AT6012 ENGINE AUXILLARY SYSTEMS

UNIT I CARBURETION 9

Properties of air-petrol mixtures, Air fuel ratio requirements or SI Engines working of a simple fixed venturi and constant vacuum carburetor, design of elementary carburetor, Chokes, Effects of altitude on carburetion, Carburetor for 2–stroke and 4-stroke engines, carburetor systems for emission control.

UNIT II GASOLINE INJECTION AND IGNITION SYSTEMS 9

Petrol Injection, Pneumatic and Electronic Fuel Injection Systems types. Ignition system requirements, Timing, Ignition Systems, breaker mechanism and spark plugs, Factors affecting energy requirement of the ignition system, factors affecting spark plug operation, Electronic Ignition
Systems.

UNIT III DIESEL FUEL INJECTION 9

Factors influencing fuel spray atomization, penetration and dispersion of diesel and heavy oils and their properties, rate and duration of injection, fuel line hydraulics, fuel pump, injectors, CRDI systems and its merits and demerits.

UNIT IV MANIFOLDS AND MIXTURE DISTRIBUTION 9

Intake system components, Discharge coefficient, Pressure drop, Air filter, Intake manifold, Connecting pipe, Exhaust system components, Exhaust manifold and exhaust pipe, Spark arresters, Waste heat recovery, Exhaust mufflers, Type of mufflers, exhaust manifold expansion.

UNIT V LUBRICATION AND COOOLING SYSTEMS 9

Lubricants, lubricating systems, Lubrication of piston rings, bearings, oil consumption, Oil cooling. Heat transfer coefficients, liquid and air cooled engines, coolants, additives and lubricity improvers, concept of adiabatic engines.

OUTCOMES:

TOTAL: 45 PERIODS

UNIT-I

CARBURETION

1.1Introduction

Spark-ignition engines normally use volatile liquid fuels. Preparation of fuel-air mixture is done outside the engine cylinder and formation of a homogeneous mixture is normally not completed in the inlet manifold. Fuel droplets, which remain in suspension, continue to evaporate and mix with air even during suction and compression processes. The process of mixture preparation is extremely important for spark-ignition engines. The purpose of carburetion is to provide a combustible mixture of fuel and air in the required quantity and quality for efficient operation of the engine under all conditions.

1.2 Definition of Carburetion

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called a carburetor.

1.3 Factors Affecting Carburetion

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

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

1.4 Principle of Carburetion

Both air and gasoline are drawn through the carburetor and into the engine cylinders by the suction created by the downward movement of the piston. This suction is due to an increase in the volume of the cylinder and a consequent decrease in the gas pressure in this chamber. It is the difference in pressure between the atmosphere and cylinder that causes the air to flow into the chamber. In the carburetor, air passing into the combustion chamber picks up discharged from a tube. This tube has a fine orifice called carburetor jet that is exposed to the air path. The rate at which fuel is discharged into the air depends on the pressure difference or pressure head between the float chamber and the throat of the venturi and on the area of the outlet of the tube. In order that the fuel drawn from the nozzle may be thoroughly atomized, the suction effect must be strong and the nozzle outlet comparatively small. In order to produce a strong suction, the pipe in the carburetor carrying air to the engine is made to have a restriction. At this restriction called throat due to increase in velocity of flow, a suction effect is created. The restriction is made in the form of a venturi to minimize throttling losses. The end of the fuel jet is located at the venturi or throat of the carburetor. The geometry of venturi tube is as shown in Fig.16.6. It has a narrower path at the center so that the flow area through which the air must pass is considerably reduced. As the same amount of air must pass through every point in thetube, its velocity will be greatest at the narrowest point. The smaller the area, the greater will be the velocity of the air, and thereby the suction is proportionately increased

As mentioned earlier, the opening of the fuel discharge jet is usually loped where the suction is maximum. Normally, this is just below the narrowest section of the venturi tube. The spray of gasoline from the nozzle and the air entering through the venturi tube are mixed together in this region and a combustible mixture is formed which passes through the intake manifold into the cylinders. Most of the fuel gets atomized and simultaneously a small part will be vaporized. Increased air velocity at the throat of the venturi helps he rate of evaporation of fuel. The difficulty of obtaining a mixture of sufficiently high fuel vapour-air ratio for efficient starting of the engine and for uniform fuel-air ratio indifferent cylinders (in case of multi cylinder engine) cannot be fully met by the increased air velocity alone at the venturi throat.

1.5 The Simple Carburetor

Carburetors are highly complex. Let us first understand the working principle Of a simple or elementary carburetor that provides an air fuel mixture for cruising or normal range at a single speed. Later, other mechanisms to provide for the various special requirements like starting, idling, variable load and speed operation and acceleration will be included. Figure 1. shows the details of a simple carburetor.

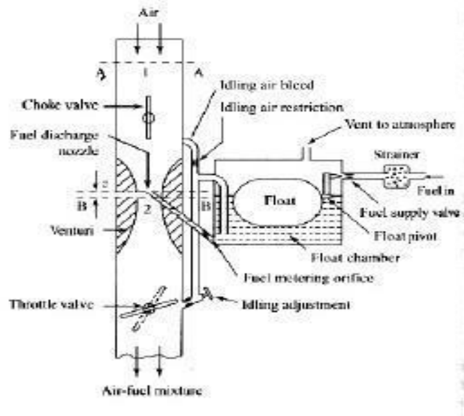

Figure: 1 The Simple Carburetor

The simple carburetor mainly consists of a float chamber, fuel discharge nozzle and a metering orifice, a venturi, a throttle valve and a choke. The float and a needle valve system maintain a constant level of gasoline in the float chamber. If the amount of fuelthe floats chamber falls below the designed level, the float goes down, thereby opening the fuel supply valve and admitting fuel. When the designed level has been reached, the float closes the fuel supply valve thus stopping additional fuel flow from the supply system. Float chamber is vented either to the atmosphere or to the" upstream side of the venturi. During suction stroke air is drawn through the venturi.

As already described, venturi is a tube of decreasing cross-section with a minimum area at the throat, Venturi tube is also known as the choke tube and is so shaped that it offers minimum resistance to the air flow. As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum. From the float chamber, the fuel is fed to a discharge jet, the tip of which is located in the throat of the venturi. Because of the differential pressure between the float chamber and the throat of the venturi, know n as carburetor depression, fuel is discharged into the air stream. The fuel discharge is affected by the size of the discharge jet and it is chosen to give the required air- fuel ratio. The pressure at the throat at the fully open throttle condition lies between 4 to 5 cm of Hg, below atmospheric and seldom exceeds8 cm Hg below atmospheric. To avoid overflow of fuel through the jet, the level of the liquid in the float chamber is maintained at a level slightly below the tip of the discharge jet. This is called the tip of the nozzle. The difference in the height between the top of the nozzle and the float chamber level is marked "h" in Fig.1.

The gasoline engine is quantity governed, which means that when power output is to be varied at a particular speed, the amount of charge delivered to the cylinder is varied. This is achieved by means of a throttle valve usually of the butterfly type that is situated after the venturi tube. As the throttle is closed less air flows through the venturi tube and less is the quantity of air- fuel mixture delivered to the cylinder and hence power output is reduced. As the" throttle is opened, more air flows through the choke tube resulting in increased quantity of mixture being delivered to the engine. This increases the engine power output. A simple carburetor of the type described above suffers from a fundamental drawback in that it provides the required A/F ratio only at one throttle position. At the other throttle positions the mixture is either leaner or richer depending on whether the throttle is opened less or more. As the throttle opening is varied, the air flow varies and creates a certain pressure differential between the float chamber and the venturi throat. The same pressure differential regulates the flow of fuel through the nozzle. Therefore, the velocity of flow of air II and fuel vary in a similar manner. At the same time, the density I of air decrease as the pressure at the venturi throat decrease with increasing air flow whereas that of the fuel remains unchanged. This results in a simple carburetor producing a progressively rich mixture with increasing throttle opening.

1.6 The Choke and the Throttle

When the vehicle is kept stationary for a long period during cool winter seasons, may be overnight, starting becomes more difficult. *As* already explained, at low cranking speeds and intake temperatures a very rich mixture is required to initiate combustion. Some times air-fuel ratio as rich as 9:1 is required. The main reason is that very large fraction of the fuel may remain as liquid suspended in air even in the cylinder. For initiating combustion, fuel-vapour and air in the form of mixture at a ratio that can sustain combustion is required. It may be noted that at very low temperature vapour fraction of the fuel is also very small and this forms combustible mixture to initiate combustion. Hence, a very rich mixture must be supplied. The most popular method of providing such mixture is by the use of choke valve. This is simple butterfly valve located between the entrance to the carburetor and the venturi throat as shown in Fig.1.

When the choke is partly closed, large pressure drop occurs at the venturi throat that would normally result from the quantity of air passing through the venturi throat. The very large depression at the throat inducts large amount of fuel from the main nozzle and provides a very rich mixture so that the ratio of the evaporated fuel to air in the cylinder is within the combustible limits. Sometimes, the choke valves are spring loaded to ensure that large carburetor depression and excessive choking does not persist after the engine has started, and reached a desired speed. This choke can be made to operate automatically by means of a thermostat so that the choke is closed when engine is cold and goes out of operation when engine warms up after starting. The speed and the output of an engine is controlled by the use of the throttle valve, which is located on the downstream side of the venturi.

The more the throttle is closed the greater is the obstruction to the flow *of* the mixture placed in the passage and the less is the quantity *of* mixture delivered to .the cylinders. The decreased quantity *of* mixture gives a less powerful impulse to the pistons and the output *of* the engine is reduced accordingly. As the throttle is opened, the output *of* the engine increases. Opening the throttle usually increases the speed *of* the engine. But this is not always the case as the load on the engine is also a factor. For example, opening the throttle when the motor vehicle is starting to climb a hill may or may not increase the vehicle speed, depending upon the steepness *of* the hill and the extent *of* throttle opening. In short, the throttle is simply a means to regulate the output *of* the engine by varying the quantity *of* charge going into the cylinder.

1.7 Compensating Devices

An automobile on road has to run on different loads and speeds. The road conditions play a vital role. Especially on city roads, one may be able to operate the vehicle between 25 to 60% of the throttle only. During such conditions the carburetor must be able to supply nearly constant air-fuel ratio mixture that is economical (16:1).However, the tendency of a simple carburetor is to progressively richen the mixture as the throttle starts opening. The main metering system alone will not be sufficient to take care of the needs of the engine. Therefore, certain compensating devices are usually added in the carburetor along with the main metering system so as to supply a mixture with the required air-fuel ratio. A number of compensating devices are in use. The important ones are

i. Air-bleed jet
ii. Compensating jet
iii. Emulsion tube
iv. Back suction control mechanism
v. Auxiliary air valve
vi. Auxiliary air port

As already mentioned, in modern carburetors automatic compensating devices are provided to maintain the desired mixture proportions at the higher speeds. The type of compensation mechanism used determines the metering system of the carburetor. The principle of operation of various compensating devices are discussed briefly in the following sections.

1.7.1 Air-bleed jet

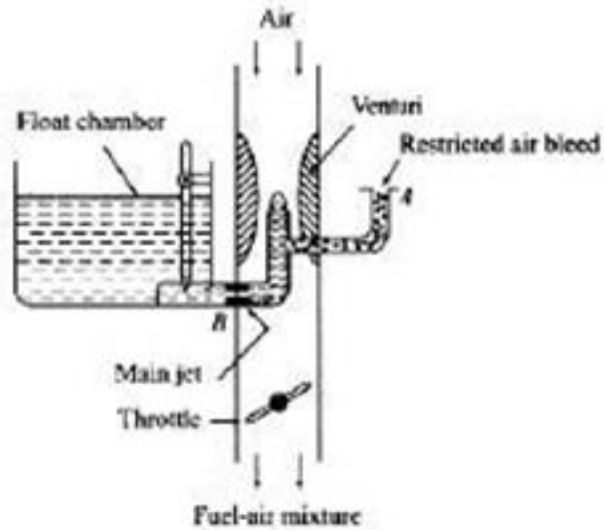

Figure: 2 Air bleed principle in a typical carburetor

Figure 2. Illustrates the principle of an air-bleed system in a typical modern downdraught carburetor. As could be seen it contains an air-bleed into the main nozzle. An orifice restricts the flow of air through this bleed and therefore it is called restricted air-bleed jet that is very popular. When the engine is not operating the main jet and the air bleed jet will be filled with fuel. When the engine starts, initially the fuel starts coming through the main as well as the air bleed jet (A). As the engine picks up, only air starts coming through the air bleed and mixes with fuel at B making a air fuel emulsion. Thus the fluid stream that has become an emulsion of air and liquid has negligible viscosity and surface tension. Thus the flow rate of fuel is augmented and more fuel is sucked at low suctions. 'By proper design of hole size at B compatible with the entry hole at A, it is possible to maintain a fairly uniform mixture ratio for the entire power range of the operation of an engine. If the fuel flow nozzle of the air-bleed system is placed in the centre of the venturi, both the air-bleed nozzle and the venturi are subjected to same engine suction resulting approximately same fuel-air mixture for the entire power range of operation.

1.7.2 Compensating Jet

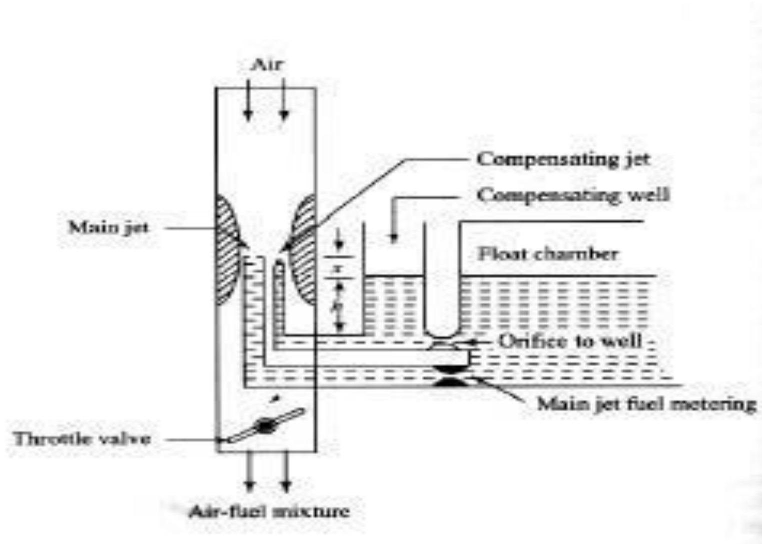

Figure: 3 Compensating Jet device

The principle of compensating jet device is to make the mixture leaner as the throttle opens progressively. In this method, as can be seen from Fig.5 in addition to the main jet, a compensating jet is incorporated. The compensating jet is connected to the compensation well. The compensating well is also vented to atmosphere like the main float chamber. The compensating well is supplied with fuel from the main float chamber through a restricting orifice. With the increase in airflow rate, there is decrease of fuel level in the compensating well, with the result that fuel supply through the compensating jet decreases. The compensating jet thus progressively makes the mixture leaner as the main jet progressively makes the mixture richer. The main jet curve and the compensating jet curve are more or less reciprocals of each other.

1.7.3 Emulsion Tube

The mixture correction is attempted by air bleeding in modern carburetor. In one such arrangement as shown in Fig.6, the main metering jet is kept at a level of about 25 mm below the fuel level in the float chamber. Therefore, it is also called submerged jet. The jet is located at the bottom of a well. The sides of the well have holes. As can be seen from the figure these holes are in communication with the atmosphere. In the beginning the level of petrol in the float chamber and the well is the same. When the throttle is opened the pressure at the venturi throat decreases and petrol is drawn into the air stream. This results in progressively uncovering the

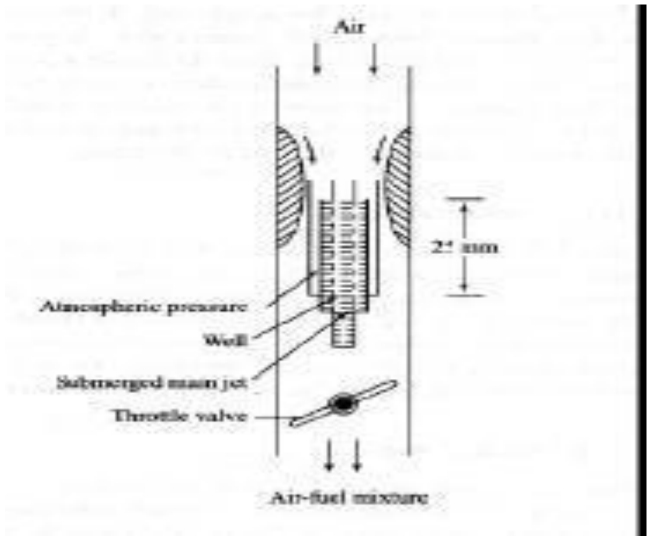

Figure: 4 Emulsion Tube

holes in the central tube leading to increasing air-fuel ratios or decreasing richness of mixture when all holes have been uncovered. Normal flow takes place from the main jet. The air is drawn through these holes in the well, and the fuel is emulsified and the pressure differential across the column of fuel is not as high as that in simple carburetor.

1.7.4 Acceleration Pump System

Acceleration is a transient phenomenon. In order to accelerate the vehicle and consequently its engine, the mixture required is very rich and the richness of the mixture has to be obtained quickly and very rapidly. In automobile engines situations arise when it is necessary to accelerate the vehicle. This requires an increased output from the engine in a very short time. If the throttle is suddenly opened there is a corresponding increase in the air flow. However, because of the inertia of the liquid fuel, the fuel flow does not increase in proportion to the increase in air flow. This results in a temporary lean mixture ca11singtheengine to misfire and a temporary reduction in power output.

To prevent this condition, all modern carburetors are equipped with an accelerating system. Figure 5. Illustrates simplified sketch of one such device. The pump comprises of a spring loaded plunger that takes care of the situation with the rapid opening of the throttle valve. The plunger moves into the cylinder and forces an additional jet of fuel at the venturi throat. When the throttle is partly open, the spring sets the plunger back. There is also an arrangement which ensures that fuel in the pump cylinder is not forced through the jet when valve is slowly opened or leaks past the plunge r or some holes into the float chamber.

Mechanical linkage system, in some carburetor, is substituted by an arrangement where by the pump plunger is held up by manifold vacuum. When this vacuum is decreased byrapid opening of the throttle, a spring forces the plunger down pumping the fuel through the jet.

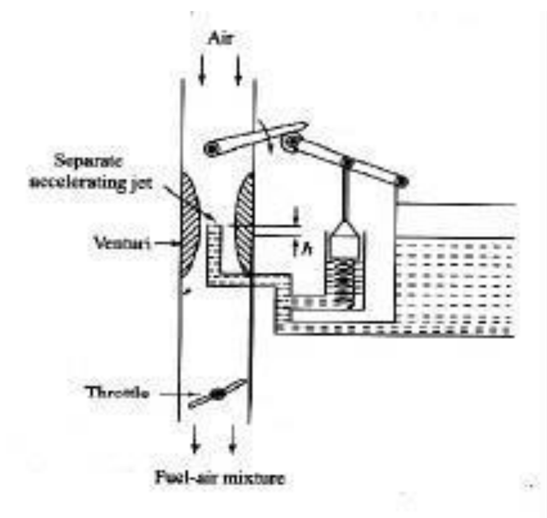

Figure: 5 Acceleration pump system

1.8 Types of Carburetors

There are three general types of carburetors depending on the direction of flow of air. The first is the up draught type shown in Fig.8(a) in which the air enters at the bottom and leaves at the top so that the direction of its flow is upwards. The disadvantage of the up draught carburetor is that it must lift the sprayed fuel droplet by air friction. Hence, it must be designed for relatively small mixing tube and throat so that even at low engine speeds the air velocity is sufficient to lift and carry the fuel particles along. Otherwise, the fuel droplets tend to separate out providing only a lean mixture to the engine. On the other hand, the mixing tube is finite and small then it cannot supply mixture to the engine at a sufficiently rapid rate at high speeds.

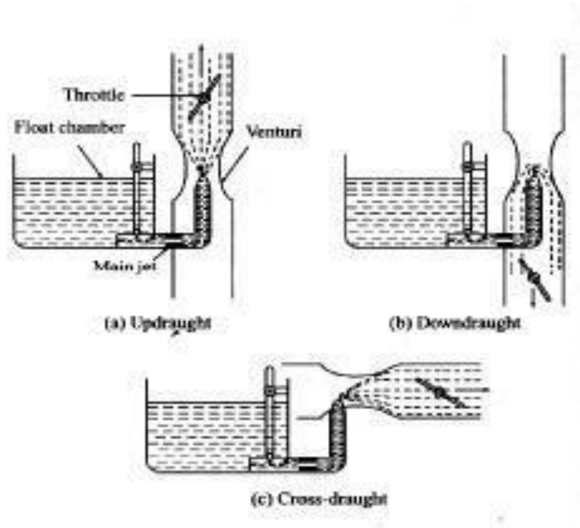

Figure: 6 Types of Carburetors

In order to overcome this drawback the downdraught carburetor [Fig.8 (b)] is adopted. It is placed at a level higher than the inlet manifold and in which the air and mixture generally follow a downward course. Here the fuel does not have to be lifted by air friction as in the up draught carburetors but move into the cylinders by gravity even if the air velocity is low. Hence, the mixing tube and throat can be made large which makes high engine speeds and high specific outputs possible.

