INTERNAL COMBUSTION ENGINES

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Lecture # 5 (Engine Fuels and Knock)

SI ENGINE FUELS

1. The main fuel for SI engines is gasoline, which is a mixture of many hydrocarbon components and is manufactured from crude petroleum.

2. Crude oil is made up almost entirely of carbon and hydrogen with some traces of other species. It varies from 83% to 87% carbon and 11% to 14% hydrogen by weight.

3. The crude oil mixture that is taken from the ground is separated into component products by cracking and/or distillation

4. The component mixture of the refining process is used for many products, including

automobile gasoline
diesel fuel
aircraft gasoline
jet fuel
home heating fuel
industrial heating fuel
natural gas
lubrication oil
asphalt
alcohol
rubber
paint
plastics
explosives

SELF-IGNITION AND KNOCK

1. If the temperature of an air–fuel mixture is raised high enough, the mixture will self ignite without the need of a spark plug or another external igniter.
2. The temperature above which this occurs is called the self-ignition temperature (SIT).
3. This is the basic principle of ignition in a compression ignition engine. The compression ratio is high enough that the temperature rises above SIT during the compression stroke. Self ignition then occurs when fuel is injected into the combustion chamber.
4. Self-ignition (or preignition, or autoignition) is not desirable in an SI engine, where a spark plug is used to ignite the air–fuel at the proper time in the cycle.
5. The compression ratios of gasoline-fueled SI engines are limited to about 11:1 to avoid self-ignition.

SELF-IGNITION AND KNOCK

1. When self-ignition does occur in an SI engine, higher than desirable pressure pulses are generated.

2. These high-pressure pulses can cause damage to the engine and quite often are in the audible frequency range.

3. This phenomenon is often called knock or ping.

4. If the mixture is heated to a temperature above SIT, self-ignition will occur after a short time delay called ignition delay (ID).

