PARALA MAHARAJA ENGINEERING COLLEGE

BERHAMPUR, ODISHA

DEPARTMENT OF AUTOMOBILE ENGINEERING

Lecture Notes

Automotive Engine

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AUTOMOTIVE ENGINES (AUPC2002)

Module - I (6 Hrs.)

Introduction to Automotive Engine - About engines, engine systems, basic engine terminology, types of engines, classification of I.C engines, engine cycles, construction working and port timing diagrams of two stroke petrol and diesel engines, construction work and valve timing diagrams of four stroke petrol and diesel engines, comparison of two stroke and four stroke engines, differences between petrol and diesel engines, firing order.

Module - II (6 Hrs.)

Fuel Supply Systems and Performance - Fuel supply system for SI engines, carburetors (Simple and Solex), fuel supply system for CI engines, fuel injection system, classification of different parts of fuel supply system for both SI and CI engines, calculation of air fuel ratio for petrol and diesel.

Losses in the engine mean effective pressure, fuel consumption, and volumetric efficiency, performance tests in IC engines and heat balance, performance curves.

Module - III (6 Hrs.)

Lubrication and Cooling Systems - Function of lubrication systems, types of lubrication systems- mist, wet and dry sump lubrication systems, properties and designation of lubricants.

Methods of cooling systems: air- and water-cooling systems, properties of coolants, cooling agents.

Module - IV (6 Hrs.)

Combustion and Power Boosters - Phenomenon of combustion in SI engines, stages of combustion, flame propagation, rate of pressure rise, abnormal combustion, effect of engine variables on knocking, fuel quality for SI engines, octane rating, and combustion chambers for SI engines.

Phenomenon of combustion in CI engines, stages of combustion, ignition delay, factors affecting delay period, knock in CI engines, comparison of knock in SI and CI engines, direct and indirect injection diesel engines, combustion chambers, supercharging and turbo charging methods.

Module - V (6 Hrs.)

Supercharging and Turbo charging - Need for supercharging, Effect of supercharging, types of superchargers, methods of supercharging, thermodynamic analysis of supercharged engine cycle, limitations of super charging. Effect of turbo charging, methods of turbo charging, thermodynamic analysis of turbo charged engine cycle, limitations of turbo charging, comparison of Super charging and Turbo charging.

Books:

- V, Ganesan. “Internal Combustion Engines”, Tata-McGraw Hill Publishing Co., NewDelhi, 1994.
- Ramalingam.K. K, “Automobile Engineering”, SCI-Tech Publication Pvt. Ltd, 2005.
- Sing Kirpal, “Automobile Engineering” Vol. Ii, Standard Publishers Distributors, 1971

Heywood, Internal Combustion Engines

- Heldt P.M, High Speed Combustion Engines, Oxford IBH Publishing Co, 1964.
- Dicksee. C.B, Diesel Engines, Blackie and Son Ltd, London, 1964.

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MODULE I

INTRODUCTION TO AUTOMOTIVE ENGINE: -

(About engines, engine systems, basic engine terminology, types of engine, classification of i.c engines, engine cycles, construction working and port timing diagrams of two stroke petrol and diesel engines, construction working and valve timing diagrams of four stroke petrol and diesel engines, comparison of two stroke and four stroke engines, differences between petrol and diesel engines, firing order.)

Introduction

Heat Engines

A heat engine or a thermal engine is a machine which converts heat energy into mechanical work. Heat is produced by burning any combustible material.

Heat engines are classified as

- Internal combustion engines (I.C engines)
- External combustion engines (E.C engines)

I.C engines

In an I.C engine, the chemical energy of fuel is released as heat by way of combustion inside the engine cylinder where power is produced. Both combustion and power developed take place inside the cylinder.

E.C engines

E.C engines are steam engines and steam turbines. In these units, heat energy is produced during combustion of fuel in a boiler furnace. This energy is used to generate steam under pressure in the boiler. The steam expands in an engine and thereby does work. In this case, power is produced in a unit other than the one where heat is generated.

In any I.C. engine, during its working, cycle of operation take place again and again. They occur one after other in the order given below:

- Suction
- Compression
- Ignition and expansion

- Exhaust

In order to perform the four operations, a piston moves within the cylinder up and down, or to and fro depending on the type of engine.

Classification of I.C engines

Based on working cycle

- Two stroke engines
- Four stroke engines

Based on method of ignition

- Compression ignition engines (C.I engines)
- Spark ignition engines (S.I engines

Based on Fuel used

- Light fuel oil engines (Petrol engines)
- Diesel engines
- Gas engines

Based on speed of the engine

- Slow speed engines
- Medium speed engines

High speed engines

Based on applications

- Stationary engines
- Portable engines
- Automobile engines
- Marine engines
- Aero engines

Based on arrangement of the cylinder

- Horizontal engines
- Vertical engines
- Radial engines
- V-type engines

Based on number of cylinders

- Single cylinder engines
- Multi-cylinder engines

Based on method of cooling

- Water cooled engines
- Air cooled engines

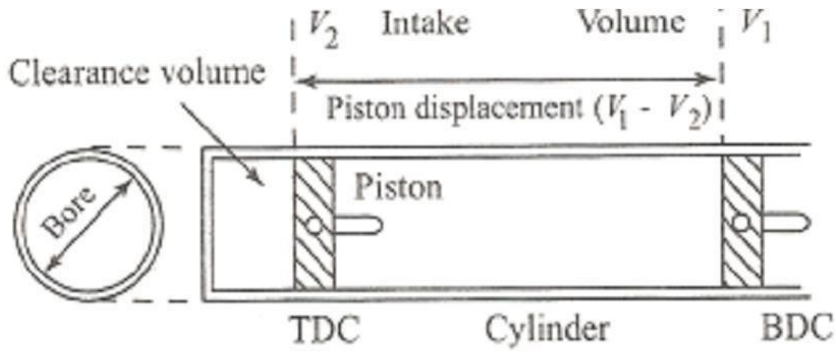
Nomenclature of IC Engine

In any engine, during its working, cycle of operation take place again and again.

In an I.C engine, the cycle consists of four operations. They occur one after other in the order given below:

- Suction

- Compression
- Ignition and expansion
- Exhaust



In order to perform the four operations, a piston moves within the cylinder up and down, or to and fro depending on the type of engine.

TDC: Top dead centre → Top most position of the piston in the cylinder of vertical engines.

BDC: Bottom dead centre → Bottom most position of the piston in the cylinder of vertical engines.

IDC: Inner dead centre → Inner most position of the piston in the cylinder of horizontal engines.

ODC: Outer dead centre → Outer most position of the piston in the cylinder of horizontal engines.

Stroke: The distance (L) between two dead centres. The piston completes one stroke in ½ revolution of the crank shaft (180°).

Bore : Diameter of the cylinder (D).

Clearance volume: The space above the piston when the piston is at TDC.

Cylinder volume: The volume above the piston when the piston is at BDC.

Stroke volume: Also called swept volume. The volume displaced by the piston during a stroke is called swept volume.

Square engine: D = L

Under square engine: D < L → Low speed engines. Large industrial engines and tractor engines are under square engines.

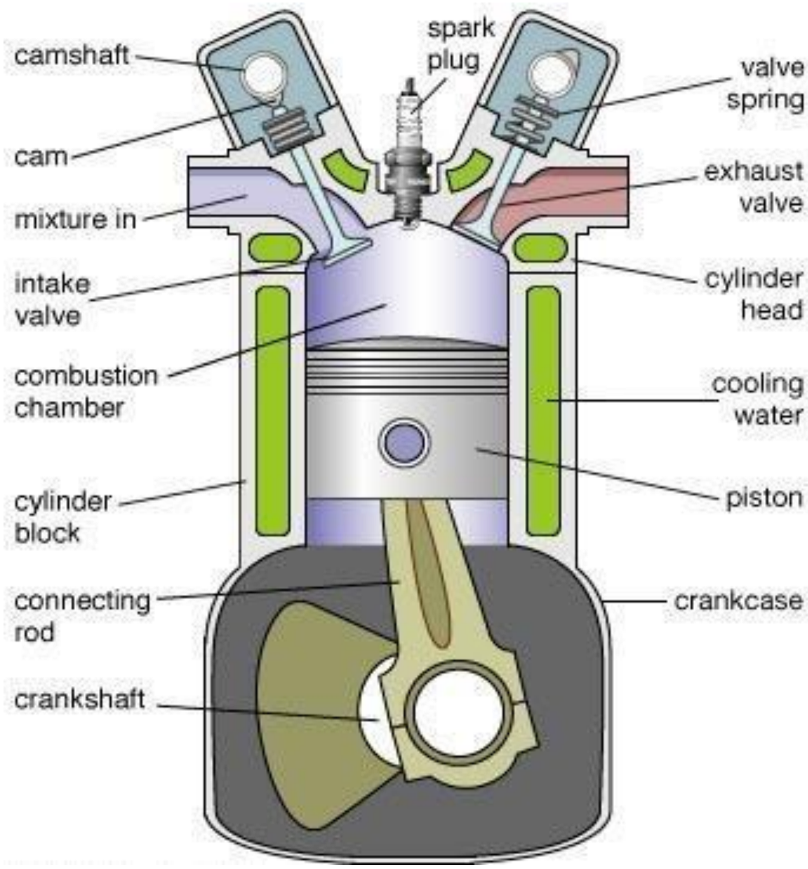
Over square engine: D > L → High speed engines. This is the most common engine design.

Cubic capacity: The cubic capacity of an engine or engine displacement or engine size is the product of stroke volume in one cylinder and the number of cylinders in the engine.*Compression ratio:* The ratio of cylinder volume to the clearance volume is called compression ratio.

Components of I.C engines

- Cylinder block
- Cylinder head
- Piston assembly
- Connecting rod
- Crank shaft
- Crank case
- Valves and Valve operating mechanism
- Fuel supply system
- Ignition system
- Lubrication system
- Cooling system
- Inlet and Exhaust system

Constructional details of Spark Ignition (SI) and Compression Ignition (CI) Engines



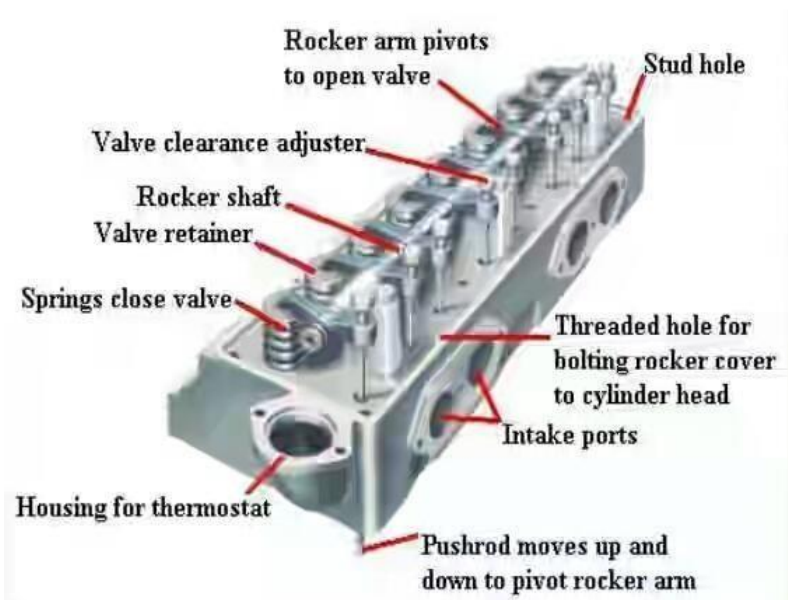
Cylinder: The circular cylinders in the engine block in which the pistons reciprocate

Cylinder block

It is a container fitted with piston, where the fuel is burnt and power is produced. Cylinder is the main body of IC engine. Cylinder is a part in which the intake of fuel, compression of fuel and burning of fuel take place. The main function of cylinder is to guide the piston.
For cooling of cylinder a water jacket (for liquid cooling used in most of cars) or fin (for air cooling used in most of bikes) are situated at the outer side of cylinder. At the upper end of cylinder, cylinder head and at the bottom end crank case is bolted. Material: Ductile (Nodular) Cast Iron, 30C8 (Low Carbon Steel)

Manufacturing method: Casting, Forging and after that heat transfer , Machining

The cylinder head is held tight to the cylinder block by number of bolts and studs.



One end of the cylinder is closed by means of cylinder head. This consists of inlet valve for admitting air fuel mixture and exhaust valve for removing the products of combustion. The inlet valve, exhaust valve, spark plug, injector etc. are bolted on the cylinder head. The main

function of cylinder head is to seal the cylinder block and not to permit entry and exit of gases on cover head valve engine.

Material: Aluminium alloys

Manufacturing Method: Casting

The bottom portion of the cylinder block is called **crank case.**

The piston reciprocates inside the cylinder and the motion of the piston is transmitted to the crank shaft by connecting rod and crank assembly.

Material : Aluminum Alloy 4652 because of its Low Specific Gravity.

Manufactuirng Method: Casting

Piston rings: Metal rings that fit into circumferential grooves around the piston and form a sliding surface against the cylinder walls.

These are used to maintain a pressure tight seal between the piston and cylinder walls and also it transfer the heat from the piston head to cylinder walls.

These rings are fitted in grooves which have been cut in the piston. They are split at one end so they can expand or slipped over the end of piston.

Material: cast iron of fine grain and high elastic material

Manufacturing Method: Pot casting method

Inlet and exhaust valves are provided for suction of charge and removal of exhaust gases.

Fuel is supplied to the engine from the fuel tank for combustion through fuel filter, fuel pump and fuel injector in case of C.I engines and carburetor in case of S.I engines.

The intake and exhaust valves open at the proper time to let in air and fuel and to let out exhaust. Note that both valves are closed during compression and combustion so that the combustion chamber is sealed.

Materials: Phosphorus Bronze and Monel metal.

Lubricating system supplies lubricating oil to the various parts of the engine where there is relative motion. This reduces friction between the parts and thereby increases engine life.

Cooling system abstracts excess heat from various engine parts which are heated due to combustion. This prevents the failure of the components due to overheating and increases the engine life. The coolant may be either liquid or air.

Inlet manifold is provided on suction side which allows the charge entering the cylinder during suction process.

Exhaust manifold is provided on exhaust side which allows the exhaust gases letting to atmosphere during exhaust process.

Combustion chamber: The end of the cylinder between the head and the piston face where combustion occurs.

> The size of combustion chamber continuously changes from minimum volume when the piston is at TDC to a maximum volume when the piston at BDC.

Crankshaft: Rotating shaft through which engine work output is supplied to external systems.

> The crankshaft is connected to the engine block with the main bearings.
>
> It is rotated by the reciprocating pistons through the connecting rods connected to the crankshaft, offset from the axis of rotation. This offset is sometimes called crank throw or crank radius.

Connecting rod: Rod connecting the piston with the rotating crankshaft, usually made of steel or alloy forging in most engines but may be aluminum in some small engines.

One end of the connecting rod is connected to piston through piston pin while the other is connected to crank through crank pin.

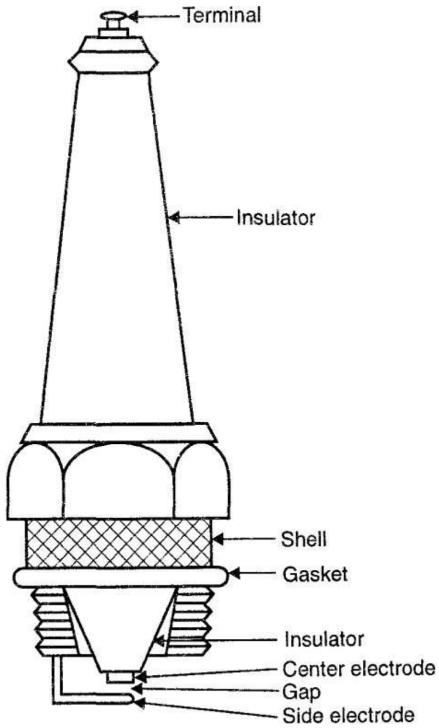
It transmits the reciprocating motion of piston to rotary crank.

There are two end of connecting rod one is known as big end and other as small end. Big end is connected to the crankshaft and the small end is connected to the piston by use of piston pin.

Material: Low Carbon steel 30C8

Manufacturing Methods: Forging and after that heat heat treatment.

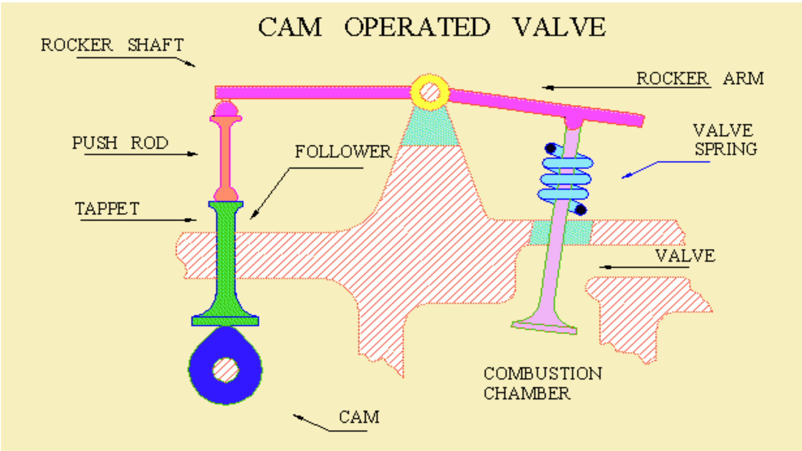
Spark plug: Electrical device used to initiate combustion in an SI engine by creating high voltage discharge across an electrode gap.


Terminal
Insulator
Shell
Gasket
Insulator
Center electrode
Gap
Side electrode

- The spark plug consists of a metal shell having two electrodes which are insulated from each other with an air gap.
- High tension current jumping from the supply electrode produces the necessary spark.
- The correct type of plug with correct width of gap between the electrodes is important factor.
- The spark plug gap can be easily checked by means of a feeler gauge and set as per manufacturer‟s specifications.

Camshaft: Rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage (push rods, rocker arms, tappets).

Push rods: The mechanical linkage between the camshaft and valves on overhead valve engines with the camshaft in the crankcase.



Carburetor: A device which meters the proper amount of fuel into the air flow by means of pressure differential.

- For many decades it was the basic fuel metering system on all automobile (and other) engines.

Flywheel: Rotating mass with a large moment of inertia connected to the crank shaft of the engine.

- The purpose of the flywheel is to store energy and furnish large angular momentum that keeps the engine rotating between power strokes and smoothes out engine operation.

Fly wheel is a rotating mass used as an energy storing device.

The main function of flywheel is to rotate the shaft during preparatory stroke. It also makes crankshaft rotation more uniform.

Material: cast iron

Manufacturing Method: Casting

Fuel injector: A pressurized nozzle that sprays fuel into the incoming air (SI engines) or into the cylinder (CI engines).

Fuel pump: Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine.

Timing Gears: Timing Gears These gears drive the camshaft from the crankshaft.

Glow plug: Small electrical resistance heater mounted inside the combustion chamber of many CI engines, used to preheat the chamber enough so that combustion will occur when first starting a cold engine.

- The glow plug is turn off after the engine is started.

Starter: Several methods are used to start IC engines. Most are started by use of an electric motor (starter) geared to the engine flywheel. Energy is supplied from an electric battery.

Governor: When the speed decreases due to increase in load, the supply valve is opened by the mechanism operated by the governor and therefore speeds up again to the original speed. If the speed increases due to a decrease in load the governor mechanism closes the supply valve sufficiently to slow the engine to its original speed. Thus the function of a governor is to control the fluctuations of engine sped due to changes of load.

Applications of I.C engines

The I.C engines are generally used for

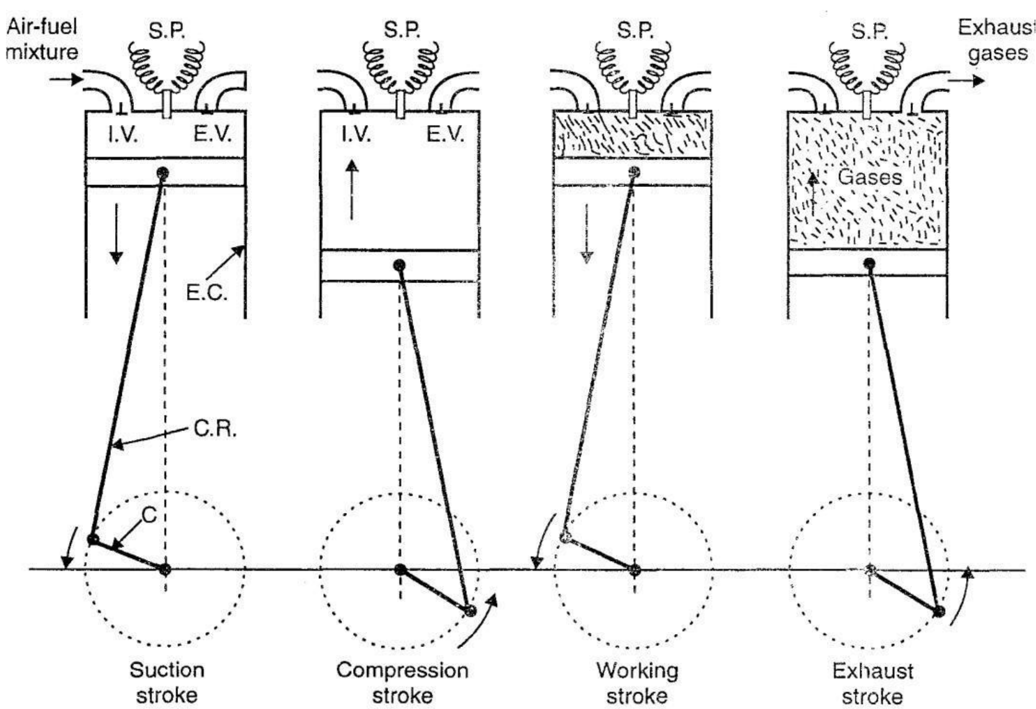
Road vehicles (Scooter, motor cycle, buses, etc)

- Air craft
    - Locomotives
- Civil engineering equipment (bull-dozer, scraper, power shovels, etc)
- Pumping sets
- Cinemas
- Hospitals
- Several industrial applications

Working of Four Stroke S.I Engines (Petrol engines and Gas engines)

Suction Stroke: During this stroke (also called induction stroke) the piston moves from TDC to BDC. The inlet valve opens and proportionate fuel-air mixture is sucked in the engine cylinder. The operation is represented by the line 5 – 1. The exhaust valve remains closed through out the stroke.

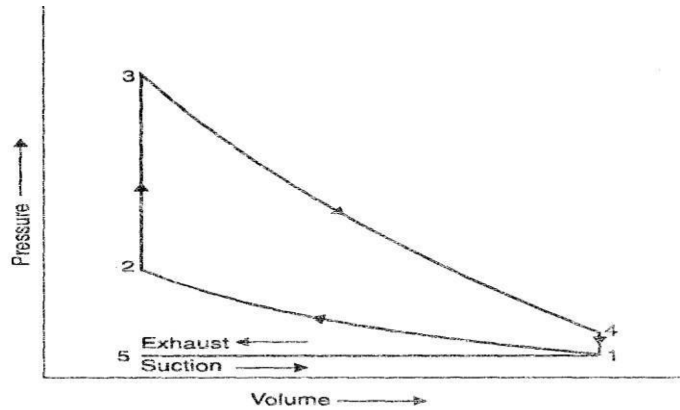
Compression Stroke: In this stroke the piston moves towards TDC and compresses the enclosed fuel air mixture drawn in the cylinder during suction stroke. The pressure of the mixture rises in the cylinder to a value of about 8 bar (1 – 2). Just before end the stroke, a high intensity spark is applied to ignite the mixture and combustion takes place at constant volume (2 – 3). Both inlet and exhaust valves remain closed during this stroke.

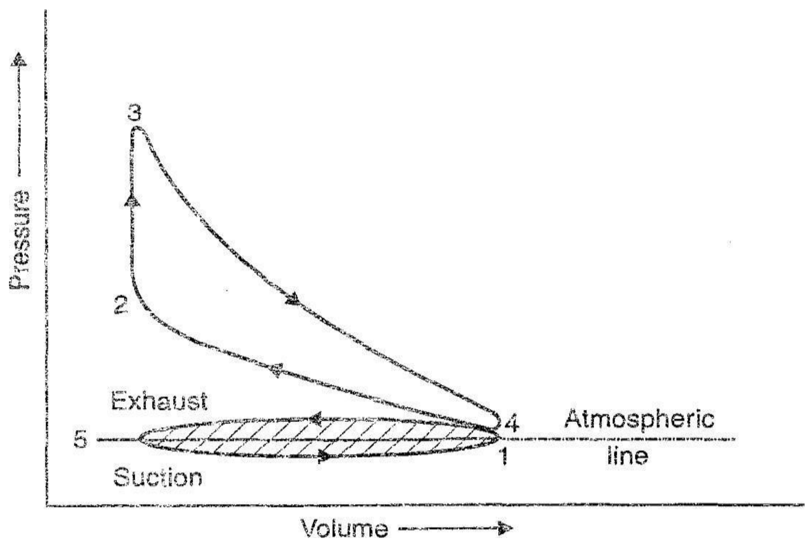


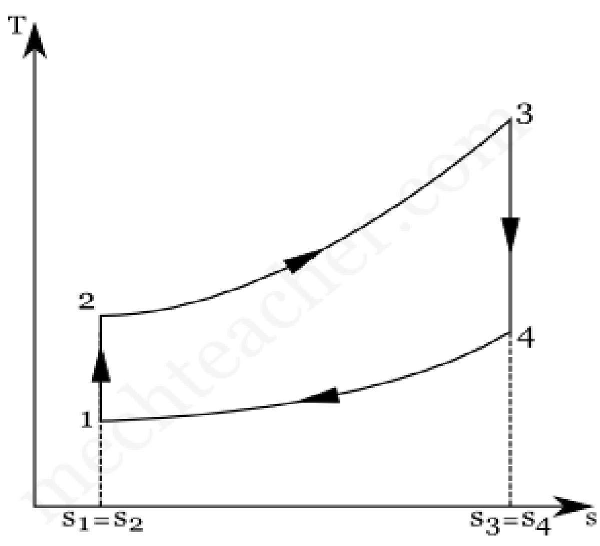
I.V = Intel valve, E.V. = Exhaust valve, E.C. = Engine cylinder, C.R. = Connecting rod
C = Crank, S.P. = Spark plug.

Expansion or Power stroke: The high pressure and high temperature hot gases obtained by the combustion, throws the piston from TDC to BDC. Thus the work is obtained in this stroke (3 – 4). Both the valves remain closed during this stroke. When the piston just reaches the BDC, the exhaust valve opens and there will be sudden pressure drop and heat rejection at constant volume (4 – 1)

Exhaust Stroke: This is last stroke of the cycle. During this stroke, the used gases are allowed to escape through exhaust valve to atmosphere. The piston moves from BDC to TDC and the exhaust gases are pushed to atmosphere.


Pressure
Volume
Exhaust
Suction
3
2
4
1
5


Pressure
Volume
Exhaust
Suction
Atmospheric line
3
2
4
1
5


T
s
3
2
4
1
s1=s2
s3=s4

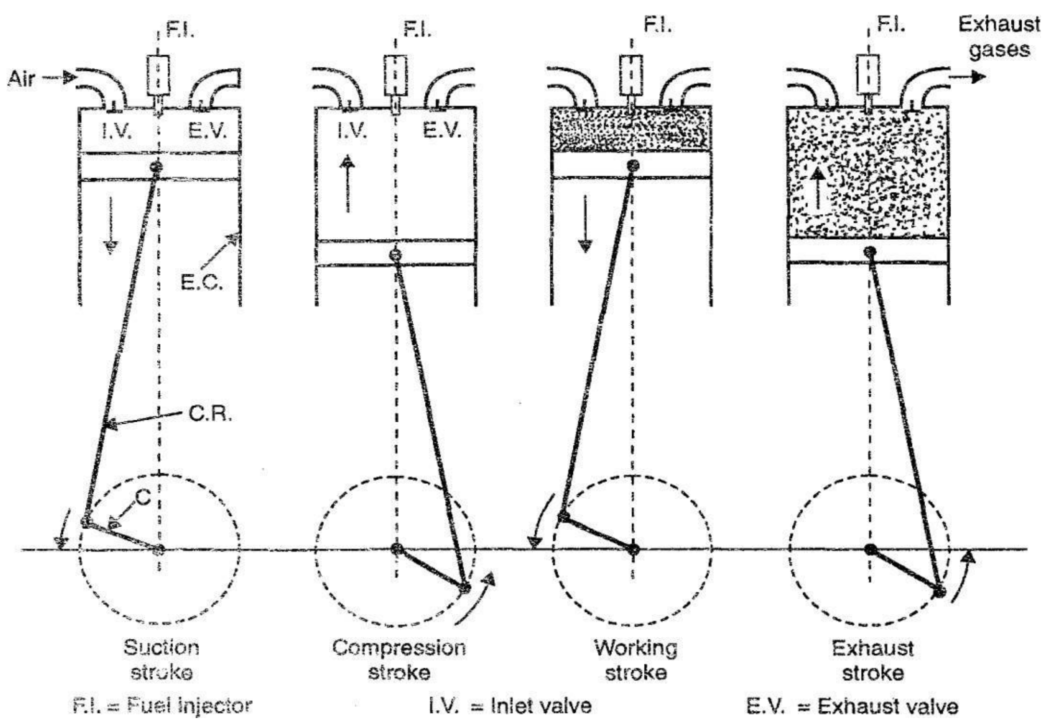
Working of Four Stroke C.I Engines (Diesel engines)

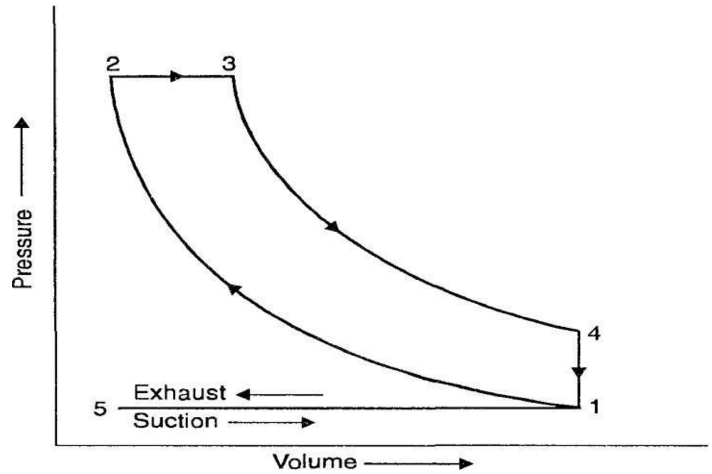
Suction Stroke: During this stroke (also called induction stroke) the piston moves from TDC to BDC. The inlet valve opens and proportionate air is sucked in the engine cylinder. The operation is represented by the line 5 – 1. The exhaust valve remains closed through out the stroke.

