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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF AUTOMOBILE ENGINEERING

SAUA1401 AUTOMOTIVE DIESEL ENGINES

UNIT I BASIC THEORY

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1. INTRODUCTION

The internal combustion engine (IE) is a heat engine that converts chemical energy in a fuel into mechanical energy, usually made available on a rotating output shaft. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. This thermal energy raises the temperature and pressure of the gases within the engine, and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine. The crankshaft, in turn, is connected to a transmission and/or power train to transmit the rotating mechanical energy to the desired final use. For engines this will often be the propulsion of a vehicle (i.e., automobile, truck, locomotive, marine vessel, or airplane).

Most internal combustion engines are reciprocating engines having pistons that reciprocate back and forth in cylinders internally within the engine. This book concentrates on the thermodynamic study of this type of engine. Other types of IC engines also exist in much fewer numbers, one important one being the rotary engine. These engines will be given brief coverage. Engine types not covered by this book include steam engines and gas turbine engines, which are better classified as external combustion engines (i.e., combustion takes place outside the mechanical engine system). Also not included in this book, but which could be classified as internal combustion engines, are rocket engines, jet engines, and firearms.

1.1 ENGINE CLASSIFICATIONS

Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition
   a. Spark Ignition (SI). An SI engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug. In early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame.
   b. Compression Ignition (CI). The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.
2. Engine Cycle
   a. Four-Stroke Cycle. A four-stroke cycle experiences four piston movements over two engine revolutions for each cycle.
   b. Two-Stroke Cycle. A two-stroke cycle has two piston movements over one revolution for each cycle.
3. Valve Location
   a. Valves in head (overhead valve), also called I Head engine.

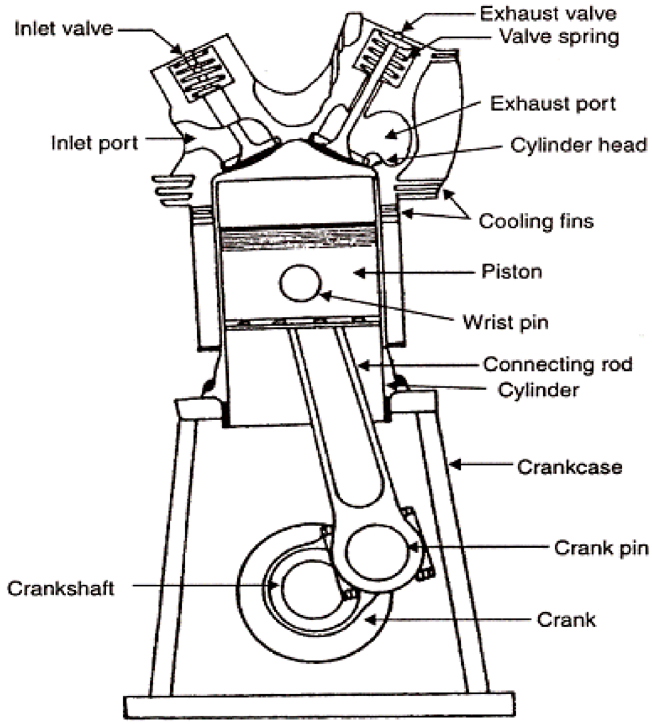
4. Valves in block (flat head), also called L Head engine. Some historic engines with valves in block had the intake valve on one side of the cylinder and the exhaust valve on the other side. These were called T Head engines.
5. Basic Design
   a. Reciprocating. Engine has one or more cylinders in which pistons reciprocate back and forth. The combustion chamber is located in the closed end of each cylinder. Power is delivered to a rotating output crankshaft by mechanical linkage with the pistons.
   b. Rotary. Engine is made of a block (stator) built around a large non-concentric rotor and crankshaft. The combustion chambers are built into the non rotating block.
6. Position and Number of Cylinders of Reciprocating Engines
   a. Single Cylinder. Engine has one cylinder and piston connected to the crankshaft.
   b) In-Line. Cylinders are positioned in a straight line, one behind the other along the length of the crankshaft. They can consist of 2 to 11 cylinders or possibly more. In-line four-cylinder engines are very common for automobile and other applications. In-line six and eight cylinders are historically common automobile engines. In-line engines are sometimes called straight(e.g., straight six or straight eight).
   c) V Engine. Two banks of cylinders at an angle with each other along a single crankshaft. The angle between the banks of cylinders can be anywhere from 15° to 120°, with 60°-90° being common. V engines have even numbers of cylinders from 2 to 20 or more. V6s and V8s are common automobile engines, with V12s and V16s (historic) found in some luxury and high-performance vehicles.
   d) W Engine. Same as a V engine except with three banks of cylinders on the same crankshaft. Not common, but some have been developed for racing automobiles, both modern and historic. Usually 12 cylinders with about a *60°* angle between each bank.
   e) Radial Engine. Engine with pistons positioned in a circular plane around the central crankshaft. The connecting rods of the pistons are connected to a master rod which, in turn, is connected to the crankshaft. A bank of cylinders on a radial engine always has an odd number of cylinders ranging from 3 to 13 or more. Operating on a four-stroke cycle, every other cylinder fires and has a power stroke as the crankshaft rotates, giving a smooth operation. Many medium- and large-size propeller-driven aircraft use radial engines. For large aircraft, two or more banks of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful, smooth engine. Very large ship engines exist with up to 54 cylinders, six banks of 9 cylinders each.
7. Air Intake Process
   a. Naturally Aspirated. No intake air pressure boost system.
   b. Supercharged. Intake air pressure increased with the compressor driven off of the engine crankshaft.
   c. Turbocharged. Intake air pressure increased with the turbine-compressor driven by the engine exhaust gases.
   d. Crankcase Compressed. Two-stroke cycle engine which uses the crankcase as the intake air compressor. Limited development work has also been done on design and construction of four-stroke cycle engines with crankcase compression.
8. Method of Fuel Input for SI Engines
   a. Carbureted.

b. Multipoint Port Fuel Injection. One or more injectors at each cylinder intake.
c. Throttle Body Fuel Injection. Injectors upstream in intake manifold.

9. Fuel Used
   a. Gasoline.
   b. Diesel Oil or Fuel Oil.
   c. Gas, Natural Gas, Methane.
   d. LPG.
   e. Alcohol-Ethyl, Methyl.
   f. Dual Fuel. There are a number of engines that use a combination of two or more fuels. Some, usually large, CI engines use a combination of methane and diesel fuel. These are attractive in developing third-world countries because of the high cost of diesel fuel. Combined gasoline-alcohol fuels engine fuel.
   g. Gasohol. Common fuel consisting of 90% gasoline and 10% alcohol.
10. Application
   a. Automobile, Truck, Bus.
   b. Locomotive.
   c. Stationary.
   d. Marine.
   e. Aircraft.
   f. Small Portable, Chain Saw, Model Airplane.
11. Type of Cooling
   a. Air Cooled.
   b. Liquid Cooled, Water Cooled.

1.2 IC ENGINE COMPONENTS

Internal combustion engine consists of a number of parts which are given below :



Cylinder:

It is a part of the engine which confines the expanding gases and forms the combustion space. It is the basic part of the engine. It provides space in which piston operates to suck the air or air-fuel mixture. The piston compresses the charge and the gas is allowed to expand in the cylinder, transmitting power for useful work. Cylinders are usually made of high grade cast iron.

Cylinder block:

It is the solid casting body which includes the cylinder and water jackets (cooling fins in the air cooled engines).

Cylinder head:

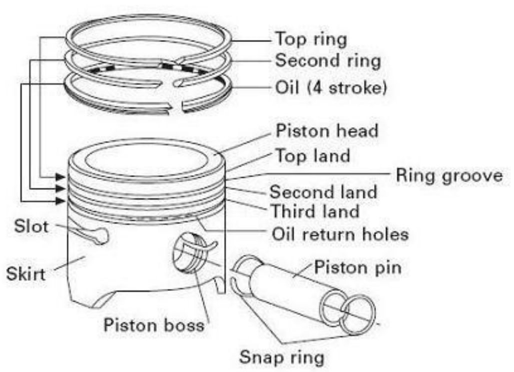
It is a detachable portion of an engine which covers the cylinder and includes the combustion chamber, spark plugs or injector and valves.

Cylinder liner or sleeve:

It is a cylindrical lining either wet or dry type which is inserted in the cylinder block in which the piston slides. Liners are classified as: (1) Dry liner and (2) Wet liner. Dry liner makes metal to metal contact with the cylinder block casing. wet liners come in contact with the cooling water, whereas dry liners do not come in contact with the cooling water.

Piston:

It is a cylindrical part closed at one end which maintains a close sliding fit in the engine cylinder. It is connected to the connecting rod by a piston pin. The force of the expanding gases against the closed end of the piston, forces the piston down in the cylinder. This causes the connecting rod to rotate the crankshaft. Cast iron is chosen due to its high compressive strength. Aluminum and its alloys preferred mainly due to it lightness.



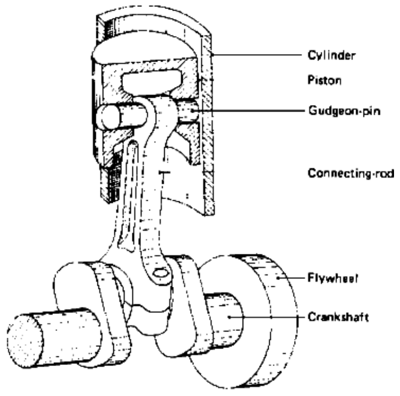


Fig. 1.1-1 Pictorial view of the basic engine.

Head (Crown) of piston: It is the top of the piston.

Skirt:

It is that portion of the piston below the piston pin which is designed to adsorb the side movements of the piston.

Piston ring:

It is a split expansion ring, placed in the groove of the piston. They are usually made of cast iron or pressed steel alloy. The function of the ring are as follows :

a) It forms a gas tight combustion chamber for all positions of piston.
b) It reduces contact area between cylinder wall and piston wall preventing friction losses and excessive wear.
c) It controls the cylinder lubrication.
d) It transmits the heat away from the piston to the cylinder walls. Piston rings are of two types: (1) Compression ring and (2) Oil ring

Compression ring:

Compression rings are usually plain, single piece and are always placed in the grooves of the piston nearest to the piston head. They prevent leakage of gases from the cylinder and helps increasing compression pressure inside the cylinder.

Oil ring:

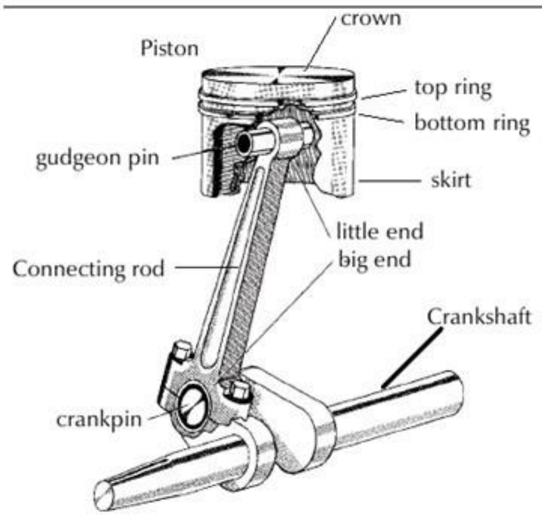
Oil rings are grooved or slotted and are located either in lowest groove above the piston pin or in a groove above the piston skirt. They control the distribution of lubrication oil in the cylinder and the piston.

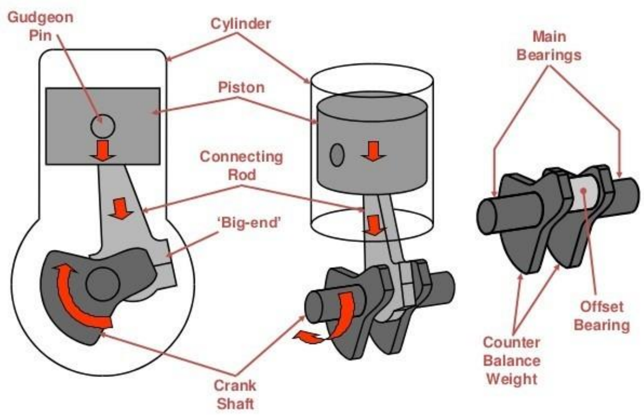
Piston Pin:

It is also called wrist pin or gudgeon pin. Piston pin is used to join the connecting rod to the piston.

Connecting rod:

It is special type of rod, one end of which is attached to the piston and the other end to the crankshaft. It transmits the power of combustion to the crankshaft and makes it rotate continuously. It is usually made of drop forged steel.





Crankshaft:

It is the main shaft of an engine which converts the reciprocating motion of the piston into rotary motion of the flywheel. Usually the crankshaft is made of drop forged steel or cast steel. The space that supports the crankshaft in the cylinder block is called *main journal*, whereas the part to which connecting rod is attached is known as *crank journal*. Crankshaft is provided with counter weights throughout its length to have counter balance of the unit.

Flywheel:

Flywheel is made of cast iron. Its main functions are as follows :

a) It stores energy during power stroke and returns back the energy during the idle strokes, providing a uniform rotary motion of flywheel.
b) The rear surface of the flywheel serves as one of the pressure surfaces for the clutch plate.
c) Engine timing marks are usually stamped on the flywheel, which helps in adjusting the timing of the engine.
d) Sometime the flywheel serves the purpose of a pulley for transmitting power.

Crankcase:

The crankcase is that part of the engine which supports and encloses the crankshaft and camshaft. It provides a reservoir for the lubricating oil. It also serves as a mounting unit for such accessories as the oil pump, oil filter, starting motor and ignition components. The upper portion of the crankcase is usually integral with cylinder block. The lower part of the crankcase is commonly called oil pan and is usually made of cast iron or cast aluminum.

Camshaft:

It is a shaft which raises and lowers the inlet and exhaust valves at proper times. Camshaft is driven by crankshaft by means of gears, chains or sprockets. The speed of the camshaft is exactly half the speed of the crankshaft in four stroke engine. Camshaft operates the ignition timing mechanism, lubricating oil pump and fuel pump. It is mounted in the crankcase, parallel to the crankshaft.

Timing gear:

Timing gear is a combination of gears, one gear of which is mounted at one end of the camshaft and the other gear at the crankshaft. Camshaft gear is bigger in size than that of the crankshaft gear and it has twice as many teeth as that of the crankshaft gear. For this reason, this gear is commonly called half time gear. Timing gear controls the timing of ignition, timing of opening and closing of valve as well as fuel injection timing.

Inlet manifold: It is that part of the engine through which air or air-fuel mixture enters into the engine cylinder. It is fitted by the side of the cylinder head.

Exhaust manifold: It is that part of the engine through which exhaust gases go out of the engine cylinder. It is capable of withstanding high temperature of burnt gases. It is fitted by the side of the cylinder head.

Fuel injector:

A pressurized nozzle that sprays fuel into the incoming air on SI engines or into the cylinder on CI engines. On SI engines, fuel injectors are located at the intake valve ports on multipoint port injector systems and upstream at the intake manifold inlet on throttle body injector systems. In a few SI engines, injectors spray directly into the combustion chamber.

Fuel pump:

Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine. Many modern automobiles have an electric fuel pump mounted submerged in the fuel tank. Some small engines and early automobiles had no fuel pump, relying on gravity feed.

1.3 TERMINOLOGIES IN IC ENGINES

Bore- Bore is the diameter of the engine cylinder.

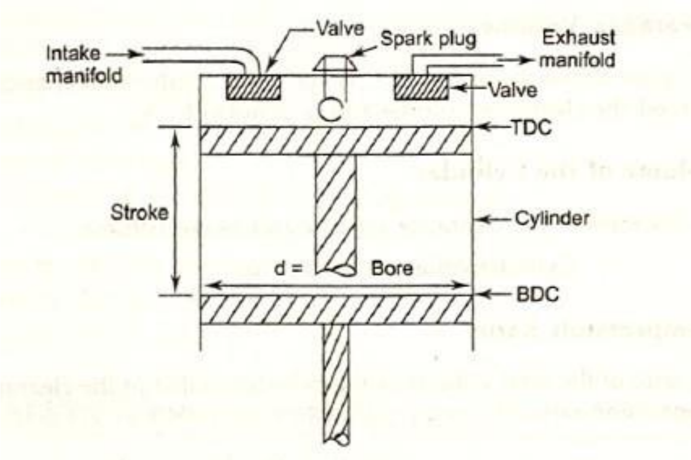
Stroke - It is the linear distance traveled by the piston from Top dead centre (TDC) to Bottom dead centre (BDC).

Stroke-bore ratio -The ratio of length of stroke (L) and diameter of bore (D) of the cylinder is called stroke-bore ratio (L/D). In general, this ratio varies between 1 to 1.45 and for tractor engines, this ratio is about 1.25.

Swept volume - It is the volume (A x L) displaced by one stroke of the piston where A is the cross sectional area of piston and L is the length of stroke

Top dead centre - When the piston is at the top of its stroke, it is said to be at the *top dead centre* (TDC),

Bottom dead centre - when the piston is at the bottom of its stroke, it is said to be at its bottom dead centre (BDC).



Compression ratio - It is the ratio of the volume of the cylinder at the beginning of the compression stroke to that at the end of compression stroke, i.e. ratio of total cylinder volume to clearance volume. The Compression ratio of diesel engine varies from 14:1 to 22:1 and that of carburetor type engine (spark ignition engine) varies from 4:1 to 8:1.

Power - It is the rate of doing work. S.I. unit of power is watt.

Watt = Joule/sec. (4.2 Joules = 1 Calorie).

In metric unit the power can be expressed in kg.m/sec.

Horse power (HP) - It is the rate of doing work. Expressed in horse power Conversion factors from work to power

4500 kg m of work /minute = 1.0 hp

75 kg. m of work /second = 1.0 hp.

Indicated horse power (IHP) - It is the power generated in the engine cylinder and received by the piston. It is the power developed in a cylinder without accounting frictional losses.

Brake horse power (BHP) - It is the power delivered by the engine at the end of the crankshaft. It is measured by a dynamometer.

Ignition Delay(ID) - Time interval between ignition initiation and the actual start of combustion.

Air-Fuel Ratio (AF) Ratio of mass of air to mass of fuel input into engine.

Fuel-Air Ratio (FA) Ratio of mass of fuel to mass of air input into engine.

1.4 BASIC ENGINE CYCLES

Most internal combustion engines, both spark ignition and compression ignition, operate on either a four-stroke cycle or a two-stroke cycle. These basic cycles are fairly standard for all engines, with only slight variations found in individual designs

1.4.1 Four-Stroke SI Engine Cycle

1. First Stroke: Intake Stroke or Induction

The piston travels from TDC to BDC with the intake valve open and exhaust valve closed. This creates an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure differential through the intake system from atmospheric pressure on the outside to the vacuum on the inside causes air to be pushed into the cylinder. As the air passes through the intake system, fuel is added to it in the desired amount by means of fuel injectors or a carburetor.

2. Second Stroke: Compression Stroke

When the piston reaches BDC, the intake valve closes and the piston travels back to TDC with all valves closed. This compresses the air-fuel mixture, raising both the pressure and temperature in the cylinder. The finite time required to close the intake valve means that actual compression doesn't start until sometime at BDC. Near the end of the compression stroke, the spark plug is fired and combustion is initiated.

3. Combustion:

Combustion of the air-fuel mixture occurs in a very short but finite length of time with the piston near TDC (i.e., nearly constant-volume combustion). It starts near the end of the compression stroke slightly by TDC and lasts into the power stroke slightly at TDC. Combustion changes the composition of the gas mixture to that of exhaust products and increases the temperature in the cylinder to a very high peak value. This, in turn, raises the pressure in the cylinder to a very high peak value.

4. Third Stroke: Expansion Stroke or Power Stroke

With all valves closed, the high pressure created by the combustion process pushes the piston away from TDC. This is the stroke which produces the work output of the engine cycle. As the piston travels from TDC to BDC, cylinder volume is increased, causing pressure and temperature to drop.

5. Exhaust Blowdown

Late in the power stroke, the exhaust valve is opened and exhaust blow down occurs. Pressure and temperature in the cylinder are still high relative to the surroundings at this point, and a pressure differential is created through the exhaust system which is open to atmospheric pressure. This pressure differential causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system when the piston is near BDC. This exhaust gas carries away a high amount of enthalpy, which lowers the cycle thermal efficiency. Opening the exhaust valve before BDC reduces the work obtained during the power stroke but is required because of the finite time needed for exhaust blow down.

6. Fourth Stroke:

Exhaust Stroke By the time the piston reaches BDC, exhaust blow down is complete, but the cylinder is still full of exhaust gases at approximately atmospheric pressure. With the exhaust valve remaining open, the piston now travels from BDC to TDC in the exhaust stroke. This pushes most of the remaining exhaust gases out of the cylinder into the exhaust system at about atmospheric pressure, leaving only that trapped in the clearance volume when the piston reaches TDC. Near the end of the exhaust stroke by TDC, the intake valve starts to open, so that it is fully open by TDC when the new intake stroke starts the next cycle. Near TDC the exhaust valve starts to close and finally is fully closed sometime at TDC. This period when both the intake valve and exhaust valve are open is called valve overlap.

