ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

(Accredited by NAAC, Approved by AICTE, New Delhi. Affiliated to Anna University, Chennai)
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DEPARTMENT OF MECHANICAL ENGINEERING

1. What is the method to detect the phenomenon of knocking?

The most widely used method of measuring knock is using a simple acceleration senor attached to the cylinder block. This method is an easy and cost-effective task. However, vibrations induced by resonances in the combustion chamber have to be detected against a complex background of heavy noise and other vibrations.

2. What are the various combustion chambers used in SI engines?

F-Head Type: The F-head type of valve arrangement is a compromise between L-head and I-head types. Combustion chambers in which one valve is in the cylinder head and the other in the cylinder block are known as F-head combustion chambers.

3. What is turbo charger and super charger

Turbochargers use the vehicle's exhaust gas; two fans – a turbine fan and a compressor fan – rotate from exhaust gas. Conversely, superchargers are powered directly by the engine; a belt pulley drives gears that cause a compressor fan to rotate. Turbochargers find a new purpose in modern engines.

4. What is ignition delay period

The definition of ignition delay is the time lag between the start of injection to start of the combustion when air-fuel mixture is ignited. In a diesel engine it can be deter- mined experimentally as the time interval between the start of injection and the. Start of combustion

5. What are soot particles? give its typical size

Soot is the common term for a type of particle pollution called PM 2.5—particulate matter that is 2.5 micrometers in diameter or smaller. Such fine particles are even smaller than dust and mold particles, or approximately 1/30 of the size of a human hair.

6. **write down zelodovich mechanism of NO formation**

Zel'dovich mechanism is a chemical mechanism that describes the oxidation of nitrogen and NO_x formation, first proposed by the Russian physicist Yakov Borisovich Zel'dovich in 1946. The reaction mechanisms read as

$O + N_2 \rightarrow NO + N$ and
$N + O_2 \rightarrow NO + O$

7. Write any two merits and demerits of using hydrogen as fuel in IC engine.

Hydrogen has a wide flammability range in comparison with all other fuels. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. A significant advantage of this is that hydrogen can run on a lean mixture.

Easiest explanation: The disadvantage of hydrogen fuel is that the detonating tendency. The other disadvantages of hydrogen fuel are high NOx emissions because of high flame temperature and difficult to refuel.

8. Write any two merits and demerits of the stratified charge engine

Better fuel distribution and better fuel charge inside the combustion chamber. During the injection process the fuel gets evaporated, cooling the cylinder chamber. Cooling effect of the pressurized fuel allows for use of a lower octane fuel leading to a cost savings for the end user.

These engines create high noise level at low load conditions. More complex design to supply rich and lean mixture, and quantity is varied with load on the engine.

9. What are the engine modifications required to use compressed natural gas as fuel?

The major modifications are (a) modification of components such as cylinder head, piston etc. and (b) development and deployment of electronic fuel injection system and (c) installation of a capacitive discharge ignition system.

10. How HCCI engines achieves simultaneous reduction in NOx and particulate matter emission

This unique property of HCCI allows the combustion of very lean or dilute mixtures, resulting in low burn as well as local combustion temperatures that dramatically reduce engine the NOx emissions. Also un like conventional diesel combustion, the charge is well mixed, so PM emissions can be very low.

11. Distinguish between multipoint fuel injection and GDI system

Unlike traditional MPFI systems, GDI injects fuel directly into the combustion chamber, bypassing the intake port. It allows for a leaner fuel-air mixture, improving fuel efficiency and power while reducing emissions.

12. List the types of combustion chambers used in SI engines

The four most commonly used shapes are the wedge, the crescent, the hemispherical, and the bowl-in-piston chamber.

L-Head type, I Head type, F-Head type, T-Head type

13. Define the term swirl and squish

Swirl is the main mechanism to spread the flame within the combustion zone.

Squish: The radial inward movement of air is called Squish. Squish can be defined as an inward flow of air towards the combustion recess

14. Why reduction catalyst is placed before the oxidation catalyst in a three way catalytic converter

The three-way catalytic converter converts three pollutants: hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx) into less harmful gases. The catalyst consists of a metallic or ceramic support material with a coating of noble metal (platinum, rhodium, iridium).

15. How formation of oxides of nitrogen occurs in an IC engine.

When fuels are burned in vehicle engines, high temperatures are reached. At these high temperatures, nitrogen and oxygen from the air combine to produce nitrogen monoxide. When this nitrogen monoxide is released from vehicle exhaust systems, it combines with oxygen in the air to form nitrogen dioxide.

16. Write the features of bio diesel fuel

Biodiesel is a clean burning fuel.

Biodiesel does not have any toxic emissions like mineral diesel.

Biodiesel is made from any vegetable oil such as Soya, Rice bran, Canola, Palm, Coconut, mustard or peanut or from any animal fat like Lard or tallow.

Biodiesel is a complete substitute of Mineral diesel (HSD).

17. List merits and demerits of alcohol fuels

Advantages of mixing alcohol with gasoline are that alcohol tends to increase the octane rating and reduce carbon monoxide and other tailpipe emissions.

There are many disadvantages to using alcohols, particularly methyl and ethyl alcohol. Alcohols may corrode certain materials used in engines.

18. Why CRDI is preferred over mechanical fuel injection system

It has revolutionised the way diesel engines function, offering numerous advantages over traditional fuel injection systems. The CRDi technology operates by injecting fuel directly into the engine cylinders at extremely high pressures, resulting in improved performance, enhanced fuel efficiency, and reduced emissions.

19. Define the term hybrid electric vehicle

Today's hybrid electric vehicles (HEVs) are powered by an internal combustion engine in combination with one or more electric motors that use energy stored in batteries. HEVs combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles.

20. List some fuel requirements for a SI engine.

- High octane number to reduce chances of engine knock.
- High calorific value. ...
- Fuel should be volatile and atomisable - for easy carburetion.
- Low sulfur content.
- Resistance to oxidation - storage stability.
- Lower crank case dilution - Petrol can dilute engine lubrication oil so it should not dilute engine oil.

21. Mention the type of fuel injection system commonly utilised in a SI engine

The basic types of fuel injection systems are single-point fuel injection, multi-point fuel injection, sequential fuel injection, and direct injection.

22. Define ignition delay

The ignition delay (ID) is the time between start of injection and start of combustion. It defines the quality of ignition in terms of the cetane number. The ID is divided in physical delay and chemical delay. Physical delay is the time required for atomization of fuel, air-fuel mixing, and vaporization.

Chemical delay includes pre combustion reactions; it has an effect on premixing of air-fuel vapor and thermodynamic efficiency.

23. **List out the major pollutants from a CI engine exhaust**
    the compression ignition engine is mainly responsible for the release of five types of pollutant emissions into the atmosphere: carbon monoxide-CO, hydrocarbons-HC, mechanical particles-PM, sulphur dioxide-SO2 and nitrogen oxides-NOx.

24. **What is the use of driving cycle?**
    A driving cycle is a series of data points representing the speed of a vehicle versus time. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for instance fuel consumption, electric vehicle autonomy and polluting emissions.

25. **What is LPG? State its chief constituent.**
    Liquefied Petroleum Gas or LPG (also called Autogas) consists mainly of propane, propylene, butane, and butylene in various mixtures. It is produced as a by-product of natural gas processing and petroleum refining. The components of LPG are gases at normal temperatures and pressures.

26. **What is HCCI**
    HCCI is the ultimate combustion method for achieving both CO2 reduction and clean exhaust using auto-ignition of gasoline, as in a diesel engine. Nissan is developing this technology for commercial use.

27. **State the necessity of on-board diagnostics**
    The benefits of on-board diagnostics are fast diagnosis, accurate data, automated health control, lower repair cost, insurance-pricing advantage, and decreased vehicle emissions.

28. **Define abnormal combustion.**
    Abnormal combustion for an SI engine is defined as that type of combustion process in which the heat is released at an abnormal rate than desired. The corresponding rise and fall of pressure with respect to crank angle does not remain smooth.

29. **Classify the factors that are involved in either producing or preventing knock**
    The factors that are involved in either producing (or) preventing knock are temperature, pressure, density of the unburned charge and the time factor.

30. **List the factors affecting the delay period.**
    Delay period is affected by atmospheric pressure, ambient temperature, engine temperature, engine condition (including the fuel injection system), fuel quality, fuel cetane rating, & engine compression ratio. Ignition delay time IDT is studied both as a proprietie of the fuel and a working engine.

31. **What are the major parts of a turbocharger**
    The turbocharger consists of three main parts, the compressor, turbine and central hub rotating assembly (CHRA). The compressor and turbine are connected on a common shaft, so both operate at the same speed (same rpm).

32. Summarize the causes for hydrogen emission from S.I engine

Hydrogen engines release near zero, trace amounts of CO_2 (from ambient air and lubrication oil), but can produce nitrogen oxides, or NOx. As a result, they are not ideal for indoor use and require exhaust after treatments to reduce NOx emissions.

33. What is photochemical smog?

Photochemical smog is a mixture of pollutants that are formed when nitrogen oxides and volatile organic compounds (VOCs) react to sunlight, creating a brown haze above cities. It tends to occur more often in summer, because that is when we have the most sunlight.

34. List the feed stocks for production of methanol.

Most methanol is made from syngas. About 55-65% of global methanol production uses natural gas feedstock, about 30-35% uses coal, with the rest using coking gas and other feedstocks.

35. Mention the techniques for fuelling SI engines with hydrogen

The simplest method of delivering fuel to a hydrogen engine is by way of a carburettor or central injection system. This system has advantages for a hydrogen engine.

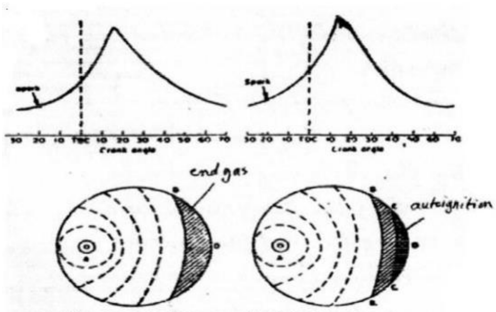
36. Why lean mixture is preferred in SI engine.

As the mixture is made lean (less fuel) the temperature rise due to combustion will be lowered as a result of reduced energy input per unit mass of mixture. This will result in lower specific heat. Further, it will lower the losses due to dissociation and variation in specific heat.

37. What are the fuels used in HCCI engine

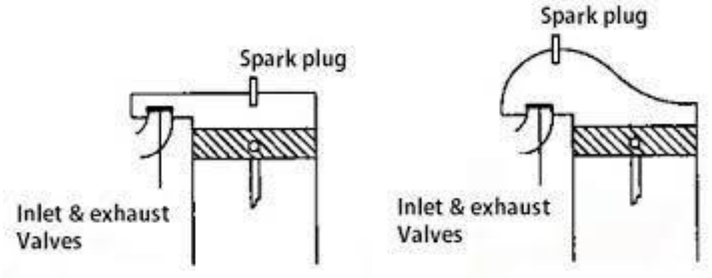
The thermal efficiency of conventional diesel (CI) engine is around 30–40%; however, if diesel is used in HCCI engine, it increases thermal efficiency to 40–45%. Natural gas cannot be used as fuel in the conventional engine but can be used in HCCI engine and it helps increase efficiency even above 50%.

38. With pressure crank angle diagram mark the normal combustion and abnormal combustion process



(a) Normal combustion (b) Detonation or knock

39. Draw any two types of SI combustion chamber write its any two special features.



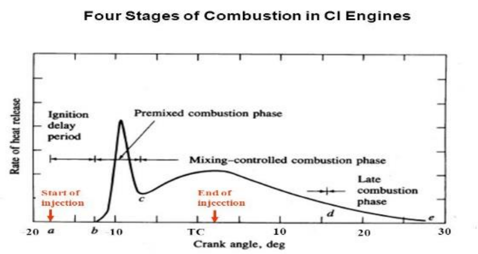
In this L-Head type combustion chamber, you can see both inlet and the exhaust valve will be on the same side operated by the same camshaft.

This I-Head type combustion chamber is also called as the overhead valve combustion chamber. The main advantage of this combustion chamber is that it can achieve high compression ratios, and also less tendency to the knock.

40. Define the term compression ignition and state how it differs from spark ignition

In spark ignition engine we require a proper mixture of air and fuel for combustion and hence carburetor is used. in compression ignition engine the air is first compressed in the cylinder and then fuel is inserted into the cylinder for combustion of fuel and hence there's no requirement of carburetor in CI engine.

41. Mark the stages of combustion of CI engines on heat release rate diagram



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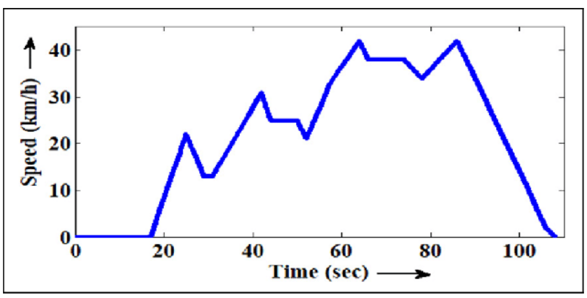
42. State the reason for formation of carbon monoxide during combustion

During complete combustion carbon and hydrogen combine with oxygen (O_2) to produce carbon dioxide (CO_2) and water (H_2O). During incomplete combustion part of the carbon is not completely oxidized producing soot or carbon monoxide (CO).

43. Draw the Indian driving cycle.



44. Define the term biodiesel and write the name of the process through which biodiesel is produced.

Biodiesel is produced from vegetable oils, yellow grease, used cooking oils, or animal fats. The fuel is produced by transesterification—a process that converts fats and oils into biodiesel and glycerine (a coproduct).

45. Ethanol or methanol which is better for IC engine.

The similar liquid and chemical properties of ethanol and methanol result in their similar behaviour and performance in internal combustion engines. This work experimentally demonstrates the interchangeability between these two high cooling potential alcohol fuels in compression ignition

<u>Part- B&C</u>

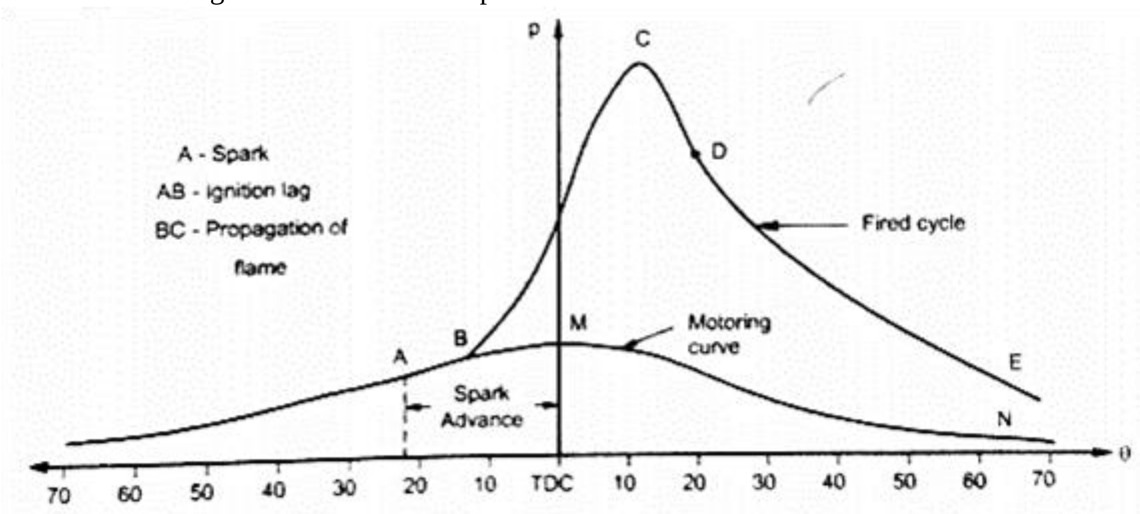
1. Explain the stages of combustion in S.I engine with P-Theta diagram (***)

Based on the experimental results the combustion in SI engines takes place in three stages as follows: Period of ignition Lag Or preparation phase. Flame propagation phase. After burning or flame termination phase.

Period of ignition Lag Or preparation phase.

Flame propagation phase.

after burning or flame termination phase.



Period of ignition lad or preparation.

The experimental results have shown that there is a certain interval of time between the instant of spark is given at point A and the instant the first tiny flame reappears at point B which corresponds to the point where there is a noticeable rise in cylinder pressure due to combustion. This time inters al corresponds to period AB and this period is called ignition delay angle.

The ignition lag depends upon the molecular structure of fuel, temperature, pressure, density, air-fuel ratio and the proportion of residual gases in the mixture.

Flame propagation phase:

Once the self-sustaining flame appears at point B, the flame travels outwards and burns the fuel in air. Initially the rate of burning of fuel and flame speeds are low with small rate of pressure rise. However as the combustion proceeds, the pressure and temperature keeps on rising with heat energy release which is transferred from burned to unburned charge, the flame propagates across the combustion chamber at high speeds. (Almost at constant speed) in the range of (15-35) m/s. It is difficult to distinguish between these two phases of combustion i.e. The phase of ignition lag and flame propagation phase. However, the start of second phase is considered when an appreciable pressure rise can be seen on (p0) diagram at point B and the second phase ends when the peak pressure is attained in the cylinder i.e. at point C. The slope of curve BC represents the rate of pressure rise. It should be noted that the rate of heat transfer to cylinder walls is low at the beginning of this phase since only the small part of the burning mixture comes in contact with the cylinder walls. The rate of heat energy released during combustion depends on the intensity of turbulence and the air-fuel ratio.

After burning of flame termination phase.

Actually combustion is not completed at point C though it represents the completion of flame travel. It is due to the fact the burning continues due to left over fuel and the association of dissociated gases existing in the combustion chamber. This combustion beyond point C continues during the expansion stroke and it is called as after burning representing the third stage of combustion up to point D. The flame velocity decreases during this phase of combustion. The effects of engine variables on ignition lag and flame propagation are being discussed below.

Effect of various parameters on combustion

The various engine variables which affect the ignition lag are as follows:

Pressure and temperature:

At high pressures the molecules are nearer and their rate of collisions increases. It help in forming the chain carriers and reduces the ignition lag.
The increased temperatures increases the kinetic energy of molecules which tend to increase the rate of collisions and also the mobility of reaction.

Compression ratio:

Higher compression ratio increases the pressure and temperature of the working substance.

Therefore, the effect of increased compression ratio is similar to increased pressure and temperature as discussed above i.e. increased compression ratio decreases the ignition lag.

Mixture strength:

It is observed that the ignition lag is minimum for about 10% rich mixtures as shown in Fig. 3.

Residual gases:

The residual gases in the combustion chamber dilutes the mixture charge consequently increases the Ignition lag. Therefore, higher the amount of residual gases in proportion to fresh charge higher will be the period of ignition lag.

Nature of fuel:

The ignition lag depends on the chemical nature of the fuel. It is found that the fuels with higher self-ignition temperatures have comparatively higher period of ignition lag.

Speed:

It has no effect in terms of time period but it shows in terms of crank angle turned. Therefore with higher speeds the ignition advance should be increased.

Electrode gap:

The air gap between the electrodes of a spark plug is important from the point at establishment of nucleus of flame. If the electrode gap is too small, quenching of the flame nucleus may occur as the range of working with range of air-fuel ratio is reduced.

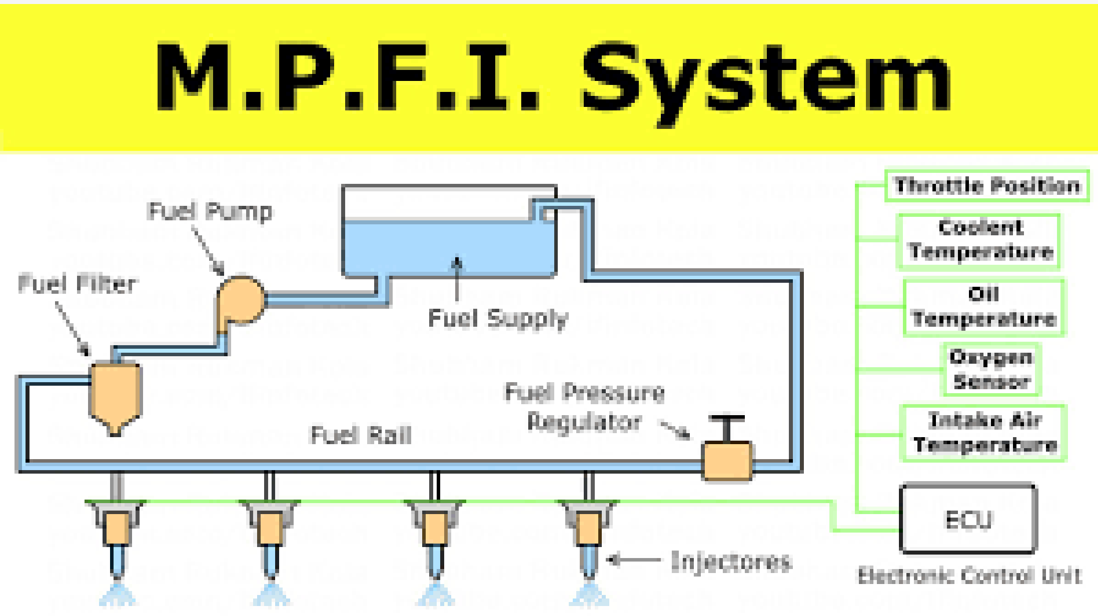
2. **Explain the working of multi-point and gasoline direct injection systems used in S.I engine with block diagram. (*)**

The carburettors mix the air-fuel in the required ratio, and supply it to the intake manifold. Due to the absence of electronic control, a carburettor cannot properly measure the air-fuel ratio with changing air pressure and fuel temperature

In multi-point fuel injection (MPFI) technology, every cylinder in the combustion chamber of the engine is given an injector at the front of their inlet valves (outside the intake port), which is why it's also called 'Port Injection'. These fuel injectors inject an optimum quantity of fuel into the combustion chamber, which also results in better atomization and swirl of fuel in the combustion chamber. As every cylinder has a specific injector, there is a negligible possibility of fuel condensation outside the intake manifold. The components of MPFI are

- Fuel pressure regulator
- Fuel injectors
- Cylinders
- Pressure spring
- Control diaphragm

In the system, multiple fuel injectors are situated upstream of the cylinders' intake valves. The fuel pressure regulator is connected to the fuel rail and governs the fuel flow. Meanwhile, the control diaphragm and pressure spring control the inlet valve opening and the amount of fuel that can return. The engine speed and load vary the pressure in the intake manifold.



Types of Multi Point Fuel Injection System

Sequential MPFI system

In a sequential multi point fuel injection system every injector nozzle works independently and they are timed like spark plugs to spray the fuel immediately before or as their respective intake valves open. This results in negligible fuel idling outside the intake valves and the maximum fuel is burnt for power generation, improving efficiency, power and reducing emission.

Batched MPFI system

Batched MPFI systems are employed in race cars that function at high engine RPM speeds. At these high RPMs, standard sequential fuel injection systems won't be able to adequately spray the fuel required by the engine to ensure combustion. To ensure the engine receives the fuel it needs, a batched MPFI system injects fuel when the intake valve is open as well as when it is closed. Thus, when the intake valve opens, the cylinder receives a 'batch' of fuel, so to speak. Based on its function, a batched MPFI system will use more fuel. However, since its use is primarily for performance engines, fuel efficiency is not a major concern.

Advantages of Multi Point Fuel Injection System

- ✓ Since there is negligible fuel idling outside the intake valves, maximum fuel is burnt resulting in maximum power output. For example, the old carburettor-equipped Maruti 800 (produced from 1983-2000) would deliver 35-40 PS of power and the MPFI-equipped Maruti 800 delivers 47 PS of power.
- ✓ MPFI-equipped engines vibrate less, resulting in a smoother driving experience as compared to that of carburettor-equipped cars.
- ✓ As every cylinder has its own fuel injector, the fuel injection in the cylinder is quicker as opposed to that in the single point fuel injection system. This makes MPFI-equipped engines more responsive.
- ✓ Maximum fuel is burnt in MPFI and there is negligible fuel deposition outside the intake valves as compared to single point fuel injection system and carburettors. Thus MPFIs deliver a better fuel efficiency and lesser emission.

Disadvantages of Multi Point Fuel Injection System

- ✓ It requires regular inspection of fuel injectors
- ✓ The system is expensive compared to carburettors.
- ✓ Complex design and can be tedious to repair as compared to carburettors

3. **Describe the phenomenon knocking in S.I engine and the factors affecting knocking in S.I engine (* *)**

The various engine variables affecting knocking can be classified as:

- **Temperature factors**
- **Density factors**
- **Time factors**
- **Composition factors**

(A) TEMPERATURE FACTORS

Increasing the temperature of the unburned mixture increase the possibility of knock in the SI engine we shall now discuss the effect of following engine parameters on the temperature of the unburned mixture:

i. Raising the Compression Ratio

Increasing the compression ratio increases both the temperature and pressure (density of the unburned mixture). Increase in temperature reduces the delay period of the end gas which in turn increases the tendency to knock.

ii. Supercharging

It also increases both temperature and density, which increase the knocking tendency of engine

iii. Coolant Temperature

Delay period decreases with increase of coolant temperature, decreased delay period increase the tendency to knock

iv.Temperature Of The Cylinder And Combustion Chamber Walls :

The temperature of the end gas depends on the design of combustion chamber. Sparking plug and exhaust valve are two hottest parts in the combustion chamber and uneven temperature leads to pre-ignition and hence the knocking.

