Automotive Engines

UNIT-I: CONSTRUCTION AND OPERATION

Constructional details of spark ignition (SI) and compression ignition (CI) engines. Working principles. Two stroke SI and CI engines – construction and working. Comparison of SI and CI engines and four stroke and two stroke engines. Engine classification, firing order. Otto, diesel and dual cycles.

ENERGY CONVERSION

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

Definition of 'Engine'

An engine is a device which transforms one form of energy into another form. However, while transforming energy from one form to another, the efficiency of conversion plays an important role. Normally, most of the, engines convert thermal energy into mechanical work and therefore they are called 'heat engines'.

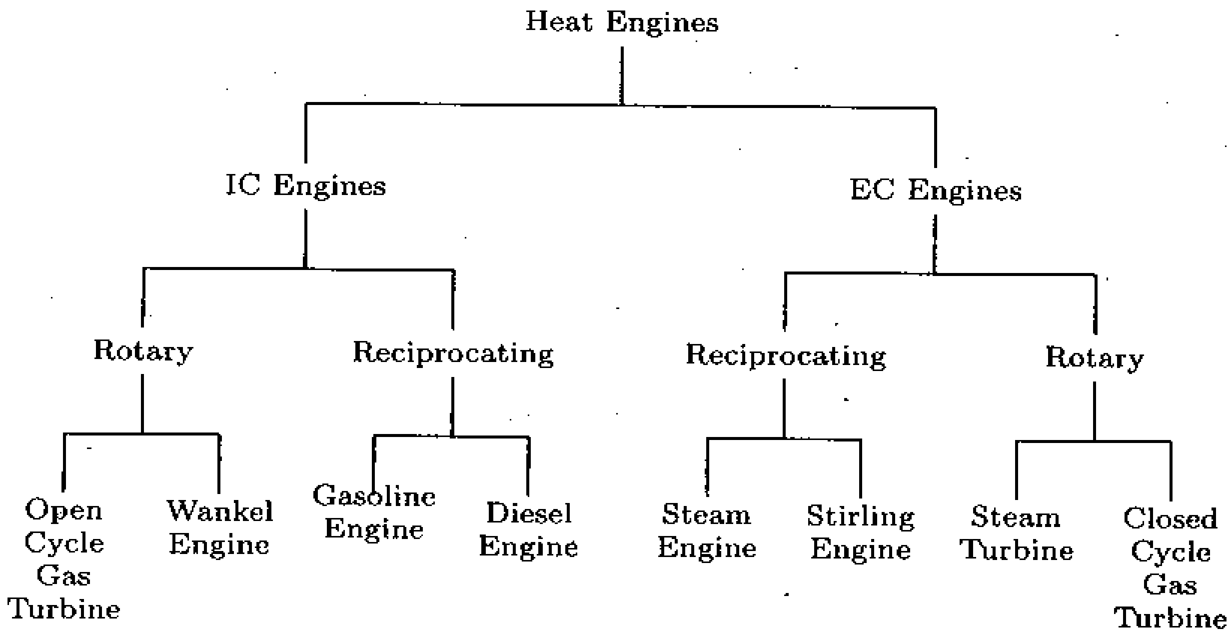
Definition of 'Heat Engine’

Heat engine is a device which transforms the chemical energy of& fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine. Heat engines can be broadly classified into two categories:

1. Internal Combustion Engines (IC Engines)
2. External Combustion Engines (EC Engines)

Classification and Some Basic Details of Heat Engines

i. Rotary engines
ii. Reciprocating engines



External Combustion and Internal Combustion Engines

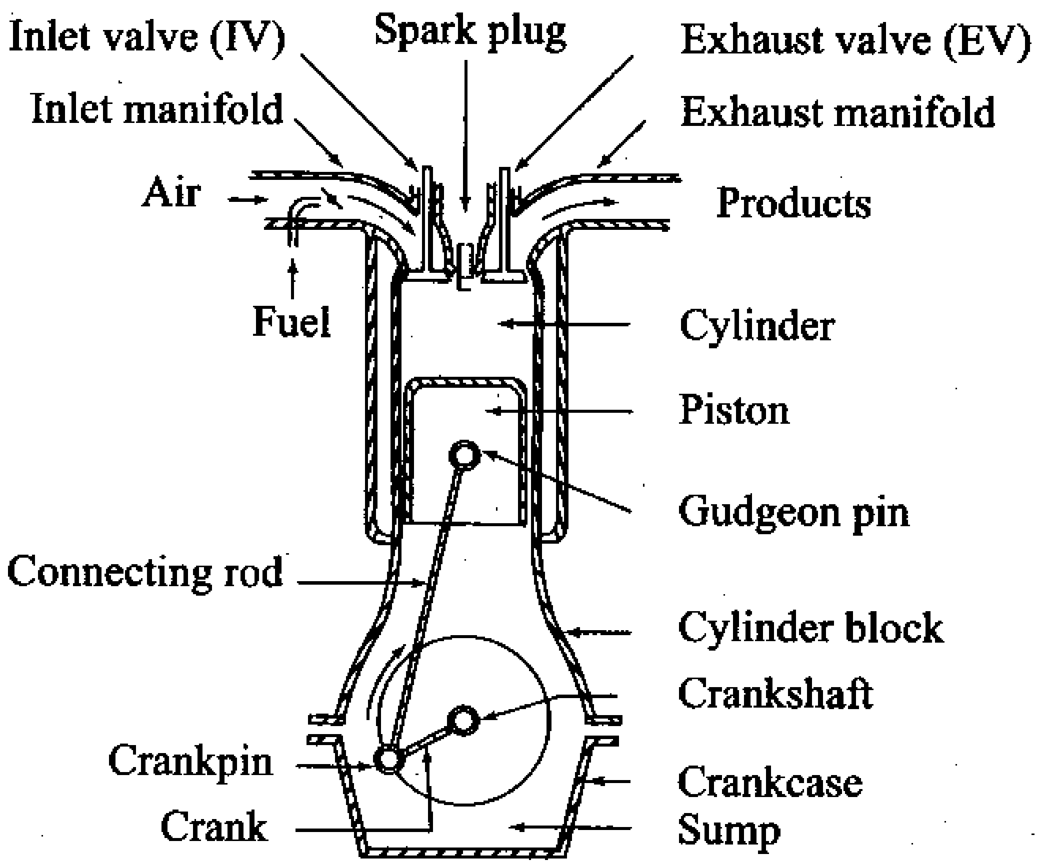
External combustion engines are those in which combustion takes place outside the engine whereas in internal combustion engines combustion takes place within the engine. For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine.
In case of gasoline or diesel engines, the products of combustion generated by the combustion of fuel and air within the cylinder form the working fluid.

BASIC ENGINE COMPONENTS AND NOMENCLATURE

Even though reciprocating internal combustion engines look quite simple, they are highly complex machines. There are hundreds of components which have to perform their functions satisfactorily to produce output power. There are two typ.es of engines, viz., spark-ignition (SI) and compression-ignition (CI) engine. Let us now go through the important engine components and the nomenclature associated with an engine.
Cylinder Block: The cylinder block is the main supporting structure for the various components. The cylinder of a multicylinder engine is cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling. Cylinder head gasket is incorporated between the cylinder block and cylinder head. The cylinder head is held tight to the cylinder

block by number of bolts or studs. The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the crankcase. The inner surface of the cylinder block which is machined and finished accurately to cylindrical shape is called bore or face.

ENGINE COMPONENTS



Cylinder: As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and subjected to different thermodynamic processes.

Combustion Chamber: The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

Inlet Manifold: The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.

Exhaust Manifold: The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

Inlet and Exhaust Valves: Valves are commonly mushroom shaped poppet type. They are provided either on the cylinder head or on the side of the cylinder for regulating the charge coming into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve) from the cylinder.

Spark Plug: It is a component to initiate the combustion process in Spark-Ignition (SI) engines and is usually located on the cylinder head.

Connecting Rod: It interconnects the piston and the crankshaft and transmits the gas forces from the piston to the crankshaft.

Crankshaft: It converts-the reciprocating motion of the piston into useful rotary motion of the output shaft. In the crankshaft of a single cylinder engine there is a pair of crank arms and balance weights. The balance weights are provided for static and dynamic balancing of the rotating system. The crankshaft is enclosed in a crankcase.

Piston Rings: Piston rings, fitted into the slots around the piston, provide a tight seal between the piston and the cylinder wall thus preventing leakage of combustion gases (Fig. 1.3).

Gudgeon Pin: It forms the link between the small end of the connecting rod and the piston.

Camshaft: The camshaft and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears.

Cams: These are made as integral parts of the camshaft and are designed in such a way to open the valves at the correct timing and to keep them open for the necessary duration.

Fly Wheel: The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change in the angular velocity of the shaft. In order to achieve a uniform torque an inertia mass in the form of a wheel is attached to the output shaft and this wheel is called the flywheel.

Cylinder Bore (d) **:** The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d and is usually expressed in millimeter (mm).

Piston Area (A) **:** The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter (cm^2).

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

Stroke to Bore Ratio : L/d ratio is an important parameter in classifying the size of the engine.

If $d < L$, it is called under-square engine. If $d = L$, it is called square engine. If $d > L$, it is called over-square engine.

An over-square engine can operate at higher speeds because of larger bore and shorter stroke.

Dead Centre: The position of the working piston and the moving parts which are mechanically connected to it, at the moment when the direction

They are:

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

(i) *Top Dead* Centre *(TDC):* It is the dead centre when the piston is farthest from the crankshaft. It is designated as *TDC* for vertical engines and Inner Dead Centre *(IDC)* for horizontal engines.

(ii) *Bottom Dead Centre (BDC):* It is the dead centre when the piston is nearest to the crankshaft. It is designated as *BDC* for vertical engines and Outer Dead Centre (*ODC*) for horizontal engines.

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

$$V_s = A \times L = \frac{\pi}{4} d^2 L \qquad (1.1)$$

Cubic Capacity or Engine Capacity : The displacement volume of a cylinder multiplied by number of cylinders in an engine will give the cubic capacity or the engine capacity. For example, if there are K cylinders in an engine, then

$$\text{Cubic capacity} = V_s \times K$$

Clearance Volume (V_C) : The nominal volume of the combustion chamber above the piston when it is at the top dead centre is the clearance volume. It is designated as V_C and expressed in cubic centimeter (cc).

It is designated by the letter r.

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

COMPARISONS OF CI AND SI ENGINES

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

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

COMPARISON OF FOUR-STROKE AND TWO-STROKE ENGINES

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

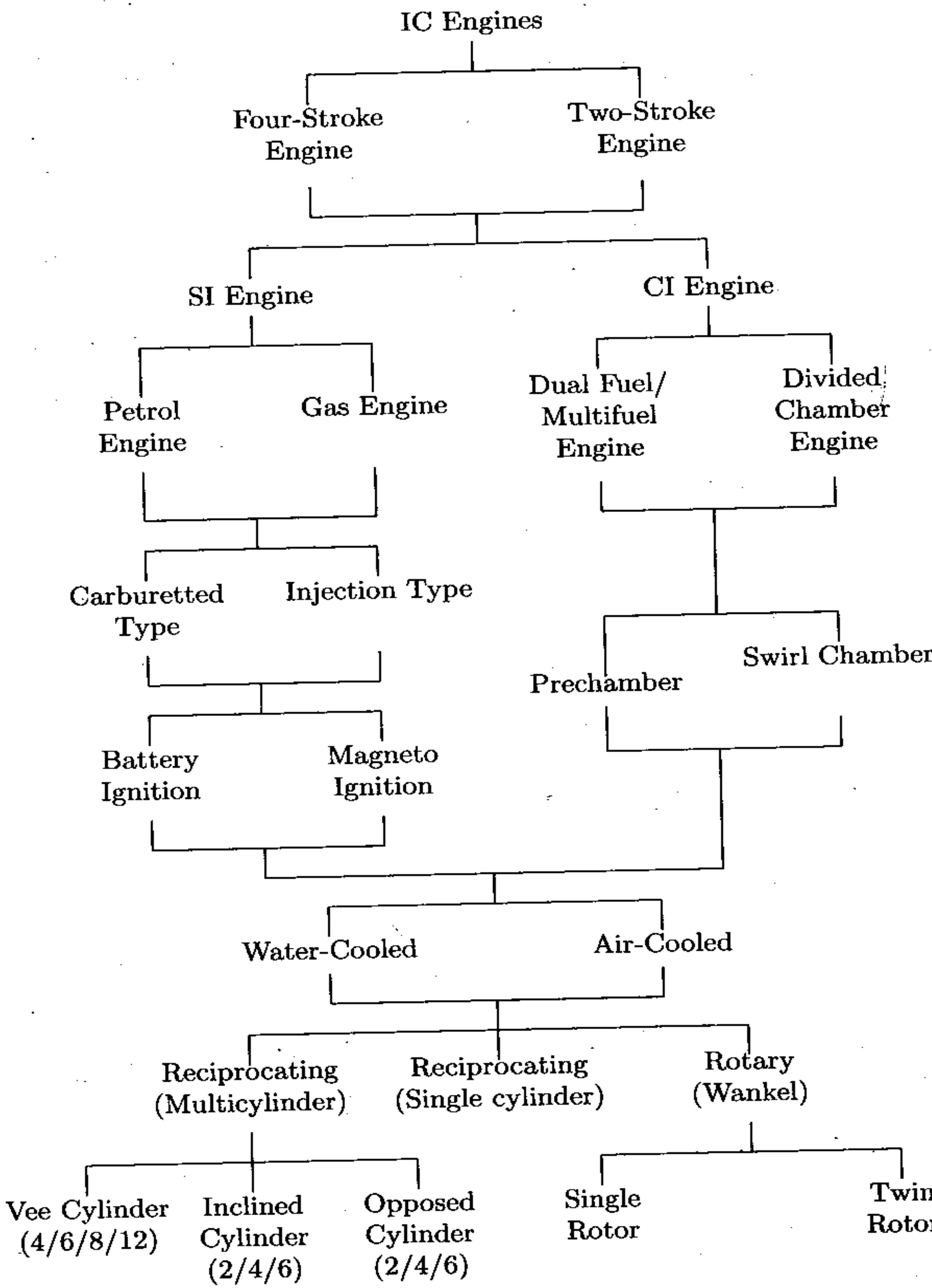
Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lower rate of wear and tear.	Because of one power stroke in one revolution greater cooling and lubrication requirements. Higher rate of wear and tear.
Four-stroke engines have valves and valve actuating mechanisms for opening and closing of the intake and exhaust valves.	Two-stroke engines have no valves but only ports (some two-stroke engines are fitted with conventional exhaust valve or reed valve).
Because of comparatively higher weight and complicated valve mechanism, the initial cost of the engine is more.	Because of light weight and simplicity due to the absence of valve actuating mechanism, initial cost of the engine is less.
Volumetric efficiency is more due to more time for induction.	Volumetric efficiency is low due to lesser time for induction.
Thermal efficiency is higher; part load efficiency is better.	Thermal efficiency is lower; part load efficiency is poor.
Used where efficiency is important, viz., in cars, buses, trucks, tractors, industrial engines, aeroplanes, power generation etc.	Used where low cost, compactness and light weight are important, viz., in mopeds, scooters, motorcycles, hand sprayers etc.

Type of fuel used

Based on the type of fuel used engines are classified as

(i) Engines using volatile liquid fuels like gasoline, alcohol, kerosene, benzene etc.
The fuel is generally mixed with air to form a homogeneous charge in a carburettor outside the cylinder and drawn into the cylinder in its suction stroke. The charge is ignited near the end of the compression stroke by an externally applied spark and therefore these engines are called spark-ignition engines.

(ii) Engines using gaseous fuels like natural gas, Liquified Petroleum Gas



IC Engines
Four-Stroke Engine
Two-Stroke Engine
SI Engine
CI Engine
Petrol Engine
Gas Engine
Dual Fuel/ Multifuel Engine
Divided Chamber Engine
Carburetted Type
Injection Type
Prechamber
Swirl Chamber
Battery Ignition
Magneto Ignition
Water-Cooled
Air-Cooled
Reciprocating (Multicylinder)
Reciprocating (Single cylinder)
Rotary (Wankel)
Vee Cylinder (4/6/8/12)
Inclined Cylinder (2/4/6)
Opposed Cylinder (2/4/6)
Single Rotor
Twin Rotor

The gas is mixed with air and the mixture is introduced into the cylinder during the suction process. Working of this type of engine is similar to that of the engines using volatile liquid fuels (SI gas engine).

(iii) Engine using solid fuels like charcoal, powdered coal etc.
Solid fuels are generally converted into gaseous fuels outside the engine in a separate gas producer and the engine works as a gas engine.

(iv) Engines using viscous (low volatility at normal atmospheric temperatures) liquid fuels like heavy and light diesel oils.
The fuel is generally introduced into the cylinder in the form of minute droplets by a fuel injection system near the end of the compression process. Combustion of the fuel takes place due to its coming into contact with the high temperature compressed air in the cylinder. Therefore, these engines are called compression-ignition engines.

(v) Engines using two fuels (dual-fuel engines)
A gaseous fuel or a highly volatile liquid fuel is supplied along with air during the suction stroke or during the initial part of compression through a gas valve in the cylinder head and the other fuel (a viscous liquid fuel) is injected into the combustion space near the end of the compression stroke (dual-fuel engines).

ENGINE PERFORMANCE PARAMETERS

The engine performance is indicated by the term *efficiency*, η. Five important engine efficiencies and other related engine performance parameters are given below:

(i)	Indicated thermal efficiency	(η_{ith})
(ii)	Brake thermal efficiency	(η_{bth})
(iii)	Mechanical efficiency	(η_m)
(iv)	Volumetric efficiency	(η_v)
(v)	Relative efficiency or Efficiency ratio	(η_{rel})
(vi)	Mean effective pressure	(p_m)
(vii)	Mean piston speed	$(\overline{s}_p)$
(viii)	Specific power output	(P_s)
(ix)	Specific fuel consumption	(sfc)
(x)	Inlet-valve Mach Index	(Z)
(x)	Fuel-air or air-fuel ratio	$(F/A$ or $A/F)$
(xi)	Calorific value of the fuel	(CV)

Indicated thermal efficiency

Indicated thermal efficiency is the ratio of energy in the indicated power, *ip*, to the input fuel energy in appropriate units.

$$[ht]\eta_{ith} = \frac{ip \text{ [kJ/s]}}{\text{energy in fuel per second [kJ/s]}}$$

Brake thermal efficiency

Brake thermal efficiency is the ratio of energy in the brake power, *bp*, to the input fuel energy in appropriate units.

$$\eta_{bth} = \frac{bp}{\text{Mass of fuel/s} \times \text{ calorific value of fuel}}$$

Mechanical efficiency

Mechanical efficiency is defined as the ratio of brake power (delivered power) to the indicated power (power provided to the piston).

$$\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp}$$

$$fp = ip - bp$$

It can also be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency.

Volumetric efficiency

Volumetric efficiency is defined as the volume flow rate of **air** into the intake system divided by the rate at which the volume is displaced by the system.

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_{disp} N/2}$$

Where p_a is the inlet density

An alternative equivalent definition for volumetric efficiency is

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_d}$$

It is to be noted that irrespective of the engine whether SI, CI or gas engine, *volumetric rate of air flow is what to be taken into account* and not the mixture flow.

Relative Efficiency or Efficiency Ratio

Relative efficiency or efficiency ratio is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle. The efficiency ratio is a very useful criterion which indicates the degree of development of the engine.

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air-standard efficiency}}$$

Mean Effective Pressure

Mean effective pressure is the average pressure inside the cylinders of an internal combustion engine based on the calculated or measured power output. It increases as manifold pressure increases. For any particular engine, operating at a given speed and power output, there will be a specific indicated mean effective pressure, imep, and a corresponding brake mean effective pressure, *bmep.* They are derived from the indicated and brake power respectively.

$$p_{im} = \frac{60000 \times ip}{LAnK}$$

Similarly,

$$p_{bm} = \frac{60000 \times bp}{LAnK}$$

where
ip = indicated power (kW)
p_{im} = indicated mean effective pressure (N/m^2)
L = length of the stroke (m)
A = area of the piston (m^2)
N = speed in revolutions per minute (rpm)
n = Number of power strokes
$N/2$ for 4-stroke and N for 2-stroke engines
K = number of cylinders

Another way of specifying the indicated mean effective pressure is from the knowledge of engine indicator diagram (*p-V* diagram). In this case, p_{im}, may be defined as

$$p_{im} = \frac{\text{Area of the indicator diagram}}{\text{Length of the indicator diagram}}$$

where the length of the indicator diagram is given by the difference between the total volume and the clearance volume.

Mean Piston Speed

It is defined as

$$\bar{s}_p = 2LN$$

where *L* is the stroke and *N* is the rotational speed of the crankshaft in rpm.

Specific Power Output

Specific power output of an engine is defined as the power output per unit piston area and is a measure of the engine designer's success in using the available piston area regardless of cylinder size.

Specific power output, $P_s = bp/A$

Specific Fuel Consumption

The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilowatt-hour. It is an important parameter that reflects how good the engine performance is.

$$\text{sfc} = \frac{\text{Fuel consumption per unit time}}{\text{Power}}$$

Fuel-Air or Air-Fuel Ratio

The relative proportions of the fuel and air in the engine are very important from the standpoint of combustion and the efficiency of the engine. This is expressed either as a ratio of the mass of the fuel to that of the air or vice versa.

In the SI engine the fuel-air ratio practically remains a Constant over a wide range of operation. In CI engines at a given speed the air flow does not vary with load; it is the fuel flow that varies directly with load. Therefore, the term fuel-air ratio is generally used instead of air-fuel ratio.

The ratio of actual fuel-air ratio to stoichiometric fuel-air ratio is called equivalence ratio and is denoted by φ

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichiometric fuel-air ratio}}$$

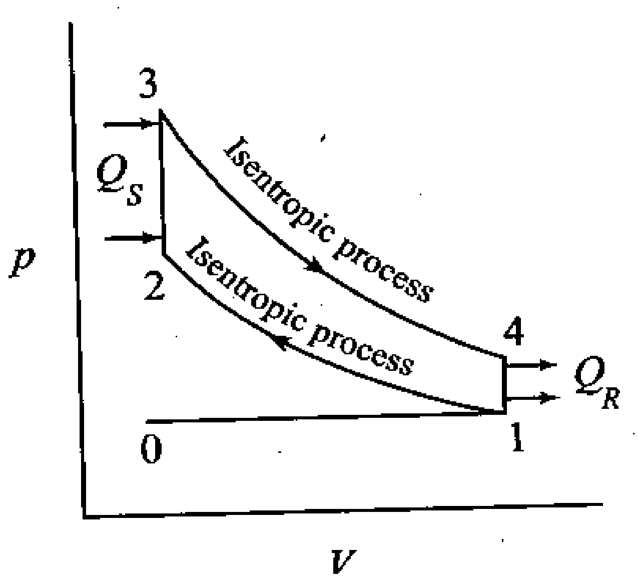
Accordingly, $\varphi = 1$ means stoichiometric (chemically correct) mixture, $\varphi < 1$ means lean mixture and $\varphi > 1$ means rich mixture.

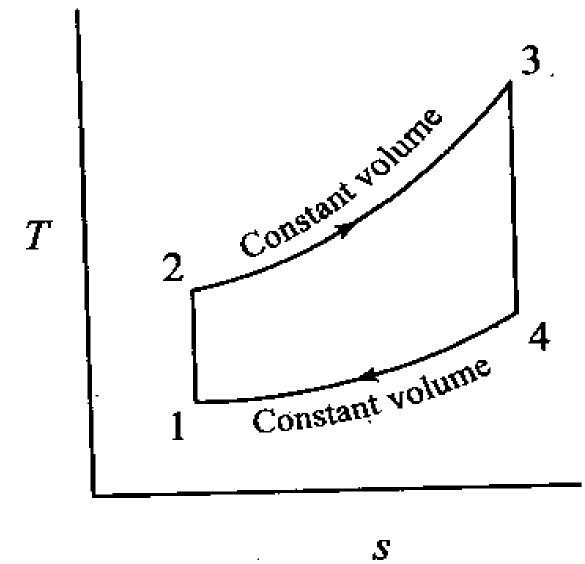
Calorific Value

Calorific value of a fuel is the thermal energy released per unit quantity of the fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. Other terms used for the calorific value are heating value and heat of combustion.

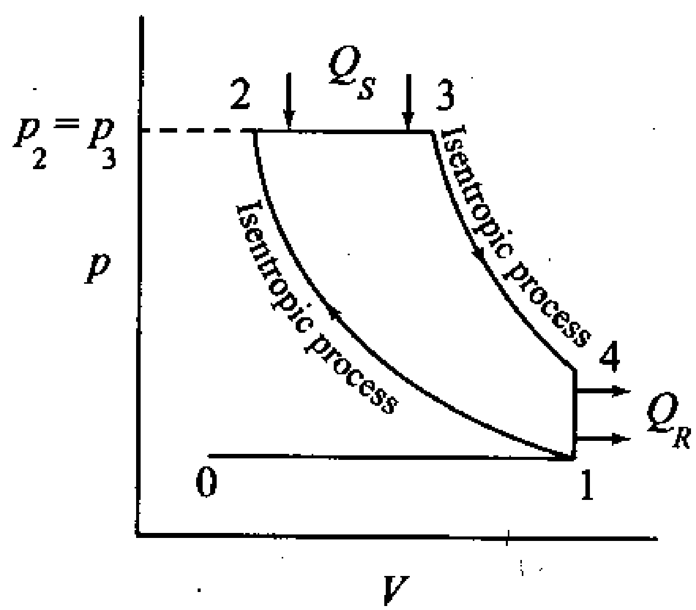
When the products of combustion are cooled to 25 °C practically all the water vapour resulting from the combustion process is condensed. The heating value so obtained is called the higher calorific value or gross calorific value of the fuel. The lower or net calorific value is the heat released when water vapour in the products of combustion is not condensed and remains in the vapour form.

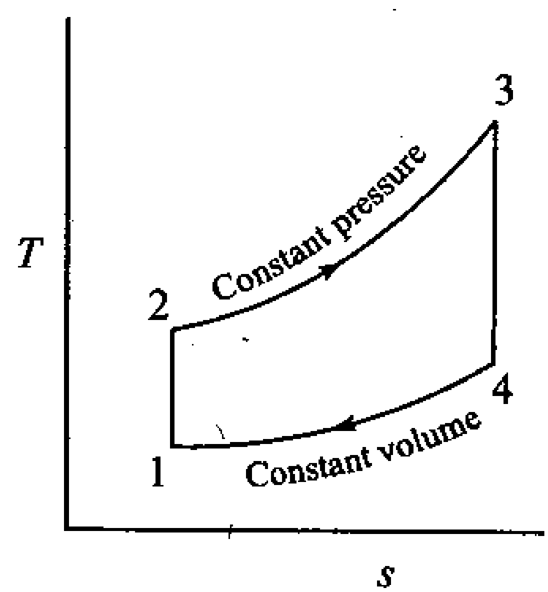
The otto cycle



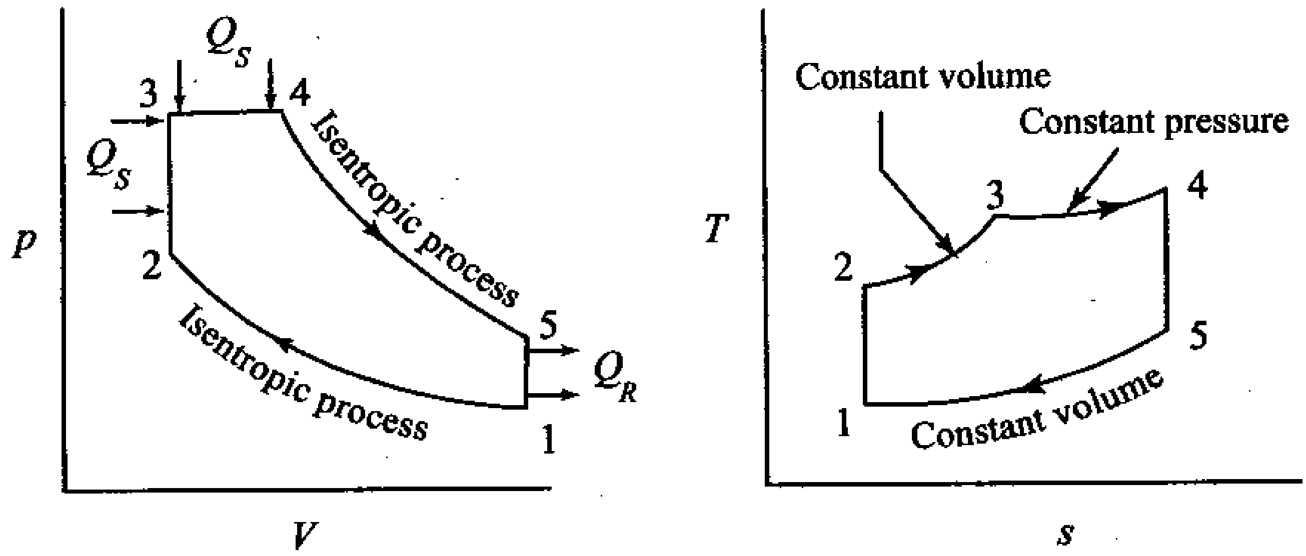


The diesel cycle

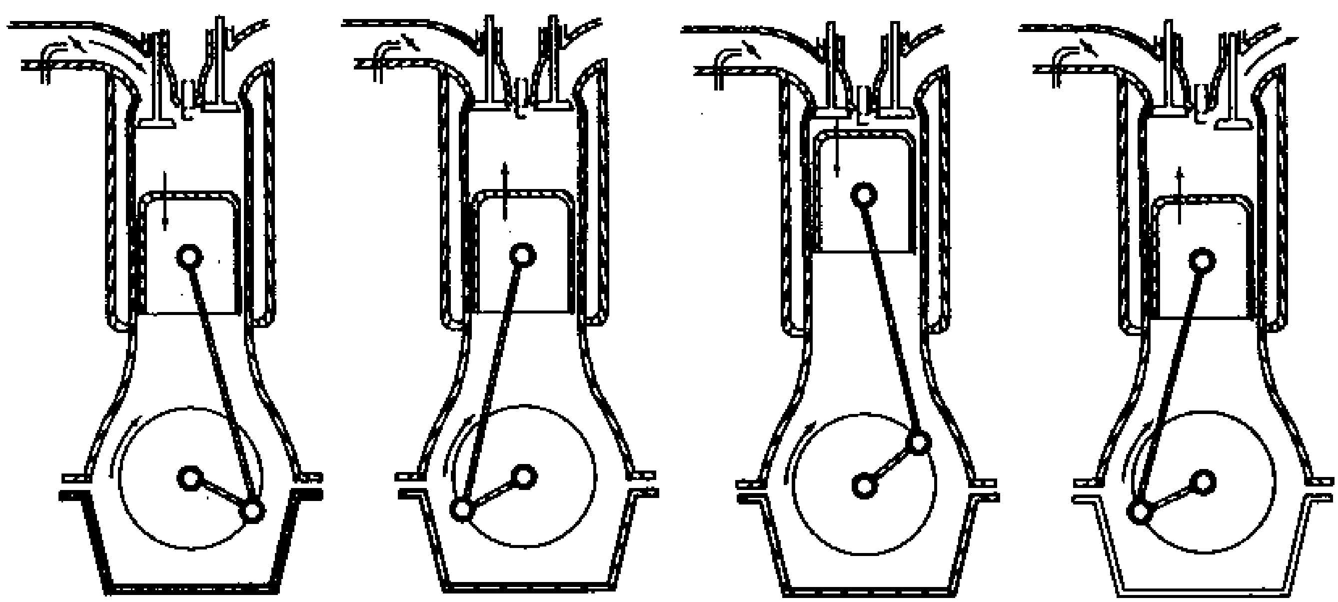




The dual cycle



WORKING STROKES OF AN ENGINE



(a) Intake (b) Compression (c) Expansion (d) Exhaust

Automotive Engines

UNIT-II: FUEL SYSTEMS

Air fuel ratio requirements of SI engines, Air fuel ratio and emissions, Working of a simple fixed venturi carburetor, Constant vacuum carburetor. Diesel fuel injection systems-Jerk pumps, distributor pumps, pintle and multihole nozzles, Unit injector and common rail injection systems. Injection pump calibration. Need for a governor for diesel engines. Description of a simple diesel engine governor.