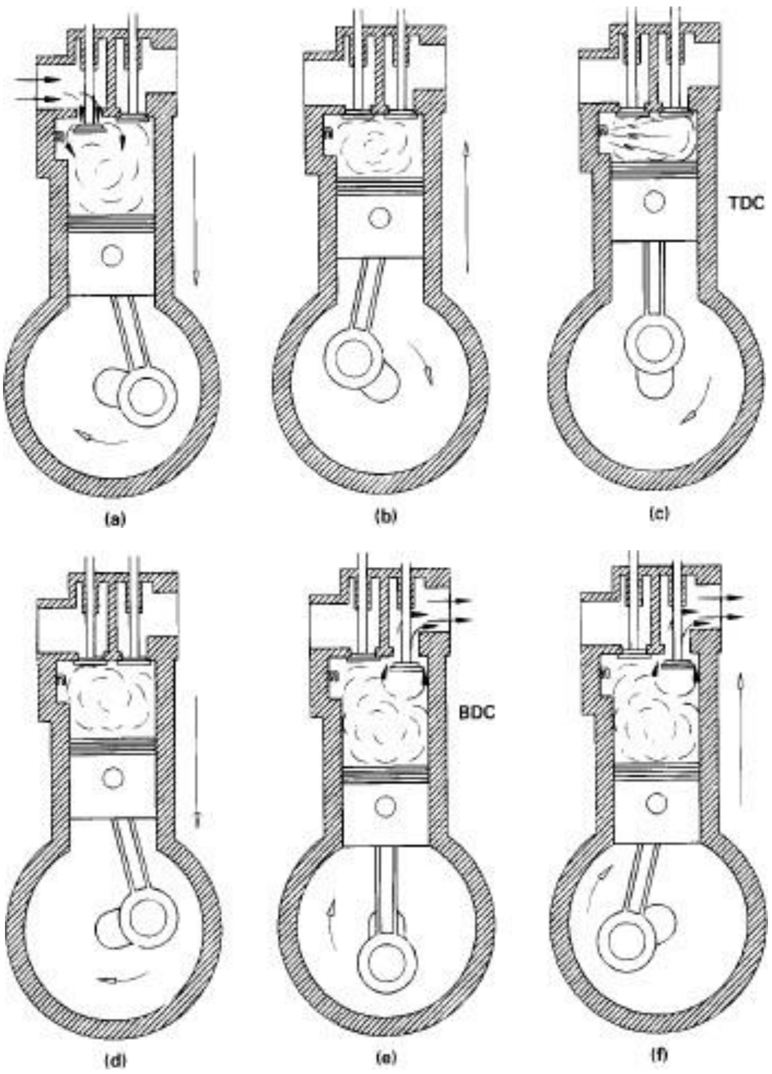


Figure Four-stroke SI engine operating cycle. **(a)** Intake stroke. Ingress of air-fuel as piston moves from TDC to BDC. **(b)** Compression stroke. Piston moves from BDC to TDC. Spark ignition occurs near end of compression stroke. **(c)** Combustion at almost constant volume near TDC. **(d)** Power or expansion stroke. High cylinder pressure pushes piston from TDC towards BDC. **(e)** Exhaust blowdown when exhaust valve opens near end of expansion stroke. **(f)** Exhaust stroke. Remaining exhaust pushed from cylinder as piston moves from BDC to TDC.

1.4.2 Four-Stroke CI Engine Cycle

1. First Stroke: Intake Stroke

The same as the intake stroke in an SI engine with one major difference: no fuel is added to the incoming air.

2. Second Stroke: Compression Stroke

The same as in an SI engine except that only air is compressed and compression is to higher pressures and temperature. Late in the compression stroke fuel is injected directly into the combustion chamber, where it mixes with the very hot air. This causes the fuel to evaporate and self-ignite, causing combustion to start.

3. Combustion

Combustion is fully developed by TDC and continues at about constant pressure until fuel injection is complete and the piston has started towards BDC.

4. Third Stroke: Power Stroke

The power stroke continues as combustion ends and the piston travels towards BDC.

5. Exhaust Blowdown Same as with an SI engine.

6. Fourth Stroke: Exhaust Stroke Same as with an SI engine.

1.4.3 Two-Stroke SI Engine Cycle

1. Combustion

With the piston at TDC combustion occurs very quickly, raising the temperature and pressure to peak values, almost at constant volume.

2. First Stroke: Expansion Stroke or Power Stroke

Very high pressure created by the combustion process forces the piston down in the power stroke. The expanding volume of the combustion chamber causes pressure and temperature to decrease as the piston travels towards BDC.

3. Exhaust Blowdown

At about 75° by BDC, the exhaust valve opens and blowdown occurs. The exhaust valve may be a poppet valve in the cylinder head, or it may be a slot in the side of the cylinder which is uncovered as the piston approaches BDC. After blowdown the cylinder remains filled with exhaust gas at lower pressure.

4. Intake and Scavenging

When blowdown is nearly complete, at about 50° by BDC, the intake slot on the side of the cylinder is uncovered and intake air-fuel enters under pressure. Fuel is added to the air with either a carburetor or fuel injection. This incoming mixture pushes much of the remaining exhaust gases out the open exhaust valve and fills the cylinder with a combustible air-fuel mixture, a process called scavenging. The piston passes BDC and very quickly covers the intake port and then the exhaust port (or the exhaust valve closes). The higher pressure at which the air enters the cylinder is established in one of two ways. Large two stroke cycle engines generally have a supercharger, while small engines will intake the air through the crankcase. On these engines the crankcase is designed to serve as a compressor in addition to serving its normal function.

5. Second Stroke:

Compression Stroke With all valves (or ports) closed, the piston travels towards TDC and compresses the air-fuel mixture to a higher pressure and temperature. Near the end of the compression stroke, the spark plug is fired; by the time the piston gets to IDC, combustion occurs and the next engine cycle begins.

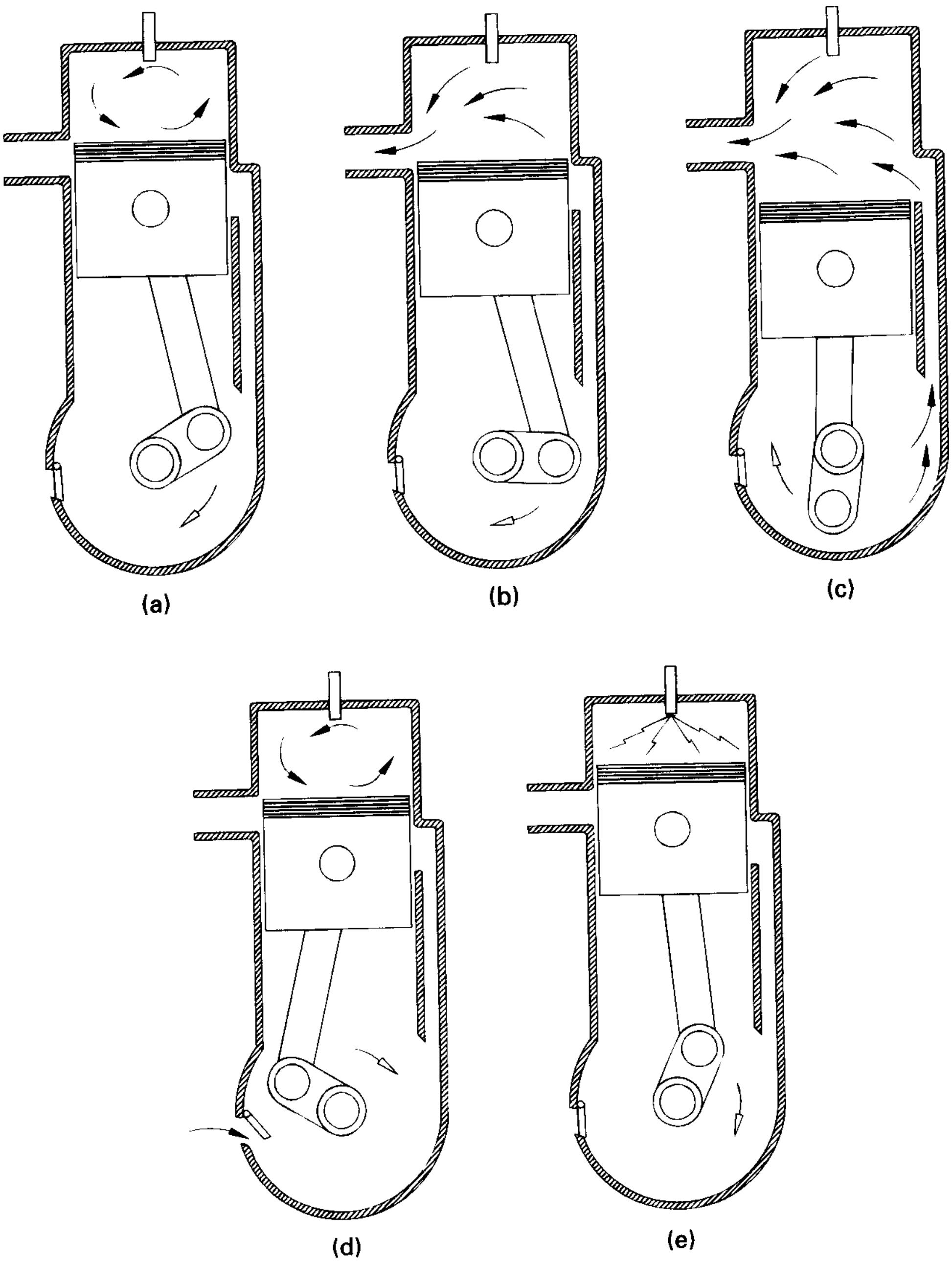


Figure Two-stroke SI engine operating cycle with crankcase compression. **(a)** Power or expansion stroke. High cylinder pressure pushes piston from TDC towards BDC with all ports closed. Air in crankcase is compressed by downward motion of piston. **(b)** Exhaust blowdown when exhaust port opens near end of power stroke. **(c)** Cylinder scavenging when intake port opens and airfuel is forced into cylinder under pressure. Intake mixture pushes some of the remaining exhaust out the open exhaust port. Scavenging lasts until piston passes BDC and closes intake and exhaust ports. **(d)** Compression stroke. Piston moves from BDC to TDC with all ports closed. Intake air fills crankcase. Spark ignition occurs near end of compression stroke. **(e)** Combustion at almost constant volume near TDC.

1.4.4 Two-Stroke CI Engine Cycle

The two-stroke cycle for a CI engine is similar to that of the SI engine, except for two changes. No fuel is added to the incoming air, so that compression is done on air only. Instead of a spark plug, a fuel injector is located in the cylinder. Near the end of the compression stroke, fuel is injected into the hot compressed air and combustion is initiated by self-ignition.

1.5 ENGINE CYCLES

1.5.1 Air-Standard Cycles

The cycle experienced in the cylinder of an internal combustion engine is very complex. First, air (CI engine) or air mixed with fuel (SI engine) is ingested and mixed with the slight amount of exhaust residual remaining from the previous cycle. This mixture is then compressed and combusted, changing the composition to exhaust products consisting largely of COz, Hz 0, and Nz with many other lesser components. Then, after an expansion process, the exhaust valve is opened and this gas mixture is expelled to the surroundings. Thus, it is an open cycle with changing composition, a difficult system to analyze. To make the analysis of the engine cycle much more manageable, the real cycle is approximated with an ideal **air-standard cycle** which differs from the actual by the following:

1. The gas mixture in the cylinder is treated as air for the entire cycle, and property values of air are used in the analysis. This is a good approximation during the first half of the cycle, when most of the gas in the cylinder is air with only up to about 7% fuel vapor. Even in the second half of the cycle, when the gas composition is mostly CO2, H20, and N2, using air properties does not create large errors in the analysis. Air will be treated as an ideal gas with constant specific heats.

2. The real open cycle is changed into a closed cycle by assuming that the gases being exhausted are fed back into the intake system. This works with ideal air-standard cycles, as both intake gases and exhaust gases are air. Closing the cycle simplifies the analysis.

3. The combustion process is replaced with a heat addition term Qin of equal energy value. Air alone cannot combust.

4. The open exhaust process, which carries a large amount of enthalpy out of the esynsetregmy,viaslureep. laced with a closed system heat rejection process Q_{out} of equal

5. Actual engine processes are approximated with ideal processes.

(a) The almost-constant-pressure intake and exhaust strokes are assumed to be constant pressure. At WOT, the intake stroke is assumed to be at a pressure P_o of one atmosphere. At partially closed throttle or when supercharged, inlet pressure will be some constant value other than one atmosphere. The exhaust stroke pressure is assumed constant at one atmosphere.

(b) Compression strokes and expansion strokes are approximated by isentropic processes. To be truly isentropic would require these strokes to be reversible and adiabatic. There is some friction between the piston and cylinder walls but, because the surfaces are highly polished and lubricated, this friction is kept to a minimum and the processes are close to frictionless and reversible. If this were not true, automobile engines would wear out long before the 150-200 thousand miles which they now last if properly

maintained. There is also fluid friction because of the gas motion within the cylinders during these strokes. This too is minimal. Heat transfer for anyone stroke will be negligibly small due to the very short time involved for that single process. Thus, an almost reversible and almost adiabatic process can quite accurately be approximated with an isentropic process.

(c) The combustion process is idealized by a constant-volume process (SI cycle), a constant-pressure process (CI cycle), or a combination of both (CI Dual cycle).

(d) Exhaust blowdown is approximated by a constant-volume process.

(e) All processes are considered reversible.

In air-standard cycles, air is considered an ideal gas such that the following ideal gas relationships can be used:

$$Pv = RT \qquad \text{(a)}$$

$$PV = mRT \qquad \text{(b)}$$

$$P = \rho RT \qquad \text{(c)}$$

$$dh = c_P dT \qquad \text{(d)}$$

$$du = c_v dT \qquad \text{(e)} \qquad \text{(3-1)}$$

$$Pv^k = \text{constant} \quad \text{isentropic process} \qquad \text{(f)}$$

$$Tv^{k-1} = \text{constant} \quad \text{isentropic process} \qquad \text{(g)}$$

$$TP^{(1-k)/k} = \text{constant} \quad \text{isentropic process} \qquad \text{(h)}$$

$$w_{1-2} = (P_2v_2 - P_1v_1)/(1-k) \quad \text{isentropic work in closed system} \qquad \text{(i)}$$

$$= R(T_2 - T_1)/(1-k)$$

$$c = \sqrt{kRT} \quad \text{speed of sound} \qquad \text{(j)}$$

where: P = gas pressure in cylinder
V = volume in cylinder
v = specific volume of gas
R = gas constant of air
T = temperature
m = mass of gas in cylinder
ρ = density
h = specific enthalpy
u = specific internal energy
c_p, c_v = specific heats
$k = c_p/c_v$
w = specific work
c = speed of sound

In addition to these, the following variables are used in this chapter for cycle analysis:

AF = air–fuel ratio
$\dot{m}$ = mass flow rate
q = heat transfer per unit mass for one cycle
$\dot{q}$ = heat transfer rate per unit mass
Q = heat transfer for one cycle
$\dot{Q}$ = heat transfer rate
Q_{HV} = heating value of fuel

r_c = compression ratio
W = work for one cycle
$\dot{W}$ = power
η_c = combustion efficiency

Subscripts used include:

a = air
f = fuel
ex = exhaust
m = mixture of all gases

of temperature, which they are, or they can be treated as constants, which simplifies calculations at a slight loss of accuracy.

In this textbook, constant specific heat analysis will be used. Because of the high temperatures and large temperature range experienced during an engine cycle, the specific heats and ratio of specific heats *k* do vary by a fair amount (see Table A-I in the Appendix). At the low-temperature end of a cycle during intake and start of compression, a value of $k = 1.4$ is correct. However, at the end of combustion the temperature has risen such that $k = 1.3$ would be more accurate. A constant average value between these extremes is found to give better results than a standard condition (25°C) value, as is often used in elementary thermodynamics textbooks. When analyzing what occurs within engines during the operating cycle and exhaust flow, this book uses the following air property values:

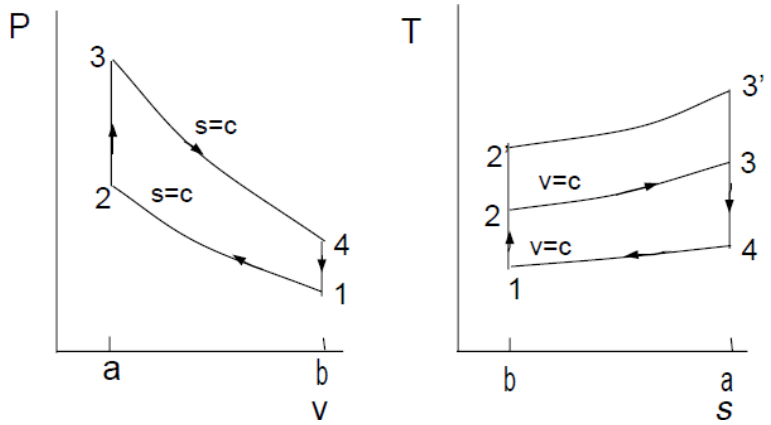
$$c_p = 1.108 \text{ kJ/kg-K} = 0.265 \text{ BTU/lbm-°R}$$
$$c_v = 0.821 \text{ kJ/kg-K} = 0.196 \text{ BTU/lbm-°R}$$
$$k = c_P/c_v = 1.108/0.821 = 1.35$$
$$R = c_P - c_v = 0.287 \text{ kJ/kg-K}$$
$$= 0.069 \text{ BTU/lbm-°R} = 53.33 \text{ ft-lbf/lbm-°R}$$

Air flow before it enters an engine is usually closer to standard temperature, and for these conditions a value of $k = 1.4$ is correct. This would include processes such as inlet flow in superchargers, turbochargers, and carburetors, and air flow through the engine radiator. For these conditions, the following air property values are used:

$$c_p = 1.005 \text{ kJ/kg-K} = 0.240 \text{ BTU/lbm-°R}$$
$$c_v = 0.718 \text{ kJ/kg-K} = 0.172 \text{ BTU/lbm-°R}$$
$$k = c_p/c_v = 1.005/0.718 = 1.40$$
$$R = c_p - c_v = 0.287 \text{ kJ/kg-K}$$

1.5.2 OTTO CYCLE

The Otto cycle is a model of the real cycle that assumes heat addition at top dead center. The Otto cycle consists of four internally reversible cycles, that describe the process of an engine. Figure, shows the p-v and T-s diagram for the Otto cycle.



Process 1-2 is an isentropic compression of air and fuel, which occurs when the piston moves from bottom dead center (BDC) to TDC. In this process air and fuel are compressed and ready for the second process. Process 2-3 is a constant volume heat addition process where the air to fuel mixture is ignited. Process 3-4 is an isentropic expansion, where work is done on the piston, but no heat is added. This process is referred to as the power stroke. The final process, 4-1, is a constant volume heat removal that ends at BDC. Work and heat are important aspects of engines, that can be represented by Figure. On the T-s diagram the area 1-4-a-b-1 corresponds to the heat rejected per unit of mass. Area 2-3-a-b-2 corresponds to the heat added per unit of mass. The enclosed area shown represents the net heat added during the process. The area 1-2-a-b-1 in the p-v diagram corresponds to the work input per unit mass and area 3-4-b-a-3 corresponds to work output per unit mass. The net work done is interpreted by the enclosed region in Figure, in the T-s diagram. In the Otto cycle there are therefore two processes that involve work but no heat transfer and two different processes that involve heat transfer but no work. The energy transfer can be expressed in the following form:

$$\begin{aligned} \frac{W_{12}}{m} &= u_2 - u_1 \\ \frac{W_{34}}{m} &= u_3 - u_4 \\ \frac{Q_{23}}{m} &= u_3 - u_2 \\ \frac{Q_{41}}{m} &= u_4 - u_1 \end{aligned}$$

The efficiency for the engine can be expressed as the net work done over the heat added. The net work per unit mass is expressed as:

$$\frac{W_{cycle}}{m} = \frac{W_{34}}{m} + \frac{W_{12}}{m}$$

Therefore the efficiency for the engine is:

$$\eta = 1 - \frac{u_4 - u_1}{u_3 - u_2}$$

The thermal efficiency of the otto cycle increases with increasing compression ratio. When the Otto cycle is analyzed on a cold air standard basis an expression relating the compression ratio, r, temperature and pressure is obtained from isentropic properties. The compress in ratio is a ratio of the volume displaced by the piston. From figure it can be seen that the compression ratio is equal to V1/V2 and V4/V3. The expressions for the otto cycle, at constant k, for the isentropic processes are:

$$\frac{T_2}{T_1} = (\frac{V_1}{V_2})^{k-1} = r^{k-1}$$

$$\frac{T_4}{T_3} = (\frac{V_3}{V_4})^{k-1} = \frac{1}{r^{k-1}}$$

The specific heat ratio is defined as the ratio of specific heat at constant pressure divided by the specific heat at constant volume. Equation defines the specific heat ratio.

$$k = \frac{c_p}{c_v}$$

From a cold air standard basis equation 2.6 can be rewritten to the following form,

$$\eta = 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2)}$$

or when rearranging to the form,

$$\eta = 1 - \frac{T_1}{T_2}(\frac{T_4/T_1 - 1}{T_3/T_2 - 1})$$

From equations 2.7 and 2.8 it is shown that $\frac{T_4}{T_1} = \frac{T_3}{T_2}$. By using this relationship in equation 2.11 the following expression for the efficiency is obtained.

$$\eta = 1 - \frac{T_1}{T_2}$$

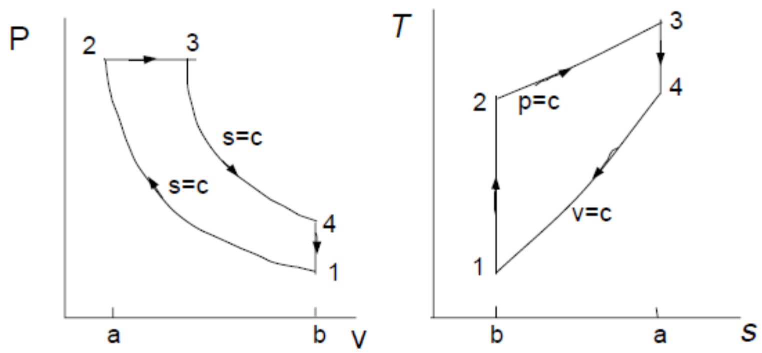
Finally using the relationship in equation 2.7 the relationship between the compression ratio, r, and the efficiency is shown by equation 2.13.

$$\eta = 1 - \frac{1}{r^{k-1}}$$

where k=1.4 for air at ambient temperature.

1.5.3 DIESEL CYCLE

The diesel cycle is similar to the Otto cycle, except that heat addition and rejection occur at different conditions. The diesel cycle is also an ideal cycle meaning that it does not give an exact representation of the actual process. The diesel cycle consists of four internally reversible processes. Process 1-2 is an isentropic compression. Process 2-3 is a constant pressure heat addition. This process makes the first part of the power stroke. Process 3-4 is an isentropic expansion, which makes up the rest of the power stroke. Process 4-1 finishes the cycle with a constant volume heat rejection with the piston at BDC. Figure shows the p-v and T-s diagram for the diesel cycle.