(B) DENSITY FACTORS

Increasing the density of unburnt mixture will increase the possibility of knock in the engine. The engine parameters which affect the density are as follows:

- Increased compression ratio increase the density
- Increasing the load opens the throttle valve more and thus the density
- Supercharging increase the density of the mixture
- Increasing the inlet pressure increases the overall pressure during the cycle.
  The high pressure end gas decreases the delay period which increase the tendency of knocking.
- Advanced spark timing: quantity of fuel burnt per cycle before and after TDC position depends on spark timing. The temperature of charge increases by increasing the spark advance and it increases with rate of burning and does not allow sufficient time to the end mixture to dissipate the heat and increase the knocking tendency

(C) TIME FACTORS

Increasing the time of exposure of the unburned mixture to auto-ignition conditions increase the possibility of knock in SI engines.

i. Flame travel distance:

If the distance of flame travel is more, then possibility of knocking is also more. This problem can be solved by combustion chamber design, spark plug location and engine size. Compact combustion chamber will have better anti-knock characteristics, since the flame travel and combustion time will be shorter. Further, if the combustion chamber is highly turbulent, the combustion rate is high and consequently combustion time is further reduced; this further reduces the tendency to knock.

ii. Location of sparkplug:

A spark plug which is centrally located in the combustion chamber has minimum tendency to knock as the flame travel is minimum. The flame travel can be reduced by using two or more spark plugs.

iii. Location of exhaust valve:

The exhaust valve should be located close to the spark plug so that it is not in the end gas region; otherwise there will be a tendency to knock.

iv. Engine size

Large engines have a greater knocking tendency because flame requires a longer time to travel across the combustion chamber. In SI engine therefore, generally limited to 100 mm

v. Turbulence of mixture

Decreasing the turbulence of the mixture decreases the flame speed and hence increases the tendency to knock. Turbulence depends on the design of combustion chamber and one engine speed.

COMPOSITION FACTORS

i. Molecular Structure

The knocking tendency is markedly affected by the type of the fuel used. Petroleum fuels usually consist of many hydro-carbons of different molecular structure. The structure of the fuel molecule has enormous effect on knocking tendency. Increasing the carbon-chain increases the knocking tendency and centralizing the carbon atoms decreases the knocking tendency. Unsaturated hydrocarbons have less knocking tendency than saturated hydrocarbons.

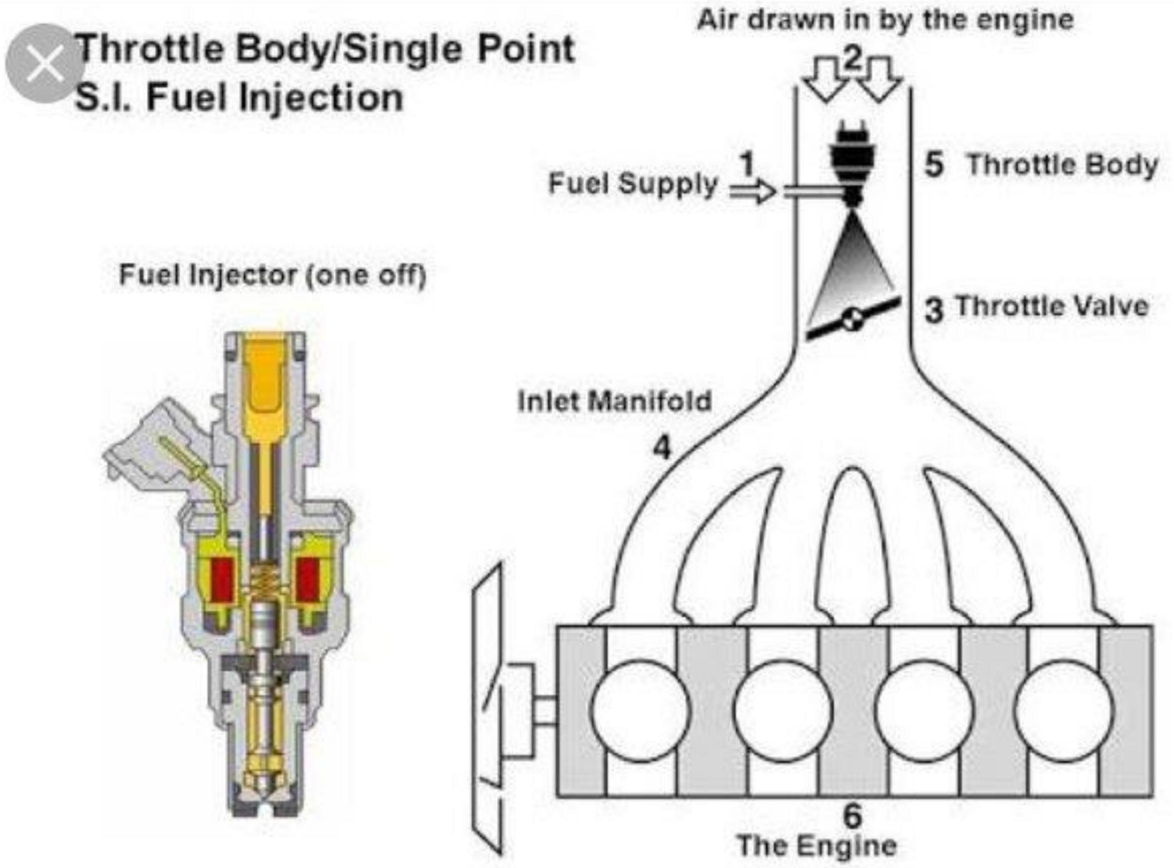
ii. Fuel-air ratio:

The most important effect of fuel-aft ratio is on the reaction time or ignition delay. When the mixture is nearly 10% richer than stoichiometric (fuel-air ratio =0.08) ignition lag of the end gas is minimum and the velocity of flame propagation is maximum. By making the mixture leaner or richer (than F/A 0.08) the tendency to knocks decreased. A too rich mixture is especially effective in decreasing or eliminating the knock due to longer delay and lower temperature of compression.

iii. Humidity of air:

Increasing atmospheric humidity decreases the tendency to knock by decreasing the reaction time of the fuel

4. Explain the port fuel injection system in a S.I engine with a schematic.



The Port Fuel Injection (PFI) system is a type of fuel injection system used in Spark Ignition (S.I.) engines, commonly found in most gasoline-powered vehicles. In a PFI system, fuel is injected into the intake ports of each cylinder before the intake valve. This allows for precise control of the air-fuel mixture and improves combustion efficiency.

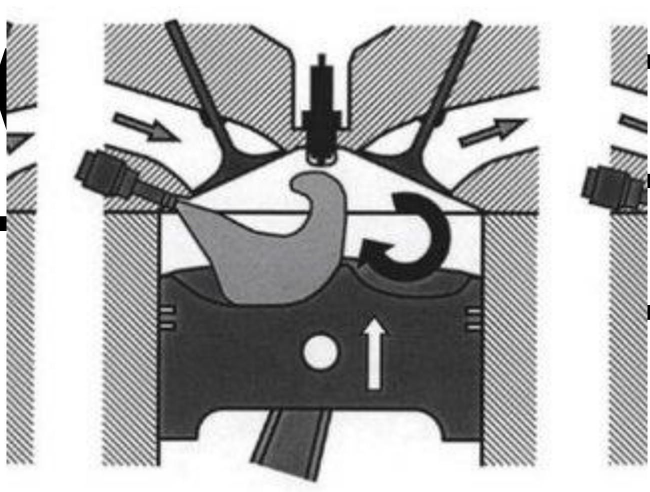
Here's a simplified schematic diagram of a Port Fuel Injection system in a Spark Ignition engine:

1. **Fuel Tank:** The fuel tank stores the gasoline, and a fuel pump is used to pump the fuel to the rest of the system.
2. **Fuel Pump:** The fuel pump pressurizes the fuel to a level suitable for injection into the engine. It maintains a constant flow of fuel to meet the engine's demands.
3. **Fuel Filter:** The fuel filter removes impurities and contaminants from the fuel before it reaches the fuel injectors, preventing damage to the injectors and ensuring a clean fuel supply.
4. **Fuel Rail:** The fuel rail is a pipe that distributes pressurized fuel to individual fuel injectors. It acts as a conduit to supply each injector with the required amount of fuel.
5. **Fuel Injectors:** Each cylinder is equipped with a fuel injector. The injectors are electronically controlled valves that spray a fine mist of fuel into the intake port just before the intake valve opens.
6. **Throttle Body:** The throttle body is equipped with a throttle plate that controls the amount of air entering the engine. It is controlled by the accelerator pedal, which is connected to the throttle position sensor.

7. **Intake Manifold:** The intake manifold is a series of tubes that distribute air to each cylinder. The fuel injectors are strategically placed in the intake manifold to ensure proper mixing of air and fuel.
8. **Intake Valve:** The intake valve opens to allow the air-fuel mixture to enter the combustion chamber. The precise injection of fuel at this point ensures a well-mixed and combustible air-fuel mixture.
9. **Combustion Chamber:** This is where the air-fuel mixture is ignited by the spark plug, leading to combustion and the generation of power to drive the engine.
10. **Exhaust Valve:** The exhaust valve opens to allow the exhaust gases to exit the combustion chamber and flow into the exhaust system.

The electronic control unit (ECU) monitors various engine parameters, such as engine speed, throttle position, and oxygen content in the exhaust, to determine the optimal fuel injection timing and duration for each cylinder. This control mechanism allows for efficient combustion and optimal performance.

5. **Draw the wall guided mode of direct injection combustion chamber for a S.I engine.**



wall-guided

6. **Explain how the power and efficiency of the S.I engine vary with air fuel ratio for different load and speed conditions.**

Air-fuel Requirement in SI Engines

The spark-ignition automobile engines run on a mixture of gasoline and air. The amount of mixture the engine can take in depends upon following major factors:
(i) Engine displacement.
(ii) Maximum revolution per minute (rpm) of engine. (Hi) Carburettor air flow capacity.
(iu) Volumetric efficiency of engine.
There is a direct relationship between an engine's air flow and it's fuel requirement. This relationship is called the air-fuel ratio.

Air-fuel Ratios

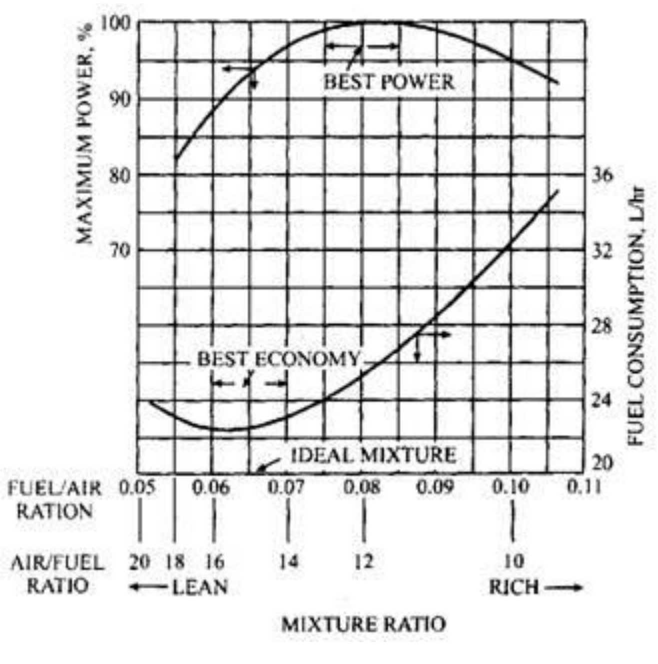
The air-fuel ratio is the proportions by weight of air and gasoline mixed by the carburettor as required for combustion by the engine. This ratio is extremely important for an engine because there are limits to how rich (with more fuel) or how lean (with less fuel) it can be, and still remain fully combustible for efficient firing. The mixtures with which the engine can operate range from 8:1 to 18.5:1 i.e. from 8 kg of air/kg of fuel to 18.5 kg of air/kg of fuel. Richer or leaner air-fuel ratio limit causes the engine to misfire, or simply refuse to run at all.

Stoichiometric Air-Fuel Ratio

The ideal mixture or ratio at which all the fuels blend with all of the oxygen in the air and be completely burned is called the stoichiometric ratio, a chemically perfect combination. In theory, an air fuel ratio of about 14.7:1 i.e. 14.7 kg of air/kg of gasoline produce this ratio, but the exact ratio at which perfect mixture and complete combustion take place depends on the molecular structure of gasoline, which can vary somewhat.

Engine Air-fuel Ratios

An automobile SI engine, as indicated above, works with the air-fuel mixture ranging from 8:1 to 18.5:1. But the ideal ratio would be one that provides both the maximum power and the best economy, while producing the least emissions. But such a ratio does not exist because the fuel requirements of an engine vary widely depending upon temperature, load, and speed conditions. The best fuel economy is obtained with a 15:1 to 16:1 ratio, while maximum power output is achieved with a 12.5:1 to 13.5:1 ratio. A rich mixture in the order of 11:1 is required for idle heavy load, and high-speed conditions. A lean mixture is required for normal cruising and light load conditions. Figure 9.36 represents the characteristic curves showing the effect of mixture ratio on efficiency and fuel consumption.



Effect of air-fuel ratio on efficiency and fuel consumption.

Practically for complete combustion, through mixing of the fuel in excess air (to a limited extent above that of the ideal condition) is needed. Lean mixtures are used to obtain best economy through minimum fuel consumption whereas rich mixtures used to suppress combustion knock and to obtain maximum power from the engine. However, improper distribution of mixture to each cylinder and imperfect/incomplete vaporization of fuel in air necessitates the use of rich mixture to obtain maximum power output. A rich mixture is also required to overcome the effect of dilution of incoming mixture due to entrapped exhaust gases in the cylinder and of air leakage because of the high vacuum in the manifold, under idling or no-load condition. Maximum power is desired at full load while best economy is expected at part throttle conditions. Thus required air fuel ratios result from maximum economy to maximum power. The carburettor must be able to vary the air-fuel ratio quickly to provide the best possible mixture for the engine's requirements at a given moment.

The best air-fuel ratio for one engine may not be the best ratio for another, even when the two engines are of the same size and design. To accurately determine the best mixture, the engine should be run on a dynamometer to measure speed, load and power requirements for all types Of driving conditions.

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With a slightly rich mixture, the combustion flame travels faster and conversely with a slightly weak mixture, the flame travel becomes slower. If a very rich mixture is used then some "neat" petrol enters cylinder, washes away lubricant from cylinder walls and gets past piston to contaminate engine oil. A very sooty deposit occurs in the combustion chamber. On the other hand, if an engine runs on an excessively weak mixture, then overheating particularly of such parts as valves, pistons and spark plugs occurs. This causes detonation and pre-ignition together Or separately.

The approximate proportions of air to petrol (by weight) suitable for the different operating conditions are indicated below:

Starting	**9 :**	**1**
Idling	**12 :**	**1**
Acceleration	**12 :**	**1**
Economy	**16:**	**1**
Full power	**12 :**	**1**

It makes no difference if an engine is carburetted or fuel injected, the engine still needs the same air-fuel mixture ratios.

7. **Discuss about the function and requirements of S.I engine combustion chambers and explain the different types of combustion chambers used in S.I engine with neat sketch.**

The design of a combustion chamber for a spark Ignition Engine involves the shape of the combustion chamber, location of the spark plug and the location of the inlet valve and exhaust valve. Due to this design, the combustion chamber has a great influence on engine performance. In this article, we are going to discuss the Different types of combustion chambers for SI Engines.

The main objectives and importance of the combustion chamber is to provide the following objectives.

- Smooth Engine operation
- High power output and thermal efficiency

Smooth engine operation can be achieved by reducing the possibility of knocking in the engine. This can be done by the locate the spark plug at the correct position, proper Cooling of the spark plug and the exhaust valves area.

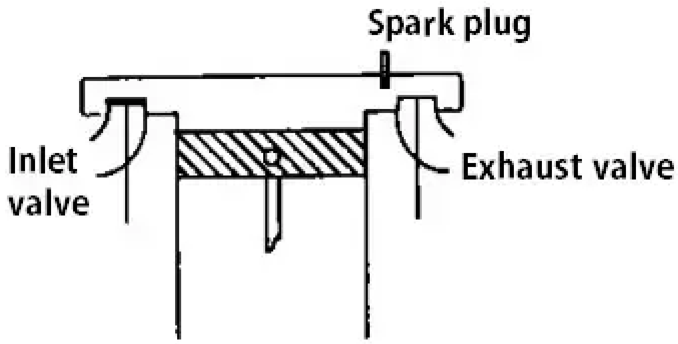
High power output and thermal efficiency can be achieved by creating a high degree of turbulence and sucking more amount of charge to attain high volumetric efficiency, improved antiknock characteristics, compact design. All these can be achieved by a suitable combustion chamber for the engine. There are different types of combustion chambers for SI engines. Let’s discuss them in detail.

Different types of combustion chambers for SI Engines

- T-Head type
- L-Head type
- I-Head type
- F-Head type

T-Head Type

T-Head type

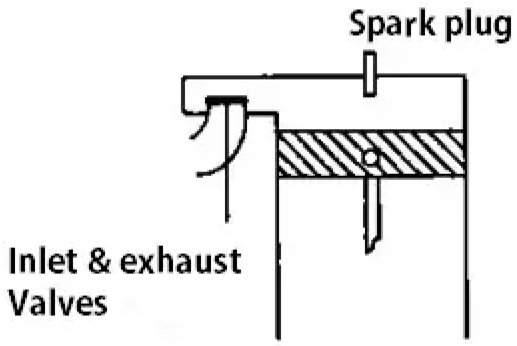


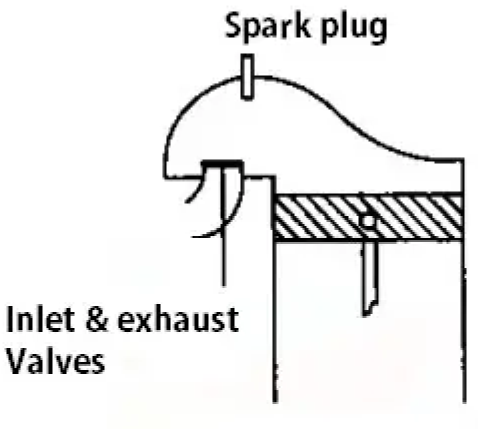
Check out the T-Head type of the combustion chamber for the spark ignition engines. As you can see there will be two valves on each side and a spark plug from the top side. This type of combustion chambers was used in the early stages of the engine’s development. In this type of combustion chamber, the knocking tendency is more because of the distance across the combustion chamber is long. There is need of two cam shafts for the two valves. Which is another disadvantage.

L-Head type

As you can see one of the disadvantages in the T-head type is having two valves on either side which needs two camshafts to operate them. Bringing these inlet and exhaust valves to the same side will solve this problem. In this L-Head type combustion chamber, you can see both inlet and the exhaust valve will be on the same side operated by the same camshaft.

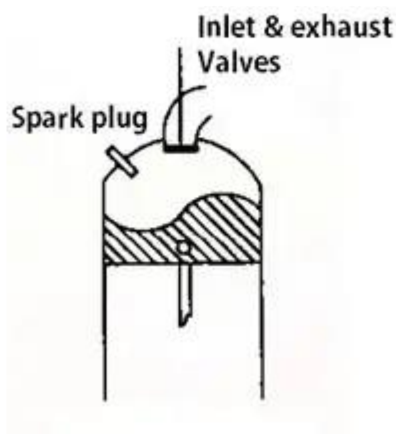
L-Head type





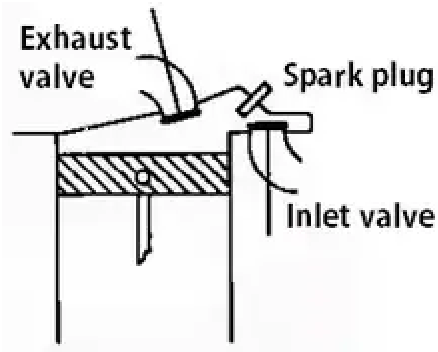
L-Head type (Left side) combustion chamber. L-Head type combustion chamber the charge need to take a right angle turn to enter into the combustion chamber. This cause the loss of velocity and low turbulence results in the slow combustion process. To avoid this we have Ricardo's turbulent head design for the L-Head combustion chamber (Right side picture). The head design will be helpful to create the turbulence for the charge to keep the velocity for improving the combustion process. Also, the spark plug is placed at the centre of the combustion chamber, the flame travel length is reduced. The knocking is also reduced with this head design.

I-Head type



This I-Head type combustion chamber is also called as the overhead valve combustion chamber. As you can see the inlet and the exhaust valves are located on the top of the cylinder head. The main advantage of this combustion chamber is that it can achieve high compression ratios, and also less tendency to the knock. High volumetric efficiency. We can avoid the thermal failures by keeping the hot exhaust valve in the head instead of the cylinder.

F-Head type



F-Head type combustion chamber is an inspired design from the L-head type and the I-Head type combustion chambers. As you can see the F-Head type combustion chamber in the above diagram, One exhaust valve is in the cylinder head, the inlet valve in the side, and the spark plug is in the cylinder head. Again this has the same disadvantage as the T-Head type combustion chamber as the two valves need to be operated by two different camshafts.

7. Give the detailed comparison of combustion phenomenon in C.I engine and S.I engine.(

The main difference between combustion in SI and CI engines is the method of ignition. In SI engines, a spark plug is used to ignite the air-fuel mixture, while in CI engines, combustion occurs spontaneously due to high temperature and pressure during compression.

Combustion in CI Engines

• Combustion in CI engines differ from SI engine due to the basic fact that CI engine combustion is unassisted combustion occurring on its' own.
• In CI engine the fuel is injected into combustion space after the compression of air is completed.
• Due to excessively high temperature and pressure of air the fuel when injected in atomised form gets burnt on its' own and burning of fuel is continued till the fuel is injected.
• Theoretically this injection of fuel and its' burning should occur simultaneously up to the cut-off point, but this does not occur in actual CI engine. Different significant phases of combustion are explained as under.

Combustion in SI engine may roughly is divided into two general types:
Normal and Abnormal (knock free or knocking). Theoretical diagram of pressure crank angle diagram is shown in figure below. ($a \rightarrow b$) is compression process, ($b \rightarrow c$) is combustion process and ($c \rightarrow d$) is an expansion process. In an ideal cycle it can be seen from the diagram,

the entire pressure rise during combustion takes place at constant volume i.e., at TDC. However, in actual cycle this does not happen

Three Stage of Combustion: According to Ricardo, There are three stages of combustion in SI Engine as shown 1. Ignition lag stage 2. Flame propagation stage 3. After burning stage

8. Give detailed comparison of knock in C.I engine and S.I engine.(8)

The knocking in SI engine takes place in homogeneous mixture, therefore, the rate of pressure rise and maximum pressure is considerably high. In case of CI engine, the mixture is not homogenous and hence the rate of pressure is lower than in SI engine.
In spark-ignition engines, the auto ignition of the end gas away from the spark plug, most likely near the end of the combustion causes knocking.

But in compression-ignition engines the auto ignition of the charge causing knocking is at the start of combustion. It is the charge that auto ignites and causes knocking in the compression-ignition engines.

Auto-ignition is more or less before the peak pressure for the compression-ignition engines. But for spark-ignition engines, the condition for auto ignition of the end charge is more favourable after the peak pressure.

Knock in Spark Ignition (S.I.) Engines:

1. **Cause of Knock:**
   In S.I. engines, knocking occurs when the air-fuel mixture ignites before the spark plug fires or when multiple flame fronts collide.
   High temperatures and pressures in the combustion chamber can lead to auto ignition, causing knocking.
2. **Fuel Characteristics:**
   S.I. engines typically use gasoline, which has a lower octane rating. Lower octane fuels are more prone to knocking.
3. **Control Mechanisms:**
   - Knock in S.I. engines is controlled by adjusting the ignition timing and using higher-octane fuels.
   - Engine control systems, including knock sensors, can detect knocking and adjust the spark timing to prevent it.
4. **Detrimental Effects:**
   - Knocking can lead to engine damage over time, causing issues like piston damage and overheating.
   - S.I. engines have a more sensitive knock tolerance, and persistent knocking can result in power loss and reduced efficiency.