A cross-draught carburetor consists of a horizontal mixing tube with a float chamber on one side of it [Fig.8(c)]. By using across-draught carburetor in engines, one right-angled turn in the inlet passage is eliminated and the resistance to flow is reduced.

1.8.1 Constant Choke Carburetor:

In the constant choke carburetor, the air and fuel flow areas are always maintained to be constant. But the pressure difference or depression, which causes the flow of fuel and air, is being varied as per the demand on the engine. Solex and Zenith carburetors belong to this class.

1.8.2 Constant Vacuum Carburetor:

In the constant vacuum carburetor, (sometimes called variable choke carburetor) air and fuel flow areas are being varied as per the demand on the engine, while the vacuum is maintained to be always same. The S.U. and Carter carburetors belong to this class.

1.8.3 Multiple Venturi Carburetor:

Multiple venturi system uses double or triple venturi. The boost venturi is located concentrically within the main venturi. The discharge edge of the boost venturi is located at the throat of the main venturi. The boost venturi is positioned upstream of the throat of the larger main venturi. Only a fraction of the total air flows though the boost venturi. Now the pressure at the boost venturi exit equals the pressure at the main venturi throat. The fuel nozzle is located at the throat of the boost venturi.

UNIT – II

GASOLINE INJECTION AND IGNITION SYSTEM

2. INTRODUCTION

In internal combustion engines, gasoline direct injection (GDI), is a variant of fuel injection employed in modern two-stroke and four-stroke gasoline engines. The gasoline is highly pressurized in a common rail fuel line and injectors injects fuel directly into the combustion chamber of each cylinder.It is opposed to conventional multi-point fuel injection which injects fuel to the intake manifold. Gasoline direct injection enables a stratified fuel charge (ultra lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load.

2.1 TRANSITION OF FUEL SUPPLY SYSTEM

The transition of the fuel supply system used in automobiles is graphically shown below. In carburetor the fuel from the fuel chamber is sucked in by the pressure variation caused due to the incoming air. The fuel then mixes with the air and reaches the cylinder through the inlet manifold. Where as in a port injection system the fuel to the cylinder is supplied by a separate fuel injector placed near the inlet valve of the cylinder. And in a direct injection system the fuel to the cylinder is supplied by a fuel injector placed inside the cylinder.

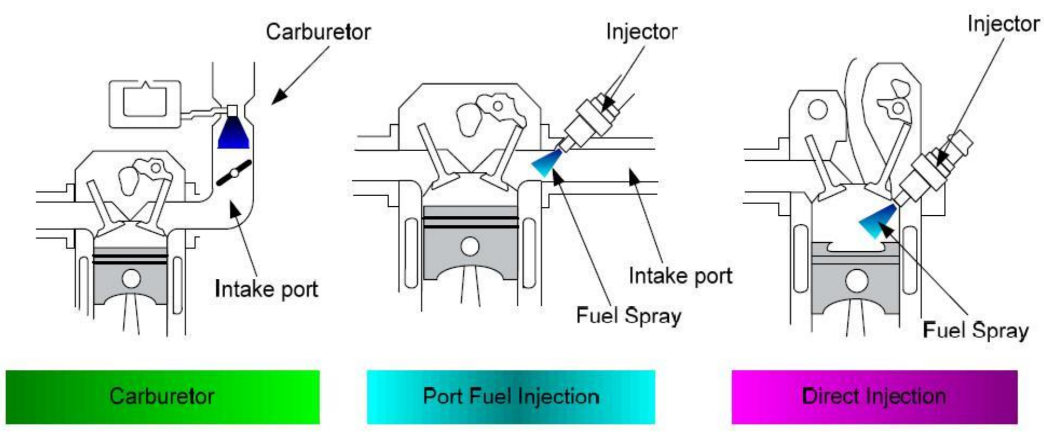

Fig2.1 Transition of Fuel Supply System

2.2 OPERATING DIFFICULTIES FOR A CARBURETOR.

Some problems associated with comfortable running of the carburetor are discussed here.

1. *Ice formation:* The vaporisation of the fuel injected in the current of the air requires latent heat and the taken mainly from the incoming air. As a result of this, the temperature of the air drops below the dew point of the water vapour in the air and it condenses and many times freeze into ice if the temperature falls below dew point temperature.

2. *Vapour Lock:* The improved volatility of modern fuels and the necessity of providing heat to prevent the ice formation, has created carburetion difficulties due to vaporisation of fuel in pipes and float chamber. The heating may also occur due to petrol pipes being near the engine. If the fuel supply is large and supply is small, a high velocity will result causing high vacuum. This causes considerable drop which may also cause the formation of vapour bubbles. If these bubbles formed accumulate at the tube bend, then they may interrupt the fuel flow from the tank or the fuel pump and engine will stop because of lack of fuel. Vapour lock is formed because of rapid bubbling of fuel and usually happens in hot summer.

3. *Back Firing:* During the starting of an engine under cold working conditions, the usual manipulation of the choke varies the mixture from too lean to too rich. A very lean mixture will burn very slowly and the flame may still exist in cylinder when the exhaust valve is about to open. The fresh charge in the intake manifold is about to open. The fresh charge in the intake manifold is not so diluted as when inducted into the cylinder and mixed with the clearance gases and consequently burn more rapidly than the charge in the cylinder. If lean charge comes in contact with flames existing in the cylinder, there will be flash of flame back through the intake manifold, burning the charge therein and causing the customary back firing in the carburetor.

2.3 ADVANTAGES OF FUEL INJECTION OVER CARBURETOR

The fuel injection eliminates several intake manifold distribution problems. One of the most difficult problems in a carbureted system is to get the same amountand richness of air-fuel mixture to each cylinder. The problem is that the intake manifold acts as a storing device, sending a richer air fuel mixture to the end cylinders. The air flows readily around the corners and through various shaped passages. However the fuel, because it is heavier is unable to travel as easily around the bends in the intake manifold. As a result, some of fuel particles continue to move to the end of the intake manifold, accumulating there. This enriches the mixture going the end cylinder. The center cylinder closest to the carburetor gets the leanest mixture . The port injection solves this problem because the same amount of fuel is injected at each intake valve port. Each cylinder gets the same amount of air-fuel mixture of the same mixture richness.

Another advantage of the fuel injection system is that the intake manifold can be designed for the most efficient flow of air only. It does not have to handle fuel. Also, because only a throttle body is used, instead of a complete carburetor.

With fuel injection, fuel mixture requires no extra heating during warm up. No manifold heat control valve or heated air system is required. Throttle response is faster because the fuel is under pressure at the injection valves at all times. An electric fuel pump supplies the pressure. The carburetor will depend on differences in air pressure as the force that causes the fuel to feed into the air passing through.

Fuel injection has no choke, but sprays atomized fuel directly into the engine. This eliminates most of the cold start problems associated with carburetors.

Electronic fuel injection also integrates more easily with computerized engine control systems because the injectors are more easily controlled than a mechanical carburetor with electronic add-ons.

Multi port fuel injection (where each cylinder has its own injector) delivers a more evenly distributed mixture of air and fuel to each of the engine's cylinders, which improves power and performance.
Sequential fuel injection (where the firing of each individual injector is controlled separately by the computer and timed to the engine's firing sequence) improves power and reduces emissions.

2.4 ELECTRONIC FUEL INJECTION

Engine Sensors:
In order to provide the correct amount of fuel for every operatingcondition, the engine control unit (ECU) has to monitor a huge number of input sensors. Here are just a few:

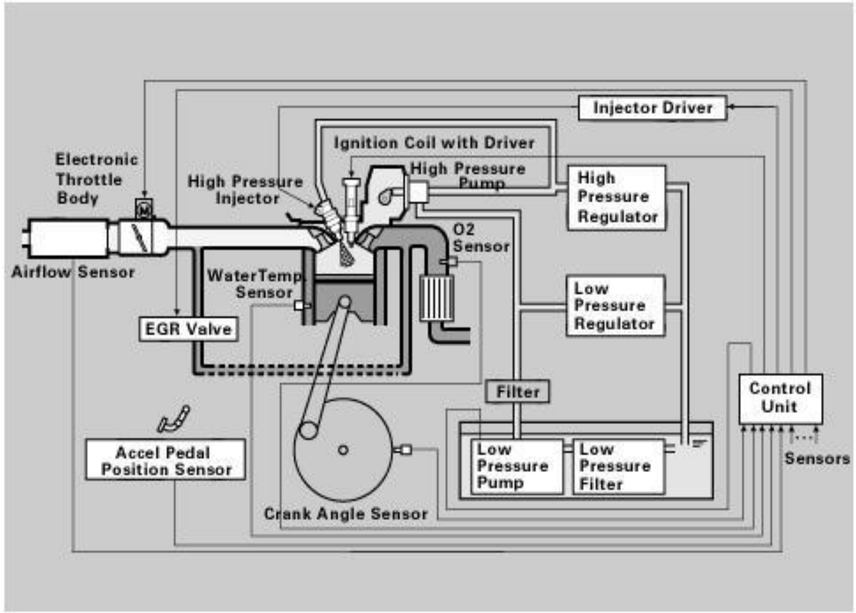

Fig2.2: Various Sensors used in a GDI system

- *Mass airflow sensor* - Tells the ECU the mass of air entering the engine

  Oxygen sensor - The device measures the amount of oxygen in the exhaust gas and sends this information to the electronic control unit. If there is too much oxygen, the mixture is too lean. If there is too little, the mixture is too rich. In either case, the electronic control unit adjusts the air fuel ratio by changing the fuel injected. It is usually used with closed loop mode of the ECU.

- *Throttle position sensor* - Monitors the throttle valve position (which determines how much air goes into the engine) so the ECU can respond quickly to changes, increasing or decreasing the fuel rate as necessary

- *Coolant temperature sensor* - Allows the ECU to determine when the engine has reached its proper operating temperature

- *Voltage sensor* - Monitors the system voltage in the car so the ECU can raise the idle speed if voltage is dropping (which would indicate a high electrical load)

- *Manifold absolute pressure sensor* - Monitors the pressure of the air in the intake manifold. The amount of air being drawn into the engine is a good indication of how much power it is producing; and the more air that goes into the engine, the lower the manifold pressure, so this reading is used to gauge how much power is being produced.

- *Engine speed sensor* - Monitors engine speed, which is one of the factors used to calculate the pulse width.
- *Crank Angle sensor* - Monitors the position of the piston and gives the information to the ECU. Accordingly the ECU adjusts the valve timing.

Fuel Injectors:

The solenoid-operated fuel injector is shown in the figure above. It consists of a valve body and needle valve to which the solenoid plunger is rigidly attached. The fuel is supplied to the injector under pressure from the electric fuel pump passing through the filter. The needle valve is pressed against a seat in the valve body by a helical spring to keep it closed until the solenoid winding is energized. When the current pulse is received from the electronic control unit, a magnetic field builds up in the solenoid which attracts a plunger and lifts the needle valve from its seat. This opens the path to pressurized fuel to emerge as a finely atomized spray.

2.5 TYPES OF ELECTRONIC FUEL INJECTION

There are two types of electronic fuel injection. They are,

1. Multipoint Fuel Injection (MPFI)
2. Gasoline Direct Injection (GDI)

2.5.1 MULTI POINT FUEL INJECTION (MPFI)

Engines with multi port injection have a separate fuel injector for each cylinder, mounted in the intake manifold or head just above the intake port. Thus, a four-cylinder engine would have four injectors, a V6 would have six injectors and a V8 would have eight injectors. Multi port injection systems are more expensive because of the added number of injectors. But having a separate injector for each cylinder makes a big difference in performance. The same engine with multi port injection will typically produce 10 to 40 more horsepower than one with carburetor because of better cylinder-to-cylinder fuel distribution. Injecting fuel directly into the intake ports also eliminates the need to preheat the intake manifold since only air flows through the manifold. This, in turn, provides more freedom for tuning the intake plumbing to produce maximum torque.

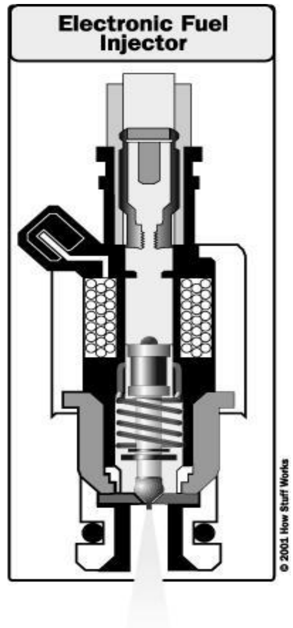

Fig2.3: Fuel Injection in a MPFI system

2.5.2 GASOLINE DIRECT INJECTION (GDI)

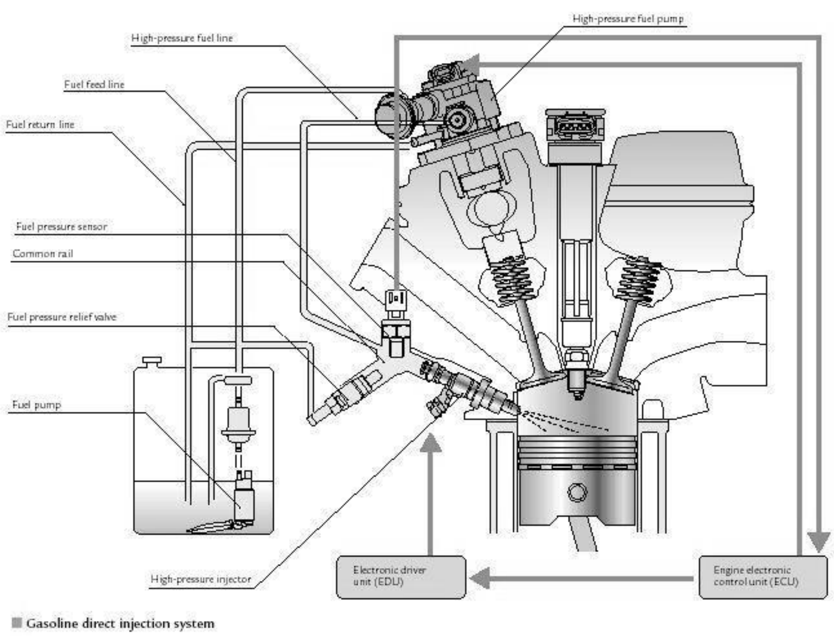

Fig 2.4 : A GDI System

In conventional engines, fuel and air are mixed outside the cylinder. This ensures waste between the mixing point and the cylinder, as well as imperfect injection timing. But in the GDI engine, petrol is injected directly into the cylinder with precise timing, eliminating waste and inefficiency.

By operating in two modes**, Ultra-Lean Combustion Mode and Superior Output Mode**, the GDI engine delivers both unsurpassed fuel efficiency and superior power and torque. The GDI engine switches automatically between modes with no noticeable shift in performance.

MAJOR OBJECTIVES OF THE GDI ENGINE

- *Ultra-low fuel consumption.*
- *Superior power to conventional MPI engines*

THE DIFFERENCE BETWEEN NEW GDI AND CURRENT MPI

For fuel supply, conventional engines use a fuel injection system, which replaced the carburetion system. MPI or Multi-Point Injection, where the fuel is injected to each intake port, is currently the one of the most widely used systems. However, even in MPI engines there are limits to fuel supply response and the combustion control because the fuel mixes with air before entering the cylinder. Mitsubishi set out to push those limits by developing an engine where gasoline is directly injected into the cylinder as in a diesel engine, and moreover, where injection timings are precisely controlled to match load conditions. The GDI engine achieved the following outstanding characteristics.

- Extremely precise control of fuel supply to achieve fuel efficiency that exceeds that of diesel engines by enabling combustion of an ultra- lean mixture supply.
- Very efficient intake and relatively high compression ratio unique to the GDI engine deliver both high performance and response that surpasses those of conventional MPI engines.

TECHNICAL FEATURES

The GDI engines foundation technologies

There are four technical features that make up the foundation technologies are described below.

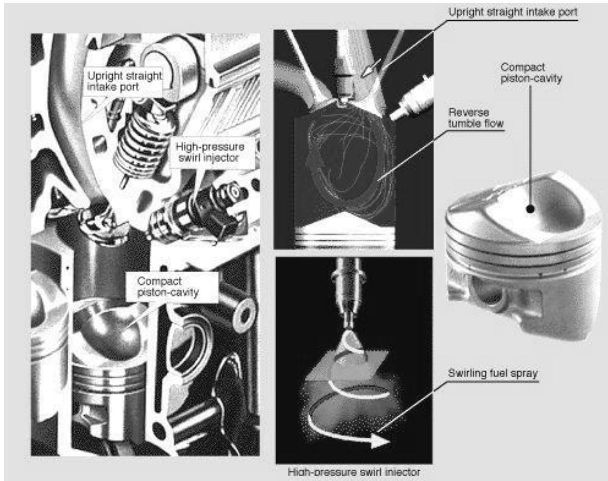

Fig 2.5: Four Technical Features

1. The Upright Straight Intake Port supplies optimal airflow into the cylinder.
2. The Curved-top Piston controls combustion by helping shape the air- fuel mixture.
3. The High Pressure Fuel Pump supplies the high pressure needed for direct in-cylinder injection.
1. The High Pressure Swirl Injector controls the vaporization and dispersion of the fuel spray.

2.6 MAJOR CHARACTERISTICS OF THE GDI ENGINE

Lower fuel consumption and higher output*:* Using methods and technologies, the GDI engine provides both lower fuel consumption and higher output. This seemingly contradictory and difficult feat is achieved with the use of two combustion modes. Put another way, injection timings change to match engine load.

For load conditions required of average urban driving, fuel is injected late in the compression stroke as in a diesel engine. By doing so, an ultra- lean combustion is achieved due to an ideal formation of a stratified air- fuel mixture. During high performance driving conditions, fuel is injected during the intake stroke. This enables a homogeneous air-fuel mixture like that of in conventional MPI engines to deliver higher output.

Two Combustion Modes: In response to driving conditions, the GDI engine changes the timing of the fuel spray injection, alternating between two distinctive combustion modes-stratified charge (Ultra-Lean combustion), and homogenous charge (Superior Output combustion).

Under normal driving conditions, when speed is stable and there is no need for sudden acceleration, the GDI engine operates in Ultra-Lean Mode. A spray of fuel is injected over the piston crown during the latter stages of the compression stroke, resulting in an optimally stratified air- fuel mixture immediately beneath the spark plug. This mode thus facilitates lean combustion and a level of fuel efficiency comparable to that of a diesel engine.

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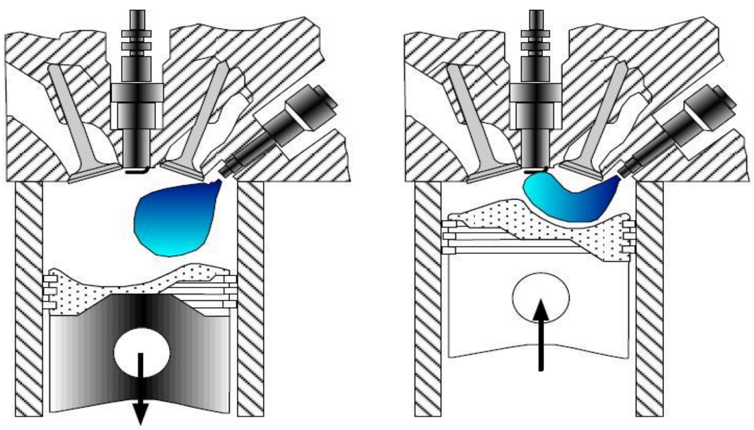

Fig2.6: Two combustion modes

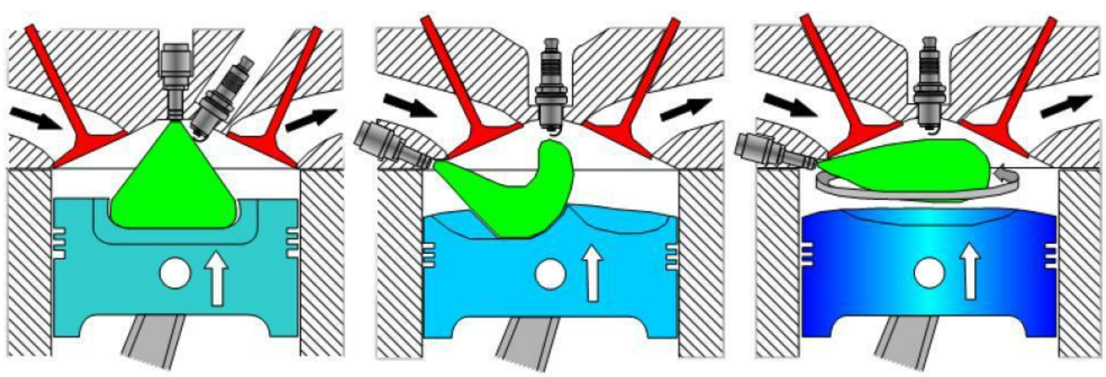

Fig. 4. The wall-guided, air-guided and spray-guided combustion systems at stratified charge (Stefan, 2004).