Since the diesel cycle consists of four internally reversible processes, areas on the p-v and T-s diagram represent work and heat. On the T-s diagram the area 2-3-a-b-2 represents the heat added to the system. Area, on the T-s curve, 1-4-a-b-1 represents the heat rejected. The enclosed area shown represents the net heat added during the process. On the p-v diagram the area 1-2-a-b-1 represent the work input and area 2-3-4-b-a-2 represents the work done as the piston moves to the BDC. The net work done is interpreted by the enclosed region in the p-v diagram. The efficiency for the engine is expressed as the net work done over the heat added. The efficiency is therefore:

$$\eta = \frac{W_{cycle}/m}{Q_{23}/m} = 1 - \frac{u_4 - u_1}{h_3 - h_2}$$

The compression ratio of a diesel engine plays a greater significance than in a spark ignition engine. The thermal efficiency of a compression ignition (CI) engine increases as the compression ratio increases. The cutoff ratio, r_c, is defined as:

$$r_c = \frac{V_3}{V_2}$$

Since $V_4 = V_1$, the volume ratio for the isentropic process is expressed as:

$$\frac{V_4}{V_3} = \frac{V_4}{V_2}\frac{V_2}{V_3} = \frac{V_1}{V_2}\frac{V_1}{V_3} = \frac{r}{r_c}$$

Just as in the spark ignition engine a cold air standard analysis, with constant specific heat ratio, for an isentropic process for the diesel cycle results in the the following expressions.

$$\frac{T_2}{T_1} = (\frac{V_1}{V_2})^{k-1} = r^{k-1}$$

$$\frac{T_4}{T_3} = (\frac{V_3}{V_4})^{k-1} = \frac{r_c}{r}^{k-1}$$

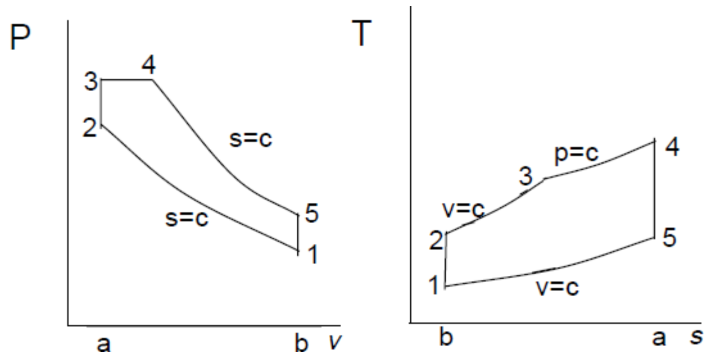
Using equation 2.16, the above expressions, and the same approach used for the otto cycle the efficiency for the diesel cycle can be expressed in terms of the compression ratio and cutoff ratio. Equation 2.19 gives the expression for the efficiency.

$$\eta = 1 - \frac{1}{r^{k-1}}[\frac{r_c^k - 1}{k(r_c - 1)}]$$

1.5.4 DUAL CYCLE

The dual cycle is a better description of the actual pressure variation in the engine. There are several differences though with the Otto and Diesel cycle. In the dual cycle there are five processes. Process 1-2 is an isentropic compression where there is no heat transfer but there is work done. Process 2-3 is a constant volume heat addition process where there is no work done. Process 3-4 is another heat addition process but with constant pressure. This process is also know as the power stroke. Process 4-5 is an isentropic expansion that finishes with the remainder of the power stroke. Finally, process 5-1, is a constant volume heat rejection process. Figure shows a p-v and T-s diagram of the dual cycle. Since the dual cycle is composed of the same processes that the Otto and Diesel cycle the efficiency is equal to the net work done divided by the heat input. The efficiency therefore can be expressed as:

$$\eta = 1 - \frac{Q_{51}}{Q_{23} + Q_{34}}$$



$$\eta = 1 - \frac{q_{out}}{q_{in}}$$

1.5.5 COMPARISON OF OTTO, DIESEL, AND DUAL CYCLES

Figure compares Otto, Diesel, and Dual cycles with the same inlet conditions and the same compression ratios. The thermal efficiency of each cycle can be written as:

TIt = 1 - *Iqout* I/Iqin I

The area under the process lines on T-s coordinates is equal to the heat transfer, so in Fig. the thermal efficiencies can be compared. For each cycle, *qout* is the same (process 4-1). *qin* of each cycle is different, and using Fig. 3-11(b) and Equation it is found for these conditions:

(*TIt*)OTIO > (*TIt*)DUAL > (*TIt*)DIESEL (3-91)

However, this is not the best way to compare these three cycles, because they do not operate on the same compression ratio. Compression ignition engines that operate on the Dual cycle or Diesel cycle have much higher compression ratios than do spark ignition engines operating on the Otto cycle. A more realistic way to compare these three cycles would be to have the same peak pressure-an actual design limitation in engines. This is done in Figure. When this figure is compared with

Equation, it is found:

(*TIt*)DIESEL > (*TIt*)DUAL > (*TIt*)OTIO (3-92)

Comparing the ideas of Eqs. would suggest that the most efficient engine would have combustion as close as possible to constant volume but would be compression ignition and operate at the higher compression ratios which that requires. This is an area where more research and development is needed.

1.6 DIESEL FUELS

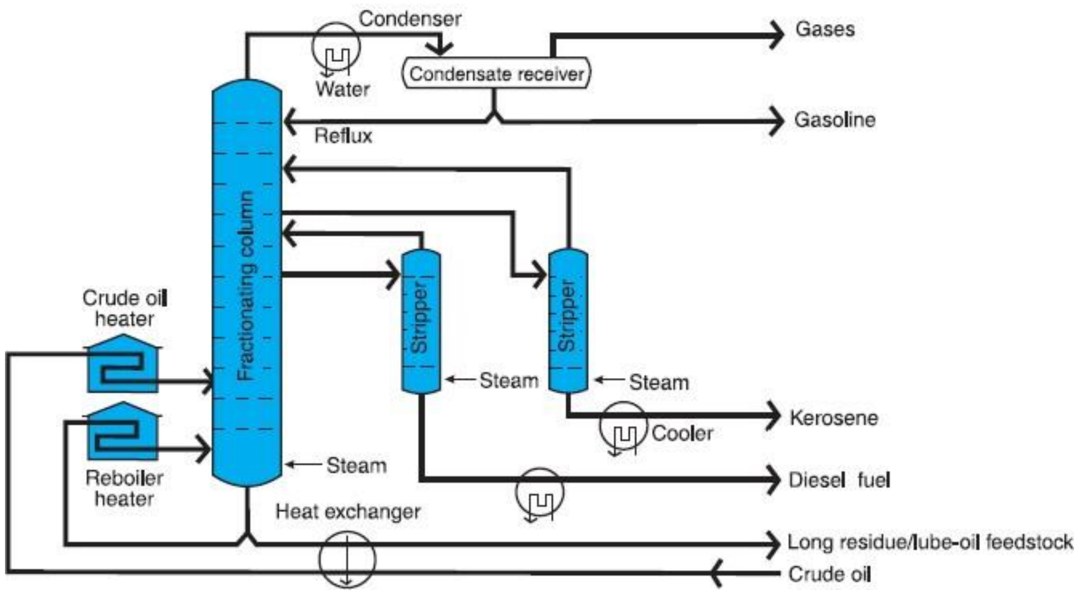
All engines have a few things in common. One of them is that they all need fuel in order to operate. Most mobile and stationary engines use fuels derived from crude oil. Diesel engines use several variations of diesel fuel, depending on their application. In this chapter, you will learn about the different types of diesel fuel used in diesel engines

Hydrocarbon Fuels The liquid fuel used to operate diesel engines is obtained from crude oil. Crude oil consists of a mixture of hydrocarbons (hydrogen and carbon) and compounds such as benzene, petane, hexane, heptane, toluene, propane, and butane. These compounds have different relative volatility points because they will vaporize, or flash, at different temperatures. Hydrocarbon fuels are separated in a fractionating column. As crude oil is heated, these hydrocarbons are given off as a vapor, Figure.

After the natural gas is vaporized from the crude oil, the applied temperature is raised and the hydrocarbon with the next highest vapor point is obtained. The first hydrocarbon engine fuel obtained is high octane aviation gasoline. If everything is working properly and you continue to raise the temperature, other hydrocarbon fuels such as commercial gasoline, kerosene, diesel fuel, domestic heating fuel, industrial fuel oil, lubricating oil, and paraffin are obtained. Finally, only coke and asphalt remain.

The type of hydrocarbons obtained will vary depending on the original geographic location of the crude oil. This heating of crude oil to obtain various hydrocarbons is known as distillation. It is a highly complicated process and precision control of pressure and temperature is required.

Diesel Technology



1.6.1 Diesel Fuel Grades

While the American Society of Testing Materials (ASTM) has divided diesel fuels into three classifications, only two recommended grades are considered acceptable for use in high-speed trucks and buses in North America.

These are the number 1D and number 2D classifications. Grade number 4D, the heaviest diesel fuel, is used in large stationary constant-speed engines or in some marine applications. Number 4 and bunker fuels are not used in high-speed mobile diesel engines, which are continually accelerating and changing speed. Grade number 3D was discontinued a number of years ago and is obsolete.

The Canadian government 3-GP-6D diesel fuel has its own fuel specifications recognizing five categories of diesel fuels, with even more restrictive standards set by ASTM.

Each individual refiner and supplier attempts to produce diesel fuels that meet as closely as possible with ASTM and American Petroleum Institute (API) standards, Figure. Depending on the crude oil source, the diesel fuel end product may be on either the high or low end of the prescribed heat energy scale in Btus per gallon. This is why individual diesel fuels grades may vary slightly from one supplier to another.

Grade 1D is generally the most refined and volatile diesel fuel available. It is a premium fuel used in high rpm engines requiring frequent changes in load and speed. Grade 2D is more widely used in truck fleets due to its greater heat value per gallon, particularly in warm to moderate climates. Although Grade 1D fuel has better properties for cold weather operation, many fleets still use Grade 2D in the winter. Other cold weather aids include a fuel heater/water separator for easier starting, as well as fuel additive conditioners that can be added directly to the fuel tank.

Like gasoline, diesel fuels are blended on a seasonal and geographical basis to satisfy anticipated temperature conditions. It is usually best and cheapest to burn the heaviest fuel that will work under given circumstances. Heavier grades of diesel can usually produce more energy than light grades, just so long as the increased viscosity does not make the fuel too thick to flow and inject properly.

It is important to remember that the wrong grade of diesel fuel can affect the operation of the engine. If an engine is not developing the proper horsepower, an improper grade of diesel fuel could be the cause. An easy way to confirm this is to use a diesel fuel quality tester such as shown in Figure.

1.6.2 Diesel Fuel Properties

In a diesel engine fuel system, the fuel itself performs three functions. It supplies chemical energy to be transformed into mechanical energy, lubricates precision parts in the fuel system components, and cools metal surfaces operating in conditions of friction. The properties or characteristics of diesel fuel must meet these three if the engine is to perform with reliability.

Fuel processors, as well as engine manufacturers, run laboratory tests on all fuel used in diesel engines. These measured properties give a good indication of the way the fuel will perform, however, there is no real substitute for an actual engine test.

The major diesel fuel properties affecting engine performance are: ❑ Heat value. ❑ Specific gravity. ❑ Flash point. ❑ Volatility. ❑ Cetane number rating. ❑ Pour point. ❑ Cloud point. ❑ Viscosity. ❑ Carbon residue. ❑ Sulfur content. ❑ Fungus and bacterial contaminants. ❑ Oxidation and water.

Heat Value

The heat value of fuel is a general indication of how heat energy is supplied to an engine and how well the engine converts heat energy into work. The heat value can be found by testing with a calorimeter. With this test, a premeasured amount of fuel is burned and the amount of heat emitted is carefully measured in Btus per pound of fuel. A British thermal unit (Btu) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The metric equivalent of this unit is known as a joule. To convert Btus into joules, multiply by 1054.8

Specific Gravity

The specific gravity of fuel is a ratio of the fuel density to the density of water. It is measured using a hydrometer. Specific gravity affects the fuel's spray penetration as it is injected into the combustion chamber. Because water is the standard, it has a specific gravity of one. Since oil floats on water, a diesel fuel's specific gravity is always less than one. Diesel fuel's specific gravity ranges from 0.8 to 0.94. Specific gravity is also a factor in measuring the heat value of the fuel. In general, heavier fuels usually have a greater heat value per gallon (Btus) than lighter fuels. Thus, specific gravity is a good indicator of the amount of heat (Btus) available in a given amount of fuel.

The American Petroleum Institute (API) employs another scale to determine specific gravity. Water has a specific gravity of 20 on the API gravity scale. Ten is the lowest value on this scale, the reverse of the system just described. Diesel fuels generally range from 20 to 45 on the API gravity scale, with most ranging between 34 to 36 at 60°F (15.5°C).

Flash Point

A fuel's flash point is the lowest temperature at which it will give off flammable vapors in sufficient quantity to flash or momentarily ignite when brought into contact with an open flame. The flash point has no effect on engine performance or on its ignition qualities. It is specified simply as an index of fire hazard–a fuel oil with an extremely low flash point is dangerous to store and handle. Diesel fuel flash points are not an indication of how they will ignite in an engine cylinder, however. This depends on the ignition quality of the fuel. For example gasoline, which has a very low flash point, would be a very poor diesel fuel due to its ignition quality. Volatility Volatility is a fuel's ability to change to a vapor.

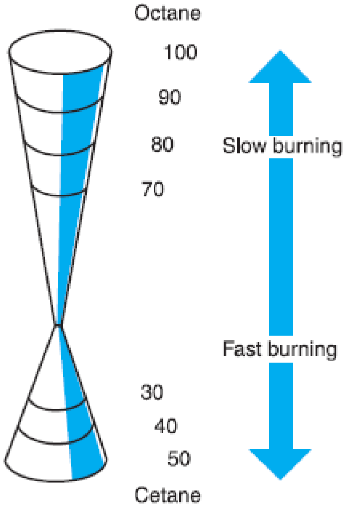
It is indicated by the air-vapor ratio that is formed at a specific temperature. Diesel fuel volatility is indicated by a 90% distillation temperature (the temperature at which 90% of the fuel is distilled off). As volatility decreases, carbon deposits and engine wear increase. Depending on such factors as the combustion chamber condition, more smoke will also affect power output, performance, starting, and warm-up.

Cetane Number Rating

The ease of diesel fuel oil ignition and the manner in which it burns determine the ignition quality of the fuel oil. Diesel fuel oil is injected into the combustion chamber in liquid form. The fuel must then be able to vaporize quickly and ignite without a flame or spark. This ability to vaporize and ignite easily is called ignition quality.

The ignition quality of a diesel fuel is determined by its cetane number rating, or cetane value. The cetane rating or value of a diesel fuel is based on the ability of the fuel to ignite. The cetane rating of a fuel is determined by comparing it with pure cetane, which is a test fuel, and is identified by a cetane number, Figure 14-4. This cetane number represents the percentage of pure cetane in a reference fuel which will exactly match the ignition quality of the fuel being tested. The cetane rating scale ranges from 0 to 100, with 100 being the highest ignition quality.

In general, the higher a fuel's cetane rating, the lower the emissions. Currently, a 40 cetane or above rating is standard for all on-highway diesel engines. (In some areas, 50 cetane and higher are current standards.) Newer diesel engines may require higher cetane fuel. The diesel engine service manual will specify what cetane number to use.



Improving Ignition Quality

Fuels with poor ignition qualities can be improved or reformulated by blending them with fuels that have good ignition properties. The cetane number of such blends are an average of the cetane numbers of the individual fuels. To meet the cetane number required by most on-highway vehicles, cetane improvers are added to the blends. The lower cetane compounds are less responsive to these improvers than the higher cetane paraffin fuels.

The improvers promote early, uniform ignition of fuel and prevent high pressure increases in the combustion cycle. Depending on the amount of cetane components in the base fuel, typical alkyl nitrate additive treatment can increase cetane by three to five numbers (1:1000 ratio). With high natural cetane premium base fuels (containing a high percentage of paraffins) and a 1:500 alkyl nitrate treatment ration, cetane may increase as much as seven numbers. Most improvers contain alkyl nitrates, which break down readily to provide extra oxygen for combustion. They also break down and oxidize fuel in storage. However, they also generate organic particulates, water, and sludge, all of which degrade fuel quality. Recently, several new cetane improvers or reformulaters without alkyl nitrates have been used and, properly blended, will improve oxidation stability while providing a cetane increase of two to five increments.

It is only recently that engineers have learned how important the cetane level is in meeting the emissions equation. The air-fuel mixing time in a direct-injected diesel is about one-tenth the time of a carbureted gasoline engine. Early ignition promotes smooth and complete combustion, leading to reduced emissions.

Excessive delay can produce very high peak cylinder pressures which make for rough and noisy engine operations. The higher the cetane number, the shorter the ignition delay, which is the time between the start of fuel injection into the cylinder and the actual start of combustion.

Cloud Point

Diesel fuel contains paraffin, and in cold temperatures wax crystals can start to form, accumulate, and clog engine filters. The temperature at which this happens is referred to as the cloud point or wax appearance point (WAP). Generally, if the fuel's cloud point is at least 10° below the ambient temperature, engine performance will be satisfactory. The most commonly available and recommended fuel oil, grade 2D, has a cloud point or WAP of 10°F (-12°C), while the thinner grade 1D has a cloud point of -20°F (-28.8°C). In extremely cold areas, engine clogging can be minimized by using only grade 1D in winter. In most places, mixing a base of grade 2D with grade 1D, or other special additives will work well in colder weather. As a rule, grade 2D's cloud point drops two degrees for every 10% of grade 1D that is added up to a ratio of 50:50.

One of the most effective chemical means for lowering the fuel's cloud point is by blending #2 diesel fuel with kerosene. Fuel suppliers will often do this themselves and market it as "winter fuel." Although this fuel will be more viscous at lower temperatures, its performance will still vary depending on where it was purchased. A 40/60 blend in one area may have a higher cloud point that a 40/60 blend in another. A fuel additive with a cloud point depressant will have limited effect. At most, it will lower the cloud point by 3-4°.

Pour Point

Pour point is another common way of measuring a diesel fuel's performance in cold weather. It is the minimum temperature at which fuel can flow and is expressed as the temperature 5°F (8.8°C) above the level at which the oil becomes solid or refuses to flow. The pour point averages about 10° lower than the cloud point.

Fuel treated with special additives called flow improvers or wax modifiers keep the wax crystals from forming clumps and choking fuel lines. They will generally give satisfactory performance at 9° lower than untreated fuel. However, fuel improvers do not have any impact on the fuel's cloud point, since they do not prevent the formation of wax or paraffin crystals themselves.

Viscosity

Viscosity or stiffness is the property of a diesel fuel that resists the force which causes the fluid to flow. It is related closely to specific gravity and pour point. Two common methods of measuring viscosity are the Saybolt test and the kinematic centistokes test. Both tests involve heating the oil to an exact temperature and measuring its flow rate through a standard sized orifice. The viscosity of diesel fuel is generally specified at 100°F (38°C).

Viscosity of fuels for medium-speed and high speed engines normally ranges from 2.4 to 4.1 centistokes (cSt), or about 39 seconds Saybolt Universal (SSU). In general, any fuel with a viscosity lower that 2.4 cSt or 34 SSU, when measured at 100°F (38°C), will be too thin and could damage injectors as well as other parts of the fuel system.

Diesel fuel also has a low viscosity index, meaning that it is thin when hot but gets thick when cold. A diesel fuel that can go through an injection system easily in warm weather may get too thick to flow properly in cold weather. As mentioned previously, diesel fuel is supplied in several grades. Grade 1D is a winterized diesel fuel.

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UNIT II FUEL INJECTION SYSTEM

UNIT II FUEL INJECTION SYSTEM

2.1 DIESEL ENGINES

The diesel engine is a type of internal combustion engine (more specifically, a compression ignition engine) in which the fuel is ignited by being suddenly exposed to the high temperature and pressure of a compressed gas containing oxygen (usually atmospheric air), rather than a separate source of ignition energy (such as a spark plug), as is the case in the petrol engine.

This is known as the diesel cycle, after German engineer Rudolf Diesel, who invented it in 1892 and received the patent on February 23, 1893.

Initial CI engines were large and slow.

• Heavy distillate petroleum was forced into the cylinder using compressed air.

• Robert Bosch began producing injection systems in 1927.

Diesel engines are rather unpopular in the United States, often being thought of as loud and dirty. Worldwide, however, diesel engines are very well established in a wide variety of applications, as they are much more efficient than gasoline engines and generally longer lasting.

In very cold weather, diesel fuel thickens and increases in viscosity and forms wax crystals or a gel. This can make it difficult for the fuel injector to get fuel into the cylinder in an effective manner, making cold weather starts difficult at times, though recent advances in diesel fuel technology have made these difficulties rare.

A common method to electrically heat the fuel filter and fuel lines. Other engines utilize small electric heaters called glow plugs inside the cylinder to warm the cylinders prior to starting.

A small number use resistive grid heaters in the intake manifold to warm the inlet air until the engine reaches operating temperature.

A vital component of any diesel engine system is the governor, which limits the speed of the engine by controlling the rate of fuel delivery.

Older governors were driven by a gear system from the engine (and thus supplied fuel only linearly with engine speed.)

Modern electronically-controlled engines achieve this through the electronic control module (ECM) or electronic control unit (ECU).

The addition of a turbocharger or supercharger (boost pressures can be higher on diesels) to the engine greatly assists in increasing fuel economy and power output.

The higher compression ratio allows a diesel engine to be more efficient than a comparable spark ignition engine, although the calorific value of the fuel is slightly lower at 45.3 MJ/kg to gasoline at 45.8 MJ/kg.

2.2 CI vs. SI Engines

- SI engines draw fuel and air into the cylinder.
- Fuel must be injected into the cylinder at the desired time of combustion in CI engines.
- Air intake is throttled to the SI engine -- no throttling in CI engines.
- Compression ratios must be high enough to cause auto-ignition in CI engines.
- Upper compression ratio in SI engines is limited by the auto-ignition temperature.
- Flame front in SI engines smooth and controlled.
- CI combustion is rapid and uncontrolled at the beginning.

