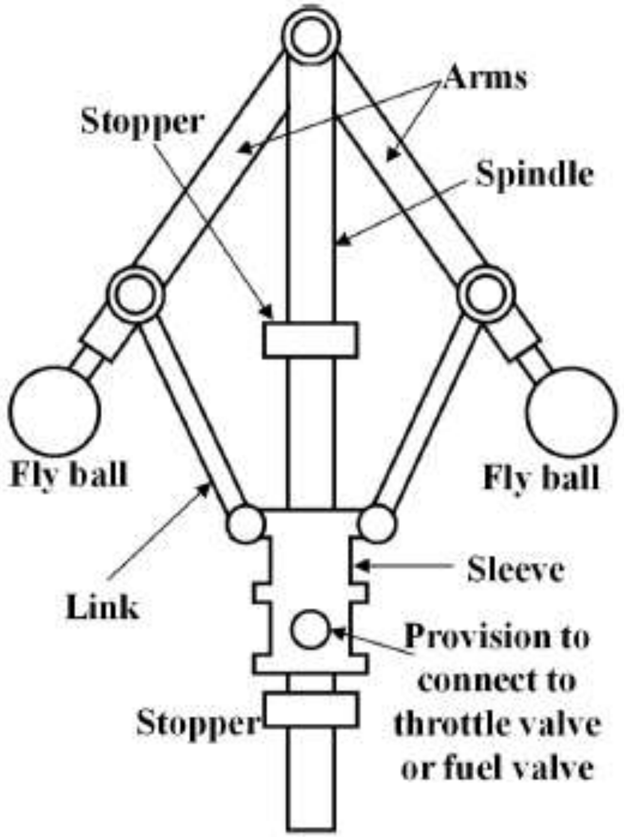
IC Engines Systems

GOVERNING OF IC ENGINES (QUALITATIVE METHOD)

The qualitative governing method is used in the CI engines, where a given quantity of air is taken into the cylinder and compressed, and diesel is injected to initiate combustion. Here, the amount of diesel injected is varied by the governor based on the engine speed. As a result, the quality (or the strength) of the resultant fuel-air mixture varies inside the cylinder. When the engine speed exceeds the mean speed, the amount of diesel injected is reduced. This results in reduced mixture quality. When the mixture quality decreases, the power developed by the engine decreases and as a result, the engine speed also decreases. The quantity of fuel injected is controlled by the governor by varying the stroke of the fuel pump or by-passing some fuel back to the fuel tank.

IC Engines Systems

GOVERNING OF IC ENGINES (SCHEMATIC DIAGRAM OF A WATT GOVERNOR)



IC Engines Systems

OBJECTIVES OF SUPERCHARGING

Supercharging in an IC engine is employed to improve its power output. It is also called forced induction of the charge. Basically, the density of the air fed into the cylinders is increased in this process. Supercharging increases the oxygen availability for combustion when compared to conventional (naturally aspirated) charging. As a result, more air and fuel are inducted into the cylinder, which can be effectively burnt, and increase the power output of the engine. Here, a certain percent of engine power output is used for compressing the air. However, the net power output due to supercharging will be more than the power output of an engine with the same capacity using the naturally aspirated charge. Engine using supercharging should be sturdier to withstand additional forces. An additional pressure of the charge may lead to detonation (auto-ignition) in SI engines.

IC Engines Systems

OBJECTIVES OF SUPERCHARGING

Therefore, fuel with improved anti-knock properties should be used. Racing cars, marine engines and heavier automotive engines use supercharging. Supercharging is favourable for engines used in high altitudes, where the pressure drop effects will be compensated by supercharging. There are three types of superchargers used. They are centrifugal type, root's type and vane type.

UNIT –IV

PERFORMANCE OF I.C. ENGINES

1. Indicated Power (I.P.)

The gross theoretical power generated inside the engine cylinder by the chemical combustion of fuel expanding against the piston face. It does not account for structural parasitic or sliding mechanical losses.

Indicated Power Calculation

Calculated derived from the cylinder's operational geometry and cycle speed characteristics:

$$\text{I.P.} = \frac{P_m \cdot L \cdot A \cdot n \cdot K}{60{,}000}(\text{kW})$$

- **P_m:** Indicated Mean Effective Pressure ($N/m2$)
- **L:** Stroke Length of the piston (m)
- **A:** Cross-sectional area of cylinder bore ($m2$)
- **K:** Total number of cylinders in the engine block
- **n:** Number of power strokes per minute:
  - $n = N$ for 2-Stroke engines
  - $n = N / 2$ for 4-Stroke engines (N = RPM)

2. Brake Power (B.P.)

The net useful power available explicitly at the engine crankshaft or output shaft for external utility. It represents the real-world operational capacity of the engine after overcoming all internal structural resistance.

Brake Power Calculation

Determined directly utilizing a mechanical brake dynamometer system configured at the output flywheel:

$$\text{B.P.} = \frac{2\pi \cdot N \cdot T}{60{,}000}(\text{kW})$$

Where Engine Output Torque (T) is derived from testing apparatus parameters:

$$T = (W - S) \cdot R(\text{N}\cdot\text{m})$$

- **W:** Dead weight hanging on the brake rope configuration (N)
- **S:** Spring balance scale registration parameter (N)
- **R:** Effective radius of the brake wheel drum (m)

3. Frictional Power (F.P.)

The segment of generated power consumed within the engine to overcome mechanical sliding frictions, pumping constraints, and auxillary operations.

$$F.P. = I.P. - B.P.$$

Loss Sources: Piston-cylinder skirt friction (up to 50% of F.P.), journal bearings, camshaft valvetrain resistance, and throttling pumping loops.

