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Theoretical Study of the effects of Ignition Delay on the Performance of DI Diesel Engine

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Abstract

The ignition delay in a diesel engine is defined as the time (or crank angle) interval between the start of injection and the start of combustion. The start of injection is usually taken as the time when the injector needle lifts off its seal. The start of combustion is more difficult to determine precisely. Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid fuel is released. The physical processes are: the atomization of the liquid fuel jet, the vaporization of the fuel droplets, the mixing of fuel vapor with air. The chemical processes are the pre-combustion reactions of the fuel, air, residual gas mixture which lead to auto ignition. These processes are affected by engine design and operating variables.

Key Words: **Ignition Delay; Exhaust Emission; Injection Timing; Compression Ratio**

Introduction

Performance and environmental requirements of Diesel engines have steadily increased over the last thirty years, which in turn has required an increase in the sophistication of employed control strategies. Advances in model based control over this period have been one of the keys in meeting the demands placed on modern combustion technologies.[2] One of the main objectives for improving the combustion process of conventional internal combustion engines is to find effective ways to reduce exhaust emissions,without making serious modification on their mechanical structure.[1] Ignition delay is an important variable in diesel cobustion because it has a strong correlation to the amount of fuel that is burned in the premixed combustion phase.longer ignition delay allow more fuel to be injected and preparedfor combustion. When ignition finally occurs, it involves more fuel and produces a violent autoignition,sometimes called diesel knock. In addition to being a source of undesirable noise, high level of premixed combustion contribute to high nitric oxide (NO) levels in the exhaust.

Model Description

During the compression phase, the cylinder charge is compressed to a high pressure and temperature as TDC is approached. Prior to reaching TDC, a small amount of diesel fuel is injected into the combustion chamber, which atomizes and evaporates forming a conical jet penetrating inside the unburned zone. As the jet penetrates, homogeneous mixture is entrained into the jet and mixes with the evaporated diesel fuel. The quantity of the mixture entrained inside the conical jets is estimated from the value of its volume change. The boundary of this jet defines the second zone; the burning zone is shown in fig1 [3-5]

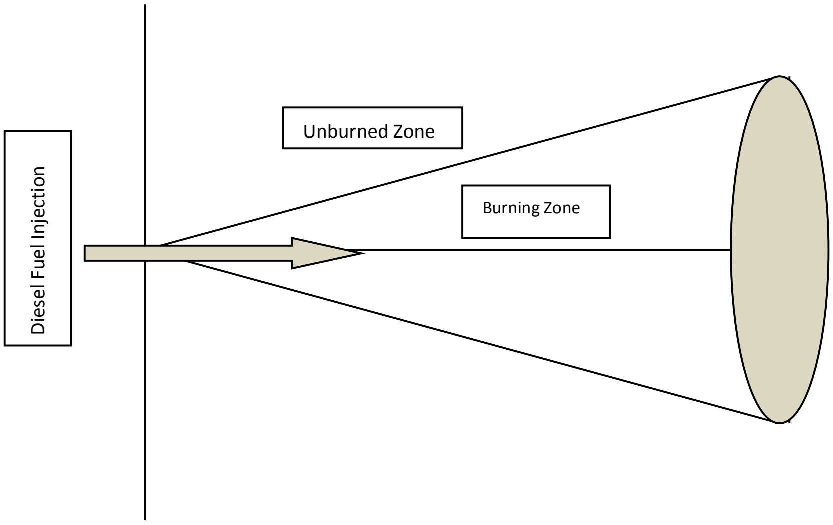

Fig. 1 Definition of the burning zone before the initiation of combustion

Inside the burning zone takes place the process of combustion, and for this reason the main constituents of the zone are combustion products, unburned evaporated diesel fuel, unburned gaseous fuel and air that have not yet participated in combustion. The ignition of the charge inside the burning zone commences after the auto-ignition of the evaporated diesel fuel. The time interval between the start of diesel fuel injection and initiation of combustion define the ignition delay period. During this period, the temperature of the burning zone and the pressure of the cylinder charge increase significantly as the piston approaches TDC. Simultaneously, the mass of evaporated diesel fuel increases forming a combustible mixture with the one entrained inside the burning zone. Thus, after the initiation of combustion, two zones exist (unburned and burning one) separated by a flame front, which is assumed to have the shape of a cone covering the outer area of the jet. [6][1]

