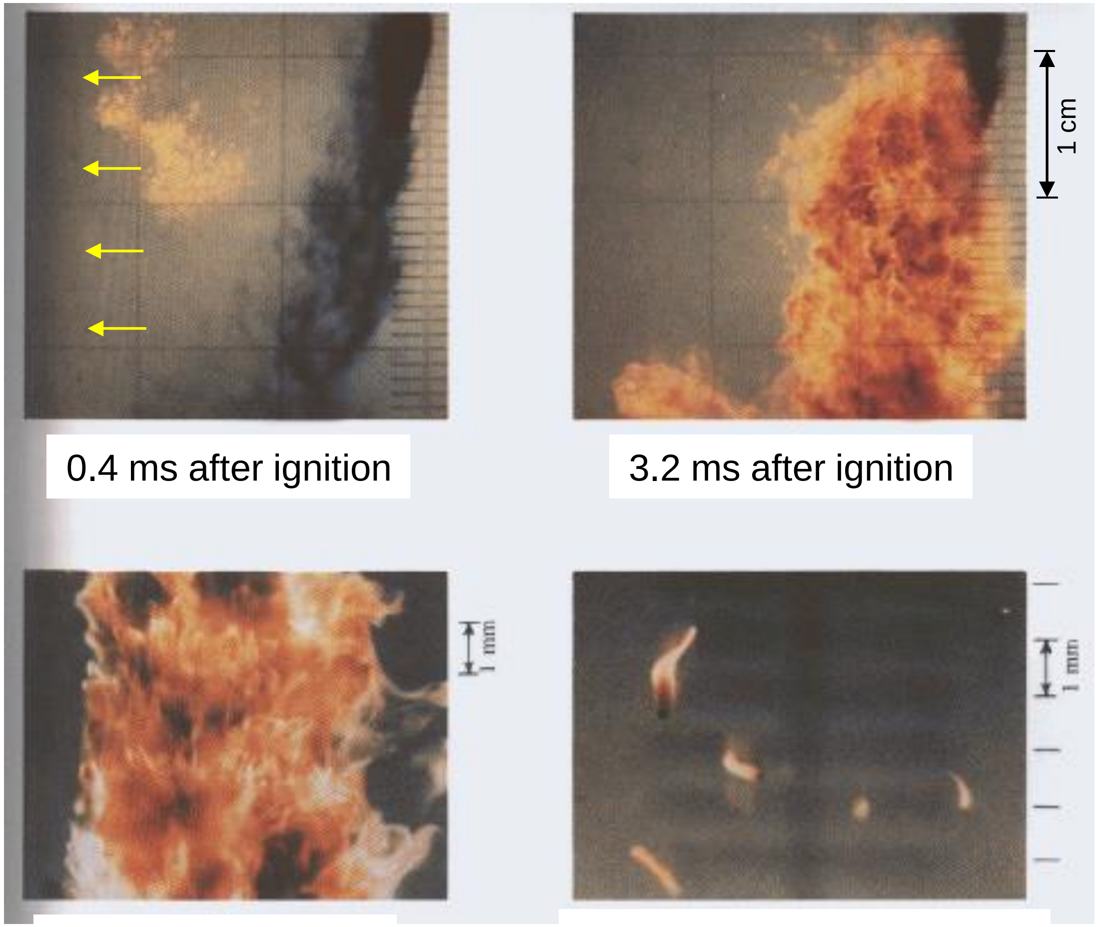
Combustion in CI Engine

In a CI engine the fuel is sprayed directly into the cylinder and the fuel-air mixture ignites spontaneously.