2.3 DIESEL ENGINES - APPLICATIONS

- High-Speed (approximately 1200 rpm and greater) engines are used to power lorries (trucks), buses, tractors, cars, yachts, compressors, pumps and small generators.
- Large electrical generators are driven by medium speed engines, (approx. 300 to 1200 rpm) optimized to run at a set speed and provide a rapid response to load changes.
- The largest diesel engines are used to power ships. These engines have power outputs over 80,000 kW, turn at about 60 to 100 rpm, and are up to 15 m tall. They often run on cheap lowgrade fuel, which require extra heat treatment in the ship for tanking and before injection due to their low volatility.
- Diesel Fuel Injection System With diesel engines fuel is sprayed directly into the cylinders power is varied by metering the amount of fuel added (no throttle). Diesel fuel injection systems operate at high-pressure, e.g., 100 Mpa. In this system, fuel pressure must be greater than the compression pressure, and the system needs high fuel jet speed to atomize droplets small enough for rapid evaporation.
- Traditional Diesels high pressure produced locally within the injector
- Latest Diesels use high pressure common rail with solenoid actuated injectors

2.4 REQUIREMENTS OF FUEL INJECTION SYSTEM

- The injected fuel must be broken into very fine droplets
- The fuel injection should occur at the correct moment
- It should supply the fuel in correct quantity as required by the varying engine loads

- The spray pattern should ensure rapid mixing of fuel and air
- It should supply equal quantities of metered fuel to all the cylinders in a multi cylinder engines
- The beginning and the end of injection should be sharp Elements of Fuel Injection System
- Distribution elements: to divide the metered fuel equally among the cylinders
- Pumping elements: to supply fuel from fuel tank to cylinder
- Metering elements: to meter fuel supply as per load and speed
- Timing controls: to adjust the start and the stop of injection
- Mixing elements: to atomize and distribute the fuel within the combustion chamber

2.5 TYPES OF INJECTION SYSTEMS

2.5.1 Air (Blast) Injection System:

In air blast injection system, fuel is forced into the cylinder by means of compressed air. This system is little used universally at present, because it requires a multistage air compressor, which increases engine weight and reduces brake power.

This method is capable of producing better atomization and penetration of fuel resulting in higher brake mean effective pressure.

2.5.2 Solid Injection System:

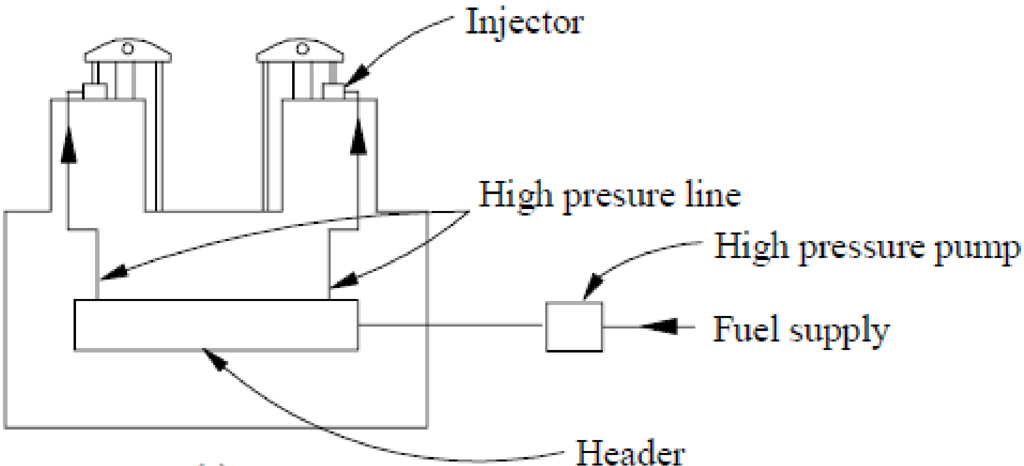
In solid injection, the liquid fuel is injected directly into the combustion chamber without the aid of compressed air. Hence, it is termed as airless mechanical injection or solid injection. Every solid injection system must have a pressuring unit (the pump) and an atomizing unit (the injector).

Solid Injection - Classification

Depending upon the location of the pumps and injectors, and the manner of their operations, solid injection systems may be further classified as follows:

1. Common Rail System
2. Unit Injection System
3. Individual Pump and Nozzle System
4. Distributor System

2.5.3 COMMON RAIL SYSTEM

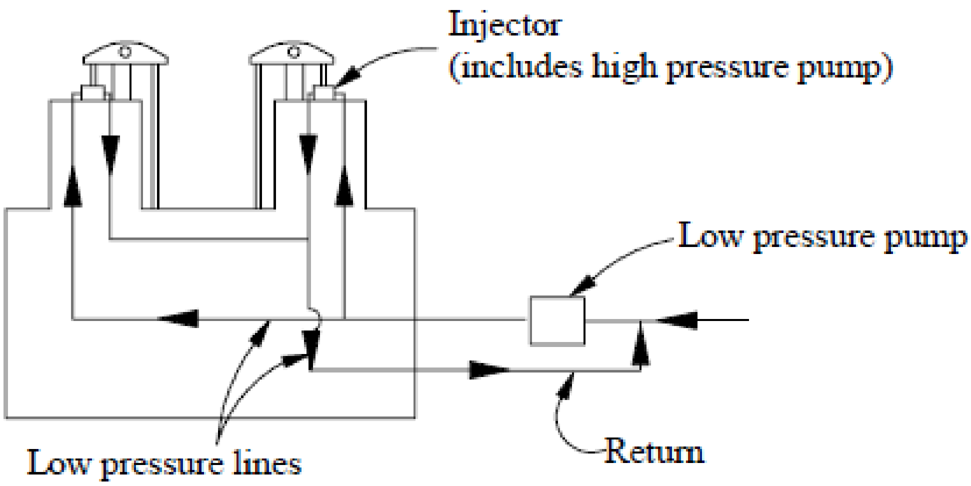


(a)

In this system, a high-pressure pump supplies fuel to a fuel header as shown. The high-pressure in the header forces the fuel to each of the nozzles located in the cylinders. At the proper time, a mechanically operated (by means of push rod and rocker arm) valve allows the fuel to enter the cylinder through nozzle.

2.5.4 UNIT INJTCTION SYSTEM

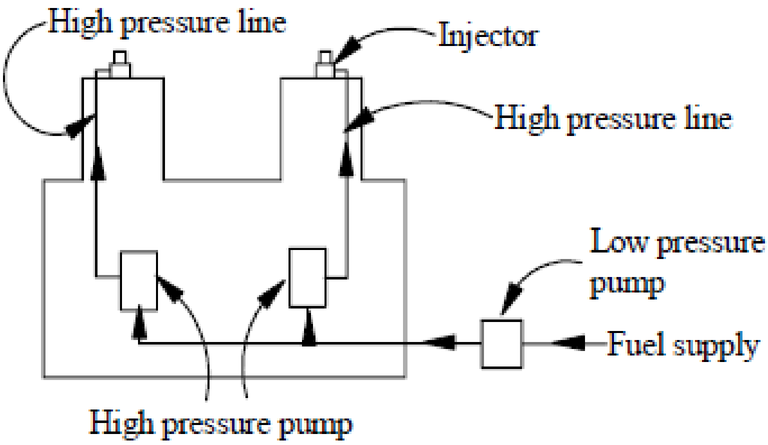
Here, the pump and nozzle are combined in one housing. Each cylinder is provided with one of these unit injectors. Fuel is brought up to the injector by a low-pressure pump, where at the proper time, a rocker arm activates the plunger and thus injects the fuel into the cylinder. The quantity of fuel injected is controlled by the effective stroke of the plunger.



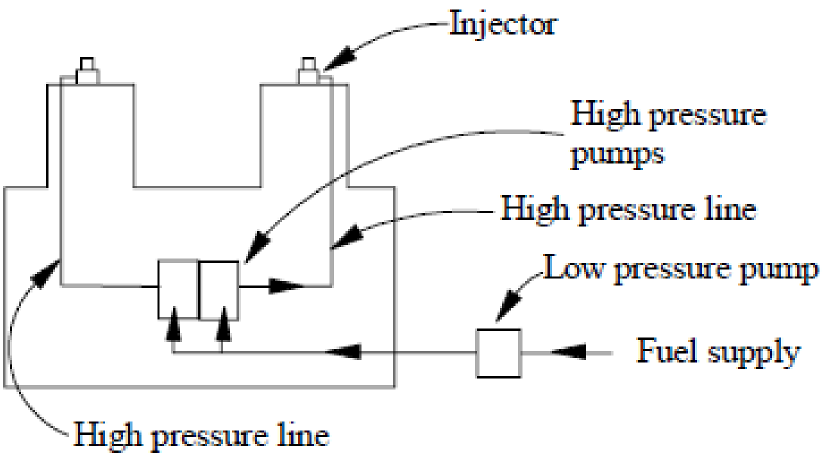
(b)

2.5.5 INDIVIDUAL PUMP & NOZZLE SYSTEMS

In this system, each cylinder is provided with one pump and one injector. This type differs from the unit injector in that the pump and injector are separated from each other, i.e., the injector is located on the cylinder, while the pump is placed on the side of the engine.



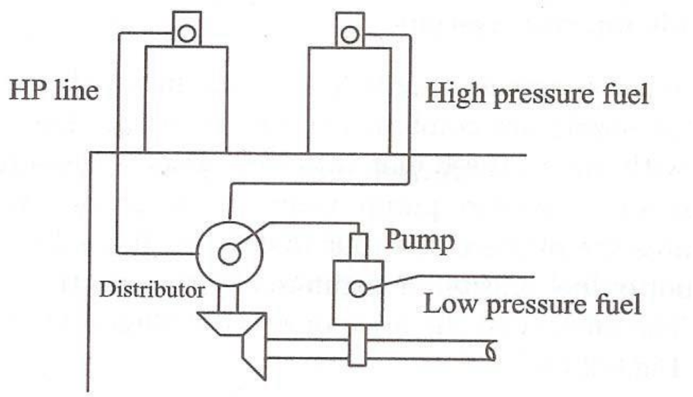
(c)



(d)

Each pump may be placed close to the cylinder, or may be arranged in a cluster. The high-pressure pump plunger is actuated by a cam, and produces the fuel pressure necessary to open the injector valve at the correct time. The quantity of fuel injected is again controlled by the effective stroke of the plunger.

2.5.6 DISTRIBUTOR SYSTEM



Here, the pump which pressurizes the fuel also meters and times it. The fuel pump after metering the required quantity of fuel supplies it to a rotating distributor at the correct time for supply to each cylinder. Since there is one metering element in each pump, a uniform distribution is ensured.

2.6 INJECTION PUMP AND GOVERNOR

The main objective of the fuel injection pump is to deliver accurately a metered quantity of fuel under high pressure at the correct instant to the injector fitted on each cylinder. Two types of pumps are generally used viz., jerk type and distributor type.

Fuel delivered by a pump increases with speed while the opposite is true about the air intake. This results in over fueling at higher speeds. At low speeds, the engine tends to stall due to insufficiency of fuel. To overcome this, injector pump governors are generally used. Two types of governors are found in applications viz.,

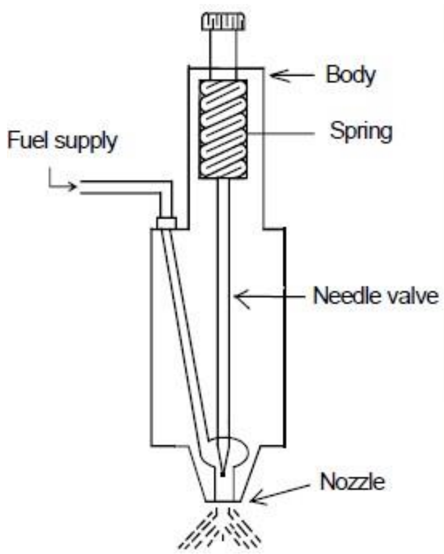
a) Mechanical governor and

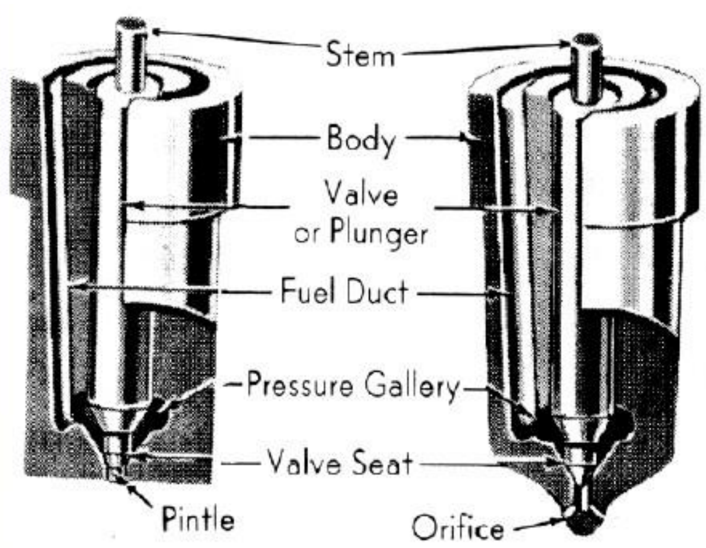
b) Pneumatic governor.

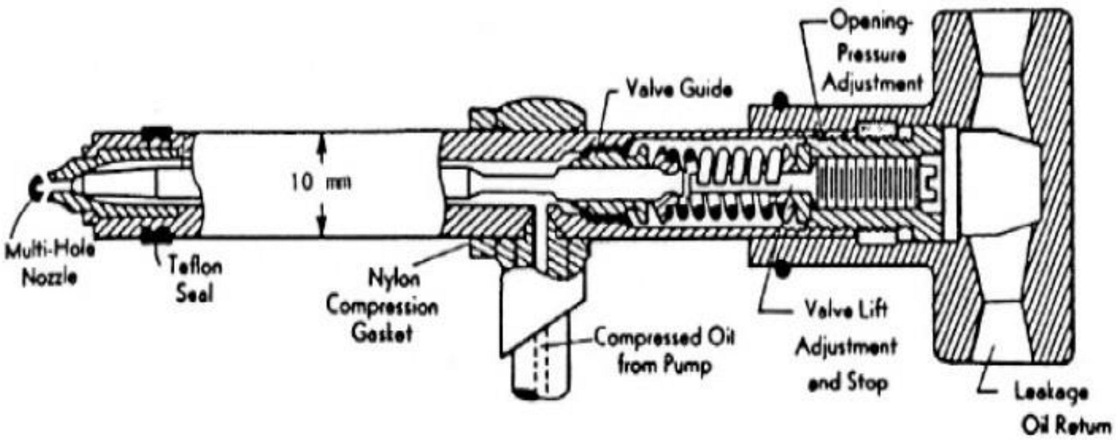
2.7 FUEL INJECTORS AND NOZZLES

Quick and complete combustion is ensured by a well designed fuel injector. By atomizing the fuel into very fine droplets, it increases the surface area of the droplets resulting in better mixing and subsequent combustion. Atomization is done by forcing the fuel through a small orifice under high pressure. An injector assembly consists of the following components.

- a needle valve
- a compression spring
- a nozzle
- an injector body







Operation

Fuel is injected by a pump. The pump exerts sufficient pressure/force that lifts the nozzle valve. The spring tension and hence the valve operating pressure is controlled by adjusting the screw at the top. When the nozzle valve is lifted up, fuel is sprayed into the combustion chamber. As the fuel supply is exhausted, the spring pushes the valve back on its seat.

2.8 NOZZLE

The nozzle sprays the liquid fuel. The functions of the nozzle are:

a) atomization,

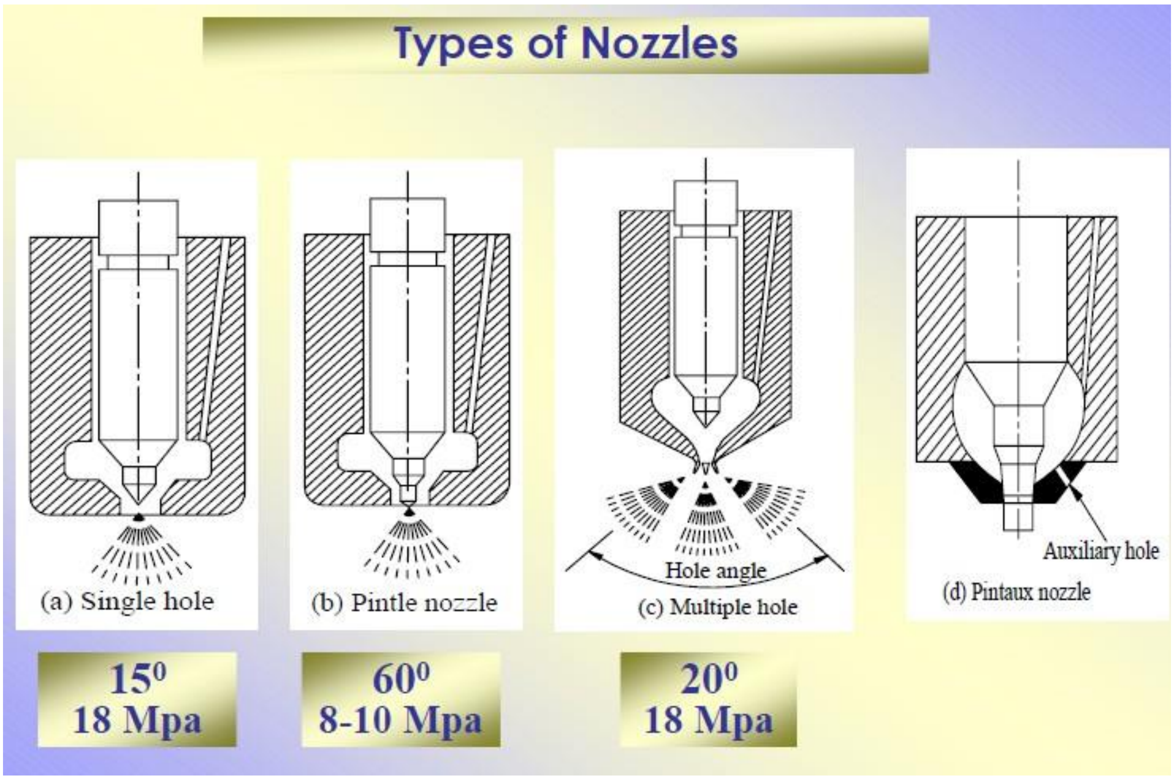
b) distribution of fuel to the required area,

c) non impingement on the walls, and

d) no dribbling.

Note: The fuel striking on the walls decomposes and produces carbon deposits. This causes smoky exhaust and increases fuel consumption.

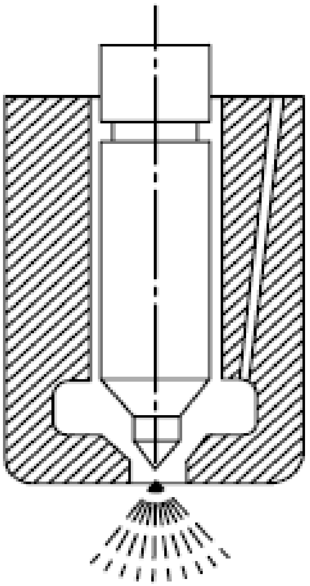
Note: High injection pressure allows better dispersion and penetration into the combustion chamber. High air density in the cylinder gives high resistance to the droplets. This further causes dispersion.



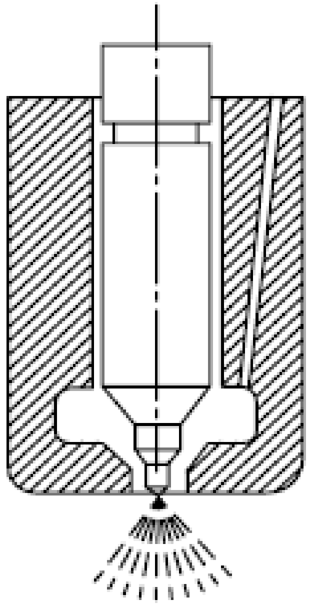
2.8.1 Types of Nozzles

The single hole nozzle requires a high injection pressure and this type of nozzle has a tendency to dribble. The spray cone angle is usually narrow, and this gives poor mixing
unless the velocity is high.

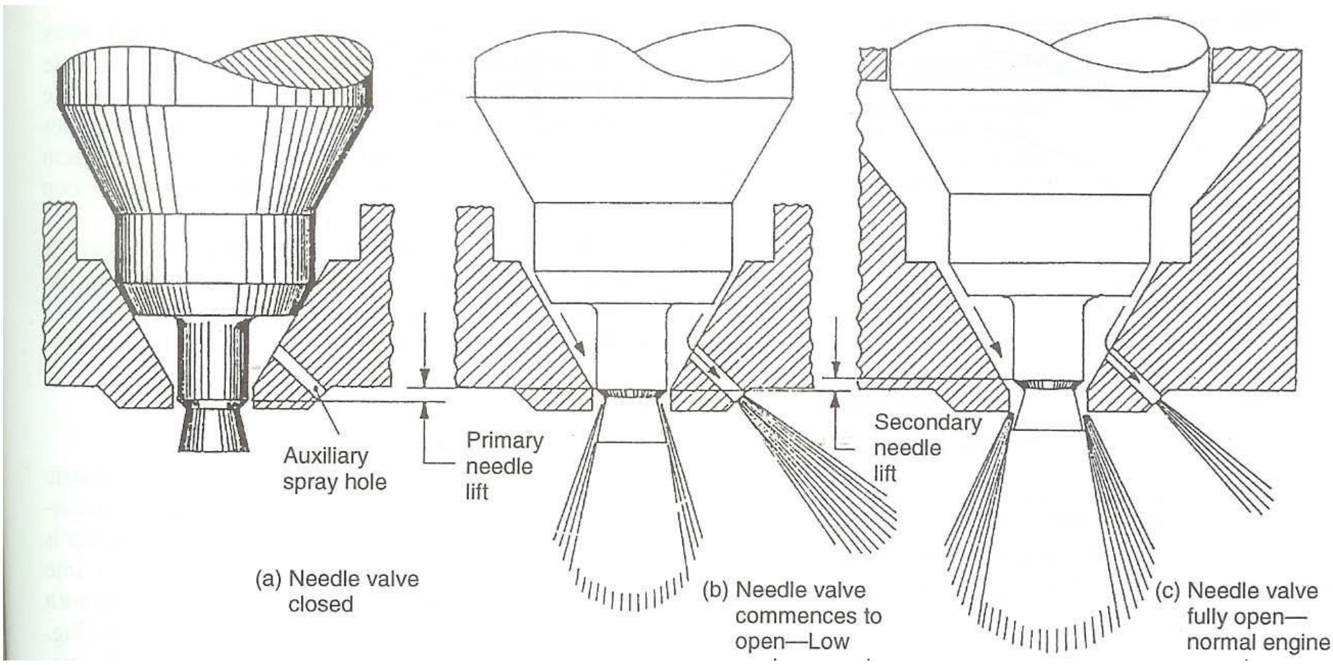
The pintle nozzle has been developed to avoid weak injection and dribbling. The spindle is provided with a pintle capable of protruding in and out. Pintle nozzle results in good atomization and reduced penetration.



