Internal Combustion Engines – ME422

COMBUSTION in CI-ENGINES

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Internal Combustion Engines

Combustion in CI Engines

- Introduction
- Diesel combustion process, combustion chambers, fuel sprays
- Phases of diesel combustion
- Factors affecting ignition delay

Introduction

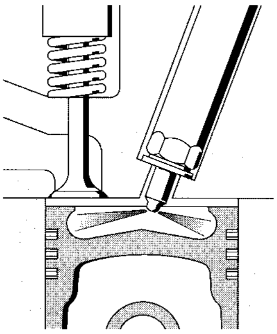
In diesel engines, only air is send into the combustion chamber during induction. This air is compressed during the compression stroke and towards the end of compression stroke, fuel is injected by the fuel-injection system into the cylinder - just before the desired start of combustion.

Liquid fuel is injected at high velocities as one or more jets through small orifices or nozzles in the injector tip. The fuel atomizes into small droplets and penetrates into the combustion chamber - the droplets vaporize and mix with with high-temperature and high-pressure cylinder air.

Since the air temperature and pressure are above the fuel's ignition point, spontaneous ignition of portions of already mixed fuel and air occurs after a delay period of a few crank angle degrees.

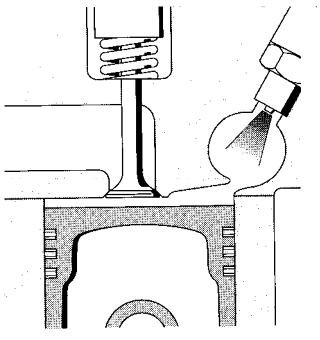
The cylinder pressure increases as combustion of fuel-air mixture occurs.

Diesel Combustion Chambers



Direct injection diesel engine

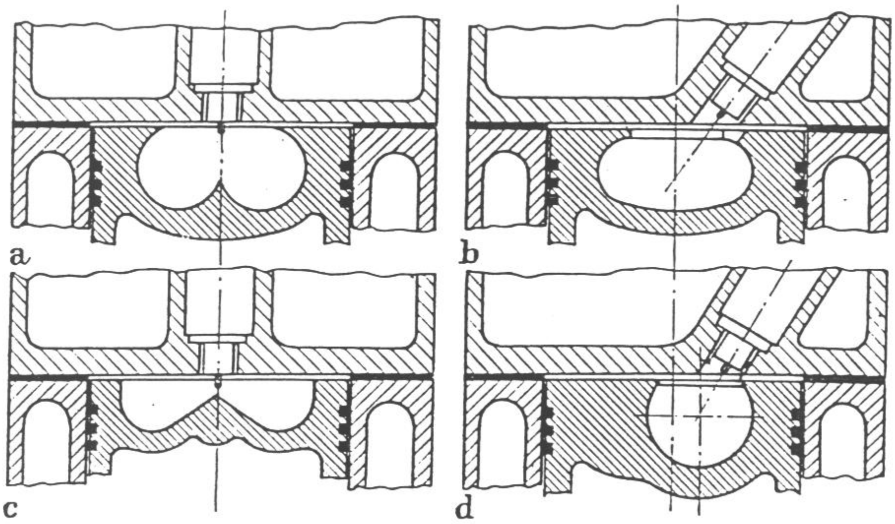
(Direkt püskürtmeli diesel)



In-Direct injection diesel engine

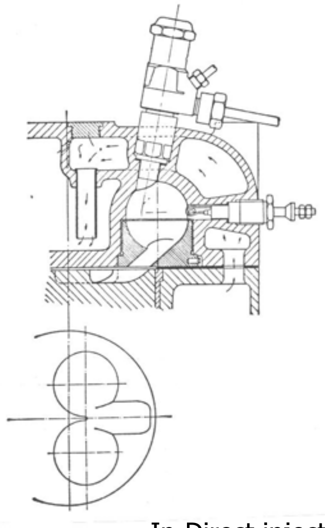
(Bölünmüş yanma odalı diesel)

