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MODULE 4

THERMODYNAMICS AND IC ENGINES

A heat engine is a device that converts the energy locked in fuel into force and motion. Fuels like coal, gasoline, natural gas, wood, and peat when burnt in an engine, release the energy it contains to power factory machinery and locomotives. As engines work by burning fuels to release heat, they are called heat engines. Hence, heat engine can be defined as a system that converts heat to mechanical energy, which can then be used to do mechanical work. The two types of heat engines are external combustion engines and internal combustion engines.

External Combustion Engines

In these types of heat engines, the fuel is burnt outside the engine or the fuel combustion occurs outside the engine. It is a heat engine where a working fluid is included internally and heated by combustion in an external source through the engine wall. This fluid then produced motion and usable work by expanding and acting on the mechanism of the engine.

Internal Combustion Engines

In these engines, the process includes the combustion of a fuel within the system. These types of engines take place where the fuel is burnt in the engine or where the fossil fuel combustion occurs. Pistons are mostly used in the internal combustion type of heat engines. These pistons move up and down within the cylinders that are present in the heat engines. A single motion of a piston in the upward or downward direction inside the cylinder is known as the stroke. For Example – Mostly Cars have four-stroke internal combustion heat engines that consist of an Intake stroke, power stroke, combustion stroke, and exhaust stroke.

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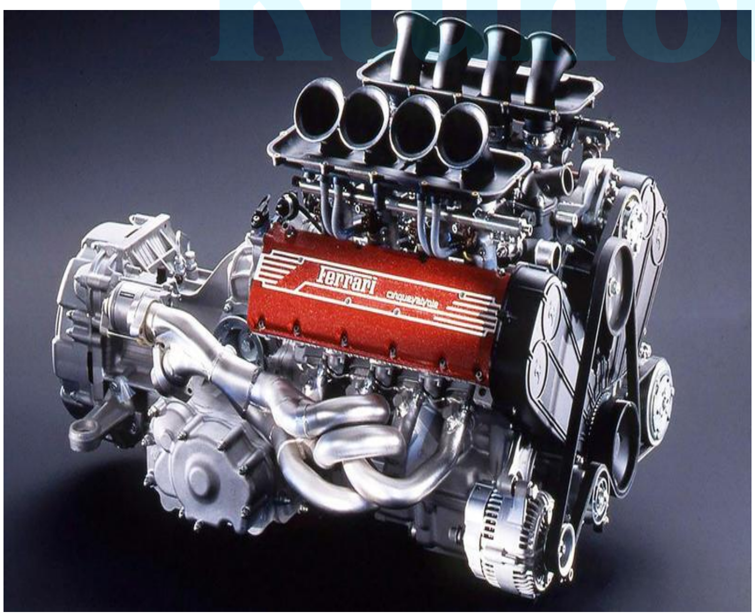

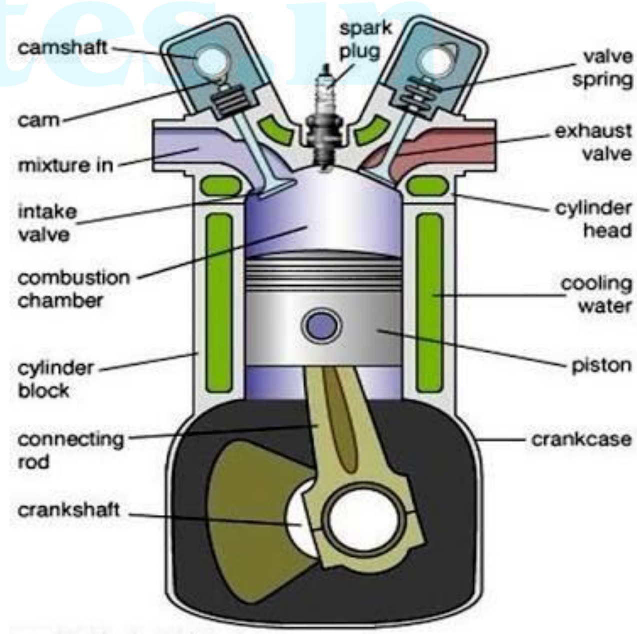

Advantages of Internal Combustion Engines

- Low initial cost.
- Simple and easy design.
- Easily used in cold conditions.
- Produces comparatively higher power output per unit weight of the fuel.
- Energy loss is minimal.

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Disadvantages of Internal Combustion Engines

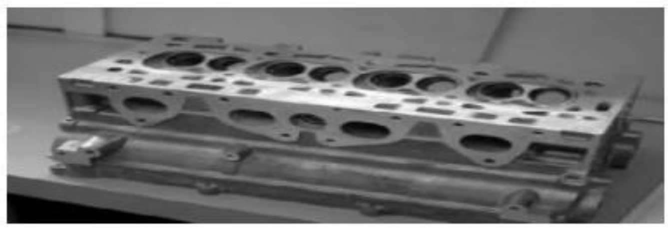
- Cannot be operated with solid fuels like coal.
- High maintenance.

Components of IC engine

Cylinder block: Cylinder block is the main body of engine. This is the main supporting structure which holds the other components together and provides mounting points. Cylinder block is manufactured by casting. The material used may be iron or aluminium. For a multi cylinder engine, cylinder block is cast as a single unit.

Cylinder block of motor cycle

Cylinder block of car



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Inlet and exhaust valves: They are the valves provided in the cylinder head to regulate the flow of working fluid into the cylinder and expelling of combustion products to the atmosphere.

Inlet manifold and Exhaust manifold: The pipe which connect the inlet system to the inlet valve is known as the inlet manifold. The air, air-fuel mixture are drawn into cylinder through inlet manifold.

Combustion chamber: Combustion chamber is the space enclosed between the cylinder and the piston top during the combustion process. The combustion of fuel, and releasing thermal energy and building up of pressure occur at the combustion chamber.

Piston: Piston is a tubular component that fitted into engine cylinder. Its motion is restricted to one dimension; it makes reciprocation movement inside the cylinder. Piston ring s and lubricants provided to make the fit is gas tight.

Piston

Piston rings

Piston rings: Piston rings are provided on the piston to provide a gas tight seal between piston and cylinder wall. This is fitted into slots on the outside diameter of the piston to prevent leakage of combustion gas during engine running.

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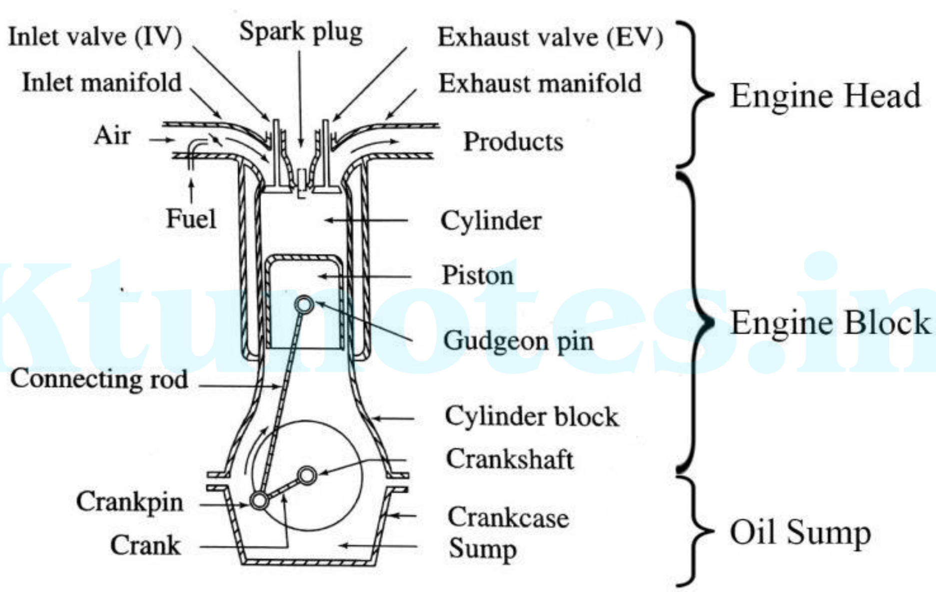
Connecting rod: It is a metal rod which connects the piston and the crankshaft. It transmits the power on piston to the crankshaft. The small end of connecting rod connected the piston by gudgeon pin and the big end of it connected to the crankshaft using crankpin.

Connecting rod

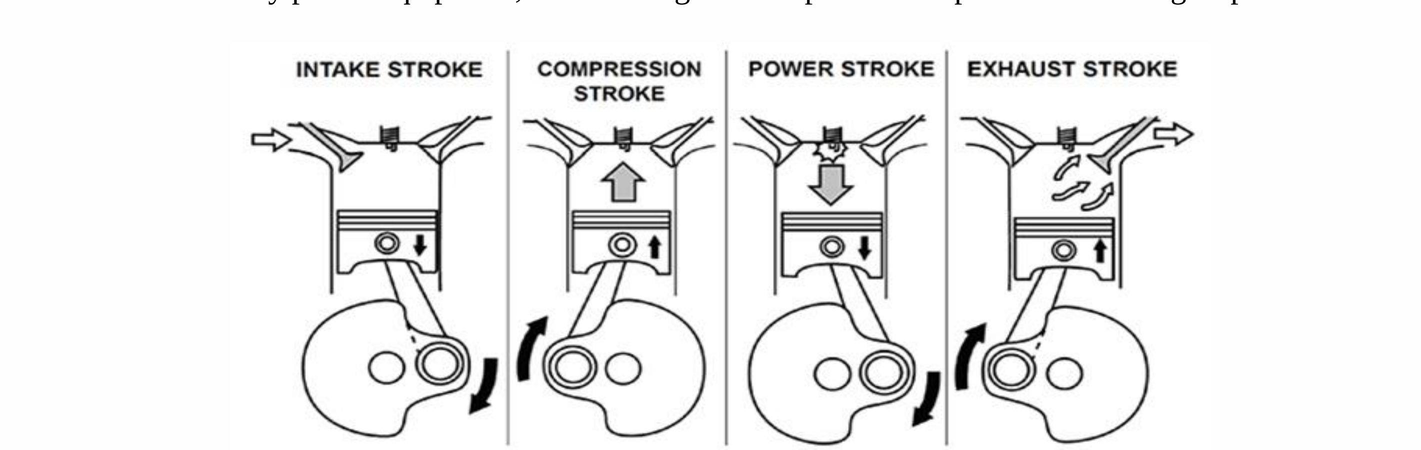
Crankshaft

Crankshaft: Crankshaft is a component which enclosed in the crankcase and converts the reciprocation motion of piston to the rotary motion of output shaft. Bearings are used to support the crack shaft, reduce friction and allows it to freely rotate under various load conditions.