These photos are taken in a RCM under CI engine conditions with swirl air flow



0.4 ms after ignition

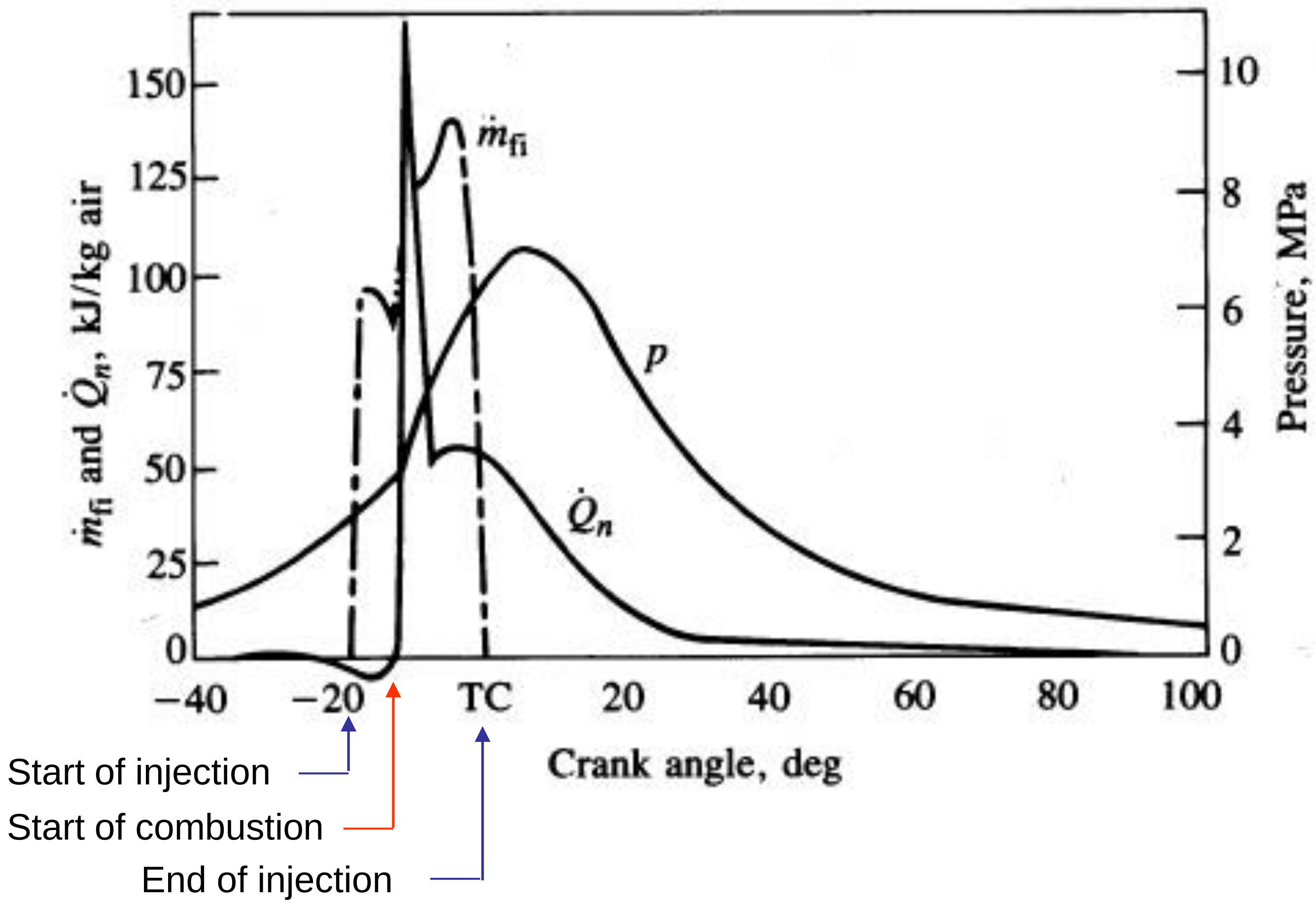
3.2 ms after ignition

3.2 ms after ignition

Late in combustion process

In Cylinder Measurements

This graph shows the fuel injection flow rate, net heat release rate and cylinder pressure for a direct injection CI engine.



Combustion in CI Engine

The combustion process proceeds by the following stages:

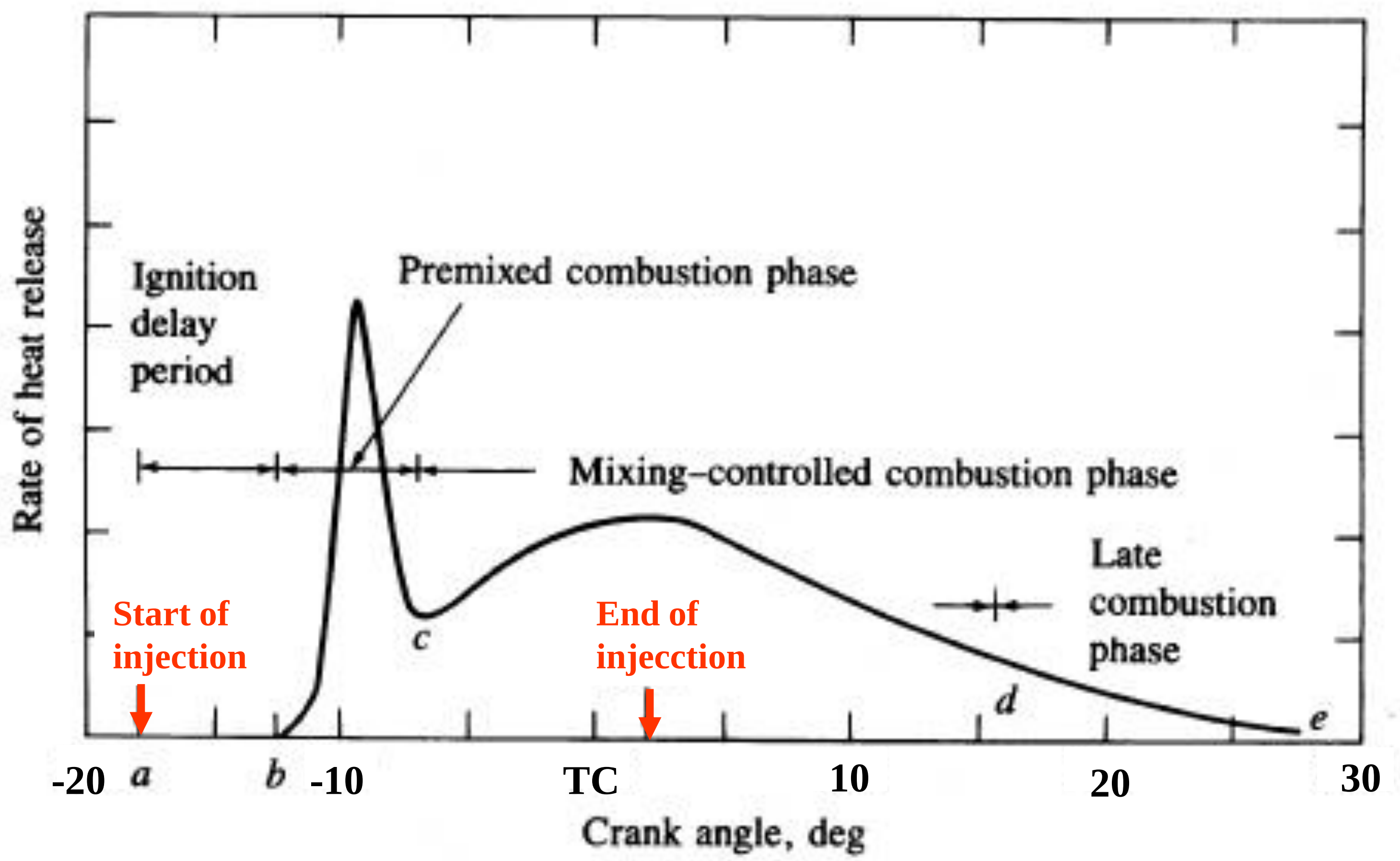
Ignition delay (ab) - fuel is injected directly into the cylinder towards the end of the compression stroke. The liquid fuel atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with the high-temperature high-pressure air.

Premixed combustion phase (bc) – combustion of the fuel which has mixed with the air to within the flammability limits (air at high-temperature and high-pressure) during the ignition delay period occurs rapidly in a few crank angles.

Mixing controlled combustion phase (cd) – after premixed gas consumed, the burning rate is controlled by the rate at which mixture becomes available for burning. The rate of burning is controlled in this phase primarily by the fuel-air mixing process.

Late combustion phase (de) – heat release may proceed at a lower rate well into the expansion stroke (no additional fuel injected during this phase). Combustion of any unburned liquid fuel and soot is responsible for this.