Mean Effective Pressures (m.e.p.)

A constant, theoretical average pressure that, if acting uniformly on the piston face throughout its entire power stroke, would produce the precise magnitude of net work equal to that of the real variable-pressure cycle.

- **Indicated m.e.p. (P_{mi}):** Obtained from indicator diagrams. Measures pressure inside the cylinder.
- **Brake m.e.p. (P_{mb}):** That portion of mean effective pressure producing the useful torque at the crankshaft:

$$P_{mb} = P_{mi} \times \eta_m$$

Mechanical Efficiency (η_m)

The definitive metric quantifying how successfully an engine converts internal thermodynamic gas work into structural shaft power output, directly reflecting frictional optimization.

$$\eta_m = \frac{B.P.}{I.P.} = \frac{P_{mb}}{P_{mi}}$$

Operational Insight: At zero load (idling), brake power becomes zero, which forces mechanical efficiency to drop to 0% because all generated Indicated Power is entirely consumed to overcome internal Frictional Power.

Indicated Thermal Efficiency (η_{ith})

The ratio of power developed within the engine cylinder (I.P.) to the total heat energy liberated per second by burning the input mass flow of fuel.

$$\eta_{ith} = \frac{\text{I.P.}}{m_f \times \text{C.V.}}$$

Brake Thermal Efficiency (η_{bth})

The overall practical thermal efficiency parameter of the system. It scales net shaft energy output against total raw heat power inputs.

$$\eta_{bth} = \frac{\text{B.P.}}{m_f \times \text{C.V.}}$$

Relative Efficiency (η_{rel})

Also recognized as the Efficiency Ratio, it offers an explicit assessment of how close the real-world operational cycle parameters approach the idealized, lossless air-standard thermodynamic bounds.

$$\eta_{rel} = \frac{\eta_{\text{thermal (Actual)}}}{\eta_{\text{Air-Standard}}}$$

Parameters Defined:

- m_f : Mass of fuel consumed per unit time (kg/s).
- **C.V.:** Calorific value of the fuel system (kJ/kg).
- $\eta_{\text{Air-Standard}}$: Idealized air cycle efficiency (e.g., Otto / Diesel cycle formula values).

EXPERIMENTAL METHODS: THE MORSE TEST

Figure 4.1: Schematic mapping multi-cylinder load responses during mechanical cylinder isolation routines.

The **Morse Test** is an elegant experimental method utilized specifically on **multi-cylinder I.C. engines** to isolate and determine individual cylinder Indicated Power values without installing integrated indicator pressure sensors inside the blocks.

Step-by-Step Testing Methodology

1. The engine is run continuously at a strictly regulated operational speed (N) under load. Total Brake Power (B_{total}) is logged.
2. Cylinder 1 is cut off (shorting spark plug for SI or closing fuel injector for CI). The engine speed drops, and external load is backed off until speed returns precisely to baseline (N).
3. Measure the remaining brake power (B_1) generated by the surviving cylinders.
4. Isolate individual cylinder Indicated Power:

$$I_1 = B_{total} - B_1$$

5. Repeat across all cylinders to calculate aggregate internal parameters:

$$I_{total} = \sum I_k$$

ENGINE HEAT BALANCE SHEET ANALYSIS

A thermodynamic ledger auditing total energy. Total heat input must balance heat distribution accounts:

$$\text{Total Heat Input Rate } (Q_{in}) = m_f \times \text{C.V. (kJ/min)}$$

Energy Distribution Account (Outputs)	Governing Analytical Expression	Typical % Range
1. Heat equivalent to useful Brake Power (Q_{bp})	$Q_{bp} = \text{B.P.} \times 60(\text{kJ/min})$	25% – 35%
2. Heat carried away by engine Cooling Water (Q_w)	$Q_w = m_w \cdot C_{pw} \cdot (T_{out} - T_{in})$	25% – 30%
3. Heat rejected into Exhaust Gases (Q_g)	$Q_g = m_g \cdot C_{pg} \cdot (T_g - T_{room})$	30% – 35%
4. Unaccounted losses (Convection, Radiation, Unburnt Fuel)	$Q_{unaccounted} = Q_{in} - (Q_{bp} + Q_w + Q_g)$	2% – 8%

UNIT –V

AIR COMPRESSORS, REFRIGERATION

&

AIR CONDITIONING

AIR COMPRESSORS: WORKING PRINCIPLE & UTILITY

Primary Functions

An air compressor is a mechanical device that takes in low-pressure air or gas from the atmosphere, performs structural work upon it via mechanical energy input (electric motor or IC engine drive), and discharges it at a substantially elevated delivery pressure level.

Industrial Applications of Compressed Air

- **Pneumatic Tool Operation:** Drives heavy-duty manufacturing tools including air impact wrenches, pneumatic drills, sandblasters, and industrial rivet hammers.
- **Process Automation:** Actuates industrial control valves, pneumatic robotic lines, and automated product sorting sorting ejectors.
- **Internal Combustion Scavenging:** Feeds supercharger and turbocharger induction manifolds to boost fuel combustion efficiency.
- **Specialty Sectors:** Mining operations, air brake line pressure architectures, and spray painting systems.