Classification of IC engine

1. 4 stroke SI (Spark Ignition) engine – Petrol Engine
In order to effectively power equipment, 4-stroke engines complete and repeat the following steps:



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1. Intake stroke

- Piston moves down the cylinder bore from top dead center (TDC) to bottom dead center (BDC)
- Intake valve is open, the exhaust valve is closed
- Downward piston motion creates a vacuum (negative air pressure) that draws that air/fuel mixture into the engine via the open intake valve

2. Compression stroke

- Piston moves up the cylinder bore from bottom dead center to top dead center
- Both the intake and exhaust valves are closed
- Upward piston motion compresses air/fuel mixture in the combustion chamber

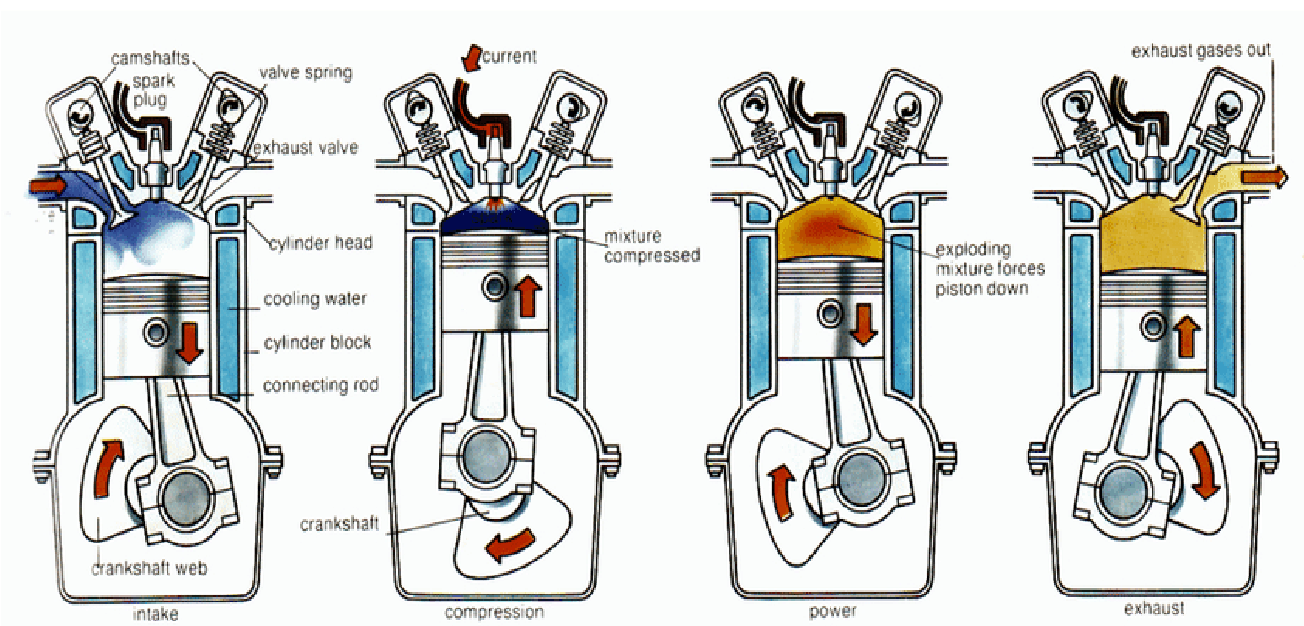
3. Power stroke

- At the end of the compression (previous) stroke, the spark plug fires and ignites the compressed air/fuel mixture. This ignition/explosion forces the piston back down the cylinder bore and rotates the crankshaft, propelling the vehicle forward.
- Piston moves down the cylinder bore from top dead center to bottom dead center
- Both the intake and exhaust valve are closed

4. Exhaust stroke

- Piston moves up the cylinder bore from bottom dead center to top dead center. The momentum caused by the power stroke is what continues the crankshaft movement and the other 3 strokes consecutively.
- Intake valve is closed, the exhaust valve is open
- This final stroke forces the spent gasses/exhaust out of the cylinder. The cycle in now complete and the piston is ready to begin the intake stroke.

The below diagram gives a visual representation of how this process works:



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2. 4 stroke CI (Compression Ignition) engine – Diesel Engine

CI has no carburetor and spark plug, but has a fuel injector. This engine works on the principle of diesel cycle. Similar to SI engine CI engine also has the four stroke in one complete burning cycle. The four strokes are known as intake, compression, expansion and exhaust. These four-stroke or one cycle of operation completed in two revolutions of crankshaft.

1. Intake or suction stroke

The piston is about to move from the top dead centre (TDC) to bottom dead centre (BDC). The inlet valve open and the exhaust valve is closed. In CI engine, air is alone drawn into the cylinder.

2. Compression stroke

Both the intake and exhaust valve is closed. The piston moves from BDC to TDC. The previously drawn air inside the air is then compressed into clearance volume. For CI engine the compression ratio is about 16 to 20. The fuel is injected into the cylinder at the end of compression stroke. The temperature at the end of compression is very high enough to self-ignite the fuel (that is the reason this engine called compression ignition engine).

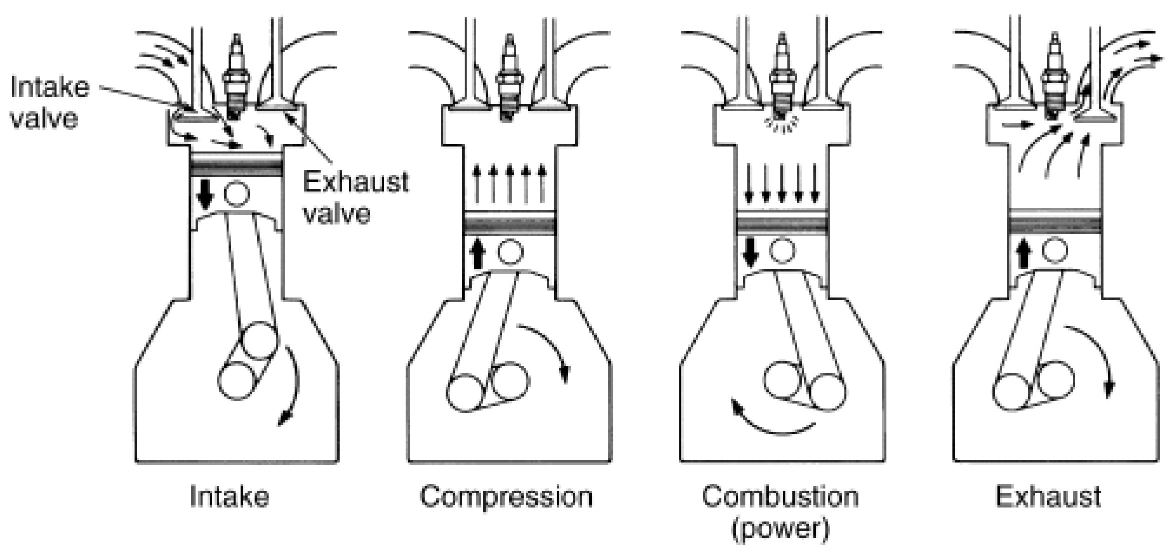
3. Combustion/ Expansion stroke or Power stroke

Both inlet and exhaust valve remain closed in this process. When the piston moving from TDC to BDC, the fuel is injected in such a way that combustion maintains the constant pressure inside the cylinder while volume increases. At the end of this stroke, the exhaust valve opens and pressure reduced to atmospheric.

4. Exhaust stroke

The exhausts valve is open. The piston travels from BDC to TDC and expels the burned gas from the cylinder. Some residual burned gas get trapped in clearance volume, this will later get mixed with fresh air during the next suction stroke.

The below diagram gives a visual representation of how this process works:



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Comparison between SI and CI Engines

S.No.	Spark Ignition Engines (SI)	Compression Ignition Engines (CI)
1	**Merits:** Otto cycle is employed in petrol engine. Otto cycle is more efficient for a given compression ratio.	**Demerits:** Diesel engines works on diesel cycle. Diesel cycle is less efficient than Otto cycle for a given compression ratio.
2	Operating speed is more. Speed range is 3000 to 6000 rpm	Operating speed is less. Speed range is400 to 3500 rpm.
3	Starting is easy, since cranking effort required is less	Starting is difficult since more cranking effort is required.
4	Merits: Initial cost and maintenance cost are less	Demerits: More initial and maintenance costs since the construction is heavy and sturdy.
5	Produces less noise.	Produces more noise.
6	Weight per unit power is less	Weight per unit power is more.
7	Specific fuel consumption is more.	Specific fuel consumption is less
8	The fuel used is petrol. It is costlier than diesel. It is volatile and fire hazard is more	The fuel used is diesel. It is cheaper than petrol. It is less volatile and fire hazard is less.

3. 2 stroke SI (Spark Ignition) engine – Petrol Engine

In the original two-stroke cycle (as developed in 1878), the compression and power stroke of the four-stroke cycle are carried out without the inlet and exhaust strokes, thus requiring only one revolution of the crankshaft to complete the cycle. A 2S petrol engine requires 2 strokes of piston and on revolution of crank shaft to complete one cycle. It means that there is one working stroke after every revolution of crankshaft. In 2S petrol engines, the valves are replaced by ports and the exhaust gases are removed from the cylinder with the help of fresh charges. In case of single cylinder as used in motor cycles three ports are provided (inlet port, transfer port and exhaust port). Fresh charge from the carburetor enters the crankcase. The principle of two stroke spark ignition engine is shown in the figure below. Its two strokes are as follows:

1. Upward Stroke

During upward stroke, the piston moves upward from the bottom dead centre to top dead centre by compressing the air petrol mixture in the combustion chamber of the cylinder. Due to upward movement of the piston, a partial vacuum is created in the crankcase. Fresh charge is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the top dead centre position. The compressed charge is ignited in the combustion chamber by a spark given by the spark plug.