Four Stages of Combustion in CI Engines



CI Engine Types

Two basic categories of CI engines:

i) Direct-injection – have a single open combustion chamber into which fuel is injected directly

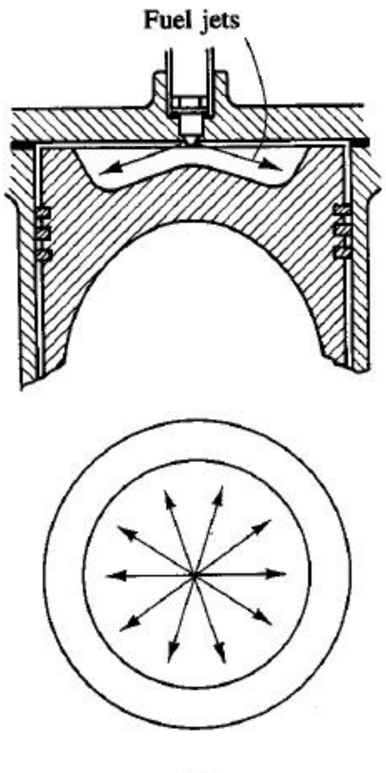
ii) Indirect-injection – chamber is divided into two regions and the fuel is injected into the “prechamber” which is connected to the main chamber via a nozzle, or one or more orifices.

- For very-large engines (stationary power generation) which operate at low engine speeds the time available for mixing is long so a direct injection quiescent chamber type is used (open or shallow bowl in piston).

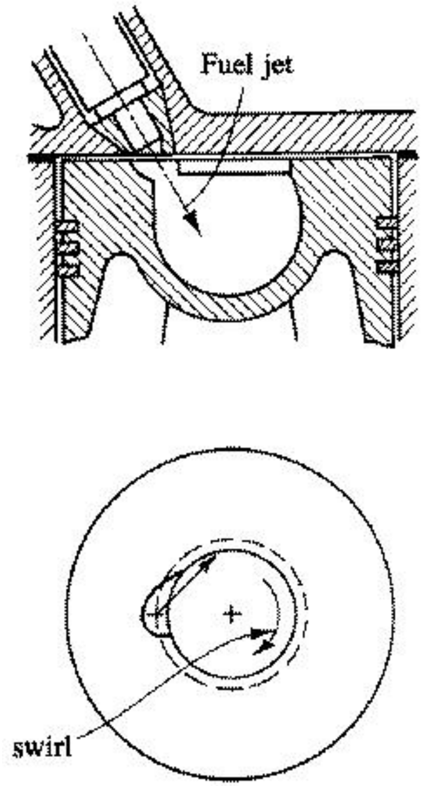
- As engine size decreases and engine speed increases, increasing amounts of swirl are used to achieve fuel-air mixing (deep bowl in piston)

- For small high-speed engines used in automobiles chamber swirl is not sufficient, indirect injection is used where high swirl or turbulence is generated in the pre-chamber during compression and products/fuel blowdown and mix with main chamber air.

