FUEL INJECTION SYSTEM FOR CI ENGINES

The function of a fuel injection system is to meter the appropriate quantity of fuel for the given engine speed and load to each cylinder, each cycle, and inject that fuel at the appropriate time in the cycle at the desired rate with the spray configuration required for the particular combustion chamber employed. It is important that injection begin and end cleanly, and avoid any secondary injections. To accomplish this function, fuel is usually drawn from the fuel tank by a supply pump, and forced through a filter to the injection pump. The injection pump sends fuel under pressure to the nozzle pipes which carry fuel to the injector nozzles located in each cylinder head. Excess fuel goes back to the fuel tank. CI engines are operated unthrottled, with engine speed and power controlled by the amount of fuel injected during each cycle. This allows for high volumetric efficiency at all speeds, with the intake system designed for very little flow restriction of the incoming air.

FUNCTIONAL REQUIREMENTS OF AN INJECTION SYSTEM

For a proper running and good performance of the engine, the following requirements must be met by the injection system:

- Accurate metering of the fuel injected per cycle. Metering errors may cause drastic variation from the desired output. The quantity of the fuel metered should vary to meet changing speed and load requirements of the engine.
- Correct timing of the injection of the fuel in the cycle so that maximum power is obtained.
- Proper control of rate of injection so that the desired heat-release pattern is achieved during combustion.
- Proper atomization of fuel into very fine droplets.
- Proper spray pattern to ensure rapid mixing of fuel and air.
- Uniform distribution of fuel droplets throughout the combustion chamber
- To supply equal quantities of metered fuel to all cylinders in case of multi-cylinder engines.
- No lag during beginning and end of injection i.e., to eliminate dribbling of fuel droplets into the cylinder.

TYPES OF INJECTION SYSTEMS

There are basically two types of injection systems: Air injection system and solid injection system.

Air Injection System: In this system, fuel is forced into the cylinder by means of compressed air. This system is little used nowadays, because it requires a bulky multi-stage air compressor. This causes an increase in engine weight and reduces the brake power output further. One advantage that is claimed for the air injection system is good mixing of fuel with the air resulting in higher mean effective pressure. Another advantage is its ability to utilize fuels of high viscosity which are less expensive than those used by the engines with solid injection systems. These advantages are off-set by the requirement of a multistage compressor thereby making the air-injection system obsolete.

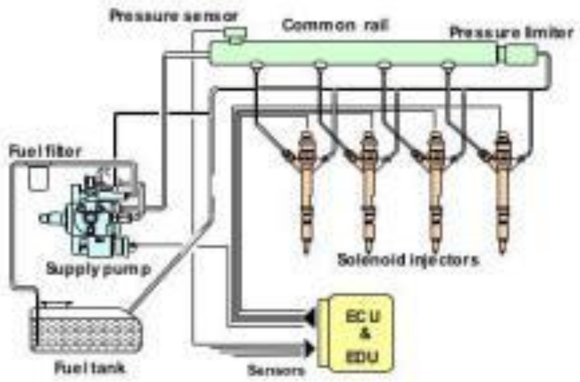
Solid Injection System: In this system the liquid fuel is injected directly into the combustion chamber without the aid of compressed air. Hence, it is also called airless mechanical injection or solid injection system. It can be classified into four types.