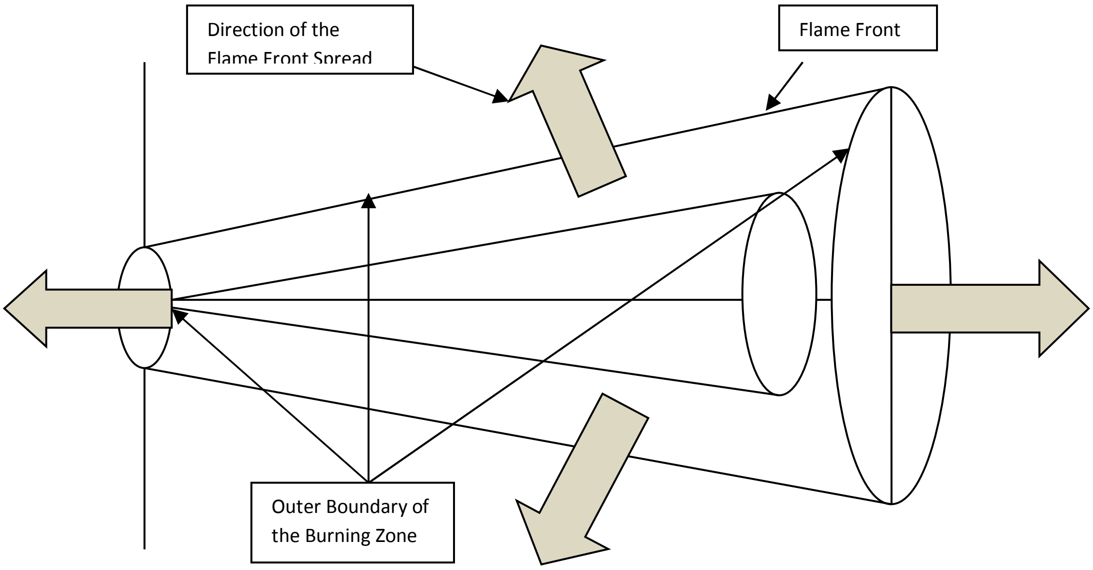

Fig 2 Definition of the burning zone after the initiation of combustion

Obtaining the desired operational engine parameters like break mean effective pressure (BMEP), overall engine efficiency, or environmental indexes (exhaust emissions, noise),essentially depends on the combustion rate, and previously on formation of flammable mixture. It particularly comes true in case of a direct injection engine. As far as a quality of combustible mixture is concerned, both the appropriate fuel atomization and fuel mixing with the air charge is important here, just as the precise metering of fuel amount injected in every cycle, and providing equal amounts of fuel for each cylinder of the engine. In direct injection engines, a fuel injection system has the main responsibility for creating proper fuel air mixture, which can be characterized by an appropriate macro- and microstructure. Air swirl has a minor importance here, or even can make the whole process worsened due to cylinder wall wetting possibility. On the whole, the mere combustion process is sensitive to many factors which may be classified into four groups (Wajand, 1988):

- Physical and chemical properties of fuel, e.g. fractional and chemical composition, cetane/octane number, temperature of fuel (auto)ignition, etc;
- Structural properties of the engine, e.g. combustion chamber shape, main engine

dimensions, compression ratio, materials used, etc;

- Operation and regulation conditions of the engine: rotational speed of the crankshaft, engine load, ignition (or start of injection) timing, etc;
- Fuel injection system layout that generates fuel delivery process with the specific fuel spray parameters; it influences directly combustion rate, as is discussed above.

These considerations indicate that the fuel injection parameters are important factors affecting combustion process and consequently the engine parameters, what has been also verified by experimental studies (Kuszewski & Szlachta, 2002; Zabłocki, 1976). A process of fuel injection into the engine cylinder might be described by parameters related to injection rate and spray characteristics. The set of injection rate parameters consists of:

- Start of injection (SOI) timing referred to crankshaft position angle [deg],
- Injection duration referred to crankshaft rotation angle [deg],
- Mean flow rate of the fuel in a whole injection duration [mm3/deg],
- Actual fuel injection rate (instantaneous fuel flow velocity) [mm3/deg],
- Maximum fuel flow velocity [mm3/deg].

Presently, the pressure-accumulative fuel systems with electronically controlled injectors are widely used, e.g. Diesel common rail (CR) one. In such systems, the injection rate essentially depends on two parameters: the shape of electrical signals in the injector and the hydraulic mechanical characteristic of the injector. The change of pressure in the fuel storage is so small and affects fuel injection rate so little that it can be neglected in simulation works on engine operation. The fuel spray characteristics may be described by the following parameters:

- Spray tip velocity and penetration,
- Spray tip angle,
- Fuel atomization quality expressed by mean diameter of droplets and its dispersion,
- Distribution of fuel mass along and across the spray,
- Equivalent mean droplets size: linear, areal, volumetric, areal-volumetric (sauter).