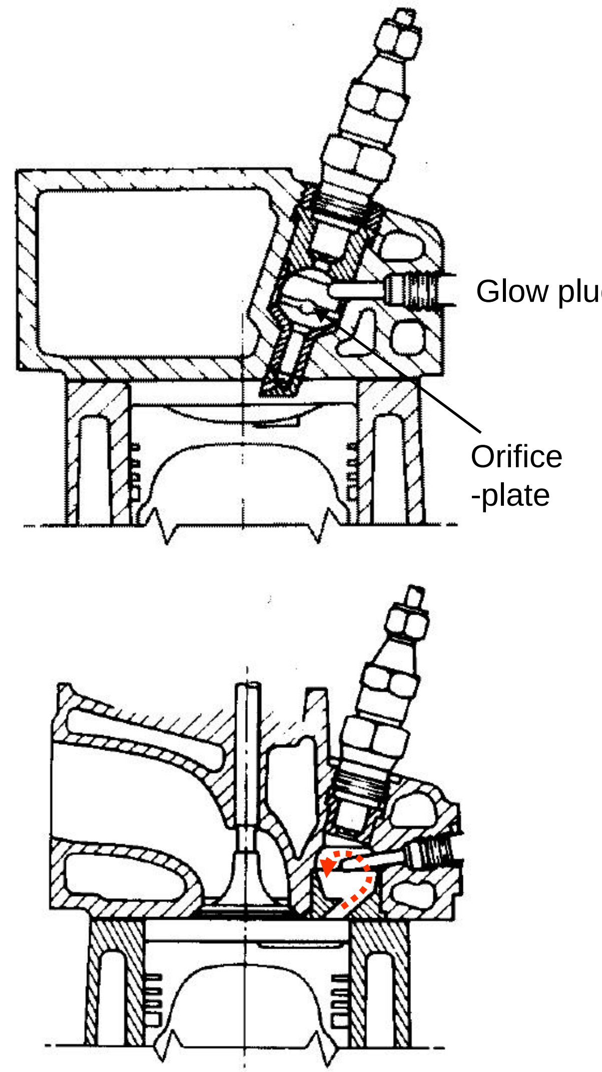
Types of CI Engines



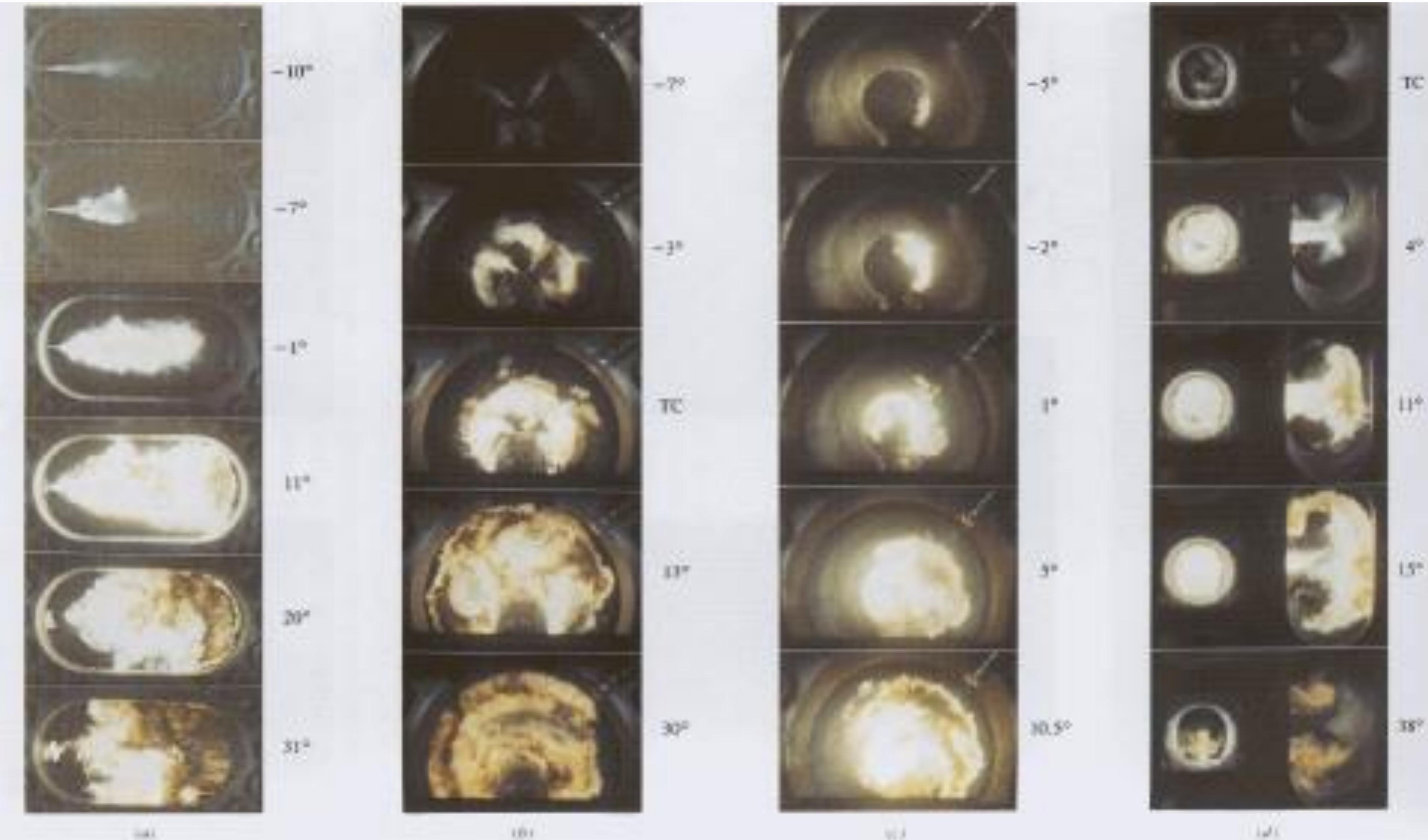
Direct injection:
quiescent chamber



Direct injection:
swirl in chamber



Indirect injection: turbulent and swirl pre-chamber



Direct Injection
quiescent chamber

Direct Injection
multi-hole nozzle
swirl in chamber

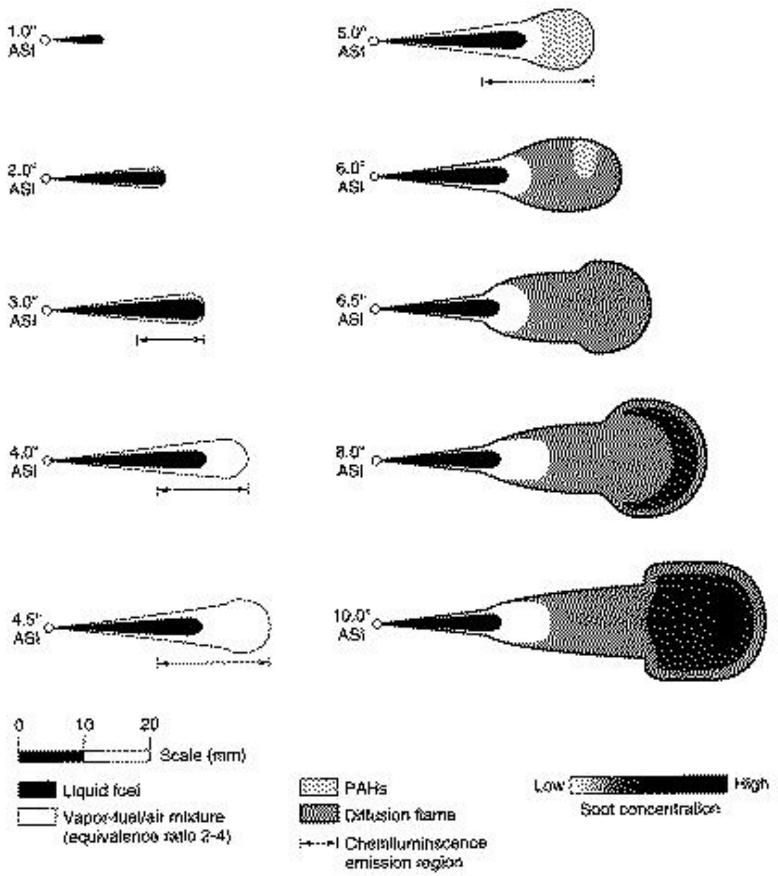
Direct Injection
single-hole nozzle
swirl in chamber

Indirect injection
swirl pre-chamber

Combustion Characteristic

Combustion occurs throughout the chamber over a range of equivalence ratios dictated by the fuel-air mixing before and during the combustion phase.

In general most of the combustion occurs under very rich conditions within the head of the jet, this produces a considerable amount of solid carbon (soot).



Ignition Delay

Ignition delay is defined as the time (or crank angle interval) from when the fuel injection starts to the onset of combustion.

Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid is released.

Physical processes are fuel spray atomization, evaporation and mixing of fuel vapour with cylinder air.

Good atomization requires high fuel-injection pressure, small injector hole diam., optimum fuel viscosity, high cylinder pressure (large divergence angle).

Rate of vaporization of the fuel droplets depends on droplet diameter, velocity, fuel volatility, pressure and temperature of the air.