Fig 2.7 Stratified operation

The GDI engine switches automatically to Superior Output Mode when the driver accelerates, indicating a need for greater power. Fuel is injected into the cylinder during the piston's intake stroke, where it mixes with air to form a homogenous mixture. The homogenous mixture is similar to that of a conventional MPI engine, but by utilising the unique features of the GDI, an even higher level of power than conventional petrol engines can be achieved.

2.7 WALL GUIDED COMBUSTION SYSTEM

The fuel is transported to the spark plug using a specially shaped piston surface.

2.7.1 Air guided combustion systems

The fuel is injected to the air flow, which moves the fuel spray near the spark plug.

2.7.2 Spray guided combustion systems

In this technique fuel is injected near spark plug where it evaporates.

In-cylinder Airflow*:* The GDI engine has upright straight intake ports rather than horizontal intake ports used in conventional engines. The upright straight intake ports efficiently direct the airflow down at the curved-top piston, which redirects the airflow into a strong reverse tumble for optimal fuel injection.

Precise Control over the Air/Fuel Mixture: The GDI engine's ability to precisely control the mixing of the air and fuel is due to a new concept called

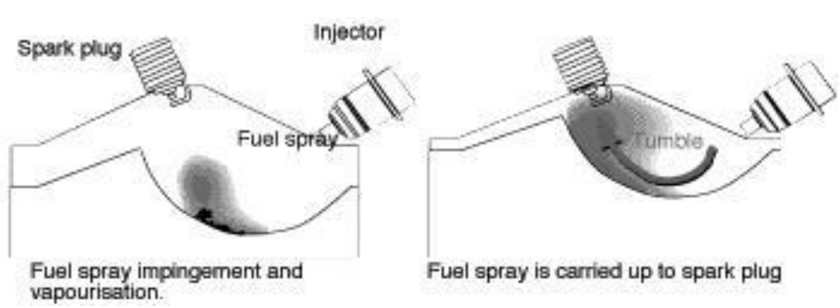

Fig2.8: Precise Control over the A/F Ratio

wide spacing," whereby injection of the fuel spray occurs further away from the spark plug than in a conventional petrol engine, creating a wide space that enables optimum mixing of gaseous fuel and air.

In stratified combustion (Ultra-Lean Mode), fuel is injected towards the curved top of the piston crown rather than towards the spark plug, during the latter stage of the compression stroke. The biggest advantage of this system is that it enables precise control over the air-to-fuel ratio at the spark plug at the point of ignition.

In addition to its ability to mix thoroughly with the surrounding air, the fuel spray does not easily wet the cylinder wall or the piston head. In homogeneous combustion (Superior Output Mode), fuel is injected during the intake stroke, when the piston is descending towards the bottom of the cylinder, vaporizing into the air flow and following the piston down. Again, it's all in the timing. By selecting the optimum timing for the injection, the fuel spray follows the movement of the piston, but cannot catch up. In this case, as the piston moves downward and the inside of the cylinder become larger in volume, the fuel spray disperses widely, ensuring a homogenous mixture.

Fuel Spray*:* Newly developed high-pressure swirl injectors provide the ideal spray pattern to match each engine operational modes. And at the same time by applying highly swirling motion to the entire fuel spray, they enable sufficient fuel atomization that is mandatory for the GDI.

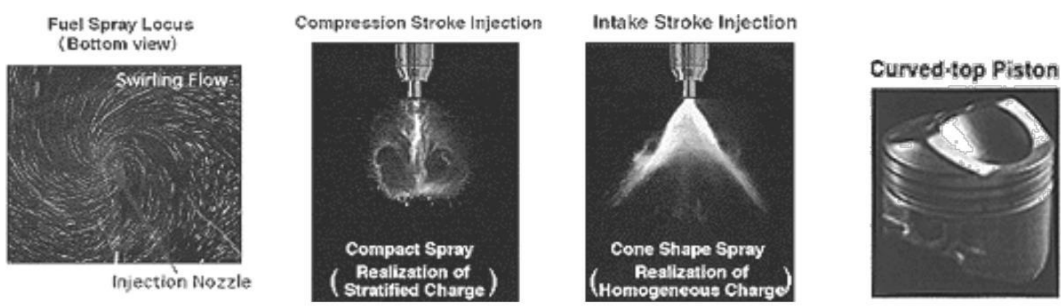

Fig2.9: Fuel Spray Characteristics

Optimized Configuration of the Combustion Chamber*:*

The curved-top piston controls the shape of the air- fuel mixture as well as the airflow inside the combustion chamber, and has an important role in maintaining a compact air fuel mixture. The mixture, which is injected late in the compression stroke, is carried toward the spark plug before it can disperse.

Realization of lower fuel consumption

In conventional gasoline engines, dispersion of an air- fuel mixture with the ideal density around the spark plug was very difficult. However, this is possible in the GDI engine. Furthermore, extremely low fuel consumption is achieved because ideal stratification enables fuel injected late in the compression stroke to maintain an ultra- lean air- fuel mixture.

An engine for analysis purpose has proved that the air- fuel mixture with the optimum density gathers around the spark plug in a stratified charge. This is also borne out by analyzing the behavior of the fuel spray immediately before ignition and the air-fuel mixture itself. As a result, extremely stable combustion of ultra-lean mixture with an air- fuel ratio of 40 is achieved.

Combustion of Ultra-lean Mixture

In conventional MPI engines, there were limits to the mixtures leanness due to large changes in combustion characteristics. However, the stratified mixture of the GDI enabled greatly decreasing the air- fuel ratio without leading to poorer combustion. For example, during idling when combustion is most inactive and unstable, the GDI engine maintains a stable and fast combustion even with an extremely lean mixture of 40 to 1 air- fuel ratio.

2.8 EMISSION CONTROL IN GDI ENGINES

CO emission is less in GDI engines. Due to wetting of the piston and cylinder walls with liquid fuel, HC emission can increase. Soot emissions occur at very rich mixtures.

The three way catalytic convertor show high performance in converting the CO, HC and NOx in engine operations. But NOx cannot be converted completely to harmless gases in lean mixture operation. therefore engines with lean mixture also requires a NOx storage type catalytic convertor to convert the NOx.

VEHICLE FUEL CONSUMPTION

2.8.1 Fuel Consumption during Idling:

The GDI engine maintains stable combustion even at low idle speeds. Moreover, it offers greater flexibility in setting the idle speed. Compared to conventional engines, its fuel consumption during idling is 40% less.

***2.8.2 Fuel Consumption during Cruising Drive**:* At 40km/h, for example, the GDI engine uses 35% less fuel than a comparably sized conventional engine.

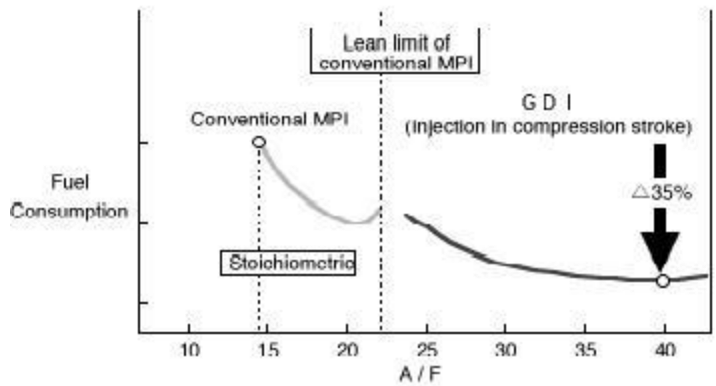

Fig2.10: fuel consumption

Better Fuel Efficiency:

The concept of wide spacing makes it possible to achieve a stratified mixture, enabling the GDI engine to offer stable, ultra- lean combustion, allowing a significant improvement in fuel efficiency. In addition to ultra- lean combustion, the GDI engine achieves a higher compression ratio because of its anti-knocking characteristic and precise control of injection timing. These features contribute to drastically lower fuel consumption. The GDI engine improves fuel economy by 33% in the Japanese 10-15 mode driving cycle which represents typical urban driving conditions.

Emission Control:

Previous efforts to burn a lean air- fuel mixture have resulted in difficulty to control NOx emission. However, in the case of GDI engine, 97% NOx reduction is achieved by utilizing high-rate EGR (Exhaust Gas Ratio) such as 30% that is allowed by the stable combustion unique to the GDI as well as a use of a newly developed lean-NOx catalyst.

Improved Volumetric Efficiency:

GDI engine provides better volumetric efficiency. The upright straight intake ports enable smoother air intake. And the vaporization of fuel, which occurs in the cylinder at a late stage of the compression stroke, cools the air for better volumetric efficiency.

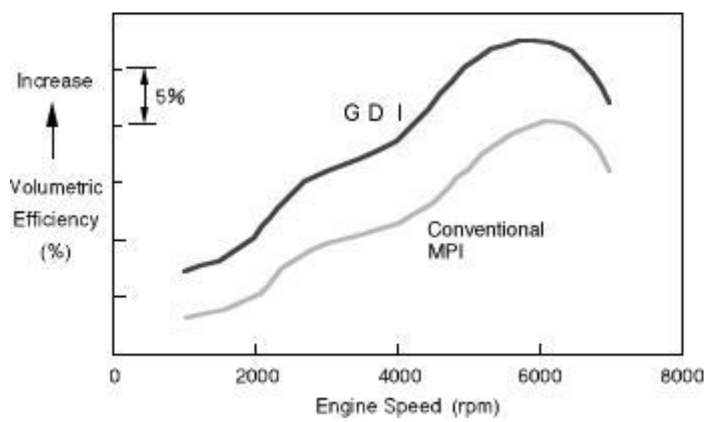

Fig 2.11 *Relation for Volumetric efficiency and engine speed.*

Increased Compression Ratio: The cooling of air inside the cylinder by the vaporization of fuel has another benefit, to minimize engine knocking. This allows a high compression ratio of 12, and thus improved combustion efficiency.

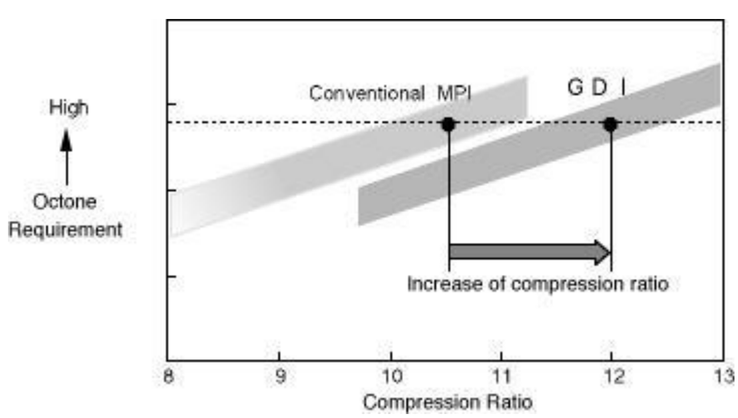

Fig2.12: Comparison of compression ratio

2.9 INTRODUCTION TO SPARK IGNITION:

In all spark ignition engines which work on the Gasoline either 2-Stroke or 4-Stroke cycle principle and utilize a carburetor or fuel injection system, the combustion of the air-fuel mixture is initiated by an electric spark.

The term ‘Spark Ignition’ means that a brief electric arc is produced between the electrodes of a spark plug, the energy for which is derived from an external power source. In most cases this power source is the vehicle battery, which is constantly being supplemented by the alternate while the vehicle is mobile.

A different method of ignition is employed in diesel engines. This is called ‘compression ignition’ and relies on the fact that when air compressed, its temperature rises. In diesel engines, compression ratio of between 16:1 and 25:1 are common, and at the end of a compression the temperature of the trapped air is sufficiently high to ignite the diesel fuel that is sprayed into the cylinder at the appropriate time.

2.9.1 The functions of ignition system

The functions of the coil ignition systems in general use on motor vehicle may be divided into three areas. Production of the high voltage necessary to produce a spark at the plug gap. Distribute the spark to all the cylinders at proper time based on the firing order. Varying the timing of the spark depending on the various operating conditions of the engine like cranking time, varying speed and load, so that the best performance is obtained from the engine under all operating conditions.

2.9.2 Mechanism of Ignition

It must be remembered that vehicle battery voltages are usually 12 volt or 24 volt and this value is too low to produce a heavy spark at the plug gap in a cylinder under compression. For this reason one of the major functions of the battery ignition system is to raise the battery voltage to the required level and then apply it to spark plugs. This process is correctly initiated in the primary circuit and completed in the secondary winding of the ignition coil. Depending on the type of engine and the conditions existing in the cylinders, a voltage of between 5,000 to 20,000 volts is required and this is called the **ionizing voltage** or **firing voltage.**

This firing voltage forces the electrons to jump between the electrodes of the spark plug in the gap to produce the required spark. The electric spark has sufficient heat energy to ignite the air- fuel mixture which later continues to burn itself.

UNIT III

DIESEL INJECTION SYSTEMS

3.1 INTRODUCTION

Older engines make use of a mechanical fuel pump and valve assembly which is driven by the engine crankshaft, usually via the timing belt or chain. These engines use simple injectors which are basically very precise spring-loaded valves which will open and close at a specific fuel pressure. The pump assembly consists of a pump which pressurizes the fuel, and a disc -shaped valve which rotates at half crankshaft speed. The valve has a single aperture to the pressurized fuel on one side, and one aperture for each injector on the other. As the engine turns the valve discs will line up and deliver a burst of pressurized fuel to the injector at the cylinder about to enter its power stroke. The injector valve is forced open by the fuel pressure and the diesel is injected until the valve rotates out of alignment and the fuel pressure to that injector is cut off. Engine speed is controlled by a third disc, which rotates only a few degrees and is controlled by the throttle lever. This disc alters the width of the aperture through which the fuel passes, and therefore how long the injectors are held open before the fuel supply is cut, controlling the amount of fuel injected.

This contrasts with the more modern method of having a separate fuel pump (or set of pumps) which supplies fuel constantly at high pressure to each injector. Each injector then has a solenoid which is operated by an electronic control unit, which enables more accurate control of injector opening times depending on other control conditions such as engine speed and loading, resulting in better engine performance and fuel economy. This design is also mechanically simpler than the combined pump and valve design, making it generally more reliable, and less noisy, than its mechanical counterpart.

Both mechanical and electronic injection systems can be used in either direct or indirect injection configurations.

3.1.1 Indirect injection

An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber, called a pre chamber, where combustion begins and then spreads into the main combustion chamber.

3.1.2 Direct injection

Modern diesel engines make use of one of the following direct injection methods:

3.2 Distributor pump direct injection

The first incarnations of direct injection diesels used a rotary pump much like indirect injection diesels; however the injectors were mounted directly in the top of the combustion chamber rather than in a separate pre-combustion chamber. Examples are vehicles such as the Ford Transit and the Austin Rover Maestro and Montego with their Perkins Prima engine. The problem with these vehicles was the harsh noise that they made and particulate (smoke) emissions. This is the reason that in the main this type of engine was limited to commercial vehicles (the notable exceptions being the Maestro, Montego and Fiat Croma passenger cars). Fuel consumption was about 15% to 20% lower than indirect injection diesels which for some buyers were enough to compensate for the extra noise.

This type of engine was transformed by electronic control of the injection pump, pioneered by Volkswagen Audi group with the Audi 100 TDI introduced in 1989. The injection pressure was still only around 300 bar, but the injection timing, fuel quantity, exhaust gas recirculation and turbo boost were all electronically controlled. This gave much more precise control of these parameters which made refinement much more acceptable and emissions acceptably low. Fairly quickly the technology trickled down to more mass market vehicles such as the Mark 3 Golf TDI where it proved to be very popular. These cars were both more economical and more powerful than indirect injection competitors of their day.

3.2.1Common rail direct injection

In older diesel engines, a distributor-type injection pump, regulated by the engine, supplies bursts of fuel to injectors which are simply nozzles through which the diesel is sprayed into the engine's combustion chamber.

In common rail systems, the distributor injection pump is eliminated. Instead an extremely high pressure pump stores a reservoir of fuel at high pressure - up to 1,800 bar (180MPa) - in a "common rail", basically a tube which in turn branches off to computer-controlled injector valves, each of which contains a precision-machined nozzle and a plunger driven by a solenoid.

Most European automakers have common rail diesels in their model lineups, even for commercial vehicles. Some Japanese manufacturers, such as Toyota, Nissan and recently Honda, have also developed common rail diesel engines. Different car makers refer to their common rail engines by different names, e.g. DaimlerChrysler's CDI, Ford Motor Company's TDCi (most of these engines are manufactured by PSA), Fiat Group's (Fiat, Alfa Romeo and Lancia) JTD, Renault's DCi, GM/Opel's CDTi (most of these engines are manufactured by Fiat, other by Isuzu), Hyundai's CRDI, Mitsubishi's D-ID, PSA Peugeot Citroen's HDI, Toyota's D-4D, Volkswagen's TDi, and so on.

3.2.2Unit direct injection

This also injects fuel directly into the cylinder of the engine. However, in this system the injector and the pump are combined into one unit positioned over each cylinder. Each cylinder thus has its own pump, feeding its own injector, which prevents pressure fluctuations and allows more consistent injection to be achieved. This type of injection system, also developed by Bosch, is used by Volkswagen AG in cars and most major diesel engine manufacturers, in large commercial engines (Cat, Cummins, Detroit Diesel). With recent advancements, the pump pressure has been raised to 2,050 bar (205 MPa), allowing injection parameters similar to common rail systems.

3.3 SPARK PLUG

Sparkplug is mounted in the combustion chamber of the engine, where working conditions are severe. During peak combustion conditions the temperature of the gases in the combustion chamber in the modern car engine may be around 2500oC and the pressure about 7 MPa. Moreover, a spark plug also exposed to thermal and load cycling fatigue due to sudden changes in temperature and pressure- from the high temperature of burnt gas to the relatively low temperature of the air/fuel mixture and from the high pressure at the time of explosion of the air/fuel mixture to low pressure during induction. In addition, the spark plug has to endure high voltage, mechanical vibration and the corrosive atmosphere of combustion gases. The modern sparkplug has an economical life about 10,000 – 16,000km.

The minimum voltage required to make the spark jump across the air gap depends upon the following:

1. Compression pressure
2. Mixture strength
3. Air gap
4. Electrode temperature
5. Vehicle speed and load

3.3.1 REQUIREMENTS

1. Very high resistance to current leakage
2. Continued maintenance of the proper gap under all conditions
3. Gas tightness
4. Resistance to corrosion
5. Sufficient reach in to the combustion chamber

6. Electrode temperature must be maintained between certain limits

3.3.2 CONSTRUCTION

The spark plug gas three main parts, the entre electrode, the ground electrode and the insulator separating them. Besides these, there are the body shell, the sealing ring and the gasket washer. The upper end of the center electrode is connected to the spark plug terminal, where H.T cable from the ignition coil in case of single cylinder engines is connected. The lower end of the center electrode projects beyond the insulator to form a gap with the ground electrode. The insulator is meant to fulfill the following functions:

1. To insulate the center electrode from body shell, thereby preventing the leakage of high voltage surge from leaking to earth within the shell.
2. The control the working temperature of the center electrode by suitably adopting the thermal conductivity of the insulating material, its shape and the length of heat path, while designing the spark plug for a given engine.

The body shell serves house the electrodes and the insulator. Gas-tight seal is necessary to prevent the hot gas from leaking between the insulator and the body shell and between the insulator and the center electrode. Such seals may be of different types, i.e. solid ring; dry power, metal powder fused into glass, etc. besides above the hot gas from the combustion chamber may also leak between the plug and the cylinder head. To seal this flat ring gasket washer is commonly used.

In some modern spark plugs, the Centre electrode is made in two pieces. By doing so the designer can be different metals to suit best the different requirements of the upper piece which has to be connected to the H.T cable and the lower piece which has to go into the combustion chamber.

In some spark plugs, Centre electrode contains a built-in resistance in series with the electrode. This resistance reduces the number of higher voltage surges accompanying the full voltage surge for the spark, thereby reducing the radio and television interference due to ignition system and also providing protection to the on-board computer. The resistance also increases the plug life by cutting down peak current that would burn the electrodes. However, the resistance increases the voltage required to jump across the spark plug gap. Such plugs are called resistor spark plugs and there life is about double the life of ordinary plugs.

3.4 MATERIALS

The body shell is generally made of low carbon steel. Porcelain was used initially for insulation; by this has the disadvantages of brittleness and low resistance to thermal shock. Porcelain was therefore replaced by mica.

The ground electrodes are usually formed of nickel or sometime any alloy of nickel and manganese. Copper cored central electrodes are also used which increase the heat range of a plug. A nickel alloy jacket around the copper core, due to its very good anti-corrosion and anti-erosion properties, protects it from the aggressive combustion environment.

Platinum tips are also used for some spark plugs due to the very high burn-off resistance of this material. Modern spark plugs use rare earth element yttrium for the center electrode.