2. Downward Stroke

As soon as the charge is ignited the hot gases compress the piston which moves downward, rotating the crankshaft thus doing the useful work. During this stroke, the inlet port is covered by the piston and the new charge is compressed in the crankcase. Further downward movement of the piston uncovers first the exhaust port and then the transfer port and hence the exhaust starts through the exhaust port. As soon as transfer port is open, the charge through it is forced into the cylinder. The charge strikes the deflector on the piston crown,

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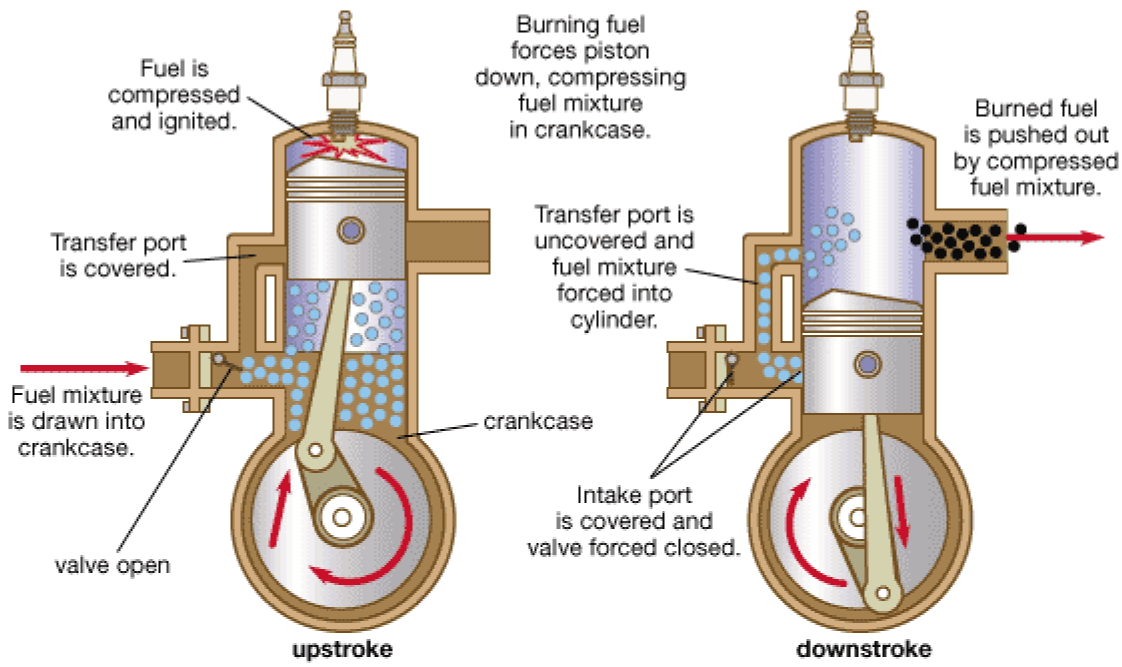
rises to the top of the cylinder and pushes out most of the exhaust gases. The piston is now at the bottom dead centre position.



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4. 2 stroke CI (Compression Ignition) engine – Diesel Engine

In this two stroke engine, only air is compressed inside the cylinder and the fuel (diesel) is injected by an injector fitted in the head of the cylinder. There is no spark plug in this engine. The remaining operations of the two stroke compression ignition engine are exactly the same as those of the spark ignition engine. The principle of two stroke compression ignition engine is shown in the figure below. Its two strokes are as follows:

Upward Stroke

During upward stroke, the piston moves upward from the bottom dead centre to top dead centre by compressing the air in the combustion chamber of the cylinder. Due to upward movement of the piston, a partial vacuum is created in the crankcase. Fresh air is drawn into the crankcase through the uncovered inlet port. The exhaust port and transfer port are covered when the piston is at the top dead centre position. Once the required pressure and temperature is achieved, the diesel fuel is injected to the cylinder with the help of fuel injector. The compressed charge is ignited in the combustion chamber.

Downward Stroke

As soon as the charge is ignited the hot gases compress the piston which moves downward, rotating the crankshaft thus doing the useful work. During this stroke, the inlet port is covered by the piston and the new charge is compressed in the crankcase. Further downward movement of the piston uncovers first the exhaust port and then the transfer port and hence the exhaust starts through the exhaust port. As soon as transfer port is open, the air through it is forced into the cylinder. The charge strikes the deflector on the piston crown, rises to the top of the cylinder and pushes out most of the exhaust gases. The piston is now at the bottom dead centre position.

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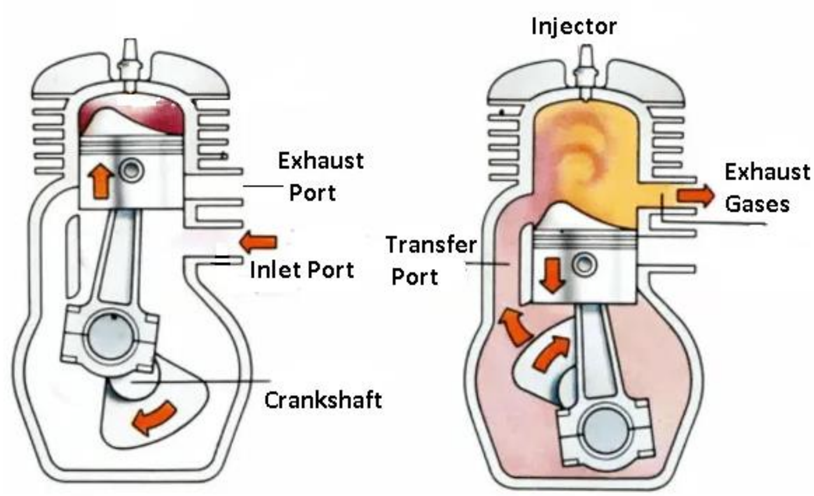

Comparison between 2 stroke and 4 stroke Engines

Two Strokes	Four Strokes
It has one revolution of the crankshaft during one power stroke	It has two revolutions of the crankshaft during one power stroke
It generates high torque	It generates less torque
Its uses port for fuel’s outlet and inlet	It uses valves for outlet and inlet of a fuel
Its engines result in lesser thermal efficiency	Its engines result in higher thermal efficiency
It generates more smoke and shows less efficiency	It generates less smoke and shows more efficiency
Requires more lubricating oil as some oil burns with the fuel	Requires less lubricating oil
Due to poor lubrication, more wear and tear occurs	Less wear and tear occurs
Engines are cheaper and are simple for manufacturing	Engines are expensive due to lubrication and valves and are tough to manufacture
Engines are basically lighter and are noisy	Engines are basically heavier because its flywheel is heavy and are less noisy

Different systems in IC Engines

1. Air intake system

2. Exhaust system

3. Fuel intake system

4. Lubrication system

5. Cooling system

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1. Air intake system

The system that allows air and fuel into the engine is known as the intake system. This system is comprised of the air filter, the intake manifold, and either a carburator or a throttle body along with pressurized fuel injectors depending on the engine. Most modern cars use a fuel injection system as opposed to the carburator to more precisely measure the amount of fuel entering the engine.

In carburated engines, fresh air enters the engine through the air filter, whose purpose is to filter out particles that could damage the engine. From the air filter, the fresh air is ducted into the carburator. The carburator works on a venturi principle whereby the air being drawn through accelerates through a narrowed passage called the venturi. As the passage begins to widen again, a vacuum occurs. It is this vacuum that draws fuel into the moving column of air through the carburator's jets. The jets are sized to permit a fairly exact amount of fuel to be drawn into the air stream, thus creating the proper mixture of air and fuel.

A modern fuel injected engine has no carburator. Instead, it relies on pressurized fuel injectors that are triggered electronically to squirt just the right amount of fuel into the air stream. Fuel injection has several advantages over a carburator. First, the electronic controls can better meter the exact amount of fuel needed to make the engine work efficiently. Second, by squirting under pressure, the fuel can be better vaporized (broken up into smaller particles) which will promote more even and complete combustion in the engine.

In either case, a throttle is used to control the amount of air into the engine. The throttle is connected directly to the accelerate pedal. Opening the throttle wider, as happens when the driver pushes the accelerate pedal, allows a greater amount of the air-fuel mixture into the combustion chamber, creating greater power output from the engine.

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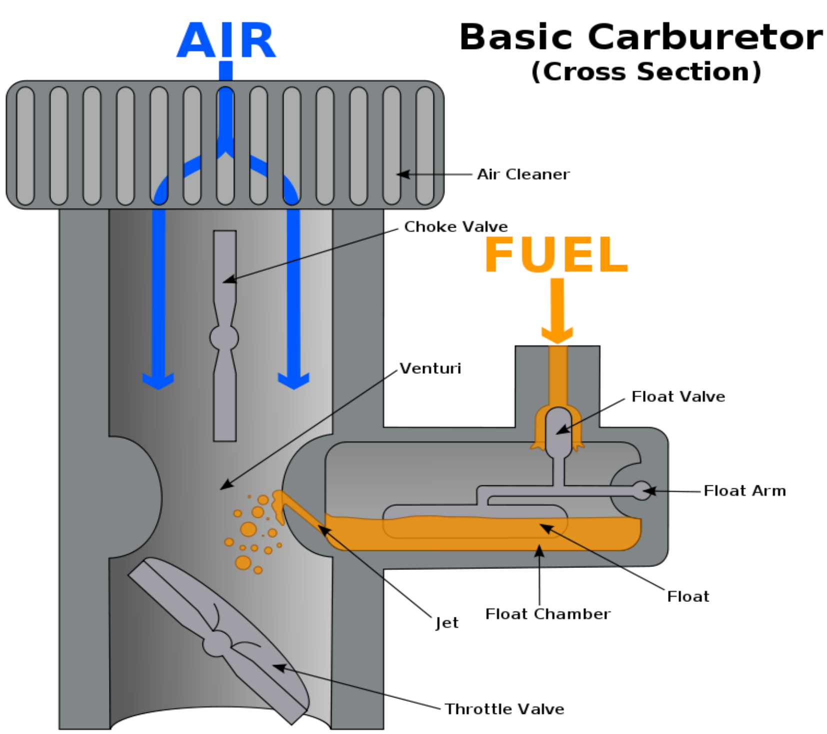
Air filter → Carburetor → Throttle valve → Intake valve → Engine



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2. Exhaust system

The exhaust system collects the exhaust gases from the cylinders, removes harmful substances, reduces the level of noise and discharges the purified exhaust gases at a suitable point of the vehicle away from its occupants.

Engine → Exhaust valve → Exhaust manifold → Catalytic converter → Muffler

Catalytic converter converts harmful carbon monoxide and hydrocarbons to water vapour and carbon dioxide. Some converters also reduce harmful nitrogen oxides. The converter is mounted between the exhaust manifold and the muffler.