Broad Taxonomy and Structural Categorization

Compressor topologies are categorized broadly based on their fundamental mechanical energy conversion style:

Positive Displacement	Dynamic / Rotodynamic
Traps discrete air volumes and structurally shrinks physical boundaries to force pressure up.	Accelerates continuous gas flows via spinning impellers, converting kinetic energy to static pressure.
• Reciprocating Piston • Rotary Sliding Vane, Screw	• Centrifugal Compressor • Axial Flow Compressor

SINGLE-STAGE RECIPROCATING COMPRESSOR MECHANICS

Mechanical Operation Cycle

Constructed around a classic piston-connecting rod-crank sequence moving within structured head clearance guides:

- **Suction Stroke:** The piston retracts downward. The internal volume expands, drawing the pressure inside the cylinder below atmospheric level. The pressure differential causes the spring-loaded inlet valve to open, filling the chamber.
- **Compression Stroke:** The piston reverses direction, traveling upward. Both inlet and delivery valves seal tightly. The shrinking physical volume compresses the trapped air mass, causing its pressure and temperature to rise according to the polytropic cycle path index.
- **Delivery Stroke:** When cylinder pressure surpasses the external receiver manifold value, the delivery valve opens. The piston displaces the high-pressure gas into the storage vessel.

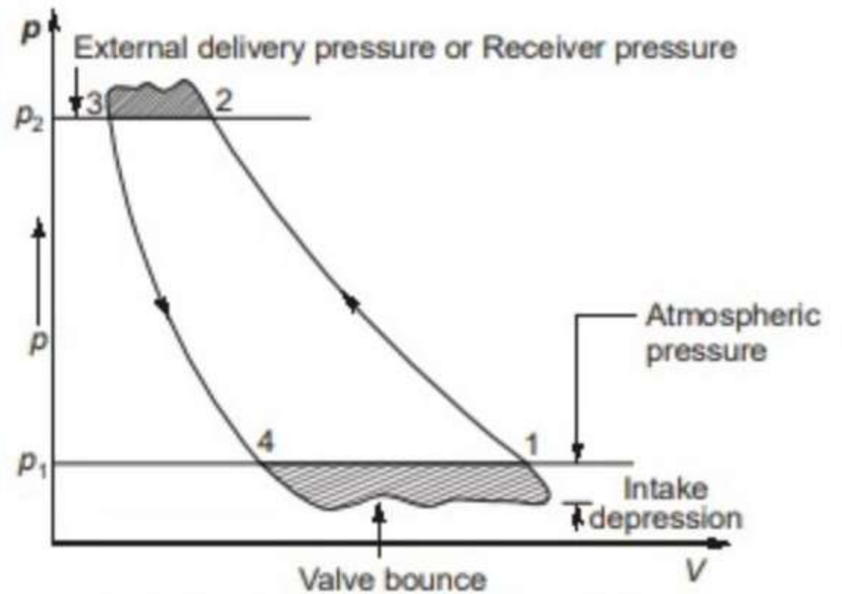


Fig. Actual compressor p-V diagram

Figure 5.1: Mathematical Indicator Diagram (P-V) detailing clearance gap tracking and the standard polytropic work loop profile.

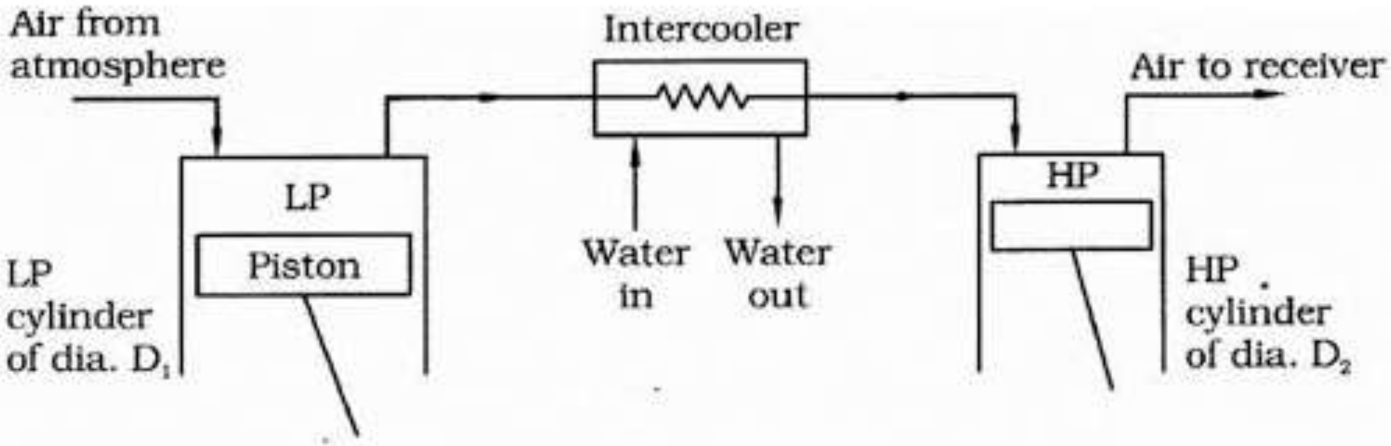
MULTI-STAGE COMPRESSION & INTERCOOLING ADVANTAGES

When high delivery pressures are required, single-stage compression becomes highly inefficient because high thermal spikes break down lubricants. Multi-stage systems resolve this by splitting compression across multiple sequential cylinders.