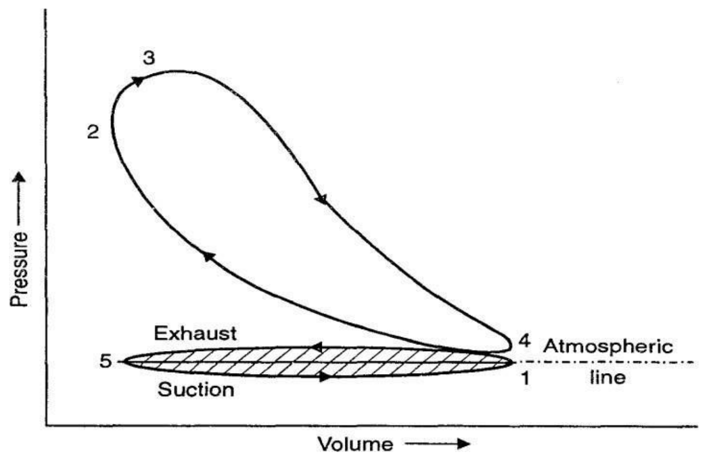
Compression Stroke: In this stroke the piston moves towards TDC and compresses the enclosed air drawn in the cylinder during suction stroke. The pressure of the mixture rises in the cylinder to a value of about 35 bar (1 – 2). The temperature will be around 600^{o}C. Just before end the stroke, fuel is injected. Both inlet and exhaust valves remain closed during this stroke.

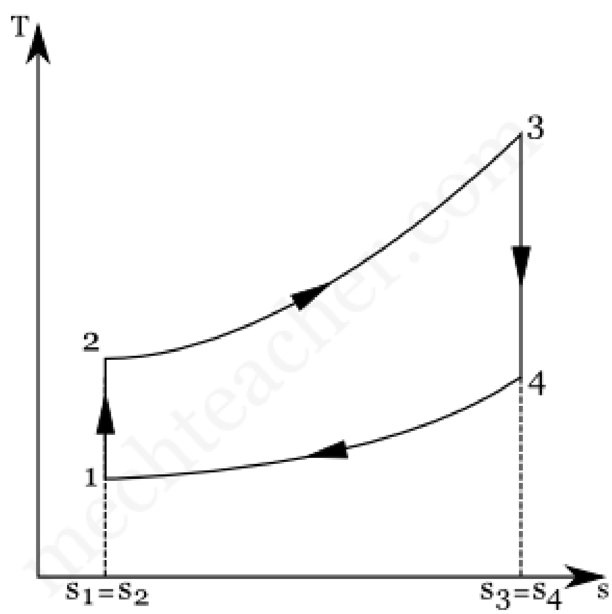
Expansion or Power stroke: As the piston starts moving from TDC, the injected fuel into the hot compressed air burn the fuel. The burning is taking place at constant pressure (2 – 3). The point 2 represents the beginning of fuel injection and point 3 represents the end of fuel injection. The expansion starts at point 3 and continues upto BDC. Thus the work is obtained in this stroke from (3 – 4). Both the valves remain closed during this stroke. When the piston just reaches the BDC, the exhaust valve opens and there will be sudden pressure drop and heat rejection at constant volume (4 – 1).

Exhaust Stroke: This is last stroke of the cycle. During this stroke, the used gases are allowed to escape through exhaust valve to atmosphere. The piston moves from BDC to TDC and the exhaust gases are driven out of the cylinder. This operation is represented by 1 – 5.



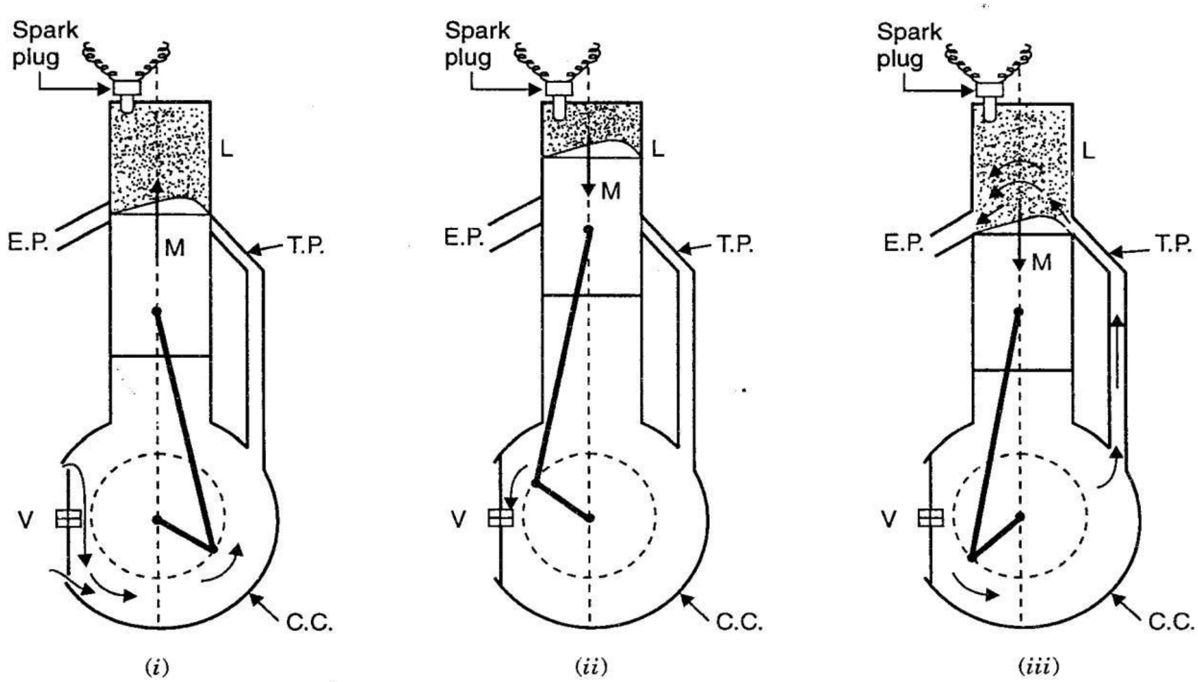






Working of Two Stroke S.I engine

In two stroke engines all the operations are completed in two strokes or in single revolution of the crank rotation. Two stroke engines have ports instead of valves. The three ports are (i) Transfer port (TP) (ii) Exhaust port (EP) and (iii) Suction port (SP) or Valve (V).



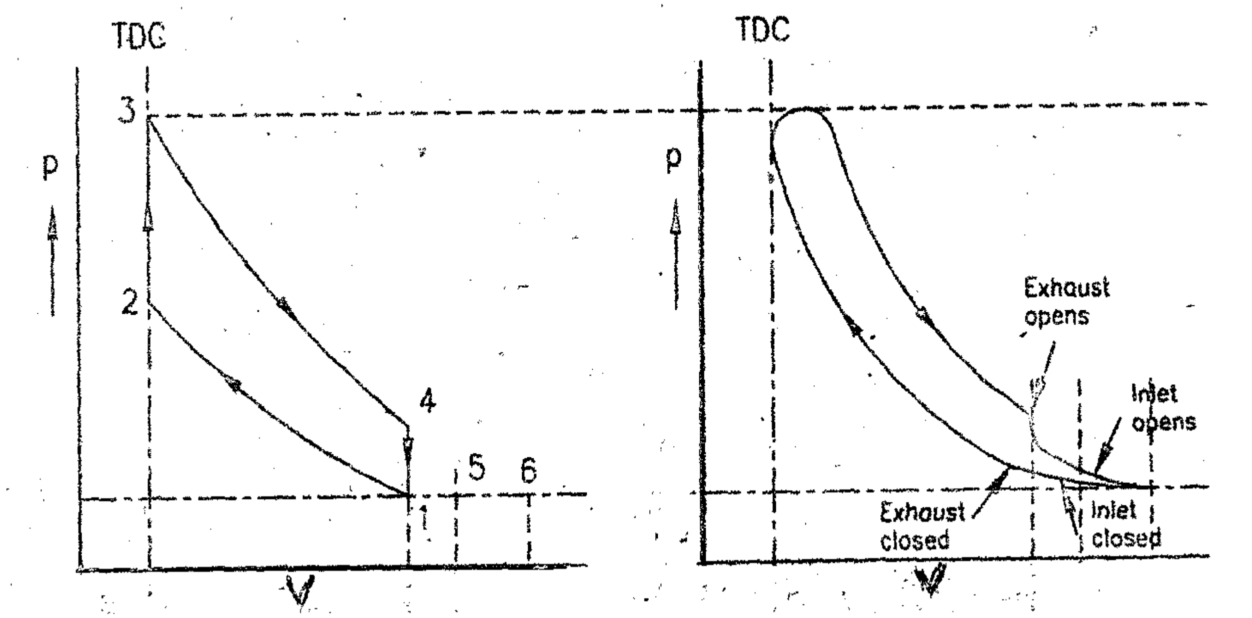
L = Cylinder E.P. = Exhaust port T.P. = Transfer port V = valve, C.C = Crank chamber

Suction stage: In this stage, while going down towards BDC, uncovers both transfer port and exhaust port. The fresh fuel-air mixture enters the cylinder through transfer port.

Compression stage: In this stage, the piston, while moving up, first covers the transfer port and then exhaust port. The air-fuel mixture is compressed. In this stage the inlet port or a valve opens and fuel air mixture enters the crank case.

Expansion stage: Shortly before the piston reaches the TDC (during compression stroke), the charge is ignited with the help of spark plug. It suddenly increases the pressure and temperature at constant volume. The piston is pushed downwards and thus the work is obtained.

Exhaust stage: In this stage, the exhaust port is opened as the piston moves downwards. The exhaust gases are sent to the atmosphere through exhaust manifold.



Theoretical and actual p-V diagrams of Two Stroke Otto cycle

Working of Two Stroke C.I engine

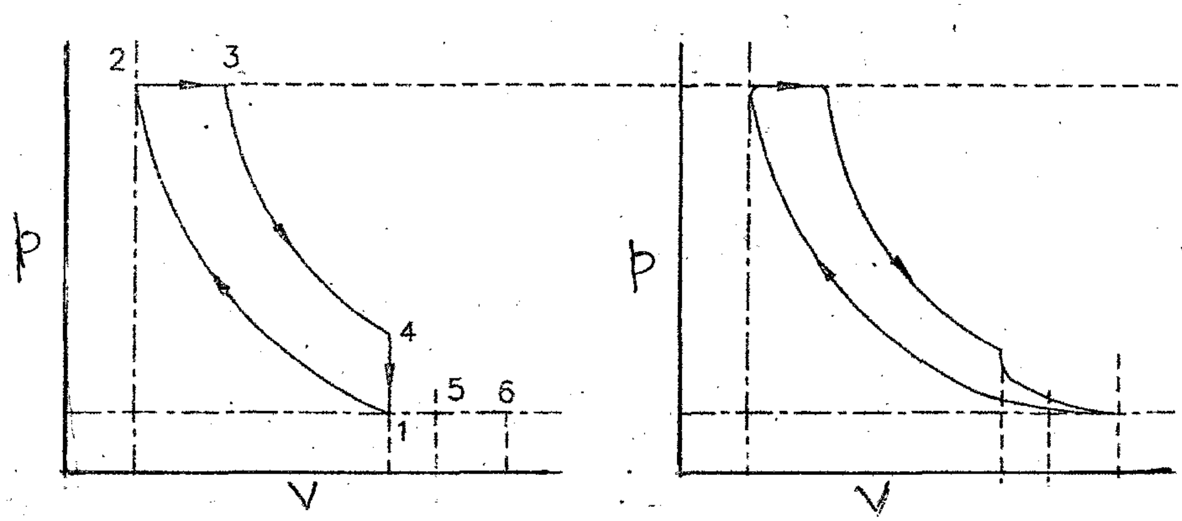
Except that fuel is admitted near the TDC, the working of two stroke cycle diesel engine is similar to that of two stroke cycle petrol engine.

Suction stage: In this stage, while going down towards BDC, uncovers both transfer port and exhaust port. The air enters the cylinder through transfer port.

Compression stage: In this stage, the piston, while moving up, first covers the transfer port and then exhaust port. The air is compressed. In this stage the inlet port or a valve opens and air enters the crank case.

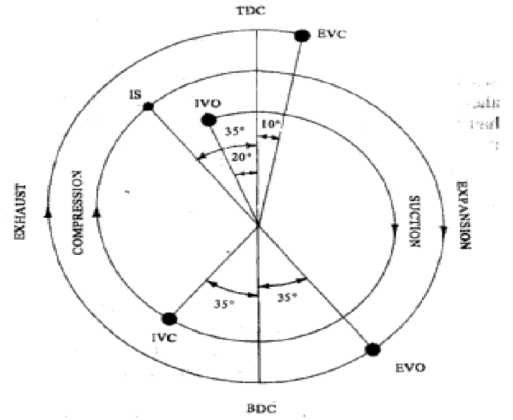
Expansion stage: Shortly before the piston reaches the TDC (during compression stroke), the fuel is injected in the form of fine spray into the cylinder through the injector. At this moment the temperature of the air is sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature. The fuel is continuously injected for a fraction of the crank revolution. The fuel is assumed to be burnt at constant pressure The piston is pushed downwards and thus the work is obtained.

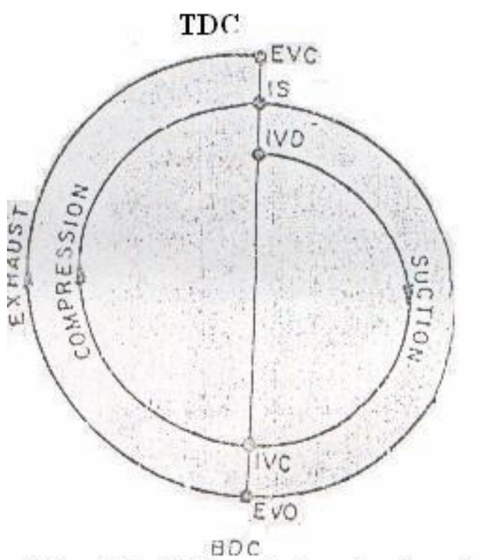
Exhaust stage: In this stage, the exhaust port is opened as the piston moves downwards. The exhaust gases are sent to the atmosphere through exhaust manifold.



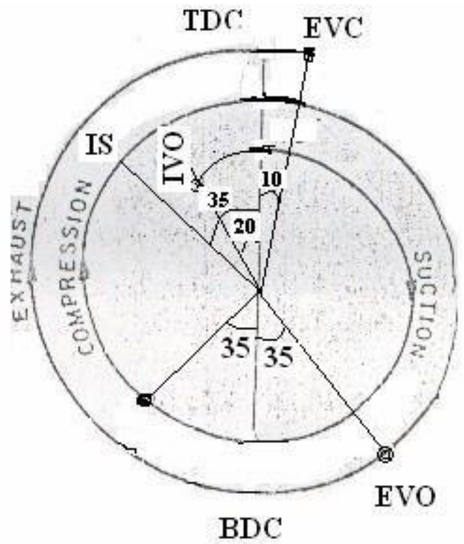
Theoretical and actual p-V diagrams of Two Stroke Diesel cycle

valve timing diagram of 4 stroke petrol engines





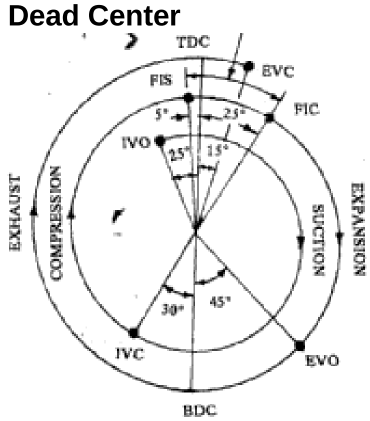
Theoritical Valve timing of a 4 stroke Petrol Engine



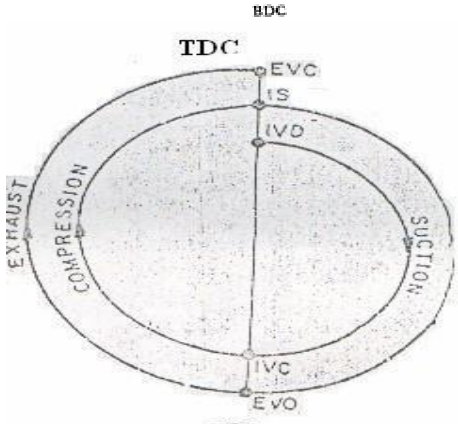
Actual Valve Timing for 4 stroke Petrol Engine

IVO – Inlet valve Opens IVC – Inlet Valve Closes IS – Ignition Starts

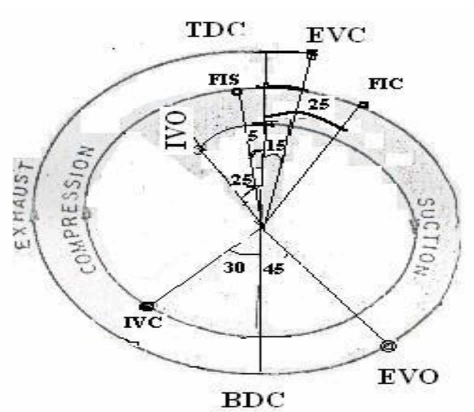
EVO – Exhaust Valve Opens
EVC – Exhaust Valve Closes
TDC – Top Dead Center BDC – Bottom Dead Center



IVO	–	Inlet valve opens
IVC	–	Inlet valve closes
FIS	–	Fuel injection starts
FIC	–	Fuel injection closes
EVO	–	Exhaust valve closes
EVC	–	Exhaust valve closes



Theoritical Valve timing of a 4 stroke Diesel Engine



Actual Valve Timing for 4 stroke Diesel Engine

Valve overlap

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

Port timing diagram:

-Drawn for 2-stroke engine

-No valve arrangement

-3 ports- inlet, transfer and exhaust

Figure 6 shows port timing diagram for 2-stroke engine

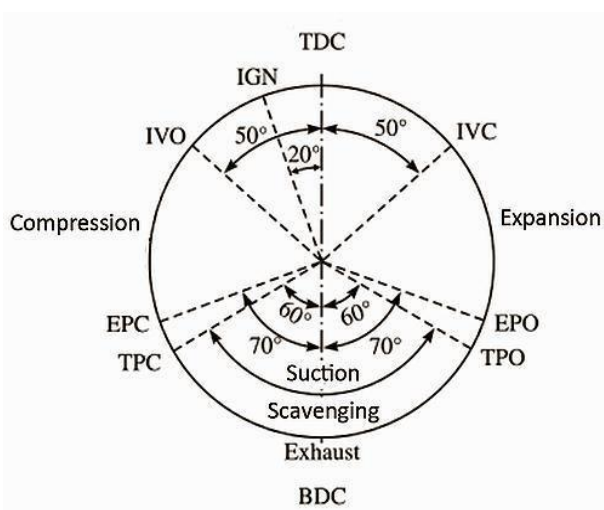


Fig. 6. Port timing diagram for 2-stroke engine

Comparison between external combustion engine and internal combustion engine:

External combustion engine	Internal combustion engine
*Combustion of air-fuel is outside the engine cylinder (in a boiler)	* Combustion of air-fuel is inside the engine cylinder (in a boiler)

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

Comparison of Four-stroke and two-stroke engine:

	Four-stroke engine	Two-stroke engine
1.	Four stroke of the piston and two revolution of crankshaft	Two stroke of the piston and one revolution of crankshaft
2.	One power stroke in every two revolution of crankshaft	One power stroke in each revolution of crankshaft
3.	Heavier flywheel due to non-uniform turning movement	Lighter flywheel due to more uniform turning movement
4.	Power produce is less	Theoretically power produce is twice than the four stroke engine for same size
5.	Heavy and bulky	Light and compact
6.	Lesser cooling and lubrication requirements	Greater cooling and lubrication requirements
7.	Lesser rate of wear and tear	Higher rate of wear and tear
8.	Contains valve and valve mechanism	Contains ports arrangement
9.	Higher initial cost	Cheaper initial cost
10.	Volumetric efficiency is more due to greater time of induction	Volumetric efficiency less due to lesser time of induction
11.	Thermal efficiency is high and also part load efficiency better	Thermal efficiency is low, part load efficiency lesser
12.	It is used where efficiency is important.	It is used where low cost, compactness and light weight are important.
	Ex-cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.	Ex-lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc.

Comparison of SI and CI engine:

SI engine	CI engine
Working cycle is Otto cycle.	Working cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
High self-ignition temperature.	Low self-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Use of spark plug for ignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Higher maximum RPM due to lower weight	Lower maximum RPM
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavier due to higher pressures

Firing order

The firing order is the sequence of power delivery of each cylinder in a multi-cylinder reciprocating engine.This is achieved by sparking of the spark plugs in a gasoline engine in the correct order, or by the sequence of fuel injection in a Diesel engine. When designing an engine, choosing an appropriate firing order is critical to minimizing vibration, to improve engine balance and achieving smooth running, for long engine fatigue life and user comfort, and heavily influences crankshaft design.

The firing order for a four cylinder engine is 1-2-4-3 or 1-3-4-2

Thefiringorderforasixcylinderengineis1-4-2-6-3-5or1-5-3-6-2-4 The firing order for a V-6 engine is 1-6-5-4-3-2.

Thefiringorderfor anopposedsixcylinderengineis1-4-5-2-3-6 Thefiringorderfor an V

8 engineis 1-8-4-3-6-5-7-2.

EXERCISE

Part A

1. Define Clearance Volume.
2. What is meant by mean piston speed?
3. What is the use of air standard cycle analysis?
4. What is the need for governor in diesel engines?
5. What is meant by scavenging?
6. What is meant by delay period in CI engine?
7. Compare SI and CI engines.
8. What is firing order? Why it is required?
9. Enumerate the various firing orders for four and six cylinder engines.
10. Write the equation for standard efficiency of Otto cycle.

Part B

1. (i) With a neat sketch explain the working principle of four stroke spark ignition engine.

(ii) Compare SI and CI engines with respect to basic cycle.

2. In a SI engine working on the ideal Otto cycle, the compression ratio is 5.5. The pressure and temperature at the beginning of compression are 1 bar and 27ºC respectively. The peak pressure is 30 bars. Determine the pressure and temperatures at the salient points, the air – standard efficiency and the mean effective pressure. Assume the ratio of specific heats to be 1.4 for air.
3. The mean effective pressure of an ideal diesel engine cycle is 8 bar. If the initial pressure is 1.03 bar and the compression ratio is 12, determine the cut-off ratio and the air standard efficiency. Assume ratio of specific heats for air to be 1.4.

4. An air-standard dual cycles has a compression ratio of 10. The pressure and temperature at the beginning of compression are 1 bar and 27 C. The maximum pressure reached is 42 bar and the maximum temperature is 1500 K. Determine (i) the temperature at the end of constant volume heat addition (ii) Cut-off ratio (iii) Work done per kg of air (iv) The cycle efficiency. Assume Cp = 1.004 KJ/Kg K and Cv = 0.717 KJ/Kg K for air.
5. Compare two stroke and four stroke cycle engines.
6. Give the classification of IC engines.
7. Give the working principle of two stroke spark ignition engine.
8. Compare Otto and diesel cycles. Draw P-V, T-S diagram of both.
9. Describe the construction and working of four stroke petrol engine with neat sketches.

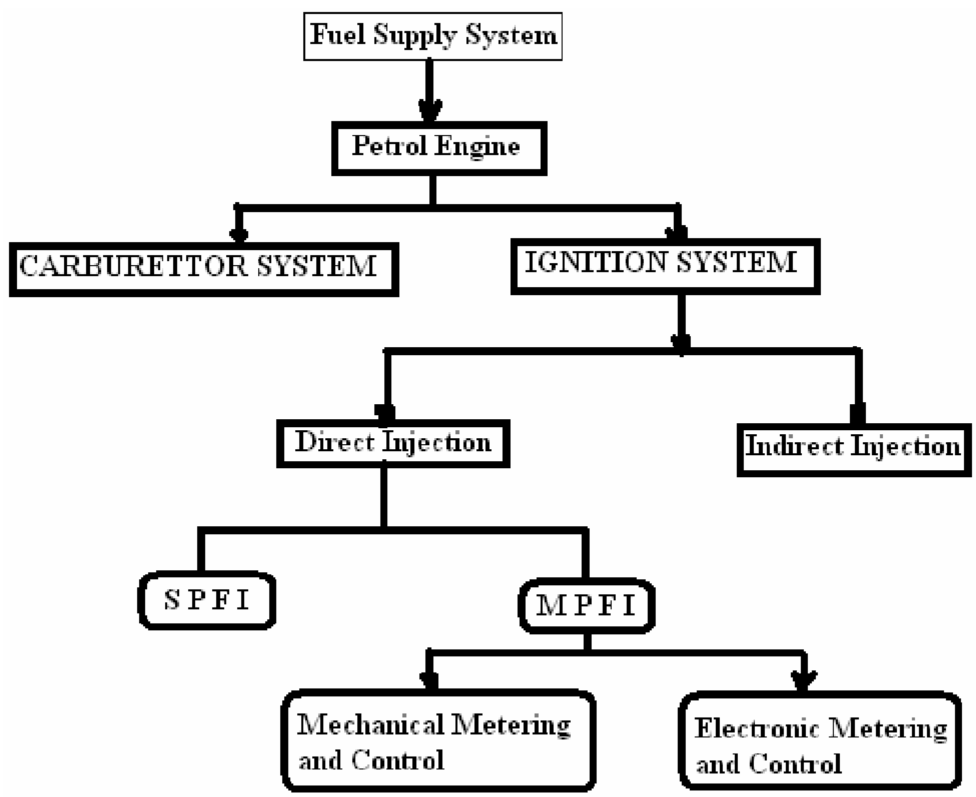
10. Describe the construction and working of four stroke diesel engine with neat sketches.
11. Compare SI and CI engines
12. Explain the construction of CI engine and explain its nomenclature.
13. Explain the Diesel cycle with PV and TS diagram. Derive the expressions for efficiency and MEP?

MODULEII

FUEL SUPPLY SYSTEMS AND PERFORMANCE: -
(Fuel supply system for SI engines, carburetors (simple and solex), fuel supply system for CI engines, fuel injection system, classification of different parts of fuel supply system for both si and ci engines, calculation of air fuel ratio for petrol and diesel. Losses in the engine, mean effective pressure, fuel consumption, and volumetric efficiency, performance tests in IC engines and heat balance, performance curve.)

Fuel supply system for SI engines

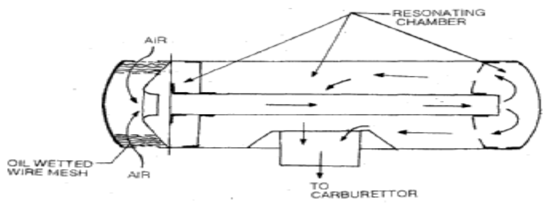
Introduction: The fuel system of an Internal Combustion engine is intended to produce a combustible mixture composed of the fuel stored in the fuel tank and the atmospheric air, and then deliver both to the cylinders. Petrol engines use light grade gasoline.



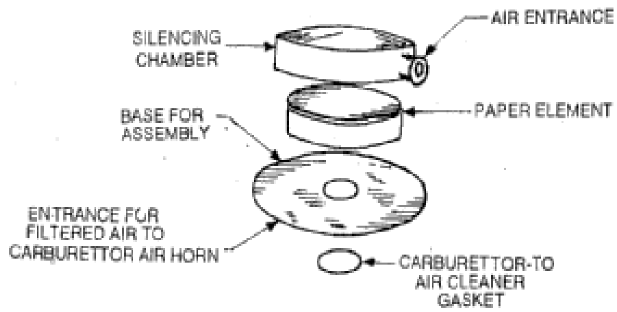
3.0. **Components of fuel feed system:** The fuel feed system of a petrol engine are having the following components.