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

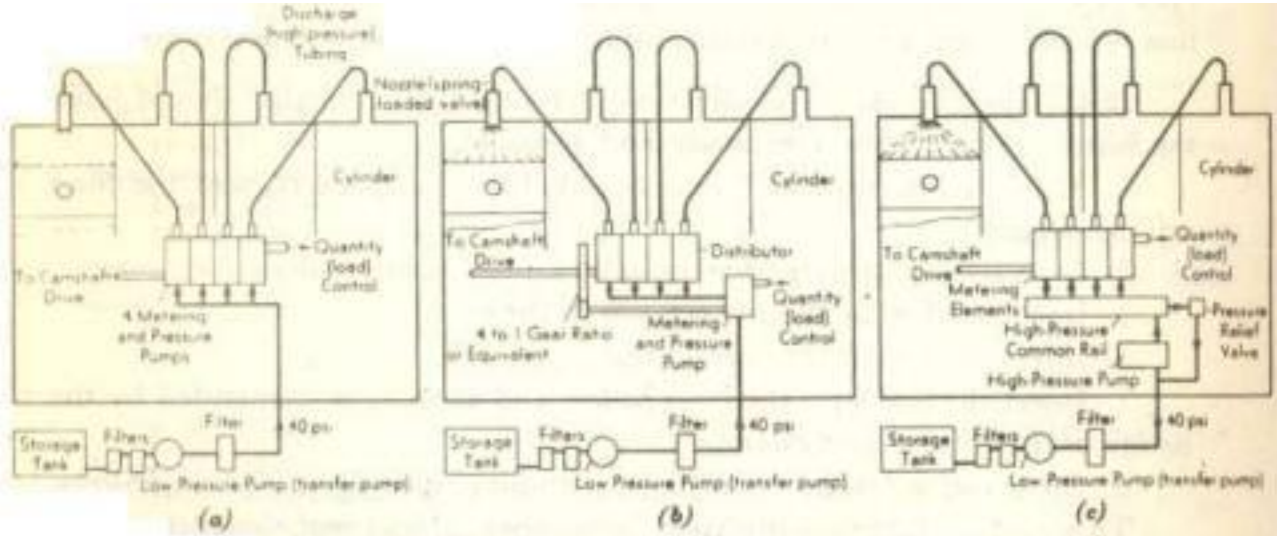
Individual Pump and Nozzle System: In this system, each cylinder is provided with one pump and one injector. A separate metering and compression pump is provided for each cylinder. The pump may be placed close to the cylinder. The high pressure pump plunger is actuated by a cam, and produces the fuel pressure necessary to open the injector valve at the correct time. The amount of fuel injected depends on the effective stroke of the plunger.

Unit Injector System: In this system a pump and the injector nozzle are combined in one housing. Each cylinder is provided with one of these unit injectors. Fuel is brought up to the injector by a low pressure pump, where at the proper time, a rocker arm actuates the plunger and thus injects the fuel into the cylinder. The amount of fuel injected is regulated by the effective stroke of the plunger.

Common Rail System: In the common rail system, a HP pump supplies fuel, to a fue l header. High pressure in the header forces the fuel to each of the nozzles located in the cylinders, at proper time. A mechanically operated (by means of a push rod and rocker arm) valve allows the fuel to enter the proper cylinder through the nozzle. The pressure in the fuel header must be so high it must enable to penetrate and disperse the fuel in the combustion chamber. The amount of fuel entering the cylinder is regulated by varying the length of the push rod stroke.



Distributor System: In this system the pump which pressurizes the fuel also meters and times it. The fuel pump after metering the required amount of fuel is supplied to a rotating distributor at the correct time for supply to each cylinder. The number of injection strokes per cycle for the pump is equal to the number of cylinders. Since there is one metering element in each pump, a uniform distribution is automatically ensured. Not only that, the cost of the fuel-injection system also reduces.



Basic solid-injection systems. Four-cylinder, four-stroke, engines. (a) Individual-pump system; (b) distributor system; (c) common-rail system.

COMPONENTS OF FUEL INJECTION SYSTEMS

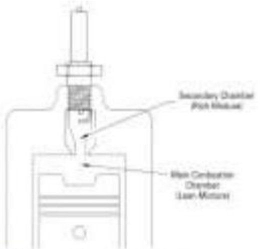
All the above systems comprise mainly of the following components.