3.5 TYPES OF SPARK PLUG

- Hot Plug
- Cold Plug

The spark plugs maybe long reach or short reach type depending upon the length of threaded portion and should be used only in the corresponding hole in the combustion chamber. From heat dissipation point of view also the spark plugs are also divided into two classes, viz., hot or hard and cold or soft. Hot plug runs hotter than the cold plug because the path of heat dissipation of the cooling water in the jackets is longer in the hot plug than in the cold plug. Some cold spark plug has a copper core in the Centre electrode to help carry heat from the tip of the electrode. Cold plugs are generally used in heavy duty, high speed engines where high temperatures are encountered. Lower speed, medium duty and colder operating conditions require a hot plug.

3.6 AIR GAP

The correct spark plug gap size is specified by the manufactures but in general it varies from 0.6 mm to 1 mm. for the new plug required higher voltage for the spark to jump across it. On the other hand the carbon deposits on the plug electrodes provide alternative paths for the current to pass, thereby limiting the maximum voltage applied across the gap to a lower value; the result is voltage surge of lower intensity which may not be sufficient to make the spark jump across the plug points, thus causing the plug to misfire. If an auxiliary air gap is introduced in the plug circuit, the same will help the voltage to build up to a high value sufficient to jump across the air gap. If the gap size is sufficient, obviously the voltage would be enough to cause sparking at the plug points. It is this basic principle of air gap only, which is made use of in the so called spark intensifiers which contain simply two screws providing an adjustable gap.

3.7 SPARK PLUG DEFECTS

1. Erosion of electrodes
2. Fouling of plug
3. Plug over heating
4. Ignition may be too much advanced
5. The plug used may be hotter than the specified one
6. Weak mixture
7. Defective cooling system
8. Loose fitting causing the exhaust gases to leak
9. Improper closing of valve

3.8 ADVANCE MECHANISM OF SPARK PLUG

When the engine is idling, the spark is timed to reach the spark plug just before the piston reaches TDC on the compression stroke. At higher speed, the spark must occur earlier. If it does not, the piston will be past TDC and moving down on the power stroke before combustion pressure reaches maximum. The piston ahead of the pressure rise which results in a weak power stroke. This wastes, much of the energy in the fuel.

To better use the energy in the fuel, the spark take place earlier as engine speed increases. This spark advance causes the mixture to burn producing maximum pressure just as the piston move through TDC. Most contact point distributes have two mechanisms to control spark advance. A centrifugal- advance mechanism adjusts the spark based on the engine speed. A vacuum advance mechanism adjusts the spark based on engine load. On the engine, both work together to provide the proper spark advance for the engine operating conditions.

3.8.1. CENTRIFUGAL ADVANCE

The centrifugal advance mechanism advances the spark by pushing the breaker cam ahead as engine speed increases. Two advance weights, two weights springs and a cam assembly provide this action. The cam assembly includes the breaker cam and an oval shaped advance cam. At low speed, the springs hold the weights in. as engine speed increases, centrifugal force causes the weights to overcome the spring and force and pivot outward. This pushes the cam assembly ahead. The contact point open and close earlier, is advancing the spark.

3.8.2. VACUUM ADVANCE

When the throttle valve is only partly open, a partial vacuum develops in the intake manifold. Less air-fuel mixture gets into the engine cylinders. Then the fuel burns slower after it is ignited. The spark must be advanced at part throttle to give the mixture more time to burn. The vacuum- advance mechanism advances spark timing of shifting the position of the breaker plate. The vacuum-advance unit has a diaphragm linked to the breaker plate. A vacuum passage connects the diaphragm to a port just above the closed throttle valve. When the throttle valve moves past the vacuum port, the intake-manifold vacuum pulls on the diaphragm. This rotates the beaker plate so the contact points open and close earlier. Any vacuum port above the throttle valve provides ported vacuum.

3.8.3 COMBINED CENTRIFUGAL AND VACUUM ADVANCE

At any speed above idle, there is some centrifugal advance. Depending on intake manifold vacuum, there may also be some vacuum advance. The total advance curve as shown in figure. At 40miles per hour, there are 15 degrees of centrifugal advance. The vacuum advance can produce up to 15 degrees of additional advance throttle. The advances combine to produce a maximum advance of 30 (15+15) degrees. When the engine runs at wide open throttle intake manifold vacuum drops to zero. There is no vacuum advance. Normally the total advance varies between the straight line (centrifugal advance) and the curved line (centrifugal plus vacuum advance).

3.9 IGNITION SYSTEM

This system is part of electrical system which carries the electrical current to the spark plug where the spark necessary to ignite the fuel air mixture in the combustion chamber is produced.

This system supplies high voltage of current (as much as 20000 Volts) to produce spark at the sparkplug. This spark is provided at the exact time in various cylinders according to the firing order of the engine.

In a four stroke, four cylinder engine operating at 3000 rpm, individual cylinders require a spark at every second revolution, and this necessitates the frequency of firing to be (3000/2) x 4 = 6000 sparks per minute or 100 sparks per seconds. This shows that there is an extremely short interval of time between firing impulses.

The internal combustion engines are not capable of starting by themselves. Engines fitted in trucks, tractors and other industrial applications are usually cranked by a small starting engine or by compressed air.

3.9.1 REQUIREMENTS OF IGNITION SYSTEM

1. It should provide a good spark between the electrodes of the plugs at the correct timing.
2. The duration of the spark must be long enough with sufficient energy to ensure that ignition of the mixture has a high chance of occurring.
3. The system must distribute this high voltage to each of the spark plug at the exact time in every cycle, i.e., it must have in it a distributing device.
4. It should function efficiently over the entire range of engine speed.
5. It should be light, effective and reliable in service.

3.9.2 GLOW PLUG IGNITION

One of the early ignition system employed was the glow plug ignition used in some kinds of simple engines like model aircraft. A glow plug is a coil of nichrome wire that will glow red hot when an electric current is passed through it. This ignites the air-fuel mixture upon contact. The coil is electrically activation from engine staring and once it runs, it will retain sufficient residual heat on each stroke due to heat generated on the previous stroke. Glow plugs are also used to aid starting of diesel engines.

3.9.3 CONTACT IGNITION

The other method used was the contact ignition. It consists of a copper or brass rod that protruded into the cylinder and was heated using an external sources. Heat conduction kept the end of the rod hot and ignition takes place when the combustible mixture comes into its contacts. Naturally this was very inefficient as the fuel would not be ignited in a controlled manner. This type of arrangement was quickly superseded by spark ignition.

3.10 TYPES OF IGNITION SYSTEM

1. Coil or Battery ignition system
2. Magneto ignition system
3. Electronic ignition system
4. Transistorized ignition system

5. Capacitive ignition system
6. Distributor less ignition system

3.10.1 BATTERY IGNITION SYSTEM

Most of SI engine used battery ignition system. In this system a 6 volt or 12 volt battery used to produce spark. Passenger cars, light truck, motorcycles and large stationary engines are fitted with this system.

MAIN PARTS OF BATTERY IGNITION SYSTEM:

1. A battery is used to provide energy for ignition. It is work as storage of energy and charged by dynamo, which is driven by engine. It converts chemical energy to electric energy. Two types of battery used in spark ignition system, lead acid battery and alkaline battery. The first one is used in light duty commercial vehicle and the other one is used in heavy duty commercial vehicle. It is housed in primary side of ignition coil.

2. Ignition switch, It is used to turn on and off the ignition system. Battery is connected to the primary winding of ignition coil by ignition switch and ballast resistor.

3. Ballast resistor, It is connected in series with primary winding to regulate current in primary winding. It is used to prevent injury due to overheating of ignition coil. It controls the current passes through primary winding. It is made by iron. Iron has property of increase electrical resistance rapidly by increase in temperature at certain limit. This additional resistance resists flowing current which control the temperature of ignition coil.

4. Ignition coil, It is the main body of battery ignition system. The purpose of ignition coil to step up the battery voltage (6 or 12) to a high voltage, which is sufficient to produce spark at spark plug. It consist a magnetic core or soft wire or sheet, and two electrical winding called primary winding and secondary winding. The primary winding has generally 200-300 turn and the end are connected to exterior terminal. The secondary has almost 21000 turns of copper wire which is insulated to withstand with high voltage. It is located inside the primary winding and its one end connected to secondary winding and other end is grounded either to primary winding or to the metal case. This entire unit is enclosed in a metal container which makes it a compact unit.

4. Contact breaker, This is a mechanical device making and breaking the primary circuit to ignition coil. When the points are closed current flow in ignition coil and when it open, flow of current stopped.

6. Capacitor It is simple electrical capacitors in which two metal plate are separated by an insulating material with a distance. Commonly air is used as insulating material but for particular technical requirement some high quality insulating material is used.

7. Distributor, It is used in multi cylinder engine to regulate spark in each spark plug at correct sequence. It distribute ignition surge in individual spark plug in correct sequence. There are two types of distributor. One is known as carbon brush type and the other one is gap type. In carbon brush type carbon brush carried by the rotor arm sliding over the metallic segment embedded into the distributor cap or moulded insulating material. This makes electric connection or secondary winding with spark plug. In gap type distributor electrode of rotor arm pass close to but does not make contact with the distributor cap. So there is no wear of electrode.

8. Spark Plug A spark plug generally has two electrodes which are separated with each other. A high potential discharge flow through it which generate spark and ignite the combustion mixture in cylinder. It mainly consist two electrodes a steel shell and an insulator. The central electrode connected with the supply of ignition coil. It is well insulated with the outer steel shell which is grounded. There is a small air gap between steel shell and central electrode, between which spark is generated. The electrode usually made by high nickel alloy so it can withstand with high temperature and corrosion resistance.

WORKING OF BATTERY IGNITION SYSTEM:

In the battery ignition system ignition coil stores the energy in form of magnetic field and deliver it at the instant of ignition, in form of high voltage current with high tension wire to correct spark plug. When the contact breaker points are closed:

1. The current flows in the primary circuit
2. It produces a magnetic field in the primary winding
3. When the primary current is at the highest peak, the contact breaker points will be opened by the cam.
4. When the contact beaker points are opened:
5. There is a break in the primary circuit

6. The magnetic field in the primary winding is suddenly collapsed
7. A high voltage (15000 volts) is generated in the secondary windings.
8. This high voltage is distributed to the respective spark plugs through the rotor of the distributor
9. The high voltage tries to cross the spark plug gap and a spark is produced in the gap. This spark ignites the fuel air mixture in the engine cylinder.

Advantages:

1. At the time of starting or at low speed good spark is available.
2. The battery which is used to generate spark can be used to light other auxiliary like headlight, tell light etc.
3. Initial expenditure is less and it has low maintenance cost.
4. Ignition system is not affected by adjusting spark timing in battery ignition system.

Disadvantages:

1. Time available of built up the current and stored energy is decrease as speed of engine increases.
2. Contact breaker subjected to both electrical and mechanical wear which results short maintenance interval.
3. The primary voltage decreases as the engine speed increase. So it is not fully reliable of high speed engine.

3.10.2 MAGNETO IGNITION SYSTEM

In this system, the battery is replaced with the magneto. It consists of a switch, magneto, contact breaker, condenser, distributor and spark plugs. This system used in the two wheelers such as motor cycles, scooters etc.

Construction:

The magneto ignition system consists of a rotating magnet assembly driven by an engine and a fixed armature. The armature consists of primary and secondary windings. The primary circuit consists of a primary winding, condenser and contact breaker. The secondary circuit consists of a secondary windings, distributor and spark plugs.

When the contact breaker points are closed:

1. The current flows in the primary circuit
2. It produces a magnetic field in the primary winding
3. When the primary current is at the highest peak, the contact breaker points will be opened by the cam.

When the contact beaker points are opened:

1. There is a break in the primary circuit
2. The magnetic field in the primary winding is suddenly collapsed
3. A high voltage (15000 volts) is generated in the secondary windings.
4. This high voltage is distributed to the respective spark plugs through the rotor of the distributor
5. The high voltage tries to cross the spark plug gap and a spark is produced in the gap. This spark ignites the fuel air mixture in the engine cylinder.

Advantages:

1. It has maintenance problem similar to a coil ignition
2. When the speed increases, it provides better intensity of spark and thus, it provides better combustion as compared to battery ignition system.
3. Less space is required as compared to battery ignition system
4. It is light in weight and compact in size.

Disadvantages:

1. Initial cost is very high compared with coil ignition system
2. Minimum 75rpm is necessary to start the engine
3. For high power engines, some other devices are necessary to start ignition.

3.10.3 ELECTRONIC IGNITION SYSTEM

There are some drawbacks in the magneto ignition system. First, the contact breaker points will wear out or burn when it is operated with heavy current. Secondly, the contact breaker is only a mechanical device with cannot operate precisely at high speed due to the dwell period which is not sufficient for building up the magnetic up the magnetic field to its full value at that particular speed. The conventional contact beaker can give satisfactory performance only about 400 sparks per second which limits the engine speed. At low speeds, relatively high current is drawn from the battery due to the contact remaining closed for longer time. Thus, the system becomes inefficient at low speeds. The disadvantages of the convention contact breaker assisted ignition system can be completely eliminated by the use of electronic controlled ignition system using contactless triggers to give timing system. The basic difference between contact point and electronic ignition system is in the primary circuit. In the contact breaker system, the primary circuit is opened and closed by the electronic control unit. The secondary circuits are similar to the battery ignition system. In the secondary circuit, the distributor, ignition coil and warning are altered to handle the higher voltage that the electronic ignition system produces. The high voltage (about 47,000 volts) has the advantage that the spark plugs with wider gaps can be used. It results a longer spark which can ignite lean air-fuel mixture. As a result, engines can run on lean mixture for better fuel economy.

Construction:

It consists of a battery, ignition switch, electronic control unit, magnetic pick-up regulator or armature, ignition coil, distributor and spark plugs. The construction of battery, ignition switch, ignition coil, distributor and spark plug is similar to battery ignition system. In this system, a magnetic pick, up is used instead of contact beaks in a conventional system. Also a cam replaced by a regulator or armature.

The magnetic pick-up consists of a sensor coil through which the magnetic flux is generated by a permanent magnet. A star shaped rotor called regulator or armature is mounted on the distributor shaft which modulates the flux density in the coil and induced voltage in the coil due to the consequent change in the flux. This voltage serves as a trigger signal for the high voltage generator circuit. Since there is one spark plug per cylinder, the number of teeth of armature is equal to the number of the engine cylinder.

Working:

When the ignition switch is closed the regulator rotates which makes the teeth of the regulator cone closer to the permanent magnet. It reduces the air gap between regulator tooth and sensor coil. Thus, the reflector provides a path for the magnetic lines from the magnet. The magnetic field is passed on to the pick up every time when the reflector teeth pass the pickup coil in which an electric pulse is generated. This small current then triggers the electronic control in which stop the flow of battery current to the ignition coil. The magnetic field in the primary winding collapses and the high voltage is generated in the secondary winding. It led spark in a spark plug via distributor. Meanwhile, the reflector teeth pass past the pickup coil. Therefore, the pulse unit is ended. It causes the electronic control unit to close the primary circuit.

Advantages:

1. The parts such as reluctor, magnetic puck-up and electronic control module are not subjected to wear as in case of a mechanical contact beaker.
2. Periodic adjustment of engine timing is not necessary
3. It gives very accurate control of timing.

3.10.4 TRANSISTORIZED IGNITION SYSTEM

A transistor interrupts a relatively high current carrying circuit, i.e., it controls high current in the collector circuit with less current in the base circuit. Therefore, a transistor is used to assist the work of a contact breaker. Hence, this system is known as transistor assisted ignition system or transistorizes ignition system.

Construction:

It consists of battery, ignition switch, transistor, collector, emitter, ballast resistor, contact breaker, ignition coil, distributor and spark plug. The emitter of the transistor is connected to the ignition coil through a ballast resistor. A collector is connected to the battery.

Working:

The cam in the distributor is rotated but the engine. It opens and closes the contact breaker points, when the contact breaker points are closed:

1. A small current flows in the base circuit of the transistor.
2. A large current flows in the emitter or collector circuit of the transistor and the primary winding of the ignition coil due to the normal transistor action.
3. A magnetic field is set up in the primary winding of the coil

When the contact beaker points are open:

1. The current flow in the base circuit is stopped

2. The primary current and the magnetic field in the coil collapse suddenly due to immediate reverting of the transistor to the nonconductive sate.
3. It produces a high voltage in the secondary circuit.
4. This high voltage is directed to the respective spark plugs through the rotor of the distributor.
5. This high voltage produces a spark when it is tried to jump the spark plug gap. It ignites air-fuel mixture in the cylinder.

Advantages:

1. It increases the life of contact breaker p [points
2. It gives higher ignition voltage
3. It gives longer duration of spark
4. It has very accurate control of timing
5. It needs less maintenance

Disadvantages

1. More mechanical points are ended similar to a conventional system
2. It has a tendency to side tracking

3.10.5 CAPACITIVE DISCHARGE IGNITION SYSTEM (CDI)

CDI is most widely used today on automotive and marine engine. A CDI module has capacitor storage of its own and it sends a short high voltage pulse through the coil. The coil now acts similar to a transformer and it multiplies this voltage even higher. Modern CDI coils step up the voltage about 100:1. So, a typical 250V CDI module output is stepped up to over 25,000V output from the coil. The huge advantages of CDI are the higher coil output and hotter spark. The spark duration is much shorter (about 10-12 microseconds) and accurate. It is better at high RPM but it can be a problem for both starting period and lean mixture or high compression situations. CDI systems can use low resistance coils.

3.10.6 DISTRIBUTOR LESS IGNITION SYSTEM

An ignition system does not use a distributor to route high voltage to spark plus called DIS. This system is also called as direct ignition system. The high voltage plug wire runs directly from the ignition coil to the spark plug. The spark timing is controlled by an ignition coil unit and engine control unit. Some DIS systems have one coil for every two spark plug while others has a separate coil for each spark plug. Eliminating the distributor makes the system more reliable and it eliminates maintenance. This system uses either a magnetic crankshaft sensor, camshaft position sensor or both to determine crankshaft position and engine speed. This signal is sent to the ignition control module or engine control module which then energizes the appropriate coil.

Advantages:

1. No timing adjustments are required
2. No distributor cap and rotor are required
3. There are no moving parts to wear out.
4. Least maintenance is required
5. It does not need a distributor which accumulates moisture and cause starting problems.
6. It does not require a distributor to drive thus providing less engine drag.

FUEL INJECTION SYSTEM

Due to the following limitation in the carburetor fuel injector used in the petrol engine they are,

1. In multi cylinder engines, it becomes very difficult for a single carburetor to supply uniform quality and quantity. Since, the induction passengers are of unequal lengths.
2. The carburetor has many wearing parts, after wear, it operates less efficiency
3. There is a loss of volumetric efficiency due to restricted flow of mixture in various parts such as choke tube, jets, throttle valves, inlet pipe bends etc.

All of above limitations of carburetor may be avoided by introducing the fuel thought injection rather than carburation. The main difference between petrol and diesel injection is that the diesel is injected at the end of compression stroke only due to high pressure ratio in diesel engines whereas it may be injected at any time of suction stroke itself in petrol injection. There is no critical timing for petrol injection.

TYPES OF GASOLINE INJECTION SYSTEM:

In a petrol injection, the fuel is injected into the intake manifold through fuel injection valves. There are two basic gasoline injection arrangements.

i) MULTI POINT INJECTION SYSTEM:

In multipoint injection system a separate injector for each cylinder is mounted the inlet manifold. The fuel is injected into each intake portion the manifold side, the inlet valve, so that the mixture preparation and distribution is high by using throttle body and butterfly valve at the intake system, the air flow is metered and controlled.
To pump to the tank, an electrically driven fuel pressure pump is mounted near the fuel tank. The fuel pressure pumps the fuel at a specified pressure (about 700KPa) into a metering distributor. The fuel supplied to the distributor unit should be at constant pressure, so that a relief valve fitter near the distributor returns the excess fuel to the tank. The high pressure fuel is injected for each injection in turn by metering distribution system. The quality of fuel delivered is also controlled in the distributor system by engine manifold pressure. The quantity of fuel delivered by metering distributor is controlled by a Manuel control on the dash board.

Multi point fuel injector is divided into two types, they are

- D-MPFI
- L-MPFI

In the D-MPFI type, the vacuum in the inlet manifold is measured. Moreover it also senses the volume of air by its density. In the L-MPFI type, fuel metering is regulated by the speed of the engine and the actual amount of air entering the engine. This is a port fuel injection system.
Port injection:
Port injection arrangement is provided with an injector placed on the side of the inlet manifold. This refers to multi point fuel injection. The injector sprays the petrol into the air system in the inlet manifold. Then the petrol air mixture passes through the inlet manifold. Each cylinder is provided with an injector in its inlet manifold.

ii) MONO POINT INJECTION SYSTEM:

In a single point injection system, the petrol injection is through a single injector. This is similar to the single carburetor supplying fuel mixture to different cylinders. The injector nozzle supplies the fuel spray by distributing to the individual cylinder of a multi cylinder engine. Air is induced separately into the cylinders. In spite of the advantages of petrol injection still the problem of uniform distribution of fuel among the cylinder may exist.

iii) Throttle body injection system (TBI):

Throttle body injector is a single or mono point injection system. The throttle body is similar to the carburetor throttle body, with the throttle valve controlling the amount of air entering the intake manifold. An injector is placed slightly above the throat of the throttle body. The petrol is sprayed in to the air in the intake manifold and gets mixed with air. Then, the mixture passes through the throttle valve and enters into the intake manifold.