1. Fuel Tank
2. Fuel Pump
3. Fuel Filter
4. Carburetor
5. Intake manifold

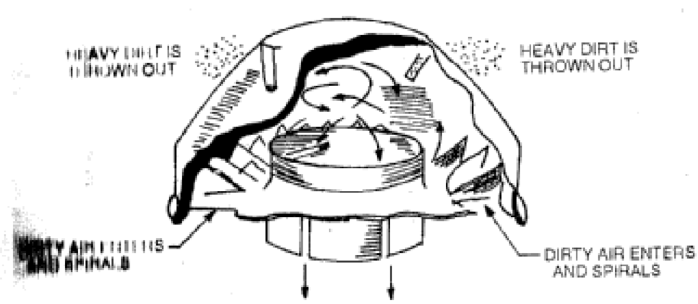
6. Fuel lines
7. Fuel Gauge



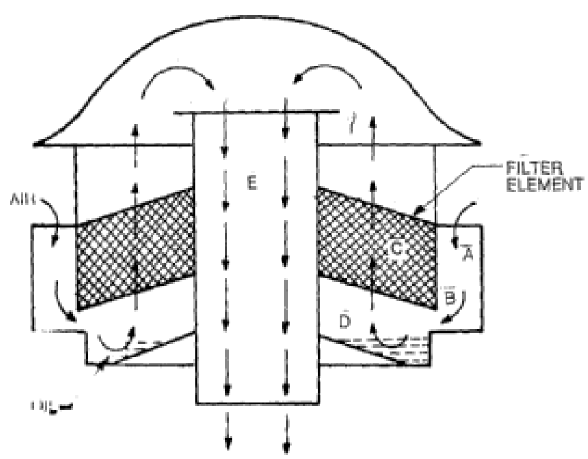
Oil Bath Type Air Cleaner



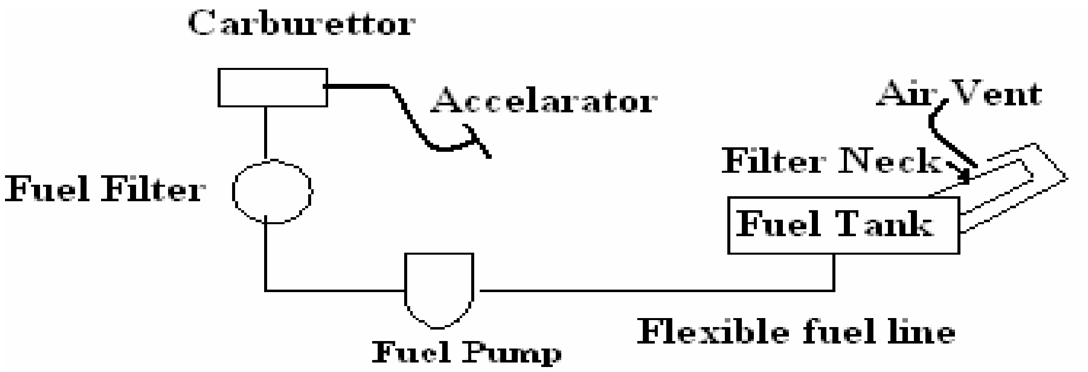
Dry Type Air Cleaner



Centrifugal Type air cleaner



OIL BATH TYPE AIR CLEANER



Types of Fuel Feed Systems: The fuel from thefuel tank can be supplied to the engine cylinder by the following systems.

1. GravitySystem. 2. Pressuresystem 3. VacuumSystem
4. Pump System 5. Fuel Injection System.

Functions of fuel feed system:

1. To store the fuel in the fuel tank.
2. To supply fuel to the engine to the required amount and in proper conditions.
3. To indicate o the driver the fuel level in the fuel tank.

In the gravity fuel feed system, the fuel tank is mounted at a place higher than that of the carburetor. The fuel flows from the tank to the carburetor due to the gravitational force. Thus the system does not require any fuel pump. The fuel tank is directly connected to the carburetor. Scooters and motorcycles use this system.

In pressure system, a pressure sealed tank is used. The pressure is created in the tank by means of a separate pump. For starting, the pump is primed by cam which produces pressure in the tank and fuel flows to the carburetor. In this system the tank can be placed above or below the carburetor.

In vacuum system, the engine suction is used for sucking the fuel from the main tank to the auxiliary fuel tank from where it flows by gravity to the carburetor.

In pump system, a fuel pump is used to feed the fuel from the fuel tank to the carburetor. The pump is driven either by the cam shaft or electrically. In this system, the fuel tank can be placed at any suitable position in the vehicle.

In the fuel injection system, a fuel injection pump is used in place of carburetor. The fuel is atomized by means of a nozzle and then delivered into an air stream. Separate fuel injection system is used for each cylinder which controls the mixture under different load and speed conditions.

3.2 Fuel Tank: The fuel tank is made of sheet metal. It is usually attached to the frame at a rear of vehicle. Its capacity ranges from 70 to 120 liters. The filler neck of the tank is closed by a cap. In some other tanks, there is a filtering element at the fuel line connection to convert dirt and prevent it from reaching to the pump and carburetor. A drain plug is provided at the bottom for emptying the tank. The tank also contains the float unit of the fuel gauge. It may also have a vent pipe which allows air to escape when the tank is being filled. In the cars, that are equipped with vapor recovering system, the vent pipe is connected to condenser which contains the vaporized gasoline in the tank and prevents its escape into the air.

Fuel line: The copper or steel tubes and hoses are used for connecting fuel tank with pump with carburetor. The tube connecting the fuel tank and pump is fastened rigidly to the frame or body. The first and last portion generally consists of a flexible tube that joints the rigid line to the fuel tank or to the pump. This allows the fuel tank to oscillate with the body and the pump with the engine without breaking or loosening the line.

Fuel Filters: The fuel is filtered at different stages in a fuel supply system. Therefore, many fuel filters are used in the fuel circuit. The fuel filter serves the purpose of filtration in the fuel delivery system by preventing foreign particles from entering into the fuel pump and the carburetor. The modern filtration practice employs a combination of coarse and fine filters.

Course filters are incorporated within the fuel tank.
Medium coarse filter are outside the fuel tank and on the inlet side of the pump.
Fine filters of built in surface type at inlet of fuel pumps pumping chamber.
Fine filter in pipe line is between fuel pump and the carburetor.

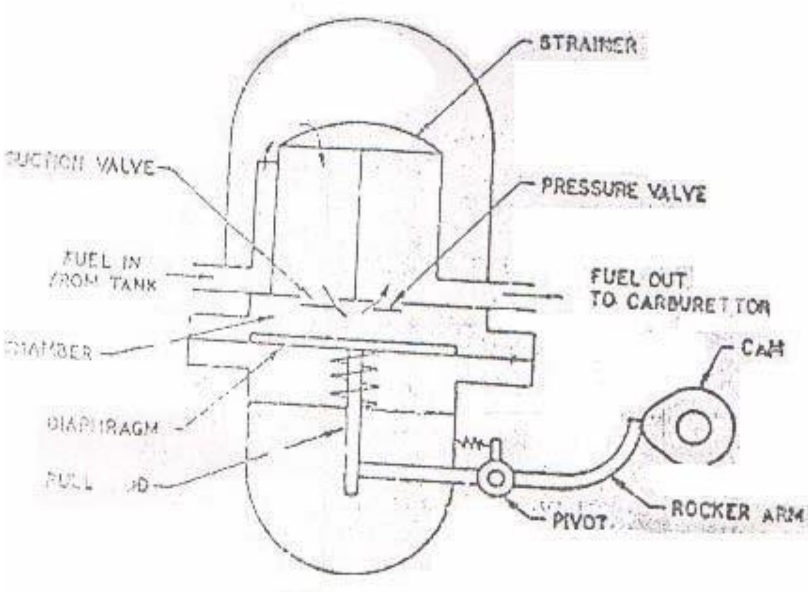
3.3 Fuel pumps: A fuel pump is used to deliver fuel from the fuel tank to the float chamber of carburetor. Main types of fuel pumps commonly used on auto vehicles.

1. A.C. Mechanical pump 2. S.U. Electrical pump
3. Electromagnet pump 4. Combined pump (fuel pump with a vacuum pump)

Mechanic al Pump: The mechanically operated diaphragm type fuel pump is operated by an eccentric mounted on the camshaft of the engine. The pump consists of a spring loaded flexible diaphragm actuated by a rocker arm. The rocker arm is actuated by the eccentric. Spring loaded valves are there in the inlet and outlet of the pump. These valves ensure flow of fuel in the properdirection.

As the rocker arm is moved by the eccentric, the diaphragm is pulled down against the spring force. This movement causes a partial vacuum in the pump chamber. Now the delivery valve remains closed and the suction valve opens. This admits fuel into the pump chamber. At the maximum position of the eccentric, the diaphragm is flexed to the maximum extent after this further rotation of the eccentric will release the rocker arm. Now the rocker arm will simply follow eccentric by the action of the return spring. The diaphragm spring will now push the diaphragm upwards and the force the fuel to flow out, opening the delivery valve, into the delivery tube. Now the suction valve remainsclosed.

In this pump, the downward movement is caused by the rocker arm, while the delivery stroke is achieved by the force of the diaphragm spring. The diaphragm spring is so designed that the fuel pressure is suitable balanced by the buoyancy of the float system of the carburetor. As such, when deliver fuel to the carburetor. In this case, the rocker arm simply continues to rock while the diaphragm remains at or near its lowest travel. However, as the carburetor uses fuel, the needle valve opens to admit fuel into the float bowl. Now the diaphragm moves downward by the rocker action and sucks the fuel to deliver back the same when required. This self regulating feature helps the pump to deliver the correct quantity of fuel at all operating conditions.

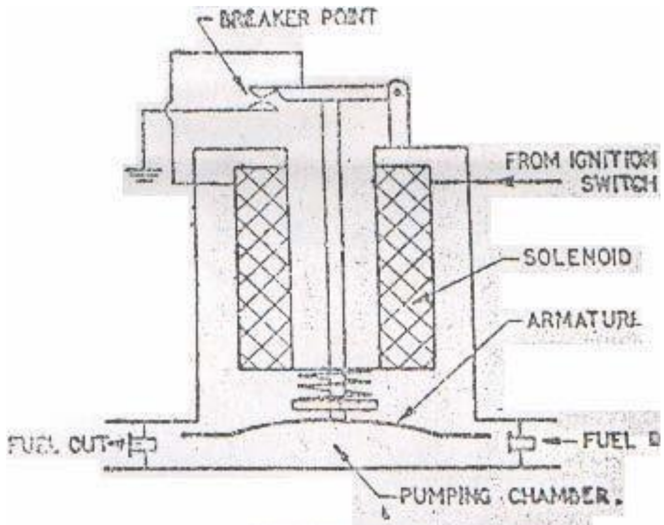


A.C. mechanical fuel pump.

Electrical Fuel Pump: The electrical fuel pump is mounted in the engine compartment. A pump with electrically operated diaphragm is the SU Horizontal pump. The pump contains a flexible diaphragm that is operated by an electromagnet instead of the mechanical system. The diaphragm consists of a number of layers of impregnated fine gut fabric. The middle of the diaphragm is clamped to an armature. A rod attached to the middle of the diaphragm passes through the center hole in the electromagnet. All the other end of the rod electrical contact points are there. There is a return spring which keeps the diaphragm in position.

When the electromagnet is connected to the battery, it produces the armature compressing the return spring and there by flexes the diaphragm. This produces vacuum in the fuel chamber. Fuel from the fuel tank enters the fuel chamber through the inlet valve. Then, as the rod attached to the diaphragm reaches its limit of travel it opens the set of electrical contact points. This disconnects the electromagnet from the battery. The compressed return spring therefore pushes the armature and the diaphragm. This forces the fuel from the fuel chamber through the outlet valve to the carburetor. As the diaphragm flexes back to its original position and the rod attached to its reaches the limit of its travel, it closes the electrical contacts. Now the electromagnet is again energized and tries to pull the armature and diaphragm. This series of actions is repeated as long as the ignition switch is turned on.

If the float chamber is so full as to close the needle valve, the pump diaphragm will remain at rest in the flexed position with the electrical circuit broken, until further delivery is required. The float mechanism of the carburetor must be method with the return spring of the pump so that flooding of the carburetor cannot occur.



S.U. electrical fuel pump.

3.4 Requirements of an automobile Carburetor:

The carburetor is a device for atomizing and vaporizing the fuel and mixing it with the air in varying proportions to suit the changing conditionsof spark ignition engines. The air fuel mixture so obtained from the carburetor is called the combustible mixture. The process of mixing the gasoline fuel with air to obtain the combustible mixture is called carburetion.

Vaporization is the change of state of the fuel from liquid to vapour. Atomization is the mechanical breaking up of the liquid fuel into small particles, so that every particle of the fuel is surrounded by air. In order to produce very quick vaporization of the liquid fuel, it is sprayed into the air passing through the carburetor. Spraying of the liquid turns it into many fine particles, so that the vaporization occurs almost instantly.

The carburetor supplies the air-fuel mixture of varying proportions to suit the changing conditions of the engine. The mixture must be rich for starting, accelerating and high speed operation. The mixture should be lean for operation at intermediate speed with a warm engine. The theoretically perfect mixture of air and gasoline contains 15 parts of air and 1 part of gasoline byweight.

3.5 Air Fuel ratio:

The Carburetor must supply the air-fuel mixture of varying proportions to suit the different operating requirements. The mixture must be rich for starting and must be relatively lean for idling and intermediate speeds. The air-fuel ratio for different speeds of a car can be as follows.

For starting of the car, the air-fuel ratio is 9:1. It is called rich mixture.

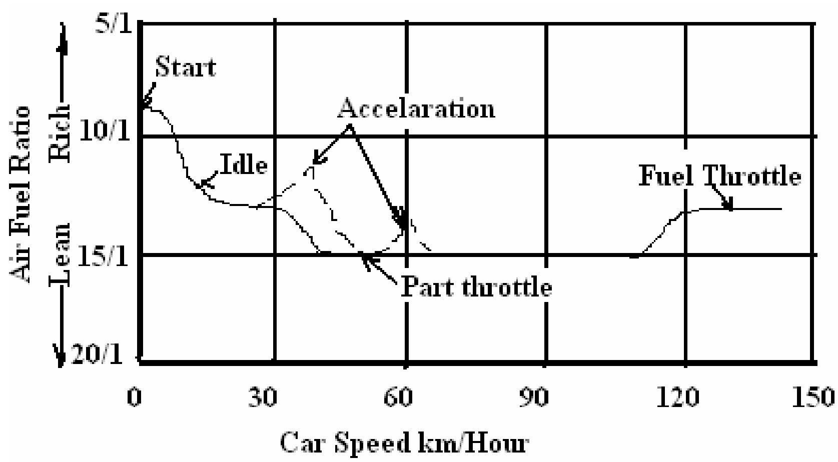
For idling condition, the air-fuel ratio lies about 12:1. It is called lean mixture.

For intermediate speeds between 35 to 105 km/hour, the air-fuel ratio varies further leans out to 15:1.

But at higher speeds from 120 to 150 km/hour, with a wide open throttle, the mixture is again enriched to about 13:1.

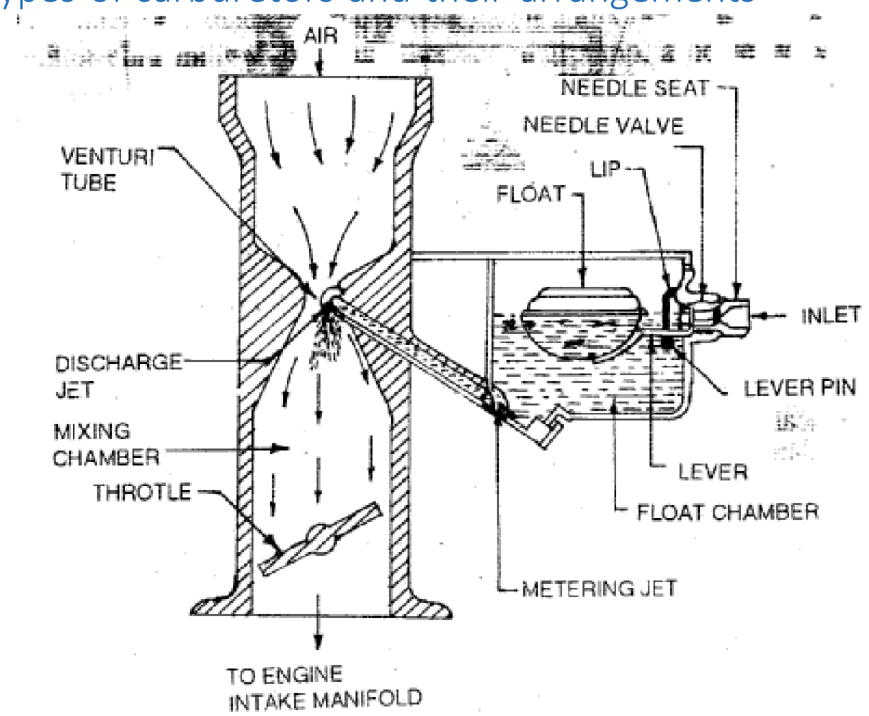
For acceleration at any speed the throttle is suddenly opened which causes a momentary enrichment of the mixture.

Two examples of acceleration are shown by dotted lines, on at 25 km/hour and the other at 45 km/hour.



Air fuel ratio for different speeds of a car

3.6 Types of carburetors and their arrangements



Carburetors used in S.I. Engines may be up draught, down draught and side draught. This classification is based on the direction of air flow into the carburetor and air fuel mixture flow at the carburetor outlet to the inlet manifold.

In down draught carburetor, the air enters top of the carburetor and leaves at the bottom. In side draught carburetor, the air enters the top of the carburetor and leaves at the side. In up draught carburetor the air entersthe bottom or side of the carburetor and leaves at the top. In semi down draught carburetor the direction of air flow is from top to bottom.

Side drought carburetors are used on Hero Honda, Kawasaki Bajaj and Sunny.

Most passenger cars are used down draught carburetors.

Air/Fuel ratio and requirements

Higher compression ratio and larger piston bore in an engine produce higher power and torque. The higher compression in a combustion chamber makes the air and fuel particles compressed in larger density and in high pressure. Larger piston geometry (bore) will let more air passin

through the combustion chamber. Both of these variables will create powerful explosion and burns fuel more efficiently. The modification will generate fuel economy and will deliver peak performance. However, these modifications have its drawbacks too. High octane gas is needed to keep the engine running in good condition which is more expensive than regular unleaded gas. Using low octane will develop engine knock. Engine knocking happens when the air-fuel combustion doesn"t happen at the exact time of spark ignition in the piston"s stroke. Furthermore, larger explosion actually create more power and will make the engine runs hotter than normal. Larger piston bore also require more fuel to burn to compensate the larger air flow through combustion chamber.

Gasoline engines burn fuel to create motions. The reaction of mixture of fuel with oxygen in the air is cause from burning of fuel. This is called air-fuel ratio (AFR). AFR is the mass ratio of air to fuel present in an internal combustion engine. For gasoline engines, the stoichiometric, A/F ratio is 14.7:1, which means 14.7 parts of air to one part of fuel. It depends on type of fuel. Different fuel gives different AFR. The AFR is necessary for controlling emission and performance-tuning reasons. The mixture combust and produce the product of carbon dioxide, water and nitrogen. The AFR calculation is based on Lambda Oxygen (O_2) sensor in gasoline engine. The AFR are defined below:

$$AFR = \frac{m_{air}}{m_{fuel}}$$

The AFR is related to mixture of air and fuel. The AFR is important measure for anti-pollution and performance tuning reasons. Furthermore, it is important to know the AFR at which exactly all the available oxygen is used to burn the fuel completely or at least to the best possible value. This ratio is called stoichiometric AFR. However, standard stoichiometric AFR is not giving best performance when modification of modified piston geometry and compression ratio is done. The stoichiometric mixture in gasoline engine and its products are defined below:

$$C_xH_y + zO_2 + 3.71zN_2 \rightarrow xCO_2 + \frac{y}{2}H_2O + 3.71zN_2$$

where the mixture of fuel, oxygen and nitrogen produce the products of water, carbon dioxide and nitrogen.

For Example:

18.0:1 = Lean

14.7:1 = Stoichiometric

13.0:1 = Rich

A chemically correct mixture is also known as stoichiometric fuel mixture. A stoichiometric mixture is the mixture with the composition in such a way that there is just enough air present in the mixture for complete combustion of the fuel. It is approximated as 15:1 air-fuel ratio.

A lean mixture is the mixture with air content more than the stoichiometric air-fuel ratio (eg: 18:1). It is used when engine is working at cruising range or when less power requirement is there.

A rich mixture is the mixture with air content less than the Chemically correct mixture (eg: 13:1). It is required when the engine is working at idling condition or when high power is required.

Lambda O_2 sensor is an electronic device that measures the proportion of oxygen (O_2) in the gas being analyzed. It controls the AFR in internal combustion engine which is lean, rich or stoichiometric. The zirconium dioxide, or zirconia, lambda sensor is based on a solid-state electrochemical fuel cell called the Nernst cell. The two electrodes provide an output voltage corresponding to the quantity of oxygen in the exhaust in the atmosphere. The ECU is a control system that adjusts the AFR based on the feedback from the sensor. The AFR calibration is crucial for performance and durability of the engine based on the sensor. A lower AFR number contains less air than the 14.7:1 stoichiometric AFR is a richer mixture. Higher AFR number contains more air and therefore it is a leaner mixture. Leaner mixture gives more power and efficiency but increase in engine temperature. Richer mixture provides cooler temperature in engine but less power and produce unburn fuel. Rich and lean mixtures depend on the type of engine.

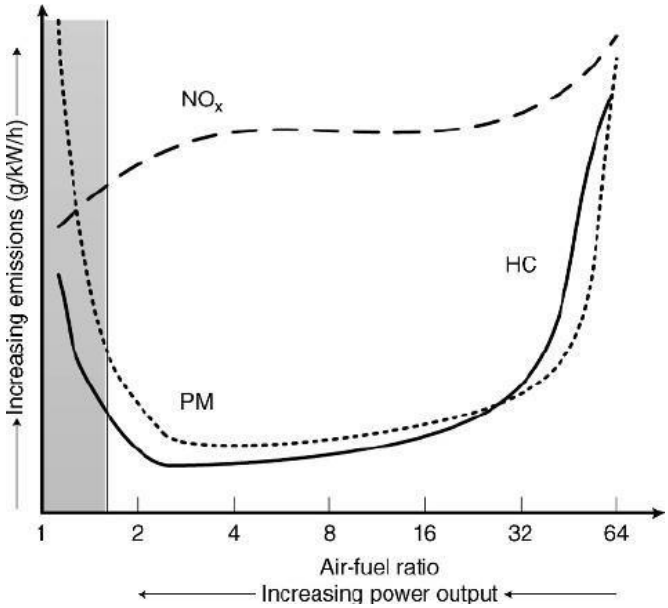
Based on the reason above it is necessary to do research deals with investigation, rebuilding and analyzing on AFR of a gasoline engine together on the modification of piston geometry and compression ratio. Therefore, it is expected to determine the best AFR for modified gasoline engine to give peak performance.

Effect of Air/Fuel ratio on Performance and Emissions

Lean mixtures improve the fuel economy but also cause sharp rises in the amount of nitrogen oxides (NO_X). If the mixture becomes too lean, the engine may fail to ignite, causing misfire and a large increase in unburned hydrocarbon (HC) emissions. Lean mixtures burn hotter and may cause rough idle, hard starting and stalling, and can even damage the catalytic converter, or burn valves in the engine. The risk of spark knock/engine knocking (detonation) is also increased when the engine is under load.

Mixtures that are richer than stoichiometric allow for greater peak engine power when using vaporized liquid fuel due to the mixture not being able to reach a perfectly homogenized state so extra fuel is added to ensure all oxygen is burned producing maximum power. The ideal mixture in this type of operation depends on the individual engine. For example, engines with forced induction such as turbochargers and superchargers typically require a richer mixture under wide open throttle than naturally aspirated engines. Forced induction engines can be catastrophically damaged by burning too lean for too long. The leaner the air–fuel mixture, the higher the combustion temperature is inside the cylinder. Too high a temperature will destroy an engine – melting the pistons and valves. This can happen if one ports the head and/or manifolds or increase boost without compensating by installing larger or more injectors, and/or increasing the fuel pressure to a sufficient level. Conversely, engine performance can be lessened by increasing fueling without increasing air flow into the engine. Furthermore, if an engine is leaned to the point where its exhaust gas temperature starts to fall, its cylinder head temperature will also fall. This is only recommended in the cruising configuration, never when accelerating hard, but is becoming increasingly popular in aviation circles, where the appropriate engine monitoring gauges are fitted and the fuel air mixture can be manually adjusted.

Cold engines also typically require more fuel and a richer mixture when first started, because fuel does not vaporize as well when cold and therefore requires more fuel to properly "saturate" the air. Rich mixtures also burn slower and decrease the risk of spark knock/engine knocking (detonation) when the engine is under load. However, rich mixtures sharply increase carbon monoxide (CO) emissions.


NOx
HC
PM
Increasing emissions (g/kW/h)
1
2
4
8
16
32
64
Air-fuel ratio
Increasing power output

Principle of carburetion

Carburetion can be defined as the process in which a fuel-air mixture is prepared for the Internal Combustion Engines by mixing correct amount of fuel with air before entering the engine cylinder. The device which is used to accomplish this function is known as carburetor.

The carburetor is used for spark ignition (petrol) engines for the preparation of fuel-air mixture (charge) for combustion.

Factors Affecting Carburetion

Of the various factors, the process of carburetion is influenced by

i. The engine speed
ii. The vaporization characteristics of the fuel
iii. The temperature of the incoming air and
iv. The design of the carburetor

Simple fixed Venturi carburetor

The carburetor is a device for atomising and vapourising the fuel and mixing it with air in varying proportions to suit the charging operation conditions in the engine.

This process of breaking up and mixing the petrol with air is called carburetion.

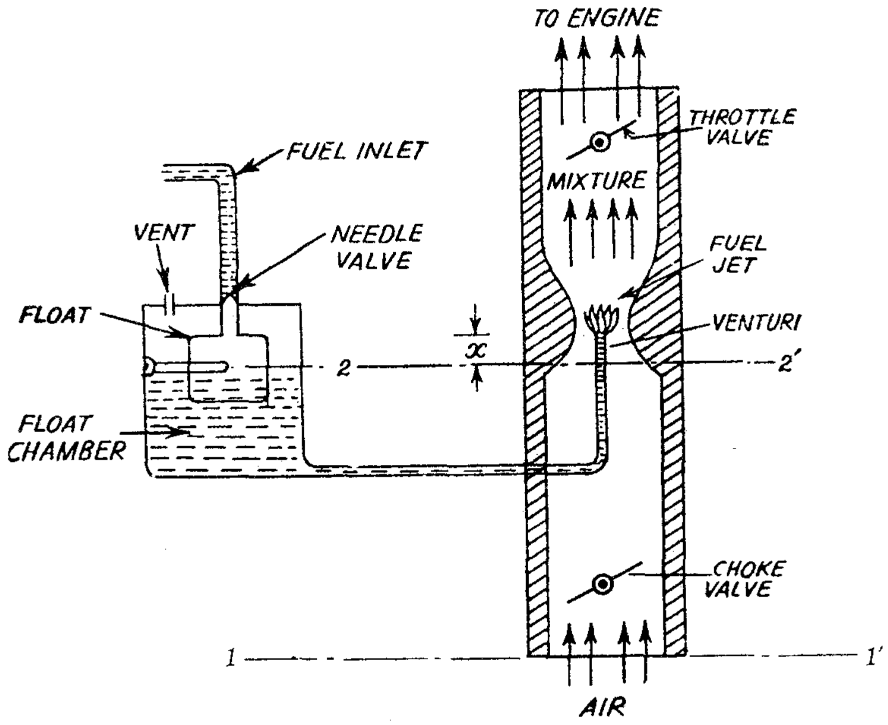
Vapourisation → Change of phase from liquid phase to vapour phase

Atomisation → Reduction of fuel into fine particles by mechanical breaking up process

The parts of a simple venturi carburetor are shown in fig.

The main function of the carburetor is to vapourise and mix the petrol and air by means of engine suction and to supply the required quantity of mixture in proper proportion. As the engine is started, suction is created inside the cylinder and the air flows from atmosphere into the cylinder. As the air passes through the venturi, the pressure of the air falls below the atmosphere. The pressure at the nozzle tip also is less than atmosphere. But the pressure in the fuel tank is atmosphere. This pressure difference causes the flow of the fuel through the fuel jet into the air.

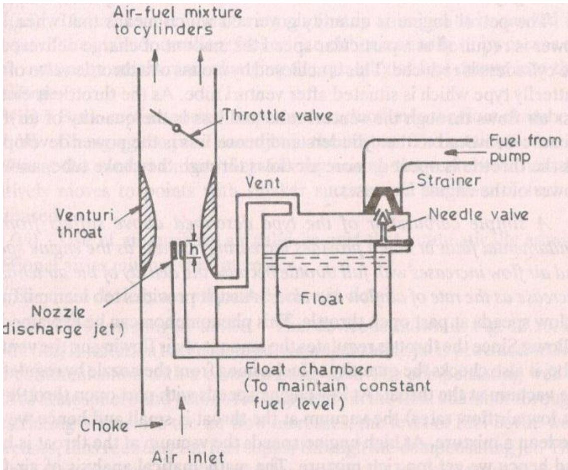
stream. As the fuel and air pass ahead, the fuel gets vapourised and uniform mixture is supplied to the engine.



The quantity of mixture supplied to the engine depends upon the opening of the throttle valve. In case of stationary engine the opening of throttle valve is controlled by the governor according to the load on the engine. In case of automobile engines on road, the opening of the throttle valve is controlled by the driver through the accelerator pedal.