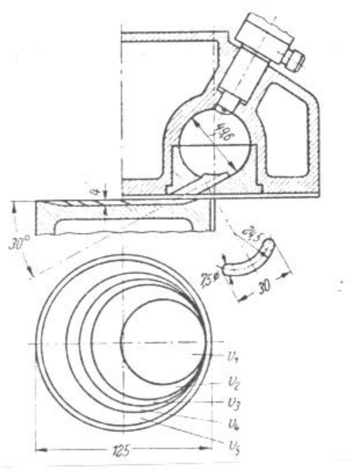
Diesel Combustion Chambers



Direct injection diesel engine

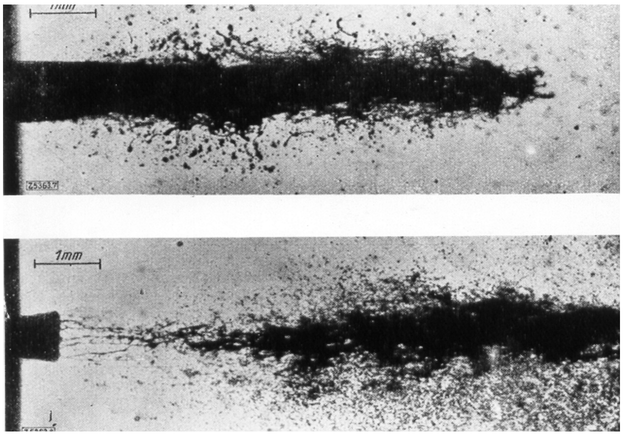
Diesel Combustion Chambers



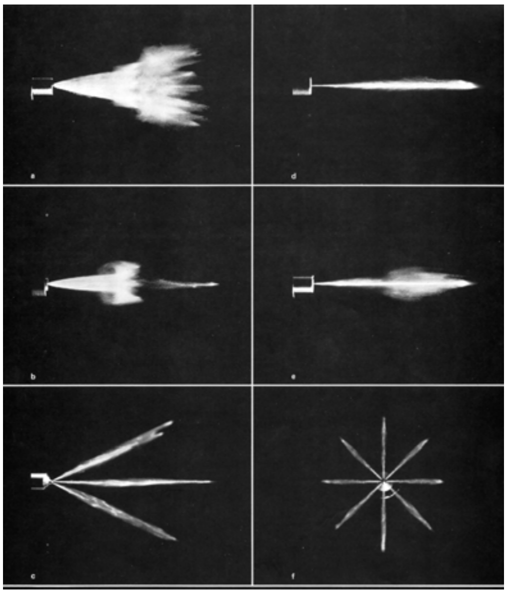


In-Direct injection diesel engine

Liquid Atomization at High Speeds



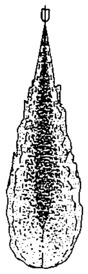
Diesel Fuel Sprays



Spray Structure

In difusion flames, combustion is controlled by the mixing rate of the fuel and air.

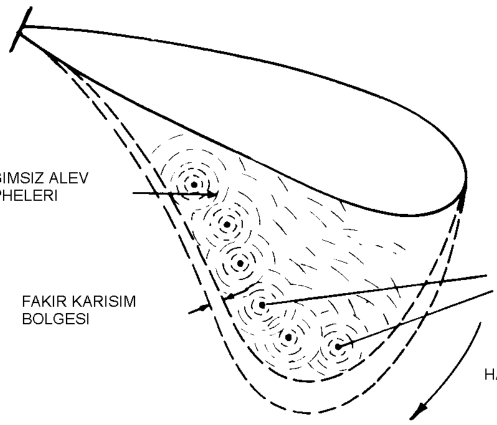
The local conditions in the combustion chamber such as the air-fuel ratio, temperature, pressure control the ignition of the fuel and the combustion process. Heat and mass transfer in the combustion chamber and the fluid flow (air flow) also effects this process.