ELECTRONICALLY CONTROLLED GASOLINE INJECTION SYSTEM

In electronically controlled gasoline injection system for SI engine, fuel supply and timings are controlled by electronic means. Electronic fuel injection has developed with the development of solid state electronic devices such as diodes and transistor. Recent days, these systems are commonly used as they function quickly and respond automatically to the change in manifold air pressure, engine speed, crank shaft angle and many other secondary factors.it consists of the following four units:

1. Fuel delivery system
2. Air induction system
3. Sensors and air flow control system
4. Electronic control unit

1. Fuel delivery system:

The reason for using gasoline fuel injection is to control the airfuel ratio of the engine more precisely. This system consists of an electrically driven fuel pump which draws fuel from the fuel tank through filter an forces it into the pressure line. At the end of the pressure line, a fuel pressure regulator is placed. The fuel pressure regulator is connected to the intake manifold. The pressure difference between fuel pressure and manifold pressure is kept constant by this regulator so that the quality of fuel injected is dependent only on the injection open time. Fuel metering is controlled by engine speed and measuring the intake air flow.

2. Air induction system:

The incoming air from atmosphere flows initially through air filter and then through air flow sensor. This air flow sensor measures the amount of air flow in the manifold and generates a voltage signal which is dependent on the amount of air flow. The air flow meter consists of a rectangular plate which turns in a rectangular shaped channel to an angular position dependent on the pressure from flowing air. It returns to original position during normal condition by using a spiral coil spring.

3. Sensor and air flow control system:

Typical sensors used in electronic gasoline injection system are as follows. Air flow sensor: a sensor senses electronic control unit how much air is being drawn into the intake manifold for adjusting the quality of fuel.
Intake air temperature sensor: this sensor measures the temperature of the intake air for fine tuning the mixture strength.

4. Exhaust gas oxygen sensor:

A sensor located in the exhaust system which provides ECU about the amount of oxygen in exhaust gases. From this, ECU can determine if the air/fuel ratio is correct. Manifold pressure sensor: it senses the vacuum pressure in the engines inlet manifold and it gives an indication of the load to the engine.
Speed/ crankshaft sensor: it provides the information to ECU about engine rotating speed send the position of the crankshaft.

5. Engine temperature sensor:

This sensor senses the temperature of the coolant in the engine. Coolant temperature is used determine if more fuel is needed when the engine is cold or warming up.

6. Crankshaft position sensor:

ECU needs to know how fast the engine spinning and where the crankshaft is in its rotation. ECU fires the spark and injectors at the right time.

7. Knock sensor:

The knock sensor is a microphone type sensor that detects the sounds of knocking so that ignition timing can be retarded. A cold start valve is fitted just behind the injection valve to inject additional fuel for cold start. This valve has exceptionally good atomization characteristics. The operation of cold start valve is controlled by a thermo time switch sensor to ensure cold start up to 33oc. The extra fuel is needed by ordinary starting and warm up period is also supplied by this valve. After cold start, the additional air required with richer air-fuel mixture is supplied by an auxiliary air valve during idling condition which by-passes the throttle valve. It is the additional idling speed. The opening of the air valve varies as a function of engine temperature. A throttle valve switch is attached to the throttle valve. It is equipped with a set of contact which generates a sequence of voltage signals during opening of the throttle valve. This signal results the injection of additional fuel required for acceleration through an electronic control unit.

8. Electronic control unit (ECU):

It is the heart of a fuel injection system. It contains a computer which takes information from sensors and controls the amount of fuel injected by operating the injector for just the right amount of time. The unit contains a number of printed circuit boards on which a series of transistors, diodes and other electronic components are mounted. It makes vital data analysis circuits respond to various input signals. The data measured in the form of signals by various sensors such as manifold air pressure, engine speed, crank angle, oxygen in exhaust etc. are transmitted to the electronic control unit. This unit computes the air-fuel ratio required for the best performance of the engine during each engine cycle and it sends signal to the injection valve and other parts of the system. The amount of fuel injected is varied by varying the injector opening time only. ECU cannot be adjusted or serviced.

Advantages:

1. Avery high quality fuel distribution is obtained. Therefore, higher compression ratio can be adopted without any danger of detonation occurring.
2. It increases the volumetric efficiency and hence, it also increases power and torque.
3. The manifold in an injection system carries only air. So, there is no problem of air and fuel separation and the design of manifold becomes simple.
4. It reduces the specific fuel consumption due to better distribution of mixture to each cylinder.
5. It is free from blowbacks and icing
6. Exhaust emissions are less due to precise air-fuel ratio according to engine requirements
7. Better starting and acceleration are ensured than a carbonator system

Disadvantages:

1. Initial cost is very high because of precise and complicated components of the electronic circuit. It is the major disadvantage.

2. More complicated mechanism because of electronic system injection nozzle and fuel injection pump
3. Increased service problem occurs
4. More noise is generated
5. Weight and space requirement are more than a conventional carburetor.

ELECTRONIC DIESEL INJECTION SYSTEM

In conventional diesel injection system, a precise controlled of various parameters related to the injection process such as timing, rate of fuel injection, end of injection, quantity of fuel injected etc. is difficult if the engine is operated at high speed. It may result the reduced efficiency and high emission levels. Conventional systems only senses a few parameters and meter the fuel quantity or adjust the injection timing. Therefore, electronically controlled diesel injection systems have been developed. This system facilitates the precise control of the following parameters.

1. Quantity of fuel injection
2. Injection timing
3. Rate of injection during various stages of injection
4. Injection pressure
5. Speed of nozzle opening
6. Pilot injection timing and its quantity.

Electronically controlled diesel injection system may use the following parameters which can significantly affects the performance of the engine as input.

1. Intake air mass flow rate
2. Intake air temperature and pressure
3. Engine temperature
4. Lubricating oil temperature
5. Engine speed
6. Crankshaft position
7. Turbocharger boost pressure
8. Accelerator pedal position
9. Exhaust gas oxygen level

Components of electronic diesel injection system:

The components of electronically controlled diesel injection systems are divided into the following three main groups. Electronic sensors for registering operating conditions and changes. A wide array of physical inputs is converted into electrical signal outputs.

Actuators or solenoids which convert the control unit's electrical output signal into mechanical control movement.

ECU (electronic control unit) with microprocessors which process information from various sensors in accordance with programmed software and outputs required electrical signals into actuators and solenoids

Various sensors used in electronically controlled diesel injection systems are as follows:

1. Injection pump speed sensor: it monitors pump rotational speed

2. Fuel rack position sensor: it monitors pump fuel rack position
   Charge air pressure sensor: it measures pressure side of the turbocharger

3. Fuel pressure sensor: it measures fuel pressure

4. Engine position sensor

5. Temperature sensors: these measure various operating temperatures such as intake temperature, charge air temperature, coolant temperature, fuel temperature, exhaust temperature, ambient temperature

6. Vehicle speed sensor: it monitors vehicle speed

7. Brake pedal sensor: it operates with cruise control, exhaust brake, idle control

8. Clutch pedal sensor: it operates with cruise control, exhaust brake, idle control
9. Accelerator senor: it monitors the amount of force given to the acceleration pedal
10. Injector needle movement sensor: it monitors the injection time and feeds the information to the ECU.

There are different types of electronically controlled diesel injection system. They are:
1. Unit injector system
2. Rotary distributor system
3. Common rail direct injection system

1. Unit injector system:

This system is also called individual pump injection system. The unit injector system combines the injection nozzle and the high pressure in a single assembly. The high pressure is built up by the activation of the pump plunger of the unit injector by the engine via a tappet or rocker arm. The basic operation can be described as a sequence of four separate phases such as filling phase, spill phase, injection phase and pressure reduction phase. A low pressure fuel delivery pump supplies filtered diesel fuel into the cylinder head fuel ducts and into each injector fuel port of constant stroke pump plunger injector.

Advantages:

1. High performance for clean and powerful engines
2. High engine power balanced against low consumption and low engine emissions
3. High degree of efficiency due to compact design
4. Low noise level due to direct assembly in the engine block

Disadvantages:

1. Separate unit is required for each cylinder with actuation

2. Unit injector system is quite compact since at all operating loads and speeds each pump in this unit should very precisely match its companies and extremely close tolerance are required during manufacturing. Therefore, it involves high costs.

2. Rotary distributor system:

In distributor systems, the fuel is metered at a central point. A pump which pressurizes the fuel also meters the fuel and times the injection. The fuel pump supplies the required amount of fuel after metering it to a rotating distributor at the correct time for supply to each cylinder. The fuel is distributed to cylinders in a correct firing order operated by poppet valves which are opened to admit the fuel to nozzles. Distributor pumps use control sleeves for metering the injected quantity. Thus they can easily make to work with an electronically controlled solenoid actuator.

Advantages:

1. Simple construction
2. Low initial cost
3. Easy maintenance
4. Balanced cylinder fueling

Disadvantages:

1. Overall reduced durability
2. Practically suitable for small engines
3. Common rail direct injection system:

Generally, diesel engines have the specific advantages of good fuel efficiency and low CO_2 emission. Therefore, various new technologies have been developed in order to reduce harmful emissions. One of such technologies is called common rail direct injection system of direct fuel injection. In this system, commencement of combustion takes place system of directly into the main combustion chamber located in a cavity on the top of the piston crown. This system injects diesel five times more accurately than the normal injection system by high response injectors with electronic control. It results the greater reduction of particulate matter and NO_x thereby improving the fuel efficiency and increasing its torque. So, they lead to reduce engine noise and vibration. Various components of CRDI system are:

1. High pressure fuel pump
2. Common fuel rail
3. Injectors
4. Engine control unit

A common rail system consists of pressure accumulator called common rail which is mounted along the engine block. The rail is fed by a high pressure multi-cylinder fuel pump. The injectors are activated by solenoid valves. Both the solenoid valves and fuel pump are electronically controlled.

Advantages:

1. It delivers 25% more power and torque than the normal direct injection engine
2. Initial cost is low

3. Superior pick up is possible
4. It maintains lower levels of noise and vibration
5. Higher mileage is obtained
6. Emissions are low
7. Fuel consumption is less
8. Improved performance is obtained

Disadvantages:

1. Many parts involve the complicated design
2. Production cost is high

UNIT IV

MANIFOLDS AND MIXTURE DISTRIBUTION

4.1 INTRODUCTION TO MANIFOLDS

The word "manifold" is derived from an Old English word meaning many folds, referring to the folding together of the inputs and outputs within the manifold. Both the intake and the exhaust manifold work together to help the engine operate more efficiently.

4.1.1 Intake Manifold

An intake manifold is responsible for evenly distributing air or a combustion mixture to each intake port in an engine's cylinder heads. This is important to optimize efficiency and performance.

4.1.2 Exhaust Manifold

Exhaust manifolds collect engine exhaust from the engine's cylinders and deliver it through one pipe to the vehicle's exhaust pipe. They are usually made of cast iron or stainless steel. Properly functioning exhaust manifolds help optimize efficiency and performance.

Functions

The two manifolds complement each other: the exhaust manifold removes the air that is brought in by the intake manifold. Working together, these two manifolds allow the engine to maximize its performance and efficiency. When it comes to modifying your exhaust or intake system, there are several components you can switch out. But, if you’re looking for the biggest performance improvements and power gains, there are some parts that deliver better results than others. Before you rush off to modify every last component, it’s important to know just how these parts work in order to decide what will deliver the best results. Here, we compare headers vs. manifolds to explain just how they work to improve your ride’s performance.

The Benefits of Exhaust Headers

Exhaust headers are one of the easiest bolt-on modifications you can make to your vehicle to improve your engine’s performance. Headers make it easier for your engine to push exhaust gases out of the cylinders. Your vehicle's engine produces all of its power during the power stroke. During this stroke, the gasoline in the cylinder burns and expands to generate power. Once the exhaust gases vacate the cylinder, they end up in the exhaust manifold and then flow into one pipe toward the catalytic converter. The exhaust header helps eliminate the manifold's back pressure. So, instead of a common manifold that all of the cylinders share, each cylinder gets its own exhaust pipe, and then they come together in a larger pipe called the collector.

Several brands craft performance headers that deliver maximum results, like Gibson headers and Bassani headers. These headers are made with the top-of-the-line materials and superior craftsmanship. Plus, they get the fumes out of your vehicle quicker, which in turn, gets your vehicle moving quicker as well.

The Benefits of Exhaust Manifolds

Exhaust manifolds traditionally funnel spent exhaust gas from the engine. Purely utilitarian, these heavy chunks of cast iron do their job adequately but don't inspire performance. Horsepower and torque is sacrificed in the name of lower manufacturing costs and increased emissions, zapping acceleration from your ride. Even worse, some factory manifolds are prone to cracking, putting even the toughest trucks out of commission. A performance exhaust manifold, like the a Blade Runner Exhaust Manifold, wakes up your street machine with high- flow ductile iron or 304 stainless steel castings. This boosts your low-end grunt for towing and increases mileage when you're just cruisin'. Performance exhaust manifolds are a great bolt- n-go part with very little maintenance needed, unlike headers that require periodical re-tightening.

The majority of exhaust manifolds currently on the road are more akin to tubular exhaust headers with attached catalytic converters. And unfortunately, poor reliability. Adding insult to injury, many drivers experience sticker-shock when the time comes to replace a cracked or failing factory manifold. Thankfully, Pace Setter Exhaust Manifold Catalytic Converters give you an affordable option to replace a damaged manifold. With 16-gauge stainless steel construction, these American- made manifold/catalytic assemblies outlast the best OEM has to offer. On top of that, Pace Setter Exhaust Manifold Catalytic Converters are designed to optimize exhaust flow, giving your ride better fuel economy and power. For a balance of leak- free reliability and a boost in power, a performance exhaust manifold can't be beat.

Benefits of Improving Exhaust Manifolds with Performance Headers & Intake Manifolds

A performance intake manifold is one of the most popular performance upgrades available. Playing an important role, an intake manifold provides the structural base for your vehicle's fuel- induction system. When you feed your engine more air and fuel, it's able to produce more power. So, when you set your ride up with a high quality intake manifold, you'll notice a big boost in power and torque.No matter how many go-fast goodies you bolt on your ride, a restrictive factory exhaust manifold creates a performance bottleneck, robbing power and MPG. All internal combustion engines obey this one rule: fresh air can't come in if spent exhaust can't get out. The solution is to replace those clunky, chunks of metal with a performance manifold, or a custom set of headers, that let your ride breathe freely. These high- flowgems crank out more juice than your stock manifolds, are built to last and often replace worn emissions equipment.

4.2 FUEL SPRAY ATOMIZATION IN COMMON-RAIL SYSTEM FOR DIESEL ENGINES

Introduction

The reasons for conducting at present a wide range of research in the field of reducing the CO2 emission are greater stress put on limiting the CO2 emission and the perspective of introducing limits on CO2 emission regarding the combustion engines producers. These are also reasons for greater interest in application of Diesel engines with direct injection to motor vehicles. Diesel engines, among internal combustion engines, are characterized by the lowest fuel consumption and therefore the minimal CO2 emission.

Alongside with introducing Diesel engines the problems with high emission of NOx and particulates may occur. There is a necessity of simultaneous reducing the CO2 emission and NOx and particulates emission. The solution of these problems may include a better preparation of the mixture, which is lately obtained by increasing the injection pressure even to 200 MPa and using appropriate fuel with strictly determined physical and chemical characteristics, such as viscosity, surface tension, density and precisely specified content of different hydrocarbons in fuel. The aim of such activity is to obtain a stream of small, homogeneous droplets.

In order to generate high-pressure injection the common-rail type fueling system has to be applied. In such system, defined for certain conditions of motor operation, constant injection pressure is maintained. It means that constant circumstances of fuel injection exist, which result in high repeatability of injection course in particular cylinders as well as in time function of engine operation.

Common-rail systems require the use of precise control system, while it is necessary to accurately measure fuel dose. This is realized by the timing of opening injection valve and by the change of injection angle. Such control assures electronic control systems but it cannot be realized with use of mechanical control systems. Investigation of the fuel spray atomization in injection engine systems allow adequate configuration of the streams of injected fuel.

The configuration of the stream should guarantee low fuel consumption and low exhaust emission of toxic components. Examinations of fuel injection can be nowadays carried out at very high, professional level due to development of optical investigation methods, such as high-speed photography, holography and laser anemometry. Reaching the low level of exhaust gas emission is relevant, while Diesel engine runs at high excess of air and hitherto efficient catalytic exhaust after treatment systems for Diesel engines
have not been designed. Experimental results of the influence of the injection pressure and fuel viscosity on the fuel droplet diameter and velocity in the fuel spray are presented in this paper. The measurements of the droplets velocity were performed with use of dynamic laser analyzer LDV (Laser Doppler Velocimeter). The measurements of the droplets diameters were performed using the

PDPA (Phase Doppler Particle Analyzer).

The distribution of droplets in fuel spray were determined by two methods, using laser analyzer PIV (Particle Imaging Velocimetry) and based on the measurement results performed using PDPA system, which also, in some sense, determined values for scaling with PIV system.

The experiments were carried out on the laboratory test stand in the constant volume chamber, at ambient constant temperature and pressure, using two types of fuel with different viscosity. The injection pressure amounted to 50 MPa, 70 MPa, 100 MPa and 130 MPa. The tests results show that injection system fuelled with the fuel of smaller viscosity has produced droplets of smaller diameters, than system fuelled with fuel with bigger viscosity. As for influence of the injection pressure, alongside with the growth of pressure the diameters of droplets decrease, however using the fuel of smaller viscosity resulted in bigger diminution of droplets diameters than with the use of fuel with bigger viscosity

4.3 Mechanism of fuel spray preparation

Many theoretical and research works have been devoted to the problem of generating fuel spray, however they did not lead to establishing synonymous views on this matter. Disintegration of the fuel spray is connected with disturbance on its surface due to performance of the internal and external forces on surface tension forces. Disintegration of the fuel spray occurs while the value of the tensile force exceeds the value of the consolidation force, which is the surface tension. The formed large droplets may experience further disintegration if they are found in the area of variable dynamic pressures growing together with the growth of relative velocity, which can be noticed especially at high injection pressures. The biggest impact on droplets diameter has aerodynamic forces as well as forces generated by surface tension. When aerodynamic force raises the deformation and further disintegration of droplets occur.

The most common criterion of droplet disintegration is Weber Number (equality of aerodynamic forces and surface tension). Disintegration occurs if $We \geq We_{kr}$.

Weber Number (We) is defined as:

$We\ d = w2\ \rho\sigma$,

where:

w – droplet relative velocity,

ρ - gas density,

d – droplet diameter,

σ - surface tension.

Weber Number shows high accordance with tests results in conditions of determined liquid flow, when the injection sets in the medium, which lacks of factor influence. If droplets are influenced by acceleration or injection sets in the stream of flowing liquid, the conditions of droplets disintegration change. There are many formulas, which take into account differences in conditions in which Weber Number was derived and the actual stream disintegration conditions.

At high injection pressures, as it occurs in common-rail systems, the droplet relative velocity increases, which influences secondary disintegration. As it was mentioned earlier in this paper, huge impact on droplets diameter and distribution is influenced by fuel viscosity and surface tension. The growth of dynamic viscosity causes larger range of fuel spray and decrease in its volume. Viscosity and surface tension influence on the size of the droplet diameter, according to empirical dependence:

$r = -\ A\ w3\sigma Ep\ \mu$

where:

Ep – pulsation energy,

μ, σ - dynamic viscosity and surface tension respectively.

The number and variety of factors that have impact on generating droplets, cause that theoretical dependences are not able to illustrate the phenomenon complexity. In the conditions of Diesel engine operation course of fuel injection is variable, which results from change in forcing, of fuel injection pump velocity, lasting effects, which accompany the outflow and disturbances caused by fuel compressibility and vibration of the system. These complicated motor operation conditions cause experimental methods of investigations of fuel spray atomization assure better tests results.

Spray Pattern Selecting a nozzle based on the pattern and other spray characteristics that are required generally yields good results. Since spray nozzles are designed to perform under many different spraying conditions, more than one nozzle may meet the requirements for a given application. Surfaces may be sprayed with any pattern shape. Results are fairly predictable, depending on the type of spray pattern specified. If the surface is stationary, the preferred nozzle is usually some type of full cone nozzle, since its pattern will cover a larger area than the other styles. Spatial applications, in which the objective is not primarily to spray onto a surface, are more likely to require specialized spray characteristics. Success in these applications is often completely dependent on factors such as drop size and spray velocity. Evaporation, cooling rates for gases and solids, and cleaning efficiency are examples of process characteristics that may depend largely on spray qualities. Each spray pattern is described below with typical end use applications.

4.3.1 Solid Stream

This type of nozzle provides a high impact per unit area and is used in many cleaning applications, for example, tank-cleaning nozzles (fixed or rotary).