Simple Carburettor:

-provide air-fuel mixture for all operating conditions
-Carburettor depression is pressure differential in the float chamber and venture throat which causes discharge of fuel into the air stream
-flow is controlled by small hole of fuel passage
-pressure at the throat at the fully open throttle condition lies between 4 and 5 cm of Hg and seldom exceeds 8 cm Hg
-petrol engine is quantity governed
-Drawback of simple carburettor is that it provides too rich and too lean mixture due to vacuum created at the throat is too high and too small which is undesirable


Air-fuel mixture
to cylinders
Throttle valve
Fuel from
pump
Strainer
Vent
Needle valve
Venturi
throat
h
Float
Nozzle
(discharge jet)
Float chamber
(To maintain constant
fuel level)
Choke
Air inlet

***Complete Carburettor:**

Additional systems used with simple carburettor can help the engine to operate at all conditions, which are given below,

(i) Main metering system:

-provide constant fuel-air ratio at wide range of speeds and loads.
-mainly based upon the best economy at full throttle (A/F ratio about 15.6:1)
The different metering systems are,

Compensating jet device:-Addition to the main jet, a compensating jet is provided to provide the leanness effect

Emulsion tube or air bleeding device:
-mixture correction is done by air bleeding alone
-in this arrangement main metering jet is fitted about 25 mm below the petrol level which is called as submerged jet

Back suction control or pressure reduction method:
-in this arrangement large vent line connects the carburettor entrance with the top of the float chamber and another small orifice line is connected with the top of the float chambers with venture throat
-it creates pressure differences according to engine operating conditions

Auxiliary valve carburettor:
-Valve spring of auxiliary valve lift the valve during increase of engine load which increases the vacuum at venture
-Allows more admittance more additional air and the mixture is not over rich

Auxiliary port carburettor:
-opening of butterfly allows more air inductance which decreases quantity of fuel drawn
-used in aircraft carburettors

(ii) Idling system:
-Idling jet is added for the idling and low load operation which requires rich mixture sof about A/F ratio 12:1
-consists of small fuel line from the float chamber to a point of throttle side
-gradual opening of throttle may stop the idling jet

(iii) Power enrichment or economiser system:
-this system provides the richer mixture for maximum power range of operation
-It has meter rod economiser of large orifice opening to the main jet as the throttle is opened beyond a certain point
-rod is tapered or stepped

(iv) Acceleration pump system:
-Engine acceleration condition or rapid increase in engine speed may open the throttle rapidly which will not able to provide rich mixture
-acceleration pump of spring loaded plunger is used for fuel supply

(v) Choke:

-Rich mixture is required during cold starting period, at low crancking speed and before the engine warmed up condition

-butterfly type valve or choke is used between the entrance to the carburettor and venture throat to meet the requirement

-spring loaded by-pass choke is used in higher speeds

*Carburettor types:

(i) Open choke:Zenith, solex and carter Constant vacuum type: S.U. carburettor

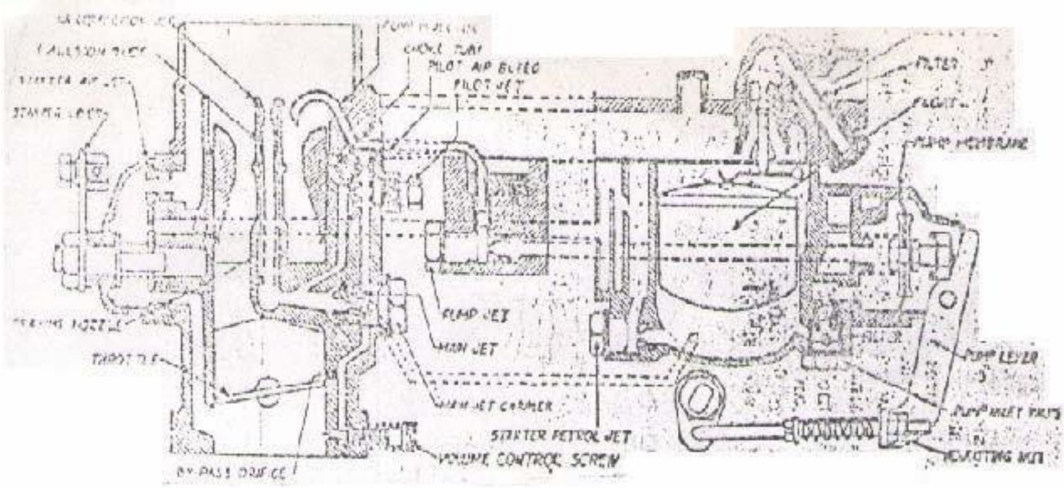
(ii) updraught type

Horizontal or downdraught: mixture is assisted by gravity in its passage to the engine induction

Solex Carburetor

The solex carburetor is a down draught type carburetor. It consists of a device for starting, idling, normal running and acceleration. It consists of starter valve in the form of flat disc having holes of different sizes. These holes connect the petrol jet and starter jet sides to the passage, which opens into the air horn just below the throttle valve. The starter lever is operated by the driver from the dash board, which adjusts the position of the starter valve, so that either bigger or smaller hole comes opposite the passage. At the time of starting, bigger holes connect the passage so that more fuel may go to the engine. The throttle valve being closed, the whole of engine suction is applied to the starting passage 1, so that the petrol from the float chamber passage through the starter petrol jet and rises into passage 2. Some of it comes out, and mixes with the air entering through the air jet. This air fuel mixture is rich enough for starting for engine.

After the engine has started, the starter lever is brought to the
second position, so that smaller holes connect the passage reducingthe amount of petrol. In this position the throttle valve is also partly opened, so that the petrol is also coming from the main jet. The reduced mixture supply from the starter system in this situation is, however, sufficient to keep the engine running. When the engine reaches the normal running temperature, the starter is brought to "OFF" position.



Solex Carburetor

Construction lay out of petrol injection system

The petrol injection fuel supply requires following main parts.

1. Petrol injection pump
2. Acceleration pump
3. Metering distributor
4. Injection nozzle.

It uses an injection pump to each cylinder, the pump being actuated through rockers by a camshaft rotating at half the engine speed. The accelerator pedal controls a butterfly throttle which regulates the air supply to the inlet manifold and at the same time varies the return stop of each pump plunger to control its stroke and thus the rate of fuel delivery. This is alone through an ingenious “3 dimensional cam” which adjusts the pivot points of the pump rockers. The same cam is also the influenced by a governor device in accordance with engine speed to maintain correct mixture over the entire petrol directly into the inlet manifold for starting purposes, operating only whilst the starter motor isenergized.

Petrol injection:

-to avoid above problem of modern carburettor, petrol injection is used like in diesel engine
-petrol injected during the suction stroke in the intake manifold at low pressure
-injection timing is not much critical as like in diesel engine
-continuous injection and timed injection methods are used

Continuous injection:

-fuel is sprayed at low pressure continuously into the air supply
-amount of fuel is governed by air throttle opening
-in supercharged engine, fuel injected in the form of multiple spray into the suction side of the centrifugal compressor
--provide efficient atomisation of fuel and uniform mixture strength to all cylinder
-higher volumetric efficiency
-one fuel injection pump and one injector

Timed injection system:

-similar to high speed diesel engine
-components are fuel feed or lift pump, fuel pump and distributor unit, fuel injection nozzles and mixture controls
-mixture controls are automatic for all engine operating conditions

(i) Multiple plunger jerk pump system:

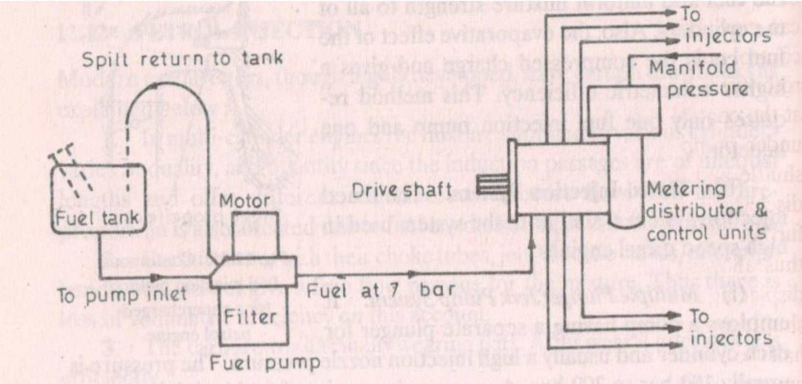
-pump with separate plunger and high injection nozzle pressure for each cylinder
-100 to 300 bar pressure
-measured quantity of fuel for definite time and over definite period is delivered

(ii) Low pressure single pump and distributor system:

-single plunger or gear pump supply fuel at low pressure to a rotating distributor
-pressure about 3.5 to 7 bar

(a) Lucas petrol injection system:

-firstly used in racing car
-single distributor system with novel metering device
-line pressure is maintained at 7 bar
-metering distributor and control unit distributes the required amount of fuel at correct time and interval
-has shuttle arrangements for metering unit
-in aircraft engine two injectors and spark plug provided for direct injection of fuel in combustion chamber

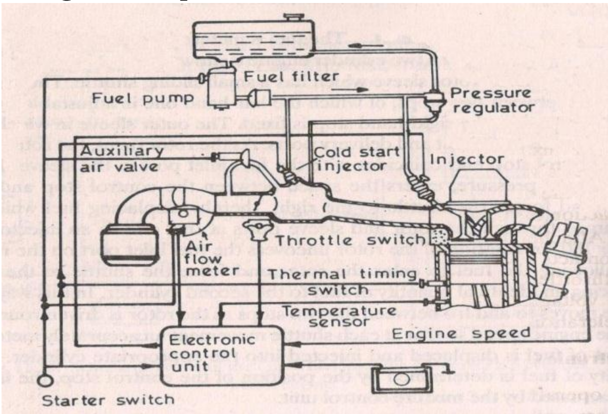


Lucas petrol injection system for 6-cylinder petrol engine

(b) *Electronic fuel injection*

Fuel delivery system:
-electrically driven fuel pump draws fuel from tanks to distribute
-fuel and manifold pressure kept constant by pressure regulator

Air induction system:
-air flow meter generate voltage signal according to air flow
-cold start magnetic injection valve give good fuel atomisation and also provide extra fuel during warm up condition



Electronic fuel injection system- L-Jetronic with air flow meter

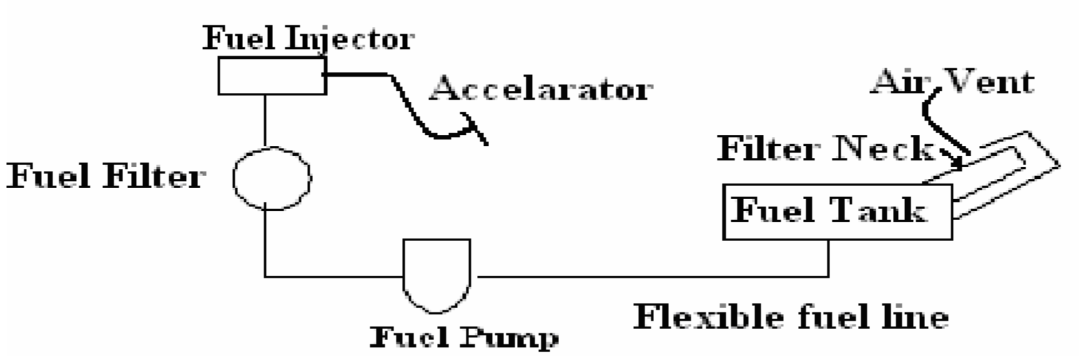
Electronic control unit (ECU):
-sensors for manifold pressure, engine speed and temperature at intake manifold
-sensor measures operating data from locations and transmitted electrically to ECU

Injection timing:
-injected twice for every revolution of crank shaft
-triggering of injectors

DIESEL ENGINE (FUEL FEED SYSTEM)

To run an engine, the fuel from the tank must reach by some means to the engine cylinder. In diesel engine, the fuel is injected into the engine cylinder by an injector. The fuel burns in the cylinder and during theexhaust stroke, the burned gases leave the cylinder passing through the exhaust pipe and silencer.

Line diagram of diesel engine fuel system.



Requirements of fuel feed system:

In the engine to develop full power and operate efficiently its fuel system must do the following:-

Meter (measure):- The fuel injection system must measure the fuel supplied to the engine very accurately. Since fuel requirements vary greatly from low to high engine speed. Fuel is measured within the injection pump or injectorby measuring it as it fills the pumping chamber or as it leaves the pumping element.

Time: - The timing of fuel injected into the cylinder is very important during engine starting, full load and high speed operation. Diesel engines start best when fuel is injected at or very close to Top Dead Center, since it is at this point that air in the chamber is the hottest. After the engine is started and running at high speed, the injection timing may have to be advanced to compensate for injection lag, ignition lag, and other factors that influence combustion within the engine cylinder.

Pressure: - The fuel system must pressurize the fuel to open the injection nozzle or the pressure required to open the nozzle. Some pressure is required to inject the fuel into the combustion chamber to offset the pressure of compression, which may be 350 to 450 psi (25 to 32 kg/cm^2).

Atomize: - The fuel must be atomized when it is injected into the combustion chamber. Since in atomized fuel will not burn easily. The degree of atomization required will vary from engine to engine depending on the combustion chamber design.

Distributor: - Closely related to timing the distribution of fuel must be accurate and according to the engines firing order distribution pumps deliver fuel to each pump outlet in succession and the lines are hooked to the cylinder in the correct firing order, much like a distributor used on a gas engine.

Control, start and stop injection: - Injection of fuel must start quickly and end quickly. Any delay in beginning will alter the pump to engine timing, causing hard starting and poor running engines.

5.3 Methods of fuel injection:There are two methods of fuel injection in compression ignition engines.

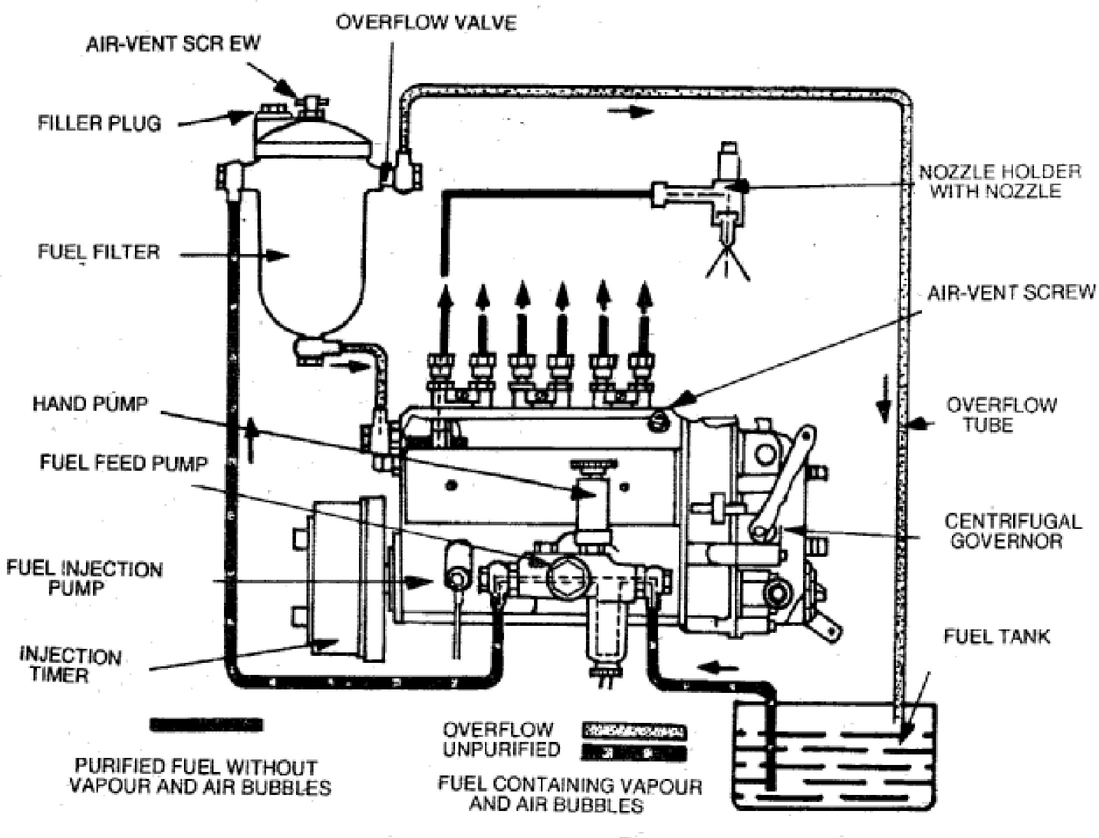
1. Air blast injection 2. Airless or solid injection.

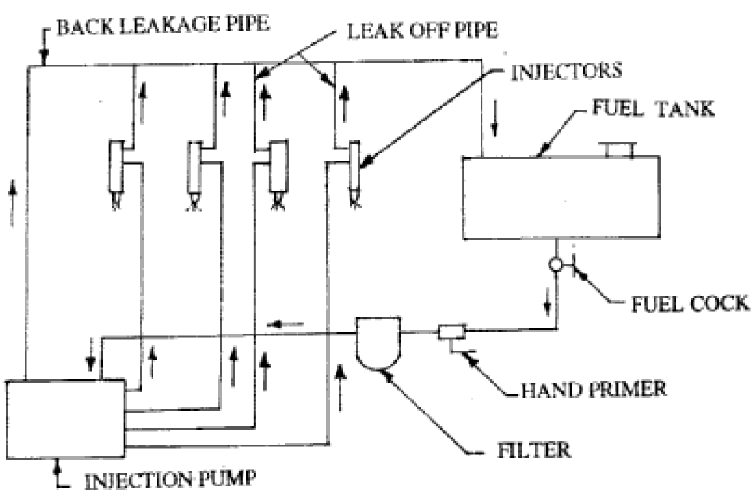
Air blast injection: This method was originally used in large stationary and marine engines. But it is now obsolete. In this method the air is first compressed to a very high pressure. A blast of this air is then injected carrying the fuel along with it into the cylinder. The rate of fuel injection is controlled by varying the pressure of the air. The high pressure air requires multistage compressor so as to keep the air bottles charged. The fuel ignition by the high temperature of the air caused by the high compression.

Airlessorsolidinjection:-In thismethodthefuelunderhighpressureisdirectly injected into the combustion chamber. It burns due to the heat of compression of the air. This method requires a fuel pump to deliver the fuel at the high pressure. This method is used for all types of small and big diesel engines. It can be divided into twosystems.

a. Individualpumpsystem. b. Common railsystem.

- **a.** Individual pump system**:** In this system, each cylinder has it individual high pressure pump and a metering unit. It is quite compact method and involves highercost.
- **b.** Common rail System: in this system, the fuel is pumped by a multi cylinder pump into a common rail, the pressureinthis rail is controlled by relief valve. A metered quantity of fuel is supplied to each cylinder from the common rail. The airless injection in comparison to air blast injection, is simple in construction, light in weight and cheap. The fuel is atomized properly. It is quitesuitablefor engineofhigher output. Butit receives higher accuracy in manufacturing the pump barrel and fuel injection plunger.

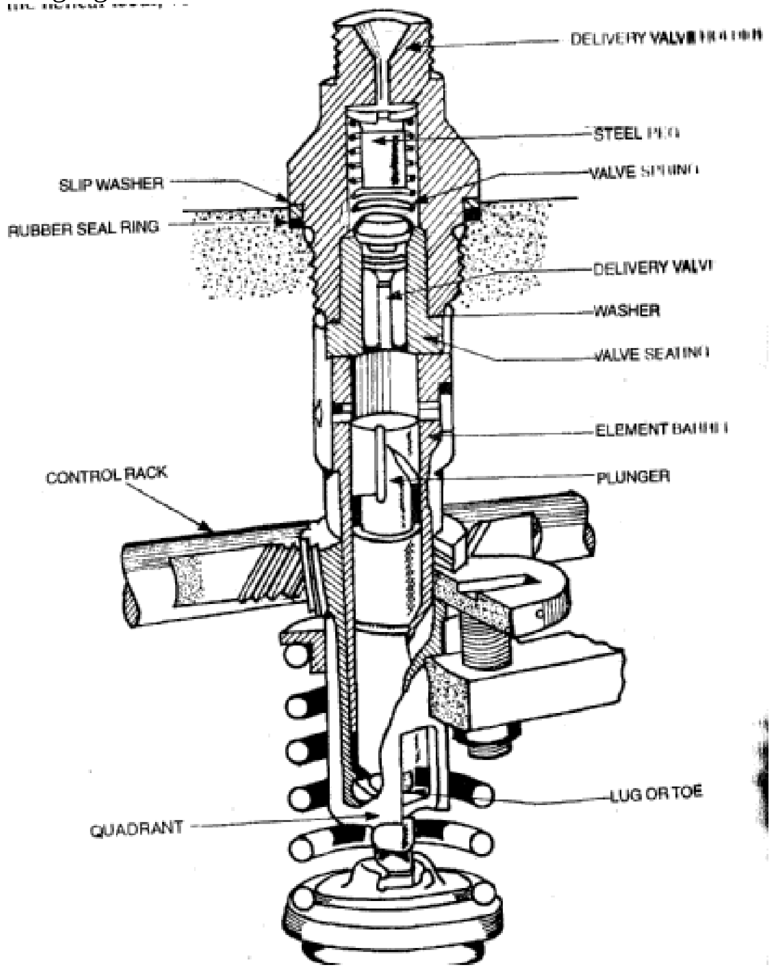




Diesel fuel feed system: The fuel system of a diesel engine consists of the following:-

1. Air cleaner
2. Fuel tank
3. fuel filter
4. injection pump
5. injector
6. fuel lines

7. fuel gauge



Fuel Injection Pump

5.4 Fuel injection pump construction andworking:-

The single plunger diesel fuel injection pump is distinguished from the conventional in line pumps of the PE and PF series by having only one plunger and barrel assembly, common to all fuel outlets of the pump where as each fuel outlet of an inline pump is served by its individual plunger and barrel assembly. The single plunger injection pump described here in features a unique hydraulic governing system which has no rotating mechanical parts and which provides extremely accurate fuel quality control and fast response to variations in fuel demand resulting in very closeregulation

A single plunger by reciprocating action pressurizes the fuel and feeds it into two distinctly separated circuits, primarily at high pressure to the nozzle and holds assemblies and secondly into an auxiliary circuit for the function of governing the fuel quantity delivered to the engine.

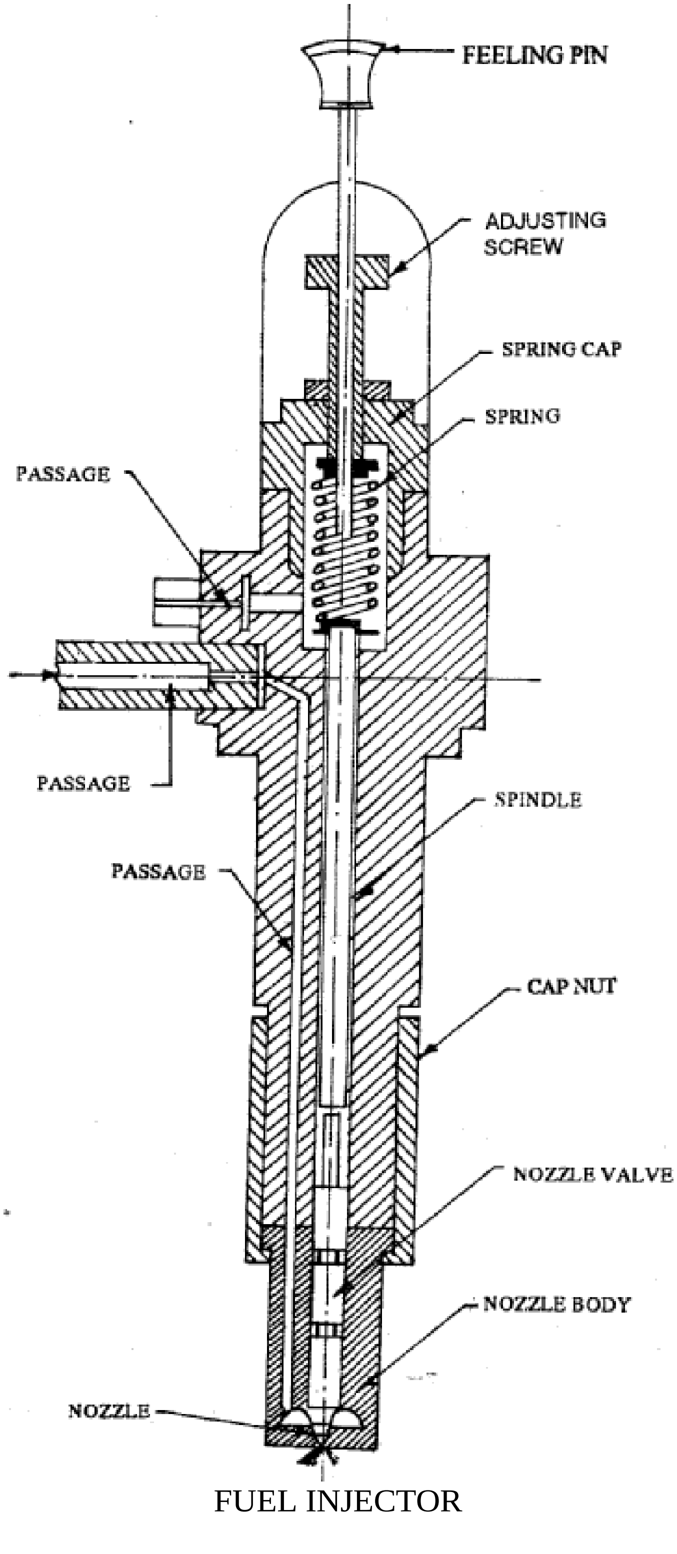
By simultaneous rotation of the plunger, the pressurized fuel quantity delivered to the engine from the primary circuit is distributed to the individual high pressure outlets. All accessory units such as governor, fuel supply pump and the automatic timing device, normally attached to the outside of an inline pump are wholly integrated into the single plunger pump to reduce bulk and weight.

The single plunger injection pump can be mounted in any position. In operation, its interior is completely filled with diesel fuel under slight pressure in order to prevent intrusion of air and dust and also to prevent rust formation caused by condensation. Excess fuel is re circulated within the pump to provide adequate cooling andlubrication.

Fuel Injector (Atomizer):-

The purpose of the fuel injector is to inject a small volume of fuel in a fire spray and to assist in bringing each droplet into contact with sufficient oxygen to give quick and complete combustion.

C.A.V. fuel injector consists of a needle valve which is pressed on its seating in the nozzle by a plunger or spindle. A compression spring controls the pressure upon the plunger by which the needle valve opens. A nozzle is attached to the body of the injector by a cap nut. The fuel enters the nozzle through drillings in the injector body. The fuel may pass from a gallery down the sides of the lower parts of the needle valve. The body or the nozzle holder provides access for the fuel and an outlet for the fuel that leaves into the area occupied by the spring.

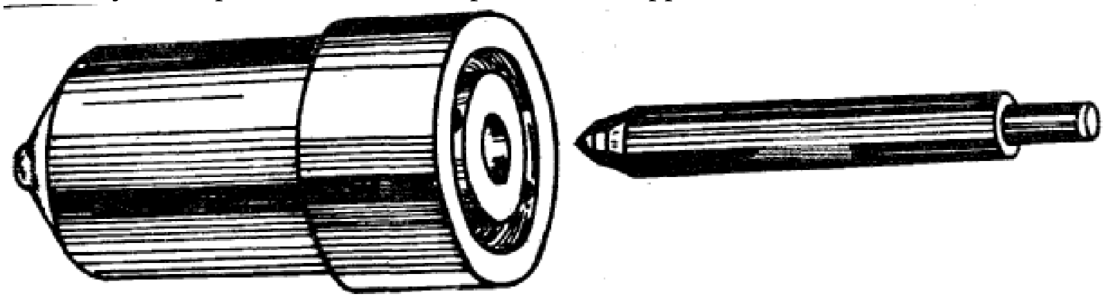


FUEL INJECTOR

Fuel injection nozzle:-

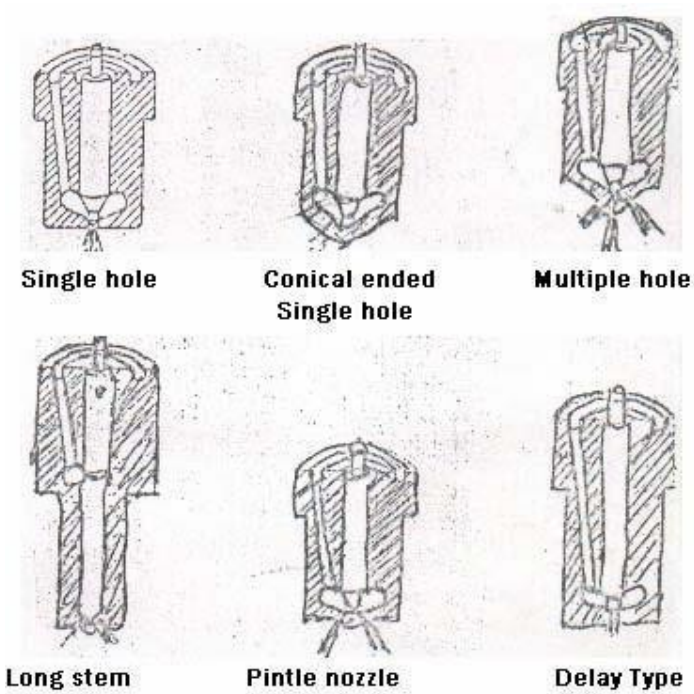
The performance of a modern high speed oil engine depends largely upon the proper functioning of its fuel injection system. The engine be not only provide with fuel in quantities exactly timed and proportional to the amount of work it is received to do.

The fraction of the nozzle, which is held in position in the cylinder head by the nozzle holder. The nozzle may have to deal with many hundreds of fuel charges per minute, with widely varying conditions of pressure and temperature, the uneven precision necessary in the production of these parts will be appreciated.