AIR FUEL RATIO

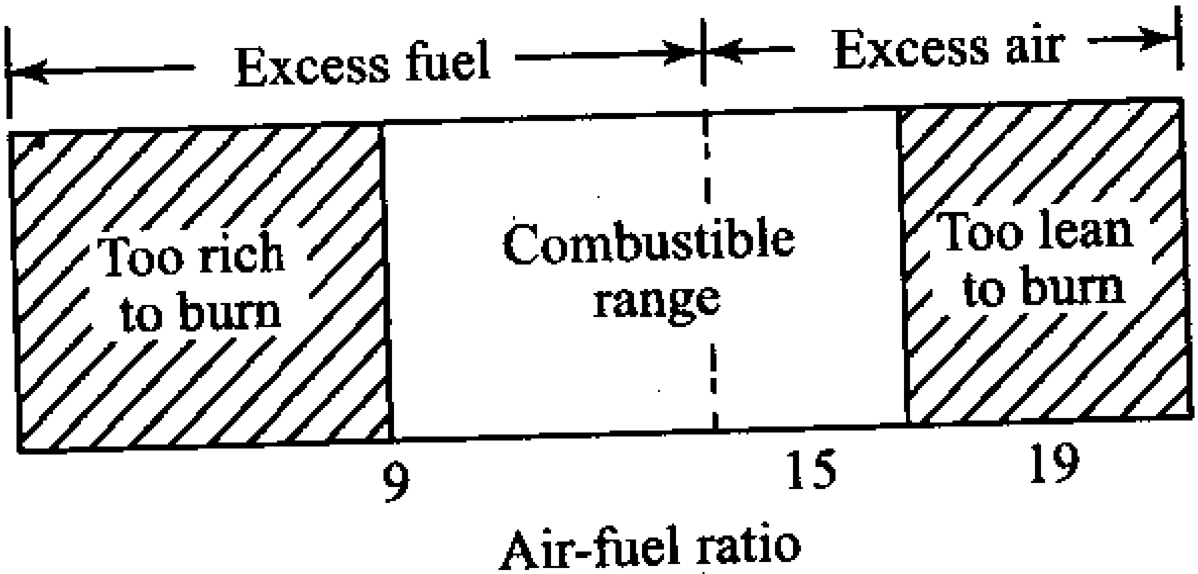
An engine is generally operated at different loads and speeds. For this, proper air-fuel mixture should be supplied to the engine cylinder. Fuel and air are mixed to form three different types of mixtures.

1. Chemically correct mixture
2. Rich mixture and
3. Lean mixture

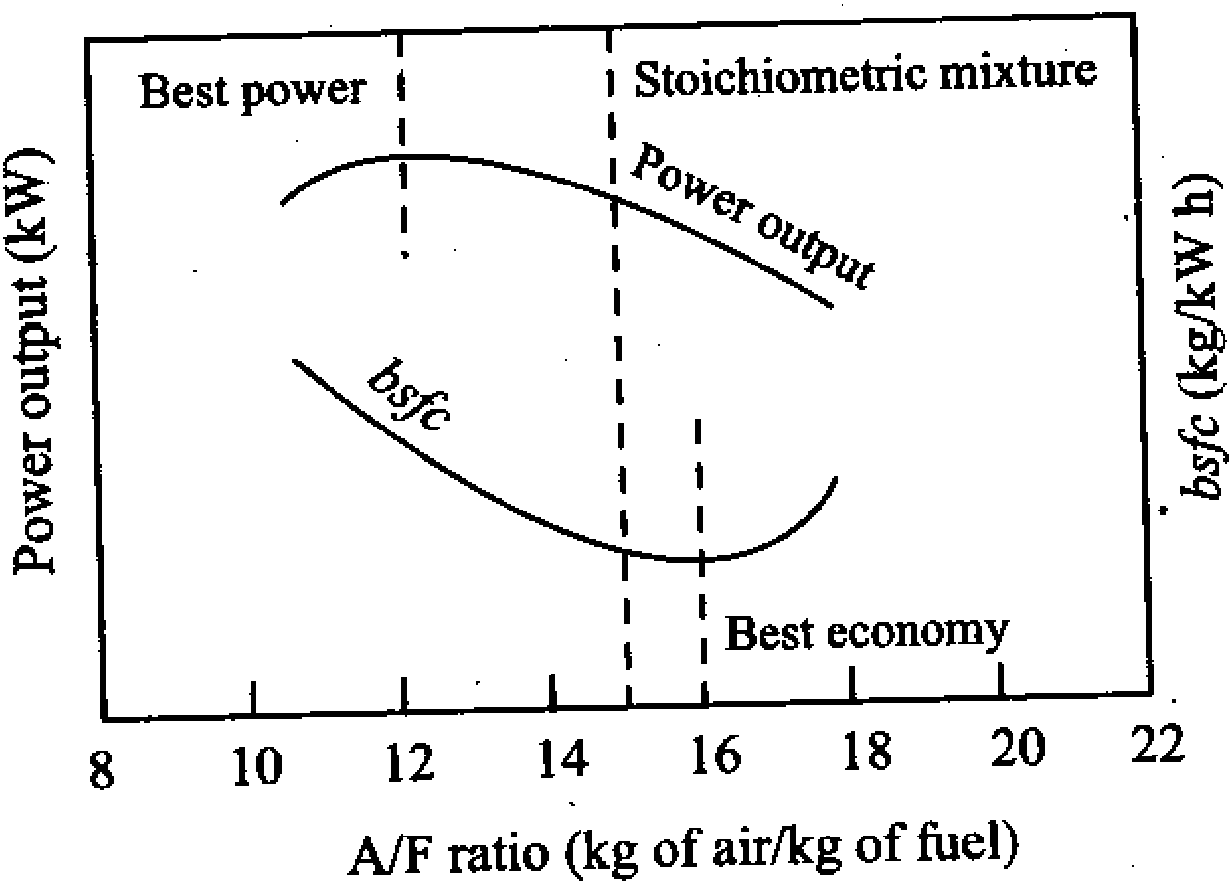
Chemically correct or stoichiometric mixture is one in which there is just enough air for complete combustion of the fuel. For example, to burn one kg of octane (C_8H_{18}) completely 15.12 kg of air is required. Hence chemically correct *A/F* ratio for C_8H_{18} is 15.12:1; usually approximated to 15:1. This chemically correct mixture will vary only slightly in numerical value between different hydrocarbon fuels. It is always computed from the chemical equation for complete combustion for a particular fuel. *Complete combustion* means all carbon in the fuel is converted to CO2 and all hydrogen to H_2O.

A mixture which contains less air than the stoichiometric requirement is called a rich mixture (example, *A/F* ratio of 12:1, 10:1 etc.).

There is, however, a limited range of *A/F* ratios in a homogeneous mixture, only within which combustion in an SI engine will occur. Outside this range, the ratio is either too rich or too lean to sustain flame propagation. This range of useful *A/F* ratio runs from approximately 9<1 (rich) to 19:1 (lean) as indicated in Fig.



Useful Air-Fuel Mixture Range of Gasoline



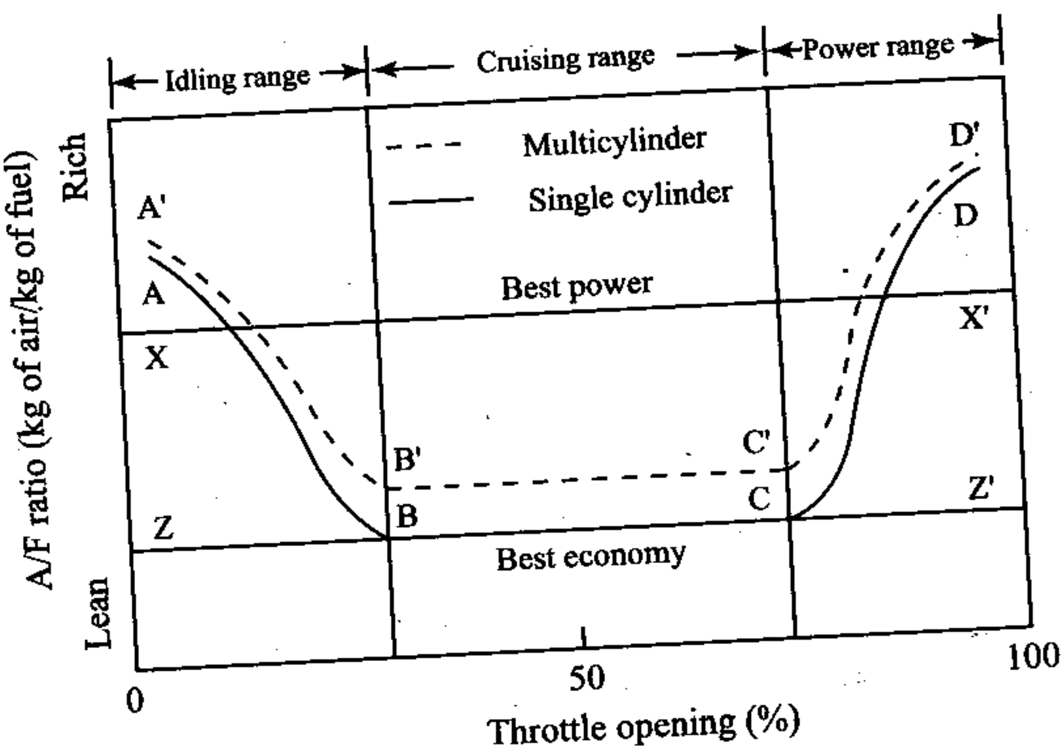
Variation of Power Output and bsfc with A/F Ratio for an SI Engine

AUTOMOTIVE ENGINE AIR-FUEL MIXTURE REQUIREMENTS

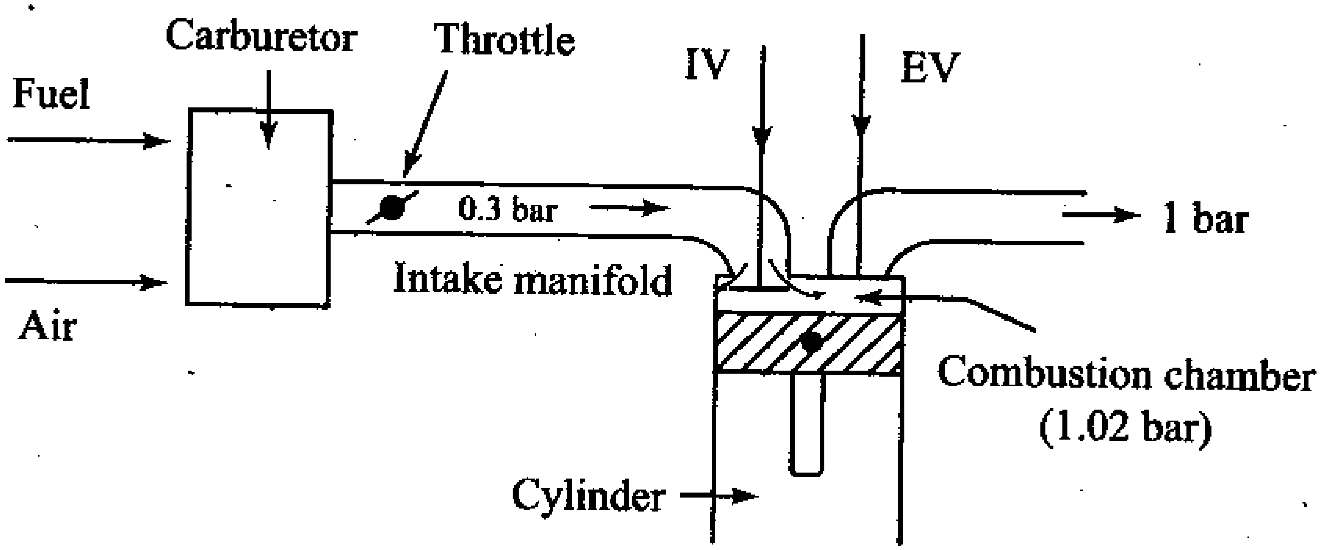
Actual air-fuel mixture requirements in an automotive engine vary considerably from the ideal conditions discussed in the previous section. For successful operation of the engine, the carburetor has to provide mixtures which follow the general shape of the curve ABCD (single cylinder) and A'B'C'D' (multicylinder) in Fig. which represents a typical automotive engine requirement. The carburetor must be suitably designed to meet the various engine requirements.

As indicated in Fig. there are three general ranges of throttle operation. In each of these, the automotive engine requirements differ. As a result, the carburetor must be able to supply the required air-fuel ratio to satisfy these demands. These ranges are:

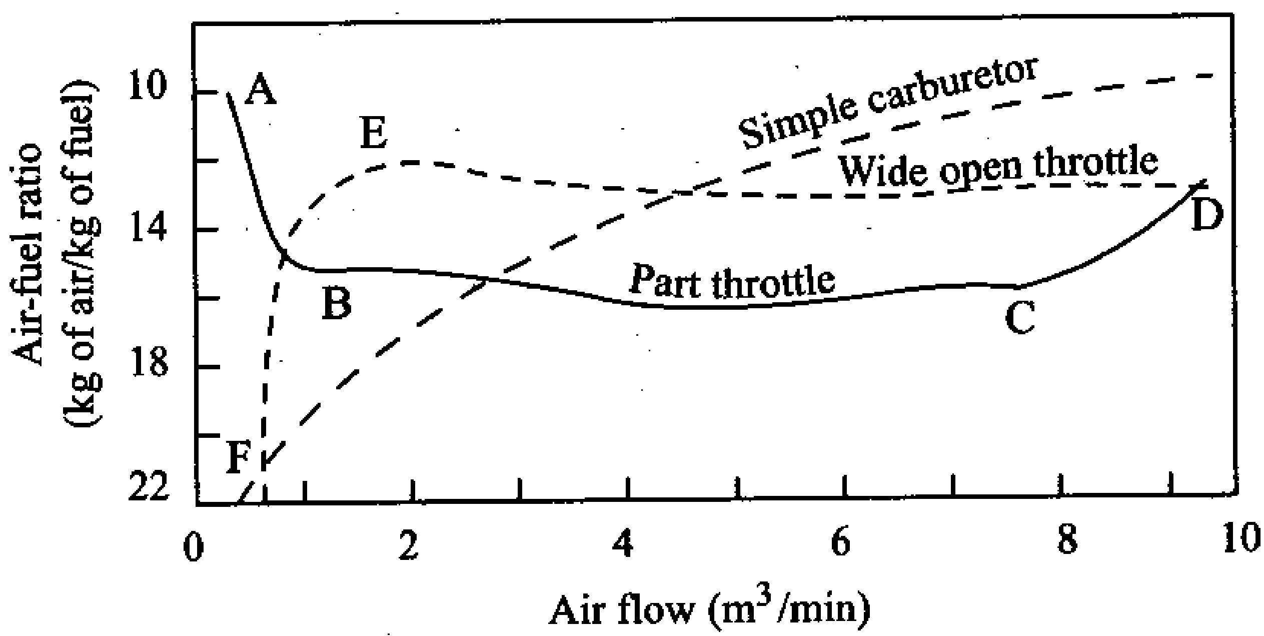
1. Idling (mixture must be enriched)
2. Cruising (mixture must be leaned)
3. High Power (mixture must be enriched)



Anticipated *Carburetor* Performance to *fulfill Engine Requirements*

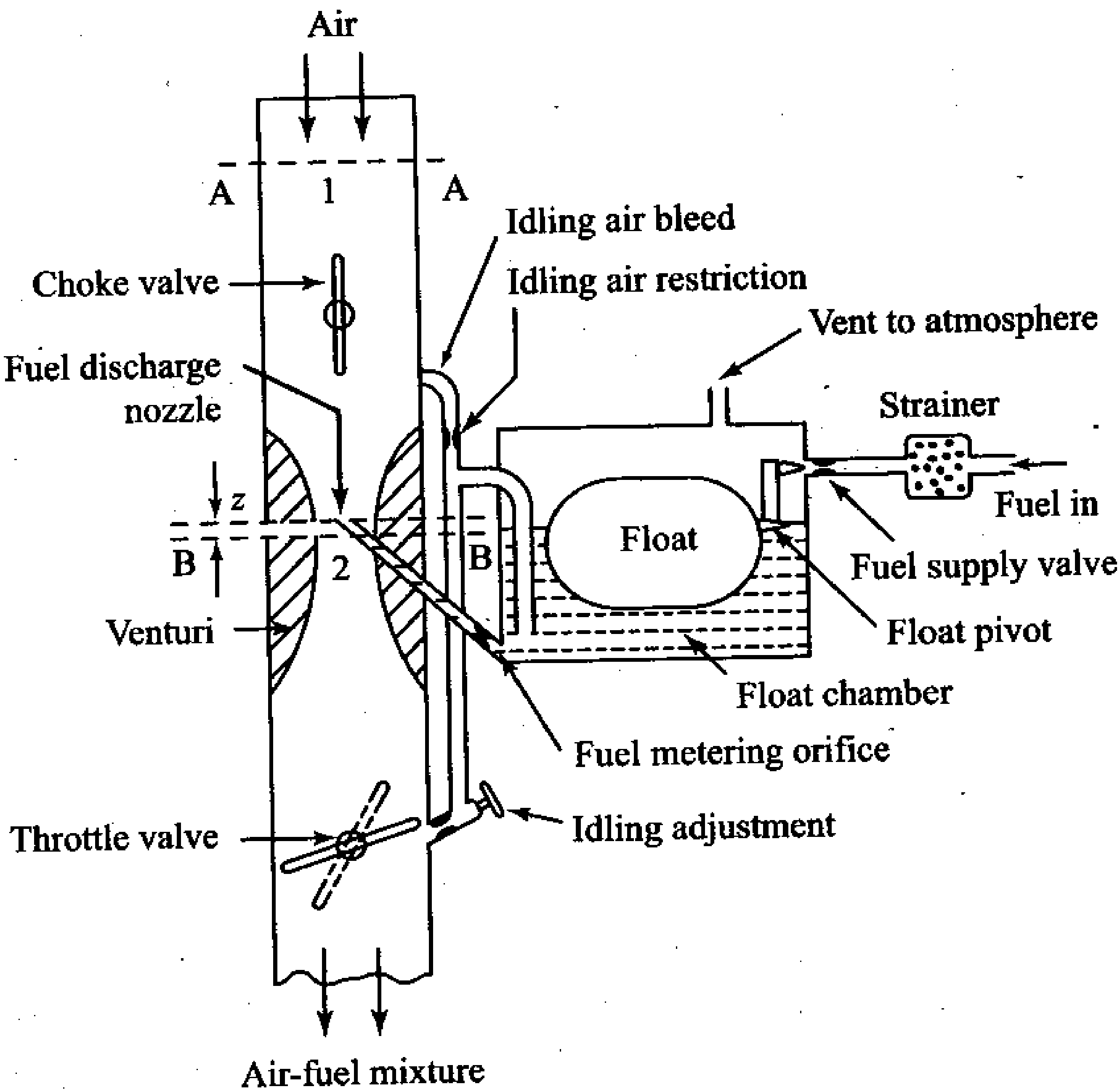


Schematic Diagram of Combustion Chamber and Induction System at the Start of Intake Stroke



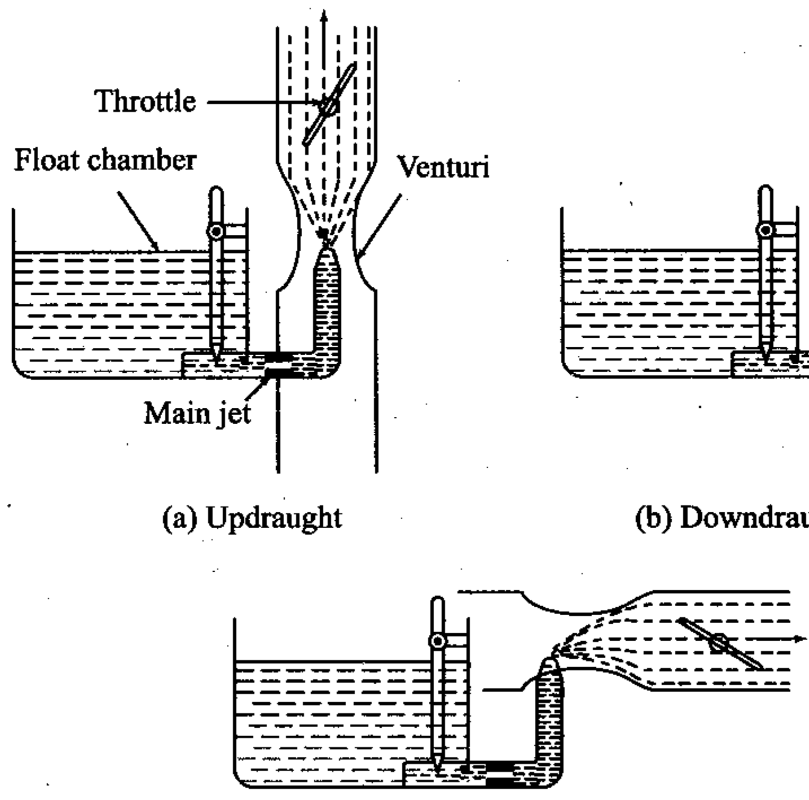
Performance Curve of *an* Automobile Carburetor

THE SIMPLE CARBURETOR



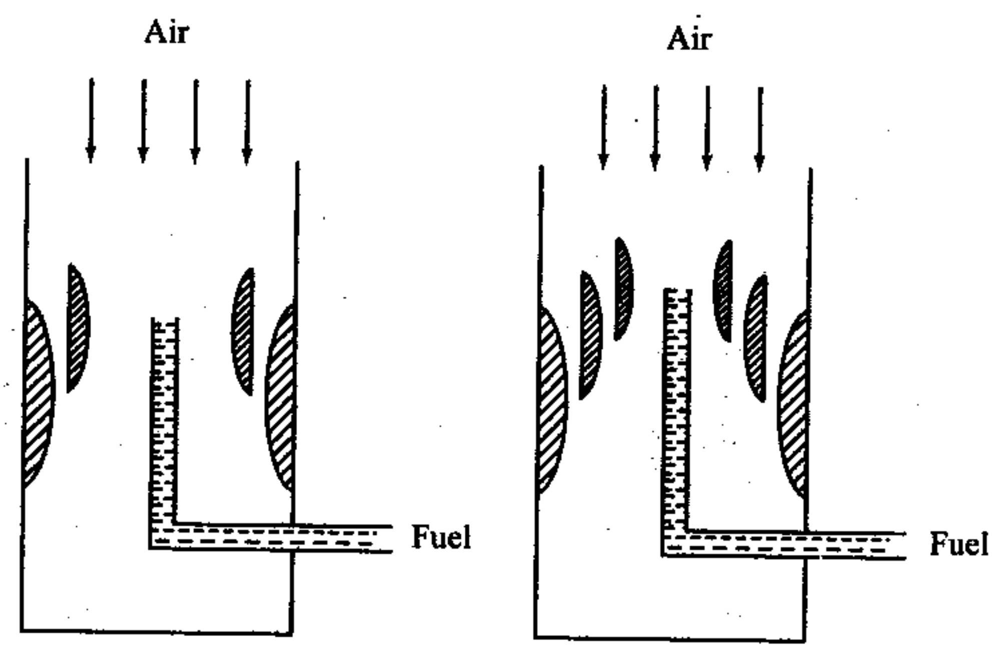
TYPES OF CARBURETORS

1. Up draught type
2. Down draught type
3. Cross draught type
4. Constant choke type
5. Constant vacuum type
6. Multiple venturi type



(a) Updraught (b) Downdraught

(c) Cross-draught



(a) Double venturi (b) Triple venturi

7. Multi jet type
8. Multi barrel venturi type

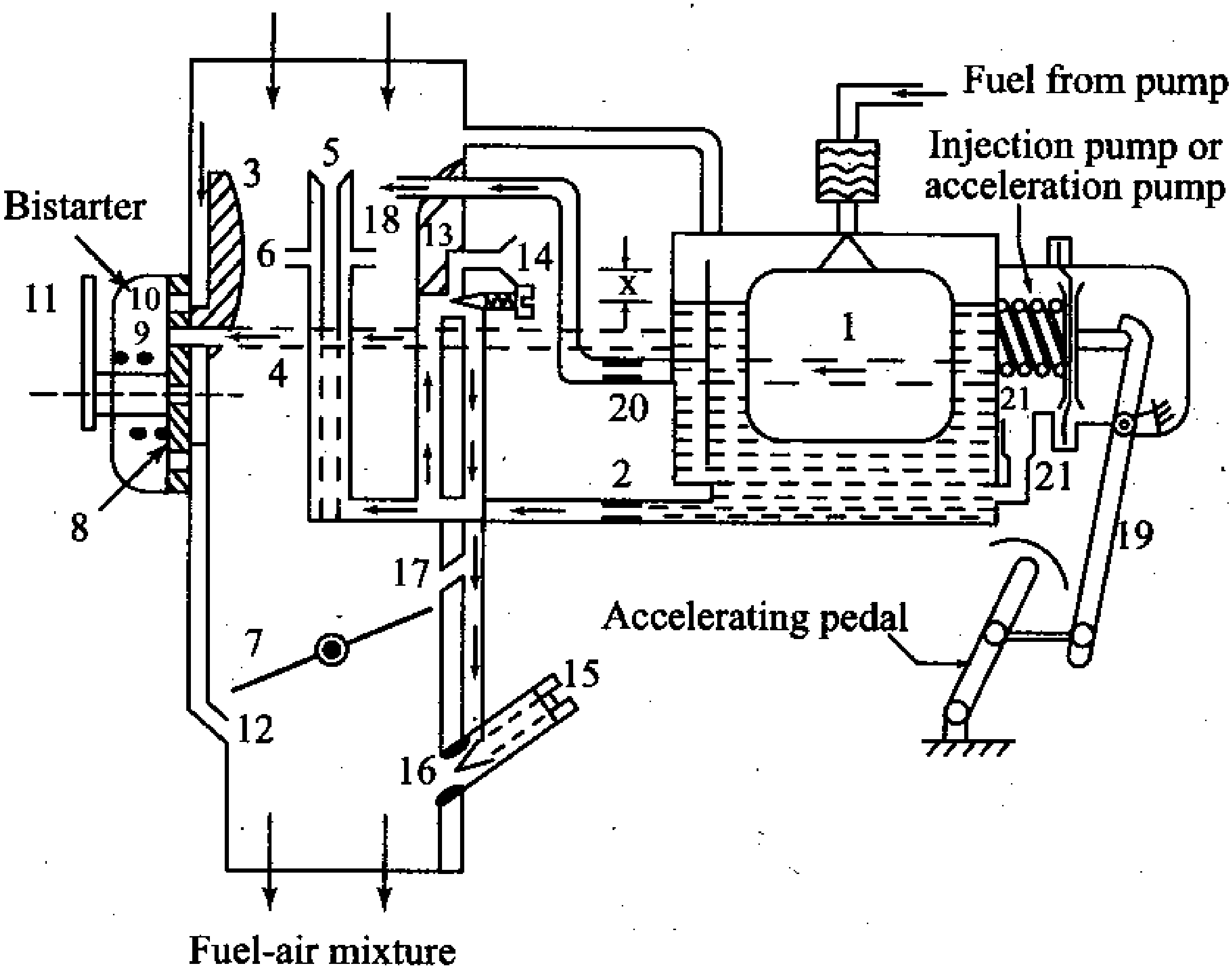
AUTOMOBILE CARBURETORS

The details of various devices for carburetors to satisfy the demand of an automobile engine under different conditions have been discussed in the previous sections. Some of the popular brands of carburetors in use are (i) Solex, (ii) Carter, and (iii) S.U. carburetor Before going into the details of these carburetors let us see the important requirements of an automobile carburetors.

1. Ease of starting the engine, particularly under low ambient conditions.
2. Ability to give full power quickly after starting the engine.
3. Equally good and smooth engine operation at various loads.
4. Good and quick acceleration of the engine.
5. Developing sufficient power at high engine speeds.
6. Simple and compact in construction.
7. Good fuel economy.
8. Absence of racing of the engine under idling condition.

Solex Carburetors

The solex carburetor is famous for its ease of starting, good performance and reliability. It is made in various models and is used in many automobile engines. The solex carburetor as shown in Fig. is a downdraught carburetor. This has the provision for the supply of richer mixture required for starting and weaker mixture during cruising speed of the vehicle. It consists of various fuel circuits such as starting, idling or low speed operation, normal running, acceleration etc.



Carter carburetor

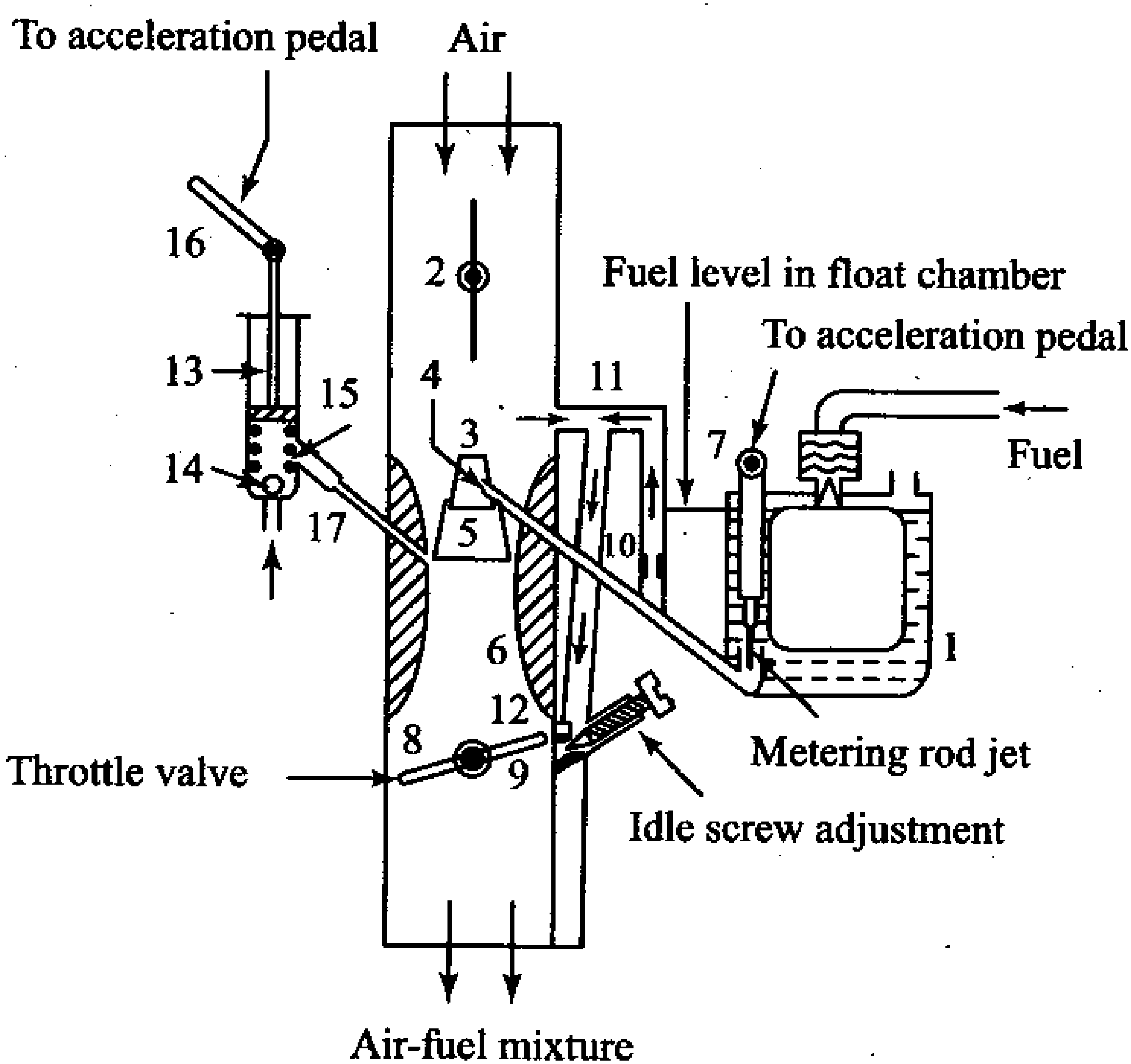
Carter carburetor is normally used in Jeeps. It is a multiple jet, plain tube type of carburetor with only one adjustment which is for idling or low speed operation. A combination of gasoline and air is drawn into the nozzle chamber through the jets on side of nozzle forming a time spray which is carried by the stand pipe to the venturi or main air passage, where it is absorbed by incoming air forming mixture on which engine operates.

Jets on the side of the nozzle come into operation in direct proportion to throttle position. More and more the throttle is opened; the more jets are in operation. At wide-open-throttle (WOT) all jets are working and engine is getting maximum supply.

Low-speed jet assembly supplies gasoline to the engine at idle engine speed and up to approximately 20 km/h, gasoline flowing through a drilled passage connecting low speed jet chamber with carburetor well.

At idling gasoline is drawn through low speed jet and idling port at the edge of the throttle valve. With the idling screw, the mixture for idle running can be enriched or made leaner as required.