4.3.2 Hollow Cone

This spray pattern is a circular ring of liquid. The pattern is achieved by the use of an inlet orifice tangential to a cylindrical swirl chamber that is open at one end. The circular orifice exit has a diameter smaller than the swirl chamber. The whirling liquid results in a circular shape; the center of the ring is hollow.Hollow cone nozzles are best for applications requiring good atomization of liquids at low pressures or when quick heat transfer is needed. These nozzles also feature large and unobstructed flow passages, which provide a relatively high resistance to clogging. Hollow cone nozzles provide the smallest drop size distributions. The relative range of drop sizes tends to be narrower than other hydraulic styles.The hollow cone pattern is also achievable by the spiral design of nozzle. This nozzle impinges the fluid upon a protruding spiral. This spiral shape breaks the fluid apart into several hollow cone patterns. By altering the topology of the spiral the hollow cone patterns can be made to converge to form a single hollow cone.

4.3.3 Full Cone

Full cone nozzles yield complete spray coverage in a round, oval or square shaped area. Usually the liquid is swirled within the nozzle and mixed with non-spinning liquid that has bypassed an internal vane. Liquid then exits through an orifice, forming a conical pattern. Spray angle and liquid distribution within the cone pattern depend on the vane design and location relative to the exit orifice. The exit orifice design and the relative geometric proportions also affect the spray angle and distribution. Full cone nozzles provide a uniform spray distribution of medium to large size drops resulting from their core design, which features large flow passages. Full cone nozzles are the style most extensively used in industry.

4.4 Flat Spray

As the name implies, the spray pattern appears as a flat sheet of liquid. The pattern is formed by an elliptical or a round orifice on a deflective surface that is tangent to the exit orifice. The orifice has an external groove with a contoured internal cylindrical radius, or “cat’s eye” shape. In the elliptical orifice design, the pattern sprays out of the orifice in line with the pipe. In the deflector design, the spray pattern is perpendicular to the pipe. There are two categories of flat spray, tapered and even, depending on the uniformity of the spray over the spray pattern. Flat spray patterns with tapering edges are produced by straight-through elliptical spray nozzles. This spray pattern is useful for overlapping patterns between multiple nozzle headers. The result is uniform distribution across the entire sprayed surface. Non-tapered flat spray nozzles are used in cleaning applications that require a uniform spray pattern without any overlap in spray area.

Multiple Plume Spray

Multiple plume sprays are routinely used in automotive injectors. The multiple plumes are primarily used to provide for the optimal mixing of fuel and air so as to reduce pollutant emission under different operating conditions. The multiple plume automotive injectors can have anywhere from 2 to 8 plumes. The precise location of the centroid of these plumes, the individual plume angles, and the percentage split of the liquid amongst the plumes are normally obtained using an optical patternator.

Spray nozzle manufacturers all tabulate capacity based on water. Since the specific gravity of a liquid affects its flow rate, the values must be adjusted using the equation below, where Qw is the water capacity and Spg is the specific gravity of the fluid used resulting the volumetric flow rate of the fluid used.

Nozzle capacity varies with spraying pressure. In general, the relationship between capacity and pressure is as follows:

where

Q1 is the known capacity at pressure P1,

Q2 is the capacity to be determined at pressure P2.

Spray Impact

Impact of a spray onto the target surface is expressed as the force/area, N/m2 or lb/in2. This value depends on the spray pattern distribution and the spray angle. Generally, solid stream nozzles or narrow spray angle flat fan nozzles are used for applications in which high impact is desired, such as cleaning. When a nozzle is used for cleaning, the impact or pressure is called impingement. As with all spray patterns, the unit impact decreases as the distance from the nozzle increases, thereby increasing the impact area size.

The spray impact, depends on the volumetric flowrate Q and pressure drop according to the equation below. The nozzle type and distance between the nozzle and surface affect the constant C.

Spray Angle and Coverage

The spray angle diverges or converges with respect to the vertical axis. As illustrated in the figure below, the spray angle tends to collapse or diverge with increasing distance from the orifice. Spray coverage varies with spray angle. The theoretical coverage, C, of spray patterns at various distances may be calculated with the equation below for spray angles less than 180 degrees. The spray angle is assumed to remain constant throughout the entire spray distance. Liquids more viscous than water form smaller spray angles, or solid streams, depending upon nozzle capacity, spray pressure, and viscosity. Liquids with surface tensions lower than water produce wider spray angles than those listed for water. Spray angles are typically measured using optical or mechanical methods. The optical methods include shadow graphy, extinction tomography, and Mie Imaging.[3] Sprays angles are important in coating applications to prevent over spraying of the coated materials, in combustion engines to prevent wetting of the cylinder walls, and in fire sprinklers to provide adequate coverage of the protected property.

Spray Drop Size

The drop size is the size of the spray drops that make up the nozzle's spray pattern. The spray drops within a given spray are not all the same size. There are several ways to describe the drop sizes within a spray:

- Sauter Mean Diameter (SMD) or D32
- Fineness of spray expressed in terms of surface area produced by the spray.
- Diameter of a drop with the same volume-to-surface area ratio as the total volume of all the drops to the total surface area of all the drops .
- Volume Median Diameter (VMD) DV0.5 and Mass Median Diameter (MMD)
- Drop size expressed in terms of the volume of liquid sprayed.
- Drop size measured in terms of volume (or mass), with 50% of total volume of liquid sprayed drops with diameters larger than median value and 50% with smaller diameter.

Drop sizes are stated in micrometers (µm). One micrometer equals 1/25,400 inch.

Drop Size Distribution

The size and/or volume distribution of drops in a spray is typically expressed by the size versus the cumulative volume percent.

Relative Span Factor

Comparing drop size distributions from alternate nozzles can be confusing. The Relative Span Factor (RSF) reduces the distribution to a single number. The parameter indicates the uniformity of the drop size distribution. The closer this number is to zero, the more uniform the spray will be (i.e. tightest distribution, smallest variance from the maximum drop size, Dmax, to the minimum drop size, Dmin). RSF provides a practical means for comparing various drop size distributions.

Drop size measurement

Sprays are typically characterized by statistical quantities obtained from size and velocity measurements over many individual droplets. The most widely used quantities are size and velocity probability density distributions as well as fluxes, e.g., number, mass, momentum etc. Through a given plane, some instruments infer such statistical quantities from individual measurements, e.g., number density from light extinction, but very few instruments are capable of making direct size and velocity measurements of individual droplets in a spray. The three most widely used methods of drop size measurements are laser diffraction, optical imaging, and phase Doppler. All of these optical methods are non-intrusive. If all the drops had the same velocity, the measurements of drop size would be the identical for all methods. However, there is a significant difference between the velocity of larger and smaller drops. These optical methods are classified as either spatial or flux based. A spatial sampling method measures the drops in a finite measurement volume. The residence time of drops in the measurement volume affects the results. The flux-based methods sample continually over a measurement cross-section. Laser diffraction, a spatial sampling method, relies on the principle of Fraunhofer diffraction, which is caused by the light interacting with the drops in the spray. The scattering angle of the diffraction pattern is inversely related to the size of the drop. This nonintrusive method utilizes a long cylindrical optical probe volume. The scattered light passes through a special transforming lens system and is collected on a number of concentric photodiode rings. The signal from the photodiodes is used to back-calculate a drop size distribution. A number of lenses allow measurements from 1.2 to 1800 µm.

The optical imaging method uses a pulsed light, laser or strobe, to generate the shadow graphic image used to determine the size of the drop in the measurement volume. This spatial measurement method has a range from 5 µm to 10,000 µm with lens and optical configuration changes. Image analysis software processes the raw images to determine a circular equivalent drop diameter. This method is best suited to quantify larger diameter drops in medium to low density sprays, opaque liquids (slurries), and ligaments (partially formed drops).Phase Doppler, a flux-based method, measures particle size and velocity simultaneously. This method, also known as PDPA, is unique because the drop size and velocity information is in the phase angle between the detector signals and the signal frequency shift. Because this method is not sensitive to intensity, it is used in more dense sprays. The range of drop sizes is 1 to 8000 µm. At the heart of the method are crossed laser beams that create interference patterns (regular spaced pattern of light and dark lines) and illuminate drops as they pass through the small measurement zone. A series of three off axis detectors collects the optical signal that is used to determine the phase angle and frequency shift caused by the drops.

Optical imaging and phase Doppler methods measure the size of individual drops. A sufficient number of drops (order of magnitude 10,000 drops) must be quantified to produce a representative distribution and to minimize the effect of random fluctuations. Often several measurement locations in a spray are necessary because the drop size varies over the spray cross-section.

Factors Affecting Drop Size

Nozzle type and capacity: Full cone nozzles have the largest drop size, followed by flat spray nozzles. Hollow cone nozzles produce the smallest drop size. Spraying pressure: Drop size increases with lower spraying pressure and decreases with higher pressure. Flow rate: Flow rate has a direct effect on drop size. An increase in flow rate will increase the pressure drop and decrease the drop size, while a decrease in flow rate will decrease the pressure drop and increase the drop size.

Spray angle:

Spray angle has an inverse effect on drop size. An increase in spray angle will reduce the drop size, whereas a reduction in spray angle will increase the drop size.

Liquid properties:

Viscosity and surface tension increase the amount of energy required to atomize the spray. An increase in any of these properties will typically increase the drop size. Within each type of spray pattern the smallest capacities produce the smallest spray drops, and the largest capacities produce the largest spray drops. Volume Median Diameter (VMD) is based on the volume of liquid sprayed; therefore, it is a widely accepted measure

Spray Drop Surface Area Density

The drop surface area density is the product of the spray drop surface area and the number of drops per unit volume. The surface area density is very important in evaporation and combustion applications since the local evaporation rate is highly correlated to the surface area density. The extinction of light caused by the drops within a spray is also directly proportion to the surface area density. The two most widely used methods of measuring the surface area density are Laser Sheet Imaging and Statistical Extinction Tomography.

Fuel Atomization

The first step in the mixture formation process in the conventional, mixing controlled diesel engine combustion is spray formation. It shows a spray formed by injecting fuel from a single hole in stagnant air. Upon leaving the nozzle hole, the jet becomes completely turbulent a very short distance from the point of discharge and mixes with the surrounding air. This entrained air is carried away by the jet and increases the mass-flow in the x-direction and causes the jet to spread out in the y-direction. Two factors lead to a decrease in the jet velocity: the conservation of momentum when air is entrained into the jet and frictional drag of the liquid droplets.. The fuel velocity is highest at the centerline and decreases to zero at the interface between the zone of disintegration (or the conical envelope of the spray) and ambient air.

Primary Atomization.

Near the injector nozzle, the continuous liquid jet disintegrates into filaments and drops through interaction with the gas in the cylinder. This initial break-up of the continuous liquid jet is referred to as primary atomization.In general, the atomization of a jet can be divided into different regimes depending on the jet velocity.

Fuel pump

A fuel pump is a frequently (but not always) essential component on a car or other internal combustion engined device. Many engines (older motorcycle engines in particular) do not require any fuel pump at all, requiring only gravity to feed fuel from the fuel tank or under high pressure to the fuel injection system. Often, carbureted engines use low pressure mechanical pumps that are mounted outside the fuel tank, whereas fuel injected engines often use electric fuel pumps that are mounted inside the fuel tank (and some fuel injected engines have two fuel pumps: one low pressure/high volume supply pump in the tank and one high pressure/low volume pump on or near the engine). Fuel pressure needs to be within certain specifications for the engine to run correctly. If the fuel pressure is too high, the engine will run rough and rich, not combusting all of the fuel being pumped making the engine inefficient and a pollutant. If the pressure is too low, the engine may run lean, misfire, or stall.

4.5 Mechanical pump

Mechanical fuel pump, fitted to cylinder head Prior to the widespread adoption of electronic fuel injection, most carbureted automobile engines used mechanical fuel pumps to transfer fuel from the fuel tank into the fuel bowls of the carburetor. The two most widely used fuel feed pumps are diaphragm and plunger-type mechanical pumps. Diaphragm pumps are a type of positive displacement pump. Diaphragm pumps contain a pump chamber whose volume is increased or decreased by the flexing of a flexible diaphragm, similar to the action of a piston pump. A check valve is located at both the inlet and outlet ports of the pump chamber to force the fuel to flow in one direction only. Specific designs vary, but in the most common configuration, these pumps are typically bolted onto the engine block or head, and the engine's camshaft has an extra eccentric lobe that operates a lever on the pump, either directly or via a pushrod, by pulling the diaphragm to bottom dead center. In doing so, the volume inside the pump chamber increased, causing pressure to decrease. This allows fuel to be pushed into the pump from the tank (caused by atmospheric pressure acting on the fuel in the tank). The return motion of the diaphragm to top dead center is accomplished by a diaphragm spring, during which the fuel in the pump chamber is squeezed through the outlet port and into the carburetor. The pressure at which the fuel is expelled from the pump is thus limited (and therefore regulated) by the force applied by the diaphragm spring.

The carburetor typically contains a float bowl into which the expelled fuel is pumped. When the fuel level in the float bowl exceeds a certain level, the inlet valve to the carburetor will close, preventing the fuel pump from pumping more fuel into the carburetor. At this point, any remaining fuel inside the pump chamber is trapped, unable to exit through the inlet port or outlet port. The diaphragm will continue to allow pressure to the diaphragm, and during the subsequent rotation, the eccentric will pull the diaphragm back to bottom dead center, where it will remain until the inlet valve to the carburetor reopens.Because one side of the pump diaphragm contains fuel under pressure and the other side is connected to the crankcase of the engine, if the diaphragm splits (a common failure), it can leak fuel into the crankcase. The capacity of both mechanical and electric fuel pump is measured in psi (which stands for pounds per square inch). Usually, this unit is the general measurement for pressure, yet it has slightly different meaning, when talking about fuel pumps[2]. In this context it denotes the speed, at which the pump delivers fuel from the tank to the engine. This is one of fuel pump characteristics. The higher pressure is, the faster fuel flows.

4.5.1 Plunger-Type Fuel Pump

Plunger-type pumps are a type of positive displacement pump that contain a pump chamber whose volume is increased and/or decreased by a plunger moving in and out of a chamber full of fuel with inlet and discharge stop-check valves. It is similar to that of a piston pump, but the high-pressure seal is stationary while the smooth cylindrical plunger slides through the seal. These pumps typically run at a higher pressure than diaphragm type pumps. Specific designs vary, but in the most common configuration, these pumps are mounted on the side of the injection pump and driven by the camshaft, either directly or via a pushrod.[3] When the camshaft lobe is at top dead center, the plunger has just finished pushing the fuel through the discharge valve. A spring is used to pull the plunger outward creating a lower pressure pulling fuel into the chamber from the inlet valve. These pumps can run between 250 and 1,800 bar (3,625 and 26,000 psi). Because it is connected to the camshaft, the discharge pressure of these pumps is constant, but the rate at which it pumps is directly correlated to the revolutions per minute (rpm) of the engine.

Both pumps create negative pressure to draw the fuel through the lines. However, the low pressure between the pump and the fuel tank, in combination with heat from the engine and/or hot weather, can cause the fuel to vaporize in the supply line. This results in fuel starvation as the fuel pump, designed to pump liquid, not vapor, is unable to suck more fuel to the engine, causing the engine to stall. This condition is different from vapor lock, where high engine heat on the pressured side of the pump (between the pump and the carburetor) boils the fuel in the lines, also starving the engine of enough fuel to run. Mechanical automotive fuel pumps generally do not generate much more than 10–15 psi, which is more than enough for most carburetors.

4.5.2 Decline of mechanical pumps

As engines moved away from carburetors and towards fuel injection, mechanical fuel pumps were replaced with electric fuel pumps, because fuel injection systems operate more efficiently at higher fuel pressures (40–60 psi) than mechanical diaphragm pumps can generate. Electric fuel pumps are generally located in the fuel tank, in order to use the fuel in the tank to cool the pump and to ensure a steady supply of fuel.

Another benefit of an in-tank mounted fuel pump is that a suction pump at the engine could suck in air through a (difficult to diagnose) faulty hose connection, while a leaking connection in a pressure line will show itself immediately. A potential hazard of a tank-mounted fuel pump is that all of the fuel lines are under (high) pressure, from the tank to the engine. Any leak will be easily detected, but is also hazardous.

4.5.3 Electric pump

In many modern cars the fuel pump is usually electric and located inside the fuel tank. The pump creates positive pressure in the fuel lines, pushing the gasoline to the engine. The higher gasoline pressure raises the boiling point. Placing the pump in the tank puts the component least likely to handle gasoline vapor well (the pump itself) farthest from the engine, submersed in cool liquid. Another benefit to placing the pump inside the tank is that it is less likely to start a fire. Though electrical components (such as a fuel pump) can spark and ignite fuel vapors, liquid fuel will not explode (see flammability limit) and therefore submerging the pump in the tank is one of the safest places to put it. In most cars, the fuel pump delivers a constant flow of gasoline to the engine; fuel not used is returned to the tank. This further reduces the chance of the fuel boiling, since it is never kept close to the hot engine for too long.

4.5.4 Electric fuel pump

An advantage of an electric fuel pump is reduced fuel consumption because it does not have the resistance associated with a mechanical drive and because the fuel supply can be monitored more accurately by the electronic control unit (ECU). Pre-delivery of fuel can also be accomplished by an electric fuel pump because it does not depend on engine rpm. Due to this, rapid engine starting can be implemented to conserve gas. This is particularly important in stop-start systems where the engine turns itself off when it senses no use, such as stopped at a stoplight.

The ignition switch does not carry the power to the fuel pump; instead, it activates a relay which will handle the higher current load. It is common for the fuel pump relay to become oxidized and cease functioning; this is much more common than the actual fuel pump failing. Modern engines utilize solid-state control which allows the fuel pressure to be controlled via pulse-width modulation of the pump voltage. This increases the life of the pump, allows a smaller and lighter device to be used, and reduces electrical load.

Cars with electronic fuel injection have an electronic control unit (ECU) and this may be programmed with safety logic that will shut the electric fuel pump off, even if the engine is running. In the event of a collision this will prevent fuel leaking from any ruptured fuel line. Additionally, cars may have an inertia switch (usually located underneath the front passenger seat) that is "tripped" in the event of an impact, or aroll-over valve that will shut off the fuel pump in case the car rolls over.

Some ECUs may also be programmed to shut off the fuel pump if they detect low or zero oil pressure, for instance if the engine has suffered a terminal failure (with the subsequent risk of fire in the engine compartment).

The fuel sending unit assembly may be a combination of the electric fuel pump, the filter, the strainer, and the electronic device used to measure the amount of fuel in the tank via a float attached to a sensor which sends data to the dash-mounted fuel gauge. The fuel pump by itself is a relatively inexpensive part. But a mechanic at a garage might have a preference to install the entire unit assembly.

4.5.5 Diesel Fuel Pumps

Diesel fuel pumps operate at a much higher pressure due to the engine's specs and are usually mechanical pumps such as common rail radial piston pump, common rail two piston radial, inline pump, port and helix, and metering unit design. Radial piston pumps used in cars and trucks are fuel lubricated, this helps with keeping oil out of the high pressure fuel. Oil in the fuel can raise emissions and clog injectors. Many diesel engines are common rail, which means all the injectors are supplied by one pipe full of high pressure fuel supplied by the fuel pump. Common rails dampen the pressure fluctuations when fuel is used by each injector and pumped into the cylinder. Common rails also make it easier for the fuel pressure to be measured by one device instead of one per cylinder. Port and Helix (plunger type) high pressure fuel pumps are most commonly used in marine diesels because of their simplicity, reliability, and its ability to be scaled up in proportion to the engine size.

4.5.6 Port and Helix type pump

Port and Helix pumps are cam driven plunger type pumps that run at one-half engine rpm for four stoke engines and at the same rpm in the case of a two stroke. The pump is similar to that of a radial piston type pump but instead of a piston it has a machined plunger that has no seals. When the plunger is at top dead center, the injection to the cylinder is finished and it is returned on its downward stroke by a compression spring.Because the height of the cam lobe cannot be easily changed, the amount of fuel being pumped to the injector is controlled by a rack and pinion device that rotates the plunger allowing variable amounts of fuel to the area above the plunger. Inlet and outlet ports are located on two sides of the pumps cylinder walls allowing fuel to flow through the compression chamber until the plunger is driven up closing the two ports and starting the compression motion. The outlet port feeds back into the fuel tank/settler of the engine. The fuel is then forced through a stop check valve, to prevent backflow to the injector nozzle at pressures that can exceed 18,000 psi.

4.5.7 Turbopumps

Many jet engines, including rocket engines use a turbopump which is a centrifugal pump usually propelled by a gas turbine or in some cases a ram-air device (particularly in ramjet engines which lack a shaft).

Basic Components of the Fuel Intake System and their function

• Air cleaner, Carburetor, Engines, Fuel Intake System, Intake Manifold. Different Internal Combustion engines work by the use of different fuel intake systems. In this article, we shall discuss the basic components of an intake system and their respective functions irrespective of the type of intake system that it functions with.

The primary components of the automotive intake system are:

- intake manifold,
- throttle body/carburetor, and
- air induction components such as air cleaner and ducting.

Intake Manifold :

The intake manifold is attached to the cylinder head. Its construction and design depends on its application. It is normally made of an aluminum alloy. On carburetor engines, the intake manifold supports or houses the carburetor. While on EFI engines it can house or support a throttle body.