Types of nozzles:-

a. Single holenozzle
b. Multi holenozzle
c. Long stemnozzle
d. Pintle nozzle
e. Delay nozzle
f. Pintaux nozzle



Types of Injection Nozzles

a. Single hole nozzle: - The single hole nozzle has one hole drilled centrally through its body which is closed by the nozzle valve. The hole can be of any diameter from 0.2 mm upwards. The single hole is bored at an angle to the vertical center line of the valve as required.
b. Multi hole nozzle: - This nozzle can have a varying number of holes drilled in the bulbous end under the valve seating. Their actual

number, size and disposition being dependent upon the requirements of the engine concerned.

c. Long stem nozzle: - For direct injection engines where, owing to a limited space between the valves in the cylinder head it is notpossible to provide adequate cooling for the standard short stem nozzle, an alternative form of nozzle with a small diameter extension has been developed.

d. Pintle nozzle: - The pintle nozzle is designed for use in the engine combustion chambers of the air cell, swirl chamber or pre-combustion type, the valve stem is extended to form a pin or pintle which produces through the mouth of the nozzle body.

e. Delay nozzle: - The Delay nozzle is a development of pintle type, having an auxiliary spray hole to assist easy starting under cold conditions. At engine starting speeds the nozzle valve is not lifted sufficiently to clear the pin hole and the fuel is discharged through auxiliary hole. At normal running speeds, however when pressures in the fuel system is higher, the nozzle valve is withdrawn from the pintle hole allowing the bulk of the fuel to be discharged through it.

Engine performance is an indication of the degree of success with which it does its assigned work, i.e., conversion of heat energy into useful mechanical work.

The basic performance parameters are

(i) Power and Mechanical efficiency

(ii) Brake thermal efficiency

(iii) Indicated thermal efficiency

(iv) Volumetric efficiency

(v) Specific fuel consumption

(vi) Mean effective pressure and Torque

Indicated Power (IP)

The ideal power developed by the combustion of fuel in the cylinder is called IP.

$$IP = \frac{Z\ p_{mi}\ L\ A\ n}{60} \quad - - W$$

Where, Z → Number of cylinders

N → Compressor speed in rpm

n → Number of working cycles = N for two stroke engines

= N/2 for four stroke

engines p_{mi} → Indicated mean effective pressure in Pa

A → Area of the cylinder = $(\pi / 4)\ D^2$

D → Bore or diameter of the cylinder

in m L → Stroke in m

Brake Power (BP)

Power available at the crank shaft is called BP.

$$BP = \frac{zplAn}{60} = \frac{2\pi NT}{60}$$

Friction Power (FP)

Power required to overcome the friction between moving parts.

$$FP = IP - BP$$

Mechanical Efficiency (η_m)

The ratio of BP and IP is called mechanical efficiency.

$$\eta_m = BP / IP$$

Mean Effective Pressure (p_m)

It is hypothetical pressure which is assumed to be acting on the piston throughout the power stroke.

$$MEP = \text{Work done} / \text{Stroke Volume}$$

Based on BP, p_{mb} = BP/Stroke volume → BMEP

Based on IP, p_{mi} = IP/Stroke volume → IMEP

Volumetric Efficiency (η_v)

It is the actual volume of charge drawn in during the suction stroke to the swept volume of the piston.

Specific Fuel Consumption (SFC)

It is defined as the quantity of fuel required per hour to produce unit power

output. Based on BP, $SFC = m_f / BP$

Based on IP, $SFC = m_f / IP$

Brake Thermal Efficiency (η_{bt})

$$\eta_{bt} = BP / (m_f \times CV)$$

IP → Indicated power in W

m_f → Mass flow rate of fuel in kg/h

CV → Calorific value of fuel in J/kg

Indicated Thermal Efficiency (η_{it})

$$\eta_{it} = IP / (m_f \times CV)$$

Relative Efficiency (η_r)

$$\eta_r = \text{Thermal efficiency} / \text{Air standard efficiency}$$

Based on η_{bt}, η_r = Brake thermal efficiency / Air standard efficiency

Based on η_{it}, η_r = Indicated thermal efficiency / Air standard Effi

EXERCISE

Part A

1. What are different air – fuel mixture on which an engine can be operated?
2. State the functional requirements of an injection system.
3. List out the factors that affect the process of carburetion.
4. State the advantages of EFI system.
5. What is the difference between air injection and solid injection?
6. What is carburetion?
7. Brief about air fuel ratio requirements of SI engine.
8. What is the need of governor inn diesel engine?
9. What is a lean mixture? State its properties.
10. Draw any one type of Nozzle and mention its parts.

Part B

1. Describe with suitable sketches the following system of a modern carburetor.
   (i) Main metering system, (ii) Idling system, (iii) Economizer system and (iv) Acceleration pump system

2. (i) With a neat sketch explain the jerk pump type injection system.

(ii) Draw a sketch of Pintaux nozzle and discuss its merits and demerits.

3. A simple jet carburetor is required to supply 5 Kg of air and 0.5 Kg of fuel per minute. The fuel specific gravity is 0.75. The air is initially at 1 bar and 300 K. Calculate the throat diameter of the choke for a flow velocity of 100 m/s. Velocity coefficient is 0.8. If the pressure drop across the fuel metering orifice is 0.80 of that of the choke, calculate orifice diameter assuming Cdf = 0.60 and = .4 .219
4. Explain the following with a neat sketch
   (i) Jerk Pumps, (ii) Pintle Nozzle and (iii) Multi-hole Nozzle

5. With a neat sketch, explain the working of simple fixed venturi carburettor.
6. Discuss the types of injector nozzles.
7. Describe with a neat sketch the simple diesel engine governor.
8. How is an injection pump calibrated?
9. Describe the distributor pump, pintle and multihole nozzles with reference to construction and working,
10. Explain the construction and working of common rail diesel injection system with neat sketches.
11. Explain the working operation of Jerk type of Fuel Injection Pump..

Explain CRDI system with a neat sketch

MODULEIII

Lubrication and cooling systems:-

(Function of lubrication systems, types of lubrication systems- mist, wet and dry sump lubrication systems, properties and designation of lubricants.

Methods of cooling systems- air and water cooling systems, properties of coolants, cooling agents.)

LUBRICATING SYSTEM

Lubrication is very important for reciprocating parts of an engine. Lubrication helps to provide cushioning to the reciprocating parts as well as it cleans the parts from dust. Lubrication helps to prevent the parts from corrosion and wear and tear.

Types of lubricants

The various lubricants used in automobiles are discussed below

a. Motor Oil: Diesel engine oil and Spark Ignition engine oil differ primarily in detergency properties. Naphthalene bake oils of low viscosity index may be used as diesel oils.
b. Lubricants: These are used to prevent friction between the parts of any machine lubricants may be liquid like gear oil, semi solid like grease.
c. Cylinder Oil: It is unfinished oil stock used directly as lubricant for steam engine cylinders or manufacture of bright stock. It is usually filtered but not dew axed.
d. Neutral oil: It is light or low viscosity lubricating oil stock used for compounding of motor oils and light machine oils
e. Bright stock: It is heavy or high viscosity lubricating oil stock for compounding of motoroils.

Lubricating is essentially required in motor vehiclemaintenance. To supply lubricating oil between the moving parts is simply termed as lubrication. Lubrication of all moving parts is essential to reduce friction wear and to prevent seizure.

Objects of lubrication

1. To reduce friction between the moving parts.
2. To reduce wear of the moving parts.
3. To act as cooling medium for removing heat.
4. To keep the engine parts clean, especially piston rings and ring grooves, Oil ways and filters.
5. To absorb shock between bearings and other engine parts thus reducing engine noises and extending engine life.
6. To form a good seal between piston rings and cylinder walls.

Properties of lubricants

An engine lubricating oil must have certain properties or characteristics for it satisfactory function as follows.

1. Viscosity 2. Flashpoint 3. Fire point 4.Cloud point 5. Pour point

6.Oiliness 7. Corrosion8. Color 9.Dilution
10.Emulsification
11.Physical stability 12.Chemicalstability 13.Sulphur content
14.Specific gravity15.Neutralisation
16.Adhesiveness 17.Filmstrength 18.Cleanliness

Viscosity: It is a measure of the resistance to flow or the internal friction of an oil. Viscosity is one of the most important properties of engine lubricating oil. It is used universally to grade lubricants and it is measured by viscosometer.

Flash Point: The flash point is defined as lowest temperature at which the lubricating oil will flash when a small flame is passed across its surface.

Fire Point: If the oil is heated further after the flash point has been reached, the lowest temperature at which the oil will burn continuously is called the fire point.

Cloud Point: the oil changes from liquid state to a plastic or solid state when subjected to low temperatures. In some cases the oil starts solidifying which makes it to appear cloudy. The temperature at which this takes place is called the cloud point.

Pour Point: It is the lowest temperature at which the lubricating oil will pour. The pour point of an oil is lubrication of its ability to move atlow temperatures. This property must be considered because of its effort on starting an engine in cold weather and on free circulation of oil through exterior feed pipes when pressure is not applied.

Oiliness: It is the characteristic property of the oil when it has oiliness. This property is highly desirable in helping the lubricant to adhere to the cylinder walls.

Corrosion: The corrosion has been defined as the destruction of asolid body by chemical or electrochemical action which starts intentionally from its outer surface. A lubricant should not corrode the working parts and it must retain its properties even in the presence of foreign matter and additives.

Color: Color of a lubricating oil is not of so much importance for its property expects as a test for checking the uniformity of any given grade or brand of oil.

Dilution: During the combustion petrol vapor may escape past the piston rings if the rings are worn or broken out considerable amount such fuel is mixed with the crank case oil and dilutes it. Thus affecting its lubricating property. The rest to determine the amount of dilution in crankcase oil indicated how far the oil could be used when mixed with petrol vapor.

Emulsification: The lubricating oil, when mixed with water is emulsified and loses its lubricatingproperty. The emulsification numberis an index of the tendency of an oil to emulsify with water.

Physical stability: Thelubricatingoilmustbestablephysical at thelower and the highest temperatures between which the oil is to be used. At the lowest temperature there should not be any separation of solids and at the highest temperature it should not vaporize beyond a certain limit.

Chemical stability: The lubricating oil should also be stable chemical when there should not be any tendency for oxide formation. The oxidation produced being sticky clog the working parts, cause the faulty piston rings and valve action. The oil should also not decompose at high temperatures to form carbon which makes spark plug and valves faulty tofunction.

Sulphur content: If sulphur is present in considerable amount in the lubricating oil it promotes corrosion. The corrosion test shows the amount of sulphur content.

Specific Gravity: The specific gravity is a measure of the density ofthe oil. It is determined by a hydrometer that floats in the oil. And the gravity is read on the scale of the hydrometer at surface of the oil. The scale used is the recommended by the American petrol institute and the result is called the API gravity.

Neutralization number: The oil may contain impurities that are not removed while refining. It may contain alkaline or acid products. The neutralization number test is a simple procedure to determine acidity or alkaline of theoil.

Adhesiveness: It is the property of the lubricating oil due to which the oil particles stick to the metal surfaces.

Film Strength: It is the property of a lubricating oil due to which theoil retains thin film between the two surfaces even at high speed and load. The film does not break and the two surfaces do not come in direct contact.

Cleanliness: The lubricating oil must be clean. It should not contain dust and dirt particles. These impurities may either be filtered out or removed with the change of the oil a periodic intervals.

S A E number: The society of automotive engineers (S A E) rates oil viscosity in two different ways, for winter and for other than winter. Winter grade oils are tested at 0^0 and 210^0F. There are 3 grades, SAE SW, SAE 10W and SAE 20W. The W indicates the oil is winter grade. For otherthan winterthe grades are SAE 20, SAE 30, SAE 40 and SAE 50, all with out the W suffix. Some oil had multiple ratings which mean they are equivalent in viscosity, to several rating oils.

Forexample– SAE 30Woiliscomparableto SAE 10W, SAE 20Wand SAE 30W oil.

6.2 Requirements of lubricants forautomobiles

1. To minimize the friction and wear.
2. To cool by carrying away heat.
3. To seal the pistons and thus preventing escape of gases in the cylinders with consequent loss of power.
4. To cushion the parts against vibration and impact.
5. To clean the parts as it lubricates them, carrying away impurities.
6. Lubrication is mainly required for main crankshaft bearings.
7. To lubricate the big end bearings.
8. Lubrication for the small end bearings.
9. Crankshaft bearings, piston rings and cylinder wall, timing gears, valve mechanism arelubricated.

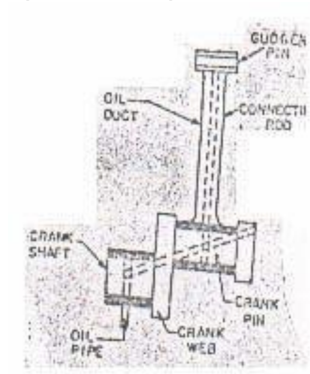
6.3 Different systems of lubricating systems

The various systems of lubrication adopted in automobiles are

1. Petroil lubricating system
2. Splash lubricating system
3. Forced feed lubricatingsystem
4. Dry sump lubricatingsystem.

Petroil lubricating system: This system of lubrication is generally adopted in two stroke petrol engines like scooters, mopeds and motor cycles. It is the simplest form of lubricating system. It does not consist of any separate part like oil pump for the purpose of lubrication. The lubricating oil is mixed into the petrol itself while filling in the petrol tank of the vehicle, in a specified ratio. When the fuel goes into the crank chamber during the engine operation, the oil particles go deep into the bearing surfaces and lubricate them. The piston rings, cylinder walls, piston pin etc. are lubricated in the same way.

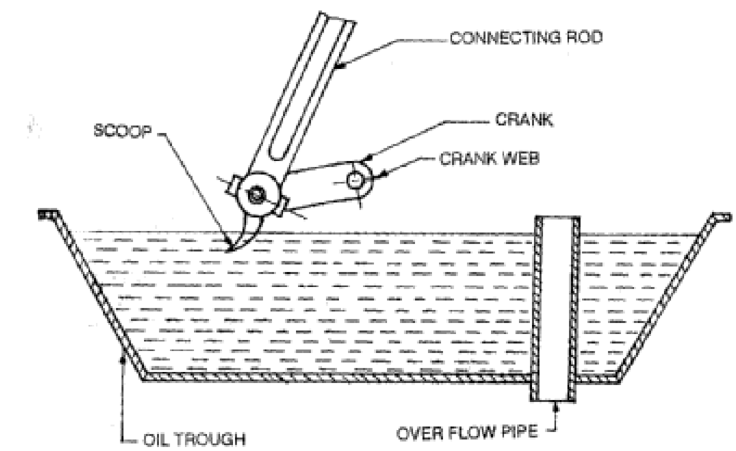
If the engine is allowed to remain unused for a considerable time, the lubricating oil separates off from petrol and leads to clogging of passages in the carburetor, resulting in the engine starting trouble.



Small End Lubrication

Splash Lubrication system: In this system of lubrication, the lubricating oil is stored in an oil trough or sump. A scoop or dipper is made in the lowest part of 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 in the cylinder walls. This action effects the lubrication of the engine walls, piston rings, crankshaft bearings and big end bearings.

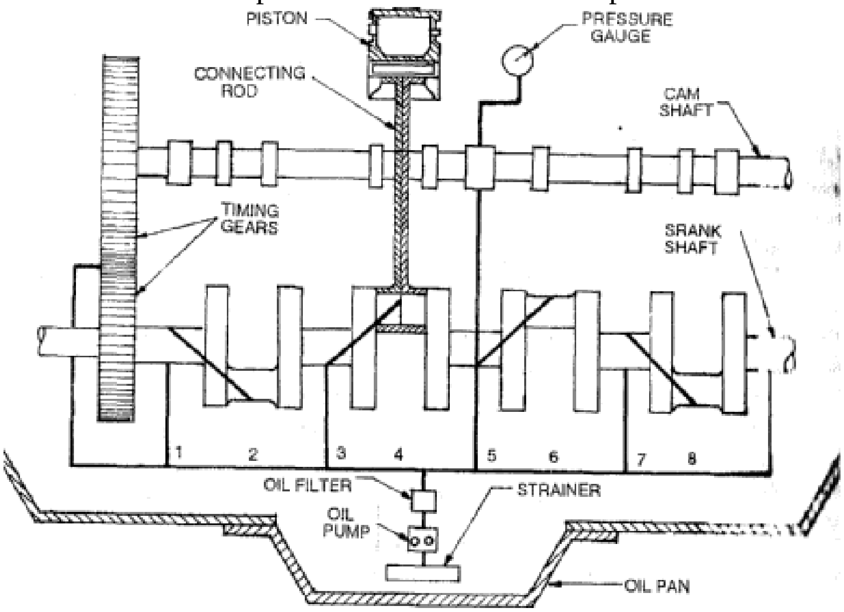
Splash system mostly works in connection with the pressure system in an engine, some ports being lubricated by splash system and other by pressuresystem.



Splash Lubricating System

Pressure system: In this system of lubrication, the engine ports are lubricated under pressure feed. The lubricating oil is stored in a separate tank on the sump, from where an oil pump takes the oil through a strainer and delivers it through a filter to the main oil gallery at a pressure of 2-4 kg/cm^2. The oilfrom the main gallery, goes to the main bearings, falls back to the sump, some is splashed to lubricate the cylinder walls and the remaining goes through a hole to the crankpin. From the crankpin it goes into the piston pin through a hole in the connecting rod web, where it lubricates the piston rings.

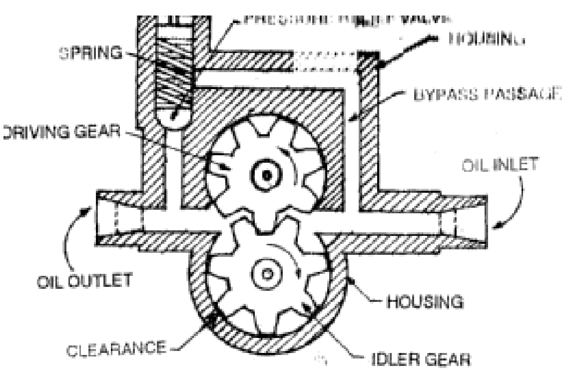
For lubricating camshaft and timing gears, the oil is led through a separate oil line from the oil gallery. The valve tappets are lubricated by connecting the main oil gallery to the tappet guide surfaces through drilled holes. An oil pressure gauge at the instrument panel indicates the oil pressure in the system clear off the oil from dust metal particles and other harmful particles.



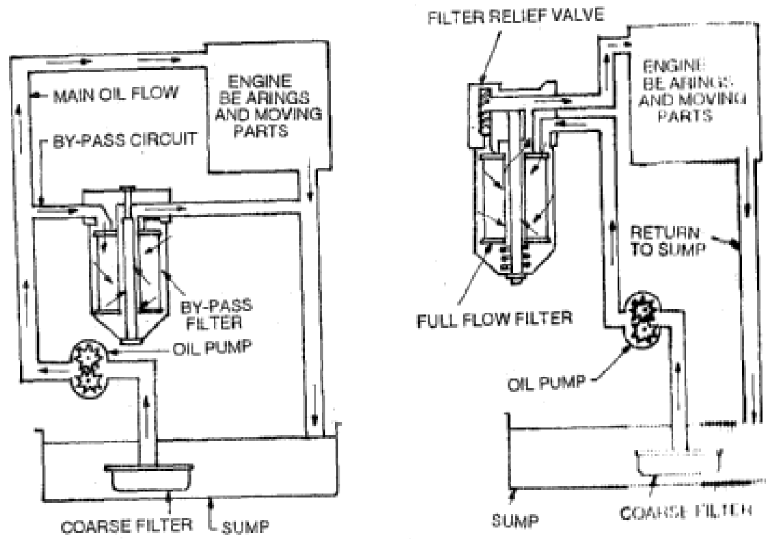
Pressure System ofLubrication

Parts of Lubricating System:

1. Oil sump ortank
2. Oil pump
3. Oil cooler
4. Oil filter andstrainer
5. Oil pressuregauge
6. Oil levelindicator
7. O.P. indicatinglight

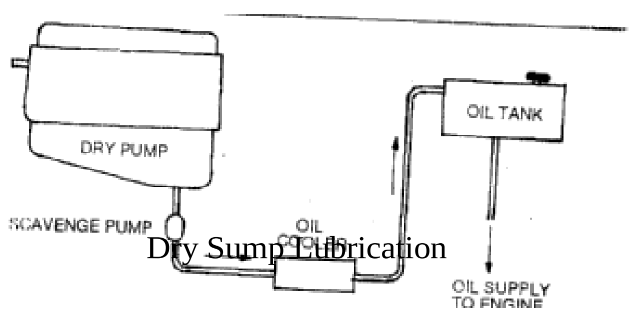


Gear Type Lubricating Pump



(a) By-pass system. (b) Full flow system.

Dry Sump Lubric ating System: The system in which the lubricating oil is stored in the oil sump is called wet sump system, like the pressure system. But the system in which the lubricating oil is not kept in the oil sump is known as dry sump system. In this system the oil is carried and separate tank from where it is fed to the engine. The oil which falls into the oil sump after lubrication is sent back to the oil tank by a separate delivery pump. The system consists of two pumps, one to feed the oil and the other to deliver it back to the oil tank. This system is used in saturation where the vehicle has to change its position continuously, like in air crafts. The main advantage of this system is that there is no chance of break down the oil supply during up and down movement of thevehicle.



Dry Sump Lubrication

Function of oil filters

The main function of the oil filters is to filter out the dirt or grit particles from theoil. Theoilfiltersclearsthedustparticlessettledinthe oil through the burning of the fuel. Thus the oil filters are helpful to clean the various parts of an engine from dust and dirt.

Types of filtering systems

There are two types of filtering systems. They are

1. Full flowsystem
2. By pass flowsystem.

In **Bypass filter system,** the whole of the oil does not pass through the filter at the same time, but some of the oil without being filtered goes to the bearings. Remaining oil passes through the filter and then goes to bearings. When the engine is running continuously for a long period, the whole oil is however filtered.
In **full flow system,** the whole oil passes first through the filters and then goes to the bearings. If the filter is clogged due to any reason, the system fails completely and bearings would be starved.

Types of filtering elements

Different types of filtering elements are used in automotive engines.

1. Cartridge type
2. Edge type
3. Centrifugal type.

The Cartridge type consists of a filtering element placed in a metallic casing. The casing has inlet and outlet oil pump enters casing through the filtering element, which takes up all the impurities. The filtered oil then comes out from the casing and goes to the oil gallery. The filtering element may be cleared when clogged.

The Edge type filtering element consists of a number of discs in a casing through which the oil passes. The alternate discs are mounted over a spindle and discs, between these are fixed to a separatesquare rod. The clearance between the discs is only a few thousand of centimeter. When the oil flows through this small clearance, it leaves impurities on the disc peripherals.

The Centrifugal type consists of a stationary casing, rotor casing, central spindle and tubes with jets. The important oil enters the hollow central spindle and through holes around its periphery, the oil goes to the rotor casing. From the rotor casing the oil goes in the tubes, at the ends of which jets under pressure, the reaction of which gives the motion to the rotor casing so that it starts rotating. The oil from the jets impinges on the walls of the stationary casing under heavy pressure, where the impurities are retained and the clean oil falls below which is taken for use. The filter walls are cleared periodically.

Necessity of Crankcase Ventilation

The products of combustion contain mainly nitrogen, water and carbon dioxide, sulphuric acid articles may also be present due to sulphur content in the fuel. It is quite possible that the product of combustion may leak through the piston rings into the crankcase oil by slipping past the piston rings. Thus the lubricating oil in the crankcase becomes dilute when mixed with water and gasoline which leak past the piston rings. The acid causes corrosion of the crankcase metals as water does. If either or both are allowed to enter and remain in the crankcase, the crankcase ventilation removes all these unwanted particles from the crankcase, which leak past the piston rings. It prevents the lubricating oil from becoming dilute and corrosion of crankcase metals due to acid formation.

In a positive crankcase ventilation, the crankcase vapor are returned to the engine through the intake manifold, instead of being exhausted into the atmosphere. The crankcase outlet tube is connected to the manifold just beneath the carburetor. So that the vapors are drawn into the intake manifold and utilized into the cylinder during theoperation.

Effect of sludge to the lubric ation system

When the water is mixed in oil and the mixture is churned up for a certain time, a thick, creamy black substance is formed known as water sludge.

In the crankcase, the water collects in two ways. First, the water is formed as a product of combustion. Second the water enters through the crankcase ventilation system with moist air which the engine is cold, the water drops into the crankcase and mixes with the lubricating oil. By the action of the crankshaft the mixture is churned up and water sludge is formed. Dirt and carbon also mix in the water sludge making it black.

The water sludge clogs oil screws and oil lines, preventing normal circulation of lubricating oil to engine parts. This can result in engine failure from oil starvations.

Cooling System

Necessity of cooling system

If the temperature developed is not dissipated out, it may cause severe damages to the engine. The excess heat developed inside the engine should be removed out frequently so as to prevent the engine from overheating. If the engine is not dissipated its excess heat, which may cause to break the lubricating film between the moving parts. If the lubricating oil film is broken it causes the engine parts to weld. At about 15 % of the total heat produced is utilized for useful work atthe crankshaft. Remaining amount of heat is absorbed in friction, removed by exhaust gases and taken by cooling system the cooling system is designed to remove above 30 to 35% of heat produced in the engine cylinder. As the temperature should not reach excessive values, they should be cooled sent out of the engine surroundings. It is also to be noted that the engine is quite in efficient when cold. The cooling system is so designed that it prevents cooling until the engine reaches to its normal operating temperature. When the engine warms up, the cooling system begins to function. It controls rapidlywhen the engine is too hot, and it cools slowly or not at all when the engine is cooled oris warming up. Most engines are designed to operate in a definite temperature range which will insure correct clearances between parts, promote vaporization of the fuel, keep the oil at its best viscosity and prevent the condensation of harmful vapor. Thus the duty of the cooling system is to keep the engine from getting too hot and not to keep it too cool.

Disadvantages of overcooling & under cooling

Engine should be cooled within a particular temperature limits. It should not be too cooled or too heated up. Getting the engine too much cooled is called overcooling. And if the engine is over heated it is to under cool. Both under cooling and over cooling have individual disadvantages. Over cooling results in the increase of viscosity of the lubricating oil, which in turn result in the increase of friction between the movingparts.

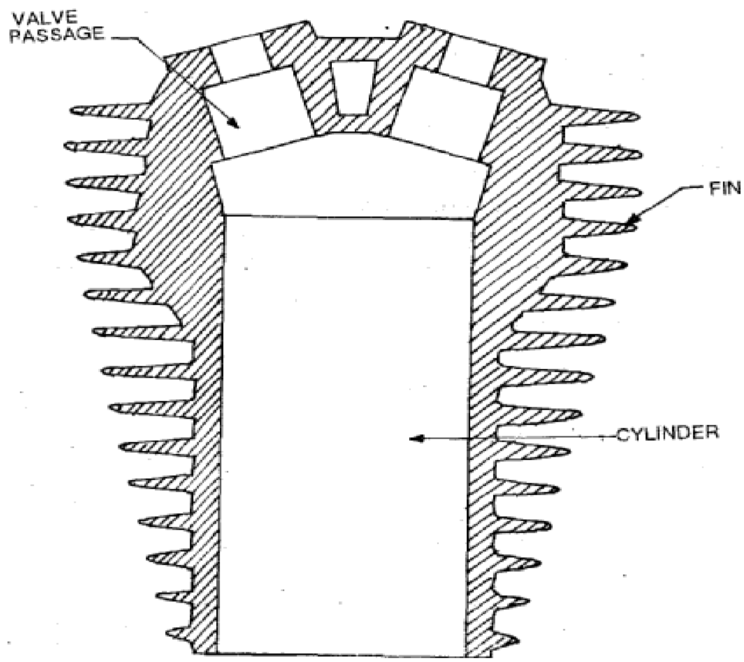
If the engine gets warmed up excessively, it should be cooled so as to keep the correct alignment of the engine. Under cooling also keeps the engine in correct position and increase the life of the engine. Evaporation of lubricating oil that lubricates the piston and cylinder wall is also another reason of under cooling. This will result in metalto metal contact of the piston and cylinder wall leading to piston crown. Burning of and warping of exhaust valves setting up of thermal stresses in the cylinder, cylinder head and piston. This may lead to cracking of them.

Types of cooling system: -

Engine cooling is of two types. They are air cooling and water cooling.

A. Direct or air cooling: - Air cooling is used on engines in scooters, motorcycles, aero planes, small stationary engines. This system employs air as the cooling medium. The air remains indirect contact with the exterior of engine surface and transfers heat from cylinders to the atmosphere. Air cooling system is simple in layout, occupies small area on the vehicle. It contains much less spare parts and has almost no moving components.

1. Air jacket cooling 2. Natural air cooling 3. Forced air cooling.



Forced Air Cooling: - It is well known fact that the rate of heat transfer due to convection increases with an increase in the velocity of the air flowing over a hot body.

Engine mounted on sunny zip, Bajaj auto vehicle, LML, Kinetic Honda employ this kind of cooling.

Natural Cooling: - In normal course, large part of an engine exposed to the atmospheric air, when the vehicle runs the air at certain relative velocity impinges upon the engine and sweeps away its heat. The heat carried away by the air is due to natural convention. Therefore this method is known as natural air cooling. As the heat dissipation is a function of frontal cross-sectional area of the engine, therefore there exists a need to enlarge this area.