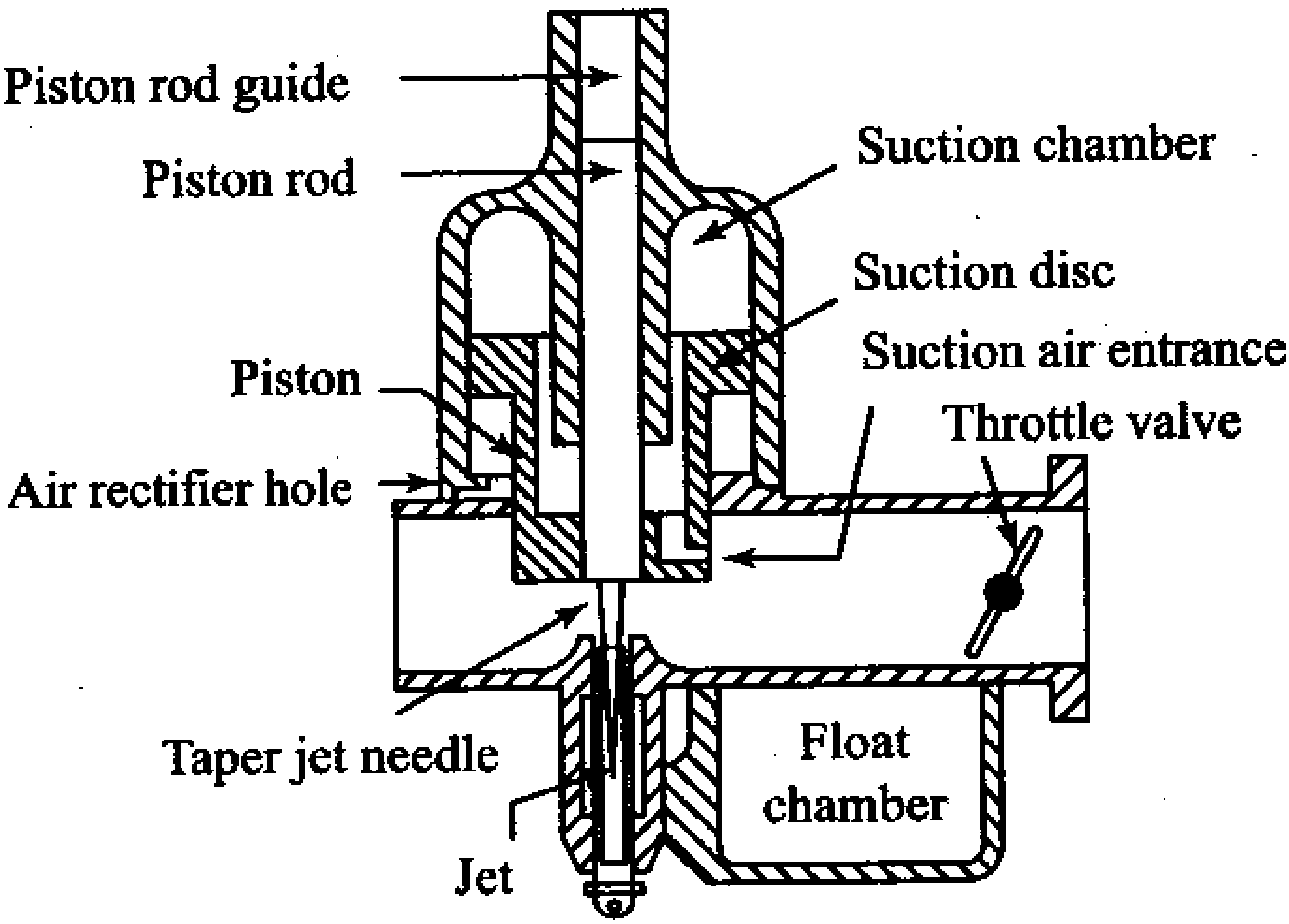
Figure shows the down draught carter carburetor.



S.U. Carburetor

Carburetors in general are constant choke type. Zenith, Solex and Carter carburetors are examples of this type. S.U. carburetors differ completely from them being constant vacuum *or* constant depression type with automatic variable choke.

A simplified sketch of this carburetor is shown in Fig.



MECHANICAL INJECTION SYSTEMS

FUNCTIONAL REQUIREMENTS OF AN INJECTION SYSTEM

1. Accurate metering of the fuel injected per cycle. This is very critical due to the fact that very small quantities of fuel being handled. Metering errors may cause drastic variation from the desired output. The quantity of the fuel metered should vary to meet changing speed and load requirements of the engine.

2. Timing the injection of the fuel correctly in the cycle so that maximum power is obtained ensuring fuel economy and clean burning.

3. Proper control of rate of injection so that- the desired heat-release pattern is achieved during combustion.
4. Proper atomization of fuel into very fine droplets.
5. Proper spray pattern to ensure rapid mixing of fuel and air.
6. Uniform distribution of fuel droplets throughout the combustion chamber.
7. To supply equal quantities of metered fuel to all cylinders in case of multi cylinder engines.
8. No lag during beginning and end of injection i.e., to eliminate dribbling of fuel droplets into the cylinder.

CLASSIFICATION OF INJECTION SYSTEMS

In a constant-pressure cycle or diesel engine, only air is compressed in the cylinder and then fuel is injected into the cylinder by means of a fuel- injection system. For producing the required pressure for atomizing the fuel either air or a mechanical means is used. Accordingly the injection systems can be classified as:

(i) Air injection systems

(ii) Solid injection systems

1. Air Injection System

In this system, fuel is forced into the cylinder by means of compressed air. This system is little used nowadays, because it requires a bulky multi-stage air compressor. This causes an increase in engine weight and reduces the brake power output further. One advantage that is claimed for the air injection system is good mixing of fuel with the air with resultant higher mean effective pressure. Another is the ability to utilize fuels of high viscosity.

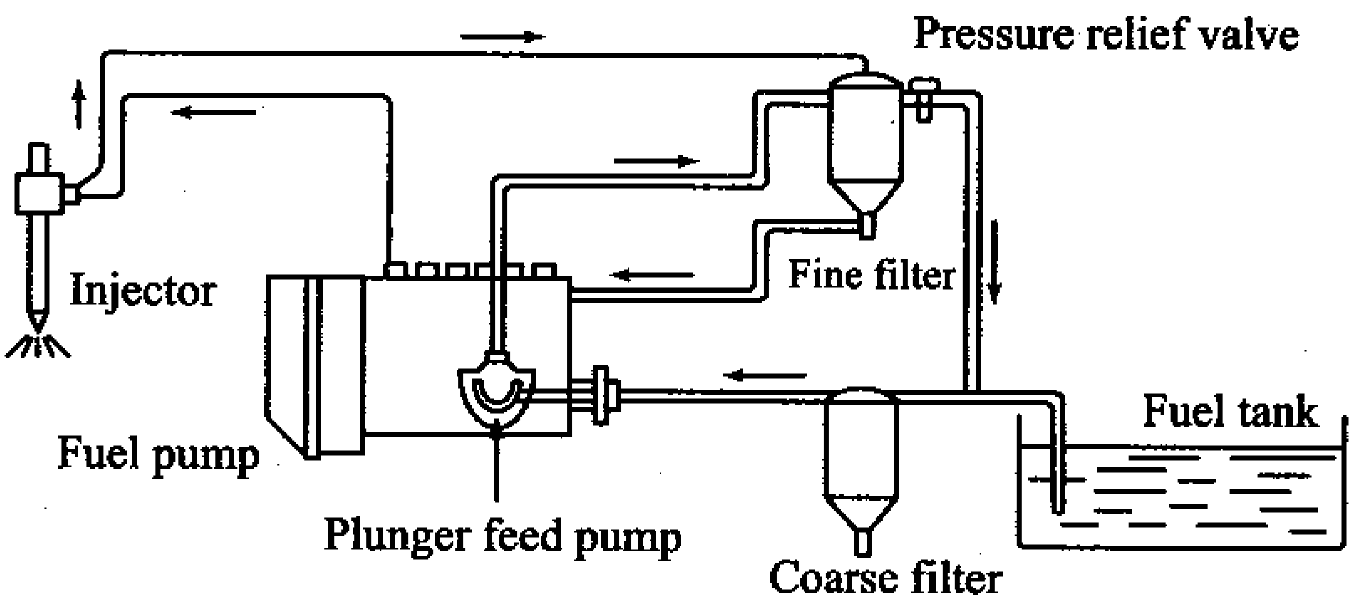
2. Solid Injection System

In this system the liquid fuel is injected directly into the combustion chamber without the aid of compressed air. Hence, it is also called airless mechanical injection or *solid injection system*. Solid injection systems can be classified into four types,

(i) Individual pump and nozzle system
(ii) Unit injector system
(iii) Common rail system
(iv) Distributor system

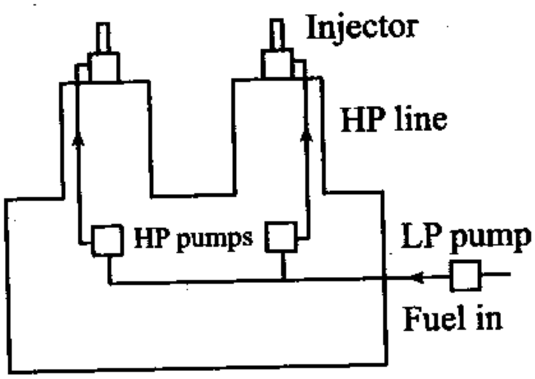
All the above systems comprise mainly of the following components.

(i) fuel tank,
(ii) fuel feed pump to supply fuel from the main fuel tank to the injection system,
(iii) injection pump to meter and pressurize the fuel for injection,
(iv) governor to ensure that the amount of fuel injected is in accordance with variation in-load,
(v) injector to take4he fuel from the pump and distribute it in the combustion chamber by atomizing it into fine droplets,
(vi) fuel filters to prevent dust and abrasive particles from entering the pump and injectors thereby minimizing the wear and tear of the components.

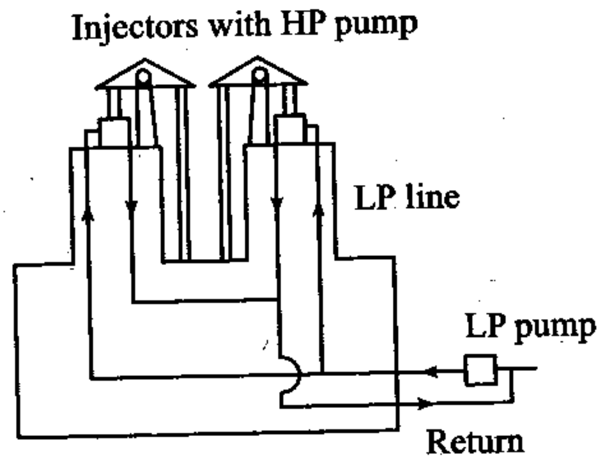


Typical fuel feed system for a CI engine

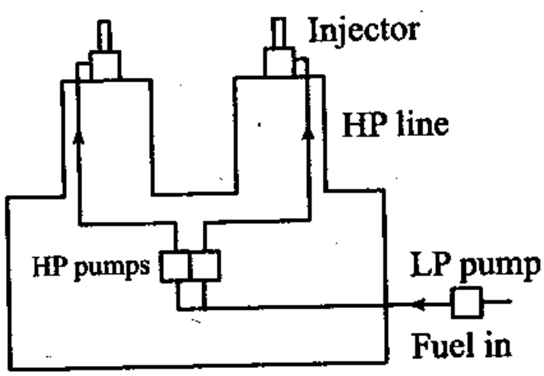
Fuel Injection systems



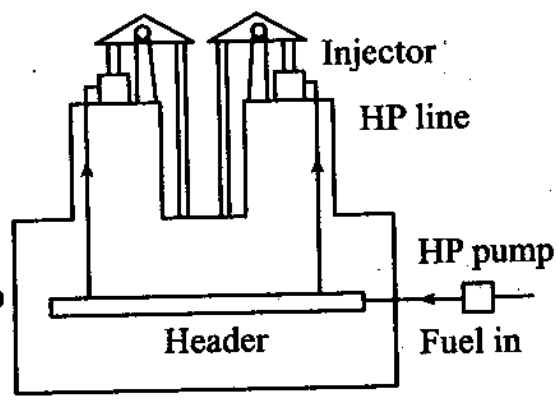
(a) Individual pump and nozzle with separated pumps



(c) Unit injector system

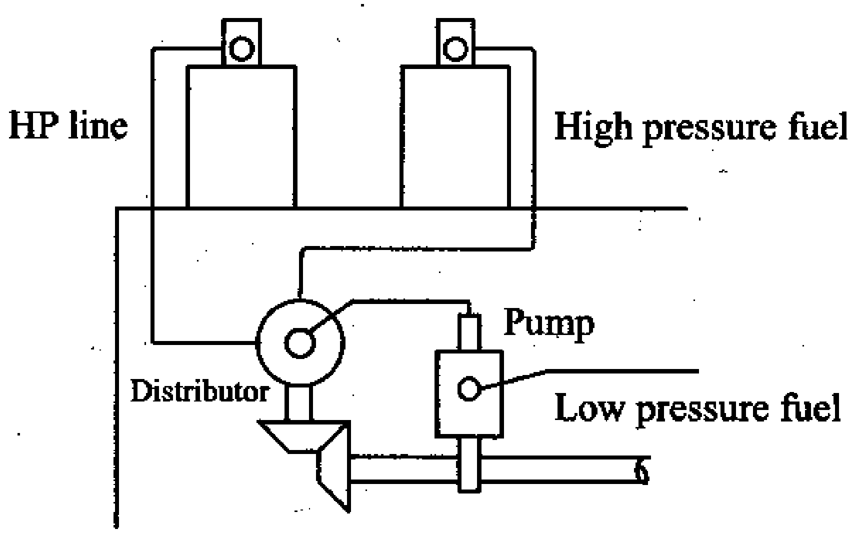


(b) Individual pump and nozzle with pumps in cluster



(d) Common rail system

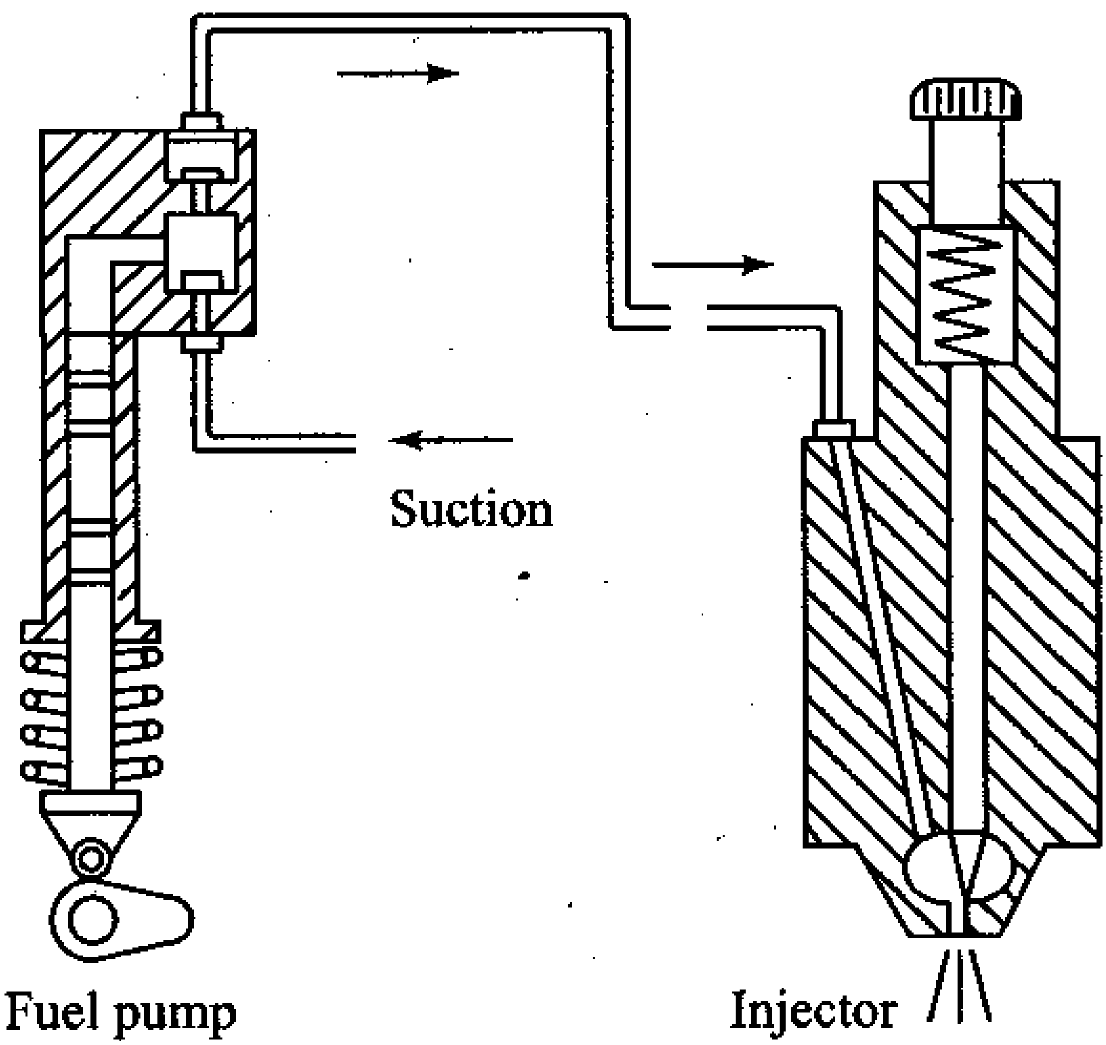
Schematic Diagram of Distributor System



Comparison of Various Fuel-Injection Systems

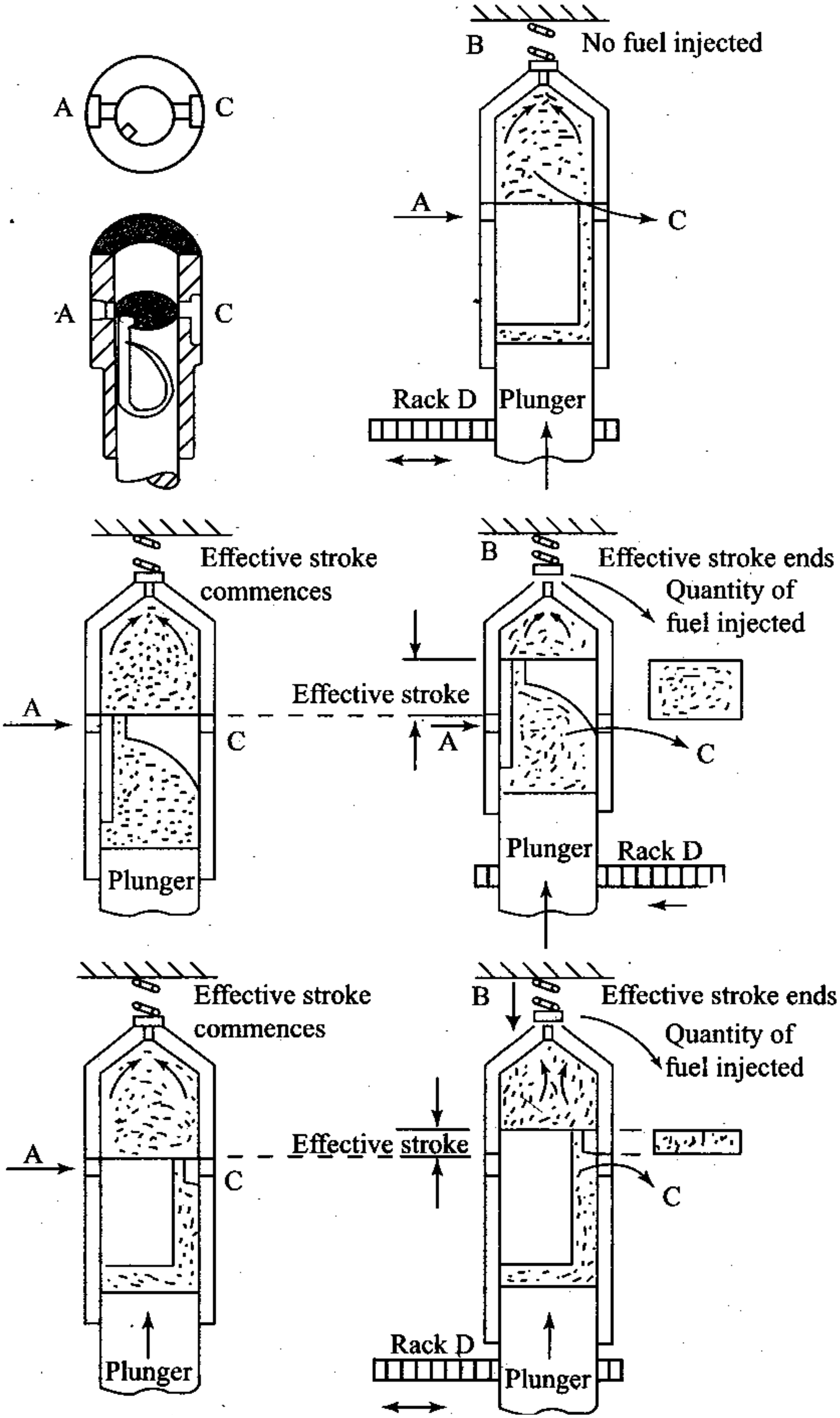
Job	Air injection system	Solid injection system		
		Individual pump	Common rail	Distributor
Metering	Pump	Pump	Injection valve	Pump
Timing	Fuel cam	Pump cam	Fuel cam	Fuel cam
Injection rate	Spray valve	Pump cam	Spray valve	Fuel cam
Atomization	Spray valve	Spray tip	Spray tip	Spray tip
Distribution	Spray valve	Spray tip	Spray tip	Spray tip

Fuel feed pump

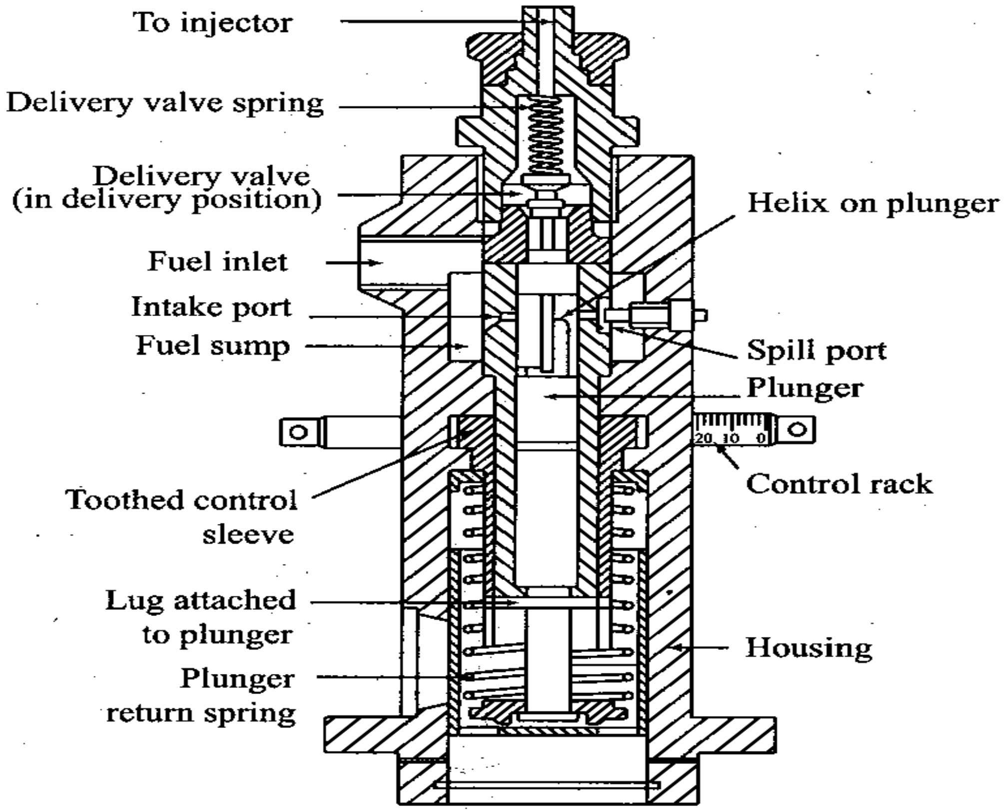


Injection pump

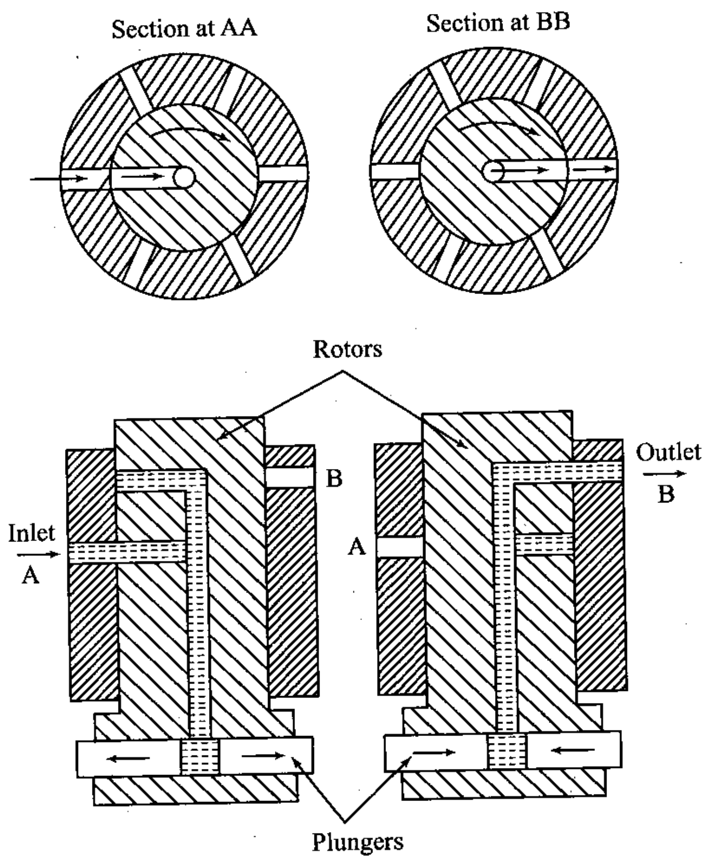
Actual Method of Controlling Quantity of Fuel Injected in a CI Engine



Jerk pump



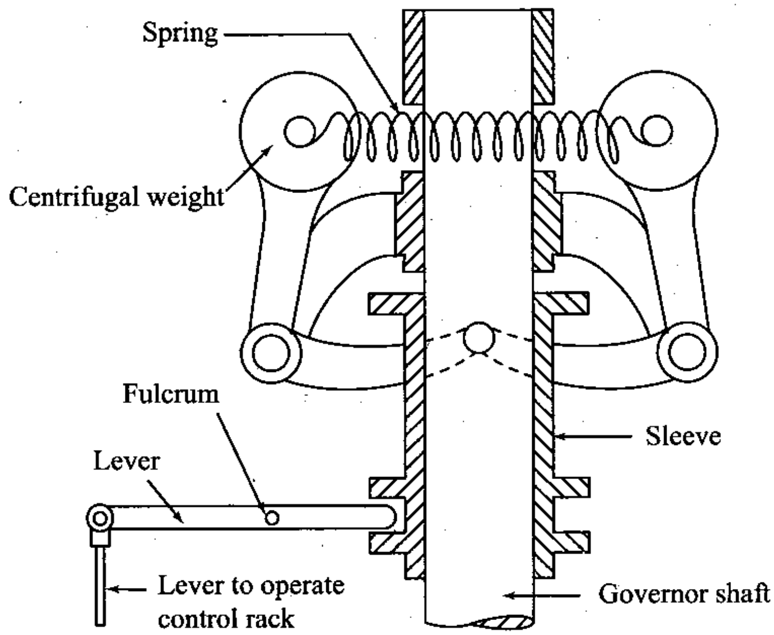
Distributor type fuel injection pump



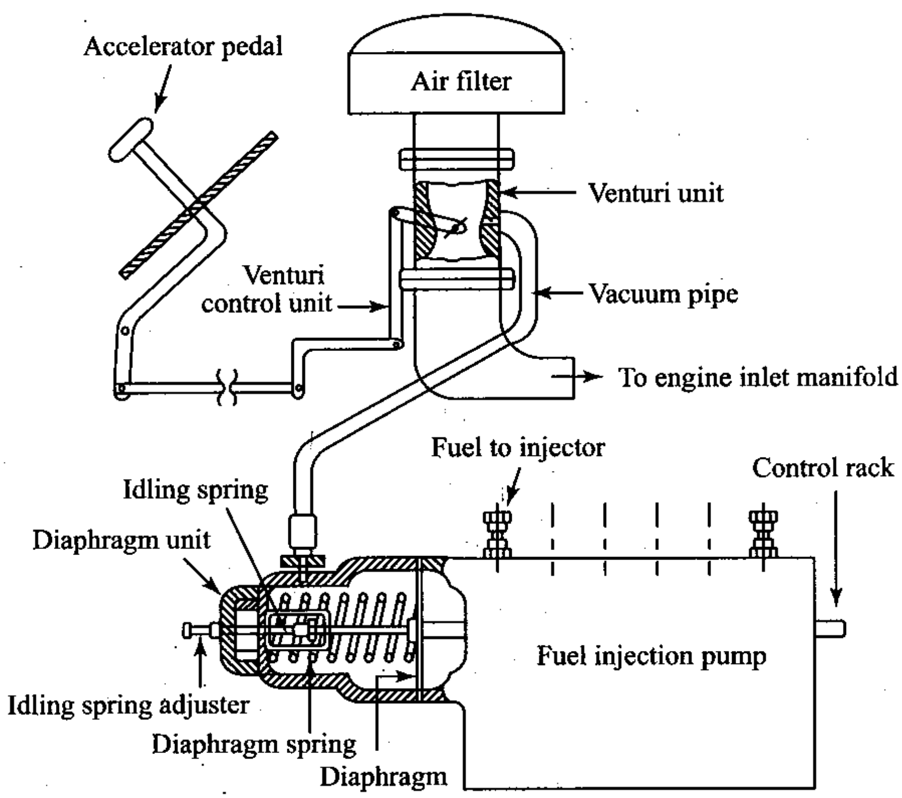
Governors

1. Mechanical governors
2. Pneumatic governors

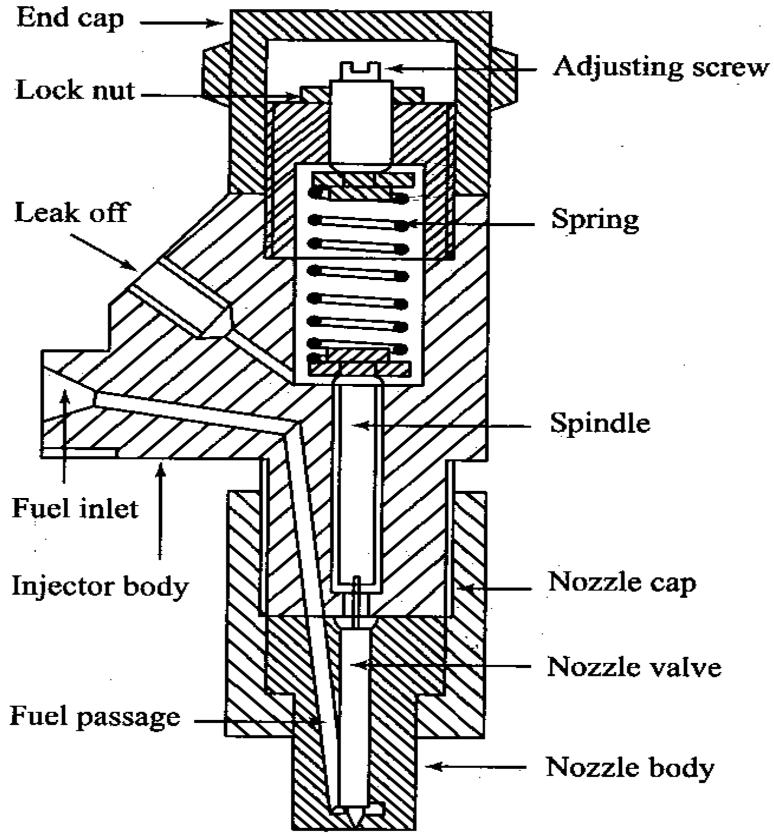
Mechanical governors



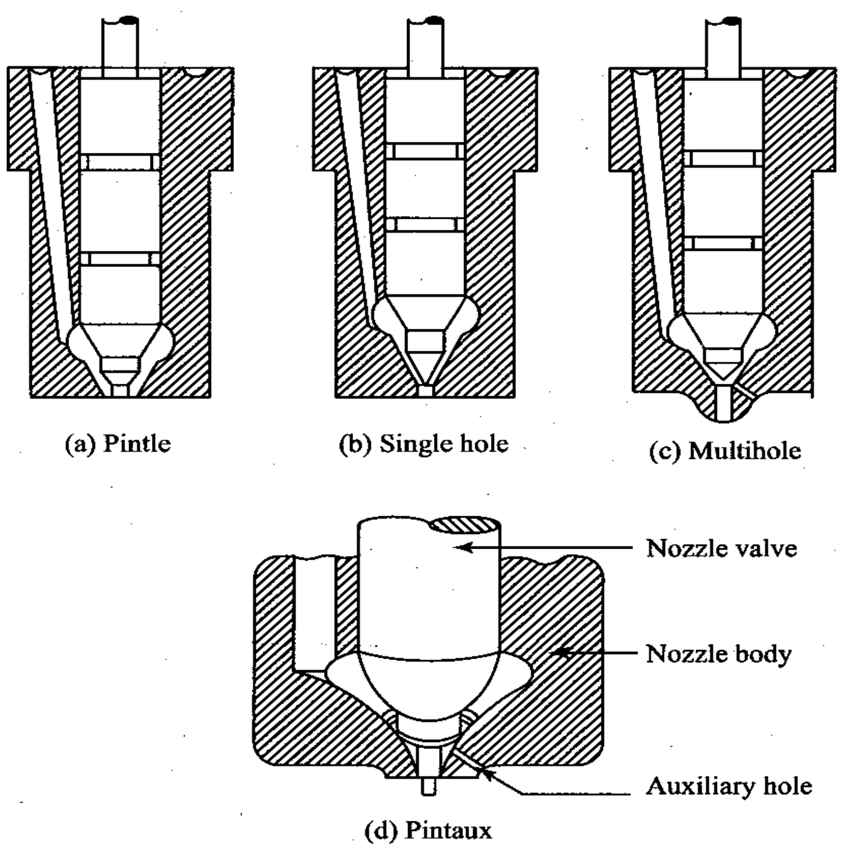
Pneumatic governors



Fuel injector



Nozzle



INJECTION IN SI ENGINE

Fuel-injection systems are commonly used in CI engines. Presently gasoline injection system is coming into vogue in SI engines because of the following drawbacks of the carburetion.