Redox reactions in catalytic converter

Oxidation Reactions

Reaction #1	$2CO + O_2 \rightarrow 2CO_2$
Reaction #2	$HC + O_2 \rightarrow CO_2 + H_2O$

Reduction Reactions

Nitric acid	$2NO \rightarrow N_2 + O_2$
Nitrogen dioxide	$2NO_2 \rightarrow N_2 + 2O_2$

Every internal combustion engine produces exhaust noise due to the pulsating emission of gases from the cylinders. This noise has to be silenced by reducing the sound energy of the exhaust gas flow. There are two basic options here: Absorption and reflection of the sound in the silencer. These two principles are generally combined in a single silencer. Exhaust chambers and exhaust flaps are other sound-absorbing and sound-modifying elements that can be used to eliminate especially undesirable frequencies from the outlet noise. Catalytic converters also have a sound-absorbing effect.

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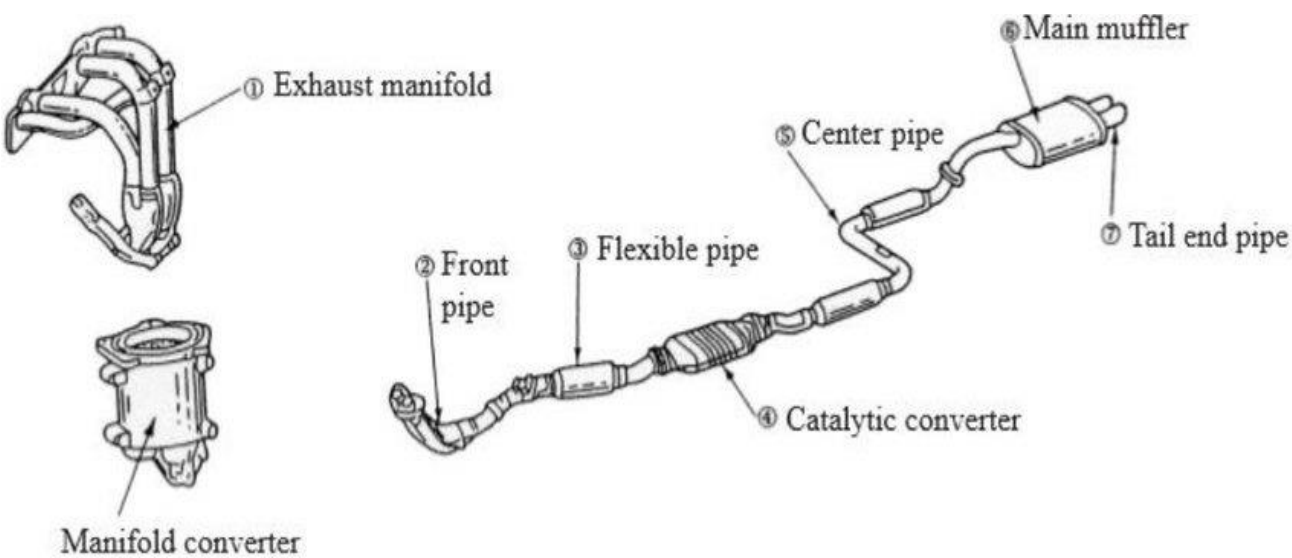

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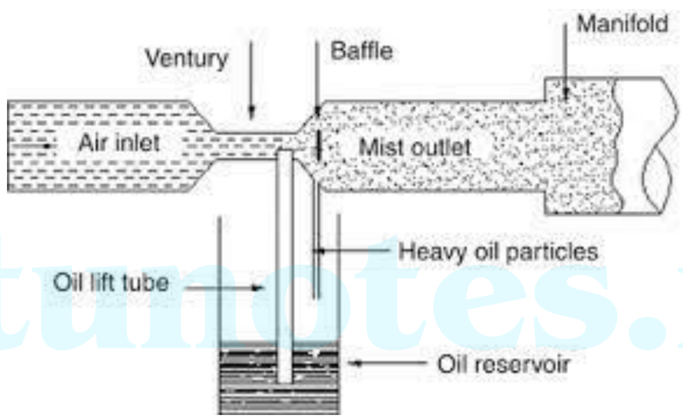
4. Lubrication system

Lubrication is essentially required in motor vehicle maintenance. To supply lubrication oil between the moving parts is simply termed as lubrication. Lubrication of all moving parts (Other than nylon, rubber bushed or pre-lubricated components) is essential to reduce friction, wear etc. Lubrication must be done properly and the right type of lubrication should be used. Improper lubrication of the engine will cause serious trouble such as scored cylinders, dirty spark plugs, worn or burned-out bearings, misfiring cylinders, stuck piston rings, engine deposits and sludge and excessive fuel consumption.

1. Mist/ petroil lubrication system

In these types of the lubrication system, it is commonly used in the two-stroke petrol engines such as scooters and motorcycles. It is the simplest form of the lubricating system. For lubrication purpose, it does not have any separate part like an oil pump. Mist lubrication system is used in a two-stroke engine, it is not possible to have the lubricating oil in the sump because the charge is compressed in the crankcase. So the mist lubrication is adopted for it.



But the lubricating oil is added to the petrol itself during filling in the petrol tank of the vehicle in a specified ratio. When fuel enters the crank chamber during engine operation, oil particles go down into the bearing surfaces and lubricate them. The piston rings, cylinder walls, piston pins, etc. are easily lubricated in the same way. If the engine is allowed to remain unused for a considerable time, the lubricating oil separates off from petrol and starts to clogging of passages in the carburettor, occurring in engine start problems. This is the main disadvantages of this system.

2. Wet sump lubrication system

In the wet sump system, an oil pan is present at the crankcase, sump from which the lubricating oil is pumped to various engine components by a pump. After lubricating these parts, the oil bows back to the sump by gravity. It is collected up by a pump and circulated through the engine lubricating system. The strainer is a fine mesh screen that prevents foreign particles from entering the oil circulating systems.

A pressure relief valve is provided which automatically keeps the delivery pressure constant and can be set to High value. When the oil pressure exceeds that for which the valve is set, the valve opens and allows some of the oil to return to the sump thereby relieving the oil pressure in the systems. Most of the oil from the pump goes directly to the engine bearings and a portion of the oil passes through a cartridge filter which removes the fluid particles from the oil. This reduces the amount of contamination from carbon dust and other impurities present in the oil. Since all the oil coming from the pump does not pass directly through the filter.

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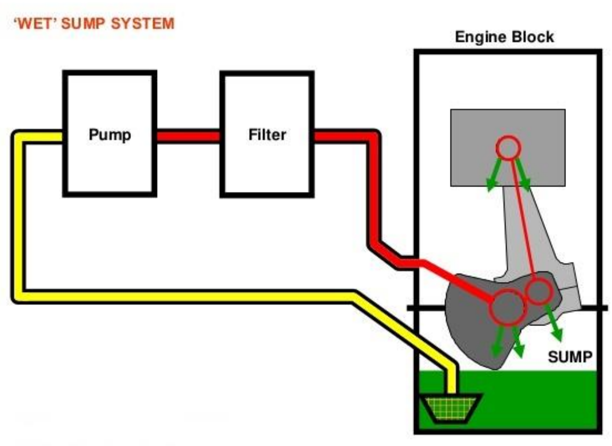
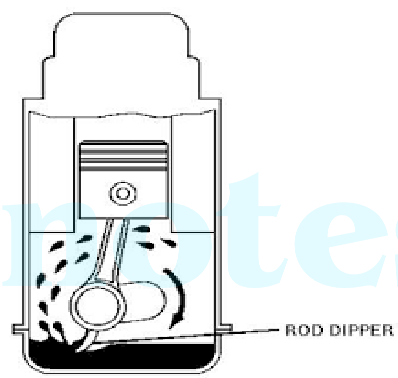


2.1 Splash lubrication System

In these types of lubrication system, the lubricating oil accumulates in an oil sump. A scoop or dipper is made in the lowest part of the connecting rod. When the engine runs, the dipper dips in the oil once in every revolution of the crankshaft and causes the oil to splash on the cylinder walls.



This action affects engine walls, piston rings, crankshaft bearings, and large end bearings. Splash system mostly works in connection with the pressure system in an engine, some parts being lubricated by splash system and the other by a pressure system.

3. Dry sump lubrication

A dry-sump system is a method to manage the lubricating motor oil in four-stroke and large two-stroke piston driven internal combustion engines. The dry-sump system uses two or more oil pumps and a separate oil reservoir, as opposed to a conventional wet-sump system, which uses only the main sump below the engine and a single pump. A dry-sump engine requires a pressure relief valve to regulate negative pressure inside the engine, so internal seals are not inverted.

Dry-sumps are common on larger diesel engines such as those used in ships, as well as gasoline engines used in racing cars, aerobatic aircraft, high-performance personal watercraft and motorcycles. Dry sump lubrication may be chosen for these applications due to increased reliability, oil capacity and oil starvation. Dry sump systems may not be suitable for all applications due to increased cost and complexity.

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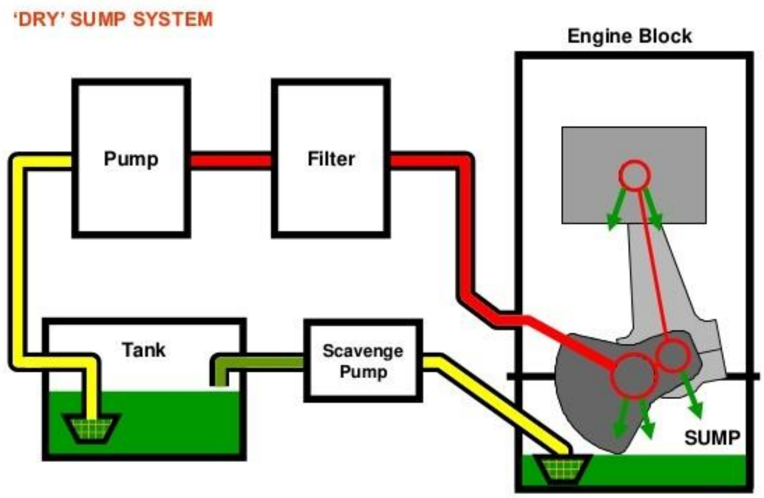

5. Cooling system

A system, which controls the engine temperature, is known as a cooling system. The temperature of the burning gases in the engine cylinder reaches up to 1500 to 2000°C, which is above the melting point of the material of the cylinder body and head of the engine. Therefore, if the heat is not dissipated, it would result in the failure of the cylinder material. Due to overheating, large temperature differences may lead to a distortion of the engine components due to the thermal stresses set up.