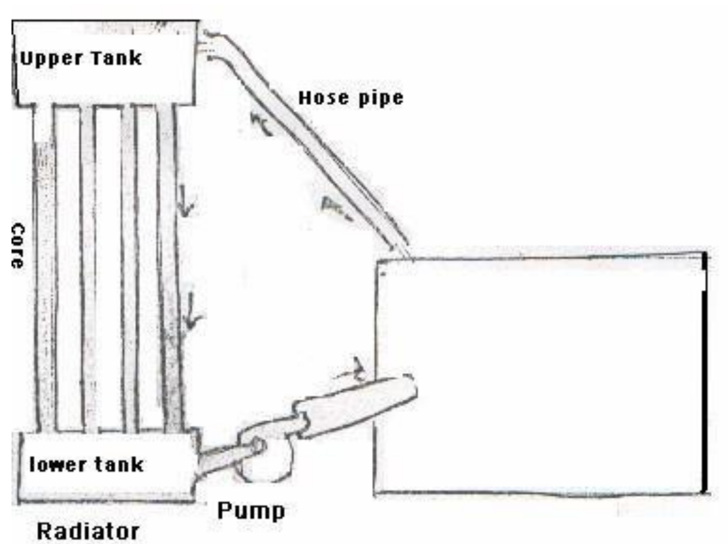
Air Jacket Cooling: - In this cooling arrangement, the air is made to pass through the small passages formed in the cylinder block and the cylinder head. The air is passed through a singular multi passages, either naturally or by artificial means.

Water Cooling or Liquid cooling system: -

Air cooling of an engine tends to became less effective when number of cylinders increases in one engine. This is because of reduced effective surface area around each cylinder. This inefficiency can be over-come by use of water cooling system on multi cylinder engines.

1. Thermo Syphon Cooling System
2. **Pump Circulation or Forced Water Cooling System.**

Thermo Syphon Cooling System: - This system involves flow of water under gravity. It does not depend on any external source to circulate the liquid coolant. Convective currents carry heat from bottom to the top of the system as cold water is heavier than the hot water. Since the water in the jackets surrounding the cylinder is heated. It becomes lighter and rises up. The heated water enters into the radiator through the upper connection and when cooled by the air passing through the radiator core. It becomes heavier and settled to the bottom of the radiator.



7.4 Thermostat water coolingsystem:

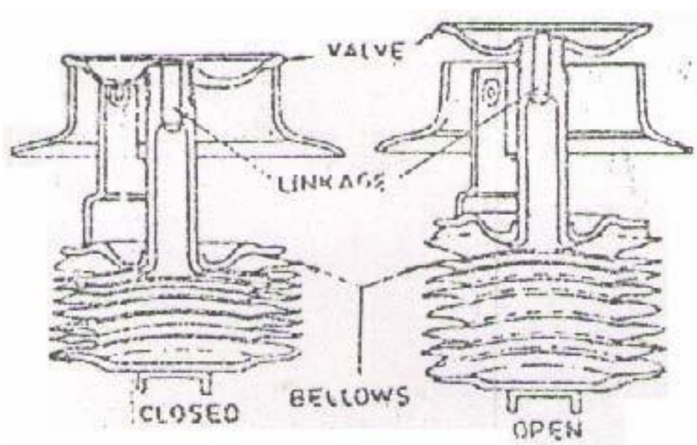
In this system of water cooling, the circulation of water is obtained due to the difference in densities of hot and cold regions of thecooling water. There is no pump to circulate the water. The hot water from the engine jacket being lighter, rises up in the hose pipe and goes in the radiator from the top side. It is cooled there and hence goes down at the bottom of the radiator, from where it goes again in the engine jackets. The system is quite simple and cheap, but the cooling is rather slow. To maintain continuity of the water flow, the water must be maintained up to a certain minimum level. If the water level falls down, the circulation will discontinue and the cooling system will fail.

A thermostat valve is used in the water cooling system to regulate the circulation of water in system to maintain the normal working temperature of the engine parts during the different operating conditions. The thermostat valve automatically work in the cooling system. When the engine is started from cold, the thermostat valve prevents the flow of water from engine to radiator so that the engine readily reaches to its normal working temperature, after which it automatically comes into action. Generally the thermostat valve does not permit the water below 70^0C.

There are two types of thermostats used in automobiles. They are bellow type and pellet type thermostat. Both the thermostat valves works on the same principle as a heat unit operating a valve.

The working of bellow type thermostat is explained with the help of figure. The heat unit consists of a closed bellows filled with a volatile liquid under reduced pressure. When the bellows is heated, the liquid vaporizes and creates enough pressure to expand the bellows. The movement of the bellows operate a linkage which open the valve to pass the water through it. When the bellows is cooled, the gas condenses, the pressure is reduced and the bellows collapse to close the valve thus stopping the water circulation.

In the pellet thermostat, the heat unit consist of a sealed in wax pallet, which expands on heating and contracts on cooling. The pellet is connected by piston and flange to a valve so that on expansion of the pellet it opens the valve. When the pellet contract on cooling, a coil spring closes the valve.



Bellows-type thermostat.

Construction and working of water pump,

radiator Water Pump :

A pump is used in the water cooling system to increase the velocity of the circulating water. Impeller type pump is mounted at the front end of the cylinder block between the block and the radiator. The pump consists of a housing with inlet and outlet, and an impeller. The impeller is a flat plate mounted on the pump shaft with a seriesof flat or curved blades or vanes. When the impeller rotates, the water between the blades is thrown outwards by centrifugal force, and is forced through the pump outlet and into the bottom of the radiator, and the water from the radiator is drawn into the pump to replace the water forced through the outlet.

The pump is driven by a belt to the drive pulley mounted on the front end of the engine crankshaft. The impeller shaft is supported on one or more bearings. A seal prevents water from leaking out around the bearing.

The pack less type pump is used in modern engine. The packing gland type pump is found only in older models.

Radiator:

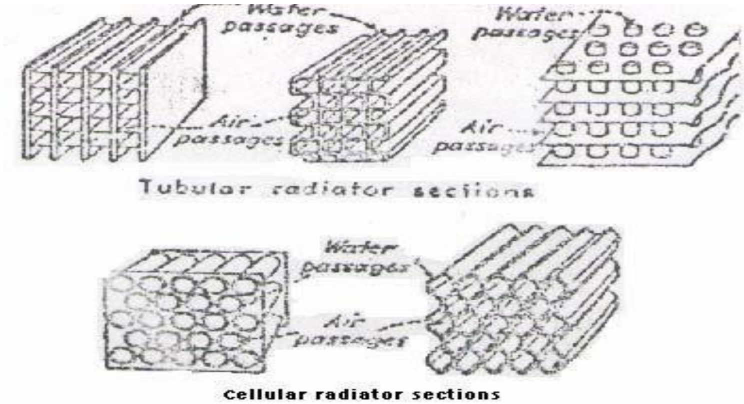
The radiator is a device for having a large amount of cooling surface to the large amount of air so that the water circulating through it is cooled efficiently. It consists of a upper tank and a lower tankand between them a core. The upper tank is connected in the water outlet or outlets from the engine jackets inlet through the water pump. The core is a radiating element, which cools the water.

There are two basic types of radiator cores – tubular type and cellular type. In tubular type core the upper and lower tanks are connected by a series of tubes through which water passes. Fins are placed around the tubes to improve heat transfer. Air passes around the outside of the tubes, between the fins, absorbing heat from the water in passing. In cellular type core, air passes through the tubes and the water flows in the spaces between them. The core is composed of a large number of individual air cells which are surrounded by water. Because of its appearance the cellular type usually is known as a honeycomb radiator, especially when the cells in front are hexagonal in form.

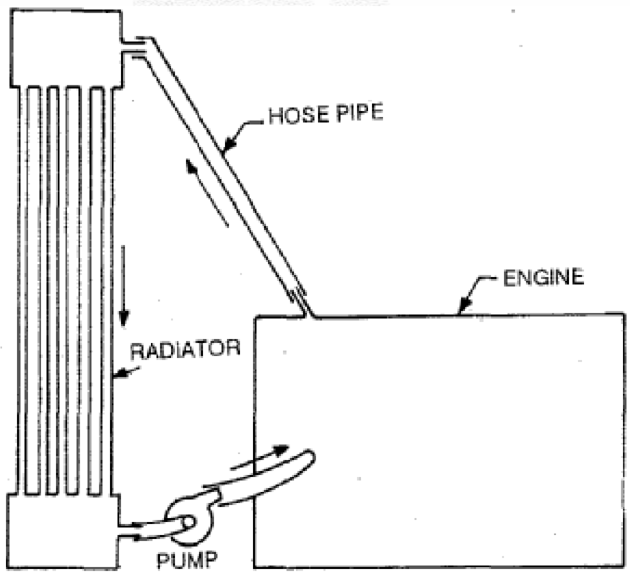
In tubular radiator, because the water passes through all the tubes, if one tube becomes clogged, the cooling of any passage results in a loss but of a small part of the total cooling surface.

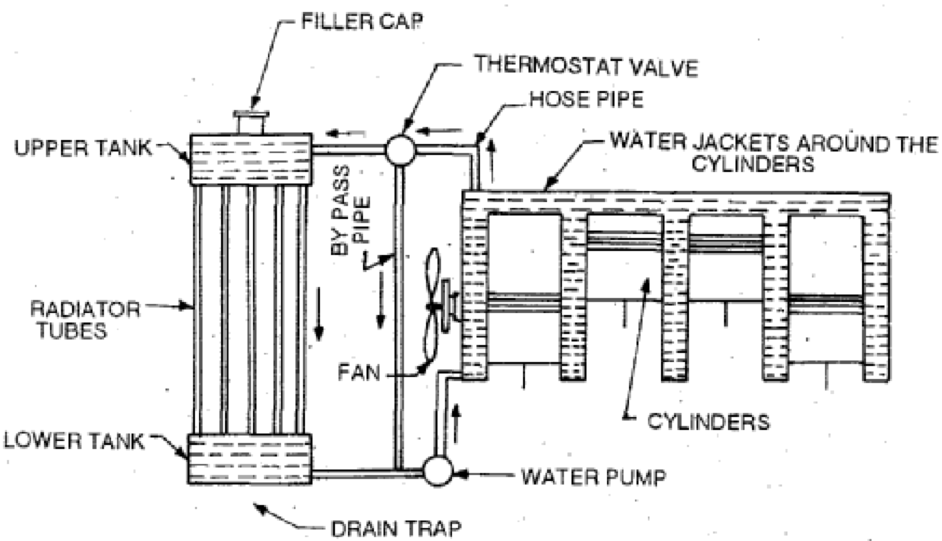
Radiators are also classified according to the direction of the water flow through them. In some, the water flows from top tobottom – down flow type radiators. In other, the water flows horizontally from an input tank on one side to another tank on the other side – cross flow type radiator.

Radiators are usually made of copper and brass because oftheir high heat conductivity. The various sections of the radiator are most completely joined together by soldering.



Types of radiator cores





WATER COOLING SYSTEM OF FOUR CYLINDER ENGINE

Anti freezing and anti rusting additives

When water in the cooling system freezes it may cause cracking the cylinder block, pipes and the radiator. Freezing of water occurs where the atmospheric temperature is very less. To prevent freezing, antifreeze mixtures or solutions are added in the water. The most commonly used antifreeze materials are

Wood alcohol, denatured alcohol, glycerine, Ethylene glycol, propylene glycol and mixture of alcohol and glycerine.

The alcohol evaporates quickly. So it should be checked frequently. Ethylene glycol is a permanent type antifreeze material. Glycerine and glycol are although costly but do not evaporate readily and hence prove cheaper in long run. But they should not enter the engine parts as they seizure of the moving parts. The lower the temperature, the higher is the percentage of antifreeze material.

Anti rusting additives prevent the engine parts from rusting and corrosion.

The antifreeze material should mix with the water readily. It should prevent freezing of the mixture at lowest temperatures. It should circulate freely in the cooling system. It should not damage the cooling system by corrosion action. It should not deposit any foreign material.

EXERCISE

Part A

1. How does the maximum pressure in the lubrication system controlled?
2. Why fins and baffles are required in an air-cooled engine?
3. Write down the equation to calculate cooling power requirement in terms of indicated power of an engine.
4. Find the brake specific fuel consumption in kg/kW-hr of a diesel engine whose fuel consumption is 5 grams per second when the power output is 80 KW.
5. Where is dry sump lubrication preferred and Why?
6. What is evaporative cooling?
7. Write the differences between thermosyphon and pump circulation cooling system.
8. What are the requirements of lubrication system?
9. Define the various properties of coolants.
10. Write down the major parts to be lubricated in a Petrol engine.

Part B

1. Clearly explain the various wet sump lubrication system. Compare wet sump and dry sump lubrication system.

2. (i) Explain the reasons for cooling an engine.

(ii)Explain forced circulation and thermosyphon cooling system.

3. Discuss the following in details
   (i) Thermosyphon System, (ii) Forced Circulation System

4. Discuss the following in details
   (i) Properties of the engine lubricants, (ii) Dry sump lubrication

5. Discuss in detail the types of cooling systems used in IC engines
6. What are the requirements of lubrication? Discuss the types of lubrication systems used in IC engines
7. Explain pump circulation and air cooling system with respect to construction, working and merits with neat sketches.
8. Write short notes on
9. (i) Pressure lubricating system (ii) Wet sump and properties of lubricants
10. Explain the following
    (i) Thermosyphon cooling system (ii) Forced circulation cooling system
    (iii) Evaporative cooling system (iv) Pressure cooling system
11. What are the desired properties of the lubricant? Explain how do additives help to achieve the desired properties.

MODULE IV

Combustion and Power Boosters: -

(Phenomenon of combustion in SI engines, stages of combustion, flame propagation, rate of pressure rise, abnormal combustion, effect of engine variables on knocking, fuel quality for SI engines, octane rating, combustion chambers for SI engines. Phenomenon of combustion in CI engines, stages of combustion, ignition delay, factors affecting delay period, knock in CI engines, comparison of knock in SI and CI engines, direct and indirect injection diesel engines, combustion chambers, supercharging and turbocharging methods.)

Combustion

- It is a chemical reaction
- Liberation of heat energy
- Increase in temperature of the gases

Fuel + Air---- → Product of combustion

Condition for Combustion:

- Presence of combustible mixture
- Some means of initiating combustion
  - Homogeneous Combustion
  - Heterogeneous Combustion

Combustion in SI Engines (Homogeneous combustion)

In a conventional SI engine, fuel and air are mixed together in the intake system, inducted through the intake valve into the cylinder where mixing with residual gas takes place, and then compressed during the compression stroke.

Under normal operating conditions, combustion is initiated towards the end of compression stroke at the spark plug by an electric discharge. Following inflammation, a turbulent flame develops, propagates through the premixed air-fuel mixture (and burned gas mixture from the previous cycle) until it reaches combustion chamber walls, then it extinguishes.

Combustion event must be properly located relative to the TDC to obtain max power or torque. Combined duration of the flame development and propagation process is typically between 30 and 90 CA degrees.

If the start of combustion process is progressively advanced before TDC, work of compression (from piston to cylinder gases) increases. If the end of combustion process is progressively delayed by retarding the spark timing, peak cylinder pressure occurs later in the expansion stroke and is reduced in magnitude. These changes reduce the expansion stroke work transfer from cylinder gases to the piston. The optimum timing which gives maximum brake torque (called maximum brake torque or MBT timing) occurs when magnitude of these two opposing trends just offset each other.

Timing which is advanced or retarded from this optimum MBT timing gives lower torque. Optimum spark setting will depend on the rate of flame development and propagation, length of flame travel path across the combustion chamber, and details of the flame termination process after it reaches the wall - these depend on engine design, operating conditions and properties of the fuel-air and burned gas mixture.

With optimum spark setting, max pressure occurs at about 15 degrees CA after TDC (10 - 15), half the charge is burned at about 10 degrees CA after TDC. In practice spark is retarded to give a 1 or 2 % reduction in brake torque from max value, to permit a more precise definition of the timing relative to the optimum

There are three stages of combustion in SI Engine.

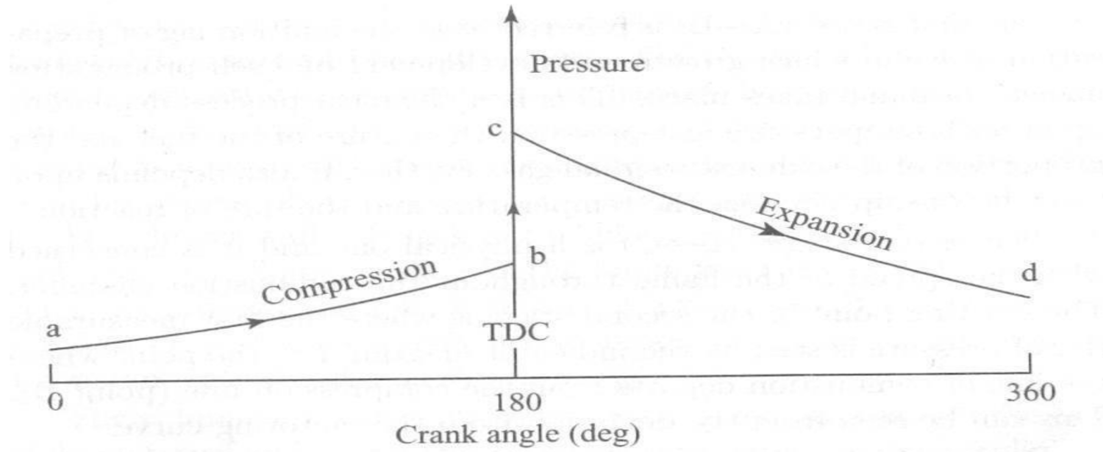
1. Ignition lag stage
2. Flame propagation stage
3. After burning stage

Ignition lag stage: There is a certain time interval between instant of spark and instant where there is a noticeable rise in pressure due to combustion. This time lag is called IGNITION LAGIgnition lag is the time interval in the process of chemical reaction during which molecules get heated up to self ignition temperature, get ignited and produce a self propagating nucleus of flame. The ignition lag is generally expressed in terms of crank angle (θ_1). The period of ignition lag is shown by path A-B. Ignition lag is very small and lies between 0.00015 to 0.0002 second. An ignition lag of 0.002 second corresponds to 35 deg crank rotation when the engine is running at 3000 rpm.Angle of advance increases with the speed. This is a chemical process depending upon the nature of fuel, temperature and pressure, proportions of exhaust gas and rate of oxidation or burn proportions of exhaust gas and rate of oxidation or burning.

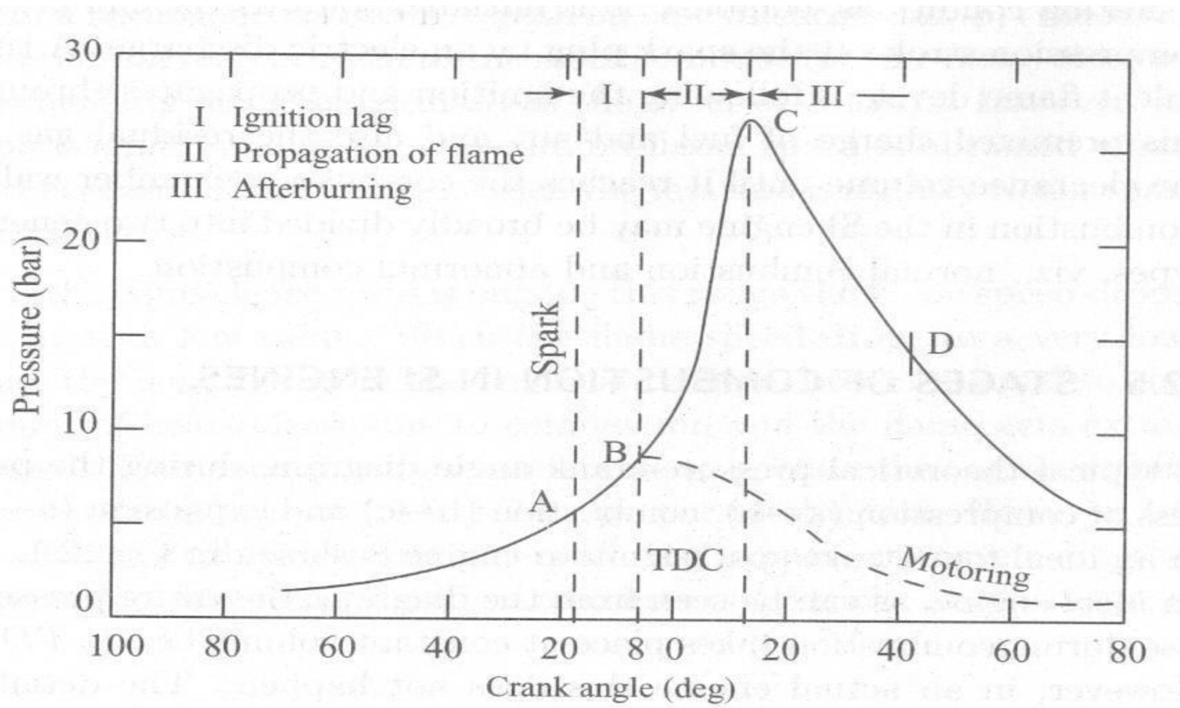
Flame propagation stage: Once the flame is formed at “B”, it should be self sustained and must be able to propagate through the mixture. This is possible when the rate of heat generation by burning is greater than heat lost by flame to surrounding. After the point “B”, the flame propagation is abnormally low at the beginning as heat lost is more than heat generated. Therefore pressure rise is also slow as mass of mixture burned is small. Therefore it is necessary to provide angle of advance 30 to 35 deg, if the peak pressure to be attained 5-10 deg after TDC. The time required for crank to rotate through an angle θ_2 is known as combustion period during which propagation of flame takes place.

After burning: Combustion will not stop at point “C” but continue after attaining peak pressure a point “C”. This combustion is known as after burning. This generally happens when the rich mixture is supplied to engine.

Stages of Combustion in SI Engines

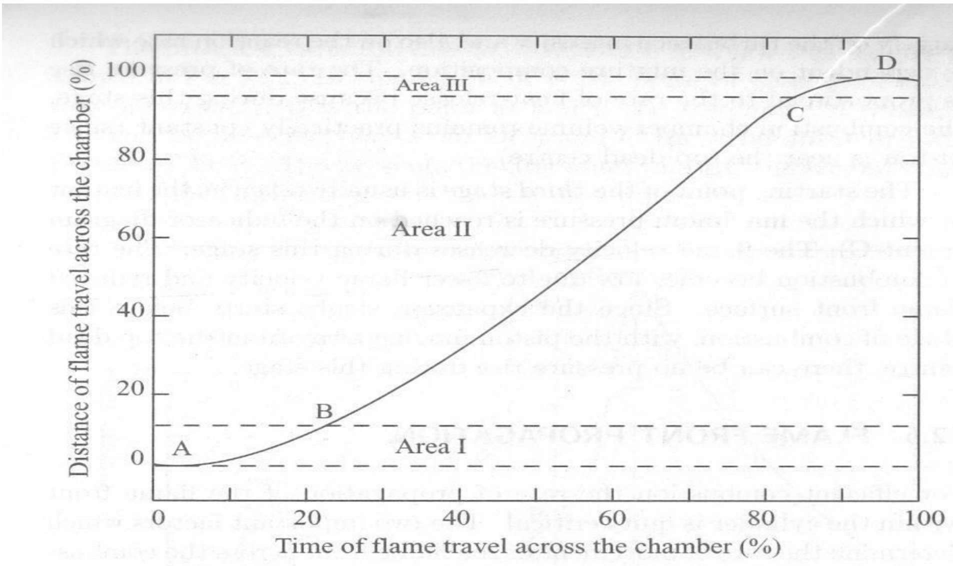


Theoretical p-θ Diagram



Flame Speed

Flame is the result of a self sustaining chemical reaction occurring within a region of space called the flame front where unburnt mixture is heated and converted into products. Flame front consists of two regions; a preheat zone (temperature of the unburnt mixture is raised mainly by heat conduction from the reaction zone, no significant reaction takes place) and a reaction zone (upon reaching a critical temperature exothermic chemical reaction begins - the temperature where exothermic reaction begins to the hot boundary at downstream equilibrium burned gas temperature).



A-B

- low transposition rate
- low reaction rate

The flame front progresses relatively slowly due to a low transposition rate. Comparatively small mass of charge burned at the start.

The low reaction rate plays a dominant role resulting in a slow advance of the flame.

The lack of turbulence reduces the reaction rate and hence theϒ flame speed.

B-C

- Increased Flame propagation
- high transposition rateϒ
- High reaction rate

As the flame front leaves the quiescent zone and proceeds into more turbulent areas (area II) where it consumes a greater mass of mixture, it progresses more rapidly and at a constant rate (B-C)

C-D

- low transposition rate
- low reaction rate

The volume of unburned charge is very less towards the end of flame travel and so the transposition rate again becomes negligible thereby reducing the flame speed.

The reaction rate is also reduced again since the flame is entering ϒ a zone of relatively low turbulence (C-D)

Factors affecting the Flame Speed

- Turbulence – During Suction & Compression stroke
- Fuel - Air Ratio (Maximum Flame speed Φ= 1.1 to 1.2)
- Intake Temperature & Pressure
- Compression Ratio
- Engine Output: Increased throttle opening will increase the charge density. So Flame speed will increase
- Engine Speed

Turbulence:

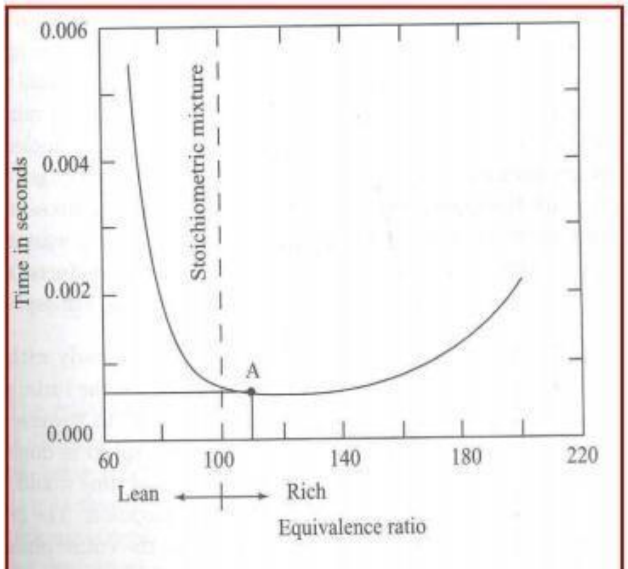
- Flame speed is quite low in non-turbulent mixtures and increases with increasing turbulence.
- Design of the combustion chamber which involves the geometry of cylinder head and piston crown increases the turbulence during the compression stroke.
- Turbulence increases the heat flow to the cylinder wall. It also accelerates the chemical reaction by increasing the rate of contact of burning and unburned particles.
- The increase of flame speed due to turbulence reduces the combustion duration and hence minimizes the tendency of abnormal combustion.

However, excessive turbulence may extinguish the flame resulting in rough and noisy operation of the Engine.

Fuel - Air Ratio:

- The fuel-air ratio has a very significant influence on the flame speed.
- The highest flame velocities (minimum time for complete combustion) are obtained with somewhat richer mixture (point A).
- When the mixture is made leaner or richer from point A, the flame speed decreases.
- Less thermal energy is released in the case of lean mixtures resulting in lower flame temperature.

- Very rich mixtures lead to incomplete combustion which results again in the release of less thermal energy



Effect of Mixture Strength on the Rate of Burning

Temperature and Pressure:

- Flame speed increases with an increase in intake temperature and pressure.
- A higher initial pressure and temperature may help to form a better homogeneous air-vapors mixture which helps in increasing the flame speed.
- This is possible because of an overall increase in the density of the charge.

Compression ratio:

- A higher compression ratio increases the pressure and temperature of the working mixture which reduce the initial preparation phase of combustion and hence less ignition advance is needed.
- Increased compression ratio reduces the clearance volume and therefore increases the density of the cylinder gases during burning.
- Increasing the density increases the peak pressure and temperature and the total combustion duration is reduced.
- Thus engines having higher compression ratios have higher flame speeds.

Engine output

With the increased throttle opening the cylinder gets filled to a higher density. The cycle pressure increases when the engine output is increased.

When the output is decreased by throttling, the initial and final compression pressures decrease and the dilution of the working mixture increases.

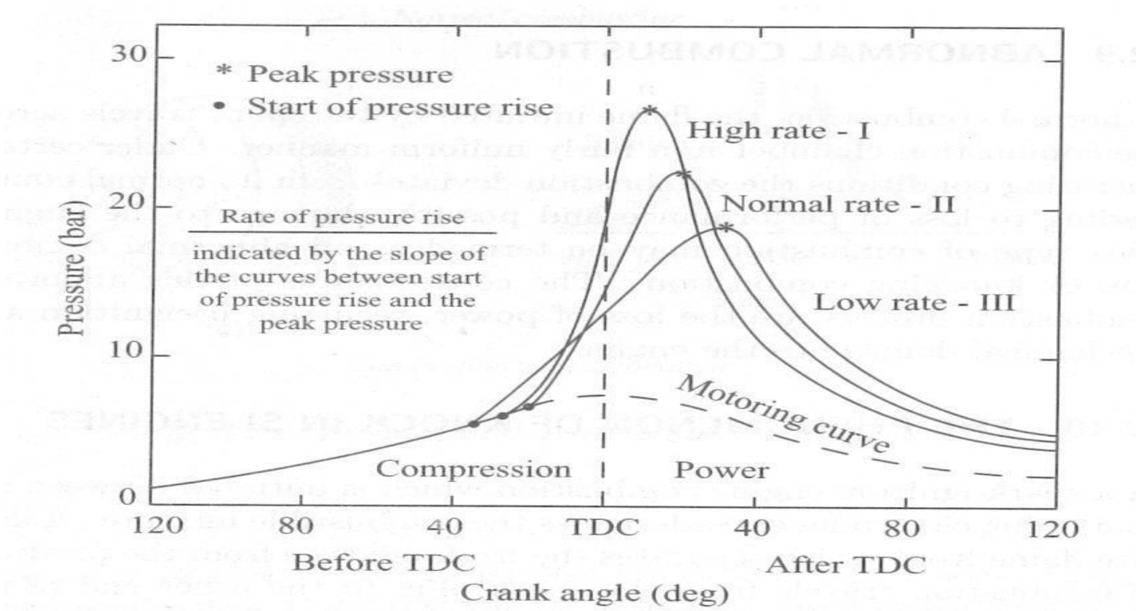
The smooth development of self-propagating nucleus of flame become unsteady and difficult.