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

COMBUSTION IN SI ENGINES

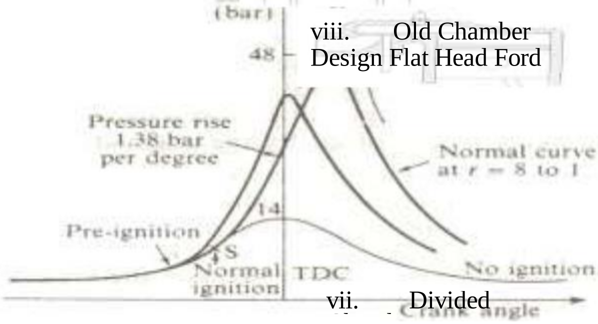
Combustion of the air-fuel mixture inside the engine cylinder is one of the processes that controls engine power, efficiency, and emissions. Combustion in an engine is a very complex process which is not completely understood. Simplified models are used to describe this not-so-simple phenomenon. Combustion in an SI engine is quite different from combustion in a CI engine.

In spark-ignition engines, the fuel is normally mixed with air in the engine intake system. Following the compression of this air-fuel mixture and the residual gas, an electric discharge initiates the combustion process; a flame develops from the “kernal” created by the spark discharge and propagates across the cylinder to the combustion chamber walls. The combustion chamber is the area inside the engine where the fuel/air mixture is compressed and then ignited.



Combustion chamber is generally formed on one side by the shape cast into the cylinder head, and on the other side by the top of the piston. The engine's overall efficiency is affected by the shape of the chamber, shape of the top of the piston, and the location of valves and spark plug and overall airflow through the intake and exhaust. Combustion starts at the spark plug and the flame front travels from spark plug. At the walls, the flame is “quenched” or extinguished because of heat transfer.

viii. Old Chamber Design Flat Head Ford



vii. Divided

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The combustion process of spark-ignition engines can be divided into three broad regions:

(1) Ignition and flame development;

(2) Flame propagation; and

(3) Flame termination

Normal combustion

So far we have described normal combustion in which the spark-ignited flame moves steadily across the combustion chamber until the charge is fully consumed. In other words, a combustion process which is initiated solely by a timed spark and in which the flame front moves completely across the combustion chamber in a uniform manner at a normal velocity is called normal combustion. However, several factors—e.g., fuel composition, certain engine design and operating parameters, and combustion chamber deposits—may prevent this normal combustion process from occurring.

Abnormal combustion is a combustion process in which a flame front may be started by hot combustion-chamber surfaces either prior to or after spark ignition, or a process in which some part or all of the charge may be consumed at extremely high rates. Two types of abnormal combustion have been identified: knock and surface ignition. These abnormal combustion phenomena are of concern because: (1) when severe, they can cause major engine damage; and (2) even if not severe, they are regarded as an objectionable source of noise. **Knock** is the most important abnormal combustion phenomenon.

Knock is the name given to the noise that results from the autoignition of a portion of the fuel, air, residual gas mixture ahead of the advancing flame. As the flame propagates across the combustion chamber, the unburned mixture ahead of the flame—called the end gas—is compressed, causing its pressure, temperature and density to increase. Some of the end-gas fuel-air mixture may undergo chemical reactions prior to normal combustion. The products of these reactions may then autoignite: i.e., spontaneously and rapidly release a large part or all of their chemical energy. When this happens, the end gas burns very rapidly, releasing its energy at a rate 5 to 25 times that characteristic of normal combustion. This cause high frequency pressure oscillations inside the cylinder that produce the sharp metallic noise called knock. One of the results of knock is that local hot spots can be created which remain at a sufficiently high temperature to ignite the next charge before the spark occurs. This is called pre-ignition, and can help to promote further knocking. The result is a noisy, overheated, and inefficient engine, and perhaps eventual mechanical failure. The cylinder pressure rises beyond its design limits and if allowed to persist, it will damage or destroy engine parts.