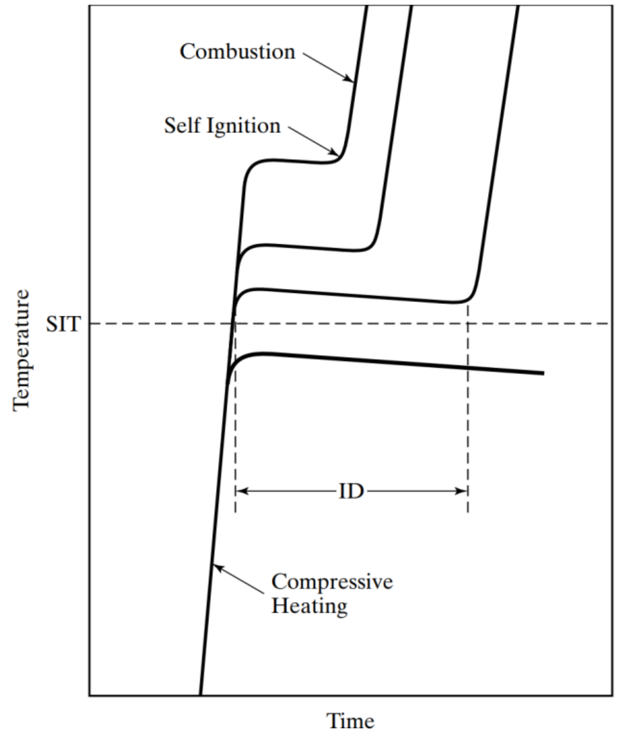


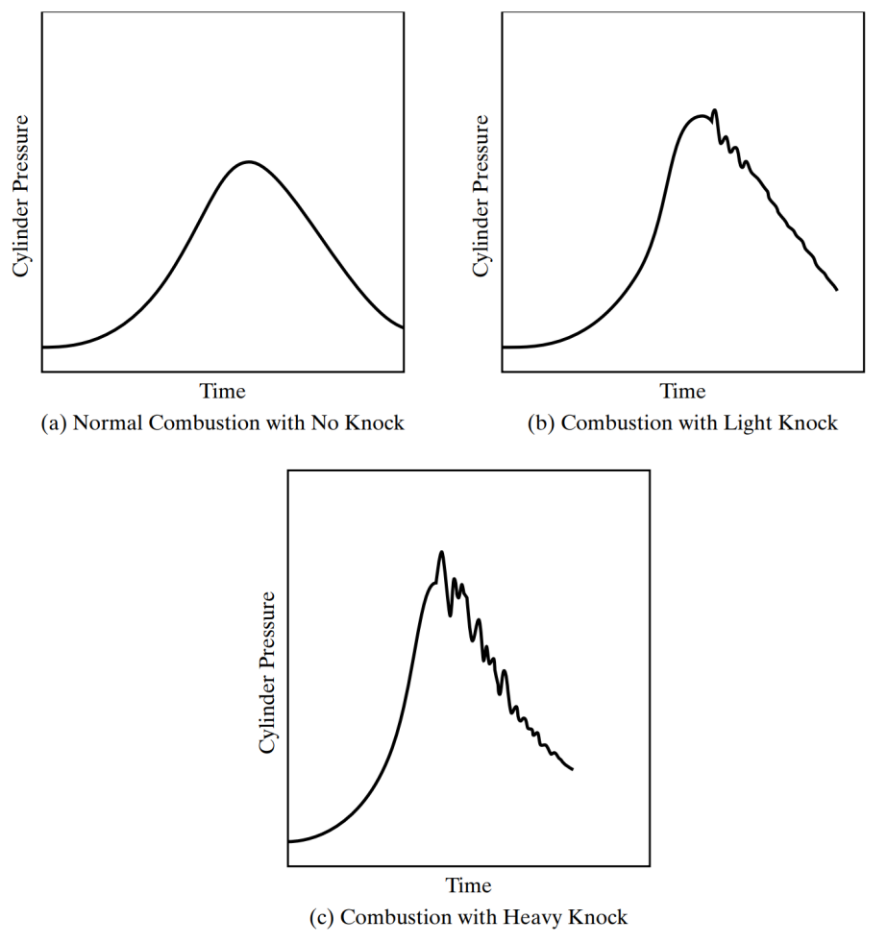
FIGURE 3

Self-ignition characteristics of fuels. If the temperature of a fuel is raised above the self-ignition temperature (SIT), the fuel will spontaneously ignite after a short ignition delay (ID) time. The higher above SIT the fuel is heated, the shorter will be the ID. Ignition delay is generally on the order of thousandths of a second. Adapted from [126].

SELF-IGNITION AND KNOCK

With no self-ignition, the pressure force on the piston follows a smooth curve, resulting in smooth engine operation.

When self-ignition does occur, pressure forces on the piston are not smooth and engine knock occurs.



Cylinder pressure as a function of time in a typical SI engine combustion chamber showing **(a)** normal combustion, **(b)** combustion with light knock, and **(c)** combustion with heavy knock. Adapted from [33].

SELF-IGNITION AND KNOCK

End gas near the end of the combustion process is where self-ignition and knock occur.

By limiting the compression ratio in an SI engine, the temperature at the end of the compression stroke where combustion starts is limited.

The reduced temperature at the start of combustion then reduces the temperature throughout the entire combustion process, and knock is avoided.