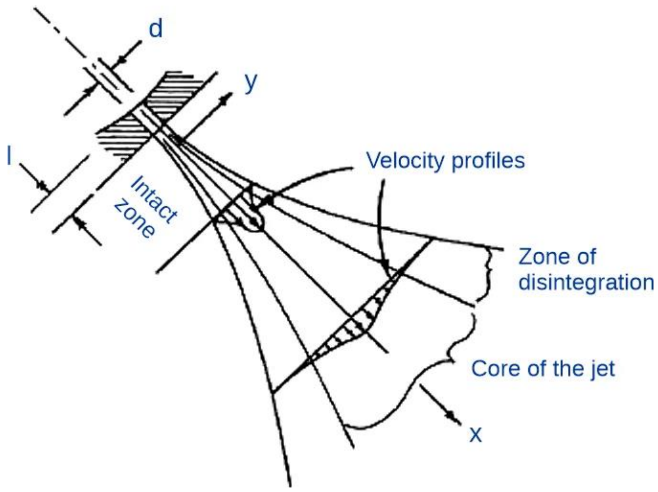
Knock in Compression Ignition (C.I.) Engines:

1. **Cause of Knock:**
    - In C.I. engines, knocking occurs when the fuel-air mixture ignites unevenly or prematurely due to high temperatures and pressures in the combustion chamber.
2. **Fuel Characteristics:**
    - C.I. engines use diesel fuel, which has a higher cetane rating. Higher cetane fuels are less prone to premature ignition.
3. **Control Mechanisms:**
    - Knock control in C.I. engines is challenging because the ignition is initiated by the heat of compression, not by a spark plug.
    - Engine design and fuel quality play crucial roles in controlling knocking in C.I. engines.
4. **Detrimental Effects:**
    - Knocking in C.I. engines can lead to increased noise, reduced engine efficiency, and potential damage to engine components.
    - C.I. engines generally have a higher knock tolerance due to the nature of the combustion process.

Commonalities:

- Both types of engines aim to optimize combustion to prevent knocking and improve efficiency.
- Knock control strategies may involve adjusting factors such as fuel quality, compression ratio, and injection timing.

10. Describe diesel fuel spray behaviour and spray structure with neat sketch.(*)



Diesel Fuel Spray Behaviour:

1. **Injection System:**
   - Diesel fuel is typically injected into the combustion chamber by a fuel injector. The injection system pressurizes the fuel and delivers it in a finely atomized spray.
2. **Injection Timing:**
   - The injection timing determines when the fuel is injected into the combustion chamber. It is carefully controlled to optimize combustion efficiency and reduce emissions.
3. **Injection Pressure:**
   - Diesel fuel is injected at high pressure to achieve proper atomization. Common rail injection systems are often used to provide precise control over injection pressure.
4. **Spray Penetration:**
   - Spray penetration refers to the distance the fuel spray travels into the combustion chamber. Proper penetration ensures that fuel is distributed evenly for efficient combustion.
5. **Spray Angle:**
   - The spray angle is the width of the fuel spray cone. It is crucial for achieving uniform mixing of fuel and air in the combustion chamber.

   6. **Fuel Spray Cone:** The fuel spray is often depicted as a cone, spreading outward from the fuel injector. The angle of the cone is the spray angle.
   7. **Spray Penetration:** The distance the spray travels into the combustion chamber is crucial for ensuring that fuel is properly distributed.
   8. **Atomization:** The fuel spray consists of finely atomized droplets. Efficient atomization is essential for proper mixing with air, promoting a homogeneous air-fuel mixture.
   9. **Uniformity:** The goal is to achieve a uniform spray pattern to ensure consistent combustion across all cylinders and reduce emissions.
   10. **Vaporization:** As the fuel spray enters the high-temperature environment of the combustion chamber, it undergoes vaporization, turning the liquid fuel into a combustible vapor.

Optimizing the diesel fuel spray structure is essential for achieving a balance between combustion efficiency, power output, and emission control in diesel engines. Advances in injection technology, such as common rail systems and multiple injections per cycle, have allowed for greater control over the fuel spray characteristics, contributing to improved engine performance and reduced environmental impact.

10. Discuss about the function, requirements and types combustion chambers used in C.I engine with neat sketch.

Function of Combustion Chambers in Compression Ignition (C.I.) Engines:

The combustion chamber in a C.I. engine plays a crucial role in the combustion process. Its primary functions include:

1. **Facilitating Combustion:** The combustion chamber provides a space for the air-fuel mixture to ignite when subjected to high pressure and temperature during the compression stroke.
2. **Promoting Efficient Mixing:** It helps in achieving a proper mixing of air and fuel, ensuring a homogenous mixture for combustion.

3. **Controlling Combustion Rate:** The design of the combustion chamber influences the rate at which combustion occurs, impacting engine efficiency, power output, and emissions.

Requirements for Combustion Chambers in C.I. Engines:

4. **Adequate Volume:** The combustion chamber must have sufficient volume to accommodate the air-fuel mixture during the compression stroke.
5. **Proper Shape:** The shape of the combustion chamber affects turbulence and swirl, which are essential for promoting proper mixing of air and fuel.
6. **Heat Dissipation:** Efficient heat dissipation is crucial to prevent overheating of engine components. The combustion chamber design should facilitate heat transfer to the engine walls and cooling systems.
7. **Minimization of Heat Loss:** While heat dissipation is essential, minimizing heat loss to the surroundings is also important for maximizing thermal efficiency.
8. **Control of Combustion:** The combustion chamber design should control the combustion process to avoid knocking, promote complete combustion, and minimize emissions.

Types of Combustion Chambers in C.I. Engines:

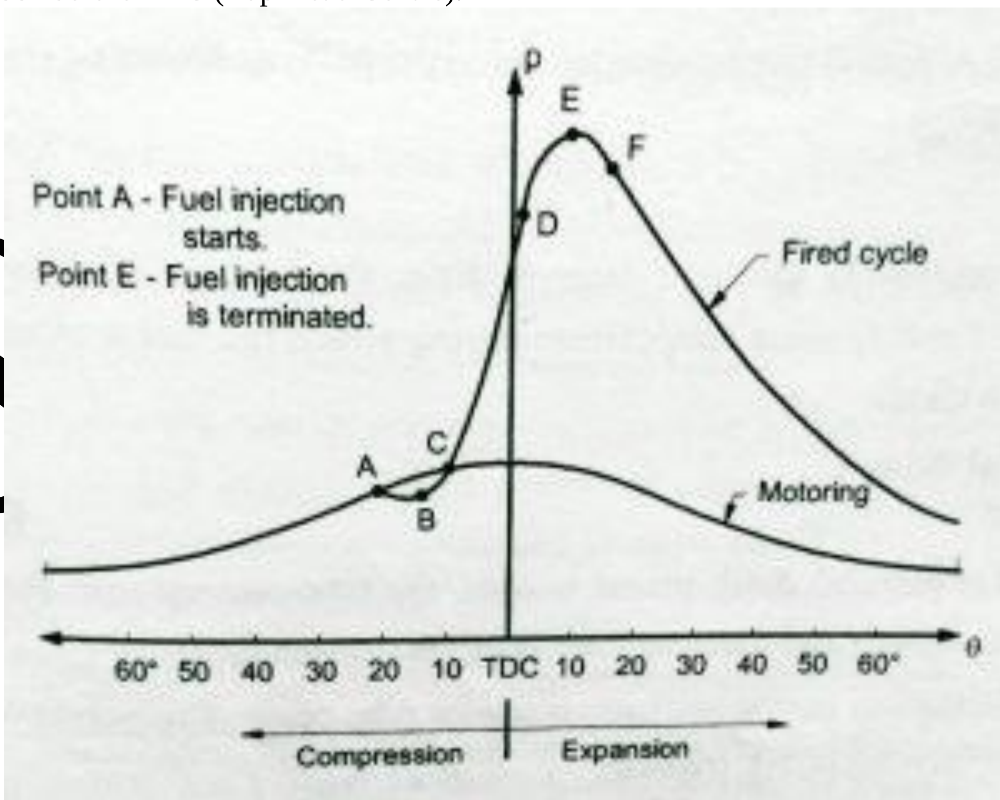
1. **Direct Injection (DI) Combustion Chamber:**
   - **Description:** In DI engines, fuel is injected directly into the combustion chamber, usually at or near the top of the compression stroke.
   - **Advantages:** Provides better control over the combustion process, promotes efficient mixing, and allows for flexibility in injection timing.
   - **Sketch:** Neat Sketch of Direct Injection Combustion Chamber
2. **Indirect Injection (IDI) Combustion Chamber:**
   - **Description:** In IDI engines, fuel is injected into a pre-combustion chamber or swirl chamber, which then communicates with the main combustion chamber.
   - **Advantages:** Easier control of combustion, lower heat loss, and reduced emissions.
   - **Sketch:** Neat Sketch of Indirect Injection Combustion Chamber
3. **Swirl Chamber Combustion Chamber:**
   - **Description:** These chambers induce a swirling motion to the incoming air, promoting better mixing with the fuel.
   - **Advantages:** Improved air-fuel mixing, enhanced combustion efficiency, and reduced emissions.
   - **Sketch:** Neat Sketch of Swirl Chamber Combustion Chamber

4. **Turbulence Chamber Combustion Chamber:**
   - **Description:** Designed to create turbulence in the air-fuel mixture, aiding in better mixing and combustion.
   - **Advantages:** Improved combustion efficiency, reduced ignition delay, and enhanced stability.
   - **Sketch:** Neat Sketch of Turbulence Chamber Combustion Chamber

11. Explain the stages of combustion in C.I engine with pressure-crank angle and heat release rate diagram. (*)

Combustion is a process of the rapid chemical reaction between fuel and the air. This process results in the generation of heat and light. In IC Engine, there are different stages of combustion for different engines. In this post, we are going to focus on stages of combustion in CI engine. Stages of combustion in SI engine are completely different than the CI engines. In CI or compression ignition engine, in the compression stroke, only air is compressed at very high pressure and temperature. The **compression ratio** used is in the range of 12 to 120.

The temperature of the air becomes higher than the temperature of the fuel which is diesel in the CI engine. Then diesel fuel is injected in the combustion chamber under very high pressure about 120 to 210 bar. The temperature of this fuel is around 20° to 35° before TDC (Top Dead Centre).



Stages of Combustion in CI engine:

There are four different stages of combustion in CI engine where proper combustion of air and fuel takes place as follows:

- Ignition Delay Period
- Period of Uncontrolled Combustion
- Period of Controlled Combustion
- After Burning

1. Ignition Delay Period

At this first stage of combustion in the CI engine, the fuel from the injection system sprayed in the combustion chamber in the form of a jet. Due to atomization and vaporization, this fuel disintegrates at the core which is surrounded by a spray of air and fuel particles.

In this vaporization process, the fuel gets heat from the compressed and hot surrounding air. It causes some pressure drop in the cylinder. You can see this pressure drop (curve AB) in the above figure.

After completion of the vaporization process, the *preflame reaction* of the mixture in the combustion chamber starts. During the preflame reaction, pressure into the cylinder starts increasing with the release of energy at a slow rate.
This preflame reaction starts slowly and then speeds up until the ignition of the fuel takes place. You can see this process at point C on the diagram.

This time interval between the starting of the fuel injection and the beginning of the combustion is called the **delay period**. This delay period can further be divided into two parts – Physical delay and chemical delay.
The period between the time of injection of the fuel and its achievement of self-ignition temperature during vaporization is called physical delay. When physical delay completes, the time interval up to the fuel ignites and the flame of the combustion appears is called chemical delay.

Preflame reaction we discussed above is taking place during the chemical delay. Due to the complex process of combustion is a CI engine, it’s difficult to separate these two delay periods.

If this delay period performs longer than usual, then we can here knocking in CI engine.

2. Period of Uncontrolled Combustion

This is the second stage of combustion in the CI engine. After the above-mentioned delay period is over, the air and fuel mixture will auto-ignite as they have achieved their self-ignition temperature.
The mixture of air and fuel in CI engines is heterogeneous unlike homogeneous in the SI engines. Due to this heterogeneous mixture, flames appear at more than one location where the concentration of the mixture is high.
When the flame formed the mixture in the other low concentration starts burning by the propagation of flames or due to auto-ignition, because of the process of heat transfer.
The accumulated fuel during the delay is now started burning at an extremely rapid rate. It causes a rise in in-cylinder pressure and temperature. So, the higher the delay period, the higher would be the rate of pressure rise.
During this stage, you can’t control the amount of fuel burning, that’s why this period is called a *period of uncontrolled combustion.* This period is represented by the curve CD in the above figure.

3. Period of Controlled Combustion

When the accumulated fuel during the delay period completely burned in the period uncontrolled combustion, the temperature and pressure of the mixture in the cylinder are so high that new injected fuel from the nozzle will burn rapidly due to the presence of sufficient oxygen in the combustion chamber.

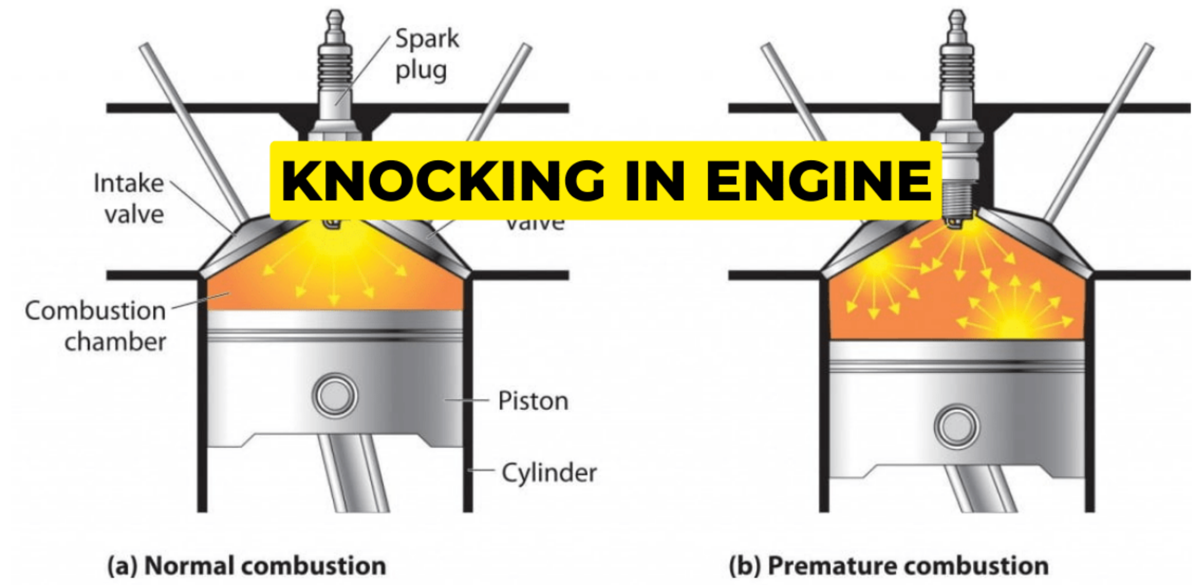
That’s the reason we can control the rise of pressure into the cylinder by controlling the fuel injection rate. Therefore, this period of combustion is called a period of controlled combustion.

4. After Burning

This is the last stage out of the four stages of combustion in CI engine.
Naturally, the combustion process is completed at the point when the maximum pressure is obtained in the combustion chamber at point E as shown in the figure.

12. **Explain the occurrence knocking in C.I engine and the factors that are influencing knocking in C.I engine.**

CI engine knocking associated with delayed ignition of the fuel. This causes a sharp pressure rise in the combustion chamber and the characteristic 'knock' sound. The CI or Diesel cycle is a 'constant pressure' combustion cycle as opposed to the SI or Otto cycle which is 'constant volume' combustion cycle.



Compressed Ignition Engine knocking:

CI engine knocking occurs when the fuel ignites too late, which can cause a knocking sound and reduce engine power. This type of knocking is often caused by fuel quality issues or incorrect injection timing.

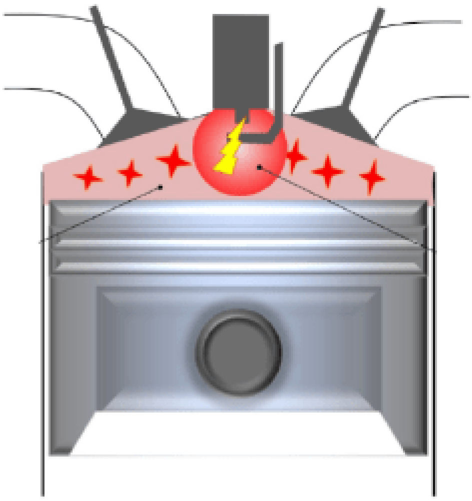
Reasons for fuel knocking are:

1. **Engine speed:** If the supply of fuel to the combustion chamber is more than you need to increase the rpm of the piston to avoid knocking.

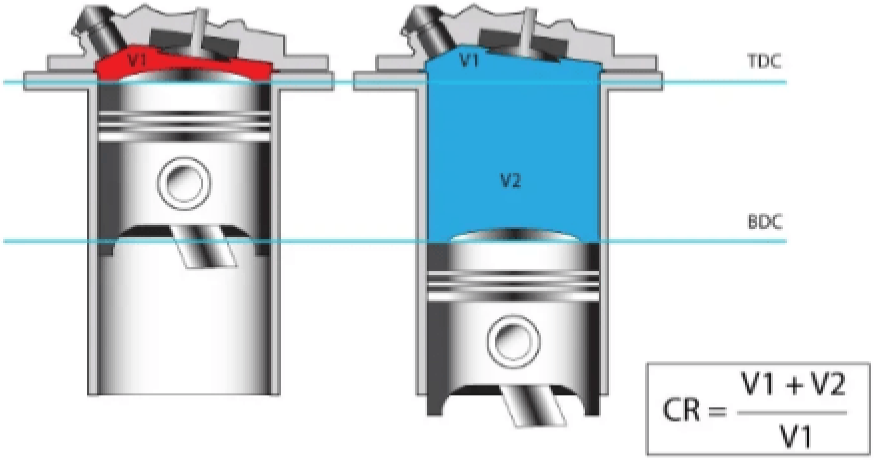
For example suppose an engine requires X amount of fuel and by chance you send X+Y amount of fuel. You will have to increase the engine speed. So that fuel is corresponding to the engine speed then knocking will stop.

2. **Load:** If load is more than fuel consumption will be required more and if load is less fuel consumption will be less in the engine otherwise there can be a chance of knocking.

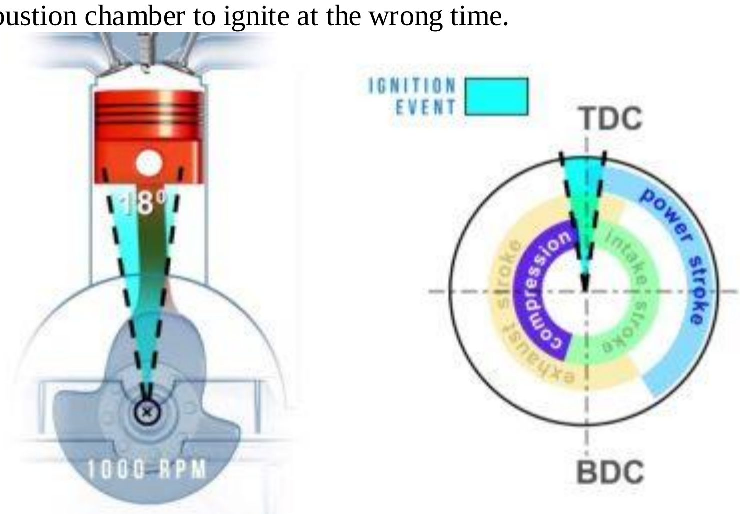
3. **Ignition delay:** If fuel is not burnt at the correct time and ignition is delayed.



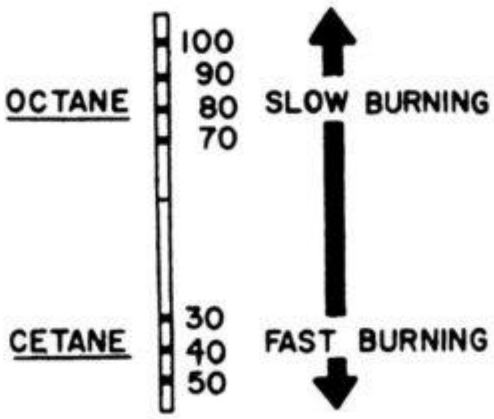
4. **Compression ratio:** It is a design thing that involves dimension of bore and length of piston stroke.



5. **Injection timing:** Incorrect injection timing can cause the air and fuel mixture in the combustion chamber to ignite at the wrong time.



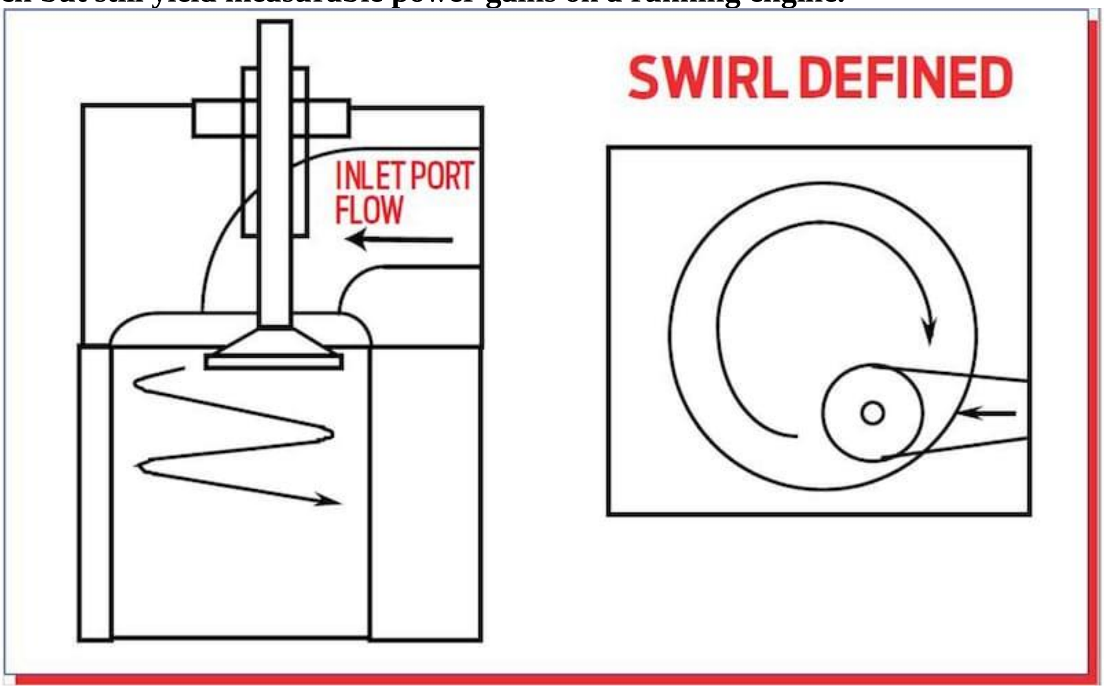
6. **Cetane & Octane number:** For Diesel engine cetane number is required as it resembles the quality of fuel, higher the cetane number better it will give less ignition delay.
7. For a Petrol engine the higher octane number means better anti-knocking properties.



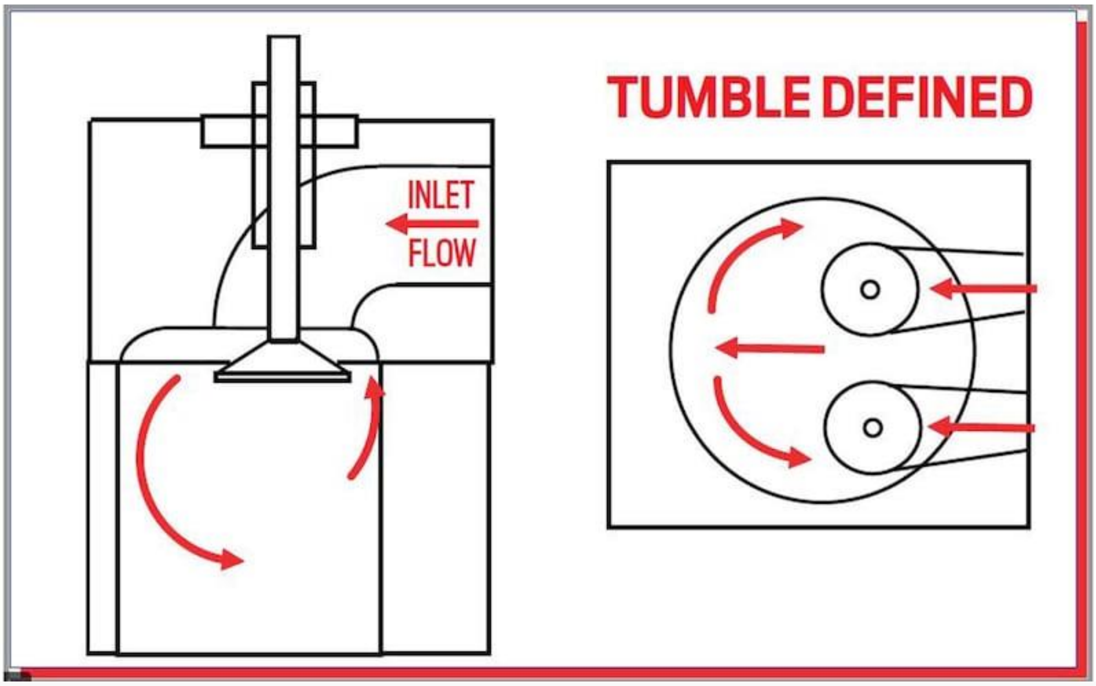
13. **Discuss the significance of air motion in a CI engine. Also define and mention the significance of swirl, tumble and squish.(10)**

Swirl in IC engines is the rotational motion of the incoming air charge about the cylinder's axis as it enters the combustion chamber on a two-valve head. Tumble in IC engines is the rotational motion of the incoming air/fuel charge in a plane approximately normal to the crankshaft on a four-valve head.