1. Non uniform distribution of mixture in multicylinder engines.
2. Loss of volumetric efficiency due to restrictions for the mixture flow and the possibility of back firing.

A gasoline injection system eliminates all these drawbacks. The injection of fuel into an SI engine can be done by employing any of the following methods which are shown in Figure

a. direct injection of fuel into the cylinder
b. injection of fuel close to the inlet valve
c. injection of fuel into the inlet manifold

Components of injection system and their functions

(i) *Pumping element* – moves the fuel from the fuel tank to the injector. This includes necessary piping, filter etc.

(ii) *Metering element* – measures and supplies the fuel at the rate demanded by load and speed conditions of the engine.

(iii) *Mixing element* – atomizes the fuel and mixes it with air to form a homogenous mixture.

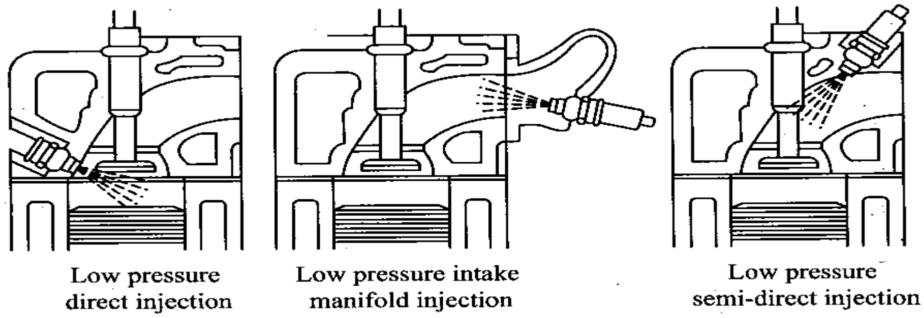
(iv) *Metering control* – adjusts the rate of metering in accordance with load and speed of the engine.

(v) *Mixture control* – adjusts fuel-air ratio as demanded by the load and speed.

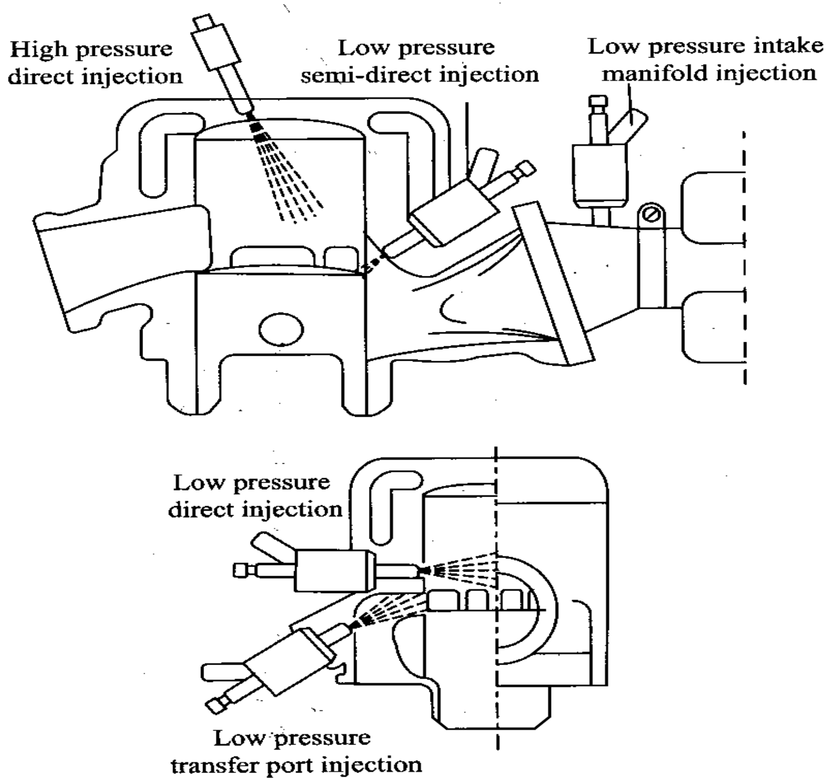
(vi) *Distributing element* – divides the metered fuel equally among the cylinders.

(vii) *Timing control* – fixes the start and stop of the fuel-air mixing process.

(viii) *Ambient control* – compensates for changes in temperature and pressure of either air or fuel that may affect the various elements of the system.



(a) Gasoline injection in four-stroke engines



(b) Fuel injection in two-stroke engines

Electronic fuel injection system

Modern gasoline injection systems use engine sensors, a computer, and solenoid operated fuel injectors to meter and inject the right amount of fuel into the engine cylinders. These systems called electronic fuel injection (EFI) use electrical and electronic devices to monitor and control engine operation.

An electronic control unit (ECU) or the computer receives electrical signals in the form of current or voltage from various sensors. It then uses the stored data to operate the injectors, ignition system and other engine related devices. As a result, less unburned fuel leaves the engine as emissions, and the vehicle gives better milage. Typical sensors for an electronic fuel injection system includes the following:

(i) *Exhaust gas or oxygen sensor* – senses the amount of oxygen in the engine exhaust and calculates air-fuel ratio. Sensor output voltage changes in proportion to air-fuel ratio.

(ii) *Engine temperature sensor* – senses the temperature of the engine coolant, and from this data the computer adjusts the mixture strength to rich side for cold starting.

(iv) *Air inlet temperature sensor* – checks the temperature of the ambient air entering the engine for fine tuning the mixture strength.

(v) *Throttle position sensor* – senses the movement of the throttle plate so that the mixture flow can be adjusted for engine speed and acceleration.

(vi) *Manifold pressure sensor* – monitors vacuum in the engine intake manifold so that the mixture strength can be adjusted with changes in engine load.

(vii) *Camshaft position sensor* – senses rotation of engine camshaft/crankshaft for speed and timing of injection.

(viii) *Knock sensor* – microphone type sensor that detects ping or preignition noise so that the ignition timing can be retarded.

Merits of EFI System

The spark ignition engine with an EFI system compared with a carburettor unit have the following favourable points:

1. Improvement in the volumetric efficiency due to comparatively less resistance in the intake manifolds which will cause less pressure losses.
2. Manifold wetting is eliminated due to the fuel being injected into or close to the cylinder and need not flow through the manifold.
3. Atomization of fuel is independent of cranking speed and therefore starting will be easier.
4. Better atomization and vapourization will make the engine less knock prone.
5. Formation of ice on the throttle plate is eliminated.
6. Distribution of fuel being independent of vapourization, less volatile fuel can be used.
7. Variation of air-fuel ratio is almost negligible even when the vehicle takes different positions like turning, moving on gradients, uneven roads etc.

8. Position of the injection unit is not so critical and thereby the height of the engine (and hood) can be less.

Demerits of EFI System

Some of the disadvantages of EFI system are:

1. high maintenance cost,
2. difficulty in servicing, and
3. Possibility of malfunction of some sensors.

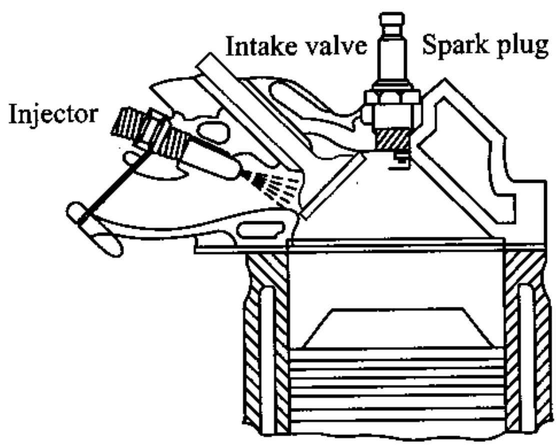
MULTI-POINT FUEL INJECTION (MPFI) SYSTEM

The main purpose of the Multi-Point Fuel Injection (MPFI) system is to supply a proper ratio of gasoline and air to the cylinders. These systems function under two basic arrangements, namely

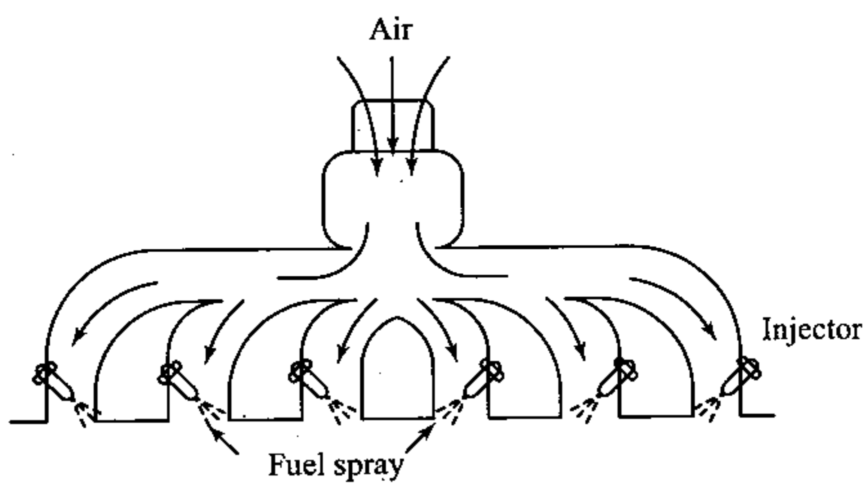
(i) Port injection

(ii) Throttle body injection

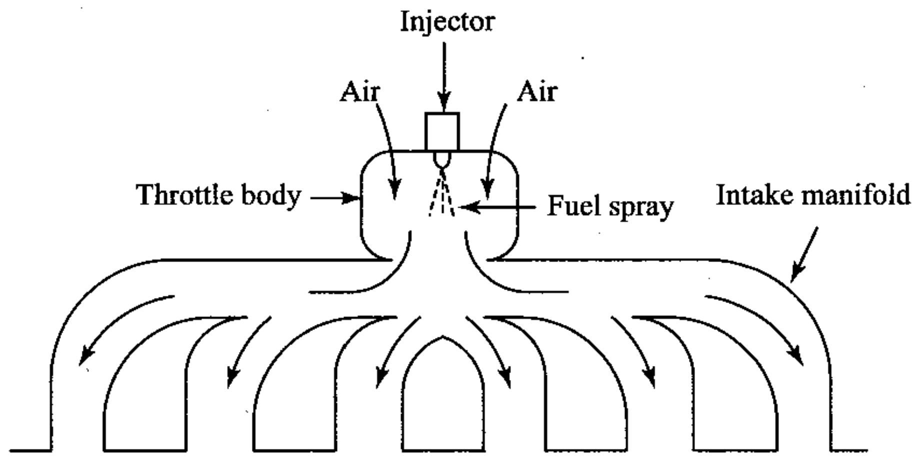
Port injection



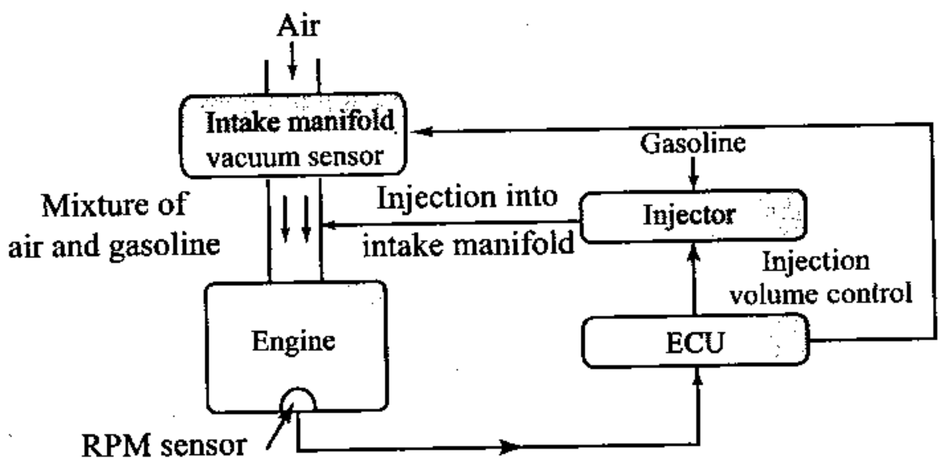
MPFI



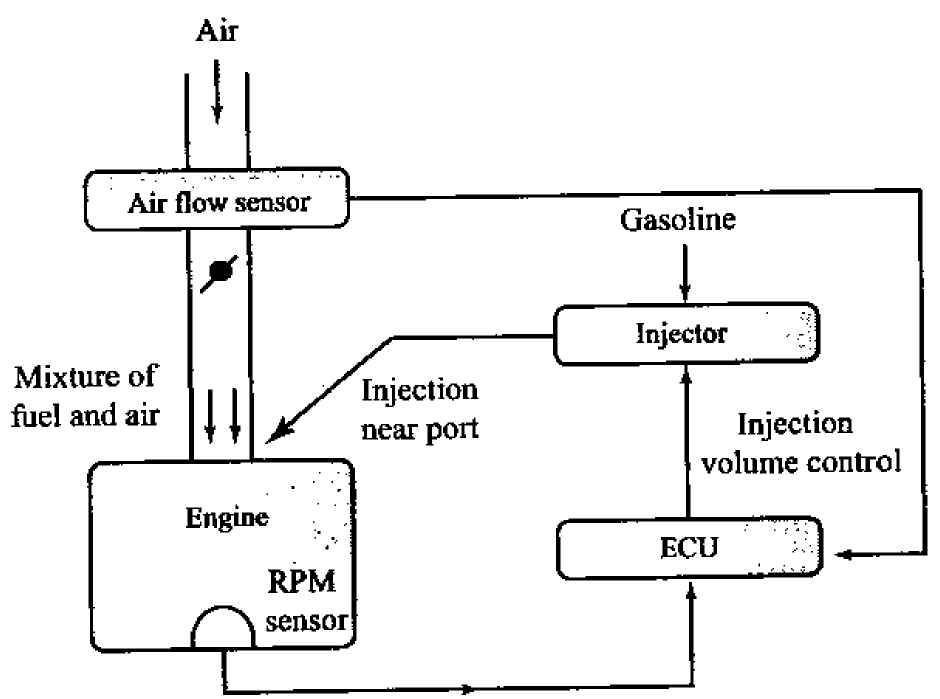
Throttle body injection system



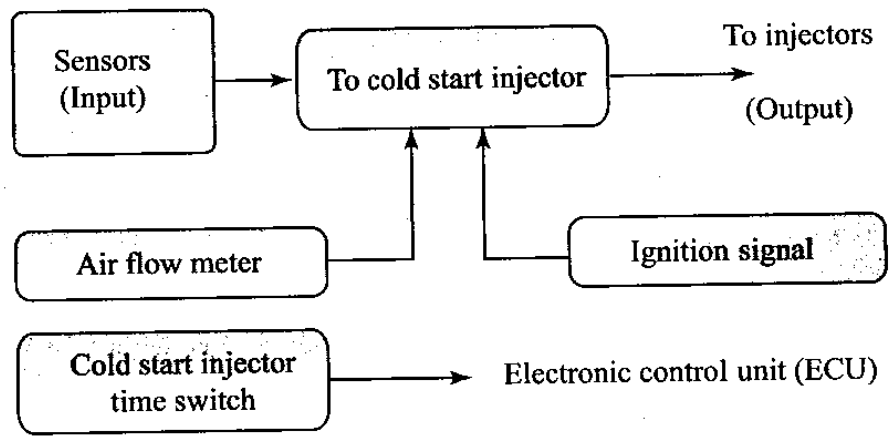
D-MPFI Gasoline injection system



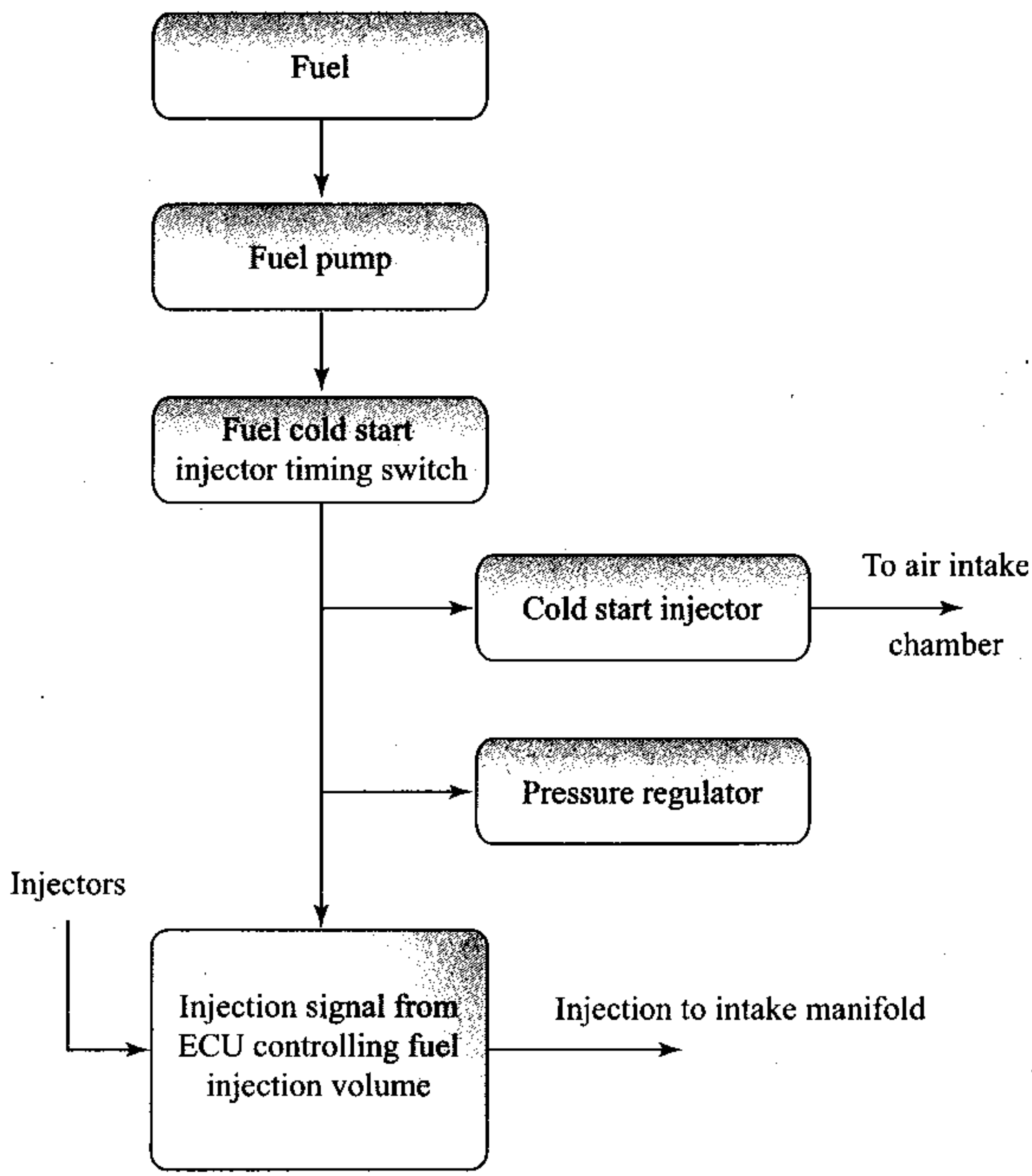
L-MPFI Gasoline injection system



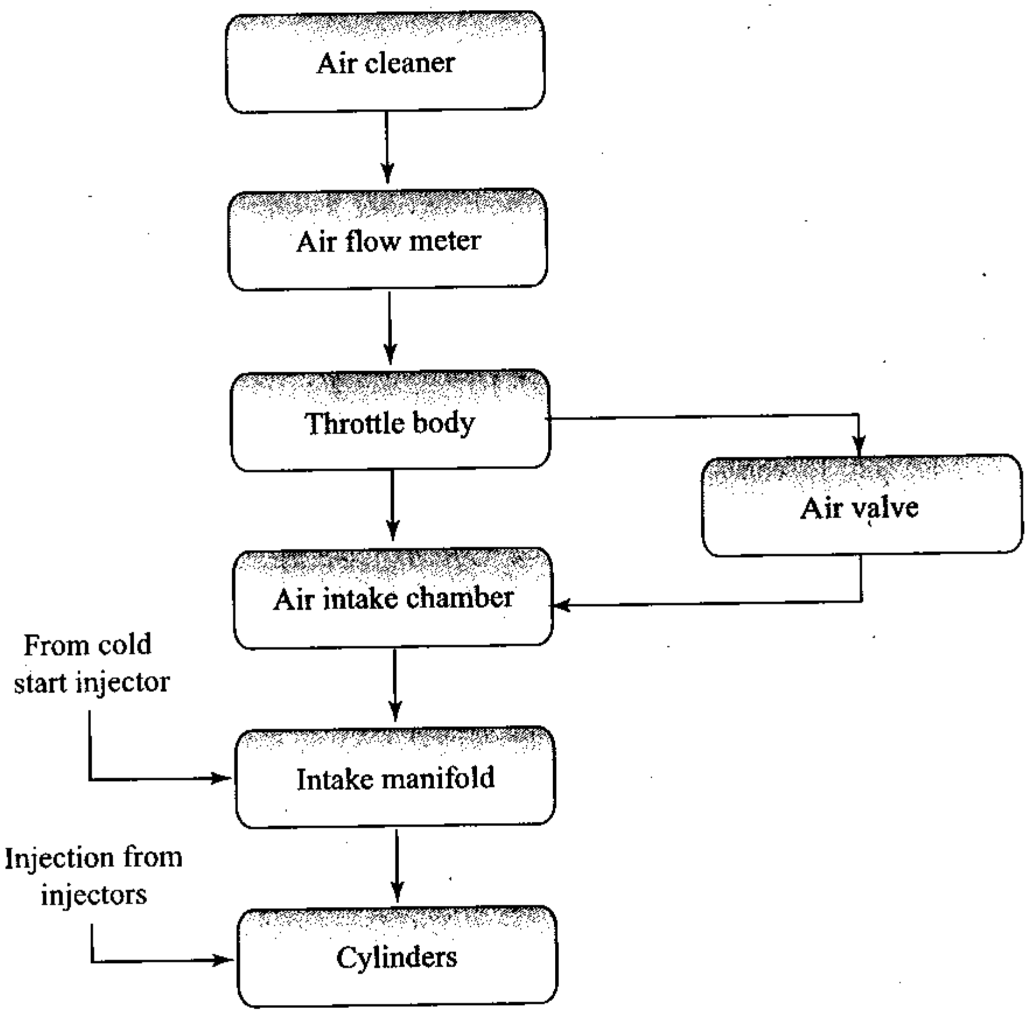
MPFI-Electronic control system



MPFI-fuel system

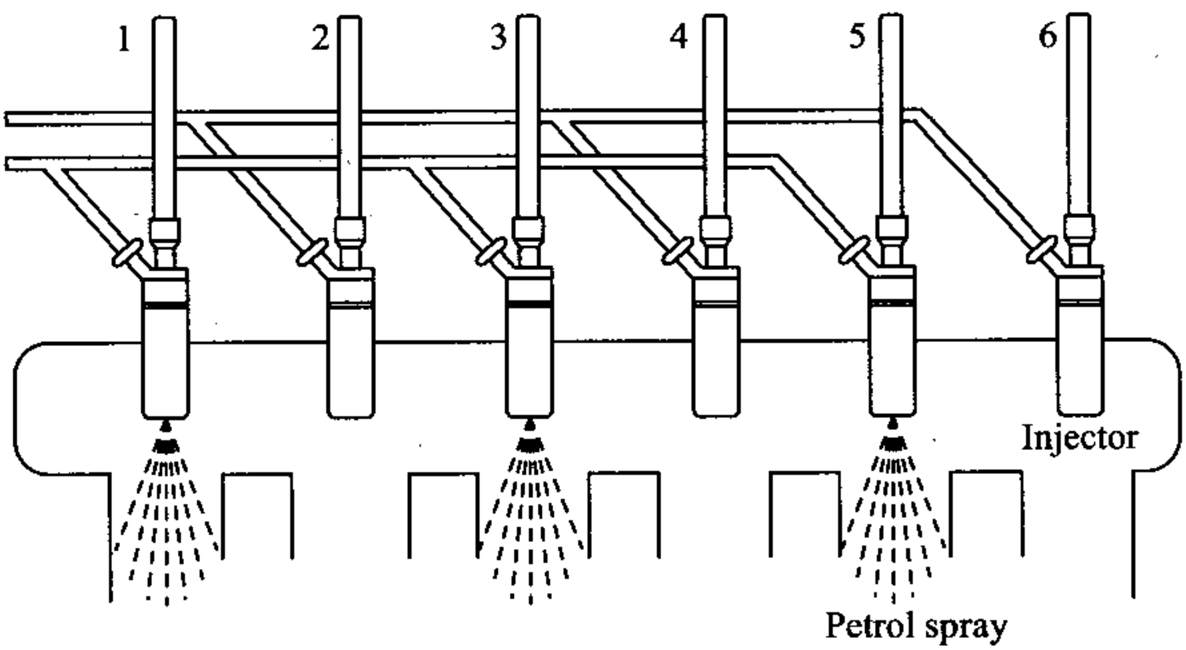


MPFI-Air induction system



Electronic diesel injection system

Injector grouping in six cylinder engine



By means of EFI systems one can achieve the precise control of:

(i) Injection timing,

(ii) Fuel injection quantity,

(iii) Injection rate during various stages of injection,

(iv) Injection pressure during injection,

(v) Nozzle opening speed and

(vi) Pilot injection timing and its quantity,

The following are easy to obtain with such systems:

(i) Very high injection pressure,

(ii) Sharp start and stop of injection,

(iii) Cylinder cut off,

(iv) Diagnostic capability,

(v) Turbocharger control and

(vi) Two stage injection

Common rail fuel injection system

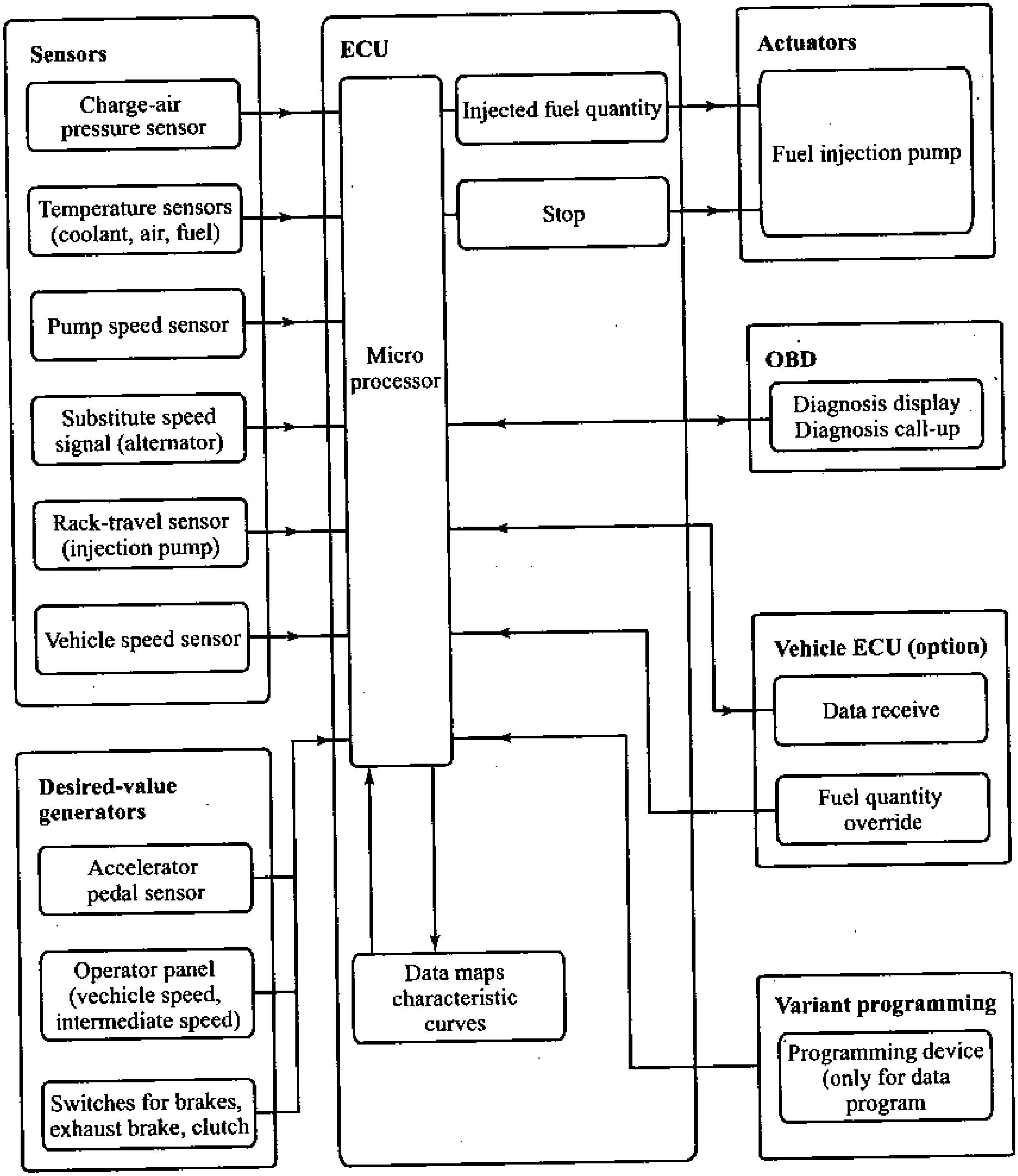
(i) Very high injection pressures of the order of 1500 bar.

(ii) Complete control over start, and end of injection

(iii) Injection pressure is independent of engine speed

(iv) Ability to have pilot, main and post injection

(v) Variable injection pressure.


Sensors
Charge-air pressure sensor
Temperature sensors (coolant, air, fuel)
Pump speed sensor
Substitute speed signal (alternator)
Rack-travel sensor (injection pump)
Vehicle speed sensor
ECU
Micro processor
Injected fuel quantity
Stop
Actuators
Fuel injection pump
OBD
Diagnosis display
Diagnosis call-up
Vehicle ECU (option)
Data receive
Fuel quantity override
Desired-value generators
Accelerator pedal sensor
Operator panel (vechicle speed, intermediate speed)
Switches for brakes, exhaust brake, clutch
Data maps characteristic curves
Variant programming
Programming device (only for data program

UNIT-III: COMBUSTION AND COMBUSTION CHAMBERS

Introduction to combustion in SI and diesel engines and stages of combustion. Dependence of ignition timing on load and speed. Knock in SI and CI engines. Combustion chambers for SI and CI engines. Direct and indirect injection combustion chambers for CI engines. Importance of Swirl, squish and turbulence. Factors controlling combustion chamber design.

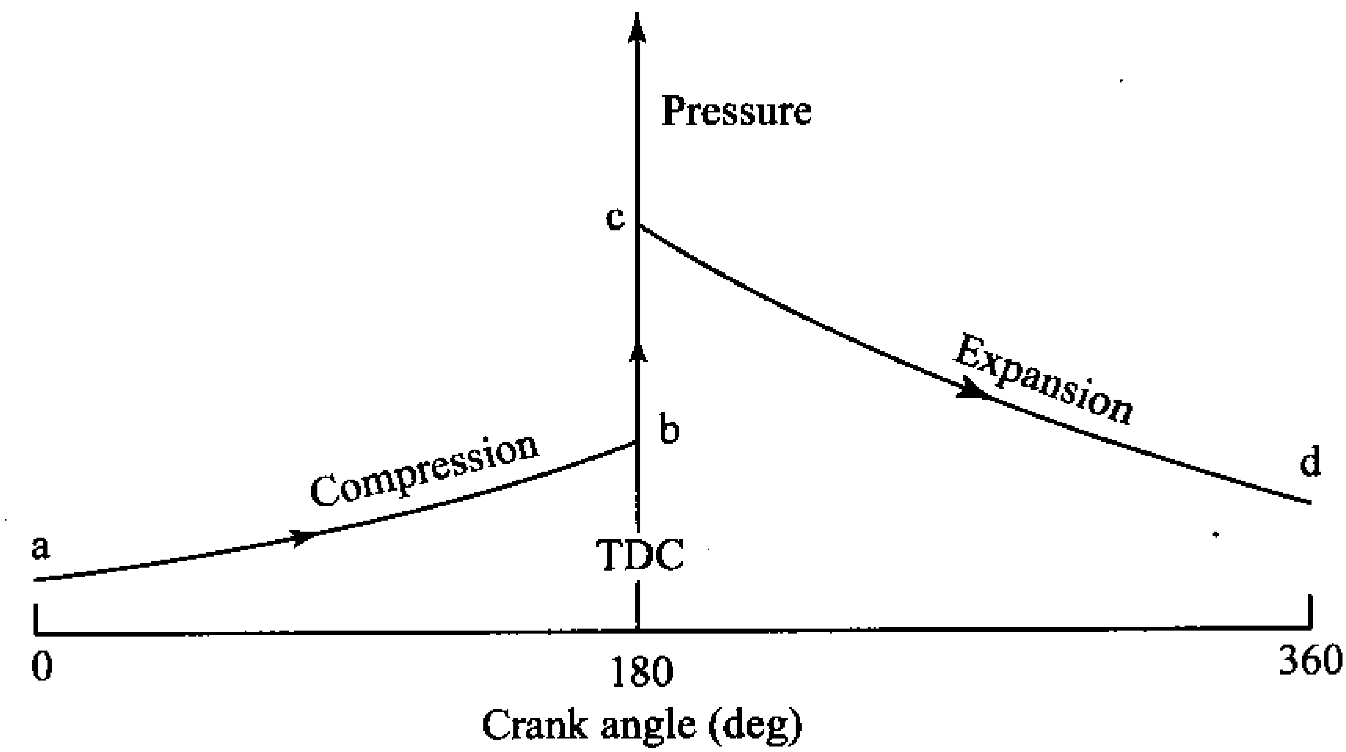
COMBUSTION

Combustion is a chemical reaction in which certain elements of the fuel like hydrogen and carbon combine with oxygen liberating heat energy and causing an increase in temperature of the gases.