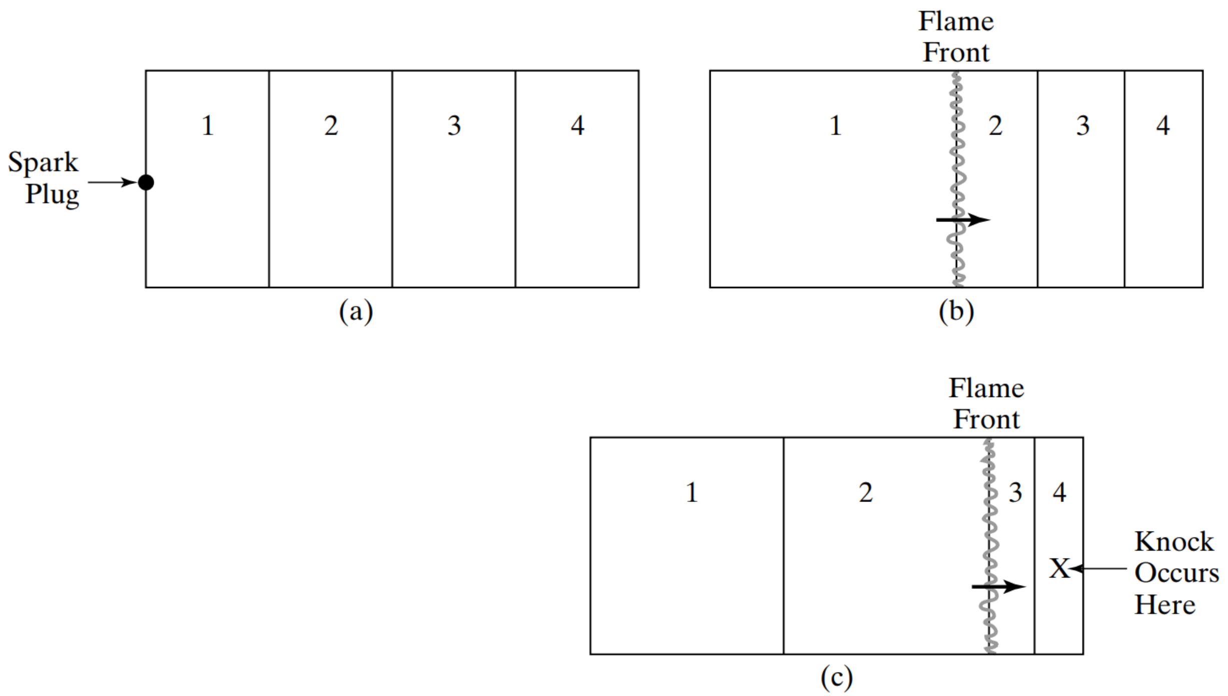


FIGURE 5

SI engine combustion chamber schematically visualized as a long hollow cylinder with the spark plug located at the left end. **(a)** Mass of air–fuel is equally distributed as spark plug is fired to start combustion. **(b)** As flame front moves across chamber, unburned mixture in front of flame is compressed into smaller volume. **(c)** Flame front continues to compress unburned mixture into smaller volume, which increases its temperature and pressure. If compression raises temperature of end gas above SIT, self-ignition and knock can occur.

OCTANE NUMBER AND ENGINE KNOCK

1. The fuel property that describes how well a fuel will or will not self-ignite is called the octane number or just octane.

2. This is a numerical scale generated by comparing the self-ignition characteristics of the fuel to that of standard fuels in a specific test engine at specific operating conditions.

3. The two standard reference fuels used are isooctane (2,2,4 trimethylpentane), which is given the octane number (ON) of 100, and n-heptane, which is given the ON of 0.

4. The higher the octane number of a fuel, the less likely it will self-ignite.

5. Engines with low compression ratios can use fuels with lower octane numbers, but high-compression engines must use high-octane fuel to avoid self-ignition and knock.

OCTANE NUMBER AND ENGINE KNOCK

There are a number of gasoline additives that are used to raise octane number (e.g., hydrotreated aliphatics and methylcyclopentadienyl manganese tricarbonyl (MMT)). For many years, the standard additive was tetraethyl lead TEL, $(C_2H_5)_4Pb$. A few milliliters of TEL in several liters of gasoline could raise the ON several points in a very predictable manner (Fig. 6).