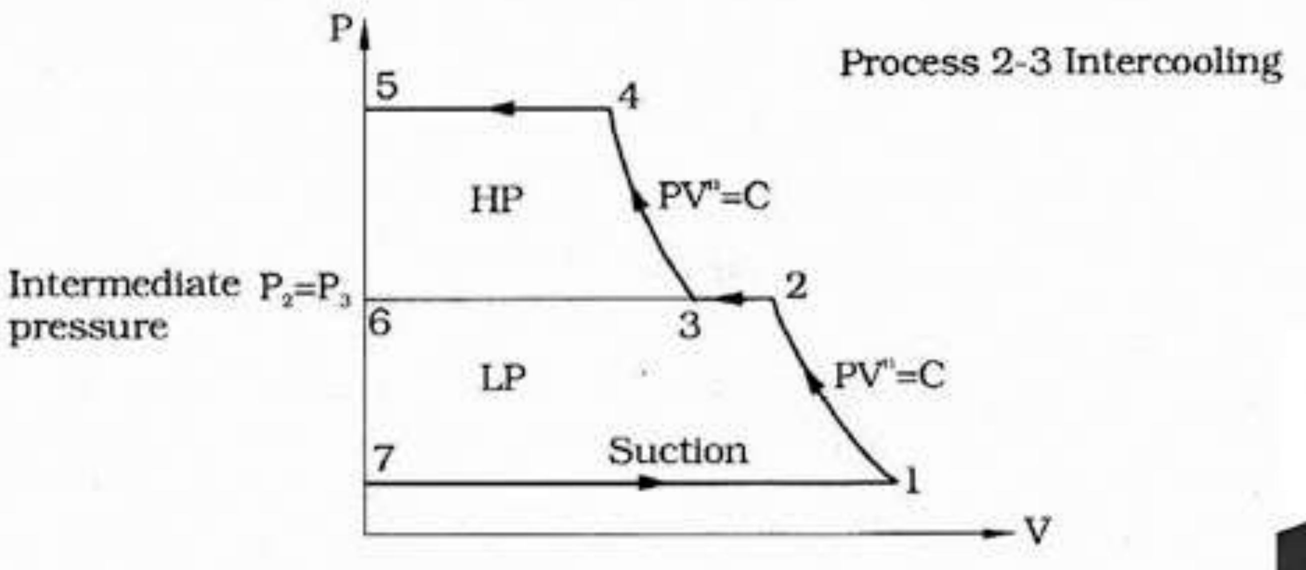
Why Multi-Staging Outperforms Single-Stage

- **Substantial Power Savings:** Passing gas through an **Intercooler** between cylinders lowers its temperature and volume toward isothermal conditions, reducing the work required for the next stage.
- **Enhanced Volumetric Efficiency:** Lower pressure ratios across individual stages prevent residual clearance gas from expanding excessively during suction, maximizing fresh air intake.
- **Thermal Safety & Reliability:** Dividing the pressure ratio limits peak discharge temperatures, preventing cylinder oil carbonization and structural degradation.
- **Mechanical Balance:** Distributing loads across multiple pistons reduces peak structural torque stress on the drive shaft.