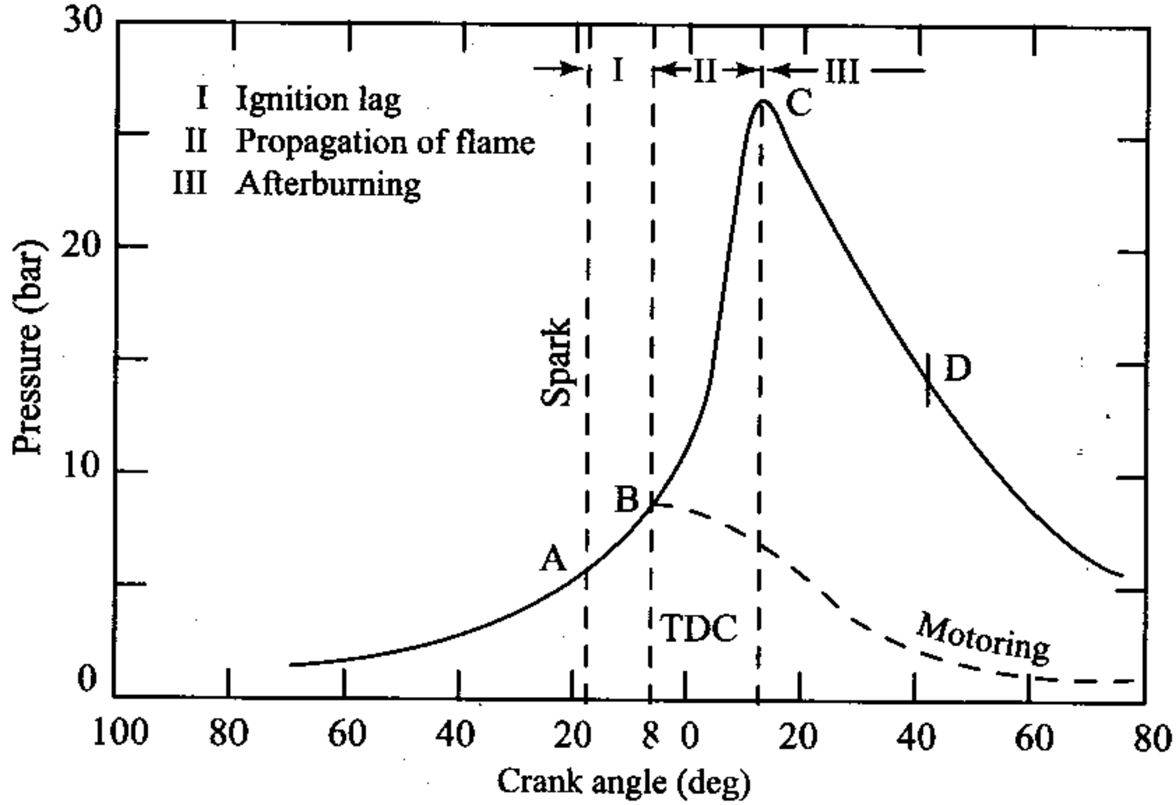
The conditions necessary for combustion are the presence of combustible mixture and some means of initiating the process.

The process of combustion in engines generally takes place either in a homogeneous or a heterogeneous fuel vapour-air mixture depending on the type of engine.

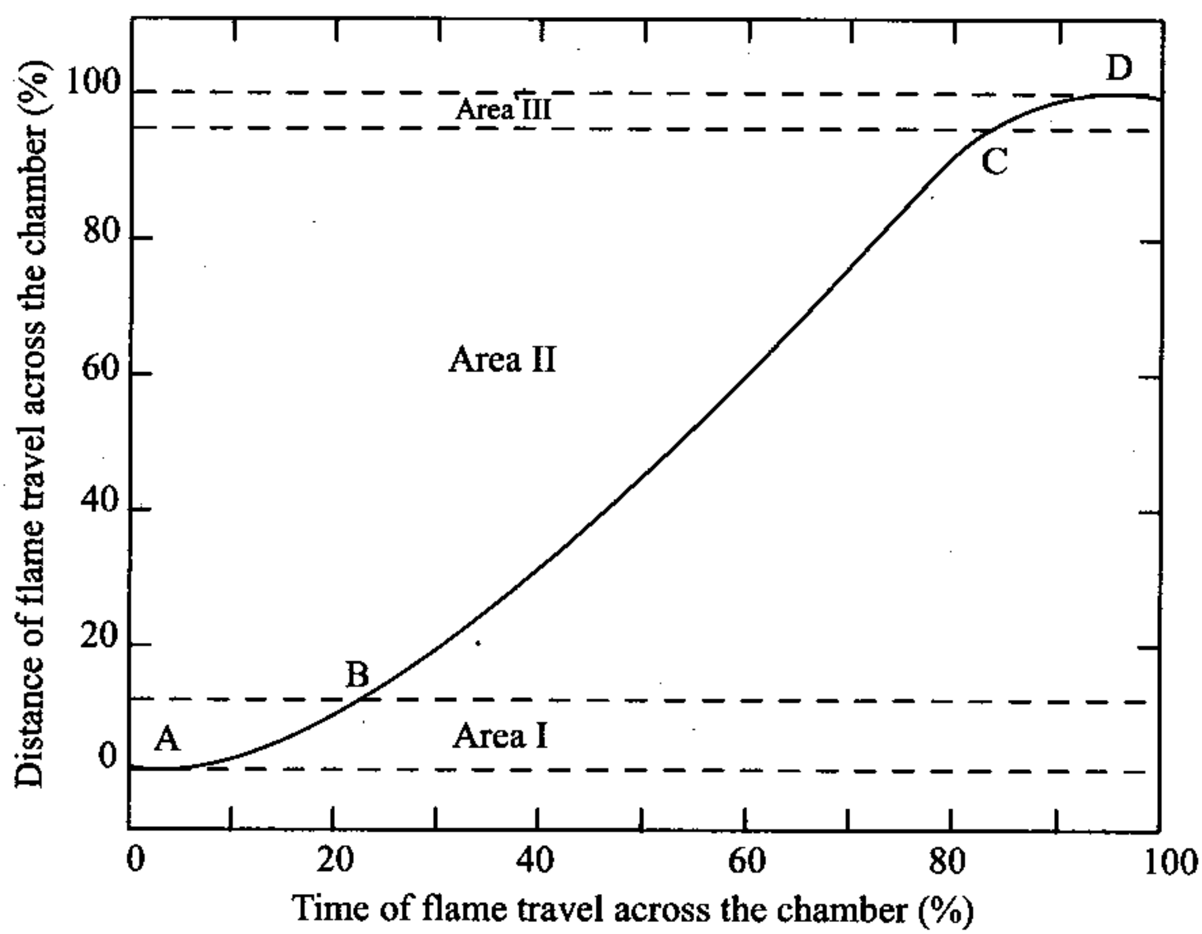
STAGES OF COMBUSTION IN SI ENGINES



p-θ diagram



FLAME FRONT PROPAGATION

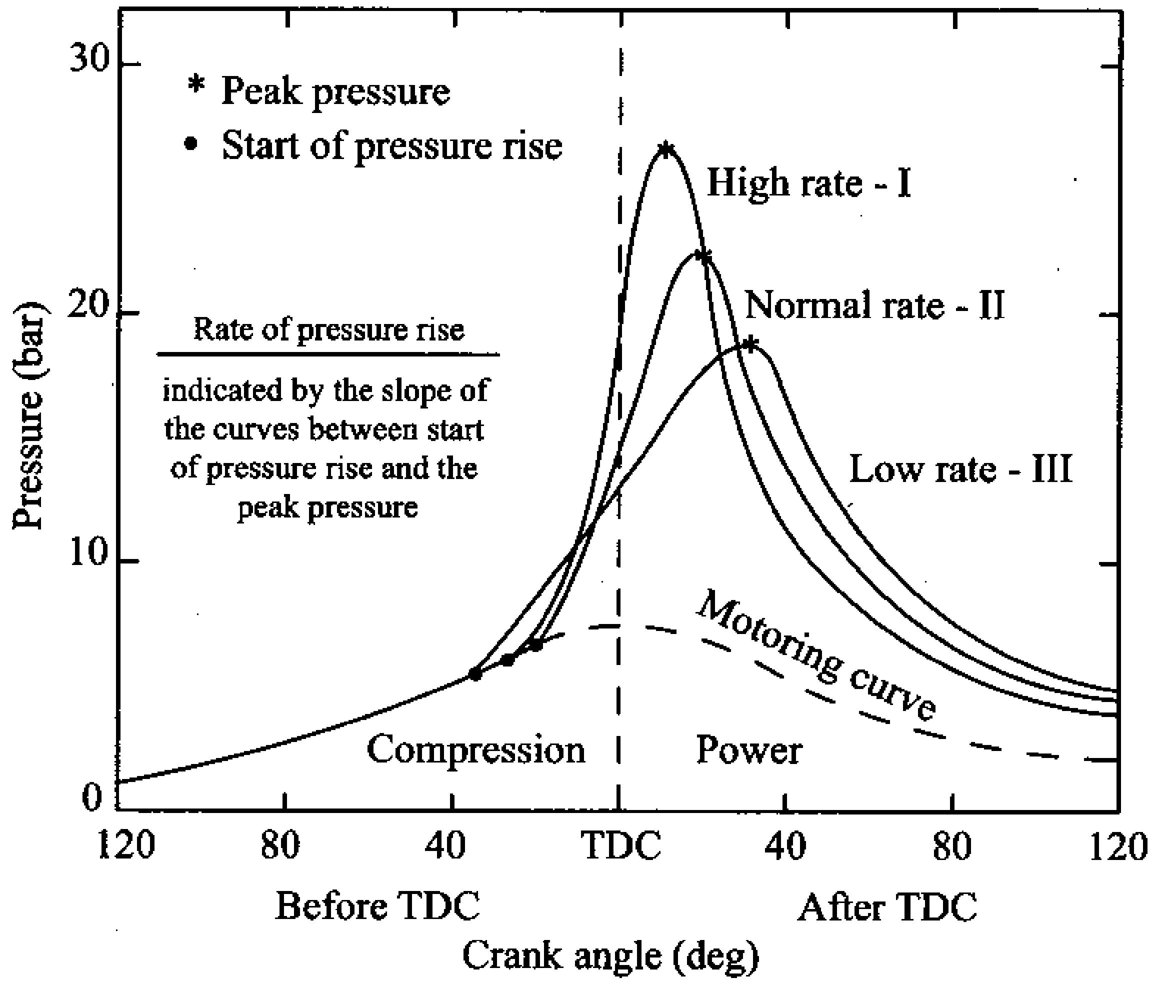


Details of flame travel

FACTORS INFLUENCING THE FLAME SPEED

1. Turbulence
2. Fuel-Air Ratio
3. Temperature and Pressure
4. Compression Ratio
5. Engine Output
6. Engine Size

RATE OF PRESSURE RISE



Illustrations of various combustion rates

ABNORMAL COMBUSTION

In normal combustion, the flame initiated by the spark travels across the combustion chamber in a fairly uniform manner.

Under certain operating conditions the combustion deviates from its normal course leading to loss of performance and possible damage to the engine.

This type of combustion may be termed as an abnormal combustion or knocking combustion.

The consequences of this abnormal combustion process are the loss of power, recurring pre-ignition and mechanical damage to the engine.

THE PHENOMENON OF KNOCK IN SI ENGINES

In a spark-ignition engine combustion which is initiated between the spark plug electrodes spreads across the combustible mixture.

A definite flame front which separates the fresh mixture from the products of combustion travels from the spark plug to the other end of the combustion chamber.

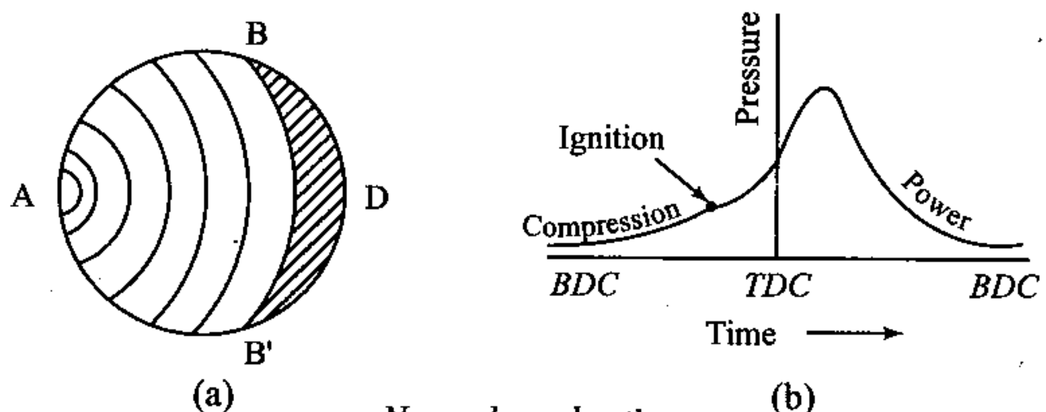
Heat-release due to combustion increases the temperature and consequently the pressure, of the burned part of the mixture above those of the unburned mixture.

In order to effect pressure equalization the burned part of the mixture will expand, and compress the unburned mixture adiabatically thereby increasing its pressure and temperature.

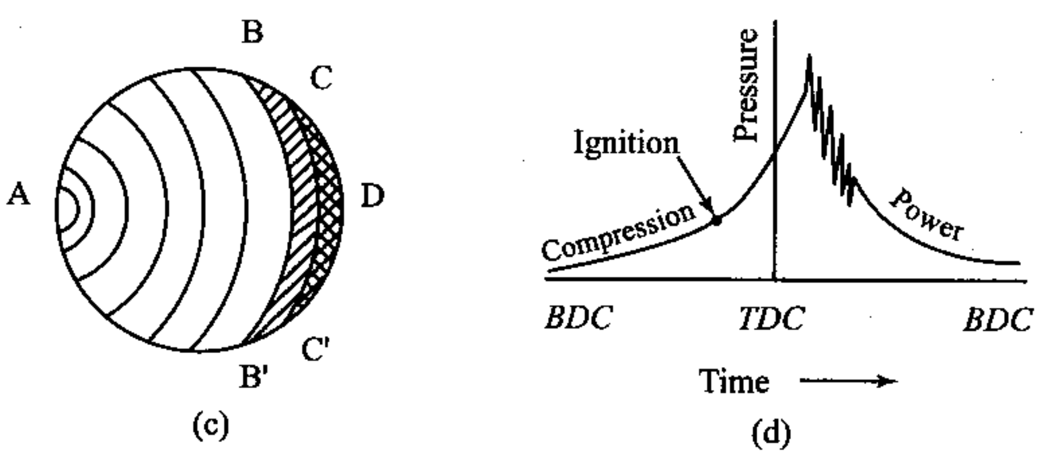
This process continues as the flame front advances through the mixture and the temperature and pressure of the unburned mixture are increased further.

If the temperature of the unburnt mixture exceeds the self-ignition temperature of the fuel and remains at or above this temperature during the period of preflame reactions (ignition lag), spontaneous ignition or autoignition occurs at various pin-point locations.

This phenomenon is called knocking. The process of autoignition leads towards engine knock.



Normal combustion

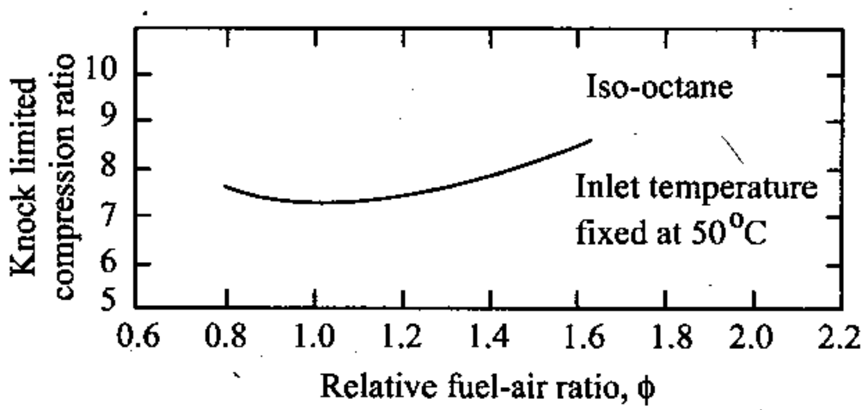


Combustion with detonation

Normal and abnormal combustion

EFFECT OF ENGINE VARIABLES ON KNOCK

1. DENSITY FACTOR
   a. Compression ratio
   b. Mass of inducted charge
   c. Inlet temperature of the mixture
   d. Temperature of the combustion chamber walls
   e. Retarding the spark timing
   f. Power output of the engine
2. TIME FACTORS
   a. Turbulence
   b. Engine speed
   c. Engine size
   d. Combustion chamber shape
   e. Location of spark plug
3. COMPOSITION FACTORS
   a. Fuel-air ratio



   b. Octane value of the fuel

COMBUSTION CHAMBERS FOR SI ENGINE

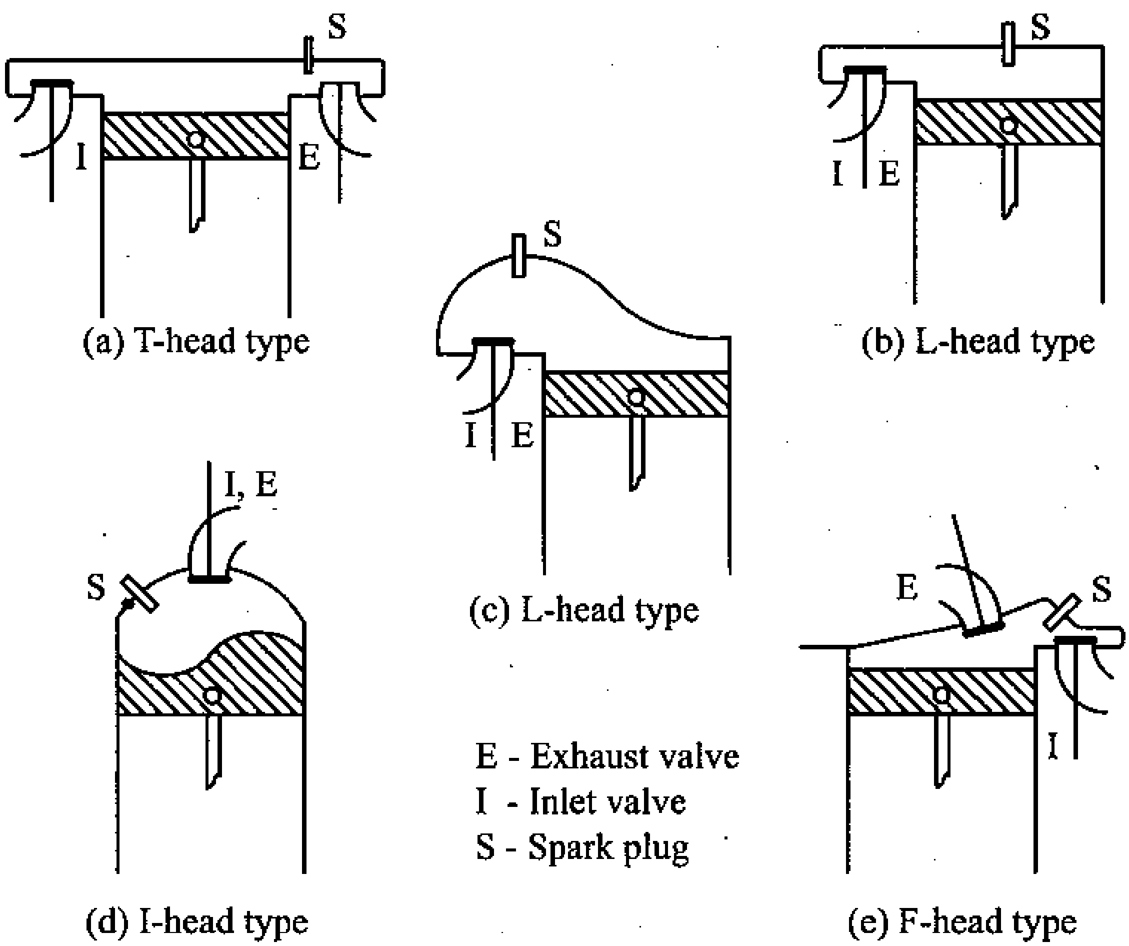
Combustion chambers must be designed carefully, keeping in mind the following general objectives.

1. Smooth engine operation
   a. Moderate rate of pressure rise
   b. Reducing the possibility of knocking
      i. 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.
      ii. 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. Heat transfer to the combustion chamber walls can be

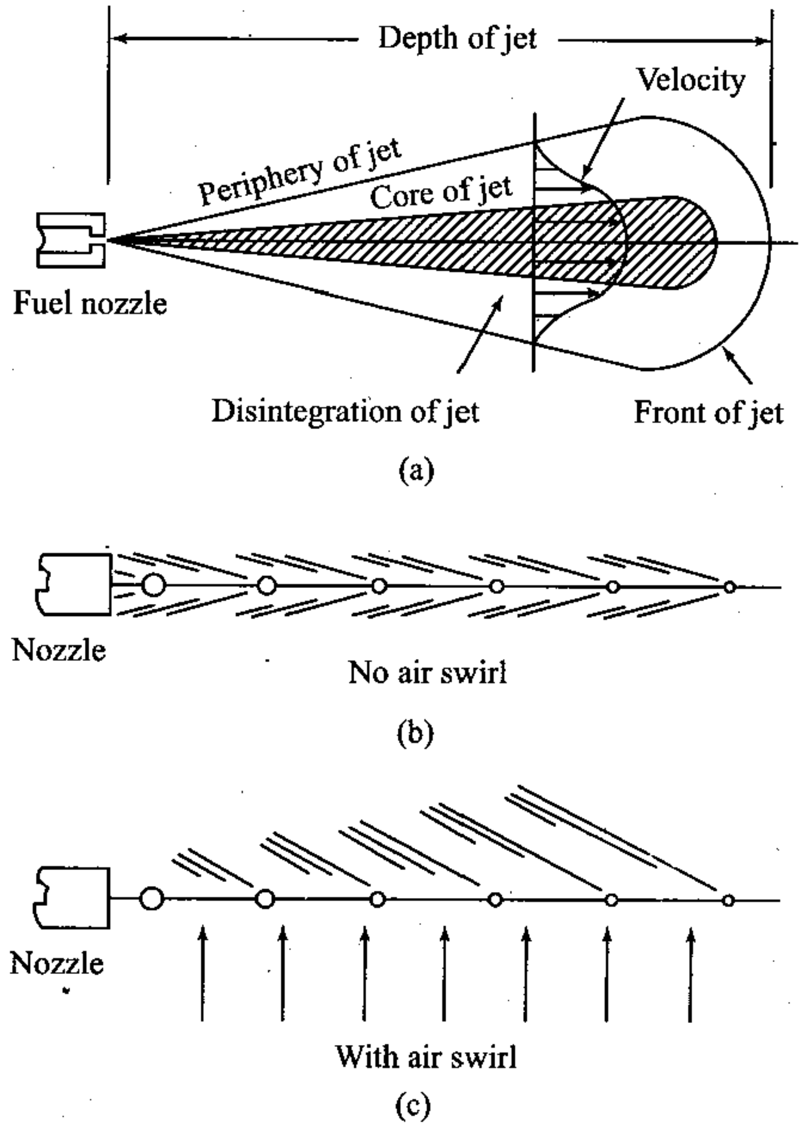
increased by using high surface to volume ratio thereby reducing the temperature.

2. High power output and thermal efficiency
   a. A high degree of turbulence is needed to achieve a high flame front velocity. Turbulence is induced by inlet flow configuration or squish. Squish can be induced in spark-ignition engines by having a bowl in piston or with a dome shaped cylinder head. Squish is the rapid radial movement of the gas trapped in between the piston and the cylinder head into the bowl or the dome.
   b. High volumetric efficiency, i.e., 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.
   c. Any design of the combustion chamber that improves its antiknock characteristics permits the use of a higher compression ratio resulting in increased output and efficiency.
   d. A compact combustion chamber reduces heat loss during combustion and increases the thermal efficiency.

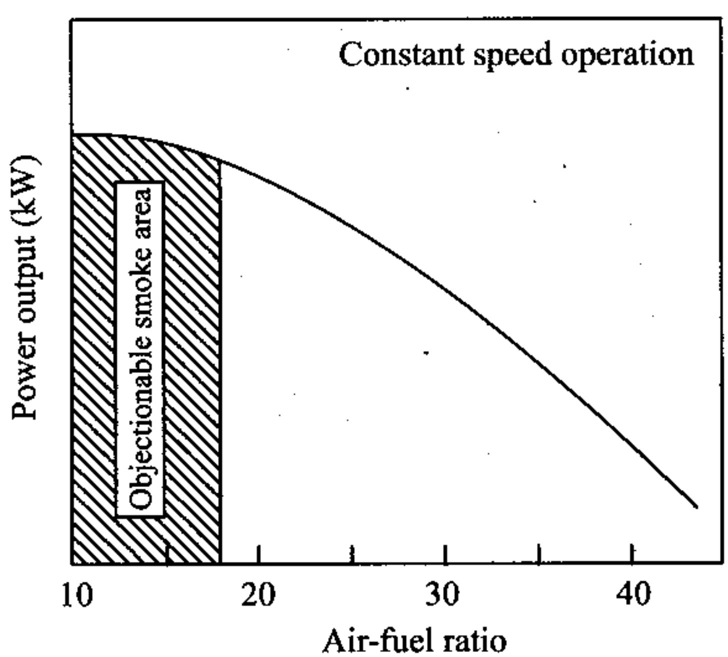
Different types of combustion chambers have been developed over a period of time. Some of them are shown in Figure.



(a) T-head type
(b) L-head type
(c) L-head type
(d) I-head type
(e) F-head type



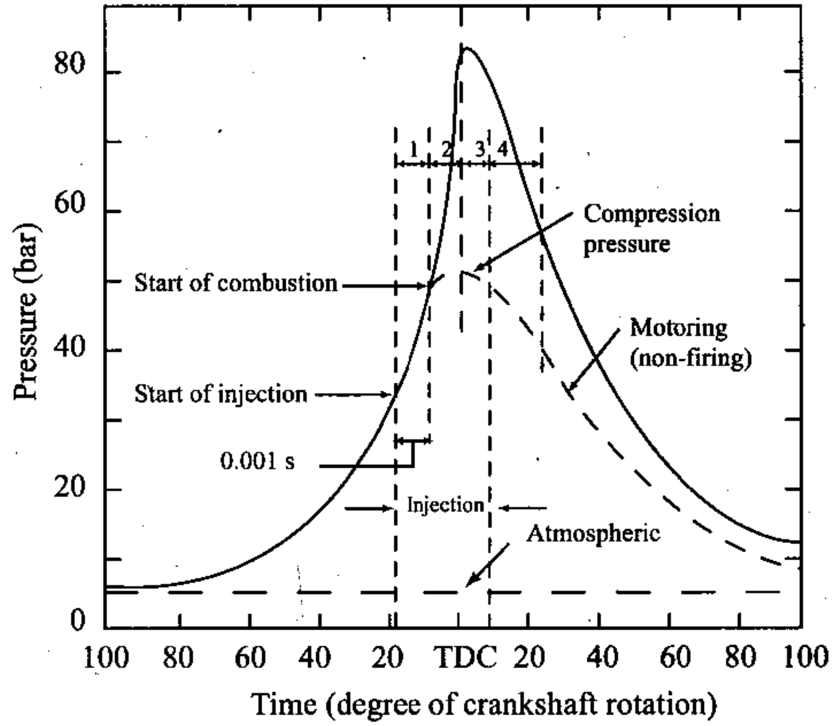
Schematic representation of the disintegration of a fuel jet

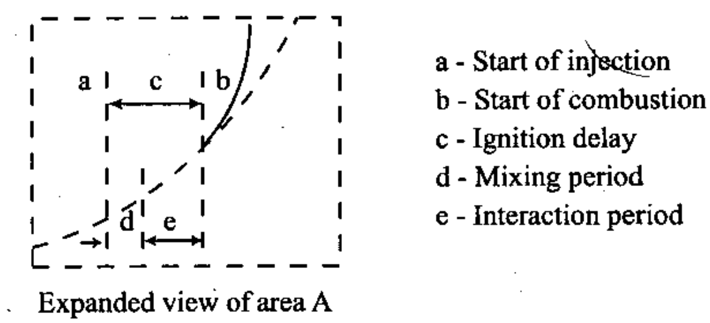


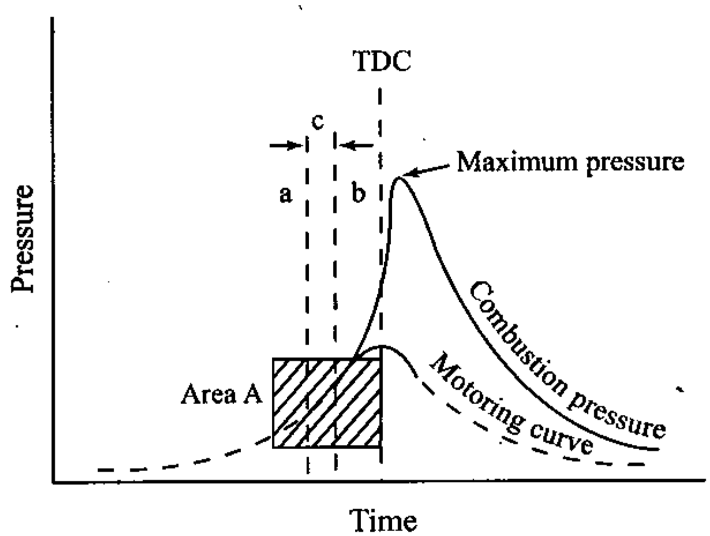
Effect of A/F ratio on power output of a CI engine

STAGES OF COMBUSTION IN A CI ENGINES

1. Ignition delay period
    a. Physical delay
    b. Chemical delay







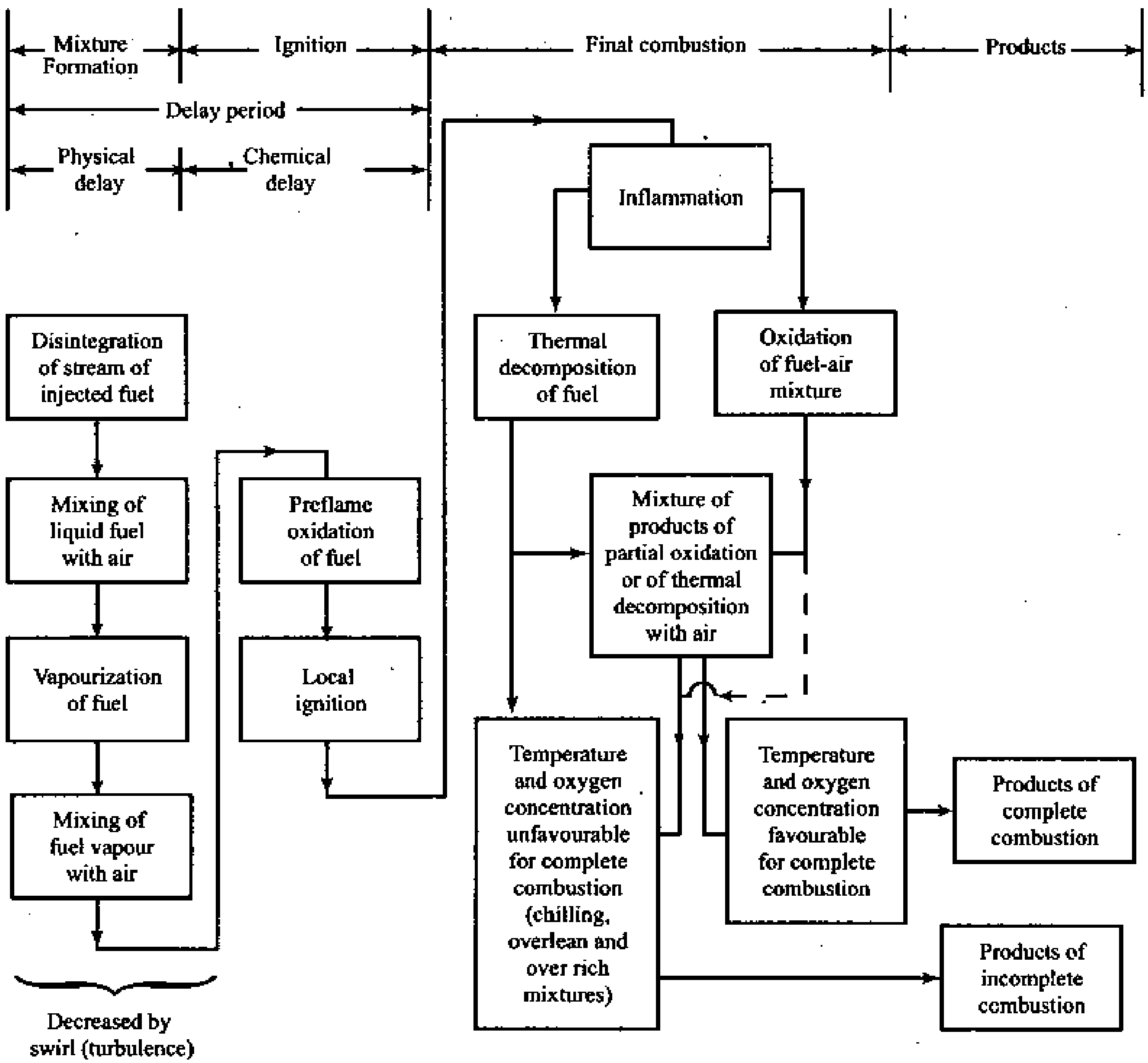
Pressure-time diagram illustrating ignition delay