"Swirl"—the rotational motion of the incoming air charge about the cylinder's axis as it enters the combustion chamber on a two-valve head—is determined by the intake valve's position relative to the bore axis, the chamber shape around the intake, and any helix in the induction tract. Swirl is maximized by paying careful attention to a wedge head's valve positioning. Think of swirl in an IC engine like the vortex generated by a flushing toilet. **Swirl should always be in one direction; swirl that changes direction at different amounts of valve-lift leads to unstable combustion,** requires more ignition lead, and reduces knock-limited power potential. **Optimized swirl-port heads sometimes flow less air on a flow bench but still yield measurable power gains on a running engine.**



Instead of swirl, **four-valve engines primarily generate "tumble," the rotational motion of the incoming air charge in a plane approximately normal to the crankshaft.** Rather than a swirl-port head's vortex like air/fuel charge rotation, tumble is more akin to a rolling barrel. Like swirl, tumble looks to increase burn rate. It can also improve combustion stability through better charge mixing. **Tumble reduces the spark knock tendency on an octane-limited IC engine.** It is, however, possible to have too much tumble and swirl, which can reduce volumetric efficiency (VE) and power.



Turbulence is very important for close to complete combustion. Swirl, Squish, and Tumble are used to create turbulence in internal combustion engines.
Kirk Harris discovered that a static fan shape with overlapping 70 degree blades creates lots of fast moving swirl at the approximately one to two meter per second velocities found in TLUDs.

1. Swirl:

The rotational motion of air within the cylinder is called Swirl. Swirl enhances mixing and makes the flue air mixtures homogeneous. Swirl is the main mechanism to spread the flame within the combustion zone.

2. Squish:

The radial inward movement of air is called Squish. Squish can be defined as an inward flow of air towards the combustion recess.

3. Tumble:

Squish generates secondary motion about the circumferential axis near the outer edges. This motion is called ‘tumble’. To achieve this either the fuel is directed towards air or air is directed towards the fuel.

14. Depict at least two types of modern day C.I engine combustion chamber shapes.(**)

In Compression Ignition engines, Turbulence is necessary to mix the fuel within a short period after injecting the fuel into the combustion chamber. It can be controlled by the combustion chamber shape and design. Compression-Ignition engine combustion chambers are classified into two categories.

Types of combustion chambers for CI Engines

There are two different types of combustion chambers for CI Engines.

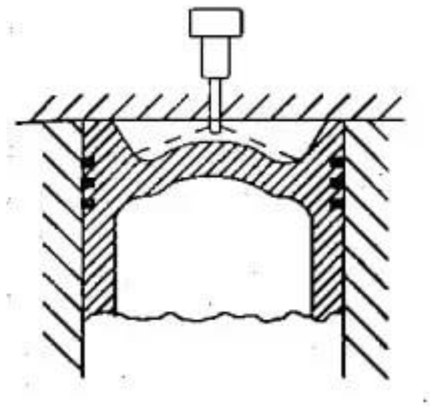
Direct Injection type
Indirect Injection type

Direct Injection type combustion chambers

Direct Injection type combustion chambers are also known as the open type combustion chambers. This open type combustion chambers, the combustion chamber volume will be located in the cylinder. The fuel will be injected directly into the combustion chamber with the help of the fuel injector.
There are four design variants available in Direct Injection type combustion chambers. those are

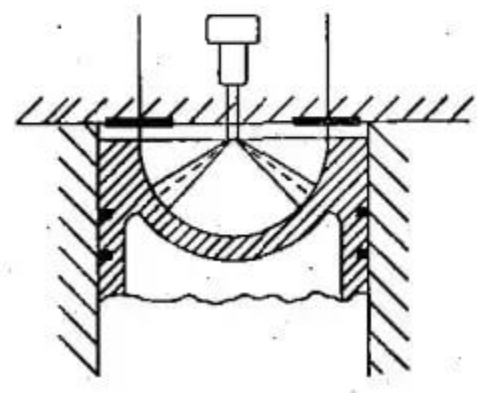
1. Shallow depth chamber
2. Hemispherical chamber
3. cylindrical chamber
4. Toroidal chamber

1. Shallow depth chamber



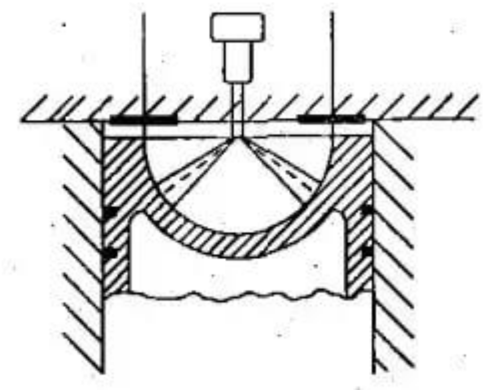
Shallow depth combustion chambers are mostly used in the heavy engines running with the low speeds. As you can see the shallow depth chamber diagram, the depth of the cavity provided in the piston is quite small and the diameter is large. Due to the large diameter, there will be almost negligible squish.

2. Hemispherical chamber



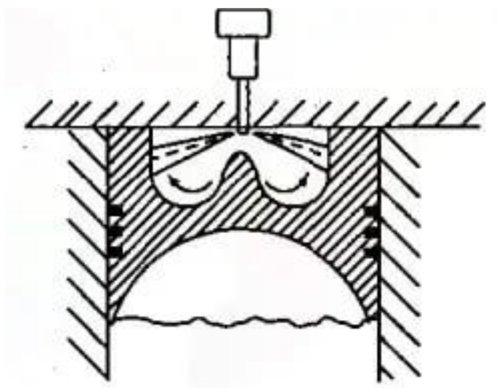
As you can see the hemispherical chamber, the depth to the diameter ratio can be varied. so that the squish can be controlled to attain better performance.

3. Cylindrical Chamber



In a few modern diesel engines, this type of combustion chambers was implemented. As you can see the Cylindrical Chamber diagram, the shape of the combustion chamber is truncated cone with the base angle of 30°. The Squish can be varied by varying the depth. The swirl can be produced by masking the valve for nearly 180°of the circumference. Squash also can be controlled by varying the depth.

4. Toroidal Chamber



This Toroidal chamber design is mainly focused to provide the powerful Squish along with the air moment. As the more Squish, the mask needed on the inlet valve is small and there is better utilization of oxygen.

Advantages of Direct Injection type combustion chambers

- Minimum Heat loss during the compression because of lower surface area to volume ratio results in better efficiency.
- Cold starting problems can be avoided.
- The multi-hole nozzle can be possible and hence fine atomization can be achieved.

Disadvantages of Direct Injection type combustion chambers

- High fuel injection pressure required. Hence complex design of fuel injection system.
- Metering of fuel should be accurate. Particularly for small engines.

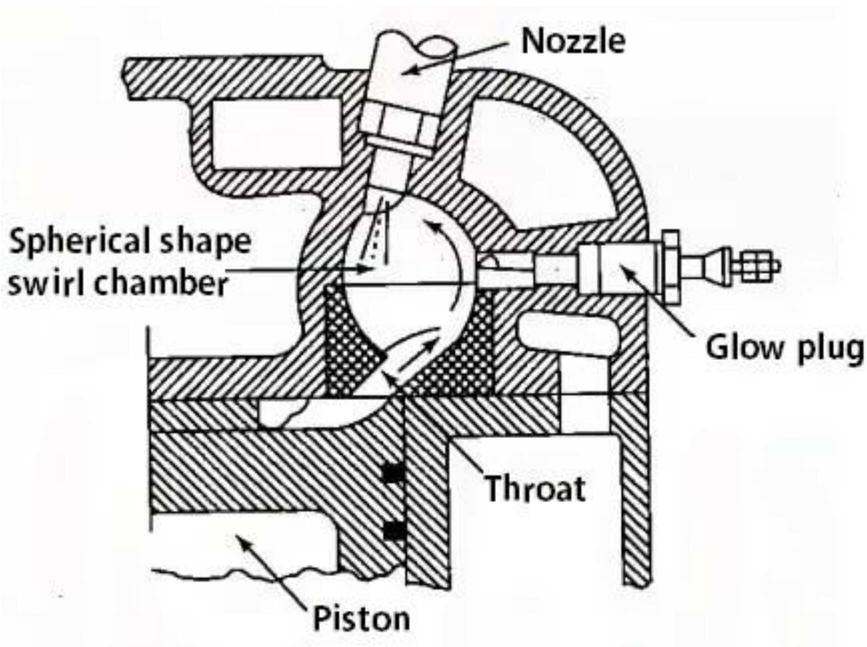
Indirect Injection type combustion chambers

In this type of combustion chambers, they are having two parts. One part will be located in the cylinder and the other part will be in the cylinder head. The fuel will be injected into the part which is located in the cylinder head.

There are three variant designs available in indirect Injection type combustion chambers. those are

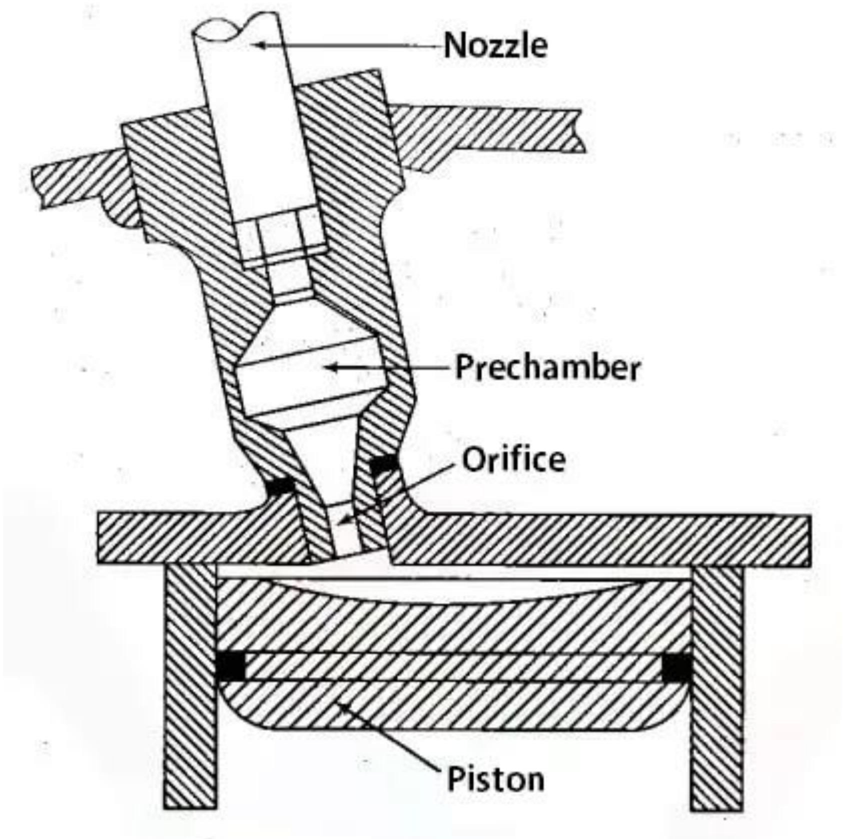
- Swirl Chamber
- Pre-combustion chamber
- Air cell chamber

1. Swirl Chamber



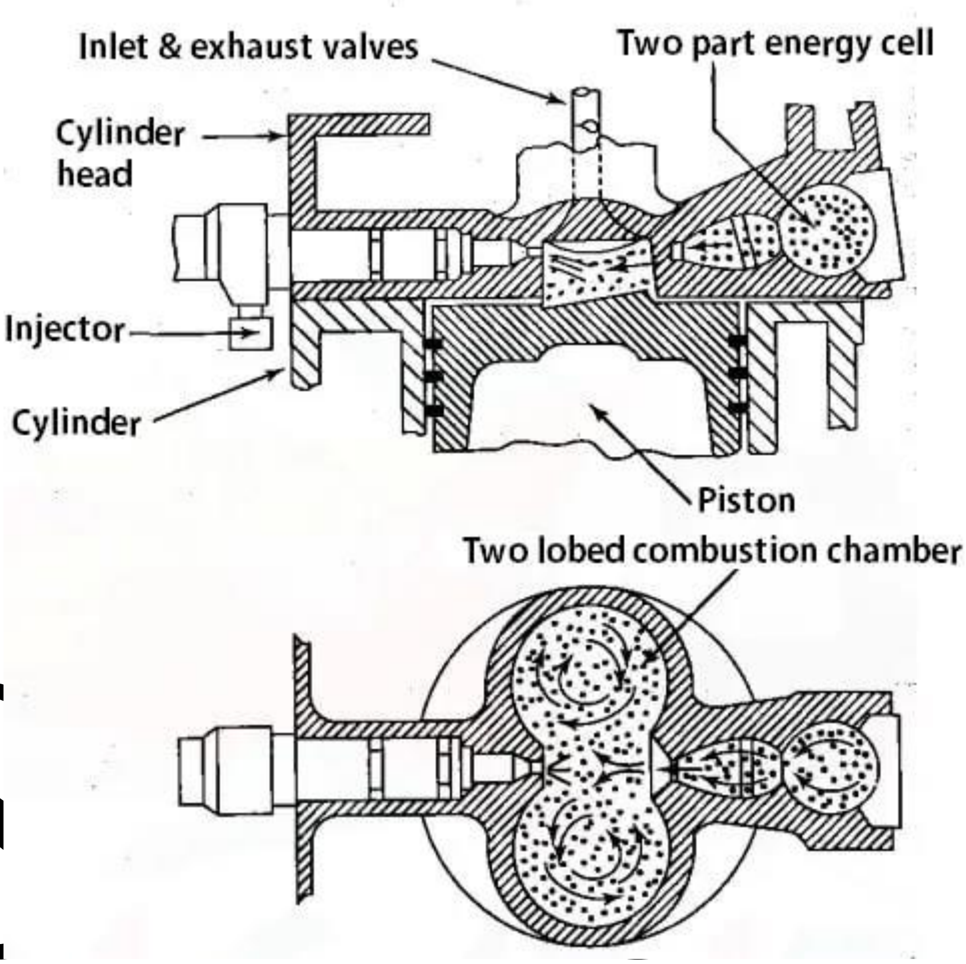
This is also known as the Ricardo swirl chamber. Swirl combustion chamber consists of the spherical-shaped chamber located in the cylinder head separated from the engine cylinder. During the compression stroke, 50% of the air will be transferred to this swirl chamber. In this spherical shaped swirl chamber, the fuel will be injected with the help of a nozzle and the combustion will be initiated. The main drawback of this chamber is that the heat loss is greater compared to the open combustion chambers. These chambers are used where the less quality of fuels are used. Where reliability is the main objective than the fuel economy.

2. Pre-combustion chamber



As you can see the above diagram of the Pre combustion chamber. It consists of the Pre chamber connected to the main chamber. This Pre chamber located in the cylinder head. This Pre chamber volume accounts for 40% of the total combustion space. During the compression stroke, the air will be injected into the Pre chamber the combustion will be initiated in it. But the bulk combustion will be taken place in the main chamber only. About 80% of the energy will be released in the main combustion chamber. The rate of pressure rise and the maximum pressure attain during the combustion process is comparatively low than the open combustion chambers.

3. Air-Cell Chamber



In this combustion chamber, the clearance volume will be shared by the two parts. One portion of the clearance will be in the main cylinder. The second portion will be called the energy cell. In energy cell itself, there will be two parts again. One is major and the other one is minor which were separated by the main chamber connected by the narrow orifices.

The nozzle injects the fuel across the main combustion chamber space towards the open neck the air cell. During the compression stroke, the main chamber pressure will be more than the energy cell pressure. When the temperature reaches high in the main chamber. The combustion will starts in the main chamber initially. In the energy, the cell contains the well-mixed charge, due to the heat release in the main chamber the high-pressure combustion particles will blow out thru the small passages into the main chamber. This high-velocity jet produces swirling motion in the main chamber thereby thoroughly mixes the fuel with the air, therefore the combustion will be completed.

Advantages of indirect Injection type combustion chambers

The main advantage of the indirect injection combustion chambers are

- Injection pressure required is low.
- The direction of the spray is not that important.

Disadvantages of indirect Injection type combustion chambers

- Poor cold starting performance.
- Specific fuel consumption is high.

15. Detail the techniques adopted for controlling diesel knock.

- Diesel knock, also known as combustion knock or engine knock, refers to the undesirable sound produced during the combustion process in a diesel engine. It occurs when the fuel-air mixture ignites spontaneously and unevenly in the combustion chamber. Diesel knock can lead to increased engine wear and reduced efficiency. Here are several techniques adopted for controlling diesel knock:

1. **Injection Timing Adjustment:**
   - Retarding the fuel injection timing can help reduce diesel knock. By delaying the start of injection, the combustion process is altered, which can mitigate knock. However, excessively retarding the timing may lead to other issues such as increased emissions and reduced efficiency.
2. **Injection Rate Shaping:**
   - Modifying the shape of the fuel injection curve can influence the combustion process. Gradual and controlled fuel injection rates can minimize sudden pressure spikes, reducing the likelihood of knock. This is often achieved through advanced fuel injection systems.
3. **EGR (Exhaust Gas Recirculation):**
   - Introducing a controlled amount of exhaust gas into the combustion chamber lowers the oxygen concentration and peak temperatures during combustion. This helps in reducing the tendency for spontaneous ignition and subsequently lessens diesel knock.
4. **Boost Pressure Control:**
   - Regulating the boost pressure in the intake manifold can influence the combustion characteristics. Lowering the boost pressure can reduce the temperature and pressure in the combustion chamber, which may help control knock.
5. **Cooling the Intake Air:**
   - Lowering the intake air temperature can be effective in reducing the likelihood of diesel knock. Cooler air reduces the tendency for auto-ignition, and intercoolers are commonly used for this purpose in turbocharged diesel engines.
6. **Cetane Number Improvement:**
   - Cetane number is a measure of the ignition quality of diesel fuel. Fuels with higher cetane numbers generally have better ignition characteristics. Using diesel fuel with a higher cetane number can help control diesel knock.
7. **Combustion Chamber Design:**

- Modifying the shape and design of the combustion chamber can influence the way fuel is burned. Smooth combustion chamber designs, along with optimized piston bowl shapes, can help control the combustion process and reduce knock.

8. **Use of Additives:**
   - Fuel additives can be employed to enhance combustion characteristics and reduce diesel knock. These additives may include cetane improvers, stabilizers, and lubricity enhancers.
9. **Engine Calibration:**
   - Advanced engine control units (ECUs) allow for precise calibration of fuel injection parameters, timing, and other relevant variables. Continuous monitoring and adjustment of these parameters can help control diesel knock under various operating conditions.

16. Discuss the mechanism of formation of HC,CO and NO in S.I engine(***)

- In a spark-ignition (S.I.) engine, the combustion process involves the conversion of fuel and air into energy, producing various exhaust gases. The major pollutants from S.I. engines include hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx). Here's a brief overview of the mechanisms behind the formation of these pollutants:

2. **Hydrocarbons (HC):**
   - HC emissions in S.I. engines are primarily a result of incomplete combustion. Several factors contribute to HC formation:
     - **Rich Air-Fuel Mixtures:** When the air-fuel mixture is excessively rich (contains more fuel than the stoichiometric ratio), not all the fuel can be burned completely. Unburned hydrocarbons are then released into the exhaust.
     - **Flame Quenching:** In certain regions of the combustion chamber, the flame may be quenched due to heat losses, leading to incomplete combustion and the production of hydrocarbons.
     - **Crevice Volume:** Hydrocarbons can also be generated in the crevice volumes, which are small gaps or pockets in the combustion chamber where the air-fuel mixture may not burn completely.
3. **Carbon Monoxide (CO):**
   - Carbon monoxide is formed as a by-product of incomplete combustion and is primarily influenced by the air-fuel mixture ratio:
     - **Rich Air-Fuel Mixtures:** Excessively rich mixtures can result in incomplete combustion, leading to the formation of CO.
     - **Combustion Chamber Design:** The design of the combustion chamber and the shape of the piston can affect turbulence and mixing, influencing the combustion efficiency and the production of CO.
4. **Nitrogen Oxides (NOx):**
   - NOx formation is more complex and involves the reaction between nitrogen (N2) and oxygen (O2) during combustion:
     - **High Combustion Temperatures:** Elevated temperatures in the combustion chamber promote the formation of nitrogen oxides. This is particularly true in regions where the flame temperature is the highest.
     - **Oxygen Availability:** The availability of oxygen in the combustion process influences NOx formation. Excess oxygen can lead to the production of nitrogen oxides.

- **Time and Pressure:** The duration of combustion and the pressure levels also play a role. High pressures and longer combustion durations can contribute to NOx formation.

To control these emissions, various technologies and strategies are employed in modern S.I. engines, including:

- **Catalytic Converters:** These devices use catalysts to promote the conversion of pollutants like CO, HC, and NOx into less harmful substances.
- **Exhaust Gas Recirculation (EGR):** Introducing a portion of exhaust gases back into the intake reduces peak combustion temperatures, limiting NOx formation.
- **Lean-Burn Operation:** Running the engine with a lean air-fuel mixture can reduce HC and CO emissions but may increase NOx. Precise control and optimization are crucial to balancing these trade-offs.

Overall, advancements in engine design, fuel injection systems, and emission control technologies continue to play a crucial role in minimizing the environmental impact of S.I. engines.

17. What is Indian driving cycle? What is the procedure adopted for it? Explain. ( )

The Indian Driving Cycle (IDC) is a set of driving conditions designed to represent typical driving patterns in India. It serves as a standard for testing the emissions and fuel efficiency of vehicles in the country. The IDC was introduced to better reflect the diverse driving conditions experienced on Indian roads, which can be quite different from the driving cycles used in other regions.

The procedure adopted for the Indian Driving Cycle involves specific driving patterns and conditions that vehicles must undergo during emissions and fuel efficiency testing. The key elements of the IDC include:

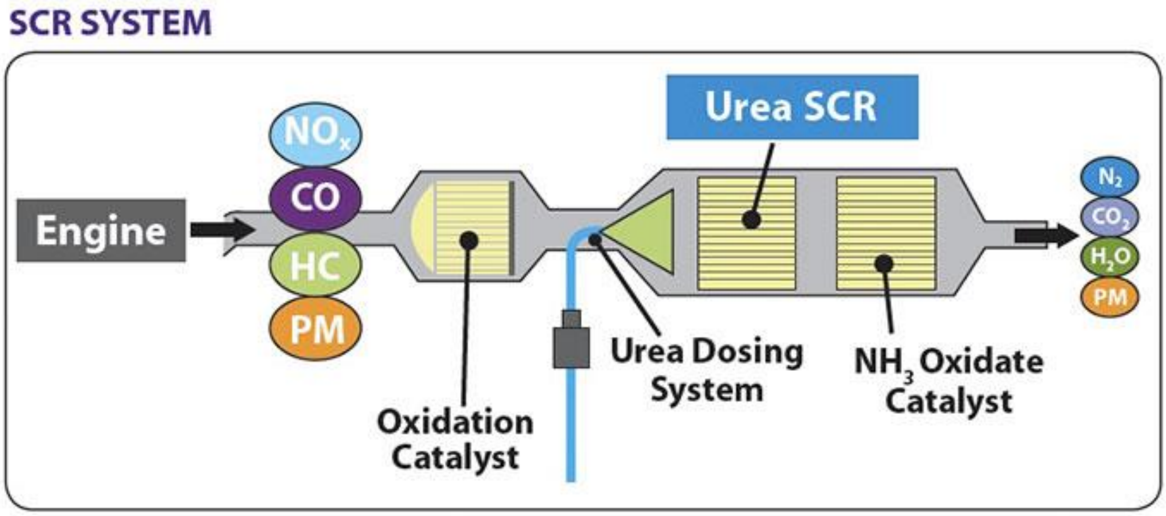
1. **Urban Driving Cycle:**
   - The IDC includes an urban driving cycle that simulates driving conditions in congested city traffic. This part of the cycle considers frequent stops, starts, and idling, which are characteristic of urban driving.
2. **Extra-Urban Driving Cycle:**
   - The extra-urban driving cycle represents driving conditions on open roads, highways, and rural areas. This segment of the cycle is designed to mimic higher speeds and more continuous driving patterns.
3. **Driving Speeds and Distances:**
   - The IDC specifies certain driving speeds and distances for both urban and extra-urban driving cycles. The speeds and distances are chosen to be representative of the typical driving conditions encountered by vehicles in India.
4. **Stop-and-Go Patterns:**
   - The urban driving cycle includes stop-and-go patterns to simulate traffic conditions in cities. This is important for evaluating emissions and fuel efficiency in situations where vehicles frequently accelerate, decelerate, and idle.