The main disadvantages of SI engines are the poor combustion at low loads and the necessity of mixture enrichment (Ø> between 1.2 to 1.3) which causes wastage of fuel and discharge of unburnt hydrocarbon and the products of incomplete combustion like carbon monoxide etc. in the atmosphere.

Engine speed:

- The flame speed increases almost linearly with engine speed since the increase in engine speed increases the turbulence inside the cylinder.
- The time required for the flame to traverse the combustion space would be halved, if the engine speed is doubled.

Rate of Pressure Rise



The rate of pressure rise in an engine combustion chamber exerts a considerable influence on:

- The peak pressure developed,
- The power produced and
- The smoothness with which the forces are transmitted to the piston.

The rate of pressure rise is mainly dependent upon the rate of combustion of mixture in the cylinder.

Curve I is for a high, curve II for the normal and curve III for a low rate of combustion.

With lower rate of combustion longer time is required to complete the combustion which necessitates the initiation of burning at an early point on the compression stroke.

Higher rate of combustion results in higher rate of pressure rise producing higher peak pressures at a point closer to TDC.

Higher peak pressures closer to TDC produce a greater force acting through a large part of the power stroke and hence, increase the power output of the engine.

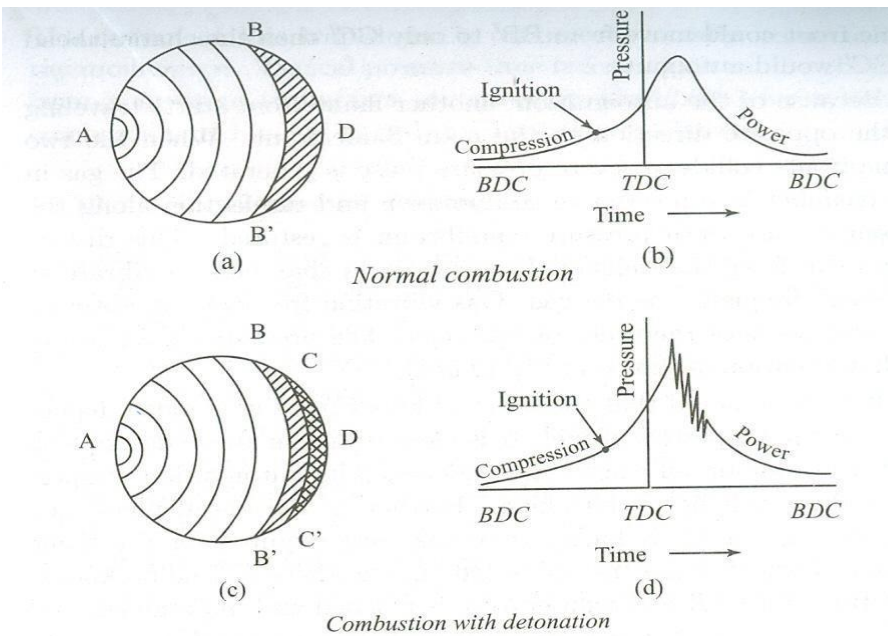
The higher rate of pressure rise causes rough running of the engine because of vibrations produced in the crankshaft rotation.

It also tends to promote an undesirable occurrence known as knocking.

A compromise between these opposing factors is accomplished by designing and operating the engine in such a manner that approximately one-half of the maximum pressure is reached by the time the piston reaches TDC.

This results in the peak pressure being reasonably close to the beginning of the power stroke, yet maintaining smooth engine operation.

Normal and Abnormal Combustion



Normal combustion

Spark-ignited flame moves steadily across the combustion chamber until the charge is fully consumed.

Abnormal combustion

Fuel composition, engine design and operating parameters, combustion chamber deposits may prevent occurring of the normal combustion process.

There are two types of abnormal combustion.

- Knock
- Surface ignition

Knock

Knock is the autoignition of the portion of fuel, air and residual gas mixture ahead of the advancing flame, that produces a noise. As the flame propagates across combustion chamber, end gas is compressed causing pressure, temperature and density to increase. Some of the end gas fuel-air mixture may undergo chemical reactions before normal combustion causing autoignition - end gases then burn very rapidly releasing energy at a rate 5 to 25 times in comparison to normal combustion. This causes high frequency pressure oscillations inside the cylinder that produce sharp metallic noise called knock.

Knock will not occur when the flame front consumes the end gas before these reactions have time to cause fuel-air mixture to autoignite.

Knock will occur if the precombustion reactions produce autoignition before the flame front arrives.

Piston Damage by knock

The following are the factors which cause the knock:

(i) The shape of the combustion chamber

(ii) The relative position of the spark plugs

(iii) The chemical nature of the fuel

(iv) The initial temperature and pressure of the fuel

(v) The rate of combustion of that portion of the fuel which is the first to ignite

Effect of Engine variables on Knock

- Compression Ratio
- Mass of Inducted Charge
- Inlet Temperature of the Mixture
- Temperature of the Combustion Chamber Walls
- Retarding the Spark Timing
- Power Output of the engine
- Turbulence
- Engine Speed
- Flame Travel Distance
- Engine Size
- Combustion Chamber Shape
- Location of Spark Plug
- Octane Value of the fuel

Surface Ignition

Surface ignition is ignition of the fuel-air charge by overheated valves or spark plugs, by glowing combustion chamber deposits or by any other hot spot in the engine combustion chamber - it is ignition by any source other than the spark plug. It may occur before the spark plug ignites the charge (preignition) or after normal ignition (postignition). It may produce a single flame or many flames.

Surface ignition may result in knock.

Factors influencing combustion

- Engine speed
- Equivalence ratio
- Residual gas fraction
- Induction pressure
- Compression ratio
- Combustion chamber design
- Spark advance

Engine speed:

Mixture burning rate is strongly influenced by engine speed. Increase of the engine speed, reduces the time available for a complete combustion. Increase in engine speed also increases the mean piston speed and turbulence intensity and increases flame speed. But this does not affect ignition delay period, thus delay period increases in CA degrees. To compensate this, ignition timing should be adjusted – spark advance is increased with increasing engine speed.

Equivalence ratio:

The fuel-air equivalence ratio affects the burning rate. Flame development show a minimum and the burning rate show a maximum for slightly rich mixtures ($\varphi \approx 1.2$). Burning rate reduces for richer and leaner mixtures.

Residual Gas Fraction:

The burned gas fraction in the unburned mixture, due to the residual gas fraction and any recycled exhaust gases (EGR), slows down both flame development and propagation. Residual gas fraction increases at part loads in SI-engines (due to closing the throttle), reducing flame propagation. Fuel composition changes can be significant. Faster burning engines (high turbulence) are less sensitive to changes in mixture composition, p and T than slower burning engines.

Induction pressure:

Increase in the induction pressure reduces flame propagation speed, but also increases the temperatures at the end of compression process which affects the flame speed, and reduces combustion duration.

Induction pressure is affected at part-loads - partially opened throttle. Flame speed is reduced. To compensate the increase in combustion duration, spark advance is increased.

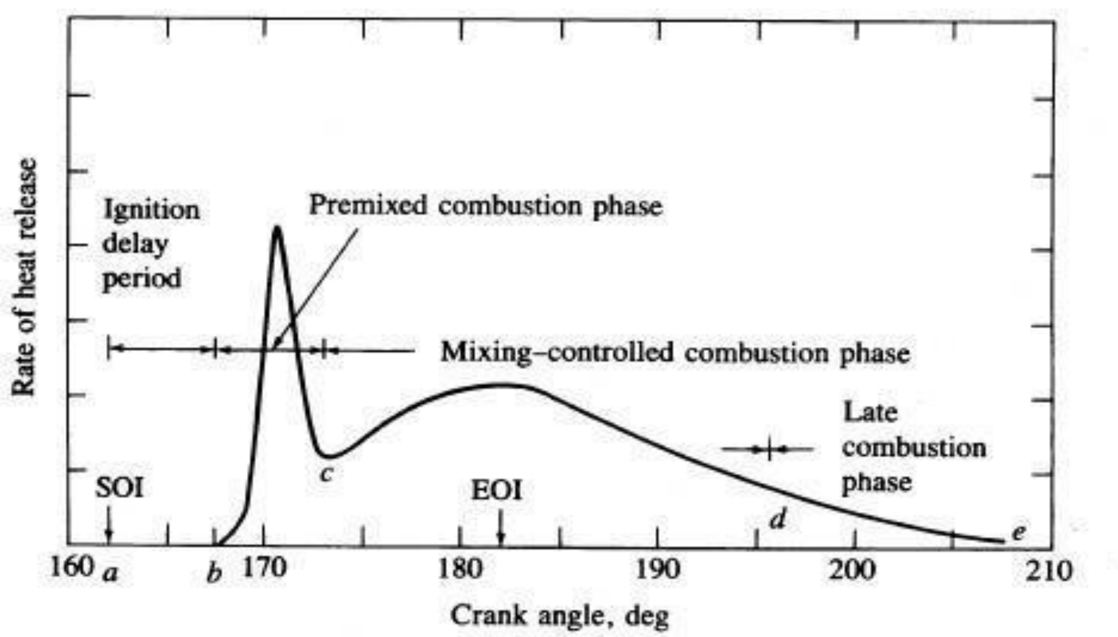
Compression ratio:

Increase in CR increases the p and T of the charge at ignition, reduces the mass fraction of the residual gases - more favorable conditions are developed for ignition which reduces the first stage of combustion, and increases flame propagation rate in the main stage. Increasing CR, increases Area/Volume ratio of the cylinder, increasing the cooling effects and the quench layers. Final stage of combustion is increased.

Combustion Chamber design:

Intake manifold design and combustion chamber shape effects the gas flow and turbulence intensity. Turbulence strongly effects burning rate of the fuel. Spark plug location effects distance traveled by the flame and flame front surface area.

Stages of Combustion in CI Engines



The combustion process proceeds by the following stages:

Ignition delay (ab) - fuel is injected directly into the cylinder towards the end of the compression stroke. The liquid fuel atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with the high-temperature high-pressure air.

Premixed combustion phase (bc) – combustion of the fuel which has mixed with the air to within the flammability limits (air at high-temperature and high-pressure) during the ignition delay period occurs rapidly in a few crank angles.

Mixing controlled combustion phase (cd) – after premixed gas consumed, the burning rate is controlled by the rate at which mixture becomes available for burning. The rate of burning is controlled in this phase primarily by the fuel-air mixing process.

Late combustion phase (de) – heat release may proceed at a lower rate well into the expansion stroke (no additional fuel injected during this phase). Combustion of any unburned liquid fuel and soot is responsible for this.

Combustion chambers of SI engines

The design of the combustion chamber for an SI engine has an important influence on the engine performance and its knocking tendencies.

The design involves

- the shape of the combustion chamber
- the location of spark plug and
- the location of inlet and exhaust valves.

Requirements:

The important requirements of an SI engine combustion chamber are

- to provide high power output with minimum octane requirement
- high thermal efficiency
- smooth engine operation.

Smooth engine operation:

The aim of any engine design is to have a smooth operation and a good economy.

These can be achieved by the following:

- Moderate Rate of Pressure Rise:
    - Limiting the rate of pressure rise as well as the position of the peak pressure with respect to TDC affect smooth engine operation.
- Reducing the Possibility of Knocking
    - Reduction in the possibility of knocking in an engine can be achieved by,
        - Reducing the distance of the flame travel by centrally locating the spark plug and also by avoiding pockets of stagnant charge.
        - Satisfactory cooling of the spark plug and of exhaust valve area which are

the source of hot spots in the majority of the combustion chambers.

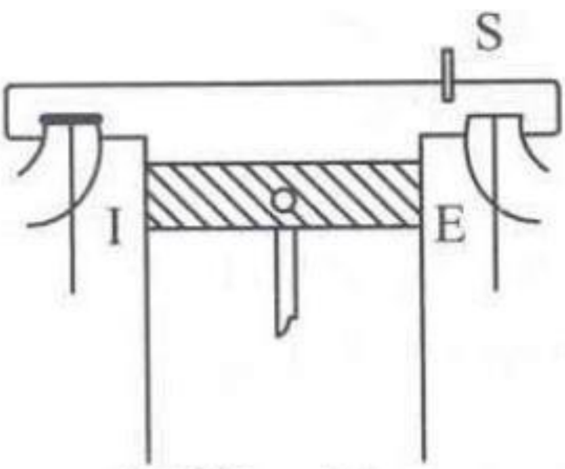
- Reducing the temperature of the last portion of the charge, through application of a high surface to volume ratio in that part where the last portion of the charge burns.

High Power Output and Thermal Efficiency:

This can be achieved by considering the following factors:

- A high degree of turbulence is needed to achieve a high flame front velocity.
  - Turbulence is induced by inlet flow configuration or squish
  - Squish is the rapid radial movement of the gas trapped in between the piston and the cylinder head into the bowl or the dome.
  - Squish can be induced in spark-ignition engines by having a bowl in piston or with a dome shaped cylinder head.
- High Volumetric Efficiency
  - More charge during the suction stroke, results in an increased power output.
  - This can be achieved by providing ample clearance around the valve heads, large diameter valves and straight passages with minimum pressure drop.
- Improved anti-knock characteristics
  - Improved anti-knock characteristics permits the use of a higher compression ratio resulting in increased output and efficiency.
- A Compact Combustion Chamber
  - Reduces heat loss during combustion and increases the thermal efficiency.

Types of Combustion chambers of SI

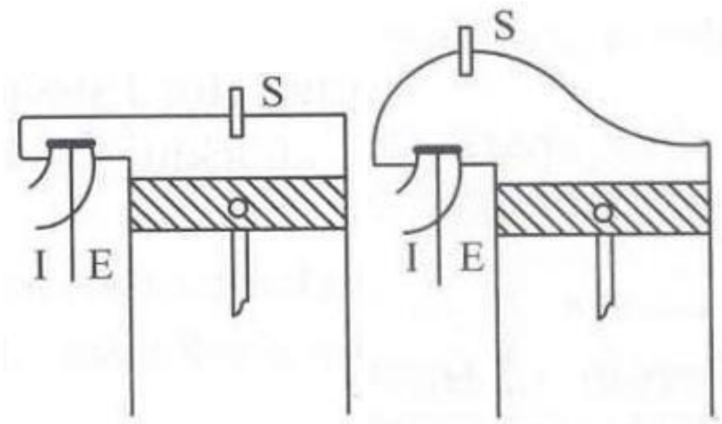


(a) T-head type

- The T-head combustion chambers were used in the early stage of engine development.
- Since the distance across the combustion chamber is very long, knocking tendency is high in this type of engines.
- This configuration provides two valves on either side of the cylinder, requiring two camshafts.
- From the manufacturing point of view, providing two camshafts is a disadvantage.

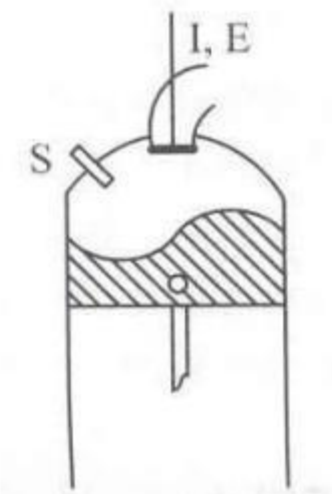
L-Head Type:

- A modification of the T-head type of combustion chamber is the L-head type which provides the two valves on the same side of the cylinder and the valves are operated by a single camshaft.
- The main objectives of the Ricardo's turbulent head design are to obtain fast flame speed and reduced knock



(b) L-head type (c) L-head type

I Head Type or Overhead Valve:



(d) I-head type

- In which both the valves are located on the cylinder head.
- The overhead valve engine is superior to a sid valve or an L-head engine at high compression ratios.
- Some of the important characteristics of this type of valve arrangement are:
  - less surface to volume ratio and therefore less heat loss
  - less flame travel length and hence greater freedom from knock

- higher volumetric efficiency from larger valves or valve lifts

Antiknock quality of gasoline:

-Knock occurs when the unburnt gases ahead of flame front (the end gases) spontaneously ignite causing a sudden rise in pressure accompanied by a characteristic pinging sound – this result in a loss of power and can lead to damage the engine.
-Combustion chamber shape, spark plug location, ignition timing, end gas temperatures, in cylinder gas motion, air-fuel ratio of the mixture, fuel specifications etc. effects the occurrence of knock.
-Compression ratio of the engine also strongly effects knock. The higher the CR, the better the thermal efficiency - but the greater the tendency for knock to occur.
-Critical compression ratio - when knock starts. So higher fuel octane quality is required.
-Autoignition of the end gases causes a rapid increase of p, producing p waves which resonate in the combustion chamber at a frequency of between 5000 - 8000 Hz, depending on the geometry of the chamber
Knock results in an increase of T in the cylinder and causes a severe damage to engine components like cylinder head gasket, piston, spark plugs etc.

Octane number:

-In 1929 Octane scale was proposed by Graham Edgar. In this scale two paraffinic HCs have been selected as standards (PRF, primary reference fuels)- iso-octane (2-2-4 trimethyl pentane) with very high resistance to knock (arbitrary assigned a value of 100) and n-heptane with extremely low knock resistance (assigned a value of 0).
-Octane number of the fuel is the volume percentage of iso-octane in a blend with n-heptane (PRF), that shows the same antiknock performance as test fuel tested in standard engine and standard conditions.
-Test engine for determining Octane values, was developed by Cooperative Fuel Research Committee (CFR). It is a single cylinder, variable CR engine.
-Two different test conditions specifies the Research Octane Number (RON) and the Motor Octane Number (MON)
-Antiknock Index = (RON + MON) / 2
-TEL is added to the PRF to increase the ON above 100 or n-heptane is added to the sample to reduce ON below 100, then nonlinear extrapolation is applied
ON can be increased by antiknock agents - at less expense than modifying HC composition by refinery process.
Most effective agents are lead alkyls -
TEL - tetraethyl lead, $(C_2H_5)_4$ Pb TML -
tetramethyl lead,

Cetane number:

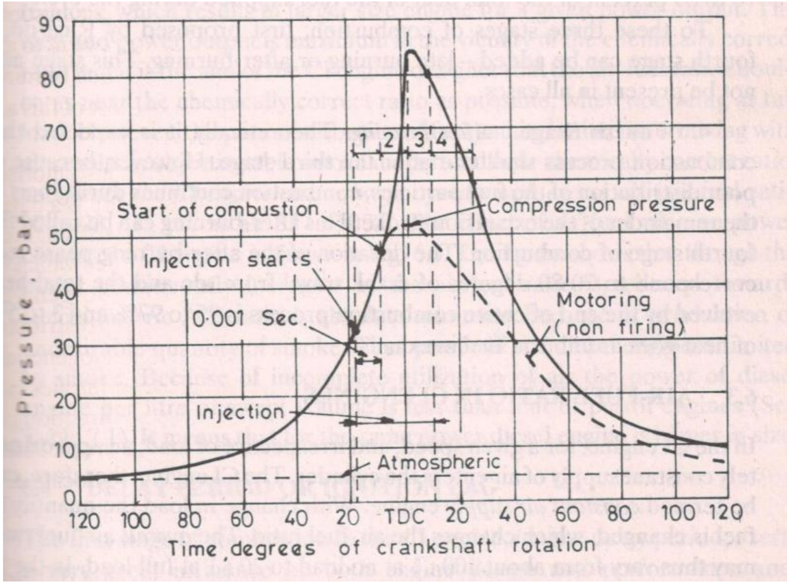
-Cetane number is used to specify the ignition quality of diesel fuel.
-Running on low Cetane number will produce cold start problems. Peak cylinder pressure, combustion noise and HC emissions will increase -more fuel will be injected before ignition, less time for combustion.
-Higher CN results in a sooner ignition - extremely high CN may ignite before adequate Fuel- Air mixing can take place - higher emissions. Power output can be reduced if burning starts too early.
Cetane number is in the range of,

50 - 60 for high speed Diesel engines 25 - 45 for low speed Diesel engines Normal Diesel fuel CN is 40 - 55

*Stages of combustion in CI engine

1. *Ignition delay period:*

The period between the start of fuel injection into the combustion chamber and the start of combustion is termed as ignition delay period. The start of combustion is determined from the change in slope on p-θ diagram or from heat release analysis of the p-θ data, or from luminosity detector in experimental conditions. Start of injection can be determined by a needle-lift indicator to record the time when injector needle lifts off its seat. Start of combustion is more difficult to determine precisely. It is best identified from the change in slope of heat release rate, determined from cylinder pressure data. In DI engines ignition is well defined, in IDI engines ignition point is harder to identify



Stages of combustion in CI engine

Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid is released.

Physical processes are fuel spray atomization, evaporation and mixing of fuel vapour with cylinder air.

Good atomization requires high fuel-injection pressure, small injector hole, optimum fuel viscosity, high cylinder pressure (large divergence angle).

Rate of vaporization of the fuel droplets depends on droplet diameter, velocity, fuel volatility, pressure and temperature of the air.

Chemical processes similar to that described for auto ignition phenomenon in premixed fuel-air, only more complex since **heterogeneous reactions** (reactions occurring on the liquid fuel drop surface) also occur.

Chemical delay is more effective for the duration of the ignition delay period.
Ignition delay period is in the range of
0.6 to 3 ms for low-compression ratio DI diesel engines,
0.4 to 1 ms for high-compression ratio, turbocharged DI diesel engines,
0.6 to 1.5 ms for IDI diesel engines

1. *Rapid or uncontrolled or pre-mixed combustion phase:*

Combustion of the fuel which has mixed with air within flammability limits during ignition delay period occurs rapidly in a few crank angle degrees - high heat release characteristics in this phase. If the amount of fuel collected in the combustion chamber during the ignition delay is much - high heat release rate results in a rapid pressure rise which causes the diesel knock.

.

For fuels with low cetane number, with long ignition delay, ignition occurs late in the expansion stroke - incomplete combustion, reduced power output, poor fuel conversion efficiency. If the pressure gradient is in the range 0.4 - 0.5 MPa/^{o}CA, engine operation is not smooth and diesels knock starts. This value should be in the range 0.2 to 0.3 MPa/^{o}CA for smooth operation (max allowable value is 1.0 MPa/^{o}CA) of the engine.

2. *Controlled or diffusion combustion phase:*

Once the fuel and air which is pre-mixed during the ignition delay is consumed, the burning rate (heat release rate) is controlled by the rate at which mixture becomes available for burning. The rate of burning in this phase is mainly controlled by the mixing process of fuel vapour and air. Liquid fuel atomization, vaporization, pre flame chemical reactions also affect the rate of heat release.

Heat release rate sometimes reaches a second peak (which is lower in magnitude) and then decreases as the phase progresses. Generally it is desirable to have the combustion process near the TDC for low particulate (soot) emissions and high performance (and efficiency).

3. *After burning or late combustion phase:*

Heat release rate continues at a lower rate into the expansion stroke -there are several reasons for this: a small fraction of the fuel may not yet burn, a fraction of the energy is present in soot and fuel-rich combustion products and can be released. The cylinder charge is non- uniform and mixing during this phase promotes more complete combustion and less dissociated product gases. Kinetics is slower.

***** Variables affecting delay period

(i) Cetane number

Both physical and chemical properties of the fuel are important. Ignition quality of the fuel is defined by its cetane number. Straight chain parafinic compounds (normal alkanes) have highest ignition quality, which improves as the chain length increases. Aromatic compounds, alcohols have poor ignition quality.

-Cetane number can be increased by ignition-accelerating additives like organic peroxides, nitrates, nitrites and various sulphur compounds. Most important (commercially) is alkyl nitrates – about 0.5% by vol in a distillate fuel increase CN by 10.
-Normal diesel fuel has CN of 40 to 55 (high speed 50 – 60, low speed 25 – 45

(ii) Injection timing

-At normal operating conditions min ignition delay (ID) occurs with start of injection at 10 to 15 ^{O}CA BTDC
-Cylinder temperature and pressure drops if injection is earlier or later (high at first but decrease as delay proceeds)

(iii) Injection quantity (load)

-Reducing engine load changes AFR, cools down the engine, reduces wall temperatures, reduces residual gas temperatures and increase ID
-Droplet size, injection velocity and rate Ignition quality within practical limits do not have significant effect on ID
-Increase in injection pressure produces only modest decrease in ID Injector nozzle diameter
-effects of droplet size but has no significant effect on ID

(iv) Intake air temperature and pressure

-Reducing intake air T and p increase ID
-Strong dependence of ID on charge temperature below 1000 K – above this value effect of intake air conditions is not significant.

(v) Engine speed

Increase in engine speed increases the air motion and turbulence, reduces ID time slightly (in ms), in terms of CA degrees ID increases almost linearly.
-A change in engine speed, changes "temp~time" and "pressure~time" relationships

(vi) Combustion chamber design

-Spray impingement on the walls effect fuel evaporation and ID increase in compression ratio, increase p and T and reduces ID
-Reducing stroke volume, increase surface area to volume ratio, increase engine cooling and increase ID

(vii) Swirl rate

-Change of evaporation rate and air-fuel mixing - under normal operating conditions the effect is small.
-At start-up (low engine speed and temperature) more important, high rate of evaporation and mixing is obtained by swirl

(viii) Oxygen concentration

Residual gases reduce O_2 concentration and reducing oxygen concentration increases ID

*Diesel knock

-CI engine detonation occurs in the beginning of combustion
-In CI engine the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally cause audible knock. Rate of pressure rise may reach as high as 10 bar/^{o}CA

High engine vibration is the symptoms of knocking
-no pre-ignition or premature ignition as like SI engine

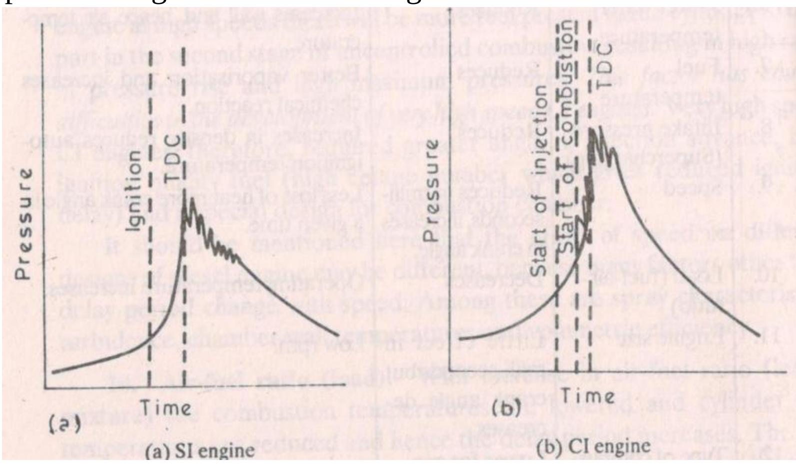


Fig. 28. Detonation in SI and CI engine

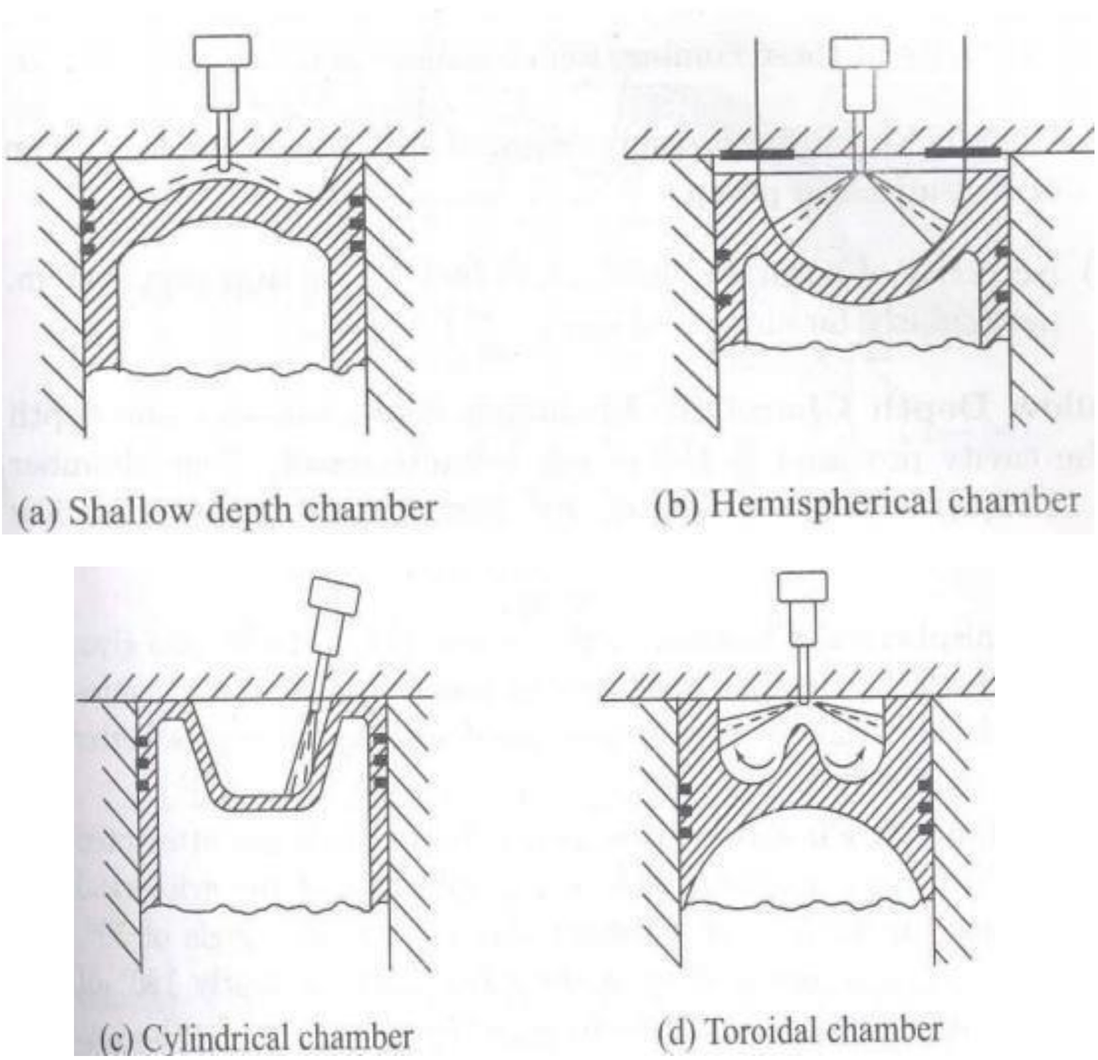
Combustion Chambers for CI Engines

- The most important function of CI engine combustion chamber is **to provide proper mixing of fuel and air in short time.**
- In order to achieve this, an organized air movement called **swirl** is provided to produce high relative velocity between the fuel droplets and the air.