Multistage Compressor

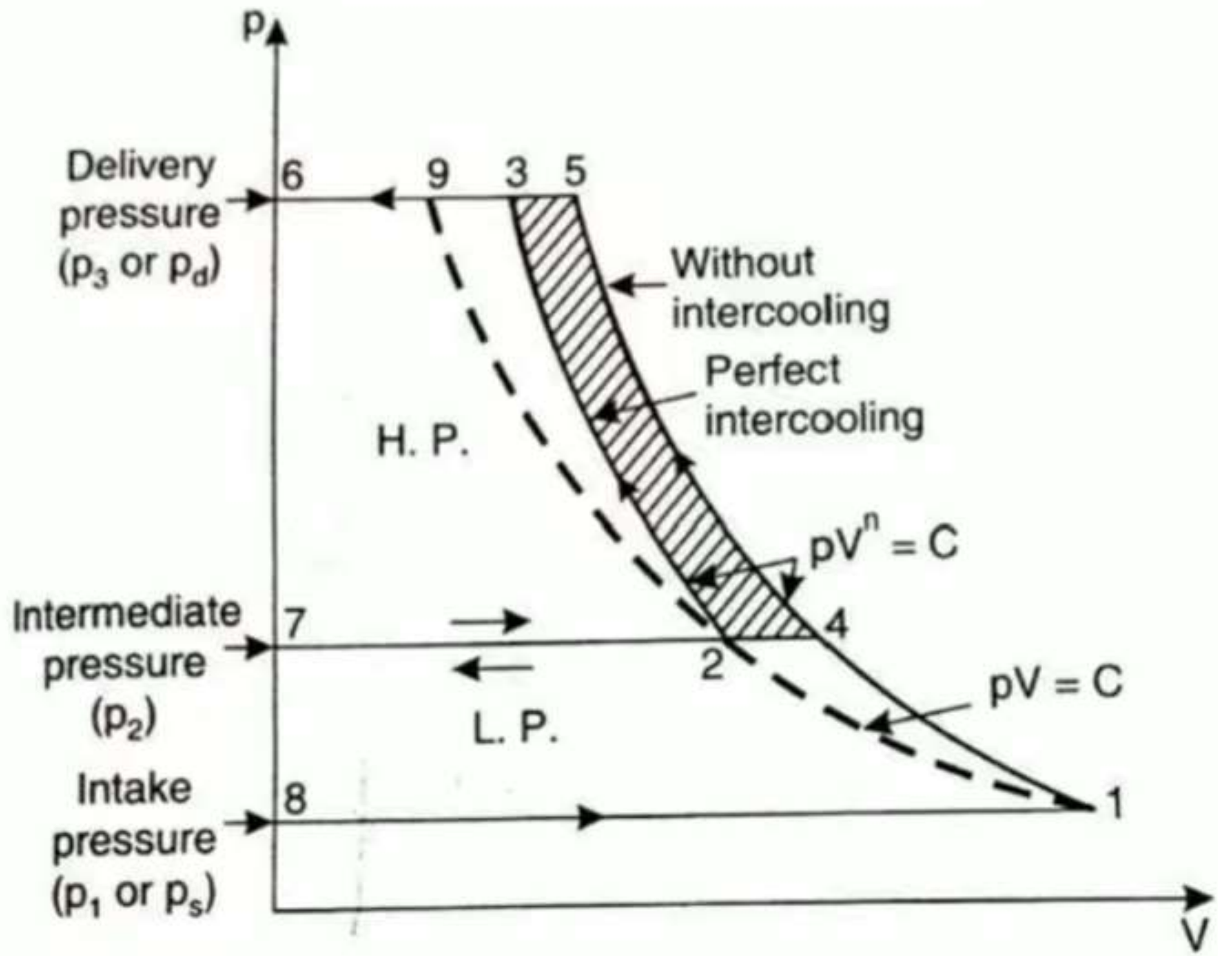


(a) 2-stage compressor



(b) P-V diagram of a 2-stage compressor

P-V diagram of multistage compressor with perfect intercooler

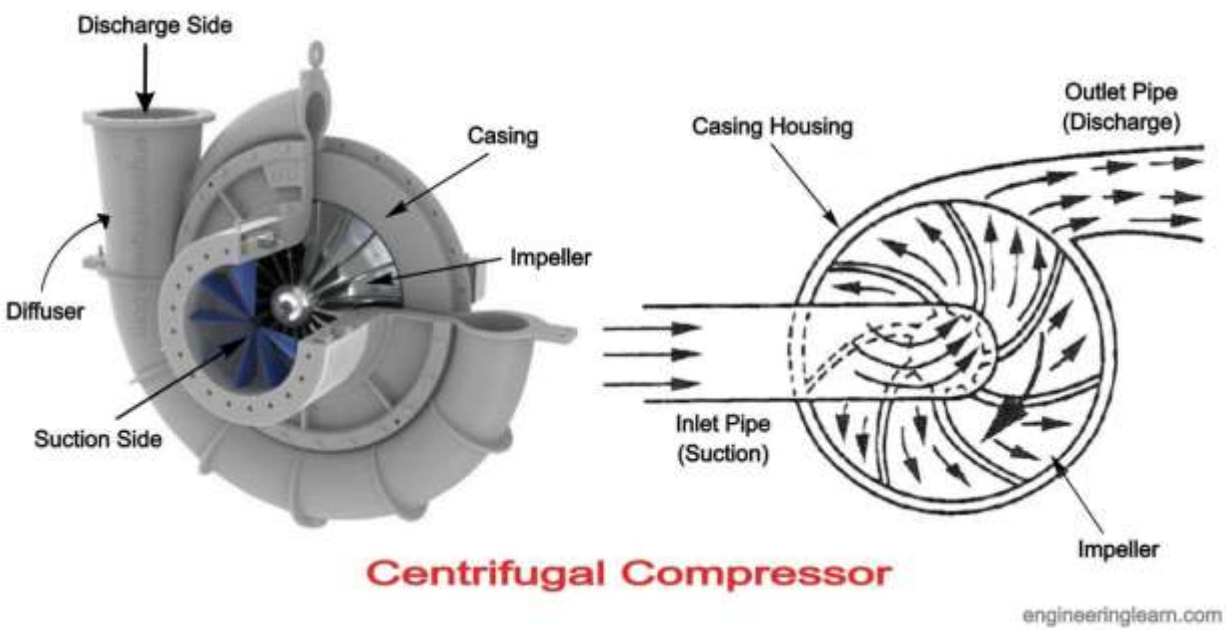


ROTARY COMPRESSORS: CENTRIFUGAL, AXIAL, & VANE

Centrifugal Type

Air enters axially into a high-speed spinning impeller, which flings it radially outward. The velocity head is then converted into static pressure inside a diverging diffuser casing.

Best for: High flow rates at moderate pressure steps (e.g., turbochargers).



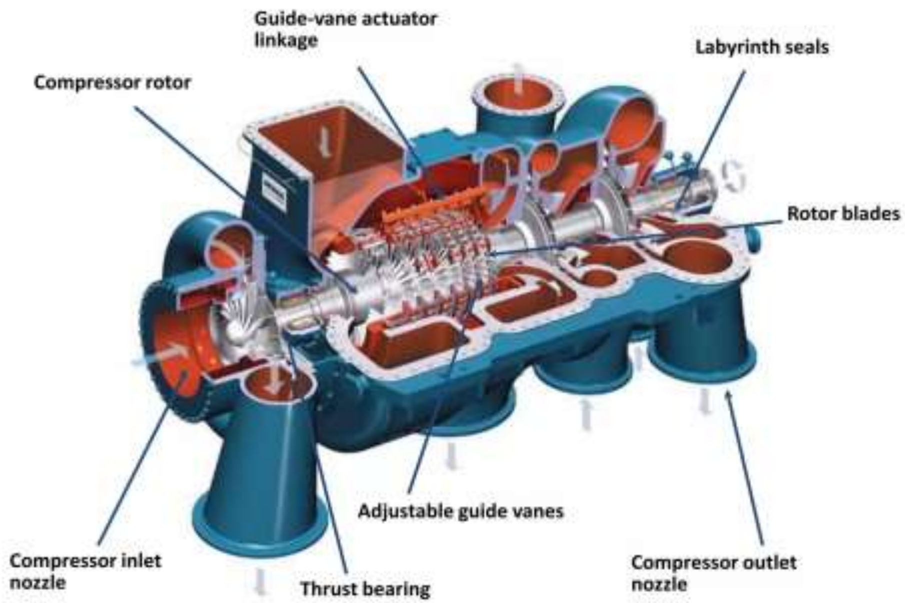
Centrifugal Compressor

Axial Flow Type

Gas flows parallel to the rotational axis through alternating rows of rotating blades (adding velocity) and stationary stator blades (diffusing kinetic energy to raise pressure).