Cooling system must be capable of removing only about 30% of the heat generated in the combustion chamber. Too much removal of heat lowers the thermal efficiency of the engine. It should remove heat at a fast rate when the engine is hot. During the starting of the engine, the cooling should be very slow so that the different working parts reach their operating temperatures in a short time. There are two types of cooling systems: (i) Air cooling system and (ii) Water-cooling system.

Air cooling system

In this type of cooling system, the heat, which is conducted to the outer parts of the engine, is radiated and conducted away by the stream of air, which is obtained from the atmosphere. In order to have efficient cooling by means of air, providing fins around the cylinder and cylinder head increases the contact area. The fins are metallic ridges, which are formed during the casting of the cylinder and cylinder head.

The amount of heat carried off by the air-cooling depends upon the following factors: (i) The total area of the fin surfaces, (ii) The velocity and amount of the cooling air Air cooled engines have the following advantages:

1. Its design of air-cooled engine is simple.

2. It is lighter in weight than water-cooled engines due to the absence of water jackets, radiator, circulating pump and the weight of the cooling water.

3. It is cheaper to manufacture.

4. It needs less care and maintenance.

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Water cooling system

The water cooling system is used in the engines of cars, buses, trucks, etc. Parts of Water Cooling System include Radiator, Thermostat valve, Water pump**,** Fan, Water Jackets and Antifreeze mixtures. In this system, the water is circulated through water jackets around each of the combustion chambers, cylinder etc. The water is kept continuously in motion by a centrifugal water pump which is driven by a V-belt from the pulley on the engine crankshaft.

It is a thermostat that acts as a valve for the coolant and only allows it to pass through the radiator when a certain temperature has been exceeded. The thermostat contains paraffin wax, which expands at a certain temperature and opens at that temperature. The cooling system uses a thermostat to regulate the normal operating temperature of the internal combustion engine. When the engine reaches standard operating temperature, the thermostat is triggered. Then the coolant can enter the radiator.

The water mixed with anti freeze solution absorbs 30% of the heat from engine. The excess absorption may reduce the thermal efficiency of engine. After passing through the engine jackets in the block and cylinder heads, the hot water is passed through the radiator. In the radiator, the water is cooled by air drawn through the radiator. When the vehicle is moving, the radiator receives the air flow and remains cool. In the stop conditions the fan is kept on to reduce the temperature of radiator. Usually, the fan and water pump are mounted and driven on a common shaft. In the modern vehicles, the radiator fan is attached with sensors. The rise in temperature is sensed and the fan gets switched on until the temperature is lowered down. After passing through the radiator, the water is drained and delivered to the water pump through a cylinder inlet passage. The water again circulated through the engine jackets.

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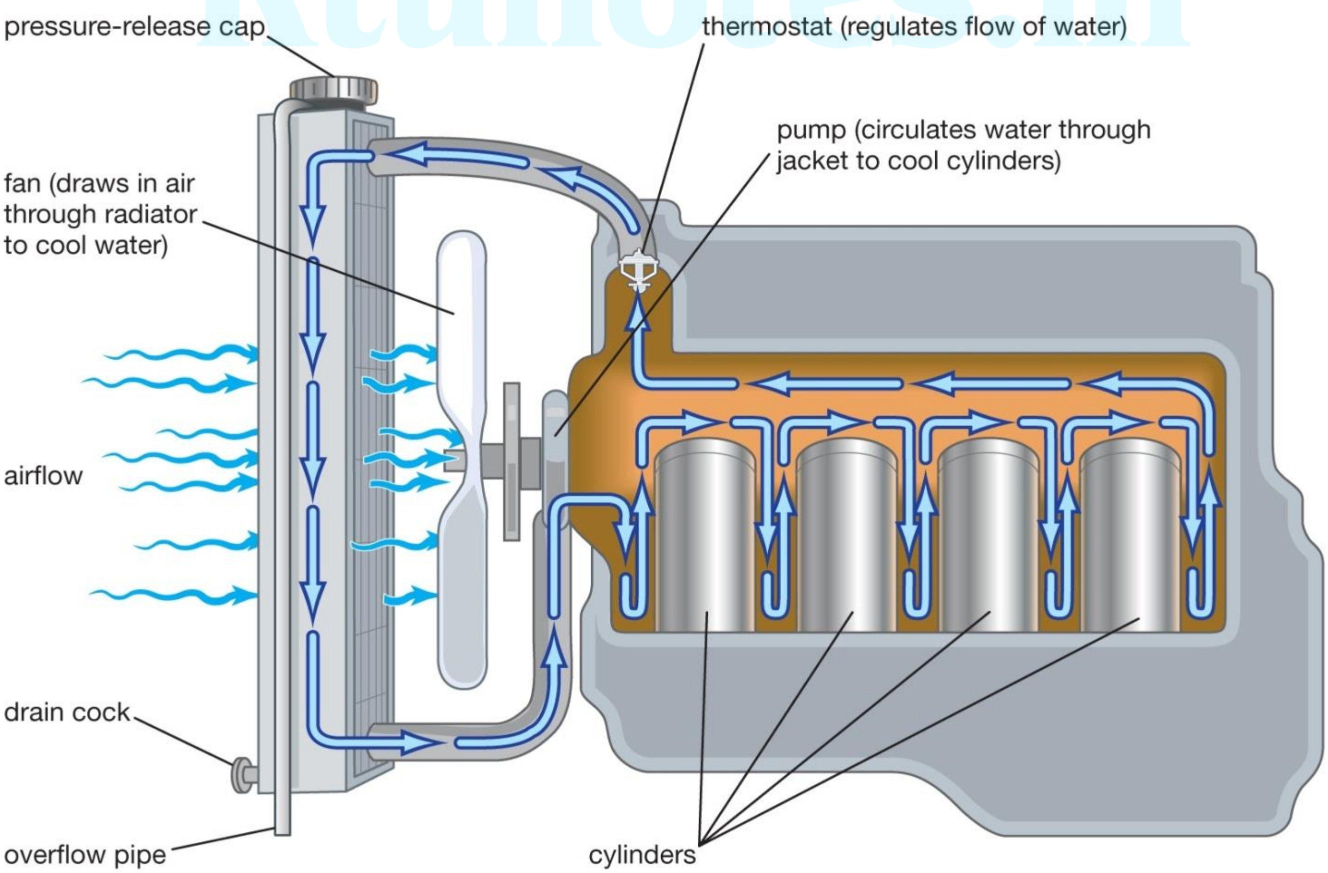

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Advantages of Water Cooling System

- Uniform cooling of the cylinder, cylinder head and valves.
- If we employ a water cooling system, the engine need not be provided at the front end of moving vehicle.
- The engine is less noisy as compared with air-cooled engines, as it has water for damping noise.

Anti-freeze solutions

In order to prevent the water in the cooling system from freezing, some chemical solutions which are known as anti-freeze solutions are mixed with water. In cold areas, if the engine is kept without this solution for some time, the water may freeze and expand leading to fractures in the cylinder block, cylinder head, pipes and/or radiators. The boiling point of the anti-freeze solution should be as high as that of water. An ideal mixture should easily dissolve in water, be reasonably cheap and should not deposit any foreign matter in the jacket pipes and radiator.

Common Rail Direct Injection (CRDI)

An increasing number of modern diesel engines employ common rail direct injection (CRDi) fuel systems for the flexibility they provide while meeting the most stringent emission control standards. In common rail systems, the fuel is supplied to the engine under pressure with electronically controlled precision. This provides a level of flexibility which can be exploited for class leading levels of emission control, power and fuel consumption.

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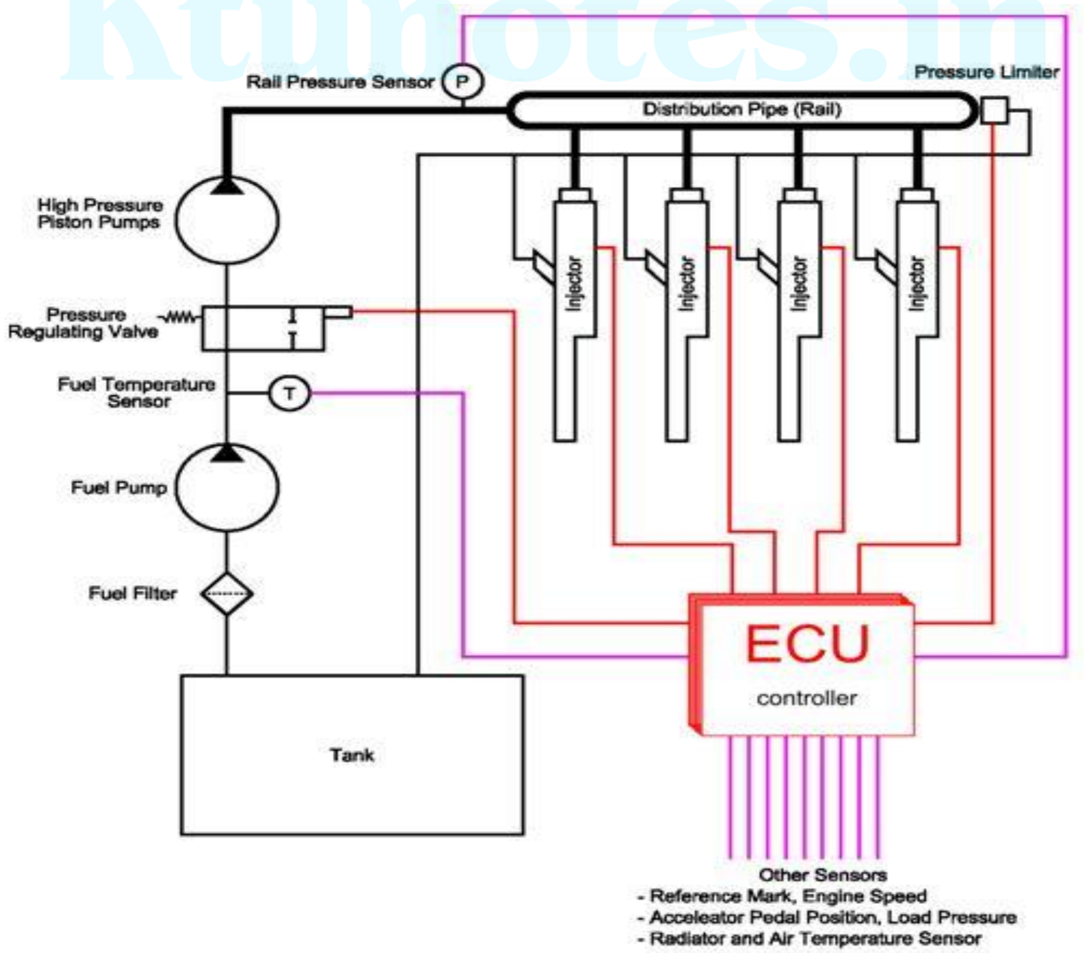

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The fuel in an electronically controlled engine is stored at variable pressure in a cylinder or 'rail' connected to the engine's fuel injectors via individual pipes, making it a 'common rail' to all the injectors. The pressure is controlled by a fuel pump but it is the fuel injectors, working in parallel with the fuel pump, that control the timing of the fuel injection and the amount of fuel injected. In contrast earlier mechanical systems rely on the fuel pump for pressure, timing and quantity. A further advantage of the CRDi system is that it injects the fuel directly into the combustion chamber.