CI engine combustion chambers are classified into two categories

- Direct-Injection (DI)
- Indirect-Injection (IDI)

Direct-Injection (DI)



(a) Shallow depth chamber (b) Hemispherical chamber

(c) Cylindrical chamber (d) Toroidal chamber

- This type of combustion chamber is also called an open combustion chamber.
- In this type the entire volume of the combustion chamber is located in the main cylinder

and the fuel is injected into this volume

- An open combustion chamber is defined as one in which the combustion space is essentially a single cavity with little restriction from one part of the chamber to the other and hence with no large difference in pressure between parts of the chamber during the combustion process.
- In four-stroke engines with open combustion chambers, induction swirl is obtained either by careful formation of the air intake passages or by masking a portion of the circumference of the inlet valve whereas in two-stroke engines it is created by suitable form for the inlet ports.
- These chambers mainly consist of space formed between a flat cylinder head and a cavity in the piston crown in different shapes.
- The fuel is injected directly into space.
- The injection nozzles used for this chamber are generally of multi hole type working at a relatively high pressure (about 200 bar)

Shallow Depth Chamber:

- ✓ In shallow depth chamber the depth of the cavity provided in the piston is quite small.
- ✓ This chamber is usually adopted for large engines running at low speeds.
- ✓ Since the cavity diameter is very large, the squish is negligible.

Hemispherical Chamber:

- ✓ This chamber also gives small squish. However, the depth to diameter ratio for a cylindrical chamber can be varied to give any desired squish to give better performance.

Cylindrical Chamber:

- ✓ This design was attempted in recent diesel engines.
- ✓ This is a modification of the cylindrical chamber in the form of a truncated cone with base angle of 30°.
- ✓ The swirl was produced by masking the valve for nearly 180° of circumference.
- ✓ Squish can also be varied by varying the depth.

Toroidal Chamber:

- ✓ The idea behind this shape is to provide a powerful squish along with the air movement, similar to that of the familiar smoke ring, within the toroidal chamber.
- ✓ Due to powerful squish the mask needed on inlet valve is small and there is better

utilisation of oxygen.

- ✓ The cone angle of spray for this type of chamber is 150° to 160°.

The main advantages of this type of chambers are:

- Minimum heat loss during compression because of lower surface area to volume ratio and hence, better efficiency.
- No cold starting problems.
- Fine atomization because of multi hole nozzle.

The drawbacks of these combustion chambers are:

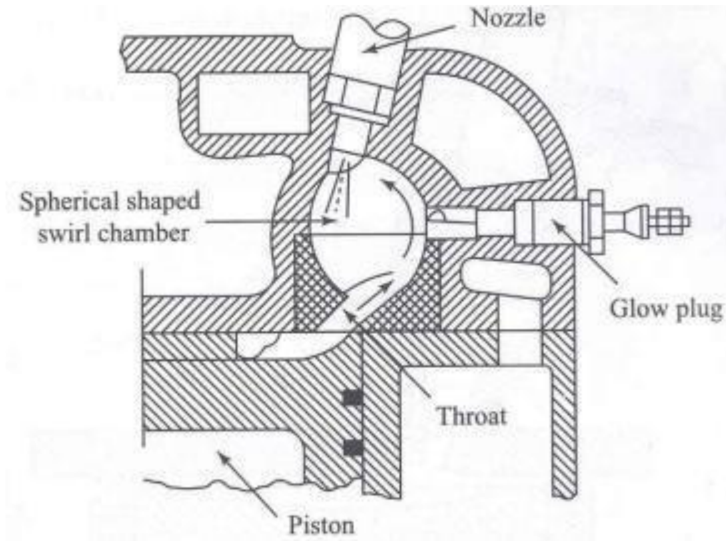
- High fuel-injection pressure required and hence complex design of fuel-injection pump.

Necessity of accurate metering of fuel by the injection system, particularly for small engines.

Indirect-Injection (IDI) Type

- In this type of combustion chambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head.
- The fuel-injection is effected usually into that part of the chamber located in the cylinder head.
- These chambers are classified further into
  - **Swirl chamber** in which compression swirl is generated.
  - **Pre combustion chamber** in which combustion swirl is induced.
  - **Air cell chamber** in which both compression and combustion swirl are induced

Ricardo Swirl Chamber

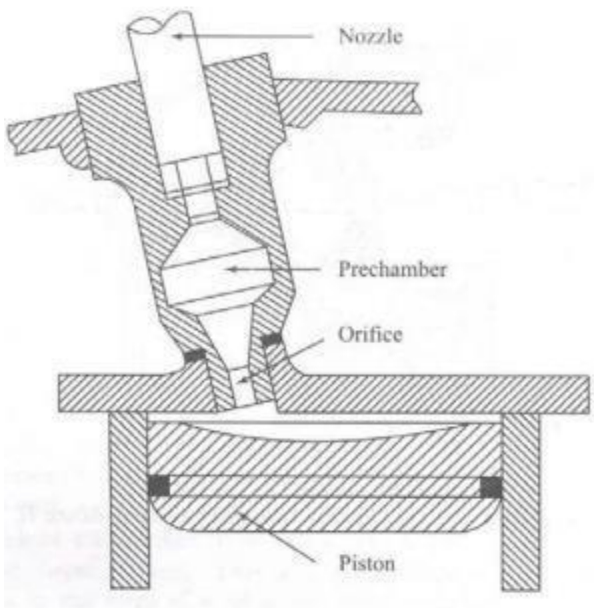


Ricardo Swirl Chamber

- Swirl chamber consists of a spherical shaped chamber separated from the engine cylinder and located in the cylinder head.
- Into this chamber, about 50% of the air is transferred during the compression stroke.
- A throat connects the chamber to the cylinder which enters the chamber in a tangential direction so that the air coming into this chamber is given a strong rotary movement inside the swirl chamber and after combustion, the products rush back into the cylinder through same throat at much higher velocity.

- This causes considerable heat loss to walls of the passage which can be reduced by employing a heat insulated passage.
- This type of combustion chamber finds it application where fuel quality is difficult to control, where reliability under adverse conditions is more important than fuel economy.
- The use of single hole of larger diameter for the fuel spray nozzle is often important consideration for the choice of swirl chamber engine.

Precombustion Chamber



Precombustion Chamber

- Typical pre-combustion chamber consists of an anti chamber connected to the main chamber through a number of small holes (compared to a relatively large passage in the swirl chamber).
- The pre-combustion chamber is located in the cylinder head and its volume accounts for about 40% of the total combustion, space.
- During the compression stroke the piston forces the air into the pre-combustion chamber.
- The fuel is injected into the pre-chamber and the combustion is initiated.
- The resulting pressure rise forces **the flaming droplets together with some air and their combustion products** to rush out into the main **cylinder at high velocity through the small holes.**

- Thus it creates both **strong secondary turbulence** and **distributes the flaming fuel droplets throughout the air** in the main combustion chamber where bulk of combustion takes place.
- About 80% of energy is released in main combustion chamber.
- The rate of pressure rise and the maximum pressure is lower compared to those in open type chamber.
- The initial shock if combustion is limited to pre-combustion chamber only.
- The pre-combustion chamber has multi fuel capability without any modification in the injection system because the temperature of pre-chamber.
- The variation in the optimum injection timing for petrol and diesel operations is only 2 deg. for this chamber compared to 8 to 10 deg in other chamber design.

Advantages:

(i) Due to **short or practically no delay period** for the fuel entering the main combustion space, **tendency to knock is minimum**, and as such running is smooth.

(ii) The combustion in the third stage is rapid.

(iii) The fuel injection system design need not be critical. Because the mixing of fuel and air takes place in pre-chamber,

Disadvantages:

(i) The velocity of burning mixture is too high during the passage from pre-chambers, so the **heat loss is very high**. This causes reduction in the thermal efficiency, which can be offset by increasing the compression ratio.

(ii) **Cold starting will be difficult** as the air loses heat to chamber walls during compression.

The Objective of Good Combustion Chamber Design

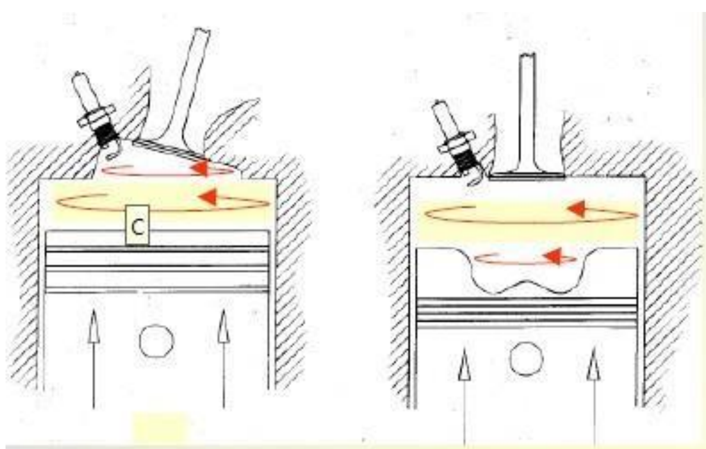
- To optimize the filling and emptying of the cylinder with fresh (unburnt) charge respectively over the engines operating range (All loads and speeds).
- To create the conditions in the cylinder for the air and fuel to mix thoroughly: Getϖ Excited into a highly turbulent state: Burning of the charge to be completed in the shortest possible time.

Important Factors Considered in Combustion Chamber Design

- Heat loss to combustion chamber walls
- Injection pressure
- Nozzle design: Number, size, & arrangement of holes in the nozzle
- Maintenance
- Ease of starting
- Fuel requirement: Ability to use less expensive fuels
- Utilization of air: Ability to use maximum amount of air in cylinder
- Weight relation of engine to power output
- Capacity for variable speed operation
- Smoothness with which forces created by expanding gases are transmitted to the piston.

Swirl

Many engines have a wedge shape cylinder head cavity or a bowl in the piston where the gas ends up at TDC.



During the compression process as the piston approaches TDC more of the air enters the cavity and the air cylinder moment of inertia decreases and the angular velocity (and thus the swirl) increases.

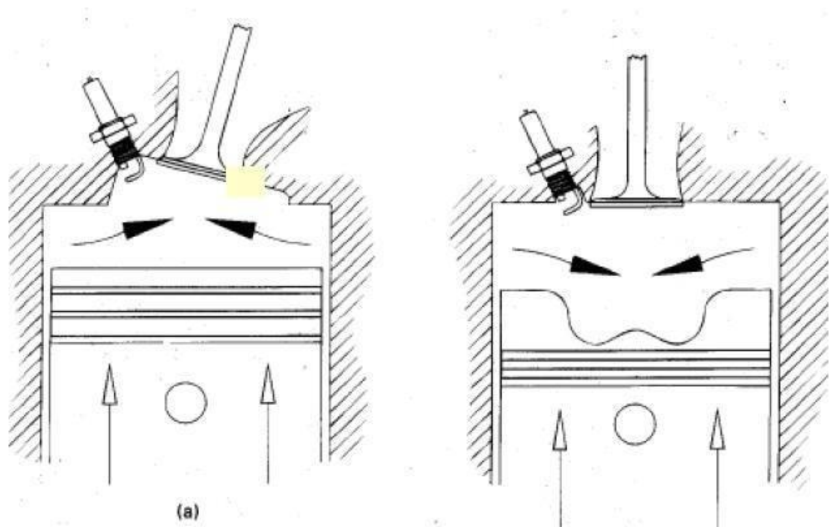
The rotational motion of the fluid mass within the cylinder is called swirl. Swirl greatly enhances the mixing of air and fuel to give a homogeneous mixture within a short time. It is also a main mechanism for very rapid spreading of flame front during the combustion process.

Swirl can be generated by constructing the intake system to give a tangential component to the intake flow as it enters the cylinder. This is done by shaping and contouring intake manifolds, valve ports and piston faces.

Swirl is used to:

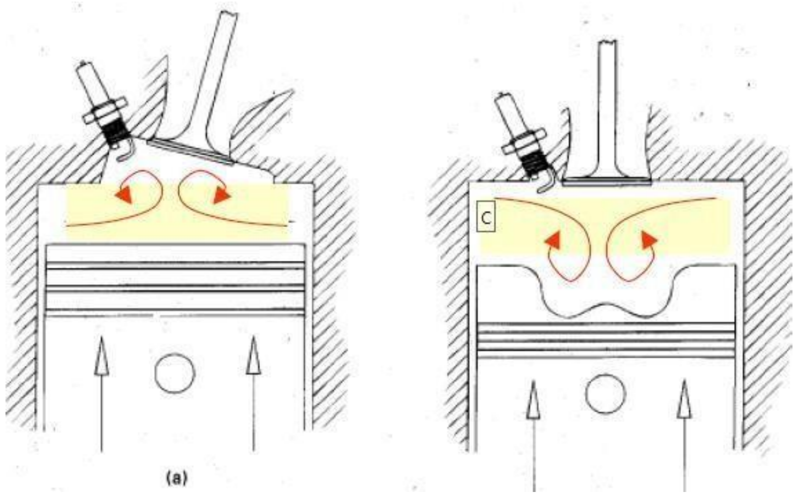
- promote rapid combustion in SI engines
- rapidly mix fuel and air in gasoline direct injection engines
- rapidly mix fuel and air in CI engines

Squish



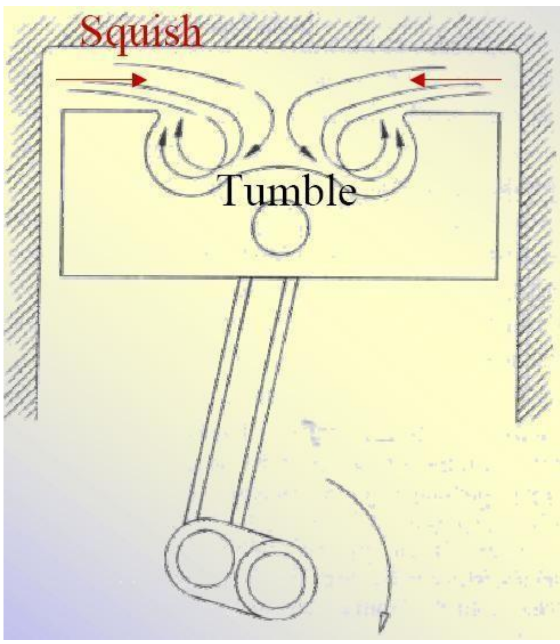
Squish is the radial flow occurring at the end of the compression stroke in which the compressed gases flow into the cavity in the piston or cylinder head.

Tumble



As the piston reaches TDC the squish motion generates a secondary flow called tumble, where rotation occurs about a circumferential axis near the outer edge of the cavity or piston bowl.

Squish and Tumble



Importance of swirl, squish and turbulence

Due to high velocities involved, all flows into, out of and within cylinder are turbulent. The exception to this is those flows in the corners and small crevices of the combustion chamber where the close proximity of the walls dampens out the turbulence.

As a result of turbulence, heat transfer, evaporation, mixing and combustion rates increase. As the engine speed increases, flow rate increases with a corresponding increase in swirl, squish and turbulence. This increases the rate of fuel evaporation, mixing of fuel vapour and air and combustion.

Turbulence in the cylinder is high during intake and decreases as the flow rate slows near BDC. It increases again during compression as swirl, squish and tumble increases near TDC.

The high turbulence near TDC when ignition occurs is very desirable for combustion. It breaks up and spreads the flame front many times faster. The air-fuel is consumed within a short time and self ignition and knock are avoided.

The shape of the combustion chamber plays an important role in generating maximum turbulence and increasing the desired rapid combustion.

The inside surface of most intake manifolds are usually made smooth to maximize the volumetric efficiency. However in some engines where high power is not desirable, the inside surfaces of the manifolds are roughened to promote higher turbulence levels to enhance evaporation and air-fuel mixing.

EXECISE

Part A

1. List out the various factors that influence the flame speed.
2. Mention the stages of combustion in SI engines.
3. What do you meant by delay period? Write down the factors that affects it.
4. Compare Knock in SI and CI engines.
5. What is the difference between pre ignition and auto ignition?
6. What is meant by knock in CI engine?
7. What is knocking? List the reasons for it.
8. Brief about different types of combustion chambers.
9. State the various stages of combustion in S.I. engine.
10. Define Swirl and Squish.

Part B

1. What is meant by abnormal combustion? Explain the phenomena of knock in SIengines.
2. Bring out clearly the process of combustion in CI engines and also explain the various stages of combustion.
3. With an aid of an neat sketch, explain the phenomenon of combustion and knocking in SI engines.
4. With an aid of P- diagram, explain about various stages of combustion in CI engines.
5. What are the stages of combustion in diesel engine. Explain.
6. Discuss how the ignition timing depends on load and speed.
7. Discuss the types of combustion chambers used in IC engines.
8. What are the general principles of SI engine chamber design

MODULE V

Supercharging and Turbocharging: - (Supercharging: Need for supercharging, Effect of supercharging, types of supercharger, methods of supercharging, thermodynamic analysis of supercharged engine cycle, limitations of supercharging, Turbocharging: Effect of turbocharging, methods of turbocharging, thermodynamic analysis of turbocharged engine cycle, limitations of turbocharging, comparison of Supercharging and Turbocharging.)

Supercharging and Turbocharging

An internal combustion engine works by drawing a mixture of air and fuel (the *intake charge*) into its cylinders, compressing that mixture, and then burning it. The more air/fuel mixture that can be crammed into the cylinders to burn, the more power the engine produces. We can increase power in three basic ways: we can improve the engine's ability to draw more air and fuel into the cylinders; we can increase the swept volume of the cylinders (the engine's *displacement*) so you can fit more air and fuel into each cylinder; or you can pump the intake charge into the cylinders under high pressure, squeezing more air and fuel into the available volume.

Forcing air (or air-fuel mixture) through an engine's intake valves at higher than atmospheric pressure is called *supercharging*.

A *supercharger*, therefore, is a mechanical air compressor that pressurizes the air going into the engine's intake manifold. There are several types of compressor used for car and truck engines, the most common being Roots-type, centrifugal, and Lysholm-type compressors; each has pros and cons, but they have the same basic purpose.

A supercharger is an air compressor and it requires a source of power to operate the compressor mechanism.

Most automotive superchargers are run by a drive belt (or occasionally a train of gears) operated by the engine, much like a power steering pump or air conditioning compressor.

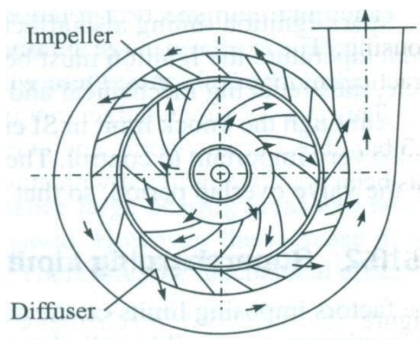
An alternative is to run the supercharger with a turbine wheel placed in the engine's exhaust manifold, turned by the flow of burned exhaust gases rushing of the engine. An exhaust-driven supercharger is called a *turbocharger*. (Years ago, they were often called *turbo-superchargers*, but that term has fallen out of common use, although it is occasionally applied to combinations of engine-driven and exhaust-driven superchargers.)

Types of Superchargers

CentrifugalType

Centrifugal Supercharging compresses the air inside the case of the supercharger using an impeller. Then, discharges the air out of a scroll to the motor. This design is similar to turbo-charging except for centrifugal superchargers don't use the exhaust to build pressure, they use a belt, driven by the crank pulley to spin the impeller. Centrifugal supercharging is definitely one of the more user-friendly ways to supercharge your motor. The ability to change the impeller sizes and to spin the impeller at different

speeds creates a more inexpensive way to have flexibility in your power curve. Centrifugal superchargers have become the standard for street use and light-duty racing and far outsell all other types of superchargers.



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Recommended Usage:

Street Use - Commercial Use - Road Racing - Drag Racing

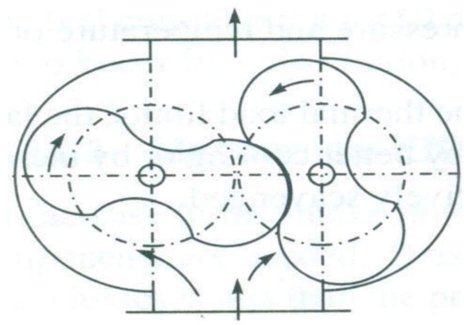
Positive Points:

- Lots of Flexibility for Power Adjustments
- Lower Discharge Temperatures
- Great Reliability
- Easy to install

Negative Points:

- Not as much power at low RPMs as Roots or Screw type superchargers

Roots Type Supercharging



The Roots Type Supercharger is the first style supercharger that was ever used and can be dated back to the 1880s when the Roots brothers designed it as an air conveyor for mine shafts. Roots blowers act like air pumps (not compressors), and In general, Roots blowers have a two or three lobe rotor design, depending on the size of the case. Roots blowers will give you positive pressure to your motor from just a crack of the throttle, and will give all that they have to offer at full throttle no matter what the rpm of the motor. Roots Type Superchargers may look awesome hanging out of the hood and are great for those looking for drastic power increases at lower RPMs. Roots blowers are also extremely reliable and require very little maintenance, which is why Ford, GM, Mercedes, Jaguar, and Austin Martin have all featured Roots blowers as original equipment on select high performance vehicles.

Recommended Usage:

Street Use - Towing - Extreme Drag Racing - Show Vehicles

Positive Points:

- Boost throughout the entire RPM range, right off of idle
- Highest Potential for Gain (A must-have for all-out drag racing)
- Excellent Reliability
- Great Appearance & Stature (Most common supercharger type for show vehicles)

Negative Points:

- Sometimes Violent Throttle Response
- Lower boost ratings at higher RPMs
- Higher Than Normal Discharge Temperatures
- Lengthy installation times

Screw Type Supercharging

Screw type superchargers are derived from the Roots type concept but with vast improvements for street use. Although from the outside, screw type superchargers may look a lot like Roots type superchargers, on the inside you will find a twin-screw design that compresses air unlike Roots type superchargers which pump the air into the motor. Screw type superchargers have an axial-flow design that compresses the air as it moves between the screws to create positive pressure without creating the heat that Roots type superchargers can create. The Screw type supercharger's ability to produce a dramatic increase of power from idle and throughout the rest of the power curve make them a great choice for heavy vehicles, towing or commercial use.

Recommended Usage:

Street Use - Towing - Road Racing - Drag Racing

Positive Points:

Great Power at Low RPMs (Great for Towing)

- Factory Fit & Appearance
- Great Reliability

Negative Points:

- The Power Doesn't Keep Climbing in the High RPMs (Power curve is very flat)
- Challenging To Achieve High Boost Levels or CFMs
- Lengthy installation times

Limitations of Supercharging

- Thermal load on various parts of the engine increases
- Oil or water is circulated through a hollow spaced provided in the piston crown for cooling
- Piston crown and seat and the edges of the exhaust valves are made of better materials that can withstand higher temperatures
- The permissible extent of supercharging depends upon the ability of the engine to withstand the increasing gas loading and thermal stresses
- Durability, reliability and fuel economy are the main considerations that limit the degree of supercharging of an engine

Methods of Turbocharging

The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing density of the intake gas (usually air) allowing more power per engine cycle.

The turbocharger's compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure. This results in a greater mass of air entering the cylinders on each intake stroke. The power needed to spin the centrifugal compressor is derived from the kinetic energy of the engine's exhaust gases.

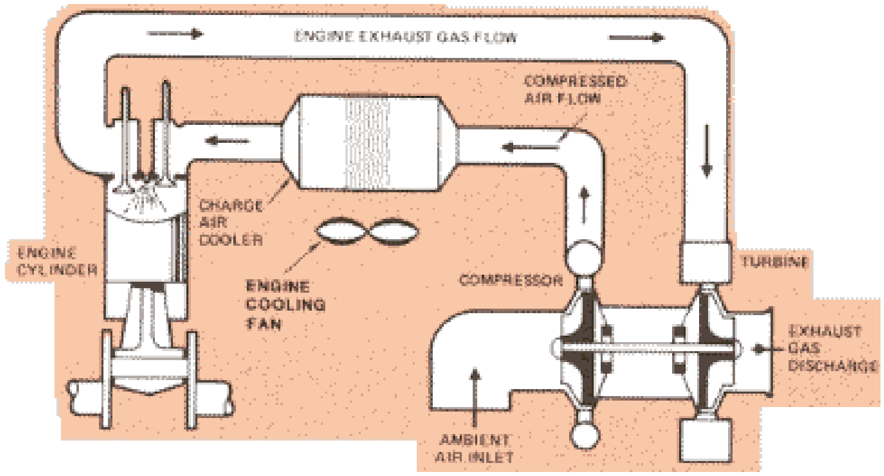
A turbocharger may also be used to increase fuel efficiency without increasing power. This is achieved by recovering waste energy in the exhaust and feeding it back into the engine intake. By using this otherwise wasted energy to increase the mass of air, it becomes easier to ensure that all fuel is burned before being vented at the start of the exhaust stage. The increased temperature from the higher pressure gives a higher Carnot efficiency.The control of turbochargers has changed dramatically over the 100-plus years of its use. Modern turbochargers can use wastegates, blow-off valves and variable geometry.

The reduced density of intake air is often compounded by the loss of atmospheric density seen with elevated altitudes. Thus, a natural use of the turbocharger is with aircraft engines. As an aircraft climbs to higher altitudes, the pressure of the surrounding air quickly falls off. At 18,000 feet (5,500 m), the air is at half the pressure of sea level, which means that the engine produces less than half-power at this altitude.

The turbocharger has three main components:

1. The turbine, which is almost always a radial inflow turbine (but is almost always a single-stage axial inflow turbine in large Diesel engines)
2. The compressor, which is almost always a centrifugal compressor

The center housing/hub rotating assembly



Many turbocharger installations use additional technologies, such as wastegates, intercooling and blow- off valves

EXERCISE

Part A

1. Why is Morse test not suitable for single cylinder engine?
2. What are the limitations of supercharging in an IC engine?
3. An indicator diagram taken from a single cylinder, four strokes CI engine has length of 100 mm and a area of 2000mm. The indicator pointer deflects a distance of 10 mm for pressure

increment of 2 bars in the cylinder. Calculate mean effective pressure in bar.

4. Define – mean effective pressure.
5. What do you mean by octane number and cetane number in fuels?
6. Differentiate turbocharging from supercharging.
7. How do you increase volumetric efficiency of an engine?
8. Compare supercharging and turbocharging in engines.
9. Explain different methods of turbocharging.
10. State any two tests used for finding the BP and IP of an engine.

Part B

(i) Explain the effect of the compression ratio and engine speed on the performance of an SI engine.
(ii) Draw a typical performance map for a four – stroke fast burn SI engine showing the contours of constant BSFC.

1. (i) Briefly explain the working of Centrifugal supercharger and Roots supercharger. (ii)Explain with a neat sketch the principle of exhaust turbo charging of a single-cylinder engine.

2. An eight cylinder, four stroke engine of 9 cm and 8 cm219stroke with a compression ratio is tested at 4500 rpm on a dynamometer which has 54 cm arm. During a 10 minutes test the dynamometer scale beam reading was 42 kg and the engine consumed 4.4 Kg of gasoline having a calorific value of 44000 KJ/KG. Air 27 °C and 1 bar was supplied to the carburetor at the rate of 6 Kg/min. Find (i) brake power delivered, (ii) brake mean effective pressure, (iii) brake specific fuel consumption, (iv) brake thermal efficiency, (v) Volumetric efficiency, and (vi) Air: Fuel ratio.
3. Explain the following in detail :
   (i) Supercharger, (ii) Turbocharger and (c) Engine Performance Maps
4. Explain briefly the supercharging of SI engine.
5. How do you measure the mass of air supplied to an IC engine.
6. Describe how the IP of a multi cylinder engine is measured
7. Describe with suitable sketch, the working of brake rope dynamometer
8. Discuss in detail the limits, applications and arrangements of supercharging in SIengines.
9. Explain the types of turbocharging methods with reference to advantages and limitations.
10. Explain with a neat sketch
    (i) Hydraulic Dynamometer (ii) Eddy current Dynamometer
11. List the emissions that are considered significant for measurement and performance study.