(a) Single hole

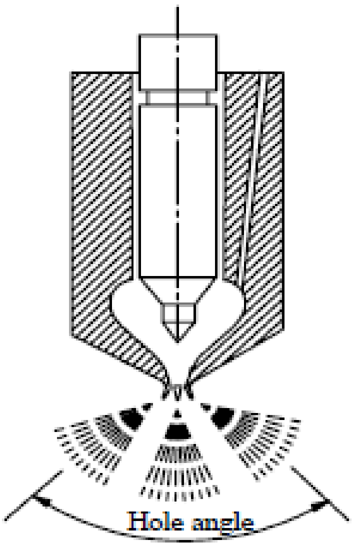


(b) Pintle nozzle

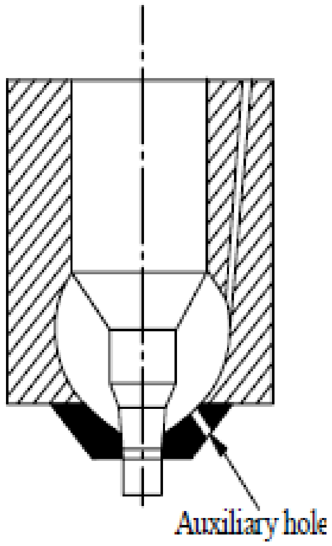


A multihole nozzle, where the number of holes may vary from 4 to 18, allows a proper mixing of air and fuel. The advantage lies with the ability to distribute the fuel properly even with lower air motion within the chamber.

The pintaux nozzle is a pintle nozzle with an auxiliary hole drilled into the nozzle body. At low speeds, the needle valve does not lift fully and most of the fuel is injected through this auxiliary hole.



(c) Multiple hole



(d) Pintaux nozzle

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UNIT III AIR MOTION AND COMBUSTION CHAMBER

UNIT III

AIR MOTION AND COMBUSTION CHAMBER

3.1 AIR MOTION WITHIN THE CYLINDER

The air motion inside the cylinder greatly influences the performance of diesel engines. It is one of the major factors that controls the fuel-air mixing in diesel engines. Air-fuel mixing influences combustion, performance and emission level in the engine.

The air motion inside the cylinder mainly depends on manifold design, inlet and exhaust valve profile and combustion chamber configuration. The initial in-cylinder intake flow pattern is set up by the intake process, and then it is modified during the compression process.

The shape of the bowl in the piston and the intake system, control the turbulence level and air-fuel mixing of the DI diesel engine. The variation of shape of intake system, shape of piston cavity, etc. lead to a change in the flow field inside the engine.

3.2 EFFECTS OF AIR MOTION

The air motion inside the cylinder

1. Atomizes the injected fuel into droplets of different sizes.
2. Distributes the fuel droplets uniformly in the air charge.
3. Mixes injected fuel droplets with the air mass.
4. Assists combustion of fuel droplets.
5. Peels off the combustion products from the surface of the burning

drops as they are being consumed.

6. Supplies fresh air to the interior portion of the fuel drops and thereby ensures complete combustion.
7. Reduces delay period.
8. Reduces after burning of the fuel.
9. Better utilization of air contained in the cylinder.

3.3 TYPES OF AIR MOTION

The air motion in a diesel engine is generally caused by either by the intake port during the suction stroke or by combustion chamber geometry during the compression stroke. Three different elements of the air motion present during intake to expansion strokes in a diesel engine cylinder have been classified as

1) Swirl
2) Squish
3) Turbulence

3.3.1 Swirl

Swirl is defined as the organized rotation of the charge about the cylinder axis. It is created by bringing the intake flow into the cylinder with an initial angular momentum. Swirl is generated during the intake process in DI diesel engines by the intake port and subsequently by combustion chamber geometry during the compression stroke. The swirl intensity increases the tangential component of the velocity of air inside the cylinder, which aids in the mixing of fuel and air, and significantly affects the combustion and emission characteristics of diesel engines.

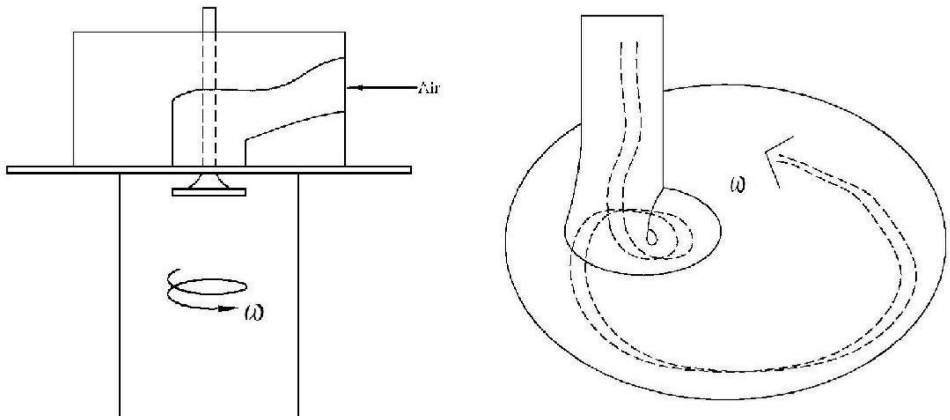


Figure 3.1 Schematic of swirl air motion

$$\text{Swirl ratio} = \frac{\text{Angular velocity of a rotating flow } (\omega)}{\text{Crank shaft angular rotational speed } (2\pi N)}$$

3.3.1.1 Suction swirl

During suction, air is admitted into the engine cylinder in a tangential direction. The entering air is deflected by the cylinder wall. Air thereby assumes a rotary motion i.e. swirl about the cylinder axis. This swirl is called suction swirl. Helical ports produce swirl upstream of the valve and directed ports have it downstream. In diesel engines, tangential entry of air is effected by one of the following methods:

1. By masking a portion of the inlet valve.
2. By angling the inlet port in the desired direction.
3. By providing a lip in the inlet port, over one side of the inlet valve.

3.3.1.2 Compression swirl

The combustion chamber cavity tends to modify the swirl as the piston approaches the Top Dead Centre (TDC) position during the compression process. As the piston approaches TDC the rotating air is forced into the piston bowl. The rotational force is magnified by the reduced diameter of the piston bowl. Thin, deep bowls have a higher swirl rate.

3.3.2 Squish

The squish motion of air is brought about by a recess in the piston crown. At the end of the compression stroke, the piston is brought to within a very small distance from the cylinder head. This fact causes a flow of air from the periphery of the cylinder to its center and into the recess in the piston crown. This radial inward movement of air is called squish by Ricardo. The combustion recess, into which the air mass is squeezed in, is located either in the piston crown or in the cylinder head. The former arrangement is preferred and is widely used. In this case, heat losses from the compressed air will be lesser. This is because the piston crown is not cooled to that extent as the cylinder head which is cooled by the coolant. The figure 3.2 shows squish motion during compression.

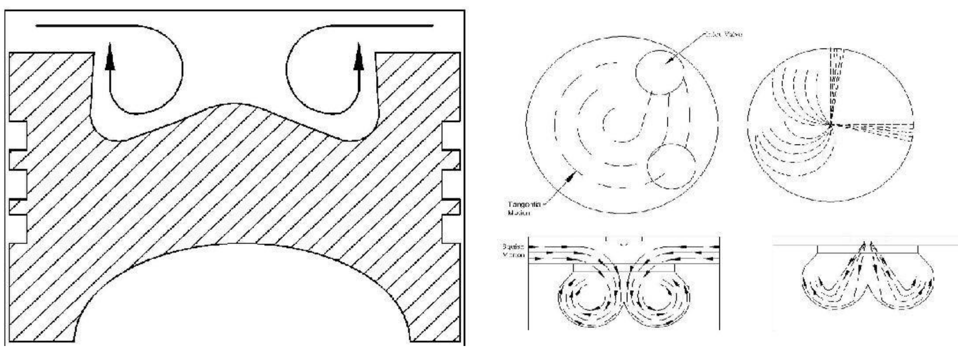


Figure 3.2 Schematic of squish air motion

3.3.3 Turbulence

Turbulence contributes to the dispersion of fuel and the micro mixing of fuel and air respectively. As such, they greatly influence the diesel engine performance. The flow processes in the engine cylinder are turbulent. In turbulent flows, the rates of transfer and mixing are several times greater than the rates due to molecular diffusion. This turbulent diffusion results from the local fluctuations in the flow field. It leads to increased rates of momentum and heat and mass transfer, and is essential to the satisfactory operation of Spark Ignition and Diesel engines.

3.4 COMBUSTION CHAMBER FOR CI ENGINES

The shape of the combustion chamber and the fluid dynamics inside the chamber are of great importance in diesel combustion. Diesel engines are divided into two basic categories according to their combustion chamber design.

1) Direct-Injection (DI) engines: 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.
2) Indirect-Injection (IDI) engines: This type of combustion chambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel injection is effected usually into that part of the chamber located in the cylinder head.

   These chambers are classified further into:

   (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.

The details of these chambers are discussed in the following sections.

3.4.1 Direct Injection Engines

These engines have a single, open combustion chamber into which the entire quantity of fuel is injected directly. An open combustion chamber is one in which the combustion space incorporates no restrictions that are sufficiently small to cause large differences in pressure between different parts of the chamber during the combustion process.

The main advantages of this type of chambers are:

(1) Minimum heat loss during compression because of lower surface area to

volume ratio and hence, better efficiency.

(2) No cold starting problems.

(3) Fine atomization because of multihole nozzle.

The drawbacks of these combustion chambers are:

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

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

3.4.1.1 Open combustion chamber

The open combustion chamber is one, in which all the air for combustion is confined in one space. These chambers mainly consist of space formed between the flat cylinder head and a cavity in the piston crown in different shapes. The fuel is injected directly into this space. The injector nozzles used for this type of chambers are generally of multihole type working at a relatively high pressure (above 200 bars). Combustion of the entire fuel takes place within this space. Figure 3.3 shows the schematic diagram of open combustion chamber. In DI diesel engines, a single combustion chamber with different piston bowl shapes such as square, cylindrical, hemispherical, shallow depth, toroidal etc. have been used. There are many designs of open chamber, some of which are shown in figure 3.4.

Shallow depth chamber

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

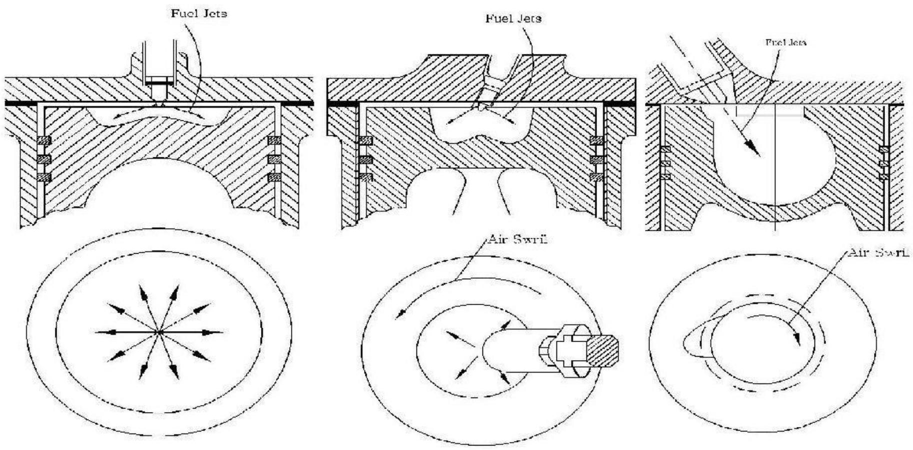


Figure 3.3 Schematic diagram of open combustion chambers

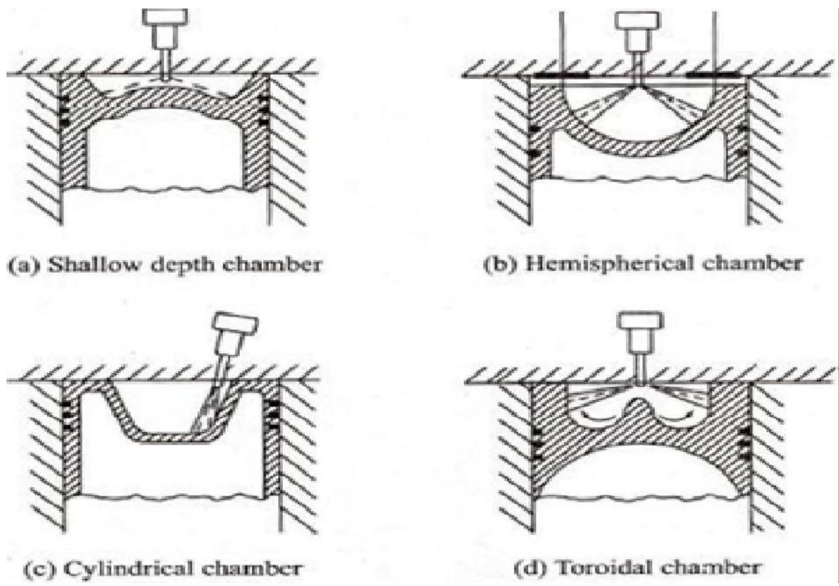


Figure 3.4 Schematic of different shapes of open combustion chambers

Hemispherical chamber

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

Cylindrical chamber

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

Toroidal chamber

The idea behind this shape is to provide a powerful squish along with the air movement, similar to that of the familiar smoke ring , within the toroidal chamber. Due to powerful squish the mask needed on inlet valve is small and there is better utilization of oxygen. The cone angle of spray for this type of chamber is 150° to 160°.

3.4.1.2 Re-entrant combustion chamber

The re-entrant combustion chamber is a type of open combustion chamber which has a smaller diameter (opening) at the entry than at the middle. In this combustion chamber, the lip of the combustion chamber protrudes beyond the walls of the bowl provides a substantial improvement in performance and emissions over the previous open straight sided bowl designs. The bowl lip prevents the air squish motion pushing fuel above the piston crown, so that the majority of the fuel charge is mixed and burnt within the bowl. The lip also creates further micro turbulence within the bowl. Deep re-entrant chambers should be more effective than shallow chambers. Figure 3.5 shows the schematic diagram of the re-entrant combustion chamber.

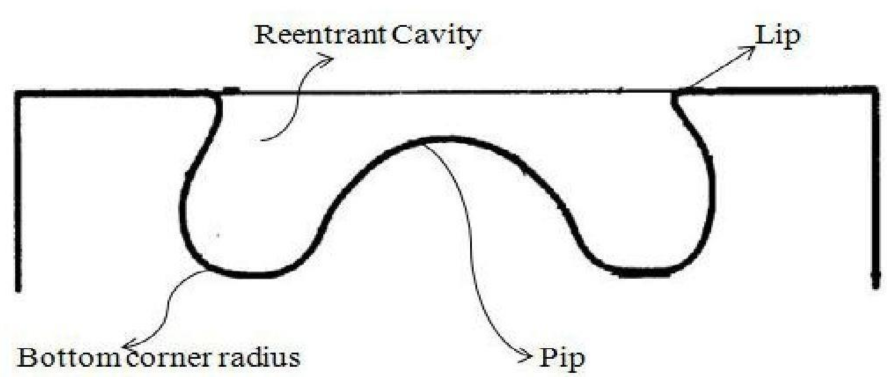


Figure 3.5 Schematic diagram of re-entrant combustion chamber

3.4.2 Indirect Injection Engines

In these engines, the combustion space is divided into two parts. 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. The fuel is injected to the auxiliary chamber, which is connected to the main chamber via a nozzle or one or more number of orifices. The main advantages of the indirect injection combustion chambers are:

(1) Injection pressure required is low.

(2) Direction of spraying is not very important.

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

(1) Poor cold starting performance requiring heater plugs.

(2) Specific fuel consumption is higher.

3.4.2.1 Swirl chamber

A swirl chamber consists of a spherical shaped chamber separated from the engine cylinder and located in the cylinder head. Into this chamber, about 50% of the air is transferred during the compression stroke. A throat connects the chamber to the cylinder which enters the chamber in a tangential direction so that the air coming into this chamber is given a strong rotary movement inside the swirl chamber and after combustion , the products rush back into the cylinder through the same throat at much higher velocity. The schematic diagram of swirl chamber is shown in Figure 3.6.

3.4.2.2 Pre-combustion chamber

A Typical pre-combustion chamber consists of an antichambers connected to the main chamber through a number of small holes. The precombustion chamber is located in the cylinder head and its volume accounts for about 40% of the total combustion space. During the compression stroke the piston forces the air into the precombustion chamber.

The fuel is injected into the prechamber and the combustion is initiated. The resulting pressure rise forces the flaming droplets together with some air and their combustion products to rush out into the main cylinder at high velocity through the small holes. Thus, it creates both strong secondary turbulence and distributes the flaming fuel droplets throughout the air in the main combustion chamber, where the bulk of combustion takes place. Figure 3.7 shows the schematic diagram of pre-combustion chamber.

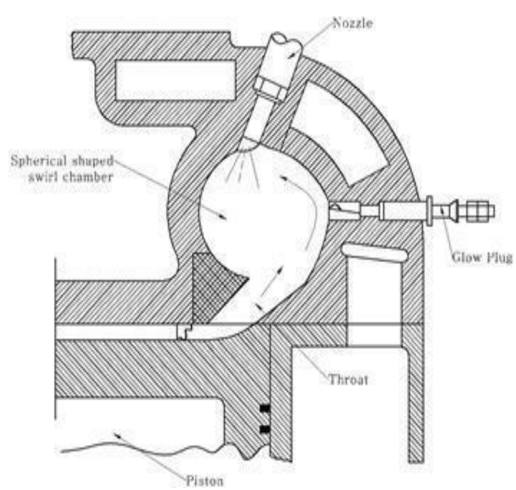


Figure 3.6 Schematic of swirl combustion chamber

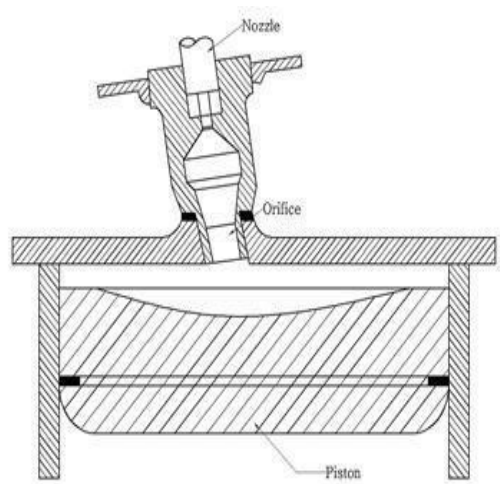
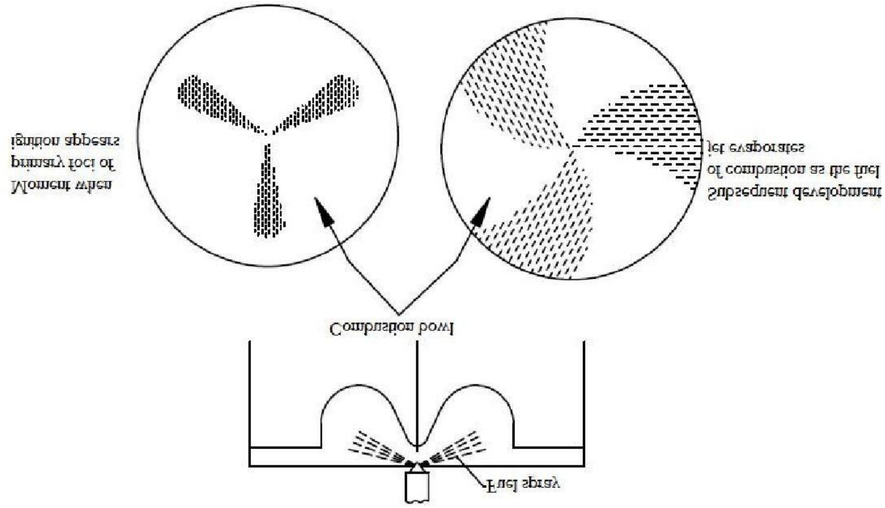


Figure 3.7 Schematic of pre-combustion chamber

3.4.2.3 Air-cell chamber

This chamber is divided into two parts, one in the main cylinder and the other called energy cell. The energy cell is divided into two parts, major and minor, which are separated from each other and from the main chamber by narrow orifices. A pintle type of nozzle injects the fuel across the main combustion chamber space towards the open neck of the air-cell.



3.5 AIR FUEL MIXING

Figure 3.8 shows Fuel sprays, air motion and the development of combustion in a CI engine. In diesel engines air fuel mixing is the important parameter with respect to combustion and pollution formation mechanism.

Figure 3.8 Fuel sprays, air motion, deflection of sprays and development of combustion

The correct movement of air in the chamber will be, for the air to move from one spray to the next spray during the period of injection. It is then that the whole air allocated to each spray will be able to pass through that spray, during the period when the fuel is looking for oxygen. This will reduce the excess air to be supplied and thereby improve thermal efficiency. The speed of air movement decides the number of sprays and vice versa.

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UNIT IV SUPERCHARGING AND TURBOCHARGING

UNIT IV SUPERCHARGING AND TURBOCHARGING

AIRFLOW REQUIREMENTS

- Naturally aspirated engines with throttle bodies rely on atmospheric pressure to push an air–fuel mixture into the combustion chamber vacuum created by the down stroke of a piston.
- The mixture is then compressed before ignition to increase the force of the burning, expanding gases.
- The greater the mixture compression, the greater the power resulting from combustion.