Preparation of flammable mixture in a direct injection engine becomes involved not only with strategy of fuel delivery, but also with areal distribution of fuel in the cylinder space. It should be noticed that a lot of factors influencing the fuel injection rate also plays an important role in fuel atomization quality, resulting in fuel mixing with air inside the cylinder.

Factors affecting the ignition delay

Combustion duration can be defined as [7]:

$$T_d = \frac{2.64}{(P^{0.8}\emptyset^{0.2})} exp\left[\frac{(1650 - 20CN)}{RT}\right]$$

Many design and operating factors affect the delay period. The important ones are:

1. Compression ratio
2. Engine speed
3. Output
4. Atomization of fuel and duration of injection
5. Injection of timing
6. Quality of the fuel
7. Intake temperature
8. Intake Pressure

Compression Ratio

The increase in the compression temperature of the air with increase in compression ratio evaluated at the end of the compression stroke. The increase in the compression temperature as well as the decrease in the minimum auto ignition temperature decreases the delay period. The peak pressure during the combustion process is only marginally affected by the compression ratio (because delay period is shorter with higher compression ratio and hence the pressure rise is lower). One of the practical disadvantages of using a very high compression ratio is that the mechanical efficiency tends to decrease due to increase in weight of the reciprocating parts. Therefore, in practice the engine designers always try to use a lower compression ratio which helps in easy cold starting and light load running at high speeds.

Engine Speed

The delay period could be given either in terms of absolute time (in millisecond) or in terms of crank angle degrees.

With increase in engine speed, the loss of heat during compression decreases, resulting in the rise of both the temperature and pressure of the compressed air thus reducing the delay period in milliseconds. However, in degree of crank travel the delay period increases as the engine operates at a higher rpm. The fuel pump is geared to the engine, and hence the amount of fuel injected during the delay period depends on crank degrees and not on absolute time. Hence, at high speeds, there will be more fuel present in the cylinder to take part in the second stage of uncontrolled combustion resulting in high rate of pressure rise.

Output

With an increase in engine output the air fuel ratio decreases, operating temperatures increases and hence delay period decreases. The rate of pressure rise is unaffected but the peak pressure reached may be high.

Atomization and Duration of Injection

Higher fuel injection pressures increases the degree of atomization. The fineness of atomization reduces ignition delay, due to higher surface volume ratio. Smaller droplet size will have low depth of penetration due to less momentum of the droplet and less velocity relative to air from where it has to find oxygen after vaporization. Because of this air utilization factor will be reduced due to fuel spray path being shorter. Also with smaller droplets, the aggregate area of inflammation will increase after ignition, resulting in higher pressure rise during the second stage of combustion. Thus, lower injection pressure, giving larger droplet size may give lower pressure rise during the second stage of combustion and probably smoother running. Hence, an optimum group means diameter of the droplet size should be attempt as a compromise. Also the fuel delivery law i.e. change in the quantity of fuel supplied with the crank angle travel will affect the rates of pressure rise during second stage of combustion though ignition delay remains unaffected by the same.

Injection Timing

The pressure and temperature at the beginning of injection are lower for higher ignition advance, the delay period increases with increase in injection advance.

Quality of Fuel

Self-ignition temperature is the most important property of the fuel which affects the delay period. A lower self-ignition temperature results in a lower delay period. Also, fuels with higher cetane number give lower delay period and smoother engine operation. Other properties of the fuel which affect the delay period are volatility, latent heat, viscosity and surface tension.

Intake Temperature

Increase in intake temperature increases the compressed air temperature resulting in reduced delay period. However, preheating of the charge for this purpose would be undesirable because it would reduce the density of air reducing the volumetric efficiency and power output.

Intake Pressure

Increase in intake pressure or supercharging reduces the auto ignition temperature and hence reduces the delay period. The peak pressure will be higher since the compression pressure will increase with intake temperature

Conclusion

When fuel is injected in to the air, a portion will be mixed beyond its lean flammability limit before it has a chance to burn. This fuel is likely to be emitted as unburned hydrocarbon, particularly at light loads where the probability that the over mixed fuel and air will encounter a high temperature rich zone is low. When ignition delays are long, there is more time for fuel to be over mixed and hydrocarbon emissions will increase.

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