2. Period of rapid combustion
3. Period of controlled combustion
4. Period of after-burning

FACTORS AFFECTING THE DELAY PERIOD

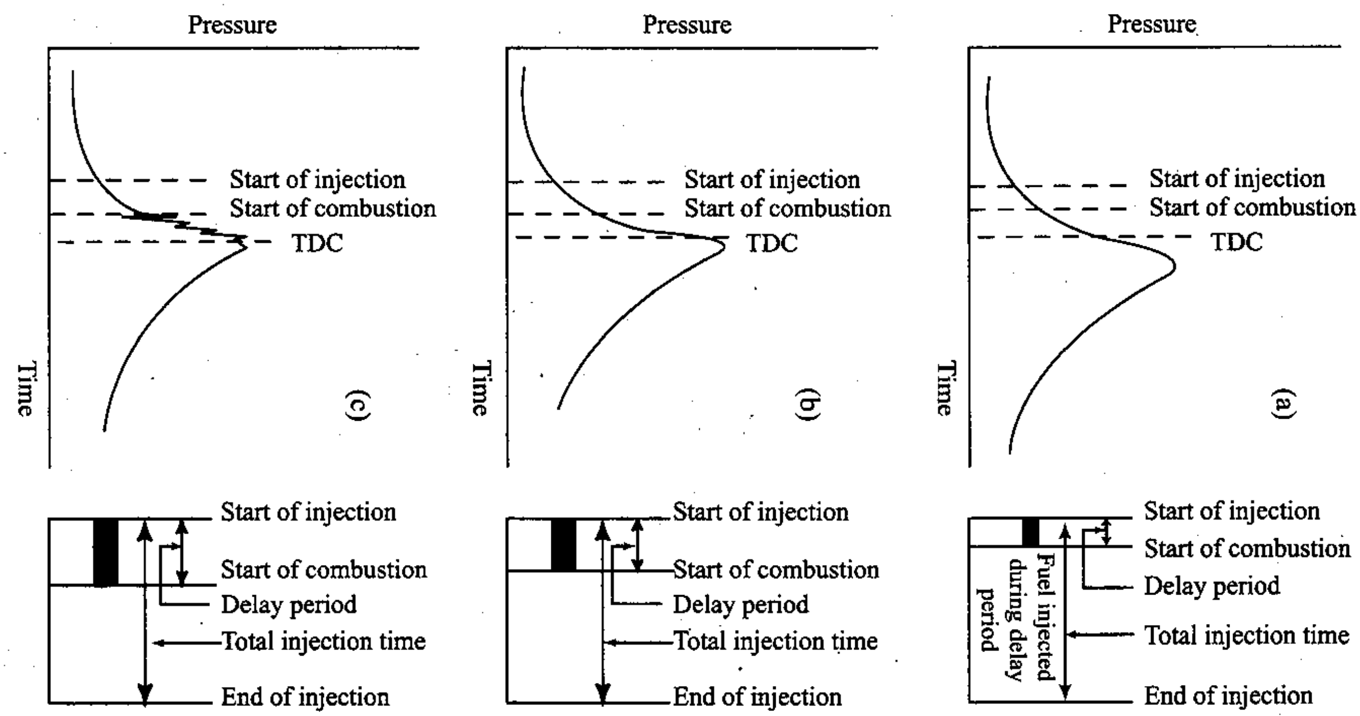
Many design and operating factors affect the delay period. The important ones are:

(i) compression ratio
(ii) engine speed
(iii) output
(iv) atomization and duration of injection
(v) quality of the fuel
(vi) intake temperature
(vii) intake pressure



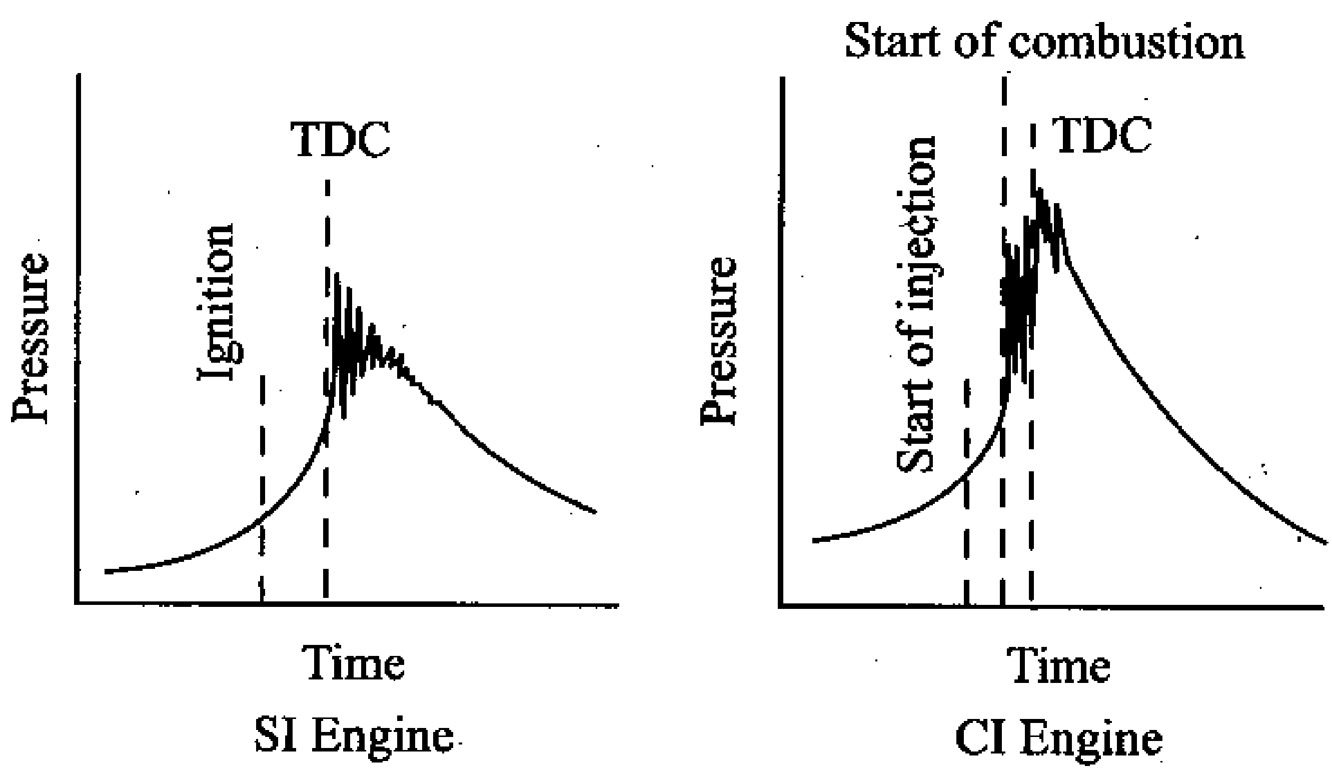
Block Diagram illustrating the Combustion Process in a CI Engine

KNOCK IN CI ENGINE



Diagrams illustrating the Effect of Ignition Delay on the Rate of Pressure Rise in a CI Engine

COMPARISIONS OF KNOCK IN SI AND CI ENGINE



Diagrams illustrating Knocking Combustion in SI and CI Engines

Characteristics tending to reduce detonation period or knock in SI and CI engine

S.No.	Characteristics	SI Engines	CI Engines
1.	Ignition temperature of fuel	High	Low
2.	Ignition delay	Long	Short
3.	Compression ratio	Low	High
4.	Inlet temperature	Low	High
5.	Inlet pressure	Low	High
6.	Combustion wall temperature	Low	High
7.	Speed, rpm	High	Low
8.	Cylinder size	Small	Large

COMBUSTION CHAMBERS FOR CI ENGINE

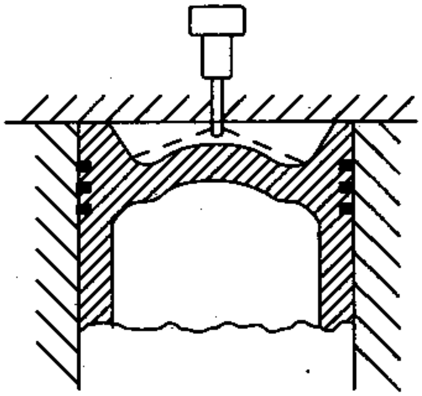
(i) **Direct-Injection (DI) Type**: This type of combustion chamber is also called an open combustion chamber. In this type the entire volume of the combustion chamber is located in the main cylinder and the fuel is injected into this volume.

(ii) **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 affected usually into that part of the chamber located in the cylinder head. These chambers are classified further into:

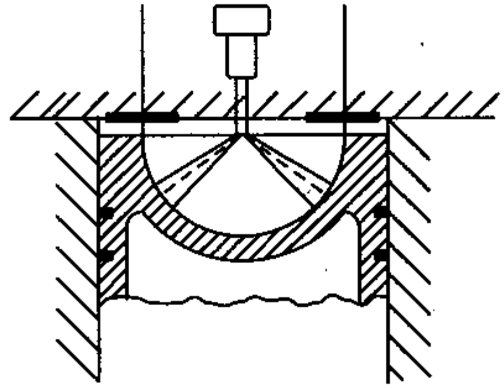
(a) Swirl chamber in which compression swirl is generated.
(b) Precombustion chamber in which combustion swirl is induced.
(c) Air cell chamber in which both compression and combustion swirl are induced.

Direct injection (DI) chamber

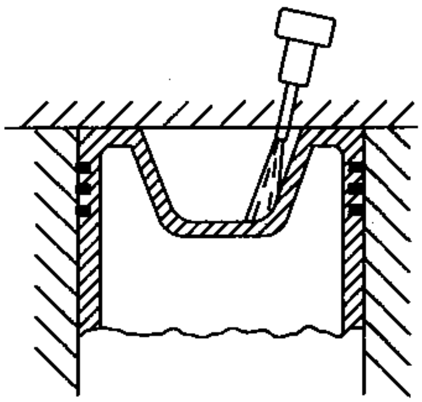
An open combustion chamber is defined as one in which the combustion space is essentially a single cavity with little restriction from one part of the chamber to the other and hence with no large difference in pressure between parts of the chamber during the combustion process.



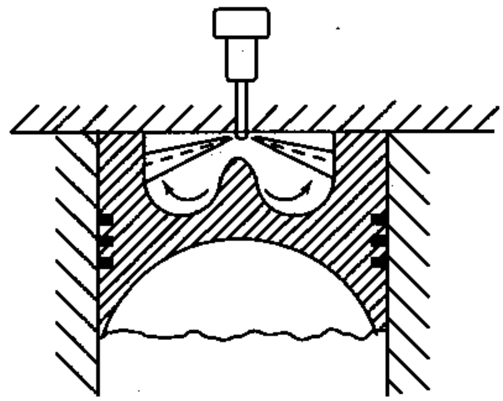
(a) Shallow depth chamber



(b) Hemispherical chamber



(c) Cylindrical chamber



(d) Toroidal chamber

The main advantages of this type of chambers are:

(i) Minimum heat loss during compression because of lower surface area to volume ratio and hence, better efficiency.

(ii) No cold starting problems.

(iii) Fine atomization because of multihole nozzle.

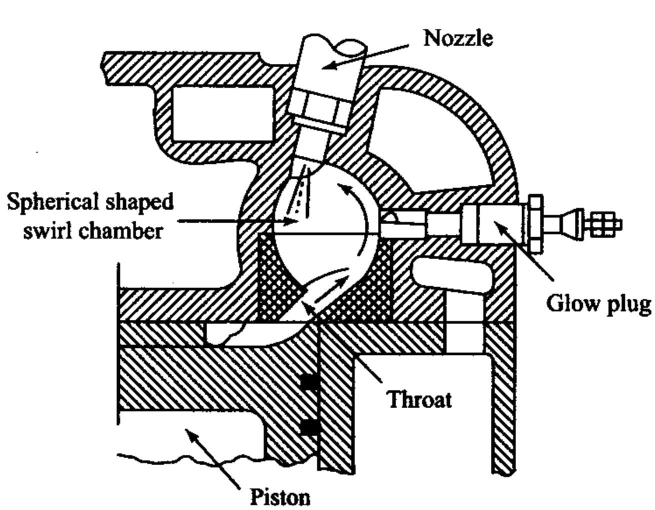
The drawbacks of these combustion chambers are:

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

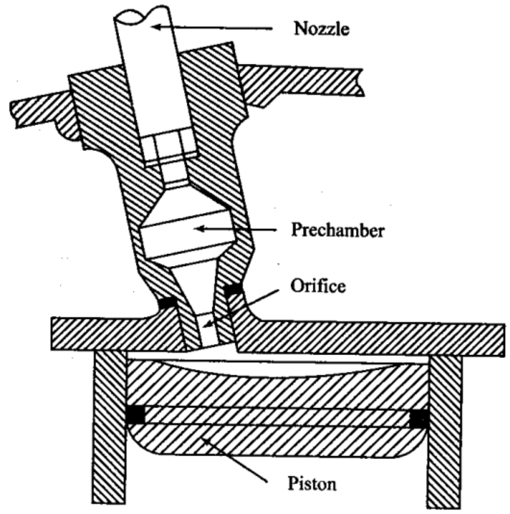
(ii) Necessity of accurate metering of fuel by the injection system, particularly for small engines.

In-Direct injection (IDI) chamber

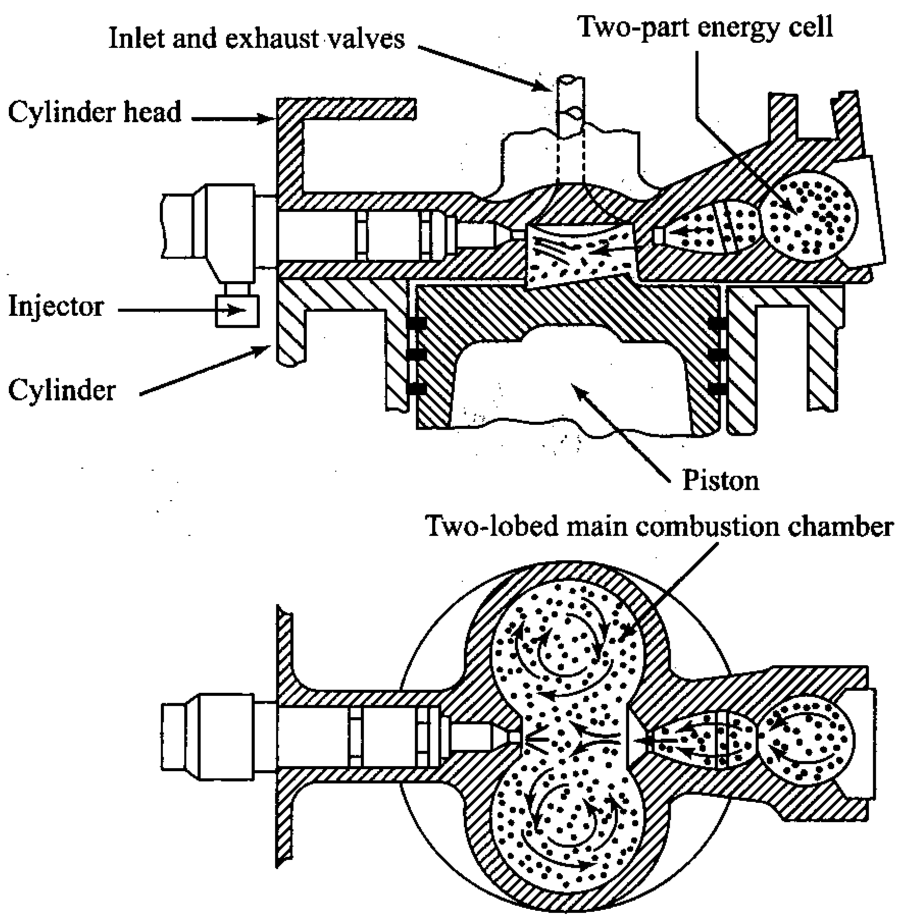
A divided combustion chamber is defined as one in which the combustion space is divided into two or more distinct compartments connected by restricted passages. This creates considerable pressure differences between them during the combustion process.



Swirl chamber



Precombustion chamber



Air-cell chamber

The main advantages of the indirect-injection combustion chambers are:

(i) Injection pressure required is low

(ii) Direction of spraying is not very important

These chambers have the following serious drawbacks which have made its application limited.

(i) Poor cold starting performance requiring heater plugs.

(ii) Specific fuel consumption is high because there is a loss of pressure due to air motion through the duet and heat loss due to large heat transfer area.

UNIT-IV: SUPERCHARGING, TURBOCHARGING AND ENGINE TESTING

Supercharging and Turbocharging, Different methods of turbocharging, Intercooling, Turbocharger controls including, waster gate, variable geometry, variable nozzle types. Dynamometers, Indicated thermal, brake thermal and volumetric efficiencies. Measurement of friction, Cylinder pressure measurement. Engine performance maps, Engine testing standards.

It will be the principal aim of the engine designer, to achieve the twin goals of improved power output and minimum exhaust emissions. The power output of a naturally aspirated engine depends mainly on the following five factors:

(i) Amount of air inducted into the cylinder.
(ii) Extent of utilization of the inducted air.
(iii) The speed of the engine.
(iv) Quantity of fuel admitted and its combustion characteristics.
(v) Thermal efficiency of the engine.

SUPER CHARGING

Supercharging of internal combustion engines is in practice for a long time as a method for improving engine power output.

A good way to meet these needs is to have supercharging which may be called forced induction.

As already stated, the purpose of supercharging an engine is to raise the density of the air charge, before it enters the cylinders.

Thus, the increased mass of air will be inducted which will then be compressed in each cylinder. This makes mor6 oxygen available for combustion than the conventional method of drawing the fresh air charge into the cylinder (naturally aspirated). Consequently, more air and fuel per cycle will be forced into the cylinder, and this can be effectively burnt during the combustion process to raise the engine power output to a higher value than would otherwise be possible.

(i) Supercharging increases the power output of the engine. It does not increase the fuel consumption, per brake kW hour.
(ii) Certain percentage of power is consumed in compressing the air. This power has to be taken from the engine itself. This will lead to some power loss. However, it is seen that the net power output will be more than the power output of an engine of the same capacity, without supercharging.
(iii) The engine should be designed to withstand the higher forces due to supercharging.

(iv) The increased pressure and temperature as a result of supercharging, may lead to detonation, therefore the fuel used must have better anti-knock characteristics.

In practice, racing car engines use supercharging. The most important areas where supercharging is of vital importance are :

Supercharger is a pressure-boosting device which supplies air (or mixture) at a higher pressure.

A centrifugal or axial flow or displacement type compressor is normally used. If the supercharger is driven by the engine crankshaft, then it is called mechanically driven supercharger.

Some superchargers are driven by a gas turbine, which derives its power from the engine exhaust gases.

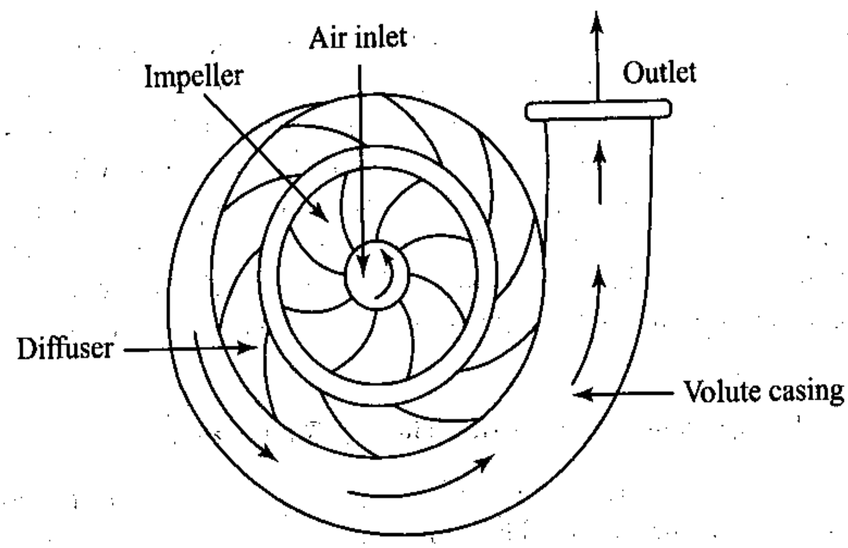
Such a supercharger is called turbocharger.

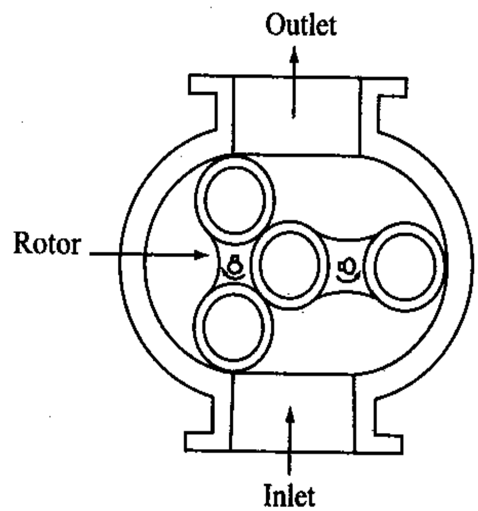
There are three types of superchargers

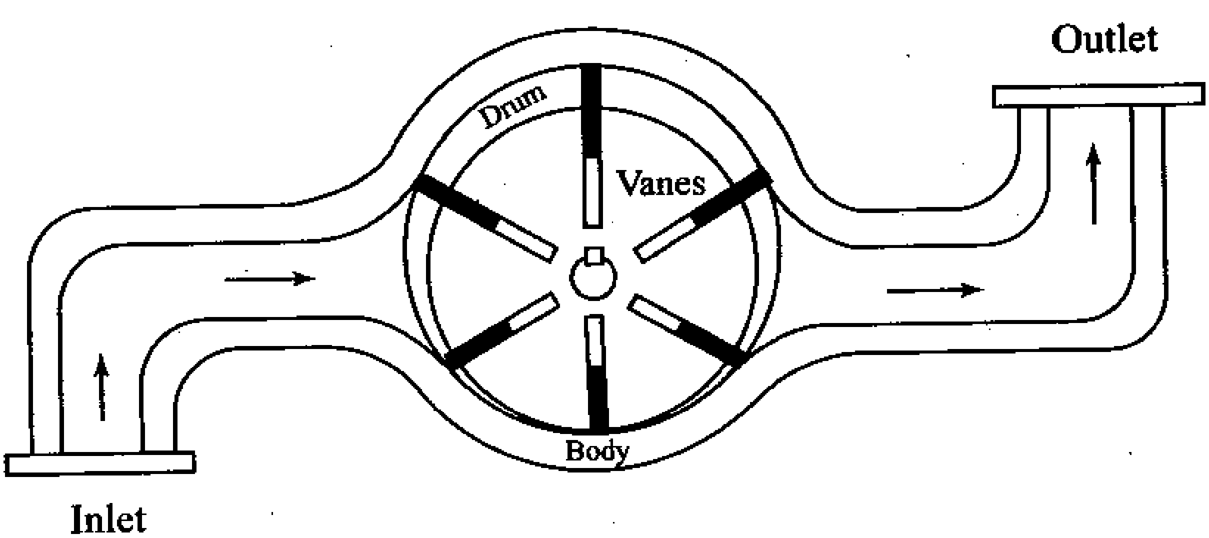
(i) Centrifugal type

(ii) Root's type

(iii) Vane type







METHODS OF SUPERCHARGING

Necessary amount of compressed air (or mixture) can be supplied to the engine in the following ways.

(i) Independently driven compressor or blower, usually driven by an electric motor.
(ii) Ram effect.
(iii) Under piston supercharging.
(iv) Kadenacy system (applied to two stroke engines).
(v) Engine driven compressor or blower.

The details of the above five methods of supercharging are briefly discussed in the following sections.

The two other important superchargers viz., gear driven supercharger and exhaust driven superchargers will be discussed in detail in subsequent sections.

EFFECTS OF SUPERCHARGING

Before supercharging an engine one should understand its effects. The following are the effects of supercharging engines. Some of the points refer to CI engines:

(i) Higher power output
(ii) Greater induction of charge mass
(iii) Better atomization of fuel
(iv) Better mixing of fuel and air
(v) Better torque characteristic over the whole speed range
(vi) Quicker acceleration of vehicle
(vii) More complete and smoother combustion
(viii) Inferior or poor ignition quality fuel usage
(ix) Smoother operation and reduction in diesel knock tendency
(x) Increased detonation tendency in SI engines
(xi) Improved cold starting
(xii) Reduced exhaust smoke
(xiii) Reduced specific fuel consumption, in turbocharging
(xiv) Increased mechanical efficiency
(xv) Increased thermal stresses
(xvi) Increased heat losses due to increased turbulence
(xvii) Increased gas loading
(xviii) Increased valve overlap period of 60 to 160° of crank angle
(xix) Increased cooling requirements of pistons and valves

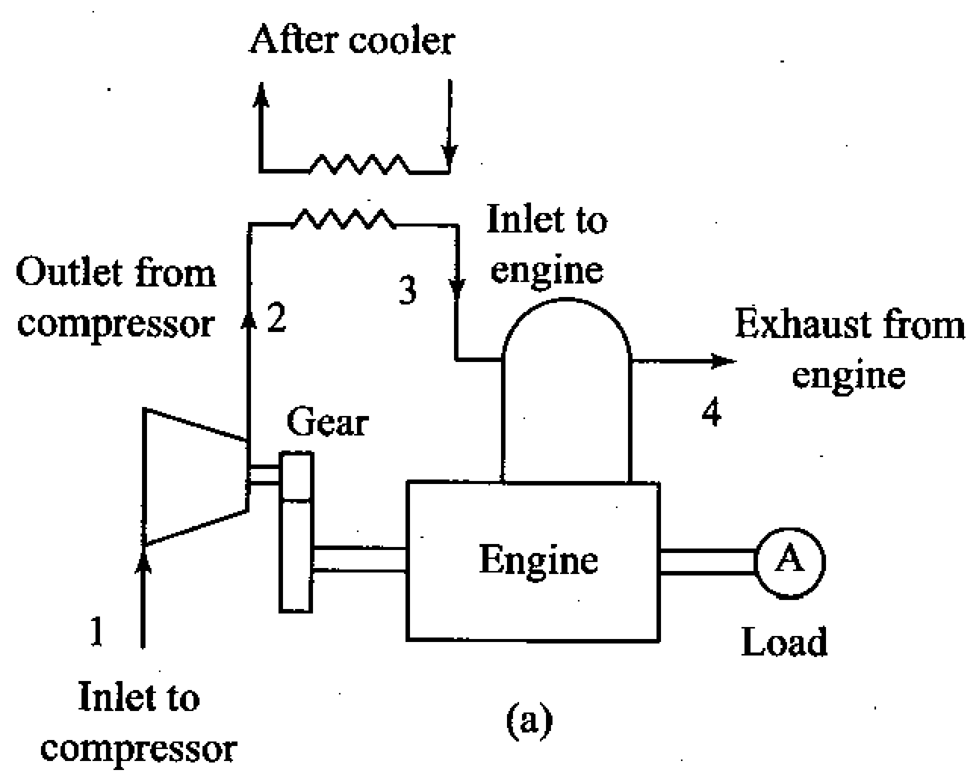
LIMITATIONS TO SUPERCHARGING

Due to supercharging, thermal load on the various parts of the engine increases.

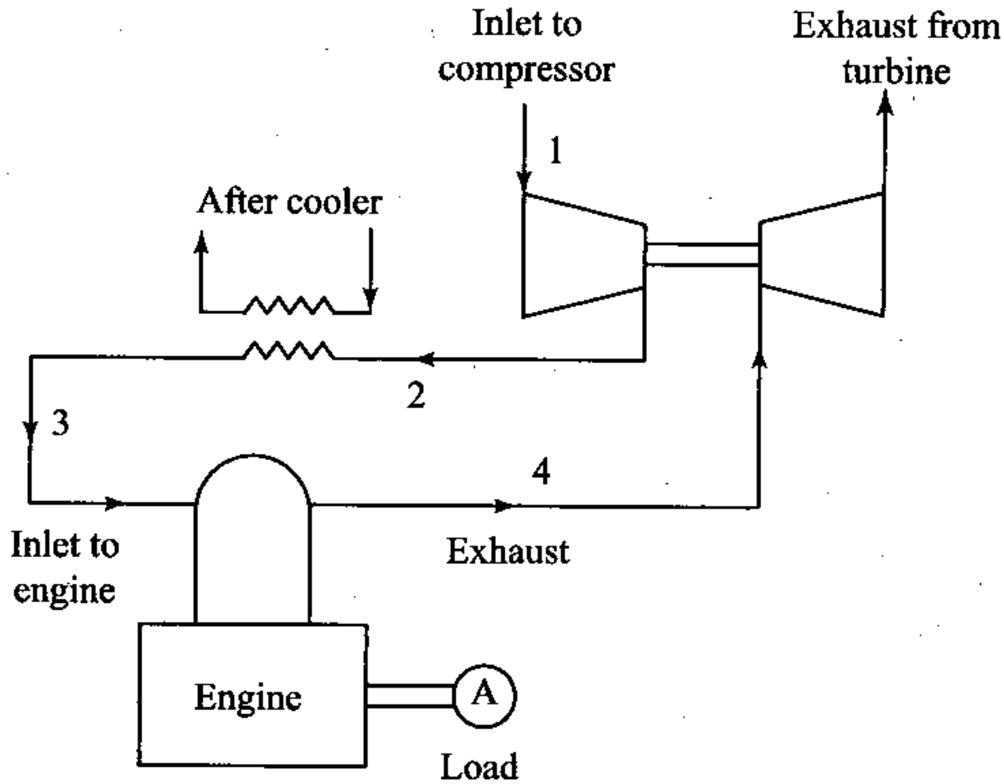
In some engines, the piston crown is provided with a hollow space.

Oil or water is circulated through this space and thereby the piston crown is cooled.
In some engines, the piston crown and the seat and the edges of the exhaust valves are usually made of better materials that can withstand higher temperatures. Increased gas loading caused by supercharging necessitates the use of larger bearing areas and heavier engine components
In an existing engine if supercharging has to be adopted, one should first study the factors "that limit the extent of supercharging that can be tried.
Further certain modifications have to be made to the engine to safeguard the same and to get the full benefit of supercharging. These are discussed below:
The permissible extent of supercharging depends upon the ability of the engine to withstand the increased gas loading and thermal stresses.
Durability, reliability and fuel economy are the main considerations that limit the degree of supercharging of an engine
Because of the increased heat generation and heat transfer, there is a greater tendency to bum the piston crown and the seat and edges of the 80 to 160 degree of crank travel.
Increased valve overlap permits greater time during which cooler air will flow past the valves and the piston crown.
This cools the exhaust valve seat, the exhaust valves and the piston crown.