Throttle body/Carburetor:

The intake manifold can accommodate a carburetor or a Throttle Body Injection unit as illustrated. In either case the mixing of the air/fuel mixture is done at the manifold base. The butterfly shaft connected to the throttle cable controls the airflow through the unit. In multi-point EFI systems, a throttle body is attached to the intake manifold. While the butterfly shaft is attached the throttle cable, it also has a Throttle Position Sensor (TPS) attached to it as well. The TPS signals the ECU of the throttle opening position so it can complete its fuel requirement calculations.

4.6 Air Induction Component

Air cleaner

The air induction components consist of an air cleaner and housing, solid and flexible-duct tubing, and connectors. The air induction system draws in ambient air from the environment. The inlet opening may be located in various positions under the hood. The air cleaner filters the incoming air. The air cleaner element may be manufactured from pleated paper, oil impregnated cloth or felt, or in an oil bath configuration. Another function of the air cleaner is to muffle the resonation (that is, dampen the noise) of the swirling incoming air.The location of the air cleaner is dependent on the available space and the hood design

Ducting

The ducting can be made of hardened plastic with flexible rubber couplings to absorb engine movement. These are usually secured in place by metal worm drive clamps.

Parts of Vehicle's Air Intake System and Its Working

1. Parts of Vehicle's Air Intake System and Its Working

2. Air intake system is built and tuned for an automobile to experience maximum power and efficiency. Most of them are bolt up installations, making them an excellent add-on for easy power gains. A good air intake system allow continuous and clean air into the engine, thereby to achieve better mileage and optimum performance for your vehicle.

3. Parts of an air intake system An air intake system is located behind the front grille, drawing air through a tube that goes in to the filter housing, which will be mixed with the vehicle's fuel and sent to the engine's cylinder. A modern automobile/ vehicle's air intake system has three main parts Air filter: It forms an important part of a vehicle's intake system through which the engine breathes. Any engine requires a mixture of air and fuel in order to run, and all the air first enters the system through the air filter. Air filter is located in a compartment of an air duct under the hood of the car.

4. Mass Air Flow Sensor: This part of the air intake system is used to measure the mass of air that enters the fuel-injected internal combustion engine. Two common types of airflow sensors are in use for automobile engines. The hot wire The vane meter Throttle Body: It controls the amount of air entering the engine's combustion chamber. It is located near the mass flow sensor and in between the intake manifold and air filter box. Working procedure of an air intake system In a carburetor equipped engine, the air comes in to air filter space.

5. The main job of the air filter is to filter out dirt particles and other foreign matter present in the air, thus preventing them to enter and cause damage to the system. Air passing through the air filter reaches the carburetor and is blended with the fuel. Through the intake manifolds, the mixture of air and fuel is drawn into the cylinders. The mass airflow sensor/ air temperature sensor prevents the icing of the carburetor, where in its absence may lead to vehicle's stall. It also promotes vaporization of the fuel into the air stream. Also, it is used to measure the temperature of the air and allows cool air in, which occurs through closing and opening of the flap. Here the working of both types of airflow sensors have been mentioned for your understanding.

6. In the hot wire type, a series of wires are embed in the air stream. Due to the rise in temperature, the electrical resistance increases thus limiting the current flow through the circuit. When air flows past the wire, it cools down, allowing more current to flow through the circuit, thus decreasing its resistance. The voltage signal developed goes to the main system where the fuel mixture is allowed to adjust. In the vane type, a flap is forced back by the incoming air. The more air coming in, the more the flap is pushed back.

7. A potentiometer attached to the flap sends a voltage signal to the power-train control module. Also, a second vane present behind the first vane suppresses its movement thus giving more accurate measurement. The air from the mass flow sensor is directed to the throttle body for further process. Throttle body contains a bored housing that consists of throttle plate rotating on a shaft. The air that flows in to the engine is controlled by the throttle chamber. When the accelerator is released, the throttle plate closes and clogs air flow into the combustion chamber and when it is depressed it opens and allows air in to the engine.

8. This process performed by the throttle body effectively controls the rate of combustion and speeds up the vehicle. So, this is how the air enters the engine and the air intake system work. Having knowledge on this will lessen the ignorance when it comes to intake matters.

9. Airtex Fuel Delivery Systems is the leading aftermarket supplier of mechanical and electric fuel pumps and modular reservoir assemblies (MRA). For over 50 years, the Airtex brand has been the benchmark of fuel delivery and cooling system components. Airtex fuel pump is an OE replacement pump. Airtex electric fuel pumps and mechanical pump models are available for old and new cars.

Exhaust heat recovery system

In transportation, an exhaust heat recovery system turns thermal losses in the exhaust pipe into energy. This technology seems to be more and more of interest by car and heavy-duty vehicle manufacturers as an efficient way to save fuel and reduce vehicles' CO_2 emissions. This technology can be used either on a hybrid vehicle or a conventional one: it produces either electric energy for batteries or mechanical energy reintroduced on the crankshaft.

Thermal losses of an internal combustion engine, Even if current engines consume less fuel than they used to, the thermal efficiency of an internal combustion engine has not really increased since its creation. The peak efficiency reached by a 4-cycle Otto cycle engine is around 35%, which means that 65% of the energy contained in the fuel is lost as pumping losses, friction losses, cooling losses, exhaust losses and accessories. High speed Diesel cycle engines fare better with around 45% peak efficiency, but are still far from the Carnot efficiency, and hence 55% of the fuel energy content is lost.

4.7 Thermal losses in the exhaust pipe

Inside the exhaust pipe of an internal combustion engine, energy losses are various: thermal, kinetic, chemical and latent heat. Most important energy parts are located in the thermal and kinetic losses, the two others are negligible. Kinetic losses can be recovered through a turbocharger or a turbo-compound.

4.8 Exhaust heat recovery technologies (EGHR)

The 2016 Chevrolet Malibu Hybrid car features an Exhaust gas Heat Recovery (EGHR) system to accelerate coolant heat up time. This gives faster heat up of the engine coolant which in turn heats up the engine faster. Less fuel is used giving reduced emissions. This will also quicken cabin heating warm up for passenger comfort and window defrosting. For hybrid applications it also can warm the battery pack. The cooling system is connected to a heat exchanger placed in the exhaust gas transferring the thermal energy from the exhaust gas to the cooling system. When the engine is warmed up the exhaust gas is diverted to a by-pass pipe.

4.9 Rankine Cycle

A typical Rankine Cycle is a thermodynamic cycle that uses a fluid and works through four reversible processes. In transportation, Rankine cycle systems vaporize a pressurized fluid, thanks to a steam generator located in the exhaust pipe. As a result of the heating by exhaust gases, the fluid is turned into steam/vapor. The pressure will then drive the expander of the Rankine engine, which could be a turbine as well as a volumetric expander. This expander can be either directly tied to the crankshaft of the thermal engine or linked to an alternator to generate electricity. The Fluid used in Rankine Cycle Engines can be a “humid” fluid (such as water) or a “dry” organic fluids. The choice of the fluid depends in particular on the running temperature of the system. Researchers at Loughborough University and the University of Sussex, both in the UK, also have concluded that using waste heat from light-duty vehicle engines in a steam power cycle could deliver fuel economy advantages of between 6.3% and 31.7%, depending upon drive cycle, and that high efficiencies can be achieved at practical operating pressures.

4.10 Electric Turbo Compounding (ETC)

Electric Turbo Compounding (ETC) is a technology solution to the challenge of improving energy efficiency for the stationary power generation industry.

Fossil fuel based power generation is predicted to continue for decades, especially in developing economies. This is against the global need to reduce carbon emissions, of which, a high percentage is produced by the power sector worldwide.

ETC works by making gas and diesel-powered gensets (Electric Generators) work more effectively and cleaner, by recovering waste energy from the exhaust to improve power density and fuel efficiency.

Advantages of using ETC

- Helps developing economies with unreliable or insufficient power infrastructure.
- Gives independent power providers (IPPs), power rental companies and generator OEMs (original equipment manufacturers) a competitive advantage and potential increased market share.
- Improves overall efficiency of the genset, including fuel input costs and helping end-users reduce amount of fuel burned.
- Typically 4-7% less fuel consumption for both diesel and gas gensets.
- Fewer carbon emissions.
- Increased power density.
- Capability to increase power output and capacity, with improved fuel efficiency.

- ETC system integration offers a step change in efficiency without increasing service or maintenance requirements.
- The cost of generating power through waste heat recovery is substantially less than burning more fuel, even with low diesel prices

Disadvantages of using ETC

- Upfront costs incur an additional expense for businesses.
- The need to update existing turbomachinery and recertification of the unit adds additional costs and can be time consuming.
- There will be additional weight to add an ETC to a current unit.
- Process still uses fossil fuels, thus still has a carbon footprint in a renewable age.
- They are bespoke to each generator so the design, build and implementation can be a lengthy process.
- There are challenges with high speed turbo generators such as high stress in the rotors, heat generation of the electrical machine and rotordynamics of the turbo generator system.

UNIT – V

COOLING AND LUBRICATION SYSTEM

5 .1 INTRODUCTION:

The study of fuels for IC engines has been carried out ever since these engines came into existence.

Petroleum as obtained from the oil wells is predominantly a mixture of many hydrocarbons with differing molecular structure. It also contains small amounts of sulphur, oxygen, nitrogen and impurities such as water and sand. The carbon and hydrogen atoms may be linked in different ways in a hydrocarbon molecule and this linking influences the chemical and physical properties of different hydrocarbon groups. Most petroleum fuels tend to exhibit the characteristics of the type of hydrocarbon which forms a major component of the fuel.

The basic families of hydrocarbons, their general formulae and their molecular arrangement are shown in table.

Table 5.1 Basic Families of Hydrocarbons

Family of Hydrocarbons	**General Formula**	**Molecular Structure**	**Saturated / Unsaturated**	**Stability**
Paraffin	CnH2n+2	Chain	Saturated	Stable
Olefin	CnH2n	Chain	Unsaturated	Unstable
Naphthene	CnH2n	Ring	Saturated	Stable
Aromatic	CnH2n-6	Ring	Highly Unsaturated	Most Unstable

5.2 PETROLEUM REFINING PROCESS:

Crude petroleum, as obtained from the oil wells contains gases (mainly methane and ethane) and certain impurities such as water, solids etc. The crude oil is separated into gasoline, kerosene, fuel oil etc. By the process of fractional distillation. This process is based on the fact that the boiling points of various hydrocarbons increase with increase in molecular weight.

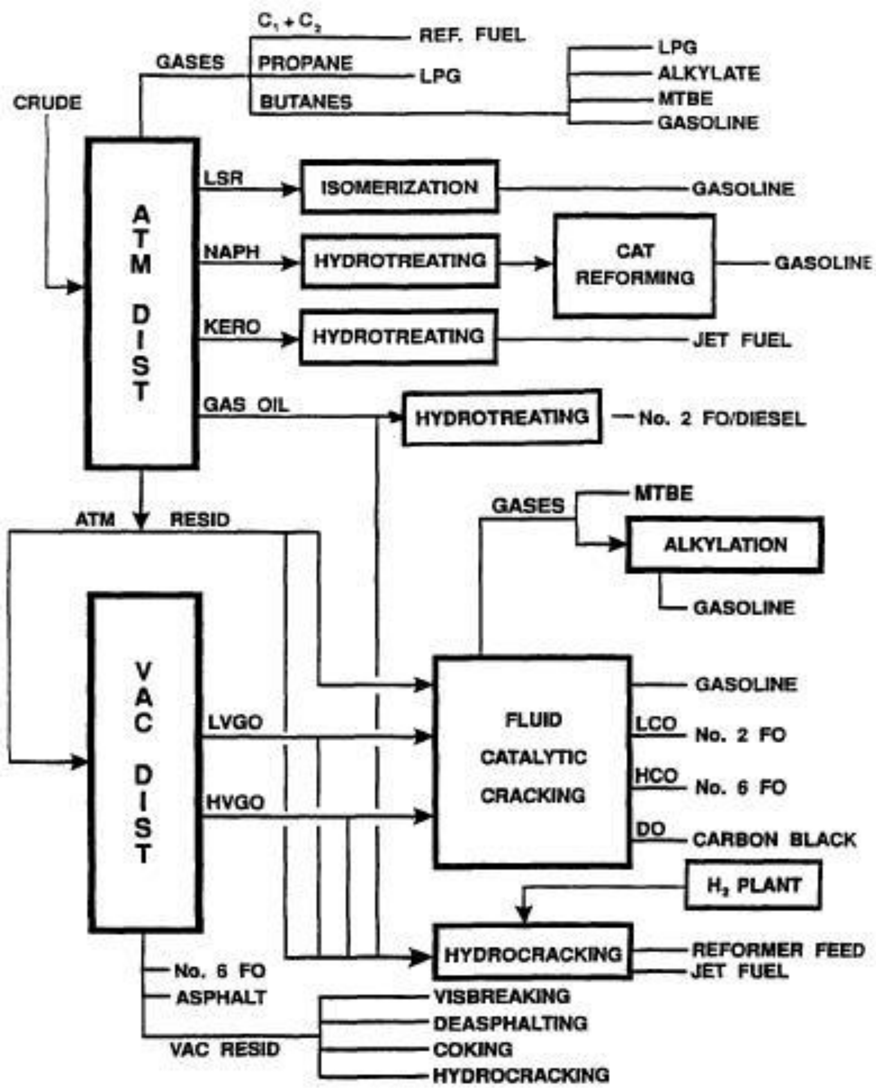

FIG. 1—Refinery block flow diagram.

The liquid petroleum is then vapourized in a still, at temperatures of 600 ^{o}C and the vapour is admitted at the bottom of the fractionation tower.

1. Cracking consists of breaking down large and complex hydrocarbon molecules into simpler compounds with lower boiling pints. Thermal cracking subjects the large hydrocarbon molecules to high temperature and pressure and they are decomposed into smaller, lower boiling point molecules. Catalytic cracking using catalysts is done at relatively lower pressure and temperature than the thermal cracking. Catalytic cracking gives better antiknock property for gasoline as compared to thermal cracking.

2. Hydrogenation consists of the addition of hydrogen atoms to certain hydrocarbons under high pressure and temperature to produce more desirable compounds.

3. Polymerization is the process of converting olefins, the unsaturated products of cracking, into heavier and stable compounds.

4. Alkylation cobines an olefin with an isoparaffin to produce a branched chain isoparaffin in the presence of a catalyst.

$$\text{Example: isobutylene} + \text{isobutene} \xleftrightarrow{\text{alkylatio}} \text{iso-octance}$$

5. Isomerization changes the relative position of the atoms within the molecule of a hydrocarbon without changing its molecular formula.

6. Cyclization joins together the ends of a straight chain molecule to form a ring compound of the naphthene family.

7. Aromatization is similar to cyclization, the exception being that the product is an aromatic compound.

Reformation is a type of cracking process which is used to convert the low antiknock quality stocks into gasolines of higher octane rating . It does not increase the total gasoline volume.

CONVENTIONALLY REFINED PETROLEUM BASE STACKS

Lubricating oils can be produced form a wide variety of crude oils, and taking into account the many variations in available processes, there are many different qualities of petroleum lubricants available. Crude oils and the conventional lubricating oils refined from them are generally classified as either paraffinic, naphthenic, or intermediate. The names relate to the relative preponderance of either paraffins (straight or branched hydrocarbon chains) or naphthenes (cycloparaffins) in their composition, both types also containing some aromatics (alkyl benzenes and multi-ring aromatics).

Each angle in these structures represents a carbone atom, and typical lubricating oil base stocks have between twenty and forty carbon atoms in each molecule. Within each type of structure many variations are possible, and literally millions of different molecular types make up the typical lubricating oil.

Long chain, higher-molecular-weight paraffins (i.e., those that boil at higher temperatures and have more atoms in each molecule) are solids at low temperatures, and when a raw paraffinic oil is cooled these separate out as wax and the oil eventually gels to a solid.

5.3 FINISHING PROCESSES

The solvent extraction process does not remove all the reactive and unstable material from the base stock, and without a finishing process the oil would soon darken and precipitate sludge, especially when exposed to light.

An early finishing process was clay treatment, whereby the oil was mixed with “fuller’s earth,” which adsorbed reactive aromatic and unstable molecules, and was then filtered off. The contaminated clay residues presented a wasted disposal problem and there were also large product losses. Hydro finishing is now the normal process, whereby the reffinate is passed through a heated reactor packed with a catalyst (typically nickel and molybdenum oxides on silica and alumina)and hydrogen is passed in under pressure . Hydrogenation reactions reactions covert the unstable compounds into stable ones. Aromatics, for example, are converted into naphthenes. Hydro finishing does not substantially reduce the product yield, it increases the V.I., and removes some of the sulfur compounds (which are converted to hydrogen sulfide) and other trace materials. The extent of these effects is very dependent on the processing conditions catalysts, temperature, pressure, etc.

5.4 AUTOMOTIVE LUBRICANTS:

Many types of lubricants are used in a vehicle. Engine oil and transmission fluid, on a volume basis, provide a major portion of the lubricants in a typical car or truck, and a great number of standard tests are associated with these fluids. Greases provide a variety of highly specialized functions and are found in many locations within a vehicle (for example, in door locks, gears for seat adjustments and windshield wipers, bearings, electrical contacts, and numerous other places).

In general, automotive lubricants consist of a base stock and various additives. The choice of base stock depends on the function of the lubricant. In the case of engine oil, various types of organic oils may be used: paraffinic, naphthenic, and synthetic. Paraffinic hydrocarbons consist of hydrogen and carbon atoms that are chemically bonded together in the form of branched chains. Naphthenic hydrocarbons contain carbon atoms that are bonded together in the form of rings. Paraffinic and naphthenic hydrocarbons are typically derived by refining oil from oil wells. Synthetic hydrocarbons are formed by combining small hydrocarbon building blocks to form longer chains of a desired composition that tends to be more resistant to chemical attack than is the case for oils produced by a refining process.

Additives are blended into a base stock to provide desirable properties such as optimum friction characteristics for the desired application, anti-wear and antioxidant capability, defoaming capability, and corrosion inhibition. The chemical nature of the additives for a given application are chosen on the basis of their ability to perform their desired function, withstand the conditions under which they must operate, and be compatible with the base stock in which they are used.

Paraffinic base oils have higher viscosity index (generally >95) and a high pour point. They are produced from feed stocks rich in paraffins, and are used for lubricants for which VI and oxidation stability are important. Paraffinic base oils are not very good at dissolving additives and they do not emulsify easily. Because of their structure - long chains - they have high film strength and excellent lubricating properties. That is why paraffins are used as the base fluid in engine oils, hydraulics and industrial lubes.

Naphthenic base oils have low viscosity index (VI) (generally 0-40) and a low pour point. They are produced from feed stocks rich in naphthenes and low in wax content. They are used mainly for lubricants in which color and color stability are important, and VI and oxidation stability are of secondary importance. Naphthenic oils also have a greater propensity to solublize additives. Their structure does not lend them to the film strength and lubricating properties of the paraffinics but they are still good. They are therefore used extensively in the formulation of oil-based metalworking fluids.

Each of these types of oil has several grades, according to its viscosity. The American Petroleum Institute has developed a classification system for base oils in order to facilitate engine oil interchange guidelines. The five groups are:

Group I: base stocks contain less than 90 percent saturates and/or greater than 0.03percent sulfur and have viscosity index greater than or equal to 80 and less than 120.

Group II: base stocks contain greater than or equal to 90 percent saturates and lessthan or equal to 0.03 percent sulfur and have viscosity index greater than or equal to 80 and less than 120.

Group III: base stocks contain greater than or equal to 90 percent saturates and lessthan or equal to 0.03 percent sulfur and have viscosity index greater than or equal to 120.

Group IV: base stocks are polyalphaolefins (PAO).

Group V: base stocks include all other base stocks not included in groups I, II, III or IV. Naphthenic oils are considered Group V.

Base Oil Category	% Saturates		% Sulfur	Viscosity Index
Group I	< 90	and/or	> 0.03	80 - 119
Group II	≥ 90	and	≤ 0.03	80 - 119
Group III	≥ 90	and	≤ 0.03	≥ 120
Group IV	All Polyalphaolefins (PAO's)			
Group V	Anything Not Covered in Groups 1-IV			

Fig. 5.1 API Base Oil Classification System

Group II base oils are differentiated from Group I base oils because they contain significantly lower levels of impurities. They also look different. Group II and Group III oils made using modern hydroisomerization technology are so pure that they have almost no color at all. From a performance standpoint, improved purity means that the base oil and the additives in the finished product can last much longer. Some refiners sell intermediate grades labeled as Group 1+ or Group II +.

Historically, PAOs have had superior lubricating performance characteristics such as VI, pour point, volatility, and oxidation stability that could not be achieved with conventional mineral oils. Now, in modern base oil manufacturing, VI, pour point, volatility, and oxidation stability can be independently controlled. Modern Group III oils today can be designed and manufactured so that their performanceclosely matches PAOs in most commercially significant finished lube applications. From a processing standpoint, modern Group III base oils are manufactured by essentially the same processing route as modern Group II base oils. Higher VI Is achieved by increasing the temperature or time in the hydro cracker.