5. **Idle Periods:**
   - The IDC includes periods of engine idling, which is common in real-world driving, especially in urban areas. Idling conditions are crucial for assessing emissions during times when the vehicle is not in motion.
6. **Specific Driving Phases:**
   - The IDC is divided into specific driving phases that include acceleration, deceleration, cruising, and idling. These phases are designed to cover a range of driving behaviours and conditions.
7. **Temperature Considerations:**
   - The driving cycle may consider variations in ambient temperature to account for the impact of temperature on vehicle performance and emissions.
8. **Standardized Test Conditions:**
   - The IDC is conducted under standardized conditions to ensure consistency in testing across different vehicles and testing facilities. This helps in making fair and accurate comparisons between vehicles.

The adoption of the Indian Driving Cycle is crucial for regulatory authorities and manufacturers to assess and compare the emissions and fuel efficiency of vehicles under conditions that are representative of the Indian driving environment. It helps in developing emission norms and standards that align with the real-world driving conditions in the country. The IDC is periodically updated to reflect changes in driving patterns and technology advancements in the automotive industry.

18. Discuss the working of Selective catalytic reduction (SCR) and particulate traps with neat sketch.

Selective Catalytic Reduction (SCR) is an emission control technology used in diesel engines to reduce nitrogen oxides (NOx) emissions. The SCR system involves the use of a catalyst to facilitate the chemical reaction between nitrogen oxides and a reducing agent. The most commonly used reducing agent is ammonia (NH_3), often supplied in the form of aqueous urea (Ad Blue).



1. **Injection of Reducing Agent:**
   - Aqueous urea (Ad Blue) is injected into the exhaust stream upstream of the SCR catalyst.
2. **Conversion of Urea to Ammonia:**
   - Urea undergoes thermal decomposition to produce ammonia and carbon dioxide. The ammonia is the active reducing agent in the SCR process.

- $(NH_2)_2CO$ (*urea*)→NH_3 (*ammonia*)+CO_2

3. **NOx Reduction:**

- In the presence of the SCR catalyst, the ammonia reacts with nitrogen oxides (NOx) to form nitrogen (N2) and water (H2O).

$$4NH_3+4NO+O_2 \rightarrow 4N_2+6H_2O$$

4. **SCR Catalyst:**

- The SCR catalyst is typically made of materials such as titanium dioxide or zeolites loaded with transition metal catalysts like vanadium or tungsten. This catalyst facilitates the reduction of NOx with ammonia at lower temperatures.

5. **Temperature Control:**

- The SCR system is more effective at higher temperatures, so temperature control strategies may be employed to optimize the conversion efficiency of NOx.

Particulate Traps (DPF - Diesel Particulate Filter):

Working Principle: Particulate traps, or Diesel Particulate Filters (DPF), are used to capture and reduce particulate matter (PM) emissions from diesel engines. The DPF is designed to trap and remove soot particles from the exhaust gas.

1. **Particulate Filtration:**
    - The DPF contains a porous ceramic or metallic filter that traps and collects particulate matter as the exhaust gas passes through.
    - The trapped particles include soot and ash produced during the combustion process.
2. **Regeneration:**
    - Over time, the trapped particles accumulate and can cause increased exhaust backpressure. To prevent excessive backpressure and maintain the filter's efficiency, a process called regeneration is employed.
    - Regeneration involves burning off the trapped particles at elevated temperatures. There are two main types of regeneration: passive and active.
3. **Passive Regeneration:**
    - Occurs automatically during normal driving conditions when exhaust temperatures are high enough to oxidize the accumulated soot.
    - Requires no intervention from the vehicle's control system.
4. **Active Regeneration:**
    - Involves the controlled increase of exhaust temperatures to burn off accumulated soot.
    - Common methods include injecting extra fuel into the exhaust or using electrical heaters.

1. **Selective Catalytic Reduction (SCR):**
    - Sketch a basic exhaust system with an SCR catalyst located downstream.
    - Show an injection point for the urea (Ad Blue) solution into the exhaust stream.
    - Illustrate the chemical reactions between urea, ammonia, and nitrogen oxides.

Depict the SCR catalyst promoting the reduction of NOx to nitrogen and water.

2. **Particulate Traps (DPF):**

Draw a diesel exhaust system with a DPF located in the exhaust stream.
Show a porous filter structure within the DPF capturing soot particles.
Illustrate arrows indicating the flow of exhaust gas through the DPF.

Include symbols for passive or active regeneration processes to burn off trapped particles.

19. Discuss about formation of Oxides of nitrogen and particulate matter in diesel engine. (*)

Emissions formed during burning of the heterogeneous diesel air/fuel mixture depend on the conditions during combustion, during the expansion stroke, and especially prior to the exhaust valve opening. NOx emissions can be formed through a number of mechanisms during both the premixed and diffusion burning.

The formation of oxides of nitrogen (NOx) and particulate matter (PM) in diesel engines is a complex process influenced by various factors such as combustion temperature, air-fuel ratio, injection timing, and the presence of impurities in the fuel. Understanding the mechanisms behind the formation of these pollutants is crucial for developing strategies to control and reduce emissions. Here's an overview of how NOx and particulate matter are formed in diesel engines:

Formation of Oxides of Nitrogen (NOx):

1. **High Combustion Temperatures:**

   Diesel engines operate at higher temperatures compared to gasoline engines. At elevated temperatures, nitrogen and oxygen in the air combine to form nitrogen oxides (NOx).

   $$N_2 + O_2 \rightarrow 2NO$$

2. **Thermal NOx:**

   Thermal NOx is formed during the combustion process when nitrogen and oxygen in the air react at high temperatures (above 1,400°C).

   The high temperatures cause the nitrogen and oxygen molecules to break apart and recombine, forming NOx.

3. **Prompt NOx:**

   Prompt NOx is formed in the early stages of combustion when nitrogen from the air reacts directly with fuel radicals or intermediate combustion products.

4. **NOx Formation in Oxygen-Rich Zones:**

   In areas of the combustion chamber with excess oxygen, such as near the flame front, NOx formation is more likely to occur.

5. **Compression Ignition Process:**

   The compression ignition process of diesel engines tends to produce higher temperatures than spark ignition engines, contributing to increased NOx formation.

6. **EGR (Exhaust Gas Recirculation):**

   While EGR is used to reduce NOx emissions, excessive use can lead to incomplete combustion and increased particulate matter formation.

Formation of Particulate Matter (PM):

1. **Incomplete Combustion:**

Particulate matter in diesel engine exhaust is primarily composed of soot, which is formed during incomplete combustion of diesel fuel.

Insufficient oxygen in certain regions of the combustion chamber can result in the production of carbon particles.

2. **Fuel Composition:**

The composition of the diesel fuel, including its cetane number and impurities, can influence the formation of particulate matter.

3. **Combustion Chamber Design:**

The design of the combustion chamber, including the piston bowl shape and swirl characteristics, affects the mixing of air and fuel, influencing combustion efficiency and particulate matter formation.

4. **Injection Timing and Pressure:**

Injection timing and pressure influence the fuel spray pattern and atomization. Poorly atomized fuel droplets may not combust completely, contributing to soot formation.

5. **High Pressure and Turbulence:**

High-pressure injection systems and turbulence in the combustion chamber can promote better mixing of air and fuel, reducing the likelihood of soot formation.

6. **EGR (Exhaust Gas Recirculation):**

While EGR is effective in reducing NOx, it can lead to increased particulate matter formation if not properly controlled.

7. **Diesel Particulate Filter (DPF):**

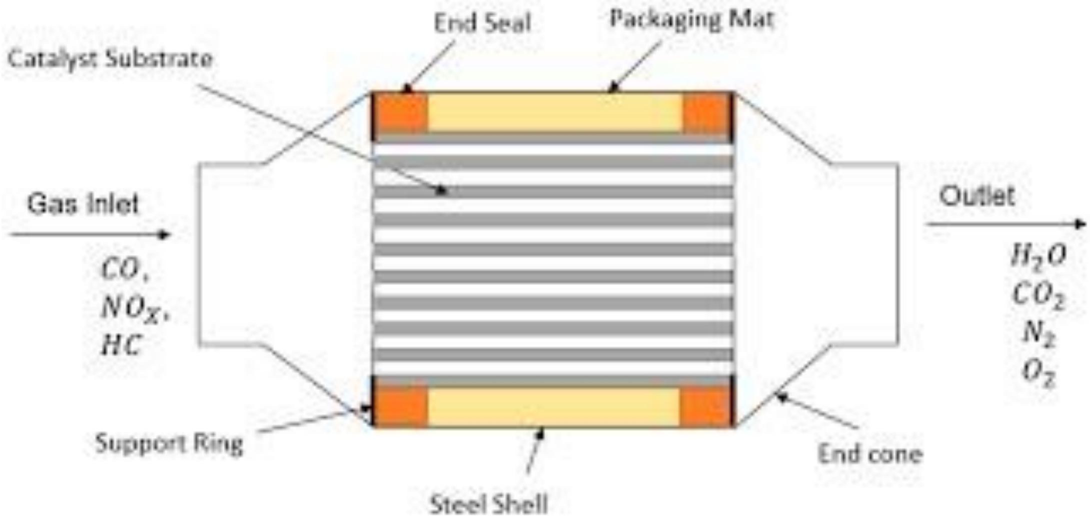
DPF is a technology used to trap and reduce particulate matter emissions. It captures soot particles, and the collected particles are periodically burned off during regeneration processes.

8. **Additives and Fuel Quality:**

The use of additives and high-quality diesel fuel can contribute to cleaner combustion and reduced particulate matter formation.

Effective emission control strategies involve a combination of advanced combustion technologies, after treatment systems (such as selective catalytic reduction), and diesel particulate filters to address both NOx and particulate matter emissions from diesel engines.

20. Explain the construction and working of three way catalytic converter with neat sketch.(*)



A three-way catalytic converter (TWC) is an emissions control device used in internal combustion engines to reduce the levels of three major pollutants: nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC). The catalytic converter achieves this through a combination of oxidation and reduction reactions within its structure. Here's an explanation of the construction and working of a three-way catalytic converter, along with a neat sketch:

Construction of Three-Way Catalytic Converter:

1. **Catalyst Core:**
   The catalytic converter has a ceramic or metallic core, often made of a substrate with a high surface area. The substrate is coated with catalyst materials, typically platinum (Pt), palladium (Pd), and rhodium (Rh).
2. **Catalyst Coating:**
   The catalyst coating facilitates the catalytic reactions. Platinum and rhodium are responsible for oxidizing CO and HC, while rhodium and palladium are crucial for reducing NOx.
3. **Monolith Structure:**
   The core is often structured as a monolith, which is a honeycomb-like ceramic or metallic structure with numerous channels. This design maximizes the surface area available for catalytic reactions.
4. **Heat Shield:**
   A heat shield may surround the catalytic converter to retain heat and optimize its efficiency. The elevated temperature helps in catalytic reactions.

Working of Three-Way Catalytic Converter:

1. **Cold Start:**
   During a cold start, the catalytic converter is not immediately effective because it requires a certain temperature to operate efficiently. Some pollutants may still be emitted until the converter reaches its optimal operating temperature.
2. **Oxidation Reactions (CO and HC):**
   Carbon Monoxide (CO): Platinum and rhodium catalysts facilitate the oxidation of carbon monoxide to carbon dioxide.

- $2CO+O_2 \rightarrow 2CO_2$

Hydrocarbons (HC): **Platinum and rhodium catalysts also oxidize unburned hydrocarbons to carbon dioxide and water.**

$$C_xH_y+(x+y/4)O_2 \rightarrow xCO_2+y/2H_2O$$

3. **Reduction Reaction (NOx):**

Nitrogen Oxides (NOx): Rhodium and palladium catalysts facilitate the reduction of nitrogen oxides to nitrogen and oxygen.

$$2NO+2CO \rightarrow N_2+2CO_2$$

$$2NO_2+4CO \rightarrow N_2+4CO_2$$

4. **Oxygen Storage and Release:**

Some catalytic converters have an oxygen storage component to temporarily store oxygen during lean conditions and release it during rich conditions. This helps in optimizing the air-fuel ratio for catalytic reactions.

5. **Monitoring and Control:**

Oxygen sensors upstream and downstream of the catalytic converter monitor the exhaust gases. The engine control unit (ECU) adjusts the air-fuel mixture based on the feedback from these sensors to maintain optimal conditions for the catalytic converter.

6. **Regeneration:**

The catalytic converter can undergo regeneration processes, often aided by additives, to remove any deposits that may accumulate over time and affect its efficiency.

21. **Explain with neat sketch i) Chemiluminescence's method of measuring oxides of nitrogen ii) FID method of measuring carbon monoxide.**

In atmospheric chemistry, NOx is a collective term used to refer to the nitrogen oxides that are most relevant for air pollution i.e. NO and NO2. NO2 (nitrogen dioxide) is a reddish-brown acidic gas having a pungent irritating odour comprising one nitrogen atom and two oxygen atoms. It is corrosive and strongly oxidizing. It can combust with compounds such as hydrocarbons, sometimes explosively. Its vapors are heavier than air and are toxic when inhaled. NO2 gas itself is non-combustible, however, it can accelerate combustion.

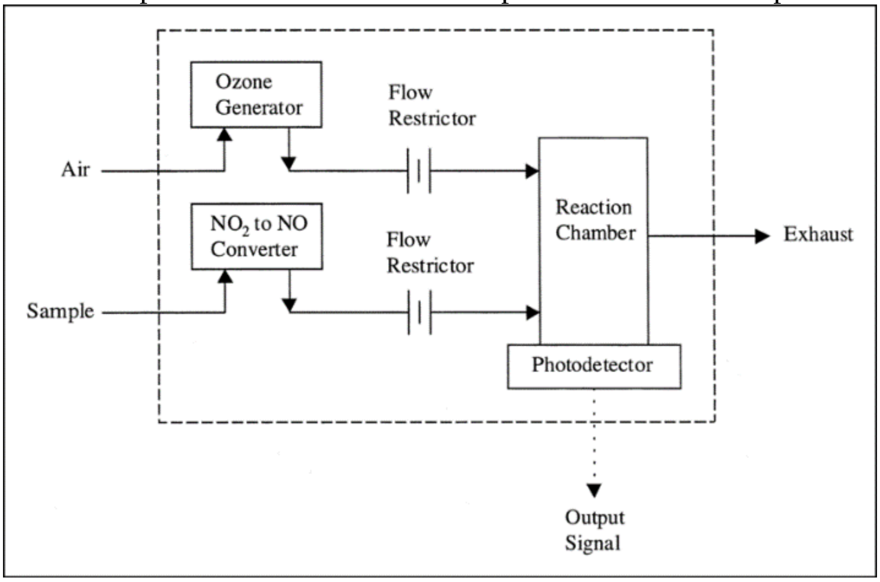
NO (nitric oxide or nitrogen monoxide) is a colourless, non-flammable, oxidizing, poisonous gas with a slightly irritating odour. It consists of one nitrogen atom bonded to one oxygen atom. It is highly reactive due to the presence of one unpaired electron. Thus, this results in rapid oxidation (within a few minutes) to form NO2.

Measurement methods of NO_x monitoring

Chemiluminescence for NO_x monitoring

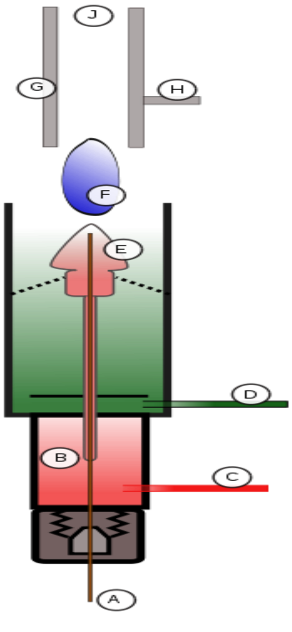
It is the most commonly used conventional method of measuring the NOx levels in the air and is based on a chemiluminescent reaction between nitric oxide (NO) and ozone (O3). In the NOx monitor, the air is drawn into two paths. In the first path, the NO2 in the sample is quantitatively reduced to NO using a converter. Hence, this converted NO2 along with NO already present in the air reacts with ozone (produced using an ozone generator) to generate activated NO2. During the conversion, light energy at a specific wavelength is produced which is proportional to the amount of NO+NO2 present in the air sample. In the second path, the air is directly reacted with O3 i.e. without passing through the reactor and the light energy produced is directly proportional to the NO present in the air.

The light intensity is measured photo metrically from both paths and recorded. The signal from the second path is the amount of NO present in the air sample while the electronic difference of the signal from both paths is the amount of NO2 present in the air sample.



FID method of measuring carbon monoxide.

Carbon monoxide and carbon dioxide are not detectable in the FID because they contain no carbon-hydrogen bonds. To overcome this limitation, methanizers have traditionally been used to catalytically convert these compounds to methane, which is easily detected in the FID.



FID Schematic: A) Capillary tube; B) Platinum jet; C) Hydrogen; D) Air; E) Flame; F) Ions; G) Collector; H) Coaxial cable to analog-to-digital converter; J) Gas outlet

The operation of the FID is based on the detection of ions formed during combustion of organic compounds in a hydrogen flame. The generation of these ions is proportional to the concentration of organic species in the sample gas stream.

To detect these ions, two electrodes are used to provide a potential difference. The positive electrode acts as the nozzle head where the flame is produced. The other, negative electrode is positioned above the flame. When first designed, the negative electrode was either tear-drop shaped or angular piece of platinum. Today, the design has been modified into a tubular electrode, commonly referred to as a collector plate. The ions thus are attracted to the collector plate and upon hitting the plate, induce a current. This current is measured with a high-impedance Pico ammeter and fed into an integrator. The manner in which the final data is displayed is based on the computer and software. In general, a graph is displayed that has time on the x-axis and total ion on the y-axis.

The current measured corresponds roughly to the proportion of reduced carbon atoms in the flame. Specifically how the ions are produced is not necessarily understood, but the response of the detector is determined by the number of carbon atoms (ions) hitting the detector per unit time. This makes the detector sensitive to the mass rather than the concentration, which is useful because the response of the detector is not greatly affected by changes in the carrier gas flow rate.

Advantages

- Flame ionization detectors are used very widely in gas chromatography because of a number of advantages.
- Cost: Flame ionization detectors are relatively inexpensive to acquire and operate.
- Low maintenance requirements: Apart from cleaning or replacing the FID jet, these detectors require little maintenance.
- Rugged construction: FIDs are relatively resistant to misuse.
- Linearity and detection ranges: FIDs can measure organic substance concentration at very low (10−13 g/s) and very high levels, having a linear response range of 107 g/s.[1]

Disadvantages

- Flame ionization detectors cannot detect inorganic substances and some highly oxygenated or functionalized species like infrared and laser technology can. In some systems, CO and CO2 can be detected in the FID using a methanizer, which is a bed of Ni catalyst that reduces CO and CO2 to methane, which can be in turn detected by the FID. The methanizer is limited by its inability to reduce compounds other than CO and CO2 and its tendency to be poisoned by a number of chemicals commonly found in gas chromatography effluents.
- Another important disadvantage is that the FID flame oxidizes all oxidizable compounds that pass through it; all hydrocarbons and oxygenates are oxidized to carbon dioxide and water and other heteroatoms are oxidized according to thermodynamics. For this reason, FIDs tend to be the last in a detector train and also cannot be used for preparatory work.

22. Compare the fuel properties of Diesel, petrol, bio diesel and LPG

	Gasoline/E10	Low Sulfur Diesel	Biodiesel	Propane (LPG)	Compressed Natural Gas (CNG)	Liquefied Natural Gas (LNG)	Ethanol/E100	Methanol	Hydrogen	Electricity
Chemical Structure [1]	C_4 to C_{12} and Ethanol ≤ to 10%	C_8 to C_{25}	Methyl esters of C_{12} to C_{22} fatty acids	C_3H_8 (majority) and C_4H_{10} (minority)	CH_4 (majority), C_2H_6 and inert gases	CH_4 same as CNG with inert gasses <0.5% (a)	CH_3CH_2OH	CH_3OH	H_2	N/A
Fuel Material (feedstocks)	Crude Oil	Crude Oil	Fats and oils from sources such as soybeans, waste cooking oil, animal fats, and rapeseed	A by-product of petroleum refining or natural gas processing	Underground reserves and renewable biogas	Underground reserves and renewable biogas	Corn, grains, or agricultural waste (cellulose)	Natural gas, coal, or woody biomass	Natural gas, methanol, and electrolysis of water	Natural gas, coal, nuclear, wind, hydro, solar, and small percentages of geothermal and biomass
Gasoline or Diesel Gallon Equivalent (GGE or DGE)	1 gal = 1.00 GGE 1 gal = 0.88 DGE	1 gal = 1.12 GGE 1 gal = 1.00 DGE	*B100* 1 gal = 1.05 GGE 1 gal = 0.93 DGE *B20* 1 gal = 1.11 GGE 1 gal = 0.99 DGE	1 gal = 0.74 GGE 1 gal = 0.66 DGE	1 lb. = 0.18 GGE 1 lb. = 0.16 DGE	1 lb. = 0.19 GGE 1 lb. = 0.17 DGE	1 gal = 0.67 GGE 1 gal = 0.59 DGE	1 gal = 0.50 GGE 1 gal = 0.45 DGE	1 lb. = 0.45 GGE 1 lb. = 0.40 DGE 1 kg = 1 GGE 1 kg = 0.9 DGE	1 kWh = 0.030 GGE 1 kWh = 0.027 DGE
Energy Comparison [2]	1 gallon of gasoline has 97%–100% of the energy in 1 GGE. Standard fuel is 90% gasoline, 10% ethanol.	1 gallon of diesel has 113% of the energy in 1 GGE due to the higher energy density of diesel fuel.	1 gallon of B100 has 93% of the energy in 1 DGE, and 1 gallon of B20 has 99% of the energy in 1 DGE due to a lower energy density in biodiesel.	1 gallon of propane has 73% of the energy in 1 GGE due to the lower energy density of propane.	5.66 lb., or 123.57 ft^3, of CNG has the same energy as 1 GGE, and 6.37 lb., or 139.30 ft^3, of CNG has the same energy as 1 DGE. [3][4](b)	5.37 lb. of LNG has the same energy as 1 GGE, and 6.06 lb. of LNG has the same energy as 1 DGE. (a)	1 gallon of E85 contains 73%–83% of the energy in 1 GGE. 1 gallon of E100 has 67% of the energy in 1 GGE. Ethanol is blended with blendstock for oxygenate blending (gasoline component). [5]	1 gallon of methanol contains 50% of the energy as 1 GGE.	2.2 lbs. (1 kg) of H_2 has the same energy as 1 GGE.	A typical battery that is the same size as a gallon of gas (0.134 ft^3), when used for transportation, can store 15.3% of the energy in 1 GGE. [6][7]
Energy Content (lower heating value)	112,114–116,090 Btu/gal (c)	128,488 Btu/gal (c)	*B100* 119,550 Btu/gal *B20* 126,700 Btu/gal (c)	84,250 Btu/gal (c)	20,160 Btu/lb [3](b)	21,240 Btu/lb (a)	76,330 Btu/gal for E100 (c)	57,250 Btu/gal (c)	51,585 Btu/lb (c) 33.3 kWh/kg	3,414 Btu/kWh
Energy Content (higher heating value)	120,388–124,340 Btu/gal (c)	138,490 Btu/gal (c)	127,960 Btu/gal for B100 (c)	91,420 Btu/gal (c)	22,453 Btu/lb [1](c)	23,726 Btu/lb (c)	84,530 Btu/gal for E100 (c)	65,200 Btu/gal (c)	61,013 Btu/lb (c)	3,414 Btu/kWh
Physical State	Liquid	Liquid	Liquid	Pressurized liquid (heavier than air as a gas)	Compressed gas (lighter than air)	Cryogenic liquid (lighter than air as a gas)	Liquid	Liquid	Compressed gas (lighter than air) or liquid	Electricity
Cetane Number	N/A	40–55 (d)	48–65 (d)	N/A	N/A	N/A	0–54 (e)	N/A	N/A	N/A
Pump Octane Number	84–93 (f)	N/A	N/A	105 (g)	120+ (h)	120+ (h)	110 (i)	112 (i)	130+ (g)	N/A
Flash Point	-45°F (j)	165°F (j)	212° to 338°F (d)	-100° to -150°F (j)	-300°F (j)	-306°F (k)	55°F (j)	52°F (j)	N/A	N/A
Autoignition Temperature	495°F (j)	~600°F (j)	~300°F (d)	850° to 950°F (j)	1,004°F (j)	1,004°F (k)	793°F (j)	897°F (j)	1,050° to 1,080°F (j)	N/A
Maintenance Issues			Lubricity is improved over that of conventional low sulfur diesel fuel. For more maintenance information see, the Biodiesel Handling and Use Guidelines—Fifth Edition. (d)		High-pressure tanks require periodic inspection and certification.	LNG is stored in cryogenic tanks with a specific hold time before the pressure build is relieved. The vehicle should be operated on a schedule to maintain a lower pressure in the tank.	Special lubricants may be required. Practices are very similar, if not identical, to those for conventionally fueled operations.	Special lubricants must be used as directed by the supplier as well as M85-compatible replacement parts. Can cause serious damage to organs in the body if a person swallows it, breathes it in, or gets it on their skin.	When hydrogen is used in fuel cell applications, maintenance should be very minimal. High-pressure tanks require periodic inspection and certification.	
Energy Security Impacts	Manufactured using oil. Transportation accounts for approximately 30% of total U.S. energy needs and 70% of petroleum consumption. (l)	Manufactured using oil. Transportation accounts for approximately 30% of total U.S. energy needs and 70% of petroleum consumption. (l)	Biodiesel is domestically produced, renewable, and reduces petroleum use 95% throughout its lifecycle. (m)	Approximately half of U.S. LPG is derived from oil, but no oil is imported specifically for LPG production.	CNG is domestically produced from natural gas and renewable biogas. The United States has vast natural gas reserves.	LNG is domestically produced from natural gas and renewable biogas. The United States has vast natural gas reserves.	Ethanol is produced domestically. E85 reduces lifecycle petroleum use by 70%, and E10 reduces petroleum use by 6.3%. (n)	Methanol is domestically produced, sometimes from renewable resources.	Hydrogen is produced domestically and can be produced from renewable sources.	Electricity is produced domestically from a wide range of sources, including through coal-fired power plants and renewable sources, making it a versatile fuel.