Chemical processes similar to that described for autoignition phenomenon in premixed fuel-air, only more complex since **heterogeneous reactions** (reactions occurring on the liquid fuel drop surface) also occur.

Fuel Ignition Quality

The ignition characteristics of the fuel affect the ignition delay.

The ignition quality of a fuel is defined by its **cetane number** CN.

For *low* cetane fuels the ignition delay is long and most of the fuel is injected before autoignition and rapidly burns, under extreme cases this produces an audible knocking sound referred to as “diesel knock”.

For *high* cetane fuels the ignition delay is short and very little fuel is injected before autoignition, the heat release rate is controlled by the rate of fuel injection and fuel-air mixing – smoother engine operation.

Cetane Number

The method used to determine the ignition quality in terms of CN is analogous to that used for determining the antiknock quality using the ON.

The cetane number scale is defined by blends of two pure hydrocarbon reference fuels.

By definition, isocetane (heptamethylnonane, HMN) has a cetane number of 15 and cetane (n-hexadecane, $C_{16}H_{34}$) has a value of 100.

In the original procedures α-methylnaphtalene ($C_{11}H_{10}$) with a cetane number of zero represented the bottom of the scale. This has since been replaced by HMN which is a more stable compound.

The higher the CN the better the ignition quality, i.e., shorter ignition delay.