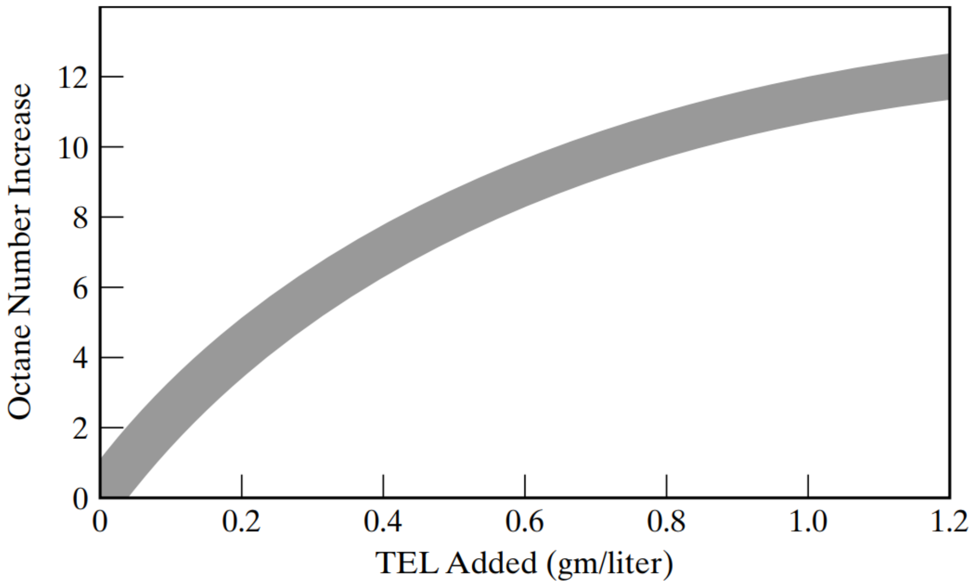


FIGURE 6

Octane number increase as a function of TEL added to gasoline; varies somewhat with gasoline blend. Octane number is MON, RON, or AKI. Adapted from [58].

DIESEL FUEL

1. Diesel fuel (diesel oil, fuel oil) is obtainable over a large range of molecular weights and physical properties.

For convenience, diesel fuels for IC engines can be divided into two extreme categories. Light diesel fuel has a molecular weight of about 170 and can be approximated by the chemical formula $C_{12.3}H_{22.2}$ (see Table 2 of the Appendix). Heavy diesel fuel has a molecular weight of about 200 and can be approximated as $C_{14.6}H_{24.8}$.

Heavy Fuel: Cheaper, More Viscous
Light Fuel: Expensive, Less viscous, good for cold weather

One environmental problem that occurs with the combustion of diesel fuel is caused by the sulfur contained in the fuel. The sulfur ends up in the exhaust products where it combines with water vapor to form acid.

CETANE NUMBER

1. In a compression ignition engine, self-ignition of the air–fuel mixture is a necessity.
2. The correct fuel must be chosen which will self-ignite at the precise proper time in the engine cycle.
3. It is therefore necessary to have knowledge and control of the ignition delay time of the fuel.
4. The property that quantifies this is called the cetane number.
5. The larger the cetane number, the shorter is the ID and the quicker the fuel will self-ignite.
6. A low cetane number means the fuel will have a long ID.

CETANE NUMBER

1. Like octane number rating, cetane numbers are established by comparing the test fuel to two standard reference fuels.

   1. The fuel component n-cetane (hexadecane), is given the cetane number value of 100,
   2. While heptamethylnonane (HMN), is given the value of 15.

2. The normal cetane number range for vehicle fuel is about 40 to 60.

3. For a given engine injection timing and rate, if the cetane number of the fuel is low, the ignition delay will be too long.

4. When this occurs, more fuel than desirable will be injected into the cylinder before the first fuel particles ignite, causing a very large, fast pressure rise at the start of combustion.

5. This results in low thermal efficiency and a rough-running engine.

CETANE NUMBER (CN)

1. Long ignition delay of fuels with cetane numbers below 40 results in a very rich fuel–air mixture in the cylinder when ignition finally occurs.

2. This results in unacceptable levels of exhaust smoke, and these fuels are illegal by many emission laws.

3. If the CN of the fuel is high, combustion will start too soon in the cycle.

4. Pressure will rise before TDC, and more work will be required in the compression stroke.

5. The cetane number of a fuel can be raised with certain additives which include nitrates and nitrites.

ALTERNATE FUELS

1. Crude Oil and Diesel are finite – 21st Century (Will become scarce and costly)

2. Emission problems of gasoline engines

3. Some Alternative Fuels
    1. Natural gas
    2. Alcohol
    3. Methanol
    4. Ethanol
    5. Hydrogen
    6. Propane–Butane
    7. Reformulated Gasoline
    8. Coal–Water Slurry

Read: Section 6 – Chapter 4

END OF THE LECTURE