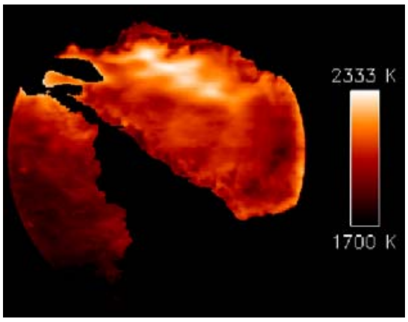
Spray structure,

- core
- breakup length
- spray tip penetration

Fuel Sprays



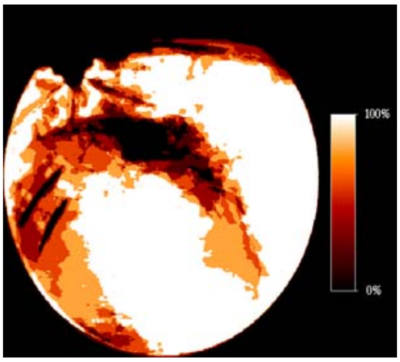
Fuel Sprays

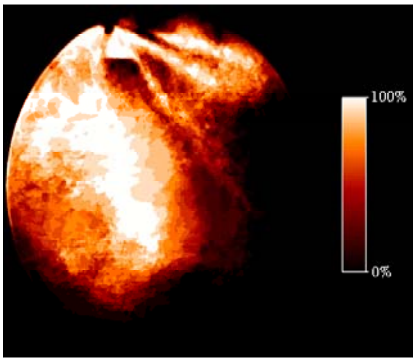


Fuel spray

Temperature distribution

Fuel Sprays

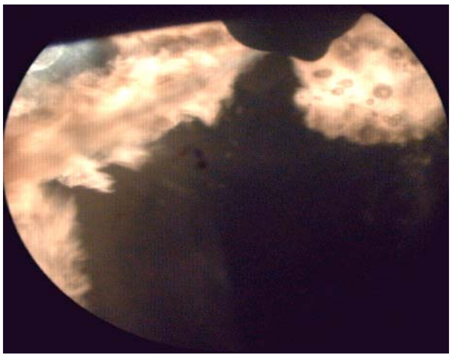


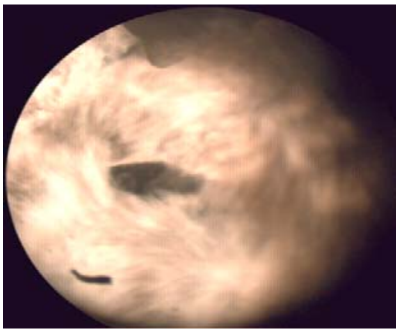


4-pictures overlapped

16-pistures overlapped

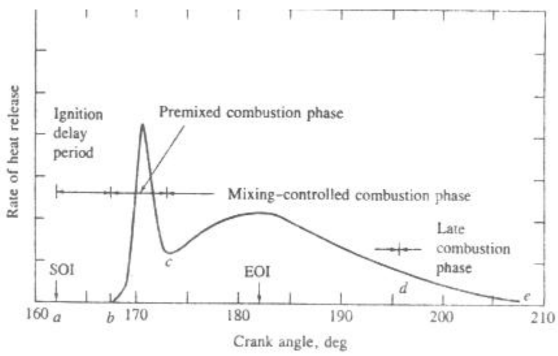
Fuel Sprays





Combustion in Diesel Engines

Ignition delay period
Premixed combustion phase
Mixing-controlled combustion phase
Late combustion phase



Ignition Delay Period

The period between the start of fuel injection into the combustion chamber and the start of combustion is termed as ignition delay period.

The start of combustion is determined from the change in slope on the p ~ α diagram, or from heat release analysis of the p(α) data, or from luminosity detector in expermental conditions.

Start of injection can be determined by a needle-lift indicator to record the time when injector needle lifts off its seat.

Start of combustion is more difficult to determine precisely. It is best identified from the change in slope of heat release rate, determined from cylinder pressure data.

In DI engines ignition is well defined, in IDI engines ignition point is harder to identify.

Ignition Delay Period

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 ; atomization of the liquid fuel jet, vaporization of the fuel droplets, mixing of the fuel vapour with air.

The chemical processes are the precombustion reactions of the fuel, air and residual gas mixture which lead to autoignition.

Chemical delay is more effective for the duration of the ignition delay period.

Ignition Delay Period

Ignition delay period is in the range of

0.6 to 3 ms for low-compression ratio DI diesel engines,

0.4 to 1 ms for high-compression ratio, turbocharged DI diesel engines,

0.6 to 1.5 ms for IDI diesel engines

over a wide range of operating conditions. (Measured data)

Premixed Combustion Phase

Combustion of the fuel which has mixed with air within flammability limits during ignition delay period, occurs rapidly in a few crank angle degrees - high heat release characteristics in this phase.

If the amount of fuel collected in the combustion chamber during the ignition delay is much - high heat release rate results in a rapid pressure rise which causes the diesel knock.

For fuels with low cetane number, with long ignition delay, ignition occurs late in the expansion stroke - incomplete combustion, reduced power output, poor fuel conversion efficiency.

If the pressure gradient is in the range 0.4 - 0.5 MPa/^{o} CA, engine operation is not smooth and diesel knock starts.
This value should be in the range 0.2 to 0.3 MPa/^{o} CA for smooth operation (max allowable value is 1.0 MPa/^{o} CA).

Mixing Controlled Combustion Phase

Once the fuel and air which is pre-mixed during the ignition delay is consumed, the burning rate (heat release rate) is controlled by the rate at which mixture becomes available for burning.

The rate of burning in this phase is mainly controlled by the mixing process of fuel vapour and air.
Liquid fuel atomization, vaporization, preflame chemical reactions also effect the rate of heat release.