5.5 Base Oil Properties

Certain properties are very important in determining the usefulness and application for a particular base oil:

5.5.1 Viscosity - The viscosity of an oil is a measure of its resistance to flow, and depends on the temperature at which the measurement is made. It has high values at low temperatures, and low values at high temperatures. A viscosity measurement has no value unless it is associated with a temperature. In the past, viscosity was expressed in Engler (Europe), Redwood (UK) and Saybolt (USA). Nowadays, centistoke (kinematic viscosity) and centipoise (dynamic viscosity) are commonly used units.

5.5.2 Viscosity index - As viscosity depends on temperature, a measure of its sensitivityto temperature is expressed by its viscosity index (VI) value. VI is determined by comparing the change of viscosity with temperature to two reference oils – one of which changes very little with temperature and is given a VI = 100, and another which changes a lot and is given a VI = 0.

5.5.3 Oxidation stability - Most oils, when exposed to air over time, react with oxygen.The Turbine Oil Stability Test (TOST) and the resulting TOST life are measures of the oxidation stability, i.e. how much it degrades in the presence of air. Oils used to blend lubricants must have high oxidation stability; otherwise, they become discolored during storage. When base oils with poor oxidation stability are used in engines, the high temperature causes them to form corrosive acids and insoluble sludge. This can hamper the engine's performance by forming a hard layer in the grooves of the piston rings.

5.5.4 Aniline Point - Aniline point is defined as the minimum temperature at which equalvolumes of anhydrous aniline and oil mix together. Its main use is determining the quality of fuels. Since aniline is an aromatic compound, it freely mixes with other aromatics so a low aniline point indicates low diesel index (because of high percentage of aromatics). High aniline point indicates that the fuel is highly paraffinic and hence has a high diesel index and very good ignition quality. In case of aromatics the aniline point is low and the ignition quality is poor.

In the metalworking industry, the aniline point is useful in determining the solvency power of your base oil. The lower the aniline point, the better the base oil will be at solublizing and holding onto additives and emulsifiers.

5.5.5 Pour point and cloud point - The cloud point of an oil is the temperature at whichthe first trace of wax starts to separate out, causing it to become turbid or cloudy. If the temperature is reduced further, more wax will crystallize out until a point is reached when the oil and wax crystallize together as a whole, and will not flow when poured. The temperature at which this just happens is the pour point of the oil. Oils used for lubricants must have a low pour point so that in areas where the temperature is very low, they remain as fluids. A low cloud point ensures that they remain clear and bright in such areas.

5.5.6 Flash point - The flash point of oil is the temperature at which its vapor ignites when exposed to a flame. A minimum flash point is normally specified for safety reasons.

What is a lubricant?

A lubricant is made from base oil and additives. The quality of a lubricant, therefore, depends on the quality of the base oil and additives used in the formulation. Additives, although used in relatively small quantities, play a very important role in the performance and composition of the lubricants. Many types of additives are used including:

1. Pour-point depressants to decrease the pour point of the oil.

2. VI improvers to increase the viscosity index, i.e. to reduce the viscosity at low temperatures

3. Anti-wear additives to decrease the engine/unit wear

4. Anti-oxidants to extend lubricant life by reducing degradation by oxygen from the air

5. Corrosion inhibitors and detergents to prevent the corrosion of various metals
6. Ash less dispersants to keep particles or deposits in suspension

7. Extreme-pressure load-carrying additives for gear oils

8. Various other additives such as anti-foams and friction modifiers

Why are additives used in lubricating oil?

Additives are used in lubricating oil to change, alter, or enhance its properties. Base oil as such cannot be used in most of the present-day lubricating applications. Their properties - like resistance to heat, oxygen, wear etc - have to be increased. This improvement is done with the use of these additives. To increase the resistance to oxidation, we add antioxidants; to increase resistance to wear, we add anti-wear additives, etc.

5.6 Lubricating Oil Refining Process

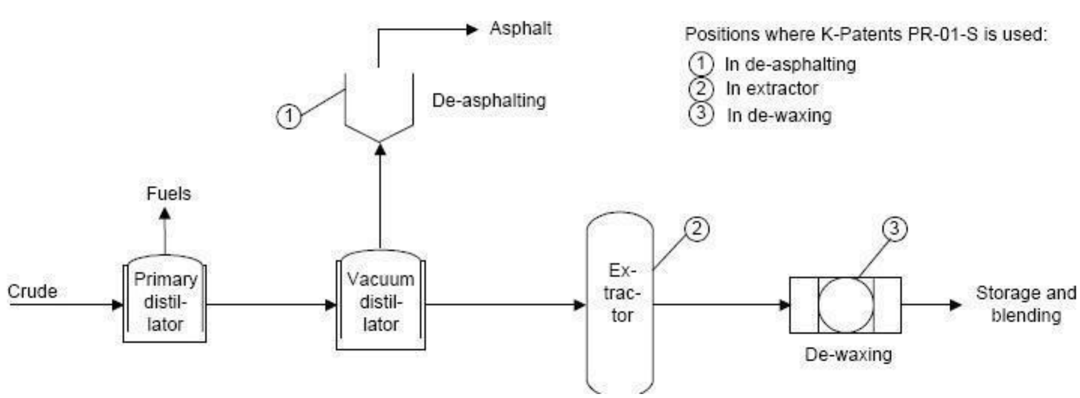

Fig 5.2 Lubricant refining process

Lubricant base oil processes

Vacuum distillation unit

The first step in the processing of lubricating oils is separation in the distillation units of the individual fractions according to viscosity and boiling range specifications. The heavier lube oil raw stocks are included in the vacuum fractionating tower bottoms with asphaltenes, resins and other undesirable materials. The raw lube oil fractions from most crude oils contain components which have undesirable characteristics for finished lubricating oils. These must be removed or reconstituted by processes such as extraction, crystallization, hydro cracking and hydrogenation. Vacuum distillation separates raw lube oil into two or three streams with increasing viscosity. The heavier stream is derived by removing asphalt from the residue in a de-asphalting unit. The lighter feed stocks are sent directly to a solvent extraction. This first stage determines the final base oil viscosity grades. The further process sequence is usually in the order of deasphalting, solvent extraction, dewaxing and finishing.

De-asphalting

Propane is usually used as the solvent in de-asphalting but it may also be used with ethane or butane in order to obtain the desired solvent properties. Propane has unusual solvent properties in temperatures from 40°C (104°F) to 60°C (140°F). Paraffins are very soluble in propane but the solubility decreases with an increase in temperature until at the critical temperature of propane (96.8°C/206.2°F) all hydrocarbons become insoluble. In the range of 40°C (104°F) to 96.8°C (206°F) the higher molecular weight asphaltenes and resins are largely insoluble in propane. Separation by distillation is generally by molecular weight of the components and solvent extraction by type of molecule structure.

Solvent extraction

There are three solvents used for the extraction of aromatics from lube oil feedstock's and the solvent recovery portions of the systems are different for each. The solvents are furfural, phenol and N-methyl-2- pyrrolidione (NMP). The purpose of solvent extraction is to improve the viscosity index (VI), oxidation resistance, and colour of the lube oil base stock and to reduce the carbon- and sludge-forming tendencies of the lubricants by separating the aromatic portion from the naphthenic and paraffinic portion of the feed stock.

Furfural extraction

The process flow through the furfural extraction unit is similar to that of the propane de-asphalting unit except for the solvent recovery section which is more complex. The oil feedstock is introduced into a continuous countercurrent extractor at a temperature which is a function of the viscosity of the feed; the greater the viscosity the higher temperature is used.

Phenol extraction

The process flow for the phenol extraction unit is somewhat similar to that of the furfural extraction unit but differs markedly in the solvent recovery section because phenol is easier to recover than furfural.

NMP extraction

NMP extraction uses N-methyl-2- pyrrolidione as the solvent to remove the condensed ring aromatics and polar components from the lubricating oil distillate bright stocks. This process was developed as a replacement for phenol extraction because of the safety, health, and environmental problems associated with the use of phenol.

De-waxing

All lube oil stocks, except those from a relatively few highly naphthenic crude oils, must be de-waxed or they will not flow properly at ambient temperatures.

De-waxing is one of the most important and most difficult processes lubricating oil manufacture. *Hydro finishing*

Hydro treating of de-waxed lube oil stocks is needed to remove chemically active compounds that affect the color and color stability of lube oils.

Need for cooling system

The cooling system has four primary functions. These functions are as follows:

1. Remove excess heat from the engine.
2. Maintain a constant engine operating temperature.

3. Increase the temperature of a cold engine as quickly as possible.
4. Provide a means for heater operation (warming the passenger compartment).

5.7 Types of cooling system:

The different Types of cooling system are

1. air cooling system
2. liquid cooling system
3. forced circulation system
4. pressure cooling system

5.7.1 Air-Cooled System :

The simplest type of cooling is the air-cooled, or direct, method in which the heat is drawn off by moving air in direct contact with the engine Several fundamental principles of cooling are embodied in this type of engine cooling. The rate of the cooling is dependent upon the following:

1. The area exposed to the cooling medium

2. The heat conductivity of the metal used & the volume of the metal or its size in cross section

3. The amount of air flowing over the heated surfaces

4. The difference in temperature between the exposed metal surfaces and the cooling air

5.7.2 LIQUID-COOLED S YSTEM

Nearly all multicylinder engines used in automotive, construction, and material-handling equipment use a liquid-cooled system. Any liquid used in this type of system is called a COOLANT.

A simple liquid-cooled system consists of a radiator, coolant pump, piping, fan, thermostat, and a system of water jackets and passages in the cylinder head and block through which the coolant circulates. Some vehicles are equipped with a coolant distribution tube inside the cooling passages that directs additional coolant to the points where temperatures are highest. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The operation of a liquid- cooled system is as follows: The pump draws the coolant from the bottom of the radiator, forcing the coolant through the water jackets and passages, and ejects it into the upper radiator tank. The coolant then passes through a set of tubes to the bottom of the radiator from which the cooling cycle begins. The radiator is situated in front of a fan that is driven either by the water pump or an electric motor. The fan ensures airflow through the radiator at times when there is no vehicle motion. The downward flow of coolant through the radiator creates what is known as a thermosiphon action. This simply means that as the coolant is heated in the jackets of the engine, it expands. As it expands, it becomes less dense and therefore lighter. This causes it to flow out of the top outlet of the engine and into the top tank of the radiator. As the coolant is cooled in the radiator, it again becomes more dense and heavier. This causes the coolant to settle to the bottom tank of the radiator. The heating in the engine and the cooling in the radiator therefore create a natural circulation that aids the water pump. The amount of engine heat that must be removed by the cooling system is much greater than is generally realized. To handle this heat load, it may be necessary for the cooling system in some engine to circulate 4,000 to 10,000 gallons of coolant per hour. The water passages, the size of the pump and radiator, and other details are so designed as to maintain the working parts of the engine at the most efficient temperature within the limitation imposed by the coolant.

5.7.3 Pressure cooling system

The radiator pressure cap is used on nearly all of the modern engines. The radiator cap locks onto the radiator tank filler neck Rubber or metal seals make the cap-to-neck joint airtight. The functions of the pressure cap are as follows: 1. Seals the top of the radiator tiller neck to prevent leakage. 2. Pressurizes system to raise boiling point of coolant. 3. Relieves excess pressure to protect against system damage. 4. In a closed system, it allows coolant flow into and from the coolant reservoir. The radiator cap pressure valve consists of a spring- loaded disc that contacts the filler neck. The spring pushes the valve into the neck to form a seal. Under pressure, the boiling point of water increases. Normally water boils at 212°F. However, for every pound of pressure increase, the boiling point goes up 3°F. Typical radiator cap pressure is 12 to 16 psi. This raises the boiling point of the engine coolant to about 250°F to 260°F. Many surfaces inside the water jackets can be above 212°F. If the engine overheats and the pressure exceeds the cap rating, the pressure valve opens. Excess pressure forces coolant out of the overflow tube and into the reservoir or onto the ground. This prevents high pressure from rupturing the radiator, gaskets, seals, or hoses. The radiator cap vacuum valve opens to allow reverse flow back into the radiator when the coolant temperature drops after engine operation. It is a smaller valve located in the center, bottom of the cap. The cooling and contraction of the coolant and air in the system could decrease coolant volume and pressure. Outside atmospheric pressure could then crush inward on the hoses and radiator. Without a cap vacuum or vent valve, the radiator hose and radiator could collapse

5.8 ENGINE LUBRICATING SYSTEMS

All internal combustion engines are equipped with an internal lubricating system. Without lubrication, an engine quickly overheats and its working parts seize due to excessive friction. All moving parts must be adequately lubricated to assure maximum wear and long engine life.

5.8.1 PURPOSES OF LUBRICATION

The functions of an engine lubrication system are as follows: Reduces friction and wear between moving parts. Helps transfer heat and cool engine parts. Cleans the inside of the engine by removing contaminants (metal, dirt, plastic, rubber, and other particles). Absorbs shocks between moving parts to quiet engine operation and increase engine life. The properties of engine oil and the design of modern engines allow the lubrication system to accomplish these functions.

5.9 TYPES OF LUBRICATING (OIL) SYSTEMS

Now that you are familiar with the lubricating system components, you are ready to study the different systems that circulate oil through the engine. The systems used to circulate oil are known as splash, combination splash force feed, force feed, and full force-feed.

5.9.1 Splash Systems

The splash system is no longer used in automotive engines. It is widely used in small four-cycle engines for lawn mowers, outboard marine operation, and so on. In the splash lubricating system, oil is splashed up from the oil pan or oil trays in the lower part of the crankcase. The oil is thrown upward as droplets or fine mist and provides adequate lubrication to valve mechanisms, piston pins, cylinder walls, and piston rings. In the engine, dippers on the connecting-rod bearing caps enter the oil pan with each crankshaft revolution to produce the oil splash. A passage is drilled in each connecting rod from the dipper to the bearing to ensure lubrication. This system is too uncertain for automotive applications. One reason is that the level of oil in the crankcase will vary greatly the amount of lubrication received by the engine. A high level results in excess lubrication and oil consumption and a slightly low level results in inadequate lubrication and failure of the engine.

5.9.2 Combination Splash and Force Feed

In a combination splash and force feed, oil is delivered to some parts by means of splashing and other parts through oil passages under pressure from the oil pump. The oil from the pump enters the oil galleries. From the oil galleries, it flows to the main bearings and camshaft bearings. The main bearings have oil-feed holes or grooves that feed oil into drilled passages in the crankshaft. The oil flows through these passages to the connecting rod bearings. From there, on some engines, it flows through holes drilled in the connecting rods to the piston-pin bearings. Cylinder walls are lubricated by splashing oil thrown off from the connecting-rod bearings. Some engines use small troughs under each connecting rod that are kept full by small nozzles which deliver oil under pressure from the oil pump. These oil nozzles deliver an increasingly heavy stream as speed increases. At very high speeds these oil streams are powerful enough to strike the dippers directly. This causes a much heavier splash so that adequate lubrication of the pistons and the connecting-rod bearings is provided at higher speeds. If a combination system is used on an overhead valve engine, the upper valve train is lubricated by pressure from the pump.

5.9.3 Force Feed

A somewhat more complete pressurization of lubrication is achieved in the force-feed lubrication system. Oil is forced by the oil pump from the crankcase to the main bearings and the camshaft bearings. Unlike the combination system the connecting-rod bearings are also fed oil under pressure from the pump. Oil passages are drilled in the crankshaft to lead oil to the connecting-rod bearings. The passages deliver oil from the main bearing journals to the rod bearing journals. In some engines, these opening are holes that line up once for every crankshaft revolution. In other engines, there are annular grooves in the main bearings through which oil can feed constantly into the hole in the crankshaft. The pressurized oil that lubricates the connecting- rod bearings goes on to lubricate the pistons and walls by squirting out through strategically drilled holes. This lubrication system is used in virtually all engines that are equipped with semi floating piston pins.

5.9.4 Full Force Feed

In full force- feed lubrication system, the main bearings, rod bearings, camshaft bearing and the complete valve lubricated by oil under pressure. In additional the force feed lubrication system provides lubrication under pressure to the pistons and the piston pins. This is accomplished by holes drilled the length of the connecting rod, creating an oil passage from the connecting rod bearing to the piston pin bearing. This passage not only feeds the piston pin bearings but also provides lubrication for the pistons and cylinder walls. This system is used in virtually all engines that are equipped with full- floating piston pin.

Lubricity

Lubricity is the measure of the reduction in friction and or wear by a lubricant. The study of lubrication and wear mechanisms is called tribology.

- 1.Measurement of lubricity
- 2.Lubricity in diesel engines

Measurement of lubricity

The lubricity of a substance is not a material property, and cannot be measured directly. Tests are performed to quantify a lubricant's performance for a specific system. This is often done by determining how much wear is caused to a surface by a given wear-inducing object in a given amount of time. Other factors such as surface size, temperature, and pressure are also specified. For two fluids with the same viscosity, the one that results in a smaller wear scar is considered to have higher lubricity. For this reason lubricity is also termed a substance's anti-wear property.

Examples of test setups include "Ball-on-cylinder" and "Ball-on-three-discs" tests.

Lubricity in diesel engines

In a modern diesel engine, the fuel is part of the engine lubrication process. Diesel fuel naturally contains compounds that provide lubricity, but because of regulations in many countries (such as the US and the EU), sulphur must be removed from the fuel before it can be sold. The hydro treatment of diesel fuel to remove sulphur also removes the compounds that provide lubricity. Reformulated diesel fuel that does not have biodiesel added has a lower lubricity and requires lubricity improving additives to prevent excessive engine wear.

5.10 Oil additive

Oil additives are chemical compounds that improve the lubricant performance of base oil (or oil "base stock"). The manufacturer of many different oils can utilize the same base stock for each formulation and can choose different additives for each specific application. Additives comprise up to 5% by weight of some oils.

Nearly all commercial motor oils contain additives, whether the oils are synthetic or petroleum based. Essentially, only the American Petroleum Institute (API) Service SA motor oils have no additives, and they are therefore incapable of protecting modern engines. The choice of additives is determined by the application, e.g. the oil for a diesel engine with direct injection in a pickup truck (API Service CJ-4) has different additives than the oil used in a small gasoline-powered outboard motor on a boat (2-cycle engine oil).

5.10.1 Types of additives

1. Controlling chemical breakdown
2. For viscosity
3. For lubricity
4. For contaminant control
5. other reasons

Oil additives are vital for the proper lubrication and prolonged use of motor oil in modern internal combustion engines. Without many of these, the oil would become contaminated, break down, leak out, or not properly protect engine parts at all operating temperatures. Just as important are additives for oils used inside gearboxes, automatic transmissions, and bearings. Some of the most important additives include those used for viscosity and lubricity, contaminant control, for the control of chemical breakdown, and for seal conditioning. Some additives permit lubricants to perform better under severe conditions, such as extreme pressures and temperatures and high levels of contamination.

Controlling chemical breakdown

- Detergent additives, dating back to the early 1930s, are used to clean and neutralize oil impurities which would normally cause deposits (oil sludge) on vital engine parts. Typical detergents are magnesium sulfonates.
- Corrosion or rust inhibiting additives retard the oxidation of metal inside an engine.
- Antioxidant additives retard the degradation of the stock oil by oxidation. Typical additives are organic amines and phenols.
- Metal deactivators create a film on metal surfaces to prevent the metal from causing the oil to be oxidized.

For viscosity

- Viscosity modifiers make an oil's viscosity higher at elevated temperatures, improving its viscosity index (VI). This combats the tendency of the oil to become thin at high temperature. The advantage of using less viscous oil with a VI improver is that it will have improved low temperature fluidity as well as being viscous enough to lubricate atoperating temperature. Most multi-grade oils have viscosity modifiers. Some synthetic oils are engineered to meet multi-grade specifications without them. Viscosity modifiers are often plastic polymers.
- Pour point depressants improve the oil's ability to flow at lower temperatures.

For lubricity

- Friction modifiers or friction reducers, like molybdenum disulfide, are used for increasing fuel economy by reducing friction between moving parts. Friction modifiers alter the lubricity of the base oil. Whale oil was used historically.
- Extreme pressure agents bond to metal surfaces, keeping them from touching even at high pressure.
- Antiwear additives or wear inhibiting additives cause a film to surround metal parts, helping to keep them separated. Zinc dia lkyldithiophosphate or zinc di thiophosphates are typically used.
- Nano particles that build diamond-like carbon coatings, which improve embeddability and can achieve super lubricity. The technology is developed with Argonne National Lab and Pacific Northwest national Lab and foundation of TriboTEX product.

- Wear metals from friction are unintentional oil additives, but most large metal particles and impurities are removed in situ using either magnets or oil filters. Tribology is the science that studies how materials wear.

For contaminant control

- Dispersants keep contaminants (e.g. soot) suspended in the oil to prevent them from coagulating.
- Anti-foam agents (defoamants) inhibit the production of air bubbles and foam in the oil which can cause a loss of lubrication, pitting, and corrosion where entrained air and combustion gases contact metal surfaces.
- Antimidsting agents prevent the atomization of the oil. Typical antimidsting agents are silicones.
- Wax crystal modifiers are dewaxing aids that improve the ability of oil filters to separate wax from oil. This type of additive has applications in the refining and transport of oil, but not for lubricant formulation.