Engineers calculate engine airflow requirements using these three factors:

- Engine displacement
- Engine revolutions per minute (RPM)
- Volumetric efficiency

Volumetric efficiency

- Is a comparison of the actual volume of air–fuel mixture drawn into an engine to the theoretical maximum volume that could be drawn in.
- Volumetric efficiency decreases as engine speed increases.

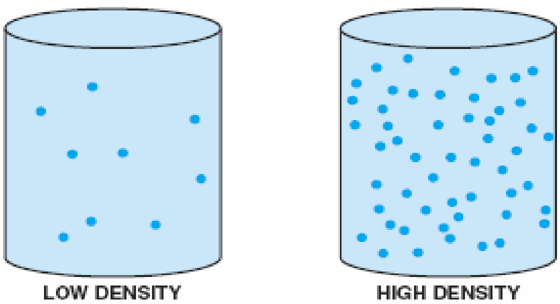
Engine Compression

- Higher compression increases the thermal efficiency of the engine because it raises compression temperatures, resulting in hotter, more complete combustion.

SUPERCHARGING PRINCIPLES

The amount of force an air-fuel charge produces when it is ignited is largely a function of the charge density.

Density is the mass of a substance in a given amount of space.



- The more air and fuel that can be packed in a cylinder, the greater the density of the air–fuel charge.
- An engine that uses atmospheric pressure for intake is called a **naturally (normally) aspirated** engine.

Another way to achieve an increase in mixture compression is called **supercharging.**

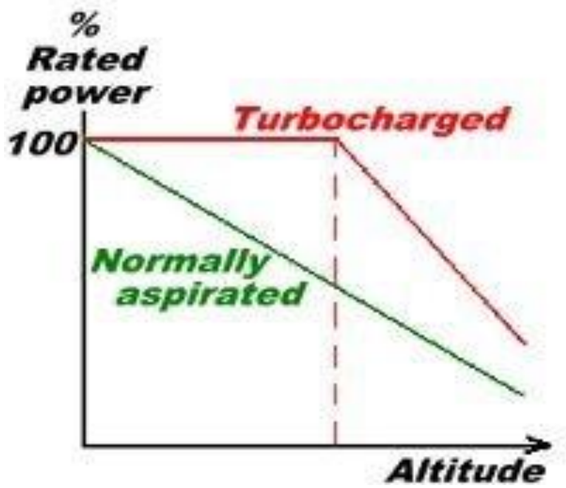
- This method uses a pump to pack a denser air–fuel charge into the cylinders.
- Since the density of the air–fuel charge is greater, so is its weight—and power is directly related to the weight of an air–fuel charge consumed within a given time period.

In addition to the increased power resulting from combustion, there are several other advantages of supercharging an engine including:

It increases the air–fuel charge density to provide high compression pressure when power is required, but allows the engine to run on lower pressures when additional power is not required.

The pumped air pushes the remaining exhaust from the combustion chamber during intake and exhaust valve overlap.

The forced airflow and removal of hot exhaust gases lowers the temperature of the cylinder head, pistons, and valves, and helps extend the life of the engine.

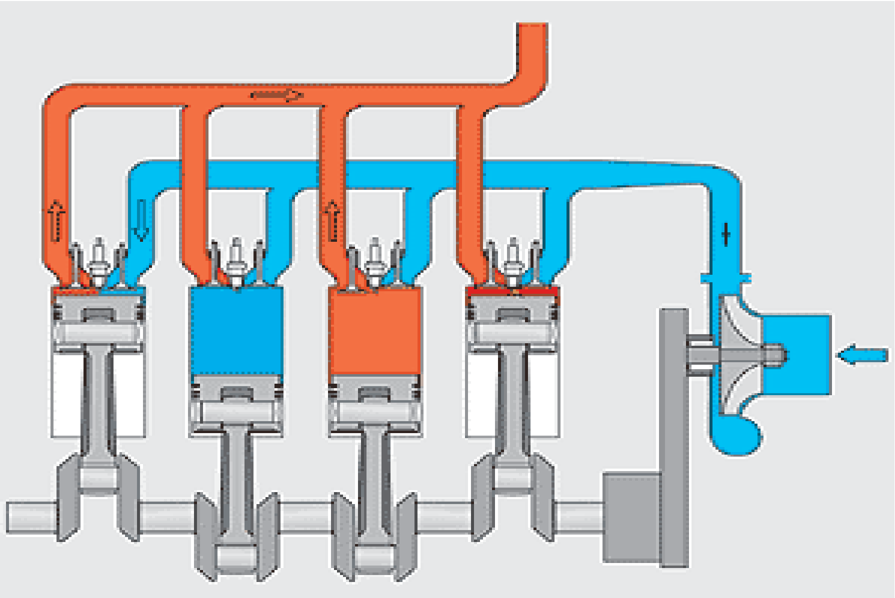


Turbocharging or supercharging is a method of increasing engine volumetric efficiency by forcing the air-fuel mixture into the intake rather than merely allowing the pistons to draw it in naturally.

Supercharging and turbocharging in some cases will push volumetric efficiencies over 100 percent. Engines must be modified to operate properly in some cases, because the extra air-fuel mixture will cause higher compression pressures, resulting in detonation.

SUPERCHARGER

A device used in connection with engine fuel-air systems to supply more air at greater pressure to the engine, thereby increasing volumetric efficiency.



- Usually compress the fuel/air mixture after it leaves the carburetor.
- A supercharger is driven directly from the engine.
- Some of the power created is offset by the power required to drive the supercharger.
- The amount of supercharging done is limited by the temperatures produced to avoid detonation problems.
- Each increase in air/fuel mixture pressure is called a **stage**.
- Single-stage, two-stage, multi-stage.
- Superchargers may also be geared to operate at variable speeds.
- Single-speed, two-speed, variable-speed.
- EX: single-stage, two-speed supercharger.
- Multi-speed superchargers are used to control supercharger output at different altitudes. (higher output for higher altitudes)
- Superchargers are usually built as an integral part of the engine.
- There most common aviation application is on high powered radial engines.
- The air entering the induction system is controlled by the throttle valve.
- The fuel is mixed with air in the carburetor.
- The fuel/air mixture enters the supercharger, where an impeller (centrifugal compressor) compresses the mixture.
- This compressed mixture is fed to the cylinders via the intake manifold.

- A supercharger is an engine-driven air pump that supplies more than the normal amount of air into the intake manifold and boosts engine torque and power.

A supercharger provides an instantaneous increase in power without the delay or lag often associated with turbochargers.

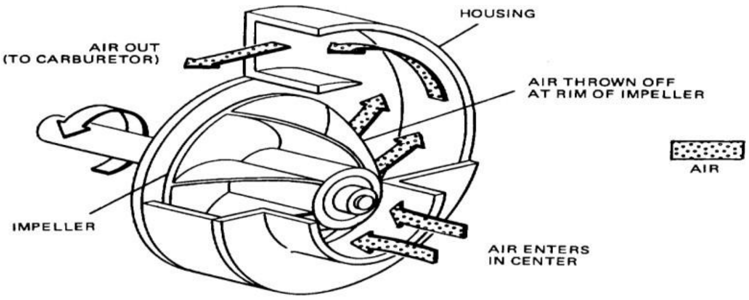
- In basic concept, a supercharger is nothing more than an air pump mechanically driven by the engine itself.

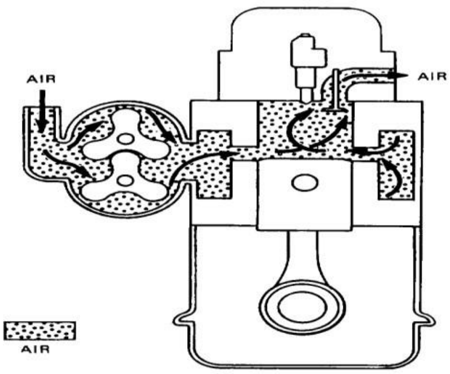
COMPONENTS OF TURBOCHARGER

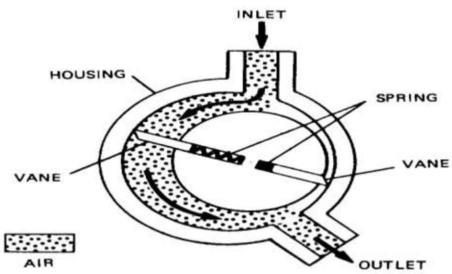
- **Air compressor**
- **Turbine**
- **Intercooler**

TYPES OF SUPERCHARGERS

- Centrifugal Supercharger
- Rootes Supercharger
- Vane Supercharger







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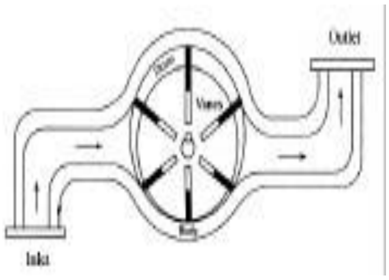
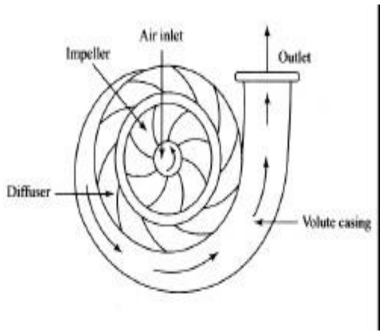


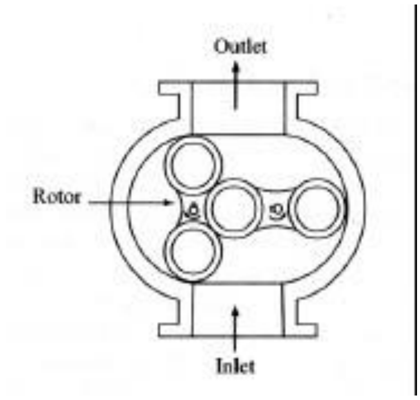
Centrifugal supercharger.

A centrifugal supercharger is similar to a turbocharger but is mechanically driven by the engine instead of being powered by the hot exhaust gases.



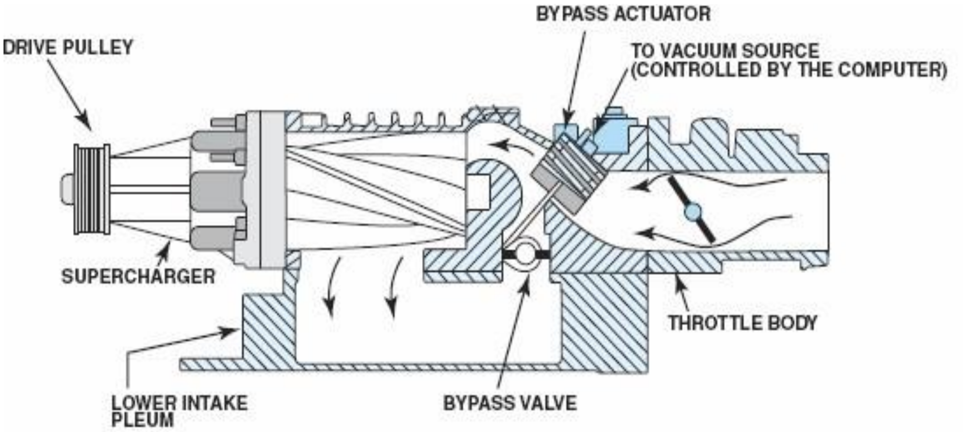
Roots-type supercharger.

- The **roots-type supercharger** is called a **positive displacement** design because all of the air that enters is forced through the unit.
- **A roots-type supercharger uses two lobes to force the air around the outside of the housing into the intake manifold.**



SUPERCHARGERS Supercharger Boost Control

- Many factory-installed superchargers are equipped with a **bypass valve** that allows intake air to flow directly into the intake manifold bypassing the supercharger.
- The computer controls the bypass valve actuator.



- The bypass actuator opens the bypass valve to control boost pressure.

Advantages:

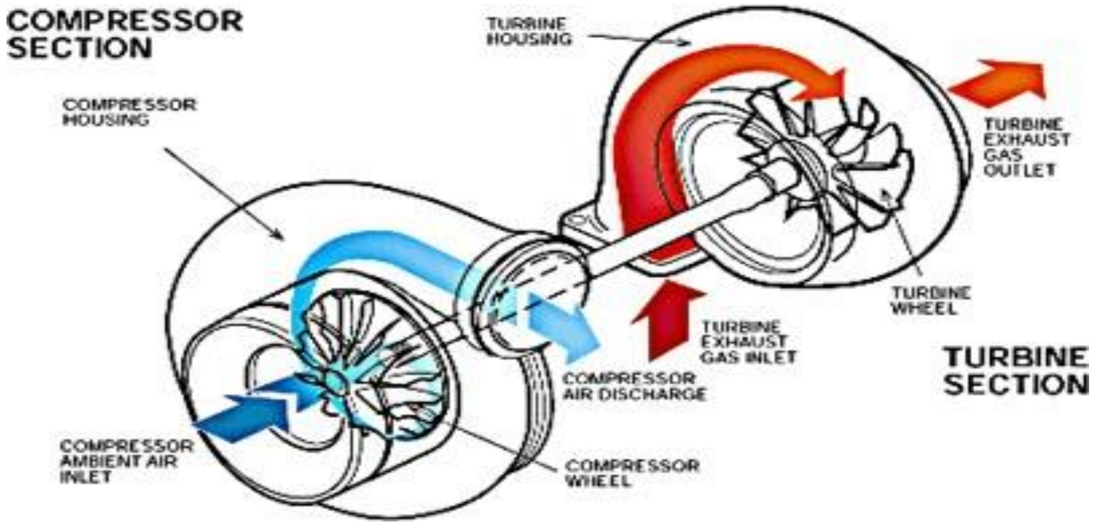
- Improved performance at altitude.
- More power for take-off.

Disdvantages:

- Power gain is offset by power used by engine to drive supercharger.
- Increased temperature of fuel/air mixture increases risk of detonation.

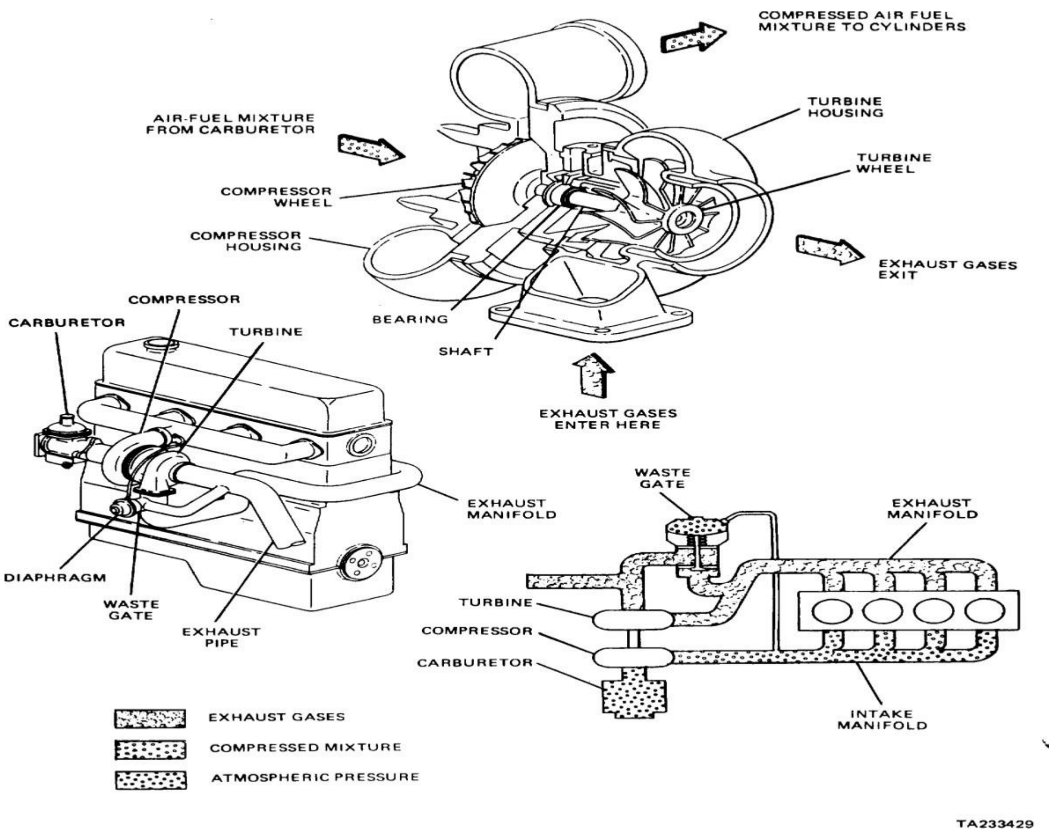
TURBOCHARGER

- An exhaust-driven compressor that forces fuel and air mixture into the engine.
- Turbochargers deliver compressed air to the inlet side of the carburetor or fuel control unit.
- Unlike a supercharger, they are driven by the exhaust gases produced by the combustion process.
- In this way turbochargers harness some of the unused energy contained in the hot exhaust gases.
- A **ground boosted** turbocharged engine will produce MP on the ground higher than ambient pressure in order to achieve its rated power.
- A **turbo-normalized** engine will maintain sea level performance to higher altitudes.
- The turbocharger consists of a compressor assembly, exhaust gas turbine assembly, and a pump and bearing casing.
- The **compressor assembly** is made up of a housing which directs air flow and a compressor wheel (impeller).



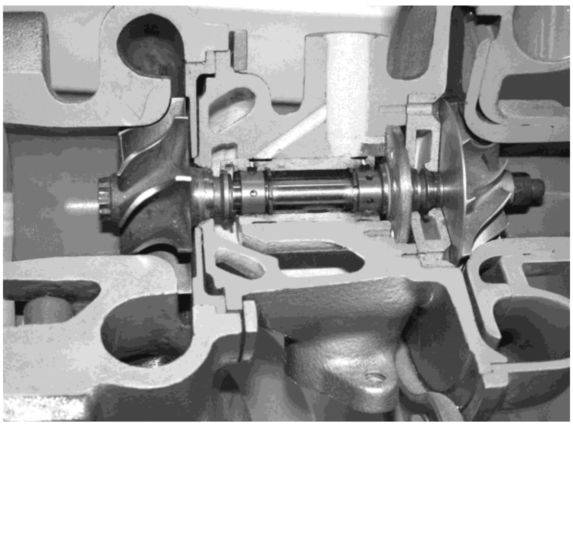
- The **exhaust gas turbine assembly** is made up of a housing which directs exhaust gas flow and a turbine wheel.
- The **center casing** contains a housing which directs cooling oil around the shaft linking the turbine and compressor. The shaft is suspended by bearings which reduce the heat created by friction.
- The impeller/compressor, turbine wheel, and connecting shaft together are called the **rotor**.
- At no time in the process do the exhaust gases come into contact with the compressed air.
- Turbocharger output is controlled by the **wastegate**.

- The major disadvantage of a supercharger is its reliance on engine power to drive the unit.
- By connecting a centrifugal supercharger to a turbine drive wheel and installing it in the exhaust path, the lost engine horsepower is regained to perform other work and the combustion heat energy lost in the engine exhaust (as much as 40% to 50%) can be harnessed to do useful work.
- The turbocharger's main advantage over a mechanically driven supercharger is that the turbocharger does not drain power from the engine.
- In a naturally aspirated engine, about half of the heat energy contained in the fuel goes out the exhaust system.



TURBOCHARGER DESIGN AND OPERATION

- A turbocharger consists of two chambers connected by a center housing.
- The two chambers contain a turbine wheel and a compressor wheel connected by a shaft which passes through the center housing.
- As exhaust gas enters the turbocharger, it rotates the turbine blades.
- The turbine wheel and compressor wheel are on the same shaft so that they turn at the same speed.
  - Rotation of the compressor wheel draws air in through a central inlet and centrifugal force pumps it through an outlet at the edge of the housing.



The exhaust drives the turbine wheel on the left, which is connected to the impeller wheel on the right through a shaft. The bushings that support the shaft are lubricated with engine oil under pressure.

- If properly maintained, the turbocharger also is a trouble-free device.
- However, to prevent problems, the following conditions must be met:
- The turbocharger bearings must be constantly lubricated with clean engine oil—turbocharged engines should have regular oil changes at half the time or mileage intervals specified for nonturbocharged engines.
- Dirt particles and other contamination must be kept out of the intake and exhaust housings.
- Whenever a basic engine bearing (crankshaft or camshaft) has been damaged, the turbocharger must be flushed with clean engine oil after the bearing has been replaced.
- If the turbocharger is damaged, the engine oil must be drained and flushed and the oil filter replaced as part of the repair procedure.

TURBOCHARGER SIZE AND RESPONSE TIME

- A time lag occurs between an increase in engine speed and the increase in the speed of the turbocharger.
- This delay between acceleration and turbo boost is called turbo lag
- To minimize turbo lag, the intake and exhaust breathing capacities of an engine must be matched to the exhaust and intake airflow capabilities of the turbocharger.

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UNIT V DIESEL ENGINE TESTING AND PERFORMANCE

UNIT V - DIESEL ENGINE TESTING & PERFORMANCE

Performance of Diesel Engine

Engine performance is an indication of the degree of success of the engine performs its assigned task, i.e. the conversion of the chemical energy contained in the fuel into the useful mechanical work. The performance of an engine is evaluated on the basis of the following;

(a) Specific Fuel Consumption.
(b) Brake Mean Effective Pressure.
(c) Specific Power Output.
(d) Specific Weight.
(e) Exhaust Smoke and Other Emissions.

Basic measurements:

The basic measurements to be undertaken to evaluate the performance of an engine on almost all tests are the following:

(a) Speed
(b) Fuel consumption
(c) Air consumption
(d) Smoke density
(e) Brake horse-power
(f) Indicated horse power and friction horse power
(g) Heat balance sheet or performance of SI and CI engine
(h) Exhaust gas analysis.

1. Measurement of speed:

One of the basic measurements is that of speed. A wide variety of speed measuring devices are available in the market. They range from a mechanical tachometer to digital and triggered electrical tachometers. The best method of measuring speed is to count the number of revolutions in a given time. This gives an accurate measurement of speed. Many engines are fitted with such revolution counters. A mechanical tachometer or an electrical tachometer can also be used for measuring the speed. The electrical tachometer has a three-phase permanent-magnet alternator to which a voltmeter is attached. The output of the alternator is a linear function of the speed and is directly indicated on the voltmeter dial. Both electrical and mechanical types of tachometers are affected by the temperature variations and are not very accurate. For accurate and continuous measurement of speed a magnetic pick-up placed near a toothed wheel coupled to the engine shaft can be used. The magnetic pick-up will produce a pulse for every revolution and a pulse counter will accurately measure the speed.