23. Discuss the methods of using alcohol as fuel in S.I and C.I engine(***)

Mixed with When the fuel of the present invention is ignited in the cylinder of the engine, the alcohol burns by thermal explosion, but at this time, hydrogen peroxide mixed with the alcohol is stimulated by the thermal explosion of the alcohol, and is rapidly decomposed to explode and expand to generate oxygen.

Using alcohol as a fuel in internal combustion engines, both spark-ignition (S.I.) and compression-ignition (C.I.) engines, has been a topic of interest due to its potential benefits such as lower emissions and renewable sourcing. Ethanol and methanol are two common types of alcohols used as fuels. Here are some key aspects related to using alcohol as fuel in both types of engines:

Spark-Ignition (S.I.) Engines:

1. **Ethanol as a Fuel:**
   - **Blending with Gasoline:** Ethanol can be blended with gasoline to create E10 (10% ethanol, 90% gasoline) or higher ethanol blends like E85 (85% ethanol, 15% gasoline).
   - **Modified Engines:** Some vehicles are designed to run on higher ethanol blends. These "flex-fuel" vehicles can adjust their engine parameters based on the ethanol content.
2. **Methanol as a Fuel:**
   - Methanol-Gasoline Blends: Similar to ethanol, methanol can be blended with gasoline to create M15, M85, etc.
   - Fuel Injection System Modifications: Methanol may require modifications to the fuel injection system due to differences in combustion characteristics.
3. **Advantages:**
   - **Higher Octane Rating:** Ethanol and methanol have higher octane ratings compared to gasoline, which can allow for higher compression ratios and increased engine efficiency.
   - **Reduced Greenhouse Gas Emissions:** Alcohol fuels can contribute to lower overall greenhouse gas emissions, particularly if derived from renewable sources.

Compression-Ignition (C.I.) Engines:

1. **Methanol as a C.I. Fuel:**
   - Dual-Fuel Engines: **Methanol can be used in dual-fuel engines, where it is mixed with diesel fuel and ignited by the heat generated during the compression stroke.**
2. **Challenges and Considerations:**
   - **Lower Energy Density:** Alcohols, including ethanol and methanol, have lower energy density compared to conventional diesel fuel, which can result in reduced fuel efficiency.
   - **Material Compatibility:** Alcohol fuels may require modifications to engine materials, especially in older engines, due to their different chemical properties.
3. **Advantages:**
   - Lower Particulate Emissions: Methanol combustion tends to produce lower levels of particulate matter compared to traditional diesel combustion.

- Renewable Sources: Ethanol and methanol can be produced from renewable sources, offering a more sustainable alternative to conventional fossil fuels.

4. **Engine Modifications:**
    - **Injection System:** C.I. engines may require modifications to the fuel injection system to accommodate the different combustion characteristics of alcohol fuels.
    - **Compression Ratio:** Adjustments to the engine's compression ratio may be necessary to optimize performance with alcohol fuels.

General Considerations:

1. **Fuel Storage and Handling:**
    - Corrosiveness: Some alcohol fuels can be corrosive, requiring special materials for fuel storage and handling.
    - Water Absorption: Ethanol has a tendency to absorb water, which can lead to phase separation and fuel system issues.
2. **Infrastructure:**
    - **Availability:** The widespread use of alcohol fuels may require changes to fuelling infrastructure, including the availability of higher ethanol or methanol blends.
3. **Economic Considerations:**
    - Production Costs: The economic feasibility of using alcohol fuels depends on factors such as production costs, subsidies, and the availability of feedstock.

- In summary, the use of alcohol fuels in internal combustion engines requires careful consideration of various factors, including engine modifications, fuel properties, and overall system compatibility. Advancements in engine technology, material science, and fuel production methods will play a crucial role in the successful integration of alcohol fuels into the transportation sector.

24. Explain the emission characteristics of using hydrogen in C.I engine

More hydrogen present inside the engine cylinder led to lower soot emissions, higher thermal efficiency, and higher NOx emissions. Ignition timing delayed as the hydrogen rate increased, due to a delay in OH radical formation.

Hydrogen seems to be a viable solution for future transportation. In order for hydrogen vehicles to become commercially feasible, challenging tasks in hydrogen production, distribution and storage have to be addressed properly. The wide flammability limits, low ignition energy and high flame speeds can result in undesirable combustion anomalies, including surface ignition and backfiring as well as auto ignition. However, the works so far reported in the literature show encouraging results from the performance and emission points of view. It is observed that thermal efficiency is improved with hydrogen addition to gasoline as fuel. For the mixed fuel, HC and CO_2 emission are found to decrease. CO emission is noted to be more particularly near stoichiometric air fuel ratio conditions.

The major toxic pollutants present in the emissions of internal combustion engines constitute of HC, CO and NOx mainly along with CO_2. In this context, an analysis of the emissions from hydrogen fuelled IC engines is done and a brief discussion is provided about the variation of concentration of pollutants present in emission at various hydrogen fractions.

Using hydrogen in a compression-ignition (C.I.) engine can have distinct emission characteristics compared to traditional diesel fuel. Hydrogen is a clean-burning fuel that produces water vapor as its primary combustion by-product, making it an attractive option for reducing emissions. However, there are some considerations and challenges associated with using hydrogen in C.I. engines:

Emission Characteristics:

1. **Zero Carbon Dioxide (CO2) Emissions:**
    - Hydrogen combustion in C.I. engines produces virtually no carbon dioxide (CO2) emissions, as the primary combustion by-product is water vapor. This can contribute to a significant reduction in greenhouse gas emissions, addressing environmental concerns.
2. **Lower Particulate Emissions:**
    - Hydrogen combustion generally leads to lower levels of particulate matter emissions compared to traditional diesel combustion. This is beneficial for air quality, as particulate matter is a known contributor to respiratory and environmental issues.
3. **Reduced Nitrogen Oxide (NOx) Emissions:**
    - Hydrogen combustion tends to result in lower nitrogen oxide (NOx) emissions compared to diesel combustion. NOx is a major contributor to air pollution and has adverse effects on human health and the environment.
4. **Combustion Efficiency:**
    - Hydrogen has a wide flammability range and burns at a high flame speed. This can lead to more complete combustion in the engine, contributing to higher combustion efficiency and potentially reducing emissions of unburned hydrocarbons and other pollutants.

Challenges and Considerations:

1. **Flame Stability:**
    - Hydrogen has a high flame speed and a tendency to ignite easily. Achieving stable combustion in a C.I. engine, which typically relies on controlled auto-ignition, can be challenging. Engine modifications may be needed to ensure proper combustion stability.
2. **Ignition Timing:**
    - Hydrogen has a wide flammability range, and its ignition characteristics differ from diesel fuel. Adjustments to ignition timing may be necessary to optimize combustion and prevent issues such as premature ignition (knocking).
3. **Engine Modifications:**
    - C.I. engines designed for conventional diesel may require modifications to accommodate the unique combustion properties of hydrogen. This could involve changes to the fuel injection system, combustion chamber design, and overall engine management.
4. **Hydrogen Storage and Distribution:**
    - Hydrogen has challenges related to storage and distribution. It has low energy density by volume, and effective storage methods are needed for practical use in vehicles. Additionally, the development of a hydrogen infrastructure for widespread use poses logistical challenges.

5. **Hydrogen Production:**
    - The overall environmental benefits of using hydrogen in C.I. engines depend on how the hydrogen is produced. If produced using renewable energy sources, the entire hydrogen fuel cycle can be considered more environmentally friendly.

In summary, while hydrogen shows promise as a clean-burning fuel for C.I. engines, there are challenges that need to be addressed, including combustion stability, ignition timing, and engine modifications. Research and development efforts are ongoing to overcome these challenges and make hydrogen a viable and sustainable option for internal combustion engines.

25. Explain the methods of using CNG and hydrogen in diesel engine.

Using Compressed Natural Gas (CNG) and hydrogen in a diesel engine involves modifications to the engine and fuelling system to accommodate the different combustion characteristics of these alternative fuels. Here are the key methods for utilizing CNG and hydrogen in a diesel engine:

1. Dual-Fuel Conversion:

CNG:

- **Introduction of CNG:** In dual-fuel conversion, diesel engines are modified to allow the introduction of CNG into the combustion chamber alongside the intake air. CNG is typically injected into the engine using dedicated injectors.
- **Combustion Process:** CNG is used as a supplementary fuel along with diesel. The diesel fuel acts as the ignition source, while CNG combusts in the air-fuel mixture. This approach reduces the dependence on diesel fuel, leading to potential fuel cost savings and lower emissions.
- **Engine Modifications:** Dual-fuel systems often require modifications to the fuel injection system, intake manifold, and engine control unit (ECU) to manage the dual-fuel operation effectively.

Hydrogen:

- Dual-Fuel Operation: Similar to CNG, hydrogen can be introduced into the diesel engine in a dual-fuel configuration. Hydrogen is injected into the intake air, and combustion occurs simultaneously with diesel fuel.
- Ignition Enhancement: Hydrogen has a high flame speed and can enhance the combustion process. It helps in more complete combustion of the diesel fuel, potentially leading to improved efficiency and reduced emissions.
- Engine Modifications: Dual-fuel hydrogen-diesel systems require modifications to accommodate hydrogen injection and optimize engine performance.

3. Hydrogen Blending:

Hydrogen:

- **Hydrogen Blending:** Hydrogen can be blended with diesel fuel in the fuel tank or introduced into the intake air. Blending involves mixing a certain percentage of hydrogen with diesel.
- **Combustion Enhancement:** Hydrogen blending can enhance combustion efficiency and reduce emissions. It allows for a smoother and more controlled combustion process when compared to pure diesel combustion.
- **Engine Adjustments:** While blending hydrogen with diesel, adjustments to the engine's fuel injection timing and quantity may be necessary to optimize performance and combustion stability.

3. Hydrogen Diesel Dual-Fuel Engines:

- Dedicated Dual-Fuel Engines: Some engine designs are specifically developed to operate as dual-fuel engines, capable of using both diesel and hydrogen as primary fuels. These engines are optimized for dual-fuel combustion.
- Injector Design: Dual-fuel engines designed for hydrogen-diesel operation may incorporate specialized injectors to deliver both fuels into the combustion chamber.
- Control System: Advanced engine control systems are used to manage the dual-fuel combustion process, adjusting parameters such as injection timing, quantity, and air-fuel ratios.

Considerations:

1. **Engine Modifications:**
   - Both CNG and hydrogen applications may require modifications to the engine, including the fuel injection system, combustion chamber design, and control systems.
2. **Fuel Storage and Handling:**
   - Proper storage and handling systems are necessary for safely storing and delivering CNG and hydrogen to the engine.
3. **Safety Considerations:**
   - Due to the high flammability of hydrogen, safety measures must be implemented in the design and operation of hydrogen-diesel dual-fuel systems.
4. **Emission Characteristics:**
   - The use of CNG and hydrogen can lead to lower emissions, including reduced levels of particulate matter, nitrogen oxides (NOx), and carbon dioxide (CO2) compared to conventional diesel combustion.
5. **Fuel Infrastructure:**
   - The availability and infrastructure for CNG and hydrogen refuelling play a crucial role in the widespread adoption of these alternative fuels.

Overall, the successful integration of CNG and hydrogen into diesel engines requires careful consideration of engine modifications, combustion characteristics, safety aspects, and infrastructure development. Ongoing research and development efforts aim to optimize these technologies for improved efficiency and environmental performance.

26. Show the modification required to use hydrogen as a fuel in S.I engine, state the functions of each modification and benefits of hydrogen over gasoline fuel.

To use hydrogen as a fuel in a spark-ignition (S.I.) engine, several modifications are required to accommodate the unique properties of hydrogen. Hydrogen has distinct combustion characteristics, including a wide flammability range and a high flame speed, which necessitate specific adjustments for optimal performance. Here are the key modifications, their functions, and the benefits of using hydrogen over gasoline:

Modifications Required:

1. **Fuel Injection System:**
   - Function: Hydrogen is typically injected into the combustion chamber in gaseous form. The fuel injection system must be modified to accommodate hydrogen injection alongside air intake.
   - Benefits: Precision control of hydrogen injection allows for better mixing with air, optimizing combustion and efficiency.
2. **Spark Timing Control:**
   - **Function:** Hydrogen has different ignition characteristics compared to gasoline. Adjustments to the spark timing are necessary to ensure proper ignition and combustion stability.
   - **Benefits:** Proper spark timing optimization enhances combustion efficiency and power output.
3. **Combustion Chamber Design:**
   - Function: The combustion chamber may require modification to account for hydrogen's high flame speed and different combustion characteristics. This can involve changes in shape and size to promote efficient combustion.
   - Benefits: Optimized combustion chamber design helps achieve more complete combustion, improving overall engine efficiency.
4. **Materials Compatibility:**
   - Function: Hydrogen has different material compatibility requirements than gasoline. Engine components, especially those in contact with hydrogen, may need to be made of materials that resist hydrogen embrittlement and leakage.
   - Benefits: Ensuring materials compatibility enhances the durability and safety of the engine.
5. **Compression Ratio Adjustment:**
   - **Function:** Hydrogen has a higher octane rating than gasoline, allowing for higher compression ratios. Adjusting the compression ratio can optimize engine performance.
   - **Benefits:** Higher compression ratios contribute to increased thermal efficiency and power output.
6. **Engine Control Unit (ECU) Calibration:**
   - Function: The ECU must be reprogrammed to control hydrogen injection, spark timing, and other parameters for optimal combustion.
   - Benefits: Proper ECU calibration ensures the engine operates efficiently and safely with hydrogen.

Benefits of Hydrogen over Gasoline:

1. **Zero Carbon Emissions:**
    - Hydrogen combustion produces only water vapor as a by-product, resulting in zero carbon dioxide emissions during combustion. This contributes to a reduction in greenhouse gas emissions.
2. **High Flame Speed:**
    - Hydrogen has a high flame speed, leading to quicker and more controlled combustion. This can result in improved engine efficiency and power delivery.
3. **Wide Flammability Range:**
    - Hydrogen has a wide flammability range, allowing for flexible engine operation. This property facilitates stable combustion under various operating conditions.
4. **Renewable Production:**
    - Hydrogen can be produced using renewable energy sources, making it a potential environmentally friendly fuel option when produced using sustainable methods.
5. **High Octane Rating:**
    - Hydrogen has a high octane rating, allowing for higher compression ratios and more efficient combustion compared to gasoline.
6. **Reduced Greenhouse Gas Impact:**
    - When produced using renewable energy, hydrogen can contribute to a reduction in the overall environmental impact of the transportation sector.

It's important to note that the successful integration of hydrogen as a fuel in S.I. engines requires a holistic approach, considering the entire fuel system, safety aspects, and infrastructure development. Research and development efforts are ongoing to optimize hydrogen-powered engines for widespread use and address associated challenges.

27. Present an overall comparative discussion about alternative fuels in terms of its usage, benefits, sustainability, modifications and performance.

Alternative fuels have gained significant attention in recent years as the need for more sustainable and environmentally friendly energy sources has become increasingly apparent. Here's a comparative discussion of various alternative fuels, considering their usage, benefits, sustainability, required modifications, and performance in the context of internal combustion engines:

1. Biofuels (Ethanol and Biodiesel):

Usage:

- Ethanol is often blended with gasoline to create biofuel blends (e.g., E10, E85).
- Biodiesel, derived from renewable sources such as vegetable oils, can be used as a substitute for diesel fuel.

Benefits: Biofuels are renewable and can be produced from organic materials like crops and waste.

- They can be used in existing internal combustion engines with minimal modifications.

Sustainability:

- Depends on feedstock and production methods; sustainably sourced biofuels can have a lower carbon footprint.

Modifications:

- Minor engine modifications may be required, especially for higher biofuel blends.

Performance:

- Generally, biofuels have lower energy density compared to conventional fuels, leading to slightly reduced fuel efficiency.
- Reduced greenhouse gas emissions compared to traditional fossil fuels.

2. Natural Gas (Compressed Natural Gas - CNG, Liquefied Natural Gas - LNG):

Usage:

CNG is used as a fuel in both spark-ignition and compression-ignition engines.

LNG is primarily used in heavy-duty vehicles and marine applications.

Benefits:

Abundant and cleaner-burning compared to traditional fossil fuels.

Lower levels of particulate matter and nitrogen oxides.

Sustainability:

Natural gas is a fossil fuel, but bio methane (renewable natural gas) derived from organic waste enhances sustainability.

Modifications:

Engine modifications required for CNG/LNG storage and combustion.

Vehicle fuel systems need to be adapted for compressed or liquefied natural gas.

Performance:

Natural gas engines generally have lower energy density than gasoline or diesel, impacting overall range.

Combustion characteristics may differ, affecting power delivery.

3. Hydrogen:

Usage:

Used in both spark-ignition and compression-ignition engines, often in dual-fuel configurations.

Hydrogen fuel cells are an alternative method for electric propulsion.

Benefits:

Zero carbon emissions during combustion.

High energy content and quick refuelling for fuel cell vehicles.

Sustainability:

Sustainability depends on production methods; green hydrogen (produced using renewable energy) is considered environmentally friendly.

Modifications:

Significant modifications to the fuel system, combustion chamber, and materials compatibility are required.

Performance:

Hydrogen combustion can enhance engine efficiency and power output.

Hydrogen fuel cells provide continuous power with zero emissions, ideal for electric propulsion.

4. Electricity (Battery Electric Vehicles - BEVs):

Usage:

Battery electric vehicles use electricity stored in batteries to power electric motors.

Benefits:

Zero tailpipe emissions.

Lower maintenance requirements compared to internal combustion engines.

Sustainability:

Depends on the source of electricity; using renewable energy makes BEVs more sustainable.

Modifications:

Extensive modifications for electric powertrains and charging infrastructure.

Performance:

Immediate torque delivery and quiet operation.

Limited range and longer refuelling (recharging) times compared to traditional fuels.

5. Hybrid Vehicles:

Usage:

Combine internal combustion engines with electric propulsion.

Benefits:

Improved fuel efficiency and reduced emissions.

Regenerative braking enhances energy recovery.

Sustainability:

Depends on the type of hybrid (mild, full, plug-in) and driving patterns.

Modifications:

Modifications to accommodate electric powertrains, battery systems, and regenerative braking.

Performance:

Enhanced fuel efficiency, especially in urban driving conditions.

Reduced reliance on internal combustion engines.

Comparative Summary:

Usage: Each alternative fuel has specific applications and compatibility with different types of engines.

Benefits: Alternative fuels offer reduced emissions, increased energy security, and potential cost savings.

Sustainability: The sustainability of alternative fuels varies based on production methods and feedstocks.

Modifications: Engine modifications range from minor adjustments to significant overhauls, depending on the fuel type.

Performance: Performance characteristics, including energy density, power delivery, and range, differ among alternative fuels.

In conclusion, the choice of alternative fuel depends on factors such as fuel availability, infrastructure, sustainability goals, and application requirements. The ongoing development of advanced technologies and increased focus on sustainability will likely drive further improvements and adoption of alternative fuels in the transportation sector.

28. What are the advantages and disadvantages of using bio diesel in C.I engine?

Biodiesel is a renewable alternative fuel that is derived from organic materials such as vegetable oils or animal fats. When used in compression-ignition (C.I.) engines, which are commonly found in diesel vehicles, biodiesel presents both advantages and disadvantages. Here's a breakdown of the key pros and cons:

Advantages of Using Biodiesel in C.I. Engines:

1. **Renewable and Sustainable:**
   Advantage: Biodiesel is produced from renewable resources such as soybean oil, canola oil, or used cooking oil, making it a more sustainable and environmentally friendly option.

2. **Reduced Greenhouse Gas Emissions:**
   Advantage: Biodiesel generally has lower carbon dioxide (CO_2) emissions compared to conventional diesel fuel. The carbon released during combustion is offset by the carbon absorbed during the growth of the feedstock plants.

3. **Biodegradable and Non-Toxic:**
   Advantage: Biodiesel is biodegradable and less toxic than traditional diesel fuel, reducing environmental impact in case of spills or leaks.

4. **Improved Lubricity:**
   Advantage: Biodiesel has better lubricating properties than conventional diesel, which can contribute to reduced wear and tear on engine components.

5. **Compatibility with Existing Infrastructure:**
   Advantage: Biodiesel can be used in existing diesel engines and requires minimal modifications to the engine or fuelling infrastructure.

6. **Domestic Production Potential:**
   Advantage: Biodiesel can be produced locally, potentially reducing dependence on foreign oil and promoting domestic energy production.

Disadvantages of Using Biodiesel in C.I. Engines:

1. **Reduced Energy Density:**
   Disadvantage: Biodiesel has a lower energy density than conventional diesel fuel, leading to slightly lower fuel efficiency and reduced overall driving range.

2. **Cold Weather Performance:**
   Disadvantage: Biodiesel can have poorer cold-weather performance, with higher cloud points and gel formation at lower temperatures. This may require engine preheating or blending with conventional diesel in colder climates.

3. **Impact on Engine Durability:**
   Disadvantage: Biodiesel's solvent properties may lead to the release of deposits in the fuel system, potentially affecting engine durability. Fuel system components may need to be more corrosion-resistant.

4. **Feedstock Competition with Food Production:**
   Disadvantage: The use of certain feedstocks for biodiesel production (e.g., soybean oil) may compete with food production, raising concerns about food security and land use.

5. **Limited Feedstock Availability:**
   Disadvantage: The availability of suitable feedstocks for biodiesel production can be limited, potentially leading to increased competition for resources.

6. **Quality and Standardization Issues:**
   Disadvantage: The quality of biodiesel can vary, and adherence to production standards is crucial. Variability in feedstock and production processes can affect fuel properties and engine performance.

7. **Fuel System Compatibility:**
   Disadvantage: Biodiesel may require modifications to the fuel system due to its different chemical composition. Older engines and infrastructure may be less compatible.

In conclusion, while biodiesel offers several environmental benefits and is a renewable option for C.I. engines, challenges such as reduced energy density, cold-weather performance, and potential impact on engine durability need to be carefully considered. Continued research and advancements in biodiesel production, engine technology, and fuel quality standards aim to address some of these challenges and improve the overall performance and sustainability of biodiesel in C.I. engines.

29. Explain with an illustration the functioning LPG fuelled S.I engine

A liquefied petroleum gas (LPG) fuelled spark-ignition (S.I.) engine operates similarly to a gasoline engine but with some modifications to the fuel system. LPG, which consists mainly of propane and butane, is a popular alternative fuel for internal combustion engines. Here's an illustration of the functioning of an LPG-fuelled S.I. engine:

Key Components and Functions:

1. **LPG Fuel Tank:**
    - **Function:** LPG is stored in a high-pressure fuel tank as a liquid. The tank is designed to withstand the pressure required to keep LPG in its liquid state.
2. **Pressure Regulator:**
    - **Function:** The pressure regulator reduces the high pressure of LPG from the tank to a lower pressure suitable for injection into the engine. It ensures a consistent fuel pressure for proper combustion.
3. **Fuel Injector:**
    - **Function:** The fuel injector sprays the LPG fuel directly into the intake manifold or combustion chamber. The injector is controlled by the engine control unit (ECU), regulating the fuel flow based on engine operating conditions.
4. **Intake Manifold:**
    - **Function:** The intake manifold distributes the air-fuel mixture (LPG and air) to each cylinder. LPG is injected into the manifold, where it mixes with incoming air before entering the combustion chamber.
5. **Throttle Body:**
    - **Function:** The throttle body regulates the airflow into the engine by adjusting the size of the throttle opening. It controls the engine's power output based on driver input.
6. **Air Filter:**
    - **Function:** The air filter removes impurities from the incoming air, ensuring that clean air mixes with the LPG for combustion.
7. **Combustion Chamber:**
    - **Function:** The combustion chamber is where the air-fuel mixture ignites. The spark plug initiates the combustion process by producing a spark that ignites the LPG and air mixture.
8. **Spark Plug:**
    - **Function:** The spark plug produces an electric spark to ignite the compressed air-fuel mixture in the combustion chamber, initiating the combustion process.
9. **Piston and Cylinder:**
    - **Function:** The piston moves up and down within the cylinder in response to combustion. The reciprocating motion of the piston is converted into rotational motion to drive the vehicle.
10. **Crankshaft:**
    - **Function:** The crankshaft converts the reciprocating motion of the pistons into rotational motion. It transfers power from the pistons to the vehicle's drivetrain.
11. **Exhaust System:**
    - **Function:** The exhaust system expels the combustion by-products, including carbon dioxide and water vapor, from the engine. It includes components such as the catalytic converter to reduce emissions.