Heat release rate sometimes reaches a second peak (which is lower in magnitude) and then decreases as the phase progresses.

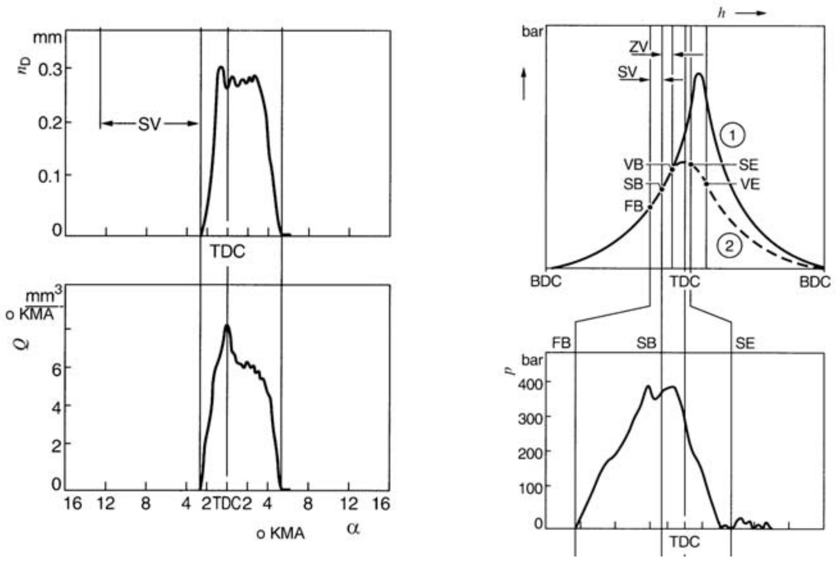
Generally it is desirable to have the combustion process near the TDC for low particulate (soot) emissions and high performance (and efficiency).

Late Combustion Phase

Heat release rate continues at a lower rate into the expansion stroke - there are several reasons for this : a small fraction of the fuel may not yet burnt, a fraction of the energy is present in soot and fuel-rich combustion products and can be released.

The cylinder charge is nonuniform and mixing during this phase promotes more complete combustion and less dissociated product gases. Kinetics is slower.

Diesel Combustion Phases



Physical Factors Affecting Ignition Delay

Injection timing

At normal operating conditions min ignition delay (ID) occurs with start of injection at 10 to 15 ^{O}CA BTDC

Cylinder temperature and pressure drops if injection is earlier or later (high at first but decrease as delay proceeds)

Injection quantity (load)

Reducing engine load changes AFR, cools down the engine, reduces wall temperatures, reduces residual gas temperatures and inc ID

Droplet size, injection velocity and rate

Ignition quality within practical limits do not have significant effect on ID

Inc in injection p produces only modest dec in ID

Injector nozzle diameter effects droplet size but has no significant effect on ID

Physical Factors Affecting Ignition Delay

Intake air temperature and pressure

- Reducing intake air T and p inc ID
- Strong dependence of ID on charge temperature below 1000 K – above this value effect of intake air conditions is not significant.

Engine speed

- Inc in engine speed increases the air motion and turbulence, reduces ID time slightly (in ms), in terms of CA degrees ID increases almost linearly.
- A change in engine speed, changes “temp~time” and “pressure~time” relationships.

Physical Factors Affecting Ignition Delay

Combustion chamber design

- Spray impingement on the walls effect fuel evaporation and ID
- Inc in compression ratio, inc p and T and reduces ID
- Reducing stroke volume, inc surface area to volume ratio, inc engine cooling and inc ID

Swirl rate

- Change evap rate and air-fuel mixing - under normal operating conditions the effect is small.
- At start-up (low engine speed and temperature) more important, high rate of evaporation and mixing is obtained by swirl

Oxygen concentration

- Residual gases reduce O2 concentration and reducing oxygen concentration increases ID

Effect of Fuel Properties on Ignition Delay

Cetane number

Both physical and chemical properties of the fuel is important.

Ignition quality of the fuel is defined by its cetane number.

Straight chain parafinic compounds (normal alkanes) have highest ignition quality, which improves as the chain length increases. Aromatic compounds, alcohols have poor ignition quality.

Cetane number can be increased by ignition-accelerating additives like organic peroxides, nitrates, nitrites and various sulphur compounds. Most important (commercially) is alkyl nitrates – about 0.5% by vol in a distillate fuel inc CN by 10.

Normal diesel fuel has CN of 40 to 55 (high speed 50 – 60, low speed 25 – 45)