Best for: Massive air flows at high efficiency (e.g., aircraft jet engines).

Cross section of axial compressor

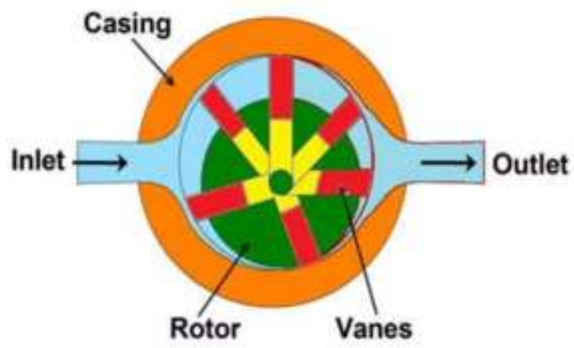


Sliding Vane Type

Features a rotor mounted eccentrically inside a cylindrical casing. As the rotor turns, spring-loaded vanes slide radially to maintain contact with the wall, compressing the air within shrinking pockets.

Best for: Compact, steady displacement needs at modest pressures.

Vane Compressors



REFRIGERATION FUNDAMENTALS & COP

Basic Concepts

Refrigeration: The science of maintaining a target space or substance at a temperature below that of its surrounding environment. This requires absorbing heat from the low-temperature source and rejecting it to a higher-temperature sink.

Refrigerant: The operational working fluid that continuously circulates through the cycle, absorbing and releasing heat as it undergoes alternating phase changes (evaporation and condensation).

Coefficient of Performance (COP)

Unlike power cycles, which are measured by thermal efficiency, refrigeration systems are evaluated by their **Coefficient of Performance (COP)**. This index is the ratio of useful refrigeration effect to the external mechanical work required to drive the cycle:

$$\text{COP} = \frac{\text{Desired Refrigerating Effect}}{(\ R_n\ )}\text{External Net Work Input (W)}$$

Key Insight: Because the heat absorbed from the cold space is added to the work input, the refrigeration effect is typically greater than the work supplied. As a result, COP values are usually greater than 1 (often ranging from 2 to 5 in practical systems).

VAPOR COMPRESSION REFRIGERATION SYSTEM (VCRS)

The **Vapor Compression Refrigeration System (VCRS)** is the most widely used industrial cooling cycle. It consists of four fundamental components that continuously process the refrigerant fluid:

- **1. Compressor:** Draws low-pressure, low-temperature superheated vapor from the evaporator and compresses it to a high-pressure, high-temperature state, which requires external work input (W_c).
- **2. Condenser:** High-pressure gas flows through this heat exchanger, rejecting thermal energy (Q_{out}) to the ambient air or cooling water, causing it to condense into a high-pressure liquid.
- **3. Expansion / Throttle Valve:** The liquid passes through a narrow restriction or capillary tube, causing its pressure and temperature to drop sharply through an isenthalpic throttling process.
- **4. Evaporator:** Cold, low-pressure liquid-vapor mixture enters this exchanger, absorbing heat (Q_{in}) from the refrigerated compartment to vaporize, cooling the target space.