Regular diesel direct fuel-injection systems have to build up pressure for every new injection cycle. Engines featuring the new common rail (line) maintains a constant pressure regardless of the injection sequence. This pressure is said to be permanently available throughout the fuel line. Instant atomization takes place and this spray is very fine and evenly distributed aiding efficiency and power delivery. Also the injectors can inject up to 5 times per combustion cycle which gives a more uniform and controlled combustion and helps extract maximum energy from the combustion cycle. Technologically the engine's electronic timing regulates injection pressure according to engine speed and load. The electronic control unit (ECU) modifies the injection pressure with precision which is in relation to the data obtained from sensors on the cam and crankshafts.

CRDi ensures the fuel injection timing, quantity of fuel and atomisation or fuel spray are controlled electronically using a programmable control module. This allows multiple injections at any pressure at any time (within pre-defined limits), providing a level of flexibility which can be exploited for better power, fuel consumption and emission control.

Multi Point Fuel Injection (MPFI)

Despite the rapid development in carburetors which are cheap and efficient, the automobile industry prefers to use a gasoline injection system in spark ignition (S I Engines). The MPFI is a system or method of injecting fuel into internal combustion engine through multi ports situated on intake valve of each cylinder. It delivers an exact quantity of fuel in each cylinder at the right time.

MPFI includes a fuel pressure regulator, fuel injectors, cylinders, pressure spring and a control diaphragm. It uses multiple individual injectors to insert fuel in each cylinder through intake port situated upstream of cylinder's intake value. The fuel pressure regulator, connected to the fuel rail by means of an inlet and outlet, directs the flow of the fuel. While the control diaphragm and pressure spring controls the outlet valve opening and the amount of fuel that can return. The pressure in the intake manifold significantly changes with the engine speed and load.

The multi-point fuel injection technology improves fuel efficiency of the vehicles. MPFI uses individual fuel injector for each cylinder, thus there is no gas wastage over time. It reduces the fuel consumption and makes the vehicle more efficient and economical. The vehicles with MPFI automobile technology have lower carbon emissions than a few decades old vehicles. It reduces the emission of the hazardous chemicals or smoke, released when fuel is burned. The more precise fuel delivery cleans the exhaust and produces less toxic byproducts. Therefore, the engine and the air remain cleaner.

MPFI system improves the engine performance. It atomizes the air in small tube instead additional air intake, and enhances the cylinder-to-cylinder fuel distribution that aid to the engine performance. It encourages distribution of more uniform air-fuel mixture to each cylinder that reduces the power difference developed in individual cylinder.

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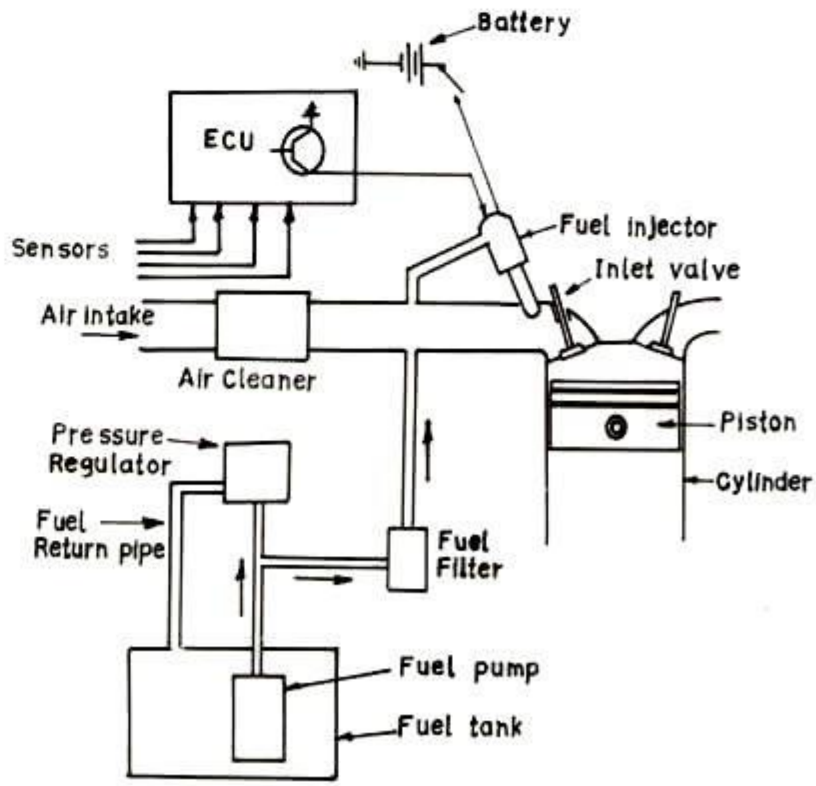

Hybrid vehicles

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A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel/electric, petrol/electric etc. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The combination of two power sources may support two separate propulsion systems. Thus to be a True hybrid, the vehicle must have at least two modes of propulsion.

Components of a hybrid drive are:

- The electric motor forms the core.
- The internal combustion engine is the conventional drive system that gets its energy mainly from gasoline or, occasionally, diesel.
- The electric control device connects the electric motor and the IC engine and automatically switches to the optimum drive, depending on which is the most efficient at that time.
- The inverter connects the battery with the electric motor. The power electronics convert the DC voltage of the battery into high-frequency AC voltage, which forms the electromagnetic field for power generation in the electric motor.
- The battery supplies electricity for the electric motor. In a hybrid vehicle, the lithium ion battery works with a battery management system.
- The fuel tank stores the fossil energy, in other words, gasoline or diesel.

Types of hybrid vehicles

Parallel hybrid: These vehicle types have two drive systems – an electric motor and an IC engine. Both can move the vehicle forwards and are connected with the driving axle. They are deployed as required: the vehicle can be driven purely electrically, with only the IC engine, or with a combination of both. With this type of drive system, the powers of the electric motor and the ICE are added together to form the total power.

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Series hybrid: Series hybrids have an electric motor and an ICE, but just one drive system. The power sources are connected in series: generally, the electric motor moves the vehicle forwards while the IC engine generates electricity for the battery. The power sources are not mechanically connected. Range extender concepts also fall into this category. To put it simply, the IC engine acts only as a generator to recharge the battery when it is empty until the vehicle reaches the next charging station.

Power split hybrids*:* Series and parallel hybrid drives can also be combined in one vehicle. With power split or series-parallel hybrids, as they are also known, the driver chooses one of the two drives.

Advantages

- Depending on the driving situation and type, a hybrid vehicle can use the optimum drive, such as in the city and on rural roads.
- Fuel consumption is 15 to 50% lower depending on the type of vehicle.
- The lower consumption and, in some cases, pure electric mode result in fewer emissions.
- The vehicle drives more efficiently.
- Compared to a conventional drive system, acceleration is increased by 10 to 20%. An internal combustion engine needs higher speeds for more torque. With an electric motor this is high from the start.
- Apart from plug-in hybrids, the vehicles do not have to be charged with electricity – consequently, drivers do not have to search for a charging station.

THERMODYNAMICS

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The name thermodynamics was formed from the Greek words thermo (heat) and dynamics (power). Thermodynamics deals with the change of one form of energy to another form. Thermodynamics can be defined as the science of energy and its effect on the physical properties of substances. Thermodynamics is a branch of Physics that deals with the relationship among heat, work and properties of system which are in equilibrium with one another.

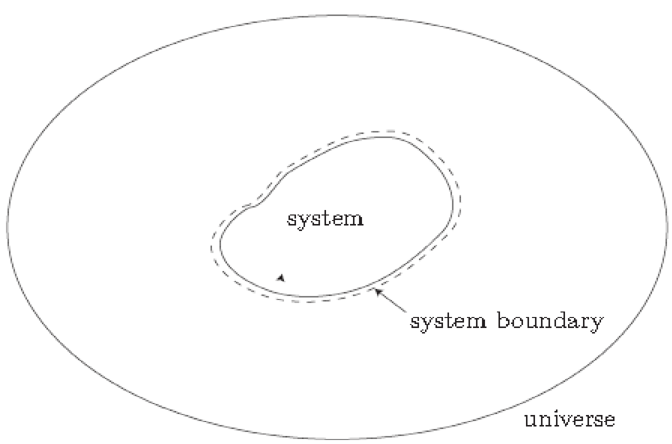
Terms

Thermodynamic System: Certain quantity of matter or region in space which is under thermodynamic study or analysis is called as a thermodynamic system.

Surroundings: Everything external to the system is called surroundings.

System boundary: Interface separating system and surroundings. Boundaries can also be fixed or moveable (e.g. a piston)

Universe: Combination of system and surroundings.



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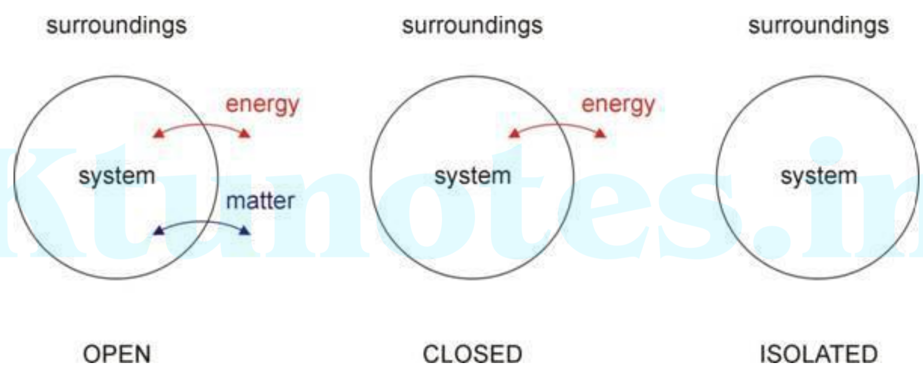
Types of Thermodynamic Systems
There are three mains types of system: open system, closed system and isolated system.