Supercharging Arrangements

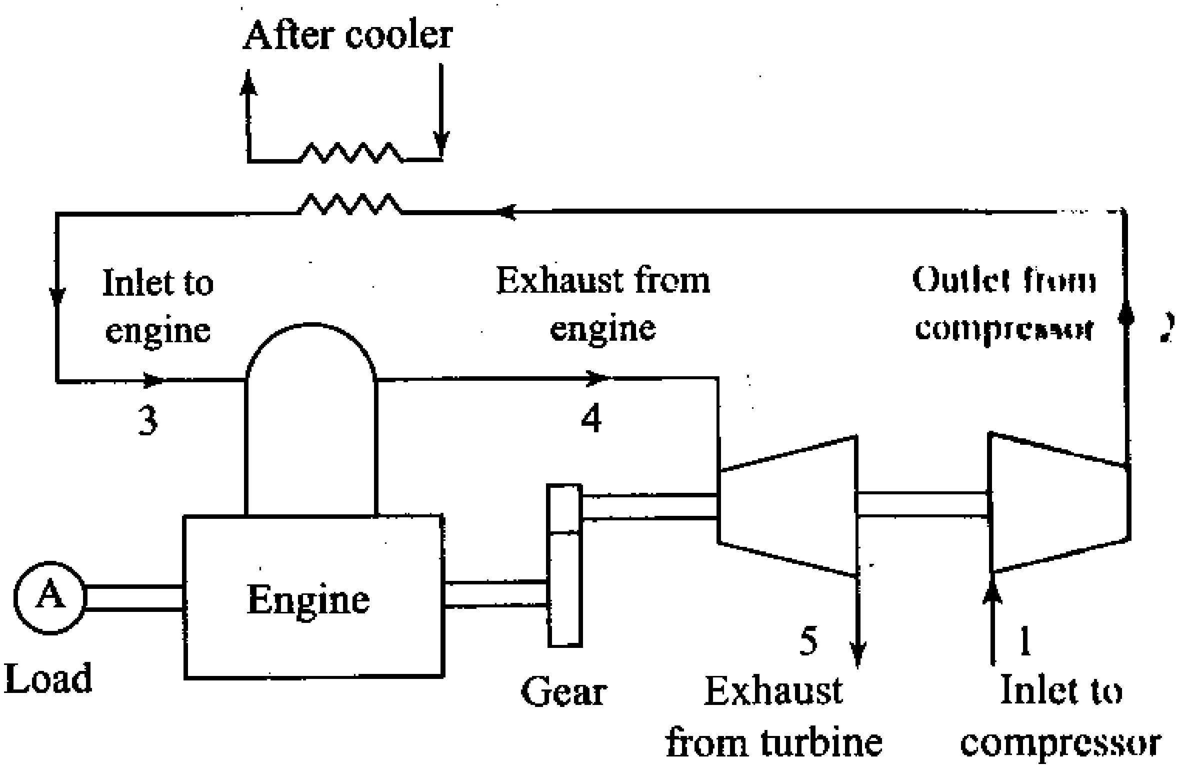


(a)

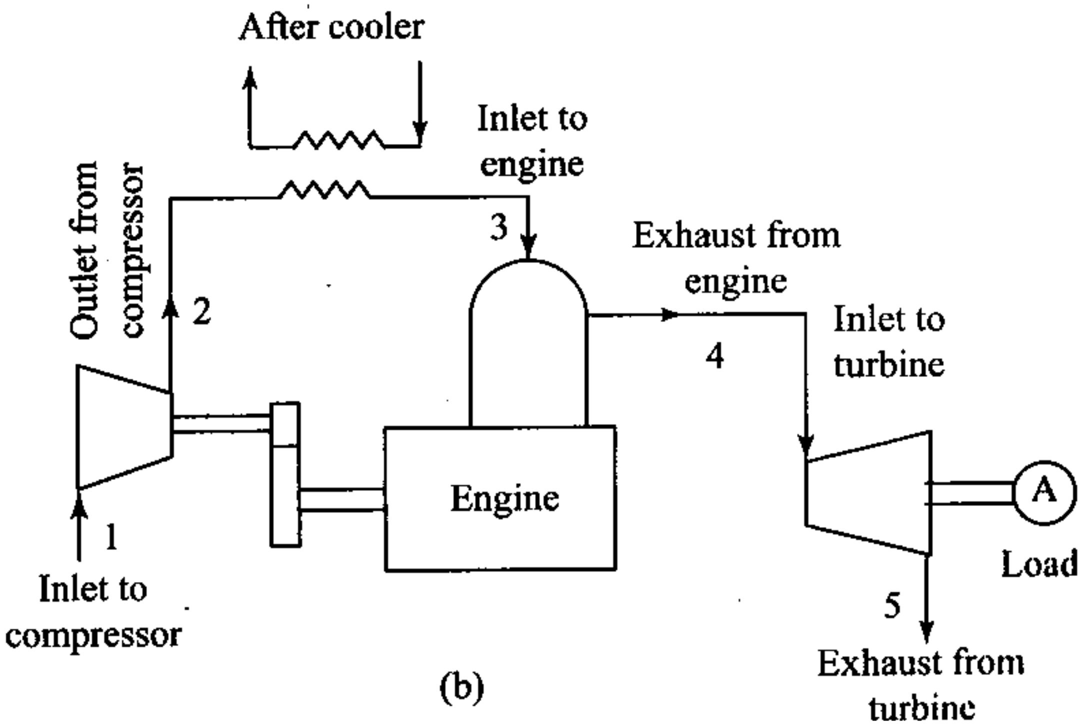


(b)

Methods of supercharging



(a)



(b)

TURBOCHARGING

In turbocharging, the supercharger is being driven by a gas turbine which uses the energy in the exhaust gases.

There is no mechanical link between the engine and the supercharger.

The major parts of a turbocharger are turbine wheel, turbine housing, turbo shaft, compressor wheel, compressor housing and bearing housing.

Figures show the principle of exhaust turbocharging of a single cylinder engine and a Vee type engine with charge cooling unit respectively.

During engine operation, hot exhaust gases blowout through the exhaust valve opening into the exhaust manifold.

The exhaust manifold and the connecting tubing route these gases into the turbine housing.

As the gases pass through the turbine housing, they strike on the fins or blades on the turbine wheel.

When the engine load is high enough, there is enough gas flow and this makes the turbine wheel to spin rapidly.

The turbine wheel is connected to the compressor wheel by the turbo shaft.

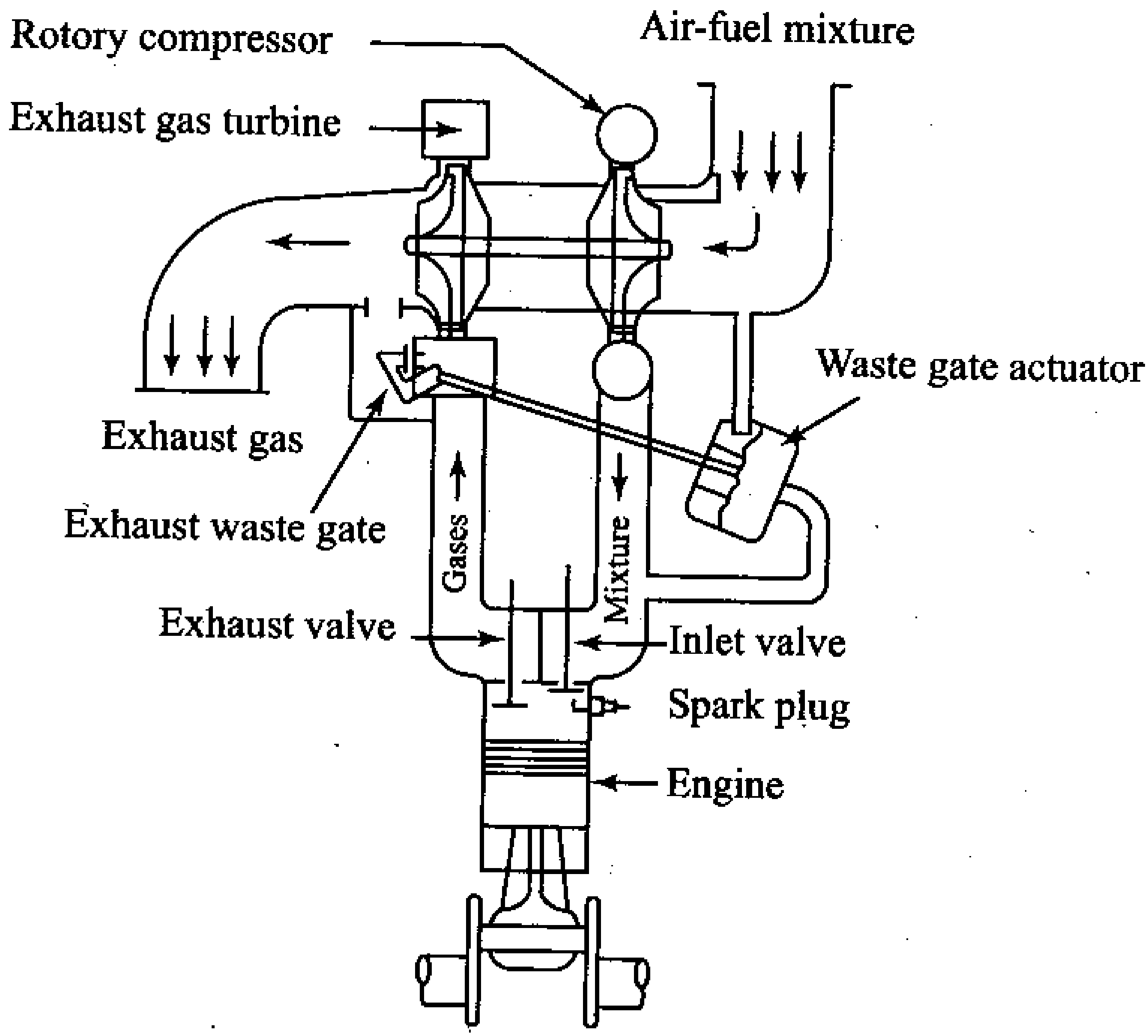
As such, the combustion exhausts flow out of the turbocharger and into the engine cylinder under pressure.

In the case of turbocharging, there is a phenomenon called turbo lag. It refers to the short delay period before the boost or manifold pressure increased.

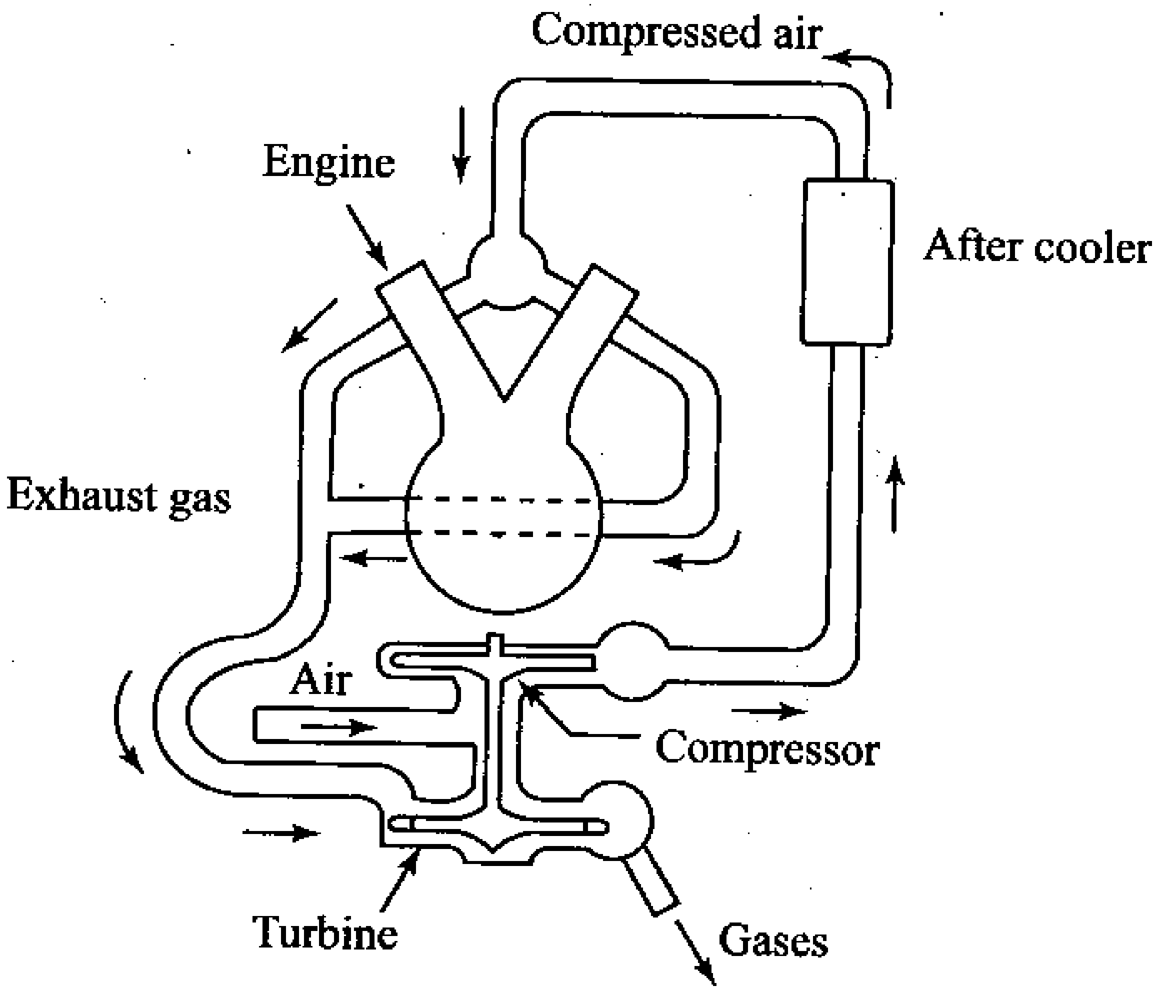
This is due to the time the turbocharger assembly takes the exhaust gases to accelerate the turbine and compressor wheel to speed up.

In the turbocharger assembly, there is a control unit called waste gate.

This unit limits the maximum boost pressure to prevent detonation in SI engines and the maximum pressure and engine damage.
It is a diaphragm operated valve that can bypass part of the gases around the turbine wheel when manifold pressure is quite high.
The computer controlled turbocharging system uses engine sensors, a microprocessor and a waste gate solenoid.
The solenoid when energized or de energized by the computer can open or close the waste gate.
By this way, the boost pressure can be controlled closely.
The exhaust smoke comparison for a diesel engine for a naturally aspirated and turbocharged version, for different loads can be seen in Figure.
There is an appreciable reduction in smoke in the case of turbocharged engine in the overload operation.



Principals of exhaust turbocharging of a single cylinder engine



Naturally aspirated turbocharger

CHARGE COOLING

When air charge is compressed, it becomes hot.

When air charge leaves the compressor, it is at a much higher temperature than ambient air temperature.

During supercharging, the temperature of air increases from 60 to 95 °C. When air gets heated, it expands and the density reduces.

Because of this, the mass of air entering the cylinder becomes lesser.

This reduces oxygen availability in the cylinder for combustion.

Further, supply of hot air to the engine may increase engine operating temperature.

As such, charge is cooled by way of intercooling and/or after cooling to overcome these problems.

However, this adds to the complexity of the system.

WASTE GATE

To manage the pressure of the air coming from the compressor (known as the "upper-deck air pressure"), the engine's exhaust gas flow is regulated before it enters the turbine with a waste gate that bypasses excess exhaust gas entering the turbocharger's turbine.

A waste gate is the most common mechanical speed control system, and is often further augmented by an electronic or manual boost controller.

The main function of a waste gate is to allow some of the exhaust to bypass the turbine when the set intake pressure is achieved.

This regulates the rotational speed of the turbine and thus the output of the compressor.

The waste gate is opened and closed by the compressed air from the turbo and can be raised by using a solenoid to regulate the pressure fed to the waste gate membrane.

This solenoid can be controlled by Automatic Performance Control, the engine's electronic control unit or a boost control computer.

External waste gates are more accurate and efficient than internal waste gates, but are far more expensive, and thus are generally only found in racing cars (where precise control of turbo boost is a necessity and any efficiency increase is welcomed).

VARIABLE GEOMETRY TURBOCHARGER

Variable geometry turbochargers (VGTs) are a family of turbochargers, usually designed to allow the effective aspect ratio (sometimes called A/R Ratio) of the turbo to be altered as conditions change.

This is done because optimum aspect ratio at low engine speeds is very different from that at high engine speeds.

If the aspect ratio is too large, the turbo will fail to create boost at low speeds; if the aspect ratio is too small, the turbo will choke the engine at high speeds, leading to high exhaust manifold pressures, high pumping losses, and ultimately lower power output.

By altering the geometry of the turbine housing as the engine accelerates, the turbo's aspect ratio can be maintained at its optimum.

Because of this, VGTs have a minimal amount of lag, have a low boost threshold, and are very efficient at higher engine speeds.

VGTs do not require a waste gate.

VGTs tend to be much more common on diesel engines as the lower exhaust temperatures mean they are less prone to failure.

The few early gasoline-engine VGTs required significant pre-charge cooling to extend the turbocharger life to reasonable levels, but advances in material technology has improved their resistance to the high temperatures of gasoline engine exhaust and they have started to appear increasingly in, e.g. gasoline-engined sports cars.

VARIABLE NOZZLE TYPE TURBOCHARGER

A variable-nozzle type turbo charger capable of temporarily decreasing the back pressure of the engine at the start of the engine.

The turbo charger is equipped with a plurality of nozzle vanes of which the opening degree can be changed.

And are capable of changing the areas of turbine nozzles at the time when exhaust gases of an engine are guided from said turbine nozzles formed among said nozzle vanes to a turbine rotor.

Where in an actuator that adjusts the opening degree of the nozzle vanes is so controlled that the areas of the turbine nozzles are larger than a minimum area for a predetermined period of time from the start of the engine.

After the passage of said predetermined period of time, said actuator is so controlled that the areas of said turbine nozzles become the minimum area to promote the warming-up of the engine when the water temperature of the engine or the engine load is smaller than a predetermined value.

DYNAMOMETER

A dynamometer is a device for measuring force, moment of force (torque), or power.

For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (RPM).

A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump.

In that case, motoring or driving dynamometer is used.

A dynamometer that is designed to be driven is called an absorption or passive dynamometer.

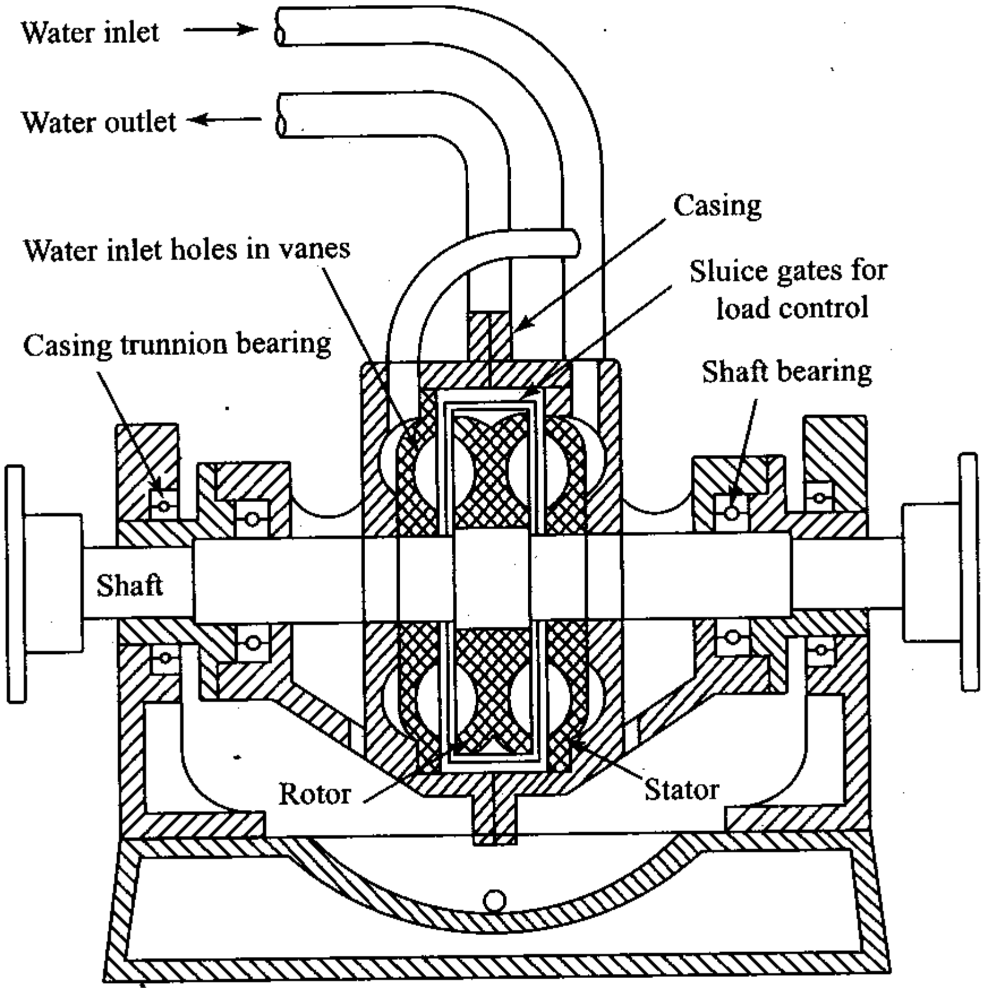
A dynamometer that can either drive or absorb is called a universal or active dynamometer.

In addition to being used to determine the torque or power characteristics of a machine under test (MUT), dynamometers are employed in a number of other roles.

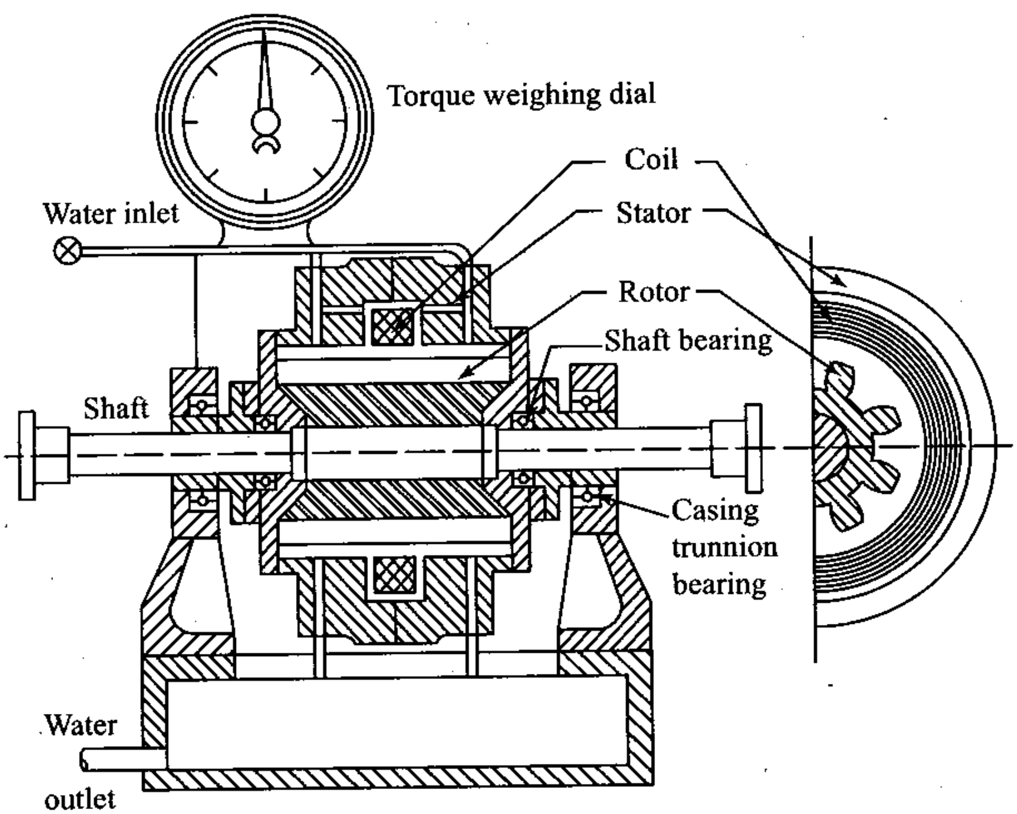
In standard emissions testing cycles such as those defined by the US Environmental Protection Agency (US EPA), dynamometers are used to provide simulated road loading of either the engine (using an engine dynamometer) or full powertrain (using a chassis dynamometer).

In fact, beyond simple power and torque measurements, dynamometers can be used as part of a test bed for a variety of engine development activities such as the calibration of engine management controllers, detailed investigations into combustion behavior and tribology.

Hydraulic dynamometer



Eddy current dynamometer



The main advantages of eddy current dynamometers are:

(i) Capable of measuring high power per unit weight of the dynamometer.

(ii) They offer the highest ratio of constant brake power to speed range (up to 5:1).

(iii) Level of field excitation is below 1 per cent of total power being handled by dynamometer, thus easy to control and operate.

(iv) Relatively higher torque under low speed conditions.

(v) Has no intricate rotating part except shaft bearing.

(vi) No natural limit to size, either small or large.

INDICATED POWER

Indicated power of an engine tells about the health of the engine and also gives an indication regarding the conversion of chemical energy in the fuel into heat energy.

Indicated power is an important variable because it is the potential output of the cycle. Therefore, to justify the measurement of indicated power, it must be more accurate than motoring and other indirect methods of measuring frictional power.

For obtaining indicated power the cycle pressure must be determined as a function of cylinder volume. It may be noted that it is of no use to determine pressure accurately unless volume or crank angle can be accurately measured.

In order to estimate the indicated power of an engine the following methods are usually followed.

(i) using the indicator diagram

(ii) by adding two measured quantities viz. brake power and friction power

BRAKE POWER

Measurement of brake power is one of the most important measurements in the test schedule of an engine.

It involves the determination of the torque and the angular speed of the engine output shaft.

The torque measuring device is called a dynamometer.

Indicated and Brake Thermal Efficiencies

The indicated and brake thermal efficiencies are based on the *ip* and *bp* of the engine respectively.

These efficiencies give an idea of the output generated by the engine with respect to heat supplied in the form of fuel.

In modern engines an indicated thermal efficiency of almost 28 per cent is obtainable with gas and gasoline spark-ignition engines having a moderate compression ratio and as high as 36 per cent or even more with high compression ratio oil engines.

VOLUMETRIC EFFICIENCY

Volumetric efficiency is a measure of the success with which the air supply, and thus the charge, is inducted into the engine.

It is a very important parameter, since it indicates the breathing capacity of the engine.

Volumetric efficiency is defined as the ratio of the actual mass of air drawn into the engine during a given period of time to the theoretical mass which should have been drawn in during that same period of time, based upon the total piston displacement of the engine, and the temperature and *pressure* of the surrounding atmosphere.

FRICTION POWER

The difference between the indicated and the brake power of an engine is known as friction power.

The internal losses in an engine are essentially of two kinds, viz., pumping losses and friction losses.

During the inlet and exhaust stroke the gaseous pressure on the piston is greater on its forward side (on the underside during the inlet and on the upper side during the exhaust stroke), hence during both strokes the piston must be moved against a gaseous pressure, and this causes the so-called pumping loss.

The friction loss is made up of the friction between the piston and cylinder walls, piston rings and cylinder walls, and between the crankshaft and camshaft and their bearings, as well as by the loss incurred by driving the essential accessories, such as the water pump, ignition unit etc.

It should be the aim of the designer to have minimum loss of power in friction.

Friction power is used for the evaluation of indicated power and mechanical efficiency.

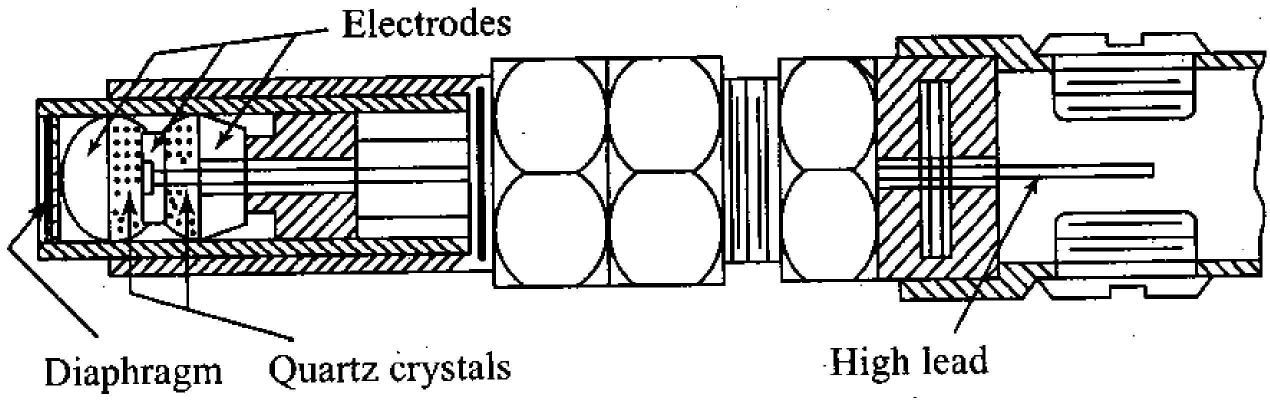
Following methods are used to find the friction power to estimate the performance of the engine.

(i) Willan's line method
(ii) Morse test
(iii) Motoring test
(iv) From the measurement of indicated and brake power
(v) Retardation test

PRESSURE PICUP

The pressure pick-up shown in Figure is usually called a pressure transducer.

It generates an electric signal in proportion to the pressure to which it is subjected.



Pressure transducer

The transducer is usually fitted in the cylinder head just like a spark plug without projecting into the combustion space.

The pressure is picked-up with respect to displacement of a diaphragm.

This diaphragm is made very stiff in order to reduce the displacement and hence the inertia effects are reduced to minimum.

The displacement of the diaphragm is transmitted to the transducer element which may be any one of the following.

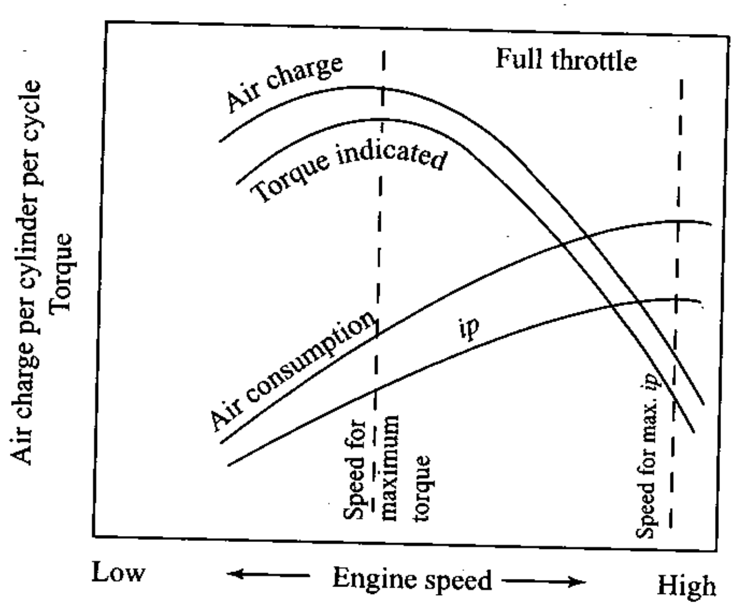
(i) Piezo electric crystal

(ii) Electromagnetic type

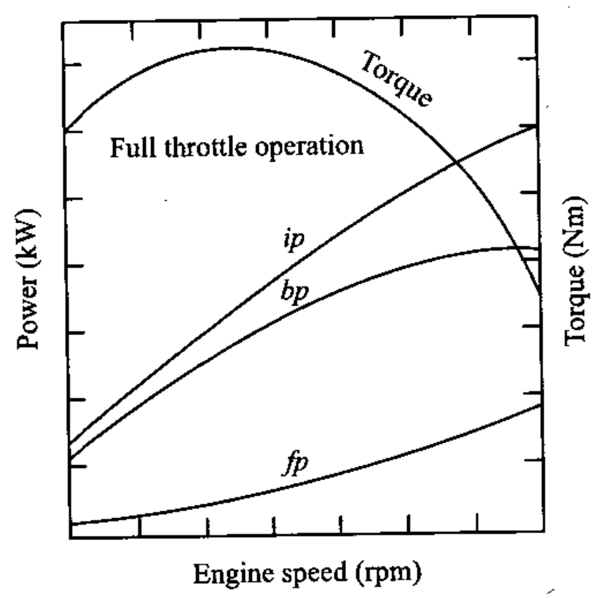
(iii) Capacitance' type

(iv) Strain gauge-type

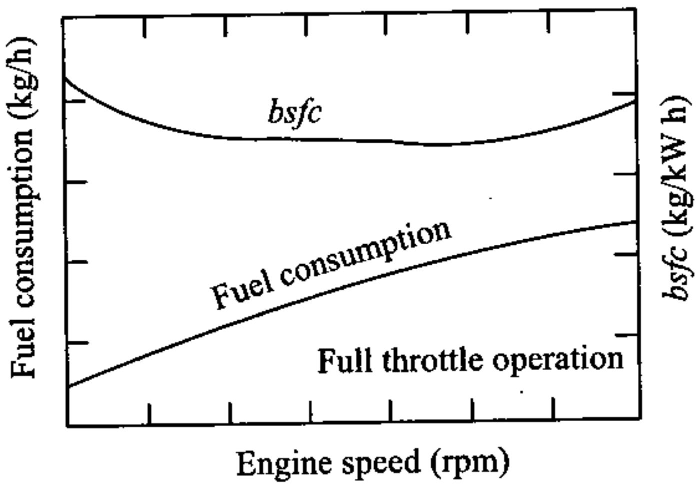
ENGINE PERFORMANCE CHARACTERISTICS



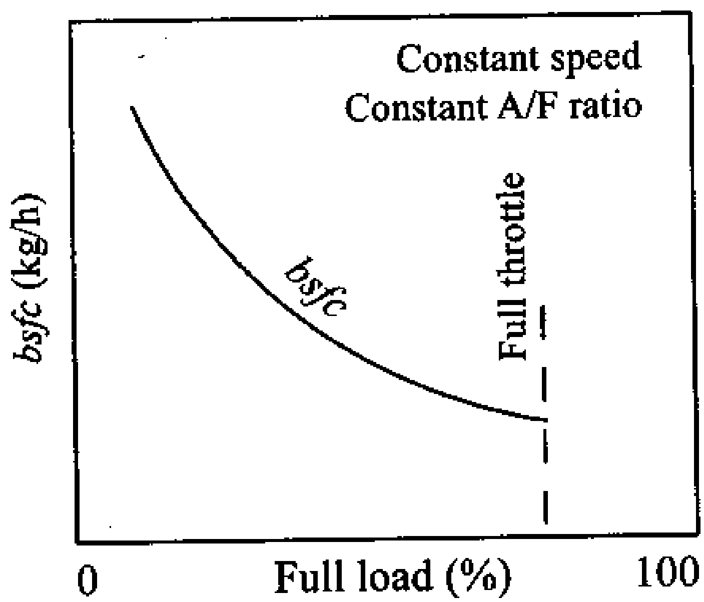
Typical Performance Plot with respect to Speed



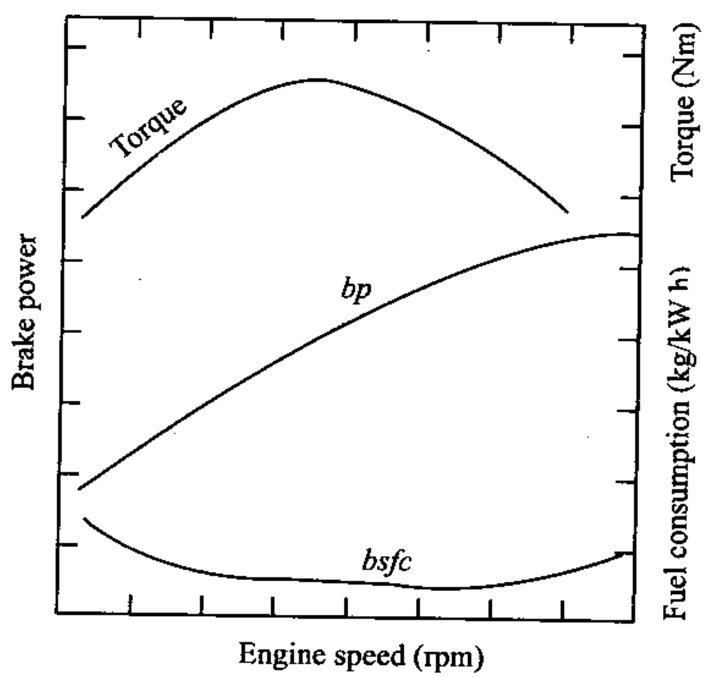
Typical SI Engine Performance Curves



Typical Fuel Consumption Curves for an SI Engine



Variation of bsfc with respect to load for an SI Engine



Variation of bsfc, Torque and bp with respect to Speed for an SI Engine

UNIT-V: COOLING AND LUBRICATION SYSTEMS

Need for cooling, types of cooling systems- air and liquid cooling systems. Thermo syphon and forced circulation and pressurized cooling systems. Properties of coolants. Requirements of lubrication systems. Types-mist, pressure feed, dry and wet sump systems. Properties of lubricants.