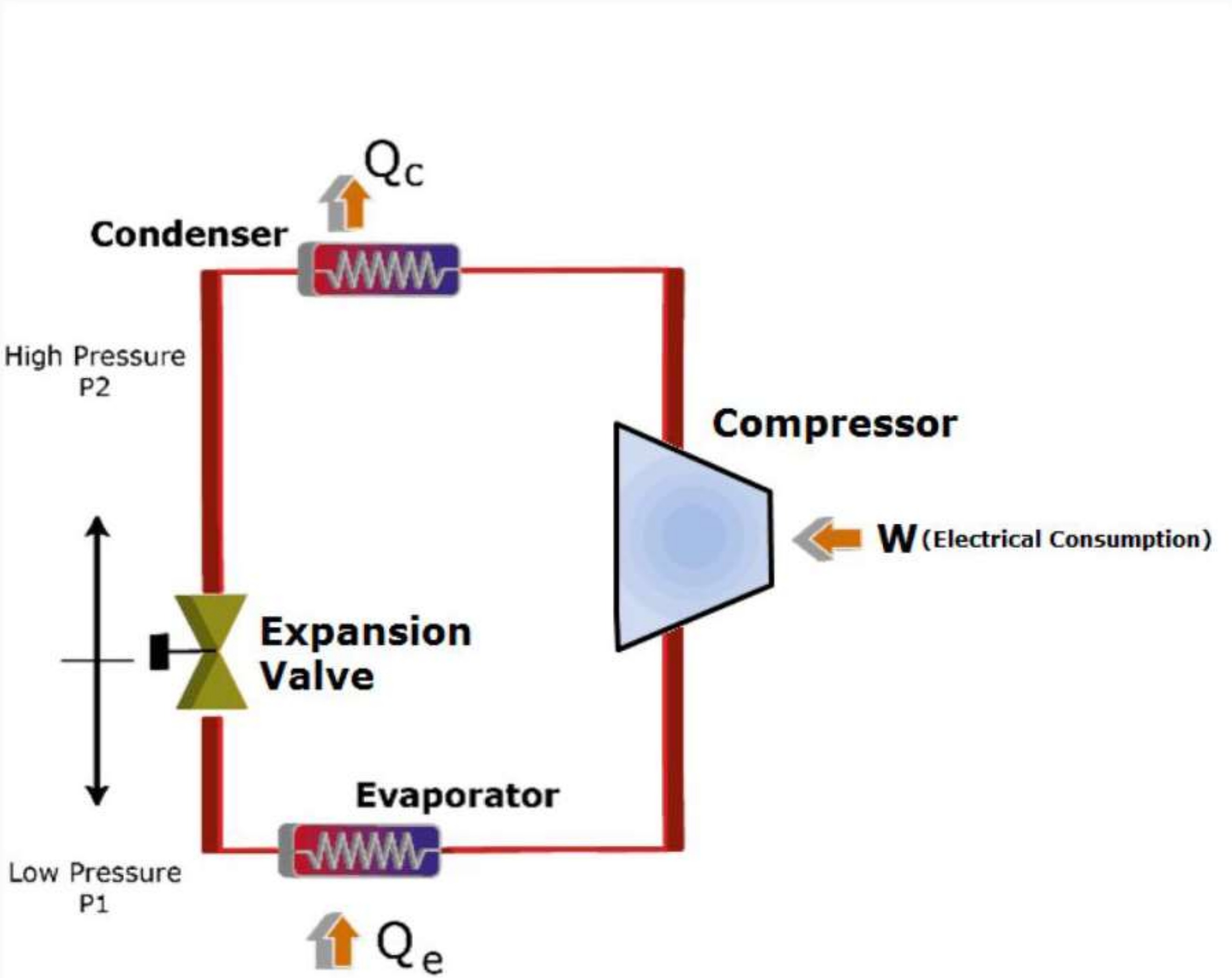


Figure 5.3: Schematic mapping structural interconnects across the VCRS system loop.

AIR REFRIGERATION SYSTEM (BELL-COLEMON CYCLE)

Unlike vapor compression systems, an **Air Refrigeration System** uses air as its permanent, non-condensing working fluid throughout the entire cycle. It operates on the reversed Brayton or **Bell-Colemon Cycle**.

Four Primary Functional Components

1. **Compressor:** Ambient or return air undergoes isentropic compression, raising its pressure and temperature.
2. **Cooler (Heat Exchanger):** High-pressure, hot air passes through a heat exchanger where it is cooled by external water or air currents at constant pressure, without changing phase.
3. **Expander (Expansion Cylinder):** The cooled high-pressure air expands isentropically behind a piston or turbine, performing work that helps drive the compressor. This expansion causes the air temperature to drop significantly.
4. **Refrigerator Room / Evaporator:** Extremely cold air enters the target cold room, absorbing heat directly to provide refrigeration.

Key Traits & Applications

- **Low Operational COP:** Air systems generally have a lower COP than VCRS systems due to the high specific work required for gas compression compared to liquid pumping.
- **Safety & Reliability:** Air is completely non-toxic, non-flammable, inexpensive, and readily available.
- **Aircraft Cabin Cooling:** Widely used in aviation because the lightweight design and readily available bleed air from jet engine compressors outweigh the cycle's lower thermal efficiency.

AIR CONDITIONING & SYSTEM CLASSIFICATIONS

Classification by End-Use Objective

- **Comfort Air Conditioning:** Designed entirely around human physiology. It maintains a comfortable environment (typically 21°C–24°C with 50% relative humidity) in residential homes, offices, commercial complexes, and passenger vehicles.
- **Industrial Air Conditioning:** Tailored to the specific processing requirements of products or machinery. It provides precise, tight tolerances for environmental control in semiconductor cleanrooms, data centers, textile mills, and pharmaceutical packaging facilities.

Classification by Equipment Layout

- **Unitary Systems:** Compact, self-contained packages containing all necessary components in a single housing. Examples include window units and split system air conditioners.
- **Centralized Systems:** A single large plant serves multiple zones across an entire building. It uses chilled water or refrigerant networks piped directly to remote air handling units (AHUs).

SEASONAL AIR CONDITIONING CONFIGURATIONS

Summer AC Systems

Used in hot, humid climates. The system must provide **Cooling and Dehumidification**.

Process Steps:

Warm outdoor air passes over a cold evaporator coil. This cools the air below its dew point, condensing out excess moisture before it is filtered and delivered to the room.

Winter AC Systems

Used in cold climates. The system must provide **Heating and Humidification**.

Process Steps:

Cold air passes over steam heating coils or electric resistance elements, which increases its temperature but lowers its relative humidity. A water spray or steam humidifier then adds moisture to achieve comfortable levels.

Year-Round AC Systems

A versatile system designed to automatically handle changing conditions across all seasons.

Process Steps:

Combines cooling coils, heating elements, and humidifiers into a single integrated system. Automatic dampers and sensors dynamically route air through the appropriate components based on real-time indoor and outdoor conditions.