The cetane number is given by:

$$\text{CN} = (\%\ \textit{hexadecane}) + 0.15\ (\%\ \text{HMN})$$

Cetane Number Measurement

The method developed to measure CN uses a standardized single-cylinder engine with variable compression ratio

The operating condition is:

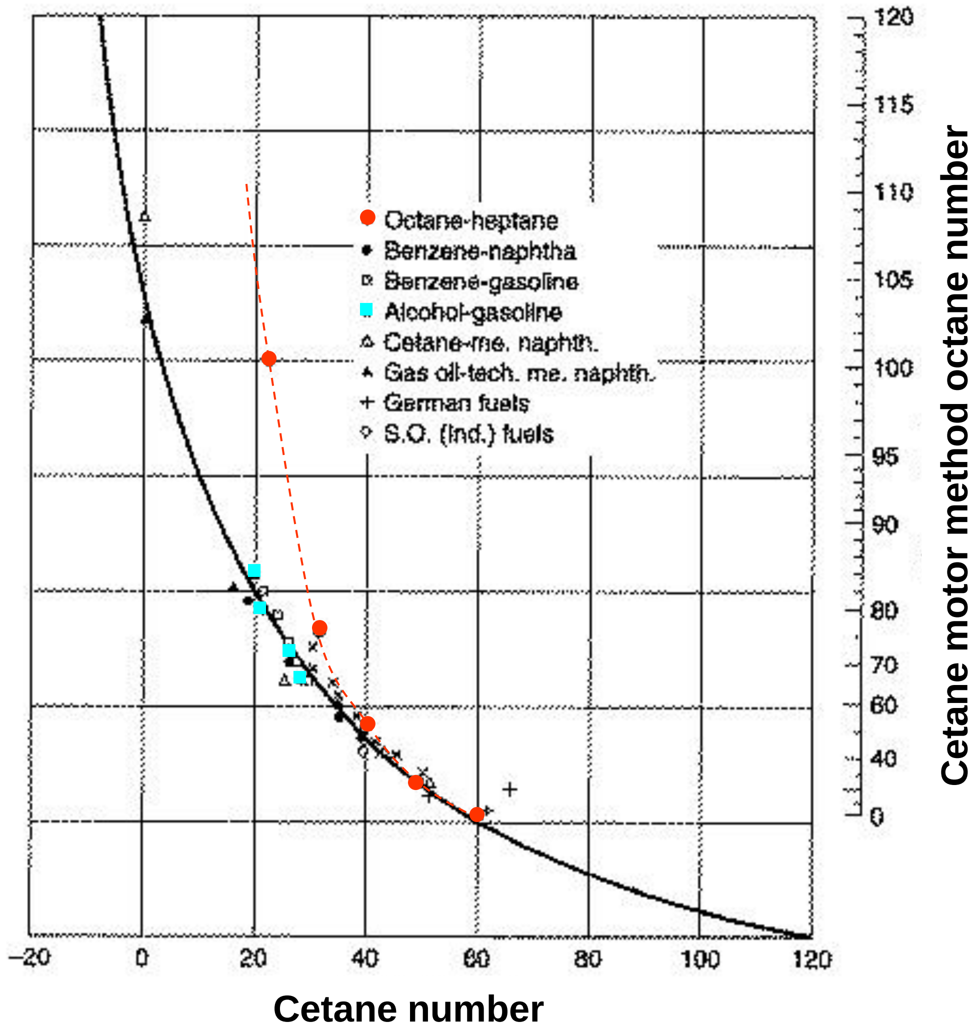
Inlet temperature (^oC)	65.6
Speed (rpm)	900
Spark advance (^{o}BTC)	13
Coolant temperature (^oC)	100
Injection pressure (MPa)	10.3

With the engine running at these conditions on the test fuel, the compression ratio is varied until combustion starts at TC, ignition delay period of 13^o.

The above procedure is repeated using blends of cetane and HMN. The blend that gives a 13^o ignition delay with the same compression ratio is used to calculate the test fuel cetane number.

Cetane vs Octane Number

The octane number and cetane number of a fuel are inversely correlated.



Gasoline is a poor diesel fuel and vice versa.

Factors Affecting Ignition Delay

<u>Injection timing</u> – At normal engine conditions the minimum delay occurs with the start of injection at about 10-15 BTC.

The increase in the delay time with earlier or later injection timing occurs because of the air temperature