Open system: The system in which the transfer of mass as well as energy can take place across its boundary is called as an open system. When studying and analysing devices such as engines, turbines as a whole… it is often useful to define the boundary of the system to be an identifiable volume with a continuous flow of working fluid in to and out of the system. This is termed a control volume. A control volume is said to be enclosed by a control surface. The example of open system is boiling water in an open vessel, where transfer of heat as well as mass in the form of steam takes place between the vessel and surrounding.

Closed system: The system in which the transfer of energy takes place across its boundary with the surrounding, but no transfer of mass takes place is called as closed system. The closed system is fixed mass system. An example is the water being heated in the closed vessel, where water will get heated but its mass will remain same. In the case of a closed system, in which the mass of matter inside the system remains constant, the control volume is referred to as control mass.

Isolated system: The system in which neither the transfer of mass nor that of energy takes place across its boundary with the surroundings is called as isolated system. Here there will neither transfer of mass nor that of energy. Hot water, coffee or tea kept in the thermos flask is closed system.



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Microscopic & macroscopic viewpoints in thermodynamics
The behaviour of matter can be studied at two levels a) Microscopic and b) Macroscopic

Thermodynamic Process
When any of the properties of the system such as temperature, pressure, volume etc change, the system is said to have undergone thermodynamic process. Various types of thermodynamic processes are: isothermal process, adiabatic process, ischoric process, isobaric process.
Isothermal process: When the system undergoes change from one state to the other, but its temperature remains constant, the system is said to have undergone isothermal process.
Adiabatic process: The process, during which the heat content of the system remains constant, is called as adiabatic process. Thus in adiabatic process no transfer of heat between the system and its surroundings takes place. The wall of the system which does not allows the flow of heat through it, is called as adiabatic wall, while the wall which allows the flow of heat is called as diathermic wall.
Isochoric process: The process, during which the volume of the system remains constant, is called as isochoric process. Heating of gas in a closed cylinder is an example of isochoric process.
Isobaric process: The process during which the pressure of the system remains constant is called as isobaric process.

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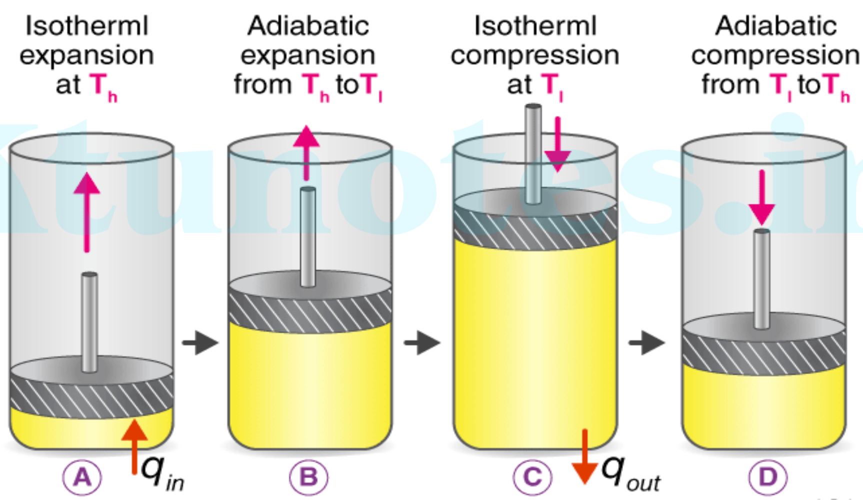
Thermodynamic property
A property is any measurable characteristic of a system. The common properties include: pressure (P), temperature (T), volume (V), velocity (v), mass (m), enthalpy (H), entropy (S). Properties can be intensive or extensive.
Intensive properties are those whose values are independent of the mass possessed by the system, such as pressure, temperature and velocity.
Extensive properties are those whose values are dependent of the mass possessed by the system, such as volume, enthalpy and entropy

Carnot Cycle & Carnot Engine

A cycle consisting of only reversible process are called reversible cycle. Carnot cycle is practically not possible. It is used as a reference or model for heat engine cycles as it gives maximum efficiency. It is used to compare actual heat engine cycle efficiencies. An engine which works on Carnot cycle is called Carnot engine. It's a hypothetical engine and is not practically possible to construct. It consists of all reversible process and engine works at a slow rate converting thermal energy to work. The concept of Carnot engine serves as a means to compare and measure the performance of other engines.
Consider a closed system that consist of a gas contained in an adiabatic piston cylinder device. The insulation of cylinder is head is such that it may be removed to bring the cylinder in to contact with reservoirs to provide heat transfer. The four reversible process that make up the Carnot cycle are



Process 1-2 : Isothermal Expansion. Initially (state 1) the temperature of the gas is T_1 and the cylinder head is in close contact with a source at temperature T_1. The gas is allowed to expand slowly doing work on the surroundings. As the gas expands the temperature of the gas tends to decrease. But as soon as the temperature drops by a small amount 'dT', some heat flows from the reservoirs in to the gas, raising the gas temperature to T_1. Thus, the gas temperature is kept constant at T_1. Since the temperature difference between the gas and the reservoir never exceeds a differential amount 'dT' ,This is a reversible heat transfer process. It continues until the piston reaches position 2. The amount of total heat transferred to the gas during this process Q_1.

Process 2-3: Reversible Adiabatic Expansion. At state 2, the reservoir that was in contact with the cylinder head is removed and replaced by insulation so that the system becomes adiabatic. The gas continues to expand slowly, doing work on the surroundings until its temperature drops from T_1 to T_2.(State 3).

Process 3-4: Reversible Isothermal Compression. At state 3, the insulation at the cylinder head is removed, and the cylinder is brought in to contact with a sink at temperature T_2. Now piston is pushed inward by an external force, doing work on the gas. As the gas is compressed, its temperature tends to rise. But as soon as it rises by a small amount dT, heat flows from the gas to the sink, causing the gas temperature to drop toT_2. Since

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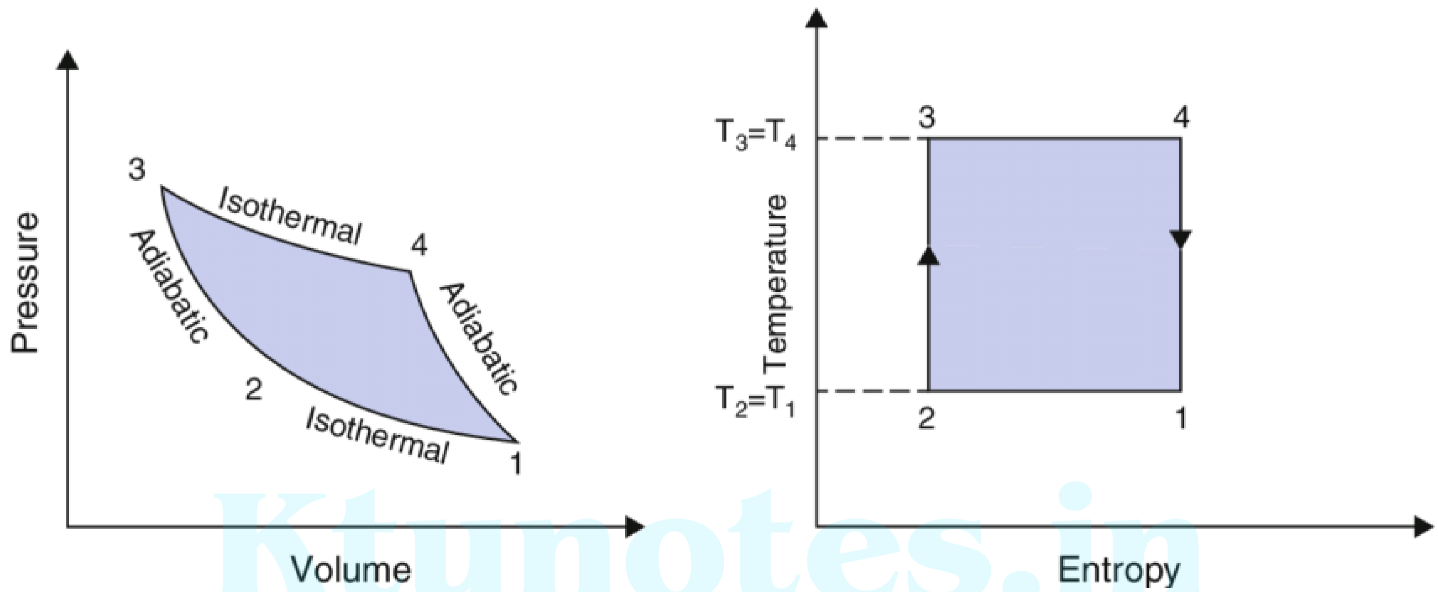
the temperature difference between the gas and the sink never exceeds a differential amount dT, this is a reversible heat transfer process. It continues until the piston reaches state 4. The amount of heat rejected from the gas during this process is Q_2

Process 3-4: Reversible Adiabatic Compression. State 4 is such that the low temperature reservoir is removed and the insulation is put back on the cylinder head, and as a result the gas is compressed in a reversible manner, the gas returns to its initial state (state 1). The temperature rises from T_2 to T_1.

The efficiency of Carnot Cycle = $1 - \frac{T3}{T1}$



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Otto cycle and petrol engine

Figure below shows the pressure-volume diagram of an ideal Otto Cycle process. It consists of two isochoric, two adiabatic and two isobaric processes (for intake and exhaust) The PV diagram (pressure-volume diagram) of the ideal Otto cycle is shown in the figure below. This diagram models how the changes in pressure and volume of the working fluid (gasoline and air fuel) change due to the combustion of hydrocarbons which powers the movements of a piston, creating heat, to provide motion for a vehicle. There are expansion (increased volume chamber) piston motions—caused when the thermal energy is released from combustion—inducing work being done by the gas and on the piston. In contrast, when the piston does work on the gas, the engine chamber is being compressed (decreasing in volume).

It is important to note that Figure depicts an ideal process for any engine using the Otto cycle. It describes the basic working steps in a gasoline engine. The slight modification which depicts a more realistic situation of the Otto Cycle's PV diagram for a two stroke and four stroke engines is explained on their respective pages.

The work done by the engine can be calculated by solving the area of the closed cycle.