UNITARY SYSTEMS: THE WINDOW AIR CONDITIONER

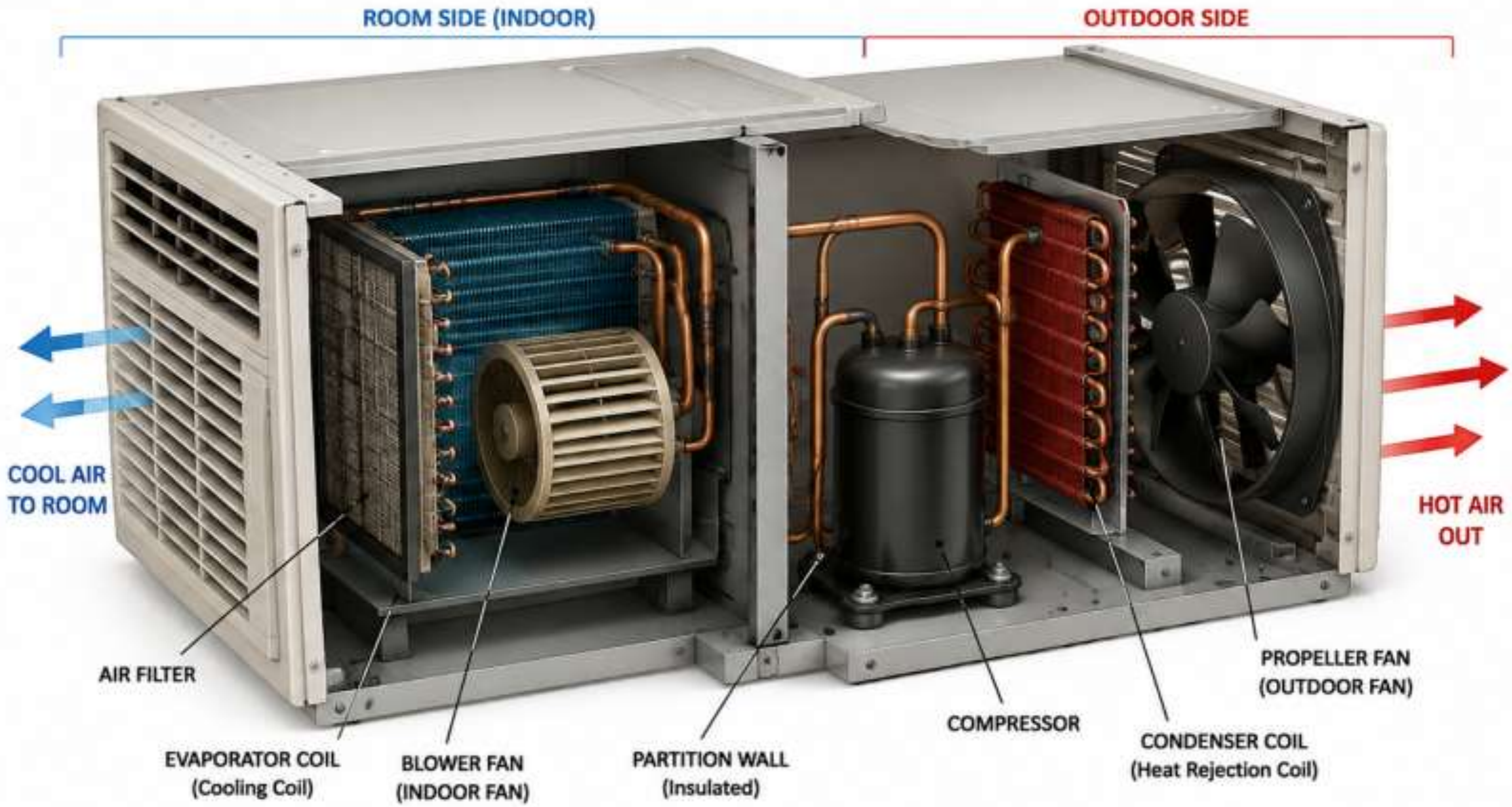
A **Window Air Conditioner** is a compact, self-contained unitary system designed to mount directly in a window sill or through an exterior wall opening to condition a single room.

Internal Design & Component Layout

The chassis is split into two distinct operational chambers by an insulated safety barrier partition:

- **Indoor-Facing Room Side:** Contains the low-pressure evaporator coil, an air filter, and a centrifugal blower fan. It pulls warm room air through the filter, cools and dehumidifies it across the evaporator, and blows it back into the space.
- **Outdoor-Facing Ambient Side:** Contains the hermetically sealed motor compressor, the high-pressure condenser coil, and an axial propeller fan. It rejects heat from the condenser into the outside air.

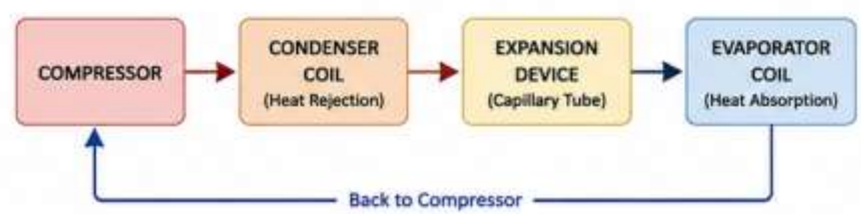
STRUCTURAL WINDOW AIR CONDITIONER – CROSS SECTION (3D VIEW)



MAIN COMPONENTS

1. **Air Filter** – Removes dust and impurities from room air.
2. **Evaporator Coil** – Absorbs heat from room air and cools it.
3. **Blower Fan (Indoor Fan)** – Circulates cooled air into the room.
4. **Partition Wall** – Separates indoor and outdoor sections.
5. **Compressor** – Compresses refrigerant and circulates it.
6. **Condenser Coil** – Releases heat to the outside atmosphere.
7. **Propeller Fan (Outdoor Fan)** – Draws outdoor air across condenser coil and exhausts hot air.

REFRIGERANT FLOW



THANK YOU