Need for cooling

Heat engines generate mechanical power by extracting energy from heat flows, much as a water wheel extracts mechanical power from a flow of mass falling through a distance.

Engines are inefficient, so more heat energy enters the engine than comes out as mechanical power; the difference is waste heat which must be removed.

Internal combustion engines remove waste heat through cool intake air, hot exhaust gases, and explicit engine cooling.

Engines with higher efficiency have more energy leave as mechanical motion and less as waste heat.

Some waste heat is essential: it guides heat through the engine, much as a water wheel works only if there is some exit velocity (energy) in the waste water to carry it away and make room for more water.

Thus, all heat engines need cooling to operate.

Cooling is also needed because high temperatures damage engine materials and lubricants.

IC engines burn fuel hotter than the melting temperature of engine materials, and hot enough to set fire to lubricants.

Engine cooling removes energy fast enough to keep temperatures low so the engine can survive.

It is to be noted that the engine is quite inefficient when it is cold and hence the cooling system is designed in such a way that it prevents cooling when the engine is warming up and till it attains to maximum efficient operating temperature, then it starts cooling.

It is also to be noted that:

(a) About 20-25% of total heat generated is used for producing brake power (useful work).

(b) Cooling system is designed to remove 30-35% of total heat.

(c) Remaining heat is lost in friction and carried away by exhaust gases.

There are mainly two types of cooling systems :

(a) Air cooled system, and

(b) Water cooled system.

Air Cooled System

Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.

In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc.

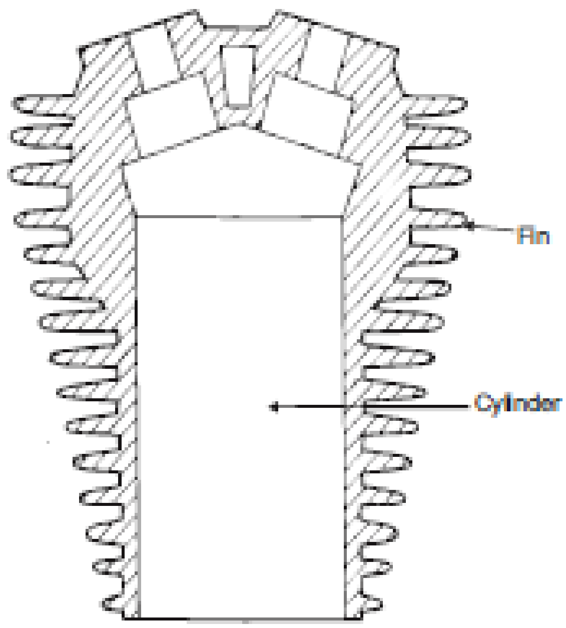
Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air.

The amount of heat dissipated to air depends upon :

(a) Amount of air flowing through the fins.

(b) Fin surface area.

(c) Thermal conductivity of metal used for fins.



Advantages of Air Cooled System

Following are the advantages of air cooled system :

(a) Radiator/pump is absent hence the system is light.

(b) In case of water cooling system there are leakages, but in this case there are no leakages.

(c) Coolant and antifreeze solutions are not required.

(d) This system can be used in cold climates, where if water is used it may freeze.

Disadvantages of Air Cooled System

(a) Comparatively it is less efficient.

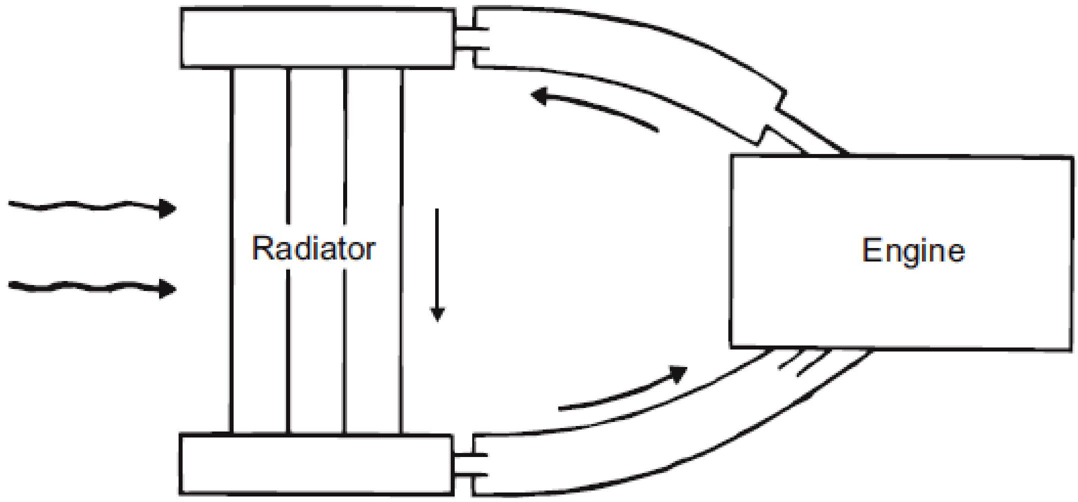
(b) It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

WATER COOLING SYSTEM

There are two types of water cooling system :

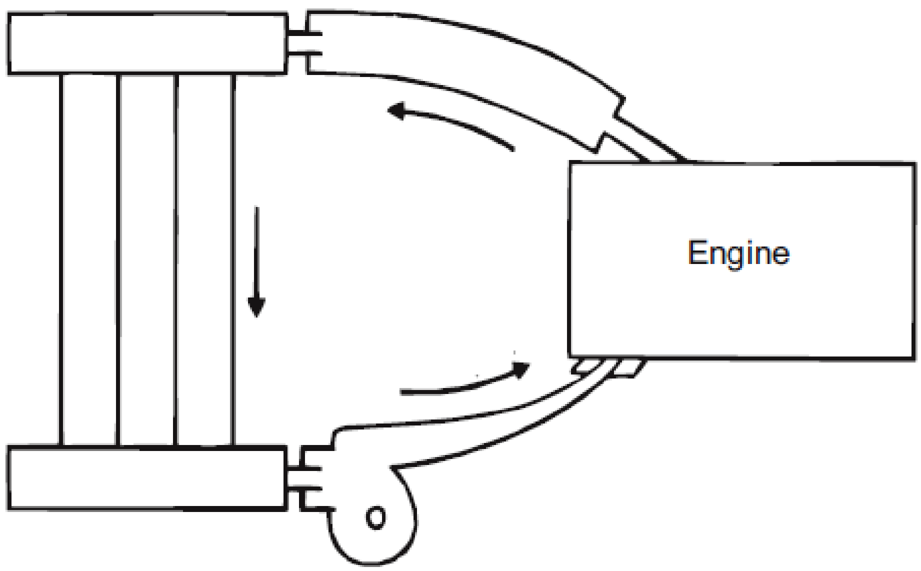
Thermo Siphon System

In this system the circulation of water is due to difference in temperature (i.e. difference in densities) of water. So in this system pump is not required but water is circulated because of density difference only.



Pump Circulation System

In this system circulation of water is obtained by a pump. This pump is driven by means of engine output shaft through V-belts.



Components of water cooling system

Water cooling system mainly consists of :

(a) Radiator,

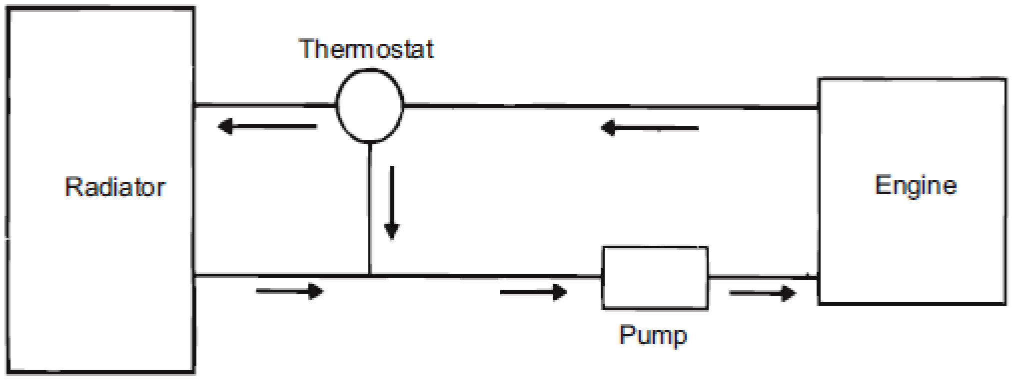
(b) Thermostat valve,

(c) Water pump,

(d) Fan,

(e) Water Jackets, and

(f) Antifreeze mixtures.



Advantages

(a) Uniform cooling of cylinder, cylinder head and valves.

(b) Specific fuel consumption of engine improves by using water cooling system.

(c) If we employ water cooling system, then engine need not be provided at the front end of moving vehicle.

(d) Engine is less noisy as compared with air cooled engines, as it has water for damping noise.

Disadvantages

(a) It depends upon the supply of water.

(b) The water pump which circulates water absorbs considerable power.

(c) If the water cooling system fails then it will result in severe damage of engine.

(d) The water cooling system is costlier as it has more number of parts. Also it requires more maintenance and care for its parts.

LUBRICATION

Function of Lubrication

Lubrication is an art of admitting a lubricant (oil, grease, etc.) between two surfaces that are in contact and in relative motion. The purpose of lubrication in an engine is to perform one or several of the following functions.

(i) To reduce friction and wear between the moving parts and thereby the energy loss and to increase the life of the engine.

(ii) To provide sealing action e.g. the lubricating oil helps the piston rings to maintain an effective seal against the high pressure gases in the cylinder from leaking out into the crankcase.

(iii) To cool the surfaces by carrying away the heat generated in engine components.

Mechanism of Lubrication

Consider two solid blocks which are in contact with each other.

In order to move the upper block over the surface of the lower block, a constant tangential force must be applied.

The force due to the weight of the upper block acting perpendicular to the surface is called the normal force.

The ratio of the tangential force to the normal force is known as the dynamic coefficient of friction or the coefficient of friction,

Coefficient of friction = Tangential force / Normal force

Elastohydrodynamic Lubrication

Elastohydrodynamic lubrication is the phenomenon that occurs when the bearing material itself deforms elastically against the pressure built up of the oil film.

This type of lubrication occurs between cams and followers, gear teeth and roller bearings where the contact pressures are extremely high.

Hydrostatic lubrication is obtained by introducing the lubricant, which is sometimes air or water, into the load-bearing area at a pressure high enough to separate the surfaces with a relatively thick film of lubricant.

So, unlike hydrodynamic lubrication, motion of one surface relative to another is not required.

Insufficient surface area, a drop in relative velocity of the moving surface during the period of starting and stopping, an inadequate quantity of lubricant, an increase in the bearing load, or a decrease in viscosity of the lubricant due to increase in temperature - anyone of these - may prevent the buildup of a film thick enough to full film lubrication.

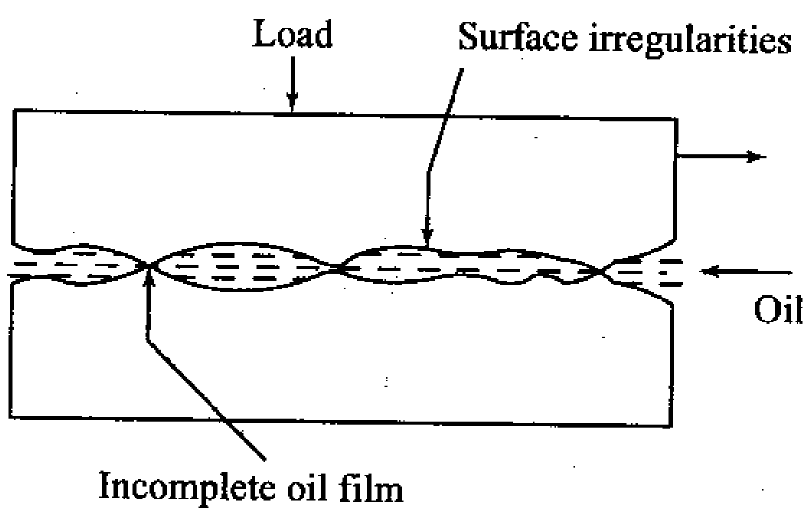
When this happens the highest asperities may be separated by lubricant films by a few micron thicknesses.

This is called boundary lubrications.

The change from hydrodynamic to boundary lubrication is not an abrupt change.

It is probable that a mixed hydrodynamic and boundary type lubrication occurs first, and as the surfaces move closer together, the boundary type lubrication becomes predominant.

The viscosity of the lubricant is not as much important with boundary lubrication as the chemical composition of the lubricant.



Lubrication of engine parts

(i) piston and cylinders

(ii) crankshaft and their bearings

(iii) crankpin and their bearings

(iv) wristpin and their bearings

(v) valve gear

Lubrication system

(i) mist lubrication system

(ii) wet sump lubrication system

(iii) dry sump lubrication system

Mist lubrication system

This system is used where crankcase lubrication is not suitable. In two- stroke engine, as the charge is compressed in the crankcase, it is not possible to have the lubricating oil in the sump.

Hence, mist lubrication is adopted in practice.

In such engines, the lubricating oil is mixed with the fuel, the usual ratio being 3% to 6%.

The oil and the fuel mixture are inducted through the carburetor.

The fuel is vaporized and the oil in the form of mist goes via the crankcase into the cylinder.

The oil which strikes the crankcase walls lubricates the main and connecting rod bearings, and the rest of the oil lubricates the piston, piston rings and the cylinder.

The advantage of this system is its simplicity and low cost as it does not require an oil pump, filter, etc.

However, there are certain disadvantages which are enumerated below.

(i) It causes heavy exhaust smoke due to burning of lubricating oil partially or fully and also forms deposits on piston crown and exhaust ports which affect engine efficiency.

(ii) Since the oil comes in close contact with acidic vapors produced during the combustion process gets contaminated and may result in the corrosion of bearing surface.

(iii) This system calls for a thorough mixing for effective lubrication. This requires either separate mixing prior to use or use of some additive to give the oil good mixing characteristics.

During closed throttle operation as in the case of the vehicle moving down the hill, the engine will suffer from insufficient lubrication as the supply of fuel is less. This is an important limitation of this system.

Wet sump lubrication system

In the wet sump system, the bottom of the crankcase contains an oil pan or sump from which the lubricating oil is pumped to various engine components by a pump. After lubricating these parts, the oil flows back to the sump by gravity.

Again it is picked up by a pump and recirculated through the engine lubricating system. There are three varieties in the wet sump lubrication system. They are

(i) the splash system

(ii) the splash and pressure system

(iii) the pressure feed system

Splash System: This type of lubrication system is used in light duty engines.

A schematic diagram of this system is shown in Figure.

The lubricating oil is charged into in the bottom of the engine crankcase into splash troughs located under the big end of all the connecting rods.

These troughs were provided with overflows and the oil in the troughs are therefore kept at a constant level.

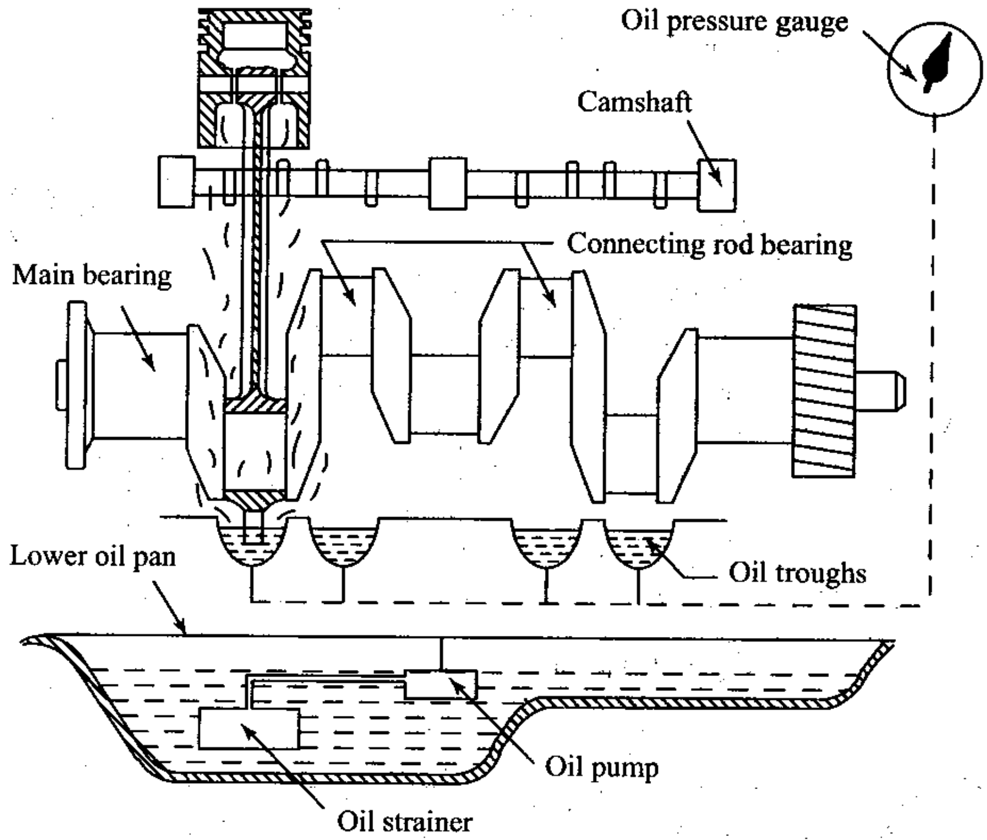
A splasher or dipper is provided under each connecting rod cap which dips into the oil in the trough at every revolution of the crankshaft and the oil is splashed all over the interior of the crankcase, into the pistons and onto the exposed portions of the cylinder walls.

A hole is drilled through the connecting rod cap through which oil will pass to the bearing surface.

Oil pockets are also provided to catch the splashing oil over all the main bearings and also over the camshaft bearings.

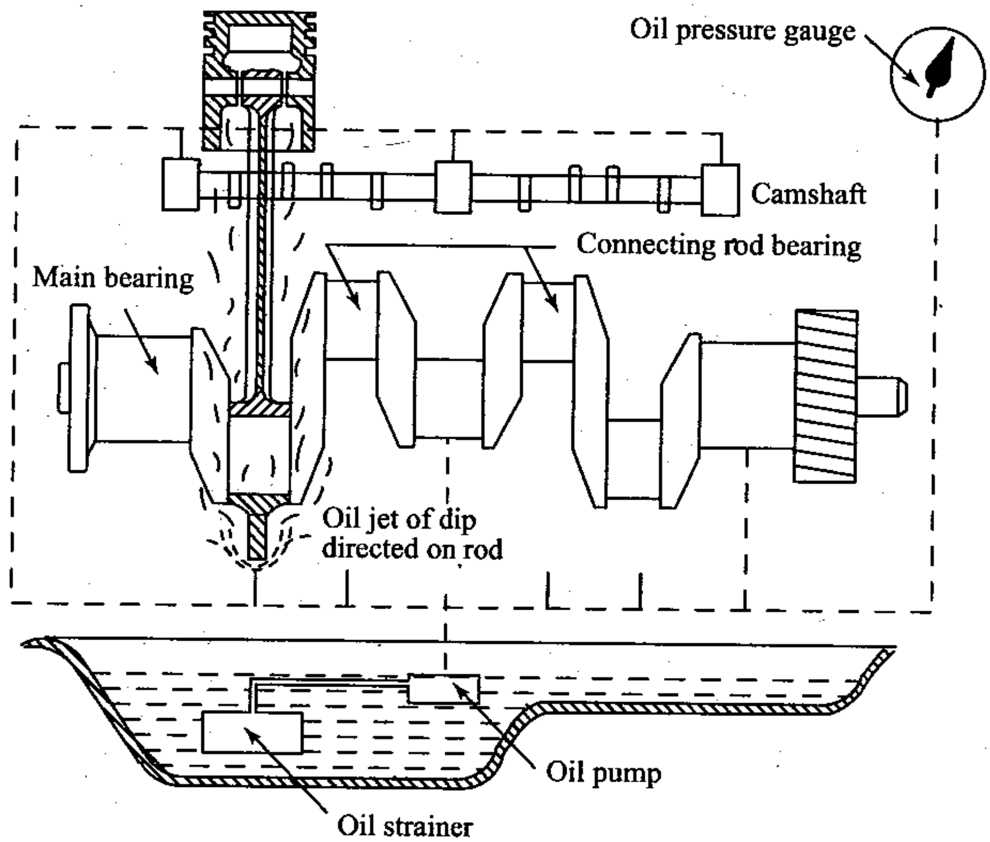
From the pockets the oil will reach the bearings surface through a drilled hole.

The oil dripping from the cylinders is collected in the sump where it is cooled by the air flowing around. The cooled oil is then recirculated.



The Splash and Pressure Lubrication System: This system is shown in Figure, where the lubricating oil is supplied under pressure to main and camshaft bearings.

Oil is also supplied under pressure to pipes which direct a stream of oil against the dippers on the big end of connecting rod bearing cup and thus the crankpin bearings are lubricated by the splash or spray of oil thrown up by the dipper.



The pressure feed system is illustrated in Figure below in which oil is drawn in from the sump and forced to all the main bearings of the crankshaft through distributing channels.

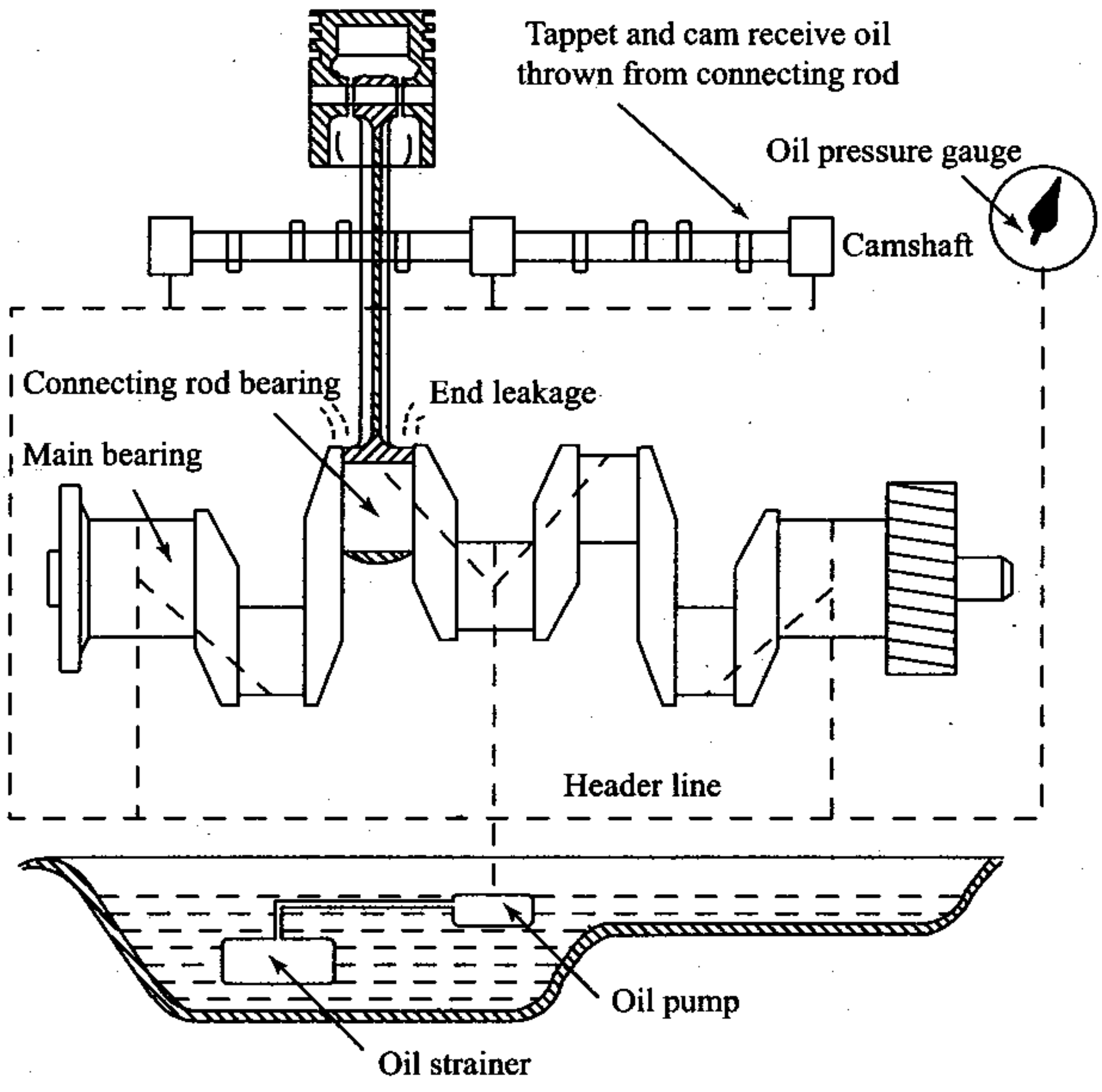
A pressure relief valve will also be fitted near the delivery point of the pump which opens when the pressure in the system attains a predetermined value.

An oil hole is drilled in the crankshaft from the centre of each crankpin to the centre of an adjacent main journal, through which oil can pass from the main bearings to the crankpin bearing.

From the crankpin it reaches piston pin bearing through a bore drilled in the connecting rod.

The cylinder walls, tappet rollers, piston and piston rings are lubricated by oil spray from around the piston pins and the main and connecting rod bearings.

The basic components of the wet sump lubrication systems are (i) pump (ii) strainer (iii) pressure regulator (iv) filter (v) breather.



Dry Sump Lubrication System

A dry sump lubricating system is illustrated in Figure.

In this, the supply of Oil is carried in an external tank.

An oil pump draws oil from the supply tank and circulates it under pressure to the various bearings of the engine.

Oil dripping from the cylinders and bearings into the sump is removed by a scavenging pump which in turn the oil is passed through a filter, and is fed back to the supply tank.

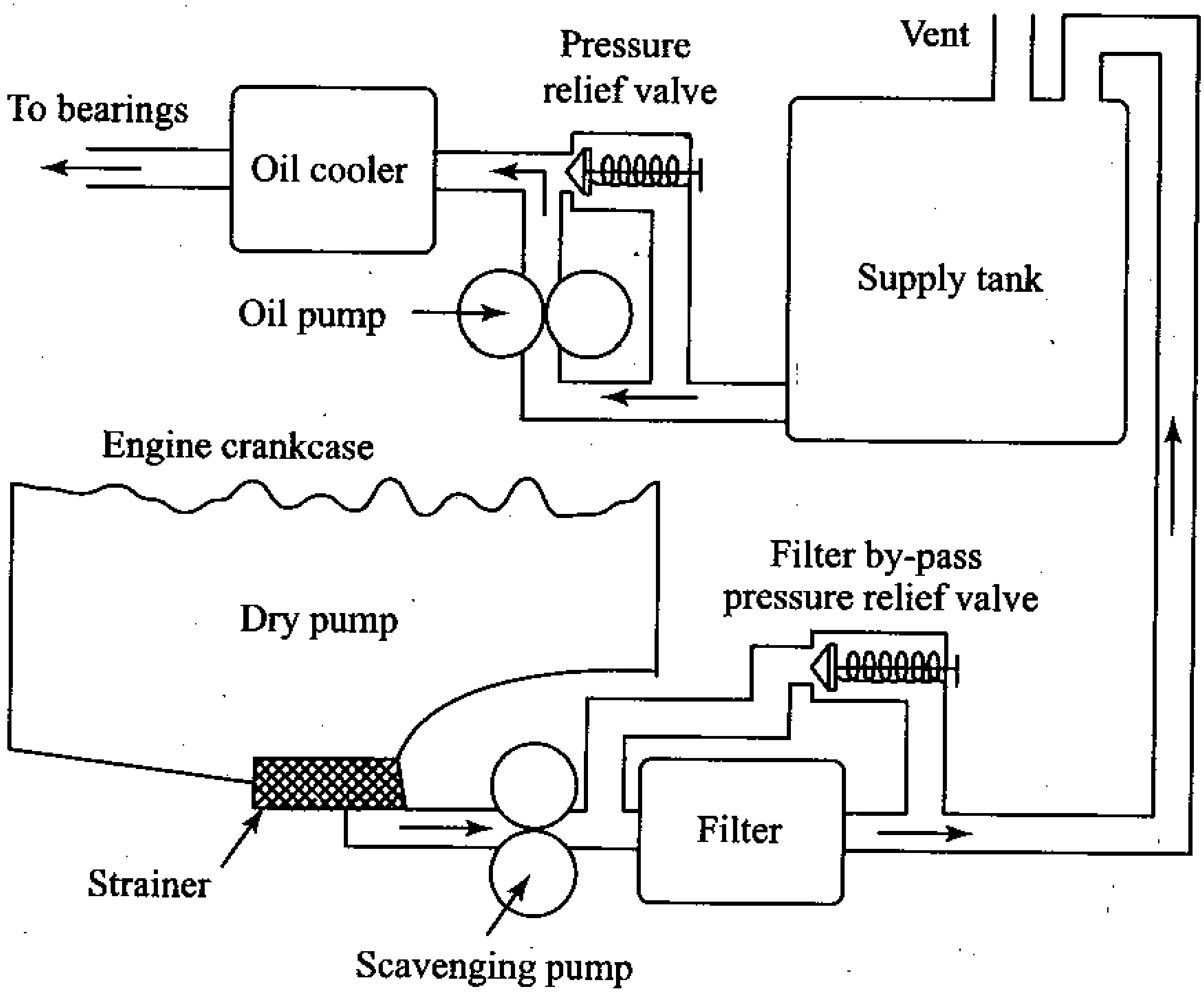
Thus, oil is prevented from accumulating in the base of the engine.

The capacity of the scavenging pump is always greater than the oil pump.

In this system a filter with a bypass valve is placed in between the scavenge pump and the supply tank.

If the filter is clogged, the pressure relief valve opens permitting oil to by-pass the filter and reaches the supply tank.

A separate oil cooler with either water or air as the cooling medium, is usually provided in the dry sump system to remove heat from the oil.



PROPERTIES OF LUBRICANTS

The duties of the lubricant in an engine are many and varied in scope.

The lubricant is called upon to limit and control the following:

(i) friction between the components and metal to metal contact
(ii) overheating of the components
(iii) wear of the components
(iv) corrosion
(v) deposits

To accomplish the above functions, the lubricant should have

(i) suitable viscosity
(ii) oiliness to ensure adherence to the bearings, and for less friction and wear when the lubrication is in the boundary region, and as a protective covering against corrosion
(iii) high strength to prevent metal to metal contact and seizure under heavy load
(iv) should not react with the lubricating surfaces
(v) cleaning ability
(vi) non-foaming characteristics
(vii) nontoxic and non-inflammable
(viii) low cost