2. Fuel consumption measurement:

Fuel consumption is measured in two ways:

(a) The fuel consumption of an engine is measured by determining the volume flow in a given time interval and multiplying it by the specific gravity of the fuel which should be measured occasionally to get an accurate value.
(b) Another method is to measure the time required for consumption of a given mass of fuel.
As already mentioned two basic types of fuel measurement methods are:
-Volumetric type
-Gravimetric type
Volumetric type flow meter includes Burette method, Automatic Burette flow meter and Turbine flow meter.

Gravimetric Fuel Flow Measurement
The efficiency of an engine is related to the kilograms of fuel which are consumed and not the number of litres. The method of measuring volume flow and then correcting it for specific gravity variations is quite inconvenient and inherently limited in accuracy. Instead if the weight of the fuel consumed is directly measured a great improvement in accuracy and cost can be obtained. There are three types of gravimetric type systems which are commercially available include Actual weighing of fuel consumed, Four Orifice Flow meter, etc.

3. Measurement of air consumption:
In IC engines, the satisfactory measurement of air consumption is quite difficult because the flow is pulsating, due to the cyclic nature of the engine and because the air a compressible fluid. Therefore, the simple method of using an orifice in the induction pipe is not satisfactory since the reading will be pulsating and unreliable.
All kinetic flow-inferring systems such as nozzles, orifices and venturies have a square law relationship between flow rate and differential pressure which gives rise to severe errors on unsteady flow. Pulsation produced errors are roughly inversely proportional to the pressure across the orifice for a given set of flow conditions. The various methods and meters used for air flow measurement include,
(a) Air box method, and
(b) Viscous-flow air meter

4. Measurement of brake power:
The brake power measurement involves the determination of the torque and the angular speed of the engine output shaft. The torque measuring device is called a dynamometer.
Dynamometers can be broadly classified into two main types, power absorption dynamometers and transmission dynamometer.

Absorption Dynamometers
These dynamometers measure and absorb the power output of the engine to which they are coupled. The power absorbed is usually dissipated as heat by some means. Example of such dynamometers is prony brake, rope brake, hydraulic dynamometer, etc.

Transmission Dynamometers

In transmission dynamometers, the power is transmitted to the load coupled to the engine after it is indicated on some type of scale. These are also called torque-meters.

(a) Prony brake dynamometer

One of the simplest methods of measuring brake power (output) is to attempt to stop the engine by means of a brake on the flywheel and measure the weight which an arm attached to the brake will support, as it tries to rotate with the flywheel.

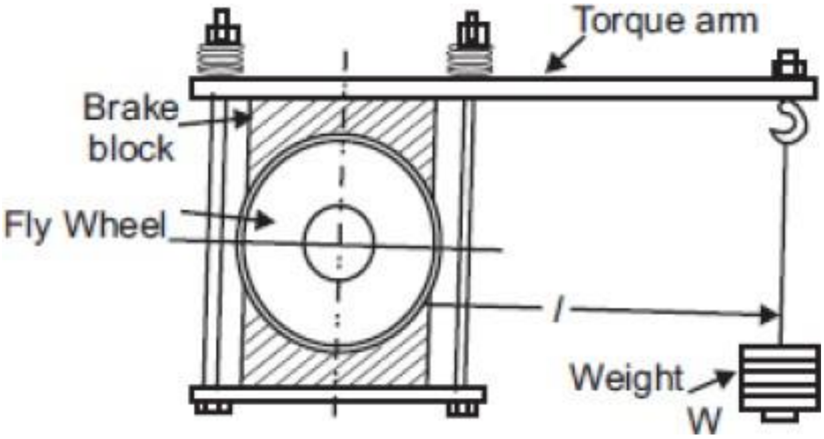
It consists of wooden block mounted on a flexible rope or band the wooden block when pressed into contact with the rotating drum takes the engine torque and the power is dissipated in frictional resistance. Spring-loaded bolts are provided to tighten the wooden block and hence increase the friction.

The whole of the power absorbed is converted into heat and hence this type of dynamometer must the cooled. The brake horsepower is given by

BP = 2p NT

where, $T = W \times l$

W being the weight applied at a radius l.



(b) Rope brake

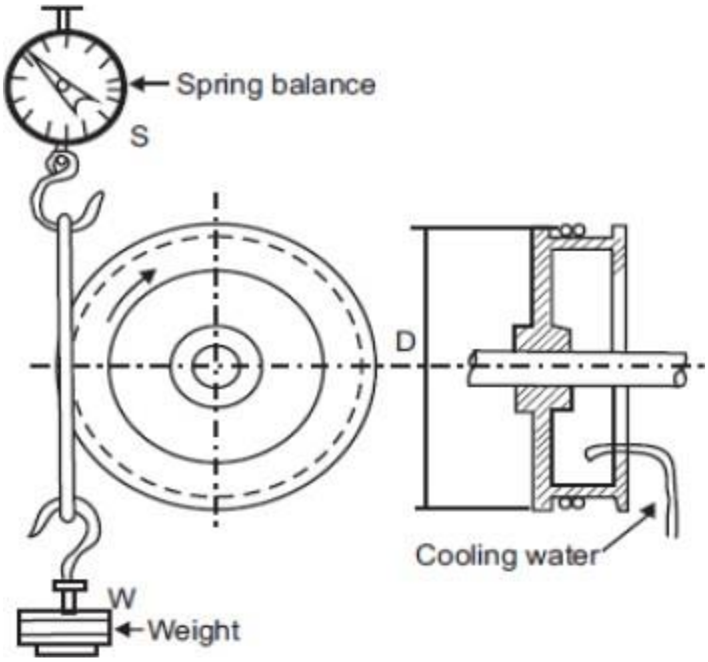
It consists of a number of turns of rope wound around the rotating drum attached to the output shaft. One side of the rope is connected to a spring balance and the other to a loading device. The power is absorbed in friction between the rope and the drum. The drum therefore requires cooling.

Rope brake is cheap and easily constructed but not a very accurate method because of changes in the friction coefficient of the rope with temperature.

The bp is given by

bp = p DN $(W - S)$

where, *D* is the brake drum diameter, *W* is the weight in Newton and *S* is the spring



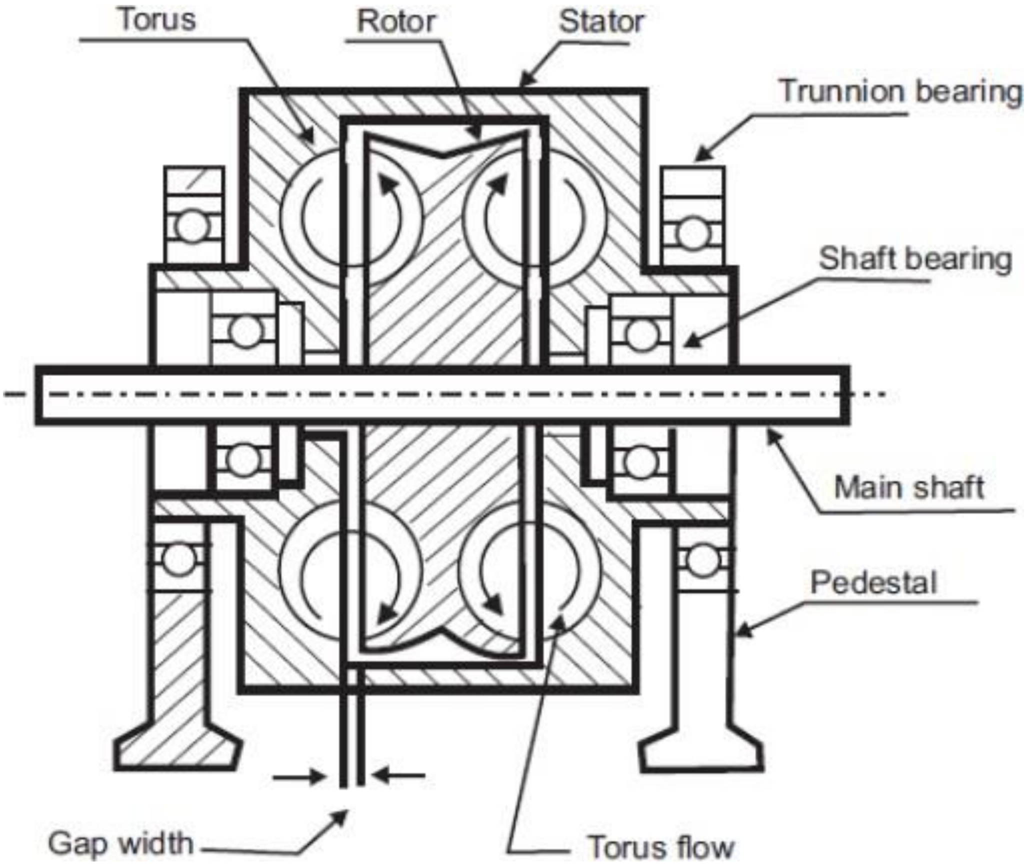
scale reading.

(c) Hydraulic Dynamometer

Hydraulic dynamometer works on the principle of dissipating the power in fluid friction rather than in dry friction.

-In principle its construction is similar to that of a fluid flywheel.

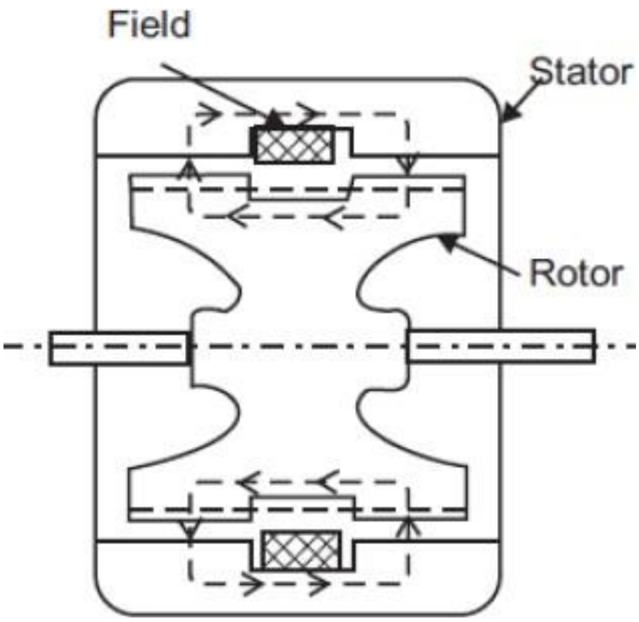
-It consists of an inner rotating member or impeller coupled to the output shaft of the



engine.

-This impeller rotates in a casing filled with fluid.
-This outer casing, due to the centrifugal force developed, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight.

The frictional forces between the impeller and the fluid are measured by the spring-balance fitted on the casing.
-The heat developed due to dissipation of power is carried away by a continuous supply of the working fluid, usually water.
-The output can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between impeller, and the casing.



(d) Eddy Current Dynamometer

It consists of a stator on which are fitted a number of electromagnets and a rotor disc made of copper or steel and coupled to the output shaft of the engine. When the rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents are dissipated in producing heat so that this type of dynamometer also requires some cooling arrangement. The torque is measured exactly as in other types of absorption dynamometers, i.e. with the help of a moment arm. The load is controlled by regulating the current in the electromagnets.

Eddy current dynamometer

The following are the main advantages of eddy current dynamometer:
(a) High brake power per unit weight of dynamometer.
(b) They offer the highest ratio of constant power speed range (up to 5 : 1).
(c) Level of field excitation is below 1% of total power being handled by dynamometer, thus, easy to control and programme.
(d) Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.

(e) Relatively higher torque under low speed conditions.
(f) It has no intricate rotating parts except shaft bearing.
(g) No natural limit to size-either small or large.

(e) Swinging Field d.c. Dynamometer

Basically, a swinging field d.c. dynamometer is a d.c. shunt motor so supported on trunnion bearings to measure their action torque that the outer case and filed coils tend to rotate with the magnetic drag. Hence, the name swinging field. The torque is measured with an arm and weighing equipment in the usual manner.

Many dynamometers are provided with suitable electric connections to run as motor also. Then the dynamometer is reversible, i.e. works as motoring as well as power absorbing device.

-When used as an absorption dynamometer it works as a d.c. generator and converts mechanical energy into electric energy which is dissipated in an external resistor or fed back to the mains.

-When used as a motoring device an external source of d.c. voltage is needed to drive the motor.

The load is controlled by changing the field current.

Fan Dynamometer

It is also an absorption type of dynamometer in that when driven by the engine it absorbs the engine power. Such dynamometers are useful mainly for rough testing and running. The accuracy of the fan dynamometer is very poor. The power absorbed is determined by using previous calibration of the fan brake.

Transmission Dynamometers

Transmission dynamometers, also called torque meters, mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as strain of the strain gauge. Usually, a four arm bridge is used to reduce the effect of temperature to minimum and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauges is avoided. Transmission dynamometers are very accurate and are used where continuous transmission of load is necessary. These are used mainly in automatic units.

5. Measurement of friction power:

-The difference between indicated power and the brake power output of an engine is the friction power.

-Almost invariably, the difference between a good engine and a bad engine is due to difference between their frictional losses.

-The frictional losses are ultimately dissipated to the cooling system (and exhaust) as they appear in the form of frictional heat and this influences the cooling capacity required. Moreover, lower friction means availability of more brake power; hence brake specific fuel consumption is lower.

-The *bsfc* rises with an increase in speed. Thus, the level of friction decides the maximum output of the engine which can be obtained economically.

The friction force power of an engine is determined by the following methods :

(a) Willan‟s line method.

(b) Morse test.

(c) Motoring test.

(d) Difference between *ip* and *bp*.

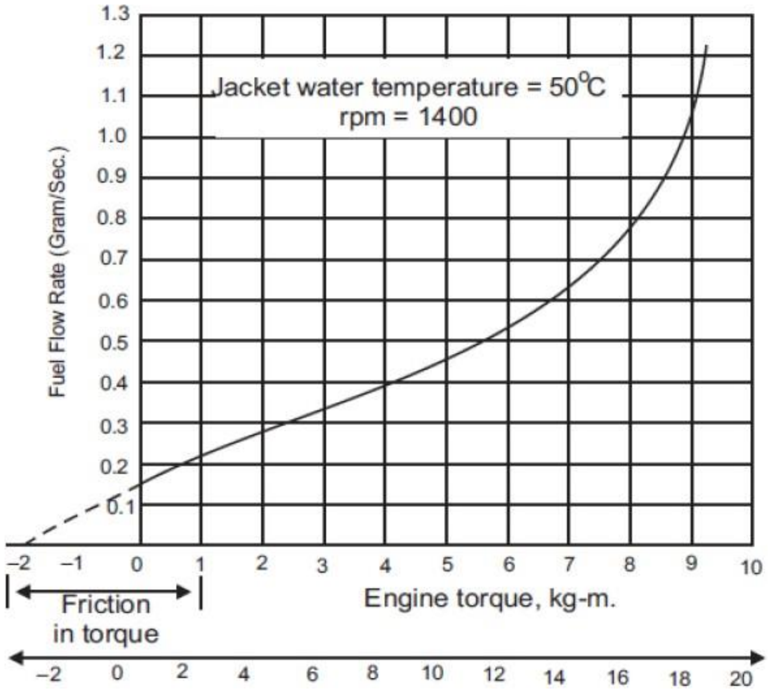
(a) Willan’s line method

-In this method, gross fuel consumption vs. *bp* at a constant speed is plotted and the graph is extrapolated back to zero fuel consumption.

-The point where this graph cuts the *bp* axis is an indication of the friction power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blow by.

-The main drawback of this method is the long distance to be extrapolated from data measured between 5 and 40% load towards the zero line of fuel input.

-The directional margin of error is rather wide because of the graph which may not be a straight line many times.



-The changing slope along the curve indicates part efficiencies of increments of fuel. The pronounced change in the slope of this line near full load reflects the limiting influence of the air-fuel ratio and of the quality of combustion. Similarly, there is a slight curvature at light loads. This is perhaps due to difficulty in injecting accurately and consistently very small quantities of fuel per cycle. Therefore, it is essential that great care should be taken at light loads to establish the true nature of the curve. -The Willan‟s line for a swirl-chamber CI engine is straighter than that for a direct injection type engine. The accuracy obtained in this method is good and compares favourably with other methods if extrapolation is carefully done.

(b) Morse Test

-The Morse test is applicable only to multicylinder engines.

-In this test, the engine is first run at the required speed and the output is measured.

-Then, one cylinder is cut out by short circuiting the spark plug or by disconnecting the injector as the case may be.

-Under this condition all other cylinders „motor" this cut-out cylinder.

-The output is measured by keeping the speed constant at its original value.

-The difference in the outputs is a measure of the indicated horse power of the cut-out cylinder.

-Thus, for each cylinder the *ip* is obtained and is added together to find the total *ip* of the engine.

-This method though gives reasonably accurate results and is liable to errors due to changes in mixture distribution and other conditions by cutting-out one cylinder. In gasoline engines, where there is a common manifold for two or more cylinders the mixture distribution as well as the volumetric efficiency both change. Again, almost all engines have a common exhaust manifold for all cylinders and cutting out of one cylinder may greatly affect the pulsations in exhaust system which may significantly change the engine performance by imposing different back pressures.

(c) Motoring Test

-In the motoring test, the engine is first run up to the desired speed by its own power and allowed to remain at the given speed and load conditions for some time so that oil, water, and engine component temperatures reach stable conditions.

-The power of the engine during this period is absorbed by a swinging field type electric dynamometer, which is most suitable for this test. The fuel supply is then cut-off and by suitable electric-switching devices the dynamometer is converted to run as a motor to drive for „motor" the engine at the same speed at which it was previously running.

-The power supply to the motor is measured which is a measure of the *fhp* of the engine. During the motoring test the water supply is also cut-off so that the actual operating temperatures are maintained.

-This method, though determines the *fp* at temperature conditions very near to the actual operating temperatures at the test speed and load, does, not give the true losses occurring under firing conditions due to the following reasons.

(i) The temperatures in the motored engine are different from those in a firing engine because even if water circulation is stopped the incoming air cools the cylinder. This reduces the lubricating oil temperature and increases friction increasing the oil viscosity. This problem is much more severing in air-cooled engines.

(ii) The pressure on the bearings and piston rings is lower than the firing pressure. Load on main and connecting road bearings are lower.

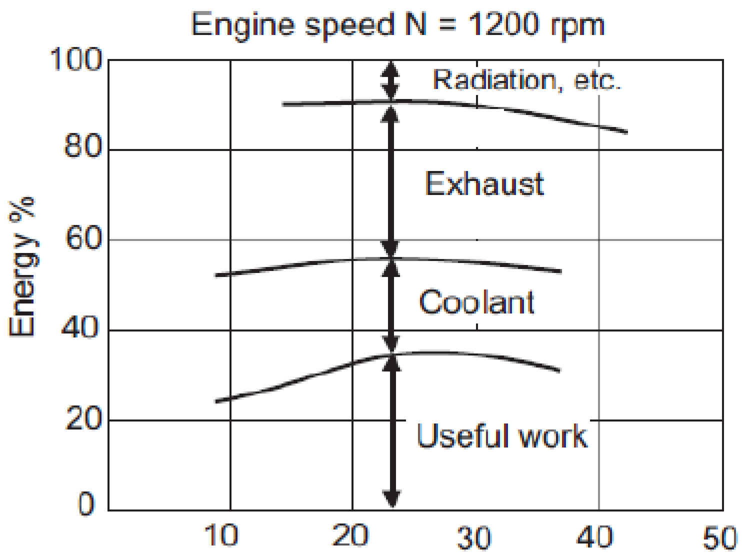
(iii) The clearance between piston and cylinder wall is more (due to cooling). This reduces the piston friction.

(iv) The air is drawn at a temperature less than when the engine is firing because it does not get heat from the cylinder (rather loses heat to the cylinder). This makes

the expansion line to be lower than the compression line on the p-v diagram. This loss is however counted in the indicator diagram.
(v) During exhaust the back pressure is more because under motoring conditions sufficient pressure difference is not available to impart gases the kinetic energy is necessary to expel them from exhaust.
Motoring method, however, gives reasonably good results and is very suitable for finding the losses due to various engine components. This insight into the losses caused by various components and other parameters is obtained by progressive stripping-off of the under progressive dismantling conditions keeping water and oil circulation intact. Then the cylinder head can be removed to evaluate, by difference, the compression loss. In this manner piston ring, piston etc. can be removed and evaluated for their effect on overall friction.

(d)* Difference between *ip* and *bp
(i) The method of finding the *fp* by computing the difference between *ip*, as obtained from an indicator diagram, and *bp*, as obtained by a dynamometer, is the ideal method.
(ii) In obtaining accurate indicator diagrams, especially at high engine speeds, this method is usually only used in research laboratories. Its use at commercial level is very limited.

6. Heat balance sheet:
The performance of an engine is usually studied by heat balance-sheet. The main components of the heat balance are:
-Heat equivalent to the effective (brake) work of the engine,
-Heat rejected to the cooling medium,
-Heat carried away from the engine with the exhaust gases, and
-Unaccounted losses.



The unaccounted losses include the radiation losses from the various parts of the engine and heat lost due to incomplete combustion. The friction loss is not shown as a separate item to the heat balance-sheet as the friction loss ultimately reappears as heat in cooling water, exhaust and radiation.

Method of controlling emissions:

To reduce atmospheric pollution, two different approaches are followed:

1. To reduce the formation of pollutants in the emission by redesigning the engine system, fuel system, cooling system and ignition system.
2. By destroying the pollutants after these have been formed.

In petrol engine, the main pollutants which are objectionable and are to be reduced are HC,

CO and NOx. These methods are

a. Modifications in the engine design.
b. Modifying the fuel used.
c. Exhaust gas treatment devices.
d. Evaporative emissive control devices.