The following describes what occurs during each step on the PV diagram, in which the combustion of the working fluid—gasoline and air (oxygen), changes the motion in the piston:

Suction: Referred to as the intake phase, the piston is drawn down to the bottom to allow the volume in the chamber to increase so it can "intake" a fuel-air mixture. In terms of thermodynamics, this is referred to as an isobaric process.

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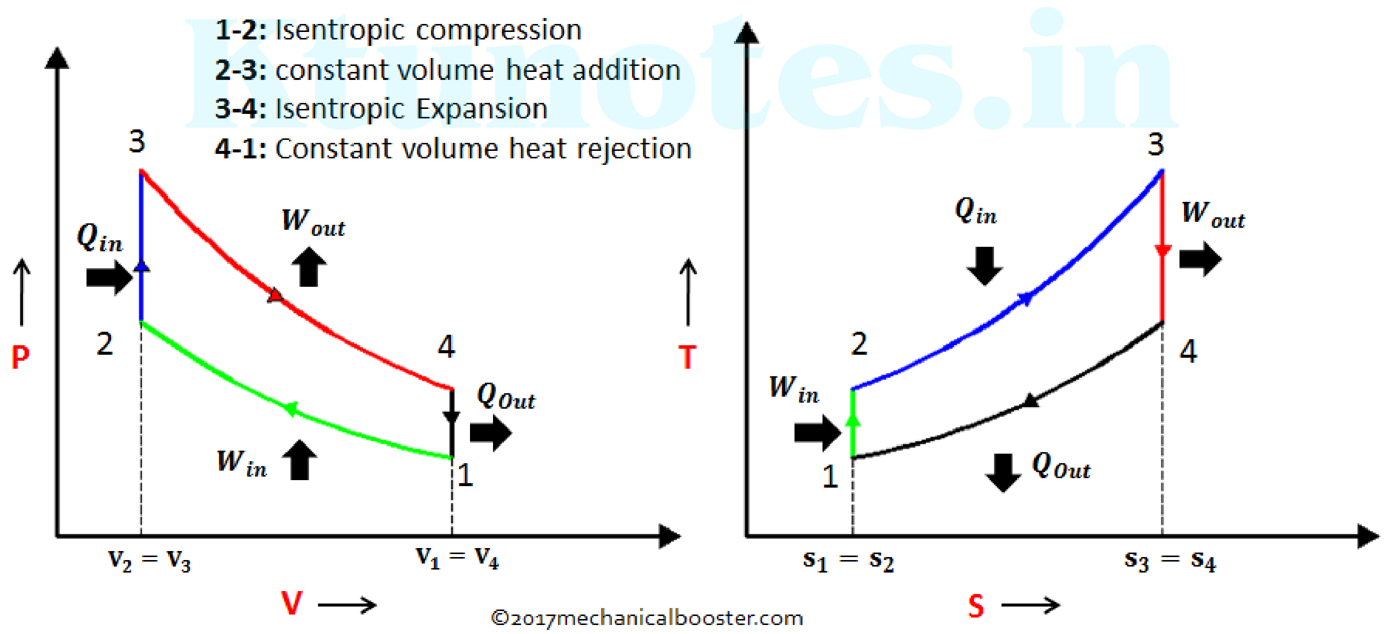
Process 1 to 2: During this phase the piston will be drawn up, so it can compress the fuel-air mixture that entered the chamber. The compression causes the mixture to increase slightly in pressure and temperature-however, no heat is exchanged. In terms of thermodynamics, this is referred to as an adiabatic process. When the cycle reaches point 2, that is when the fuel is met by the spark plug to be ignited.

Process 2 to 3: This is where combustion occurs due to the ignition of fuel by the spark plug. The combustion of the gas is complete at point 3, which results in a highly pressurized chamber that has a lot of heat (thermal energy). In terms of thermodynamics, this is referred to as an isochoric process.

Process 3 to 4: The thermal energy in the chamber as a result of combustion is used to do work on the piston—which pushes the piston down—increasing the volume of the chamber. This is also known as the power stoke because it is when the thermal energy is turned into motion to power the machine or vehicle.

Process 4 to 1: From process 4 to 1, all waste heat is expelled from the engine chamber. As the heat leaves the gas, the molecules lose kinetic energy causing the decrease in pressure. Then the exhaust phase occurs when the remaining mixture in the chamber is compressed by the piston to be "exhausted" out, without changing the pressure.



P-V and T-S Diagram of Otto Cycle

The efficiency of Otto Cycle = $1 - (1/ r^{\gamma-1})$

Swept volume is the displacement of one cylinder. It is the volume between top dead centre (TDC) and bottom dead centre (BDC). It is also known as displacement volume.

Clearance volume is the volume remaining above the piston of an engine when it reaches top dead centre. The maximum compression pressure in the piston is controlled by the clearance volume.

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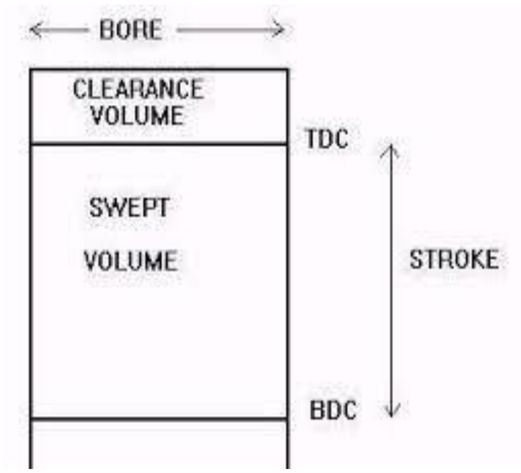
Compression ratio (r)



$$r = \frac{\text{Volume above piston at BDC}}{\text{Volume above piston at TDC}}$$

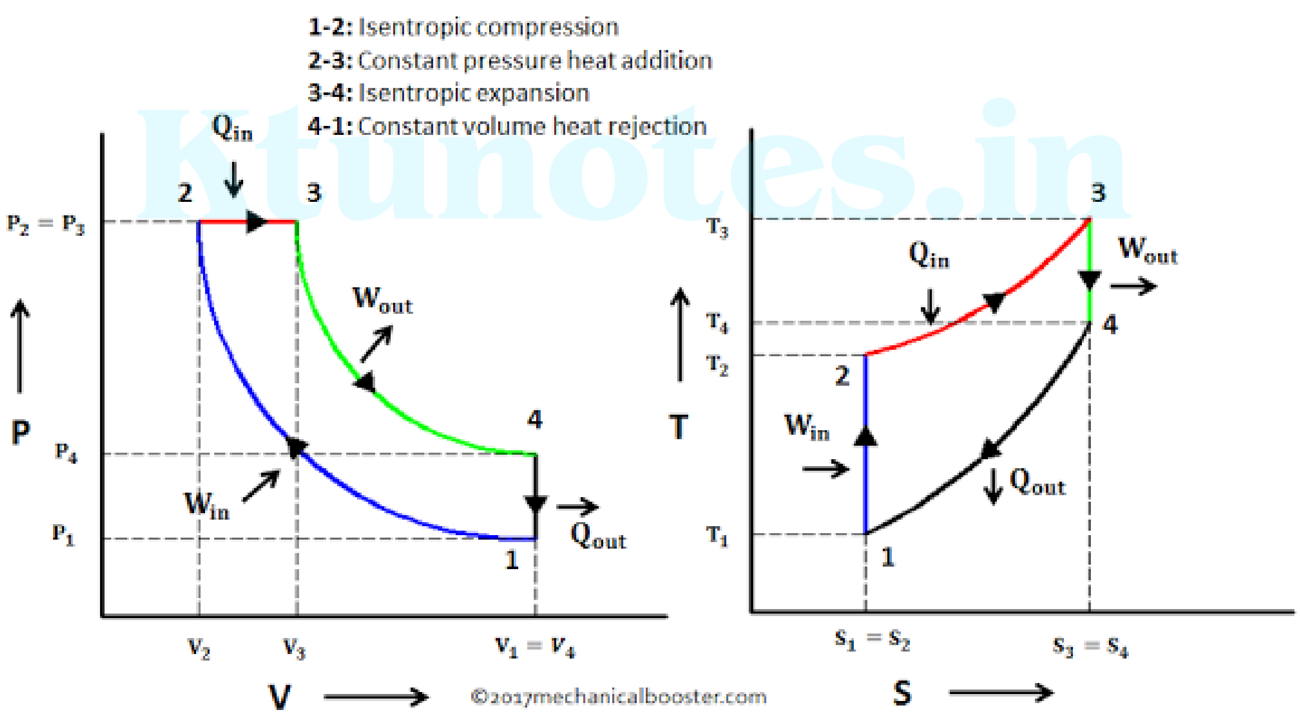
$$r = \frac{V_C + V_S}{V_C}$$

$$r = 1 + \frac{V_S}{V_C}$$

- V_C = Clearance volume
- V_S = Swept volume = $\pi/4\ D^2\ L$

where: L (stroke) = 2 ρ, ρ is the crankshaft radius

Diesel cycle and Diesel engine



P-V and T-S Diagram of Diesel Cycle

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Isentropic Compression (Process 1–2)

- This process is called isentropic as there is no heat transferred (adiabatic) to or from the system and it is a reversible process.
- The gas inside the cylinder is compressed isentropically from a volume V1 to V2.
- The ratio of V1 and V2 is referred to as the compression ratio.
- Work is done by the piston on gases (negative work), which means external work has to be done to compress the gases.
- This process is characterized by the compression stroke of the 4-stroke cycle.

Constant pressure heating (Process 2–3)

- Isobaric means that the process carried out at constant pressure.
- With the pressure being constant, heat is added externally until volume V3 is reached.
- The ratio of V3 and V2 is referred to as the cut-off ratio.
- Heat is added to the system (positive heat), by combusting the air-fuel mixture.
- This process is characterized by the initial part of the power stroke of the 4-stroke cycle, until volume has expanded to V3.

Isentropic Expansion (Process 3–4)

- This process is also isentropic.
- The gas inside the cylinder expands from V3 to V4 which is equal to V1.
- The ratio of V4 (or V1) and V3 is known as the expansion ratio.
- Work is done by the gases on the piston (positive work), thus powering the engine by pushing the piston down.
- This process is characterized by the final part of the power stroke of the 4-stroke cycle, until volume has expanded to V4.

Constant volume cooling (Process 4–1)

- Isobaric means that the process carried out at constant volume.
- With the volume being constant, heat is removed until pressure comes down to P1.
- Heat is removed from the system (negative heat), by flushing out the combusted gases.
- This process is characterized by the exhaust and intake stroke of the 4-stroke cycle.

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