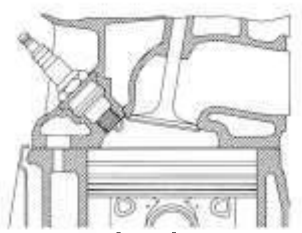
Combustion events leave trace on piston head

Detonation (heavy knock) waves cause metal degradation

High temperatures cause lubrication drop-out and scuffing

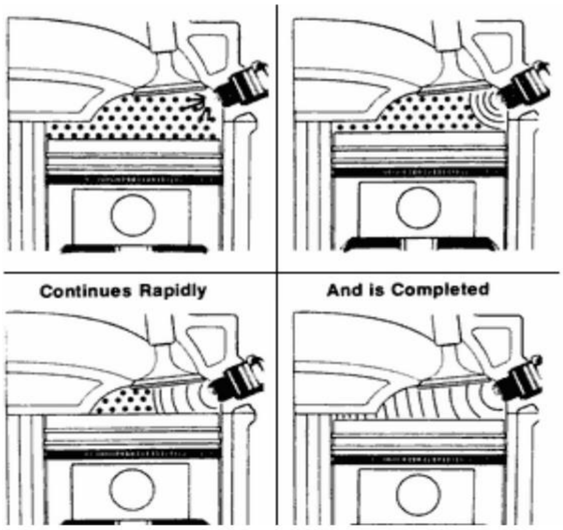
The presence and absence of knock reflects the outcome of a race between advancing flame front and the precombustion reactions in the unburned gas. Knock will not occur if the flame front consumes the end gas before these reactions have time to cause the air-fuel mixture to autoignite. Knock will occur if the precombustion reactions produce autoignition before the flame front arrives. The right combination of fuel and operating characteristics is such that knock is avoided or almost avoided. Knocking can be prevented by:

- The use of a fuel with higher octane rating.
- The addition of octane-increasing "lead".
- Increasing the amount of fuel injected/inducted (resulting in lower Air to Fuel Ratio).
- Retardation of spark plug ignition.
- Use of a spark plug of colder heat range, in cases, where the spark plug insulator has become a source of pre-ignition leading to knock.
- Reduction of charge temperatures, such as through cooling.
- Proper combustion chamber design.



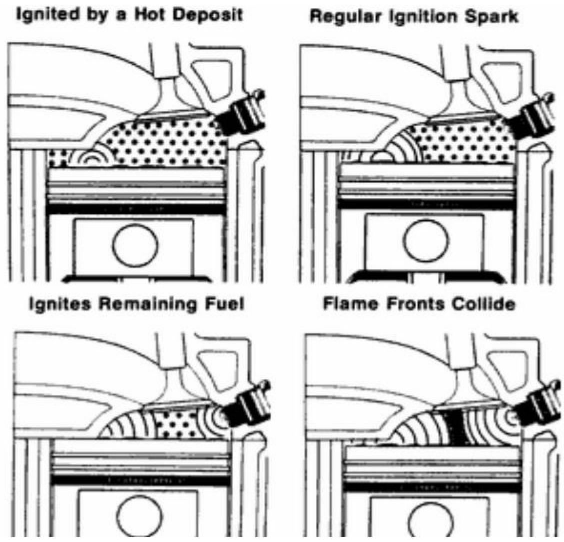
Good combustion chamber design: Short flame paths and exhaust valve close to spark plug

The other important abnormal combustion phenomenon is surface ignition. <u>Surface ignition</u> is ignition of the fuel-air mixture by a hot spot on the combustion chamber walls such as an overheated valve or spark plug, glowing combustion-chamber deposit; i.e., by any means other than the normal spark discharge. It may occur before the spark plug ignites the charge (preignition) or after normal ignition (postignition). It may produce a single flame or many flames. Uncontrolled combustion is most evident and its effect most severe when it results from preignition. However, even when surface ignition occurs after the spark plug fires (postignition), the spark discharge no longer has complete control of the combustion process. Following surface ignition, a turbulent flame develops at each surface-ignition location and starts to propagate across the chamber. Surface ignition may result in knock. Knock which occurs following normal spark ignition is called spark knock to distinguish it from knock which has been preceded by surface ignition. Spark-knock is controlled by the spark advance: advancing the spark increases the knock severity or intensity and retarding the spark decreases the knock. The knock phenomenon varies substantially cycle-by-cycle, and between the cylinders of a multi-cylinder engine, and does not necessarily occur every cycle. Since surface ignition usually cause a more rapid rise in end-gas pressure and temperature than normal spark ignition (because the flame either starts propagating sooner, or propagates from more than one source), knock is a likely outcome following the occurrence of surface ignition. To identify whether or not surface ignition causes knock, the terms knocking surface ignition and non-knocking surface ignition are used. Knocking surface ignition usually originates from preignition caused by glowing combustion chamber deposits: the severity of knock generally increases the earlier that preignition occurs.



Normal combustion

Knocking surface ignition cannot normally be controlled by retarding the spark timing, since the spark-ignited flame is not the cause of knock. Nonknocking surface ignition is usually associated with the surface ignition that occurs late in the operating cycle. Surface ignition is a problem that can be solved by appropriate attention to engine design, and fuel and lubricant quality.
In contrast, knocking is an inherent constraint on engine performance and efficiency since it limits the maximum compression ratio that can be used with any given fuel. Knocking primarily occurs under wide-open-throttle operating conditions. It is thus a direct constraint on engine performance.



Pre-ignition

COMBUSTION IN CI ENGINES

Combustion in a compression-ignition engine is quite different from that in an SI engine. Whereas combustion in an SI engine is essentially a flame front moving through a homogeneous mixture, combustion in a CI engine is an unsteady process occurring simultaneously at many spots in a very non-homogeneous mixture at a rate controlled by fuel injection. Diesel fuel should posses the ability to autoignite easily, whereas gasoline should resist autoignition. Air intake into a CI engine is unthrottled, with engine torque and power output controlled by the amount of fuel injected per cycle. Because the incoming air is not throttled, pressure in the intake manifold is consistently at a value close to one atmosphere. This makes the pump work loop of the engine cycle very small, with a corresponding better thermal efficiency compared to an SI engine. This is especially true at low speeds and low loads when an SI engine would be at part throttle with a large pump work. CI engines are able to operate at higher compression ratios than SI engines because only air is compressed in the cylinder during the compression stroke in CI engines. For combustion to occur at the temperature produced by the compression of the air a compression ratio of 12/1 is required. The normal range of compression ratio is 13 to 17, but may be anything up to 25. Compression ratios of modern CI engines range from 12 to 24. Compared to normal SI engines, high thermal efficiencies (fuel conversion efficiencies) are obtained when these compression ratios are used. The efficiency of the cycle increases with higher value of compression ratio and the limit is a mechanical one imposed by the high pressure developed in the cylinder, a factor which adversely affects the power-weight ratio. However, because the overall air-fuel ratio on which CI engines operate is quite lean ($\phi \approx 0.8$), less brake power output is often obtained for a given engine displacement. In CI engines, the liquid fuel is injected at high velocity into the engine cylinder near the end of the compression stroke. The fuel vaporizes and mixes with the high-pressure high-temperature cylinder air. Since the air temperature and pressure are above the fuel's ignition point, the autoignition, or self-ignition, of portions of the already-mixed fuel and air occurs after a delay period of a few crank angle degrees. Burning then proceeds as fuel and air mix to the appropriate composition for combustion to take place. The cylinder pressure increases as combustion of the fuel-air mixture occurs. Thus, fuel-air mixing plays a controlling role in the diesel combustion process. One of the main factors in a controlled combustion is the swirl which is induced by the design of the combustion chamber. In addition to the swirl and turbulence of the air, a high injection velocity is needed to spread the fuel throughout the cylinder and cause it to mix with the air. After injection the fuel must go through a series of events to assure the proper combustion process:

Figure 1 shows how the inner liquid core is surrounded by successive vapor zones of air-fuel that are:
A: too rich to burnB: rich combustible
C: stoichiometricD: lean combustible
E: too lean to burn Self-ignition starts mainly in zone B. Solid carbon soot is generated mostly in zones A and B.