Emission measuring equipment:

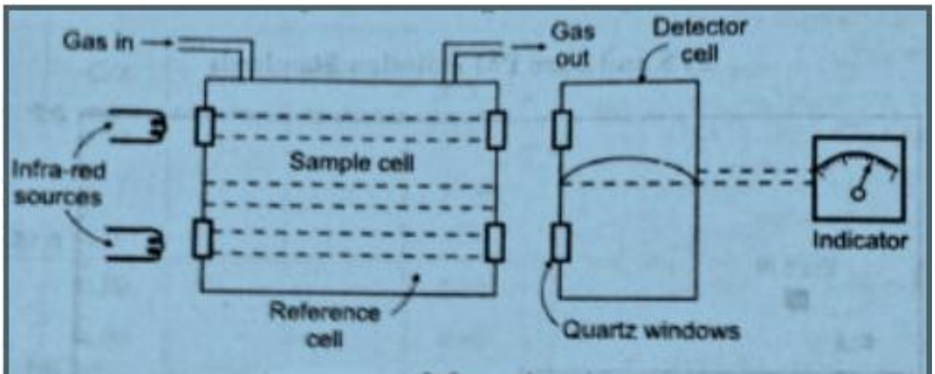
Infra-red Absorption Gas analyser for measuring CO:

Principle:

Infra-red radiation is absorbed by a wide range of gas molecules, each of which has characteristics absorption spectrum. The fraction of radiation (τ_λ) at a particular wavelength λ is given by Beer's law as

$$\tau_\lambda = (e)^{-\rho\alpha_\lambda L}$$

where ρ is gas density and α_λ is the monochromatic absorbity and L is the path length. Fig below shows the arrangement of this analyser. The detector cells are filled with the gas that to be measured (CO of CO_2), so that they absorb the radiation in the wave length band associated with that gas. The energy absorbed in the detector cells causes the cell pressure to rise. The reference cell is present in the sample then infra-red will be absorbed in the sample cell and less infra-red will be absorbed in the detector cell. This cell leads to a differential pressure in the detector cells which can be measured and related to the gas (CO) concentration. The calibration is carried out by passing gasses of known composition through the sample cell.

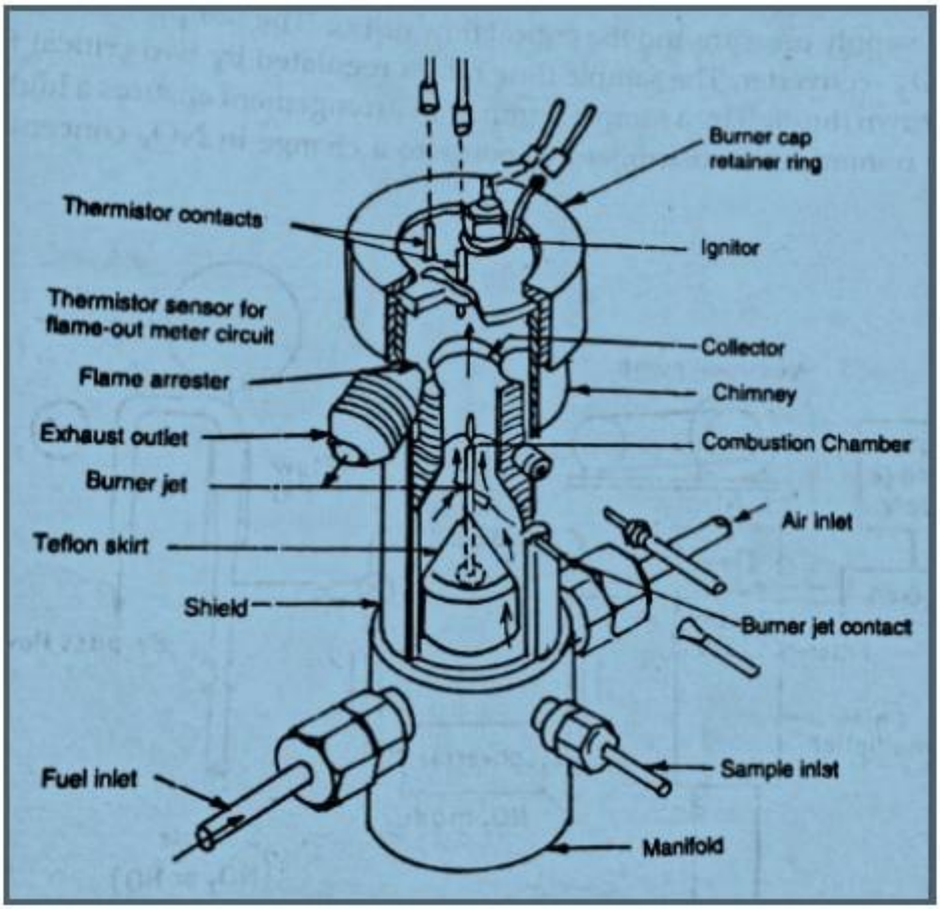


Infra-red analyser.

The below figure shows the absorption spectra of CO and CO2. This shows that, infra-red radiation is absorbed by both in the region of 4.4μ. This means that when CO2 is present in the sample, it will affect the reading of CO and vice versa. This problem is eliminated by using a filter cell between the infra-red sources and the sample and reference cells. If the CO is to be measured, then the filter cell is filled with CO2 and any CO2 in the sample should not lead to any infra-red absorption. The windows of the analyser should be made of such materials (mica or quartz) which are transparent to infra-red radiation.

Flame ionisation detector for measuring HC-emissions:

Principle: When hydro-carbons are burned, electrons and positive ions are formed. If unburned hydrocarbons are burned in the electric field, then the current flow corresponds very closely to the number of carbon atoms present. Flame ionisation detector is shown in figure given below. The sample is mixed with the fuel and burned in air. The fuel should not cause any ionisation so a hydrogen-helium mixture is used. The air should be of high purity for reducing the risk of introducing hydrocarbons. The fuel and sample flows are to be regulated as the response of the instrument is directly proportional to the flow rate of sample as the influences the burner temperature. The flow is regulated by maintaining fixed pressure difference across the device.



The burner jet and annular collector from the electrodes and a potential of about 100V is applied between them. The signals are amplified and calibration is achieved by zeroing instrument with a sample containing pure N2.

Chemiluminescence of measuring NO:

Principle: Chemiluminescence technique depends on the emission of light. NO (nitric oxide) reacts with O3 to produce NO2 in activated NO2 which emits in due course as it converts to normal state (NO2).

NO + O3 > NO2 + O2

NO2 > NO2 + photon

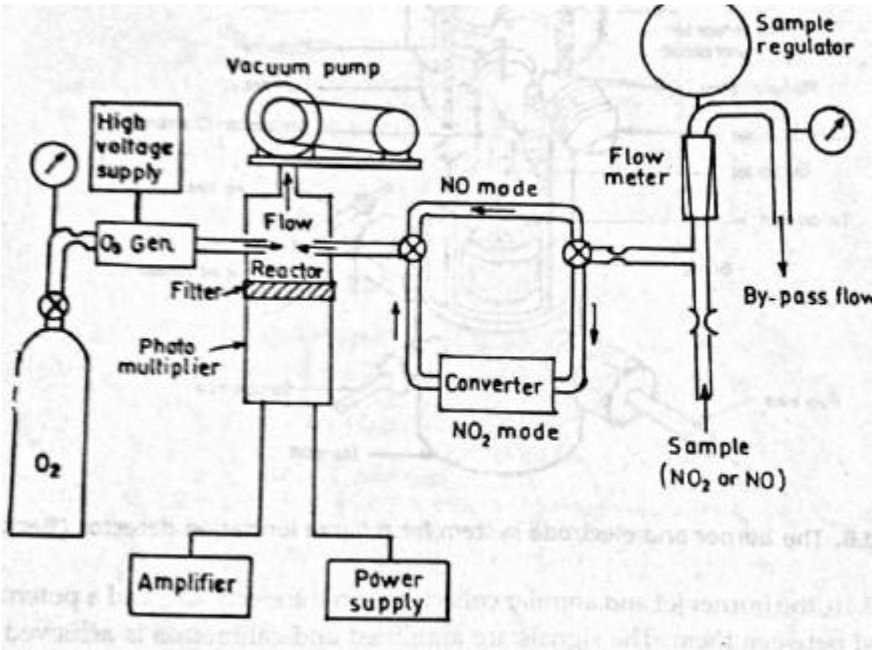
The photon light emitted is proportional to the concentration of NO in the sample stream. Both NO and NO2 exists in the engine exhaust NO2 can be measured by passing the sample over a catalyst that converts

2NO2 > 2NO + O2

By switching the convertor in and out of the sample line the concentration of NO and (NO + NO2) can be measured in the exhaust sample.

The below figure represents the key element of NOx, (NO + NO2) analyser. The vacuum pump controls the pressure in the reaction chamber and responsible for drawing in O3 and exhaust sample. The O3 is generated by an electric discharge in O2 at low pressure and flow of O3 is controlled by O2 supply pressure and the critical flow orifice. The sample can be either by-pass or flow through the NO2-

convertor. The sample flow rate is regulated by two critical flow rate orifices. The bypass flow is drawn through by a sample pump. This arrangement ensures a high flow rate of sample gas, so as to minimise the instrument response to change in NOx concentration in the sample.

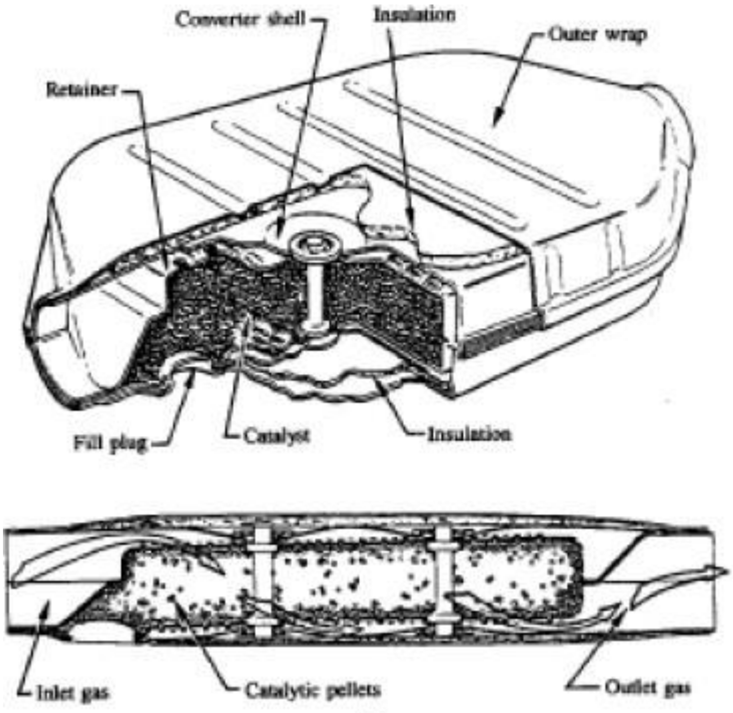


The flow of the sample into the reactor is controlled by the pressure differential across the critical flow orifice upstream of the NOx converter. This pressure differential is controlled by a differential pressure regulator. The light emission in the reactor is measured by a photo multiplier and then amplified.

Catalytic convertor:

The catalytic converters used in spark-ignition engines consist of an active catalytic material in a specially designed metal casing which directs the exhaust gas flow through the catalyst bed. The active material employed for CO and HC oxidation or NO reduction (normally noble metals, though base metals oxides can be used) must be distributed over a large surface area so that the mass transfer characteristics between the gas phase and the active catalyst surface are sufficient to allow close to 100 percent conversion with high catalytic activity. The two configurations commonly used are shown in Fig

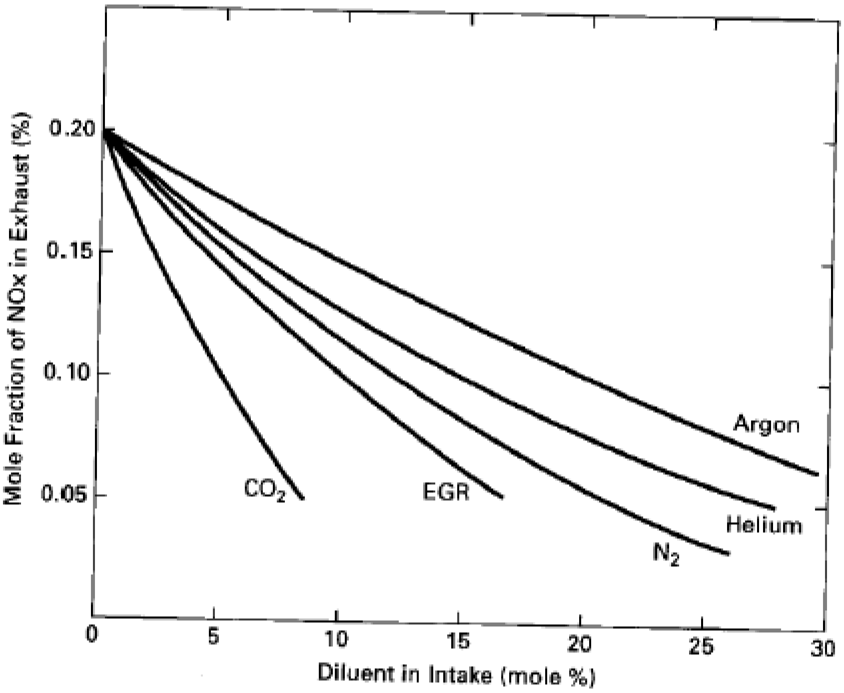
system employs a ceramic honeycomb structure or monolith held in a metal can in the exhaust stream. The active (noble metal) catalyst material is impregnated into a highly porous alumina wash coat about 20 pm thick that is applied to the passage way walls. The typical monolith has square-cross-section passageways with inside dimensions of 1 mm separated by thin (0.15 to 0.3 **mm)** porous walls. The number of passageways per square centimetre varies between about 30 and60. The wash coat, 5 to 15 percent of the weight of the monolith, has a surface area of 100 to 200 m2/g. The other converter design uses a bed of spherical ceramic pellets to provide a large surface area in contact with the flow. With pellet catalysts, the noble metal catalyst is impregnated into the highly porous surface of the spherical alumina pellets (typically 3 mm diameter) to a depth of about 250 pm. The pellet material is chosen to have good crush and abrasion resistance after exposure to temperatures of order 1000•C. The gas flow is directed down through the bed as shown to provide a large flow area and low pressure drop. The gas flow is turbulent which results in high mass transfer rates in the monolith catalyst passageways, it is laminar.



(b)

EXHAUST GAS RECYCLE-EGR

The most effective way of reducing NOx emissions is to hold combustion chamber temperatures down. Although practical, this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. We have been taught since infancy in our first thermodynamics course that for maximum engine thermal efficiency, Qin should be at the highest temperature possible. Probably the simplest practical method of reducing maximum flame temperature is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input. The net result is a lower flame temperature. Any non-reacting gas would work as a diluent, as shown in Fig. Those gases with larger specific heats would absorb the most energy per unit mass and would therefore require the least amount; thus less C02 would be required than argon for the same maximum temperature. However, neither C02 nor argon is readily available for use in an engine. Air is available as a diluent but is not totally non-reacting. Adding air changes the AF and combustion characteristics.



Exhaust gas recycle (EGR) is done by ducting some of the exhaust flow back into the intake system, usually immediately after the throttle. The amount of flow can be as high as 30% of the total intake. EGR gas combines with the exhaust residual left in the cylinder from the previous cycle to effectively reduce the maximum combustion temperature. Not only does EGR reduce the maximum temperature in the combustion chamber, but it also lowers the overall combustion efficiency. Above Fig shows that as EGR are increased, the percent of inefficient *slow-burn* cycles increases. Further increase in EGR results in some cycle *partial burns* and, in the extreme, total misfires. Thus, by using EGR to reduce NOx emissions, a costly price of increased HC emissions and lower thermal efficiency must be paid. The amount of EGR is controlled by the EMS. By sensing inlet and exhaust conditions the flow is controlled, ranging from 0 up to 15-30%. Lowest NOx emissions with relatively good fuel economy occur at about stoichiometric combustion, with as much EGR as possible without adversely affecting combustion. No EGR is used during WOT, when maximum power is desired. No EGR is used at idle and very little at low speeds. Under these conditions, there is already maximum exhaust residual and greater combustion inefficiency. Engines with fast-burn combustion chambers can tolerate a greater amount of EGR. A problem unique to CI engines when using EGR is the solid carbon soot in the exhaust. The soot acts as an abrasive and breaks down the lubricant. Greater wear on the piston rings and valve train results.

The performance of the diesel engine focuses on the power and efficiency. The engine varies with parameters of the engine like piston speed, air-fuel ratio, compression ratio inlet air-pressure and temperature. The two usual conditions under which I.C. engines are operated are :

(a) constant speed with variable load, and
(b) variable speed with variable load.

The first situation is found in a.c. generator drives and the second one in automobiles, railway engines and tractors etc. A series of tests are carried out on the engine to determine its performance characteristics, such as : indicated power (I.P.), Brake power (B.P.), Frictional Power (F.P.), Mechanical efficiency (ηm), thermal efficiency, fuel consumption and also specific fuel consumption etc. The measurement of these quantities is discussed below.

Indicated Mean Effective Pressure (IMRP)

In order to determine the power developed by the engine, the indicator diagram of engine should be available. From the area of indicator diagram it is possible to find an average gas pressure which, while acting on piston throughout one stroke, would account for the network done. This pressure is called indicated mean effective pressure (IMEP).

Indicated Horse Power (IHP)

The indicated horse power (IHP) of the engine can be calculated as follows

$$IHP = \frac{P_m \ LANn}{4500 \times k}$$

Pm = IMEP, kg/cm2,
L = Length of stroke, metres,
A = Piston areas, cm2,
N = Speed, RPM,
n = Number of cylinders, and
k = 1 for two stroke engine
= 2 for four stroke engine.

Brake Horse Power (BHP)

Brake horse power is defined as the net power available at the crankshaft. It is found by measuring the output torque with a dynamometer.

$$BHP = \frac{2\pi \ NT}{4500}$$

Frictional Horse Power (FHP)

The difference of IHP and BHP is called FHP. It is utilized in overcoming frictional resistance of rotating and sliding parts of the engine.

FHP = IHP – BHP

Indicated Thermal Efficiency (ηi)

It is defined as the ratio of indicated work to thermal input.

$$\eta_i = \frac{IHP \times 4500}{(W \times C_v \times J)}$$

W = Weight of fuel supplied, kg per minute,
Cv = Calorific value of fuel oil, kcal/kg, and
J = Joules equivalent = 427.

Brake Thermal Efficiency (Overall Efficiency)

It is defined as the ratio of brake output to thermal input.

$$\eta_b = \frac{BHP \times 4500}{(W \times C_v \times J)}$$

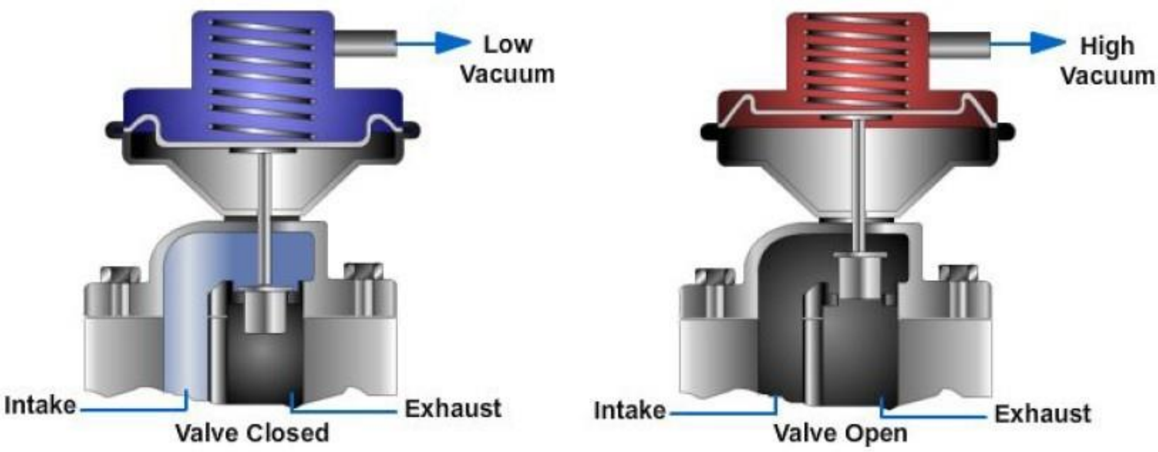
Mechanical Efficiency (η*m*)

It is defined as the ratio of BHP to IHP. Therefore,

$$\eta_i = \frac{BHP}{IHP}$$

Exhaust Gas Recirculation (EGR) System

The exhaust gas recirculation system allows burned gases to enter the engine intake manifold to help reduce oxides of nitrogen (NOx) emissions. When exhaust gases are added to the air-fuel mixture, they decrease peak combustion temperatures (maximum temperature produced when the air-fuel mixture burns). For this reason, an exhaust gas recirculation system lowers the amount of NOx in the engine exhaust. EGR systems can be controlled by engine vacuum or by the engine control module. Vacuum controlled EGR systems use engine vacuum to operate the EGR valve This system is found on older vehicles. The basic vacuum EGR system consists of a vacuum-operated EGR valve and a vacuum line from the throttle body or carburetor. The EGR valve is bolted to the engine intake manifold to control the air-fuel ratio and reduce exhaust emissions. Exhaust gases are routed through the cylinder head and intake manifold to the EGR valve. The EGR valve consists of a vacuum diaphragm, spring, plunger, exhaust gas valve, and diaphragm housing. It is designed to control exhaust flow into the intake when the throttle is opened and the increased vacuum pulls the diaphragm open on the EGR valve, in turn opening the exhaust outlet to allow exhaust gas into the intake manifold. An electronic-vacuum EGR valve uses both engine vacuum and electronic control for better exhaust gas metering. An EGR position sensor is located on top of the EGR valve. This sensor sends data to the ECM and allows the computer to determine how far to open the EGR valve. Electronic EGR systems use vehicle sensors, the ECM, and a solenoid-operated EGR valve. This is the most common type of EGR system used on late model engines. The ECM uses data from the EGR position sensor, engine coolant temperature sensor, mass airflow sensor, throttle position sensor, crankshaft position sensor, and various other sensors to control the air fuel ratio and reduce exhaust emission. The data collected will determine the duty cycle for the EGR valve to allow certain amounts of gases to be recirculated for maximum efficiency.



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