Operating Cycle:

1. **Intake Stroke:**
    - The piston moves downward, creating a vacuum in the cylinder.
    - The throttle opens, allowing the air-fuel mixture (LPG and air) to enter the cylinder.
2. **Compression Stroke:**
    - The piston moves upward, compressing the air-fuel mixture.
    - The spark plug produces a spark, igniting the compressed mixture.
3. **Power Stroke:**
    - The ignited mixture rapidly expands, forcing the piston down.
    - The crankshaft converts the piston's linear motion into rotational motion.
4. **Exhaust Stroke:**
    - The piston moves upward, expelling the exhaust gases from the cylinder.

- The exhaust valve opens, and the combustion by-products exit through the exhaust system.

Benefits of LPG-Fuelled S.I. Engines:

1. **Lower Emissions:**
   - LPG combustion generally results in lower emissions of pollutants such as carbon monoxide (CO) and nitrogen oxides (NOx) compared to gasoline.
2. **Energy Security:**
   - LPG is a domestically available fuel source, contributing to energy security and reducing dependence on imported oil.
3. **Cost-Effective:**
   - LPG is often more cost-effective than gasoline, providing potential fuel cost savings for vehicle owners.
4. **Dual-Fuel Capability:**
   - Some engines can run on both gasoline and LPG, offering flexibility and extended driving range.
5. **Similar Infrastructure:**
   - LPG-fuelled vehicles can use existing gasoline refuelling infrastructure with minor modifications.

Challenges:

1. **Reduced Energy Density:**
   - LPG has a lower energy density than gasoline, leading to slightly reduced fuel efficiency and driving range.
2. **Fuel Storage:**
   - LPG requires specialized high-pressure storage systems, which can add complexity to the vehicle's design.
3. **Cold-Weather Performance:**
   - LPG may have cold-weather performance challenges, requiring additional measures for proper engine operation in low temperatures.

In summary, LPG-fuelled S.I. engines offer a cleaner and cost-effective alternative to traditional gasoline engines. However, there are considerations regarding energy density, fuel storage, and cold-weather performance that need to be addressed for widespread adoption.

30. Compare any five properties of ethanol, LPG, Hydrogen and CNG. (**)

Here's a comparison of five properties of ethanol, LPG (liquefied petroleum gas), hydrogen, and CNG (compressed natural gas):

1. Energy Density:

- **Ethanol:**
  - Energy density is lower than gasoline, leading to a slight reduction in fuel efficiency.
- **LPG:**
  - Lower energy density compared to gasoline but higher than ethanol.
- **Hydrogen:**

- Low energy density by volume but high energy content per unit mass.

- **CNG:**
  - Lower energy density than gasoline but higher than LPG.

2. Combustion Characteristics:

- **Ethanol:**
  - Requires specific engine modifications due to different combustion characteristics.
- **LPG:**
  - Combusts efficiently with relatively low emissions.
- **Hydrogen:**
  - High flame speed, leading to quick and controlled combustion.
- **CNG:**
  - Combustion is generally efficient, producing lower emissions compared to conventional fuels.

3. Greenhouse Gas Emissions:

- **Ethanol:**
  - Can result in lower net greenhouse gas emissions, especially if derived from renewable sources.
- **LPG:**
  - Produces fewer greenhouse gas emissions compared to traditional fossil fuels.
- **Hydrogen:**
  - Zero carbon emissions during combustion when produced from renewable sources.
- **CNG:**
  - Lower carbon emissions compared to gasoline and diesel.

4. Storage and Infrastructure:

- **Ethanol:**
  - Can be stored and transported using existing infrastructure, but special modifications may be needed for higher ethanol blends.
- **LPG:**
  - Requires specialized high-pressure storage tanks and modified fuel systems.
- **Hydrogen:**
  - Requires dedicated storage and transportation infrastructure, often in high-pressure tanks.
- **CNG:**
  - Requires high-pressure storage tanks and a separate refuelling infrastructure.

5. Safety Considerations:

- **Ethanol:**
  - Generally considered safe but has a lower flashpoint than gasoline.
- **LPG:**
  - Heavier than air, may pool in low-lying areas, posing a potential fire hazard.
- **Hydrogen:**

- Highly flammable and has specific safety considerations; dissipates quickly in the atmosphere.
- **CNG:**
  - Lighter than air and tends to disperse rapidly, reducing fire hazards.

Additional Note:

- **Renewability:**
  - **Ethanol:**
    - Derived from renewable sources like corn, sugarcane, or cellulosic feedstocks.
  - **LPG:**
    - A fossil fuel derived from natural gas processing and petroleum refining.
  - **Hydrogen:**
    - Can be produced from renewable sources using electrolysis or from fossil fuels (grey hydrogen) with carbon capture and storage.
  - **CNG:**
    - Mainly derived from fossil natural gas but can include bio methane produced from organic waste.

These properties highlight the diverse characteristics of ethanol, LPG, hydrogen, and CNG, each with its advantages and challenges. The choice of fuel depends on factors such as energy efficiency, emissions, infrastructure, and safety considerations, as well as the specific requirements of the application.

31. Mention atleast four properties of Hydrogen and natural gas

Here are four properties each for hydrogen and natural gas (typically composed of methane):

Hydrogen:

1. **Flammability:**
   - Hydrogen is highly flammable and has a wide flammability range. It forms explosive mixtures with air at concentrations between 4% and 75% by volume.
2. **Energy Content:**
   - Hydrogen has a high energy content per unit mass, making it a potent fuel. However, its energy density by volume is relatively low, requiring specialized storage and transportation methods.
3. **Combustion Characteristics:**
   - Hydrogen has a high flame speed and a low ignition energy. Its combustion is clean, producing water vapor as the primary by-product, making it environmentally friendly.
4. **Storage Challenges:**
   - Hydrogen poses challenges related to storage due to its low density by volume. Various methods, such as compression, liquefaction, and advanced materials for solid-state storage, are being explored to address this issue.

Natural Gas (Methane):

1. **Composition:**
   - Natural gas is primarily composed of methane (CH_4), with smaller amounts of other hydrocarbons, carbon dioxide (CO_2), nitrogen (N_2), and trace elements. The specific composition can vary depending on the source.

2. **Energy Content:**
    - Methane is a high-energy fuel with a higher energy density by volume compared to hydrogen. It provides a cleaner combustion compared to other fossil fuels, with lower carbon emissions.
3. **Storage and Transportation:**
    - Natural gas is stored and transported in gaseous form, typically in high-pressure cylinders or pipelines. It can also be liquefied (LNG) for more efficient storage and transport over long distances.
4. **Emissions:**
    - Combustion of methane produces fewer carbon dioxide (CO_2) emissions compared to other fossil fuels. However, methane itself is a potent greenhouse gas, and un combusted or leaked methane can contribute to environmental concerns.

These properties highlight some of the key characteristics of hydrogen and natural gas. Both fuels have their advantages and challenges, and their use is influenced by factors such as energy density, emissions, storage, and safety considerations in various applications, including transportation and energy production.

32. Give the suitability of LPG as fuel for a C.I engine.

Liquefied Petroleum Gas (LPG), which primarily consists of propane and butane, is a suitable alternative fuel for compression-ignition (C.I.) engines under certain conditions. However, there are considerations and modifications needed to optimize the use of LPG in a C.I. engine. Here's an overview of the suitability of LPG for C.I. engines:

Suitability:

1. **Calorific Value:**
    - **Advantage:** LPG has a relatively high calorific value, providing good energy content. This contributes to efficient combustion and power generation in C.I. engines.
2. **Clean Combustion:**
    - **Advantage:** LPG combustion generally produces fewer particulate matter and lower levels of nitrogen oxides (NOx) compared to conventional diesel fuel. This can lead to reduced environmental impact and compliance with emission standards.
3. **Adaptability to Existing C.I. Engines:**
    - **Advantage:** LPG can be used in existing compression-ignition engines with some modifications. The fuel system, injection timing, and combustion parameters may need adjustments to optimize performance.
4. **Fuel Storage:**
    - **Advantage:** LPG can be stored in liquid form under moderate pressure, allowing for convenient storage and transportation. This ease of handling is beneficial for vehicle applications.
5. **Dual-Fuel Capability:**
    - **Advantage:** C.I. engines can be designed to operate on dual-fuel systems, allowing the use of both diesel and LPG. This provides flexibility and ensures the availability of fuel, especially in regions with limited infrastructure for alternative fuels.
6. **Reduced Carbon Emissions:**
    - **Advantage:** LPG combustion generally results in lower carbon dioxide (CO_2) emissions compared to traditional diesel fuel. This contributes to addressing environmental concerns related to greenhouse gas emissions.

Considerations and Modifications:

1. **Fuel System Modification:**
    - **Consideration:** The fuel injection system may need modifications to accommodate the different combustion characteristics of LPG. Injection timing and quantity adjustments are crucial for optimal combustion.
2. **Compression Ratio Adjustment:**
    - **Consideration:** The compression ratio of the C.I. engine may need adjustment to optimize the combustion of LPG. Higher compression ratios may be suitable for LPG compared to diesel.
3. **Ignition System:**
    - **Consideration:** C.I. engines designed for diesel fuel may require modifications to the ignition system to ensure reliable ignition of the LPG-air mixture.
4. **Engine Control Unit (ECU) Calibration:**
    - **Consideration:** The ECU needs to be calibrated to manage LPG injection and combustion parameters. Proper calibration ensures efficient and stable engine operation.
5. **Materials Compatibility:**
    - **Consideration:** Some materials in the fuel system may need to be compatible with LPG. This includes seals, gaskets, and other components that come into contact with the fuel.

Challenges:

1. **Energy Density:**
    - **Challenge:** LPG has a lower energy density compared to diesel, which may result in a reduction in fuel efficiency and overall driving range.
2. **Cold Weather Performance:**
    - **Challenge:** LPG may experience challenges in cold weather, requiring additional measures such as preheating to ensure proper vaporization and combustion.
3. **Storage and Infrastructure:**
    - **Challenge:** LPG storage and refuelling infrastructure may not be as widely available as conventional diesel infrastructure, limiting the widespread adoption of LPG in C.I. engines.

In conclusion, LPG is suitable for use in compression-ignition engines, provided that appropriate modifications are made to the engine and fuel system. Its clean combustion characteristics and adaptability to existing diesel engines make it a viable alternative, especially in applications where emissions reduction and flexibility in fuel usage are priorities.

33. Discuss the change in properties of alcohol-petrol blends and their effect on the performance of the engine.

Alcohol-petrol blends, commonly known as gasohol or ethanol blends, involve mixing alcohol-based fuels, such as ethanol, with conventional gasoline. The most common ethanol blends include E10 (10% ethanol, 90% gasoline) and E85 (85% ethanol, 15% gasoline). The addition of ethanol to petrol can result in changes in several properties, and these changes can have both positive and negative effects on the performance of internal combustion engines. Here's a discussion of the key properties and their impact:

1. Octane Rating:

- **Change:** Ethanol has a higher octane rating than gasoline. Blending ethanol with petrol increases the overall octane rating of the fuel.

- **Effect on Performance:**
  - **Positive:** Higher octane ratings contribute to better resistance against knock or pre-ignition, allowing for increased engine efficiency and the potential for higher compression ratios.
  - **Negative:** Some older engines may not be optimized for higher octane fuels, and the benefits may not be fully realized without corresponding engine modifications.

2. Energy Content:

- **Change:** Ethanol has a lower energy content per unit volume compared to gasoline.
- **Effect on Performance:**
  - **Negative:** Blending ethanol with gasoline reduces the overall energy density of the fuel, resulting in a slight decrease in fuel efficiency and range. More fuel is needed to produce the same amount of energy.

3. Oxygen Content:

- **Change:** Ethanol contains oxygen, and blending it with gasoline increases the oxygen content of the fuel.
- **Effect on Performance:**
  - **Positive:** The higher oxygen content can lead to more complete combustion, potentially reducing emissions of carbon monoxide (CO) and unburned hydrocarbons.
  - **Negative:** In some cases, increased oxygen levels may necessitate adjustments to the air-fuel mixture, timing, and fuel injection systems for optimal combustion.

4. Vaporization Characteristics:

- **Change:** Ethanol has different vaporization characteristics compared to gasoline.
- **Effect on Performance:**
  - **Positive:** Ethanol's higher latent heat of vaporization can improve the cooling effect during the intake stroke, contributing to reduced engine temperatures.
  - **Negative:** Cold starting may be more challenging in certain conditions due to ethanol's lower vapor pressure at low temperatures.

5. Corrosively and Material Compatibility:

- **Change:** Ethanol is hygroscopic and can be corrosive, potentially affecting certain materials in the fuel system.
- **Effect on Performance:**
  - **Negative:** Corrosion of certain materials, particularly in older vehicles, can lead to fuel system issues, such as clogged fuel filters and damaged fuel pumps.

6. Lubrication:

- **Change:** Ethanol has lower lubricity compared to gasoline.
- **Effect on Performance:**
  - **Negative:** In engines without proper lubrication measures, ethanol blends may contribute to increased wear on fuel system components, particularly in older vehicles.

7. Heat of Combustion:

- **Change:** Ethanol has a higher heat of combustion compared to gasoline.
- **Effect on Performance:**
  - **Positive:** The higher heat of combustion contributes to improved thermal efficiency, potentially leading to increased power output and better overall engine performance.

8. Cylinder Pressure and Temperatures:

- **Change:** The higher octane and heat of combustion of ethanol can result in higher cylinder pressures and temperatures.
- **Effect on Performance:**
  - **Positive:** In optimized engines, higher cylinder pressures can contribute to increased efficiency and power output.
  - **Negative:** Older engines may not be designed to handle the increased pressures and temperatures, potentially leading to durability issues.

Conclusion:

The impact of alcohol-petrol blends on engine performance is multifaceted, with both positive and negative effects. Vehicle compatibility, engine design, and modifications play a crucial role in determining the overall impact on performance. Modern engines designed for flexible fuel use or specifically calibrated for ethanol blends tend to experience more positive outcomes, including improved efficiency and reduced emissions. However, older engines may require modifications to fully harness the benefits of alcohol-petrol blends and careful consideration of the trade-offs is

34. Explain the construction and working of CRDI system with neat block diagram. (*****)

Common Rail Direct Injection (CRDI) System: Construction and Working

The Common Rail Direct Injection (CRDI) system is a modern fuel injection technology used in diesel engines to enhance efficiency, power, and reduce emissions. Here is an explanation of its construction and working, along with a neat block diagram:

Construction:

1. **Fuel Tank:**
   - The fuel tank stores diesel fuel, which is then fed to the high-pressure pump.
2. **High-Pressure Pump:**
   - The high-pressure pump pressurizes the diesel fuel to very high pressures, typically ranging from 1,000 to 2,500 bar. This pump ensures a constant high pressure in the common rail.
3. **Common Rail:**
   - The common rail is a high-pressure fuel reservoir that stores the pressurized fuel from the high-pressure pump. It is connected to each fuel injector through high-pressure lines.
4. **Fuel Injectors:**
   - The fuel injectors are responsible for injecting precise amounts of fuel directly into the combustion chamber of each cylinder. Each injector is connected to the common rail by a high-pressure line.

5. **Electronic Control Unit (ECU):**
    - The ECU is the brain of the CRDI system. It receives inputs from various sensors and determines the optimal fuel injection timing, duration, and pressure for each cylinder.
6. **Sensors:**
    - Various sensors provide input to the ECU, including:
        - **Crankshaft Position Sensor:** Determines the position of the crankshaft for precise fuel injection timing.
        - **Camshaft Position Sensor:** Provides information about the camshaft position for synchronizing fuel injection.
        - **Pressure Sensor:** Monitors the pressure in the common rail.
7. **Pressure Control Valve (PCV):**
    - The PCV regulates the pressure in the common rail by controlling the amount of fuel returned to the fuel tank. It helps maintain a constant pressure for optimal fuel injection.

Common-Rail Direct Injection (CRDI) System

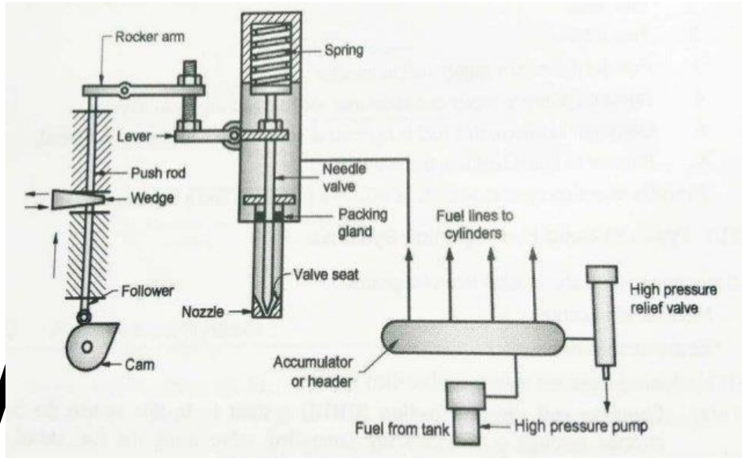


Fig. 4.31.1 : Common rail system

Working:

1. **Fuel Pressurization:**
    - The high-pressure pump pressurizes the diesel fuel to very high pressures, typically ranging from 1,000 to 2,500 bar.
2. **Common Rail Reservoir:**
    - The pressurized fuel is stored in the common rail, maintaining a constant high pressure.
3. **Sensor Inputs:**
    - The ECU receives inputs from sensors, including crankshaft position, camshaft position, and pressure sensors.
4. **Optimal Injection Parameters:**
    - Based on sensor inputs and various operating conditions, the ECU calculates the optimal injection timing, duration, and pressure for each cylinder.
5. **Injector Actuation:**
    - The ECU sends signals to the fuel injectors to actuate, controlling the precise amount of fuel to be injected into each combustion chamber.
6. **High-Pressure Injection:**
    - The fuel injectors spray a precisely metered amount of pressurized fuel directly into the combustion chamber at high pressure.

7. **Combustion:**
    - The injected fuel mixes with the compressed air in the combustion chamber. Ignition occurs, leading to the combustion of the fuel and the generation of power.
8. **Optimized Performance:**
    - The CRDI system allows for multiple injections per combustion cycle, enabling precise control over the combustion process. This results in improved fuel efficiency, reduced emissions, and enhanced engine performance.

Neat Block Diagram:

The CRDI system's ability to control the injection parameters for each cylinder independently enhances overall engine efficiency, reduces emissions, and provides better performance across a wide range of operating conditions.

35. Discuss the following Hybrid Electric vehicle.(HEV) (***)

A Hybrid Electric Vehicle (HEV) is a type of vehicle that combines an internal combustion engine (usually fuelled by gasoline) with one or more electric motors. The integration of both power sources allows HEVs to achieve improved fuel efficiency, reduced emissions, and increased overall performance compared to traditional internal combustion engine vehicles. Here are key aspects to discuss about Hybrid Electric Vehicles:

Components of a Hybrid Electric Vehicle:

1. **Internal Combustion Engine (ICE):**
    - Most HEVs have a conventional gasoline engine, although diesel and other fuel types are used in some models. The engine is usually smaller and more fuel-efficient than those in traditional vehicles.
2. **Electric Motor(s):**
    - HEVs feature one or more electric motors powered by a traction battery. These motors assist the internal combustion engine during acceleration and can operate independently at low speeds or in certain driving conditions.
3. **Traction Battery:**
    - The traction battery stores electrical energy to power the electric motor(s). It is rechargeable and is a crucial component for the electric-only driving mode and regenerative braking.
4. **Power Split Device (Transmission):**
    - The power split device, often used in Continuously Variable Transmissions (CVTs), efficiently manages power distribution between the internal combustion engine, electric motor(s), and wheels.
5. **Regenerative Braking System:**
    - HEVs use regenerative braking to recover kinetic energy during braking, converting it into electricity to recharge the traction battery. This enhances overall energy efficiency.
6. **Controller/Power Electronics:**
    - The controller manages the flow of energy between the internal combustion engine, electric motor(s), and traction battery. Power electronics convert and control the flow of electrical energy.
7. **Hybrid Control System:**
    - Advanced algorithms and sensors optimize the coordination between the internal combustion engine and electric motor(s) for maximum efficiency and performance.
8. **Accessory Battery:**
    - An accessory battery powers the vehicle's accessories, lights, and other electrical components.

Operating Modes:

1. **Electric Mode (EV):**
   - The vehicle operates solely on electric power at low speeds, typically during city driving or at low loads.
2. **Internal Combustion Engine Mode (ICE):**
   - The internal combustion engine powers the vehicle during high-speed driving or when additional power is required.
3. **Parallel Hybrid Mode:**
   - Both the internal combustion engine and electric motor contribute power to the wheels simultaneously during acceleration or cruising.
4. **Series Hybrid Mode:**
   - The internal combustion engine acts as a generator to recharge the battery, and the electric motor exclusively drives the wheels. This mode is often used during low-speed or low-load conditions.

Benefits of Hybrid Electric Vehicles:

1. **Improved Fuel Efficiency:**
   - HEVs can achieve better fuel efficiency and reduced fuel consumption compared to traditional vehicles, especially in city driving conditions.
2. **Reduced Emissions:**
   - The use of electric power during low-speed or stop-and-go traffic reduces tailpipe emissions, contributing to lower overall greenhouse gas emissions.
3. **Regenerative Braking:**
   - Regenerative braking captures energy during braking, converting it into electricity and improving overall energy efficiency.
4. **Enhanced Performance:**
   - The combination of the internal combustion engine and electric motor(s) provides improved acceleration and performance.
5. **Increased Range:**
   - Some HEVs offer an electric-only driving range, reducing the overall dependence on the internal combustion engine.
6. **Lower Operating Costs:**
   - Regenerative braking and the ability to operate on electric power during certain conditions contribute to reduced brake wear and lower maintenance costs.

Challenges and Considerations:

1. **Cost:**
   - HEVs can be more expensive upfront due to the additional components, although the price gap has been decreasing with advancements in technology.
2. **Battery Technology:**
   - The cost and energy density of batteries are critical factors. Advances in battery technology are essential to improve range, reduce weight, and enhance overall efficiency.
3. **Charging Infrastructure:**
   - Unlike plug-in hybrid electric vehicles (PHEVs), HEVs do not require external charging. However, limited charging infrastructure can still be a concern for PHEVs.
4. **Weight:**

- The additional components, especially the traction battery, can contribute to increased vehicle weight, potentially affecting handling and overall efficiency.

5. **Maintenance Complexity:**
    - The presence of both an internal combustion engine and electric components may require specialized maintenance skills and equipment.

Hybrid Electric Vehicles represent a significant step toward achieving more sustainable and fuel-efficient transportation. As technology continues to advance, HEVs will likely evolve, offering even greater benefits in terms of efficiency, range, and reduced environmental impact.

36. Detail about methods of achieving HCCI combustion mode in C.I engine and list the challenges and advantages of HCCI. (**)

Homogeneous Charge Compression Ignition (HCCI) is a combustion mode that combines features of both Spark Ignition (SI) and Compression Ignition (CI) engines. In HCCI, a homogeneous mixture of fuel and air is compressed to the point of auto ignition without the need for an external spark source. Achieving and controlling HCCI combustion in a Compression Ignition (C.I) engine involves several methods. Here's an overview:

Methods of Achieving HCCI Combustion in C.I. Engines:

1. **Variable Compression Ratio:**
    - By adjusting the compression ratio of the engine, it is possible to control the temperature and pressure conditions in the combustion chamber, promoting auto ignition.
2. **Charge Dilution:**
    - Introducing excess air or exhaust gas recirculation (EGR) into the combustion chamber reduces the peak temperature and pressure, facilitating auto ignition.
3. **Use of Advanced Fuels:**
    - Fuels with higher octane numbers and better auto ignition characteristics, such as high-octane gasoline, can be used to achieve HCCI combustion in C.I. engines.
4. **Multi-Pulse Fuel Injection:**
    - Precise control of fuel injection timing and duration in multiple pulses helps in achieving a homogeneous mixture and proper conditions for auto ignition.
5. **Combustion Chamber Design:**
    - Optimizing the shape and size of the combustion chamber can influence the mixing of fuel and air, promoting homogeneity and facilitating HCCI combustion.
6. **Variable Valve Timing (VVT):**
    - VVT systems allow control over the opening and closing timings of intake and exhaust valves, influencing the trapping and dilution of the air-fuel mixture.
7. **Cylinder Deactivation:**
    - Deactivating cylinders during certain operating conditions reduces the overall load on the engine, influencing the combustion characteristics and promoting HCCI.
8. **Feedback Control Systems:**
    - Closed-loop control systems incorporating sensors for parameters such as pressure, temperature, and ionization currents enable real-time adjustments for achieving and maintaining HCCI combustion.

Challenges of HCCI Combustion:

1. **Control and Stability:**
   - Achieving and maintaining stable HCCI combustion over a wide range of operating conditions is challenging due to the sensitivity of auto ignition to factors like temperature and pressure.
2. **Limited Load Range:**
   - HCCI combustion is typically limited to medium and low loads. Achieving stable combustion at high loads without knocking or misfiring is challenging.
3. **Cold Start and Transient Response:**
   - Cold starting and rapid transient response present challenges in HCCI engines. Controlling combustion under these conditions requires advanced control strategies.
4. **Engine Knock:**
   - The risk of knocking, especially at higher loads, poses challenges. Knock control strategies are necessary to prevent engine damage.
5. **Emission Control:**
   - Managing emissions, particularly nitrogen oxides (NOx) and unburned hydrocarbons, can be challenging in HCCI combustion due to the high temperatures and pressures involved.

Advantages of HCCI Combustion:

1. **Improved Fuel Efficiency:**
   - HCCI engines can achieve high thermal efficiency and improved fuel efficiency compared to traditional combustion modes.
2. **Reduced NOx Emissions:**
   - HCCI combustion tends to produce lower levels of nitrogen oxides (NOx) compared to conventional diesel combustion.
3. **Lower Particulate Emissions:**
   - The homogeneous mixture in HCCI combustion results in lower particulate matter emissions, contributing to cleaner exhaust.
4. **Fuel Flexibility:**
   - HCCI engines have the potential to run on a variety of fuels, including gasoline, diesel, and alternative fuels, enhancing fuel flexibility.
5. **Combination of SI and CI Benefits:**
   - HCCI combines the efficiency benefits of compression ignition with the lower emissions characteristics of spark ignition, offering a balance between the two combustion modes.
6. **Reduced CO2 Emissions:**
   - The high efficiency of HCCI combustion contributes to lower carbon dioxide (CO2) emissions, supporting environmental sustainability.

HCCI combustion represents a promising avenue for achieving higher efficiency and cleaner emissions in internal combustion engines. However, addressing challenges related to control, stability, and emissions remains critical for widespread adoption of HCCI technology in practical applications. Ongoing research and advancements in combustion control systems and engine design are essential for realizing the full potential of HCCI in Compression Ignition engines.

37. Discuss in detail about the promises and challenges exist in biodiesel production, sustainability and utilisation in IC engine.

Promises of Biodiesel Production, Sustainability, and Utilization in IC Engines:

Promises:

1. **Renewable Energy Source:**
   - **Promise:** Biodiesel is produced from renewable resources, such as vegetable oils, animal fats, or waste cooking oil. It provides an alternative to fossil diesel, contributing to energy diversification.
2. **Reduced Greenhouse Gas Emissions:**
   - **Promise:** Biodiesel has lower lifecycle carbon dioxide (CO2) emissions compared to conventional diesel, as the carbon released during combustion is offset by the carbon absorbed during the growth of the feedstock.
3. **Biodegradability and Lower Toxicity:**
   - **Promise:** Biodiesel is biodegradable and has lower toxicity than conventional diesel, reducing the environmental impact in case of spills or leaks.
4. **Domestically Sourced Feedstocks:**
   - **Promise:** Biodiesel feedstocks can be grown domestically, reducing dependence on imported fossil fuels and enhancing energy security.
5. **Use of Waste Feedstocks:**
   - **Promise:** Biodiesel can be produced from waste feedstocks such as used cooking oil or animal fats, contributing to waste reduction and recycling.
6. **Engine Compatibility:**
   - **Promise:** Biodiesel can be used in existing diesel engines with little to no modification. It has similar combustion properties to diesel fuel, allowing for a seamless transition.
7. **Renewable Energy Policy Support:**
   - **Promise:** Many countries promote biodiesel production and utilization through renewable energy policies and incentives, fostering the growth of the biodiesel industry.

Challenges:

1. **Feedstock Availability and Competition:**
   - **Challenge:** The availability of feedstocks for biodiesel production can be limited, and competition for land between food and fuel crops may arise. Striking a balance between food and fuel production is crucial.
2. **Land Use Change and Deforestation:**
   - **Challenge:** The expansion of biodiesel feedstock cultivation can lead to land use change, potentially causing deforestation and biodiversity loss. Sustainable practices are essential to mitigate these impacts.
3. **Energy Intensity of Production:**
   - **Challenge:** Biodiesel production processes, especially transesterification, can be energy-intensive. Advancements in production technologies and the use of renewable energy sources are needed to improve the overall energy balance.
4. **Water Usage and Impact:**
   - **Challenge:** Biodiesel production may require significant water resources, especially if the feedstocks are water-intensive crops. Sustainable water management practices are essential to address potential environmental concerns.

5. **Technological and Infrastructure Challenges:**
    - **Challenge:** Biodiesel has different properties than conventional diesel, and adjustments to engine designs and fuel infrastructure may be necessary. This includes addressing issues related to cold-weather performance and material compatibility.
6. **Biodiesel Stability and Oxidation:**
    - **Challenge:** Biodiesel can have stability and oxidation issues during storage, leading to the formation of sediments and gum deposits. Antioxidants and proper storage practices are essential to address these challenges.
7. **Economic Viability:**
    - **Challenge:** The economic competitiveness of biodiesel is influenced by factors such as feedstock prices, production costs, and market demand. Government incentives and policy support play a crucial role in enhancing economic viability.
8. **Quality Standards and Certification:**
    - **Challenge:** Ensuring the quality and consistency of biodiesel products is crucial. Adherence to quality standards and certification programs helps build consumer confidence and facilitates market acceptance.
9. **Public Perception and Acceptance:**
    - **Challenge:** Public perception and acceptance of biodiesel may be influenced by factors such as concerns about land use change, deforestation, and competition with food crops. Transparent communication and education are essential to address these concerns.
10. **Blending Limits and Compatibility:**
    - **Challenge:** The blending limits of biodiesel with conventional diesel may be restricted due to issues such as cold flow properties and stability. Engine modifications and infrastructure upgrades may be required to accommodate higher biodiesel blends.

Addressing these challenges requires a holistic approach involving advancements in technology, sustainable practices, policy support, and ongoing research and development. As the biodiesel industry continues to evolve, overcoming these challenges will contribute to the broader adoption of biodiesel as a sustainable and environmentally friendly alternative to conventional diesel.

38. Present a discussion about the evolution or development pathway of S.I engine.

The evolution of the Spark Ignition (S.I.) engine spans over a century, marked by significant advancements in technology, design, and efficiency. The development pathway of S.I. engines can be traced through various stages, each characterized by notable innovations and improvements. Here's a discussion on the evolution of the S.I. engine:

1. Early Combustion Engines (Late 19th Century):

- The roots of the S.I. engine can be traced back to the late 19th century with inventors like Nicolaus Otto and Étienne Lenoir. These early engines utilized a simple form of spark ignition through external flame ignition or hot-tube ignition.

2. Introduction of the Four-Stroke Cycle (Late 19th Century - Early 20th Century):

- Nicolaus Otto introduced the concept of the four-stroke cycle in the 1870s, which became the foundation for modern S.I. engines. This cycle includes intake, compression, power, and exhaust strokes, providing a more efficient and practical combustion process.

3. Development of Carburetion (Early 20th Century):

- The early 20th century saw the development of carburettors, which became integral to S.I. engines. Carburettors mixed air and fuel in precise proportions before entering the combustion chamber, improving the combustion efficiency.

4. Advancements in Ignition Systems (Early to Mid-20th Century):

- The early to mid-20th century witnessed advancements in ignition systems. Magneto ignition systems were replaced by battery-and-coil systems, leading to more reliable and consistent spark ignition.

5. Introduction of Leaded Gasoline (1920s - 1970s):

- Leaded gasoline was introduced to improve combustion stability and prevent engine knocking. However, concerns about environmental and health impacts led to the phase-out of leaded gasoline in the 1970s.

6. Turbocharging and Supercharging (Mid-20th Century):

- Turbocharging and supercharging technologies were introduced to increase engine power and efficiency. These technologies became especially prominent in high-performance and racing engines.

7. Era of Electronic Ignition (1970s Onward):

- The 1970s marked the shift from mechanical to electronic ignition systems, improving ignition timing control and overall engine performance. Electronic control modules (ECMs) became central to engine management systems.

8. Introduction of Fuel Injection (1970s - 1980s):

- The transition from carburettors to electronic fuel injection (EFI) systems in the late 20th century marked a significant leap in combustion control, fuel efficiency, and emissions reduction.

9. Advancements in Emission Control (1980s Onward):

- The late 20th century and beyond saw an increased focus on emissions control. Catalytic converters, oxygen sensors, and other technologies were integrated to meet stringent emission standards.

10. Development of Variable Valve Timing (VVT) and Variable Valve Lift (VVL) (Late 20th Century Onward):

11. Introduction of Direct Injection (2000s Onward):

12. Hybridization and Electrification (21st Century):

Future Trends and Challenges:

- **Downsizing and Turbocharging:** Engines are becoming smaller in displacement but are often turbocharged for improved power density and efficiency.
- **Advanced Combustion Strategies:** Ongoing research is focused on advanced combustion modes, such as Homogeneous Charge Compression Ignition (HCCI), to further improve efficiency.
- **Electrification:** The integration of hybrid and electric powertrains is expected to continue, with a gradual shift towards more electrified vehicles.
- **Advanced Materials:** The use of advanced materials, such as carbon fibre and high-strength alloys, is likely to increase for weight reduction and improved efficiency.
- **Autonomous Vehicles:** The evolution of SI engines is also influenced by the development of autonomous vehicles, where powertrain requirements may differ.
- **Alternative Fuels:** The exploration of alternative fuels, including biofuels, synthetic fuels, and hydrogen, is expected to play a role in the future of SI engines.

In summary, the evolution of the S.I. engine has been marked by a continuous quest for efficiency, performance, and environmental sustainability. Ongoing developments in combustion technologies, materials science, and electrification are shaping the future of internal combustion engines, ensuring their relevance in a rapidly changing automotive landscape.

9. What is a variable geometry turbocharger? Discuss its functioning with a schematic.

A Variable Geometry Turbocharger (VGT), also known as a Variable Nozzle Turbine (VNT) or Variable Turbine Geometry (VTG), is a type of turbocharger that incorporates adjustable vanes or nozzles in the turbine housing. This design allows the turbocharger to vary the geometry of the turbine housing based on operating conditions, optimizing performance across a wide range of engine speeds and loads.

Functioning of Variable Geometry Turbocharger:

The main components of a variable geometry turbocharger include the turbine housing, vanes/nozzles, actuator, and control system. Here's a breakdown of its functioning:

1. **Turbine Housing:**
   - The turbine housing contains the turbine wheel, which is connected to the compressor wheel by a common shaft. Exhaust gases from the engine flow through the turbine housing and cause the turbine wheel to spin.
2. **Vanes/Nozzles:**
   - The vanes or nozzles are positioned around the turbine wheel within the turbine housing. These vanes can be adjusted to change the flow of exhaust gases onto the turbine wheel.
3. **Actuator:**
   - The actuator is responsible for adjusting the position of the vanes. It responds to signals from the engine control unit (ECU) based on parameters such as engine speed, load, and throttle position.

4. **Control System:**
    - The ECU monitors various engine parameters and determines the optimal position of the vanes to achieve the desired boost pressure. The control system sends signals to the actuator to adjust the vanes accordingly.

Functioning Steps:

1. **Low Engine Speeds (Low Exhaust Gas Flow):**
    - At low engine speeds, when exhaust gas flow is limited, the vanes are adjusted to narrow the nozzle opening. This increases the exhaust gas velocity, maintaining turbine wheel speed and preventing turbo lag.
2. **Medium Engine Speeds (Moderate Exhaust Gas Flow):**
    - As engine speed increases, the vanes are adjusted to a more neutral position, optimizing the balance between exhaust gas flow and turbine wheel speed. This allows for efficient power delivery without excessive turbo lag.
3. **High Engine Speeds (High Exhaust Gas Flow):**
    - At high engine speeds and loads, the vanes open to widen the nozzle. This reduces exhaust gas velocity and prevents over-speeding of the turbine wheel. It also helps in providing the required boost pressure for high-power output.

Schematic of Variable Geometry Turbocharger:

1. **Compressor Wheel:** Draws in and compresses air for combustion.
2. **Shaft:** Connects the compressor wheel and turbine wheel.
3. **Turbine Wheel:** Driven by exhaust gases, powers the compressor wheel.
4. **Variable Geometry Vanes/Nozzles:** Adjustable components in the turbine housing that control the flow of exhaust gases onto the turbine wheel.
5. **Actuator:** Adjusts the position of the vanes based on signals from the engine control unit.
6. **Engine Control Unit (ECU):** Monitors engine parameters and controls the position of the vanes to optimize turbocharger performance.

The ability to vary the geometry of the turbine housing in a variable geometry turbocharger allows for improved responsiveness, increased efficiency, and better performance across a broad range of engine operating conditions. This technology has become common in modern diesel engines and is increasingly being used in certain gasoline engines to achieve better fuel efficiency and lower emissions.

40. What are NOx adsorbers? Briefly discuss about its characteristics.

NOx adsorbers, also known as NOx storage catalysts or NOx traps, are emission control devices used in the exhaust systems of internal combustion engines, particularly in gasoline and lean-burn diesel engines. They are designed to reduce nitrogen oxides (NOx) emissions, which are major contributors to air pollution and smog formation. NOx adsorbers are a key component in meeting stringent emission standards.

Characteristics of NOx Adsorbers:

1. **Functionality:**
    - NOx adsorbers primarily target nitrogen oxides, including nitric oxide (NO) and nitrogen dioxide (NO2), present in the exhaust gases. They operate by temporarily

adsorbing NOx during lean-burn conditions and releasing it for subsequent reduction under rich conditions.

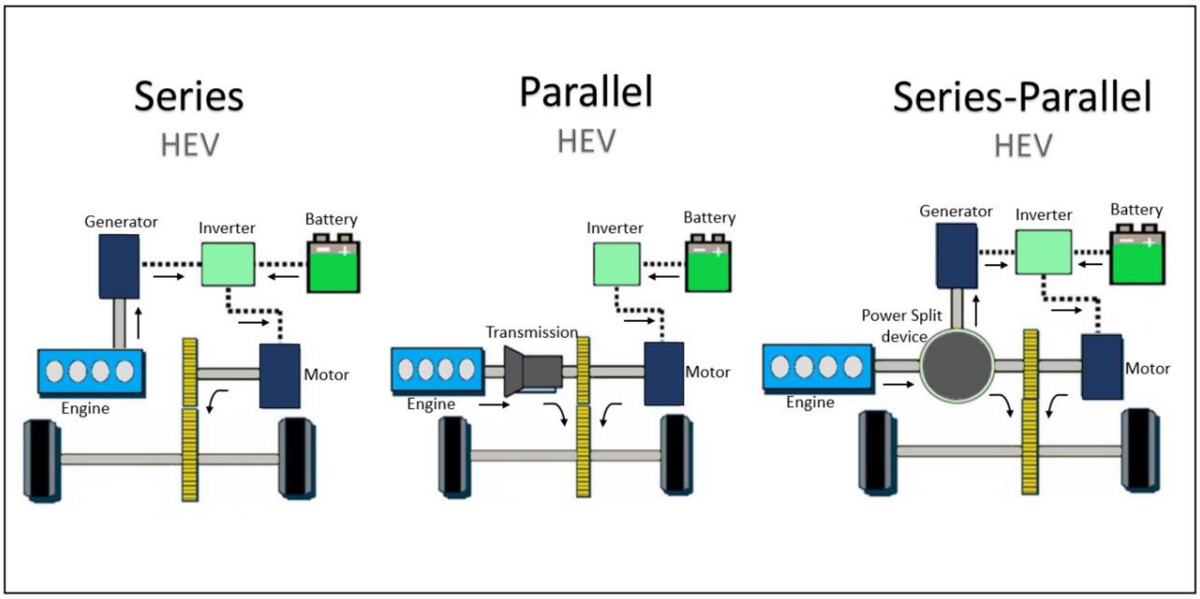
2. **Composition:**
   - The core of a NOx adsorber is typically composed of a high-surface-area material, such as a zeolite or a mixed metal oxide, coated onto a ceramic or metallic substrate. Precious metals like platinum and palladium are often incorporated to enhance catalytic activity.
3. **Operation under Lean Conditions:**
   - During lean-burn operation (excess air), NOx adsorbers trap NOx on their surface through a chemical reaction, forming compounds like nitrates. This occurs at higher temperatures, typically above 200°C.
4. **Switch to Rich Conditions:**
   - To regenerate the NOx adsorber, the engine control system periodically switches the air-fuel mixture to rich conditions (excess fuel). This triggers a reduction reaction, releasing the stored NOx and converting it into nitrogen and other harmless gases.
5. **Temperature Sensitivity:**
   - NOx adsorption and regeneration are temperature-sensitive processes. Effective operation usually requires the exhaust gases to reach a certain temperature for optimal performance.
6. **Catalytic Coating:**
   - The catalytic coating, often containing precious metals, facilitates the reduction of stored NOx during regeneration. These catalysts play a crucial role in promoting efficient and rapid reactions.
7. **Integration with Other Emission Control Devices:**
   - NOx adsorbers are often integrated with other emission control devices, such as diesel oxidation catalysts (DOCs) and particulate filters, in a system commonly known as a three-way catalyst or aftertreatment system.
8. **Challenges:**
   - NOx adsorbers face challenges related to durability, as the repeated adsorption and regeneration cycles can lead to degradation over time. Sulphur in the fuel can also negatively impact their performance.
9. **Application in Diesel Engines:**
   - While NOx adsorbers are commonly associated with gasoline engines, similar technology has been adapted for certain diesel engines, especially in passenger cars and light-duty vehicles, to comply with strict emission standards.
10. **Emission Standards Compliance:**
    - NOx adsorbers play a significant role in helping vehicles meet stringent emission standards such as Euro 6 for gasoline engines and other regional standards for diesel engines.

NOx adsorbers are part of a broader strategy to control harmful emissions from internal combustion engines, contributing to cleaner air and environmental protection. While effective, ongoing research focuses on improving their durability, expanding their operating temperature range, and addressing challenges associated with real-world driving conditions.

41. With a neat sketch explain the working of a series and parallel hybrid electric vehicle.

Series Hybrid Electric Vehicle (SHEV):

A Series Hybrid Electric Vehicle (SHEV) has an internal combustion engine (ICE) that acts as a generator to produce electricity. The generated electricity is then used to power an electric motor, which propels the vehicle. Here's a sketch and explanation of the working of a Series Hybrid Electric Vehicle:



1. **Internal Combustion Engine (ICE):**
   - The ICE in a series hybrid does not directly drive the wheels. Instead, it functions as a generator to produce electricity.
2. **Generator:**
   - The generator is connected to the ICE and converts mechanical energy from the engine into electrical energy.
3. **Electric Motor:**
   - The electric motor is responsible for driving the wheels of the vehicle. It is powered by the electricity generated by the generator.
4. **Battery Pack:**
   - The battery pack stores electrical energy, providing additional power to the electric motor when needed, such as during acceleration.
5. **Power Electronics:**
   - Power electronics control the flow of electricity between the generator, battery pack, and electric motor. They optimize the overall efficiency of the system.
6. **Vehicle Control Unit (VCU):**
   - The VCU manages the overall operation of the hybrid system, determining when to use the internal combustion engine, when to charge the battery, and when to rely on electric power.

Working:

- During low-speed operation or when the vehicle requires less power, the electric motor draws power from the battery pack.
- When the battery charge is low or additional power is needed (during acceleration or high-speed driving), the internal combustion engine starts and operates as a generator, producing electricity to power the electric motor and charge the battery.

Parallel Hybrid Electric Vehicle (PHEV):

In a Parallel Hybrid Electric Vehicle (PHEV), both the internal combustion engine (ICE) and the electric motor are mechanically connected to the wheels. This allows the vehicle to be propelled by either the ICE, the electric motor, or a combination of both. Here's a sketch and explanation of the working of a Parallel Hybrid Electric Vehicle:

1. **Internal Combustion Engine (ICE):**
    - The ICE in a parallel hybrid directly drives the wheels and can work independently of the electric motor.
2. **Electric Motor:**
    - The electric motor is also connected to the wheels and can provide additional power or operate independently.
3. **Transmission:**
    - The transmission system allows the power from the internal combustion engine and the electric motor to be blended and transmitted to the wheels.
4. **Clutch or Coupler:**
    - A clutch or coupler is used to engage or disengage the internal combustion engine from the transmission, allowing for different driving modes.
5. **Battery Pack:**
    - Similar to a series hybrid, a parallel hybrid has a battery pack to store electrical energy for use by the electric motor.
6. **Power Electronics:**
    - Power electronics control the flow of electricity between the battery, electric motor, and internal combustion engine.
7. **Vehicle Control Unit (VCU):**
    - The VCU manages the operation of the hybrid system, deciding when to use the internal combustion engine, when to use the electric motor, or when to combine their power for optimal efficiency.

Working:

- During low-speed operation or when cruising at constant speeds, the vehicle can be powered solely by the electric motor, drawing energy from the battery.
- When additional power is needed, such as during acceleration or high-speed driving, the internal combustion engine engages, and both the engine and electric motor work together to propel the vehicle.
- The system can also operate in a mode where only the internal combustion engine drives the vehicle, with the electric motor disengaged.

Both series and parallel hybrid configurations offer advantages in terms of fuel efficiency, reduced emissions, and improved overall performance, catering to different driving conditions and requirements.

42. Scientifically justify “the best fuel for a S.I engine is the worst one for C.I engine”.

The statement "the best fuel for a Spark Ignition (S.I.) engine is the worst one for a Compression Ignition (C.I.) engine" can be scientifically justified based on the fundamental differences in the combustion processes of these two types of engines.

Spark Ignition (S.I.) Engine:

1. **Combustion Process:**
    - S.I. engines operate on the Otto cycle, where the air-fuel mixture is ignited by a spark plug. The combustion process is initiated and controlled by a spark, and the air-fuel mixture is typically homogeneous.
2. **Fuel Characteristics:**
    - S.I. engines perform well with fuels that have good volatility, higher octane ratings, and can easily form a homogeneous mixture with air. Gasoline is the primary fuel for S.I. engines due to these characteristics.
3. **Ignition Temperature:**
    - Gasoline has a lower auto ignition temperature, which means it requires an external spark to initiate combustion. This property aligns with the spark ignition process used in S.I. engines.

Compression Ignition (C.I.) Engine:

1. **Combustion Process:**
    - C.I. engines operate on the Diesel cycle, where air is compressed and fuel is injected directly into the hot, compressed air. Combustion is initiated by the high temperature and pressure within the cylinder.
2. **Fuel Characteristics:**
    - C.I. engines require fuels with higher ignition temperatures and good self-ignition characteristics. Diesel fuel is commonly used in C.I. engines because it has a higher auto ignition temperature and can ignite under the high pressure and temperature conditions of compression.
3. **Compression Ratio:**
    - C.I. engines typically have higher compression ratios compared to S.I. engines. This higher compression generates the conditions necessary for spontaneous ignition of the fuel.

Justification:

1. **Octane Number vs. Cetane Number:**
    - Gasoline used in S.I. engines has a higher octane number, indicating its resistance to knocking. On the other hand, diesel fuel used in C.I. engines has a higher cetane number, indicating its ability to ignite under compression.
2. **Flammability and Auto ignition:**
    - Gasoline is more volatile and prone to premature ignition (knocking) under high pressure, making it unsuitable for the compression ignition process in C.I. engines. Diesel fuel, with its higher auto ignition temperature, is better suited to the high-pressure and high-temperature conditions inside a C.I. engine.

3. **Combustion Characteristics:**

- The combustion characteristics required for optimal performance in S.I. and C.I. engines are inherently different due to their distinct combustion processes. Fuels that are well-suited for one type of engine may not perform optimally in the other.

In summary, the statement is justified based on the specific requirements of each engine type. Gasoline, with its lower auto ignition temperature and good volatility, is well-suited for the spark ignition process in S.I. engines. On the other hand, diesel fuel, with its higher auto ignition temperature, is better suited for the compression ignition process in C.I. engines. The optimal fuel choice depends on the combustion characteristics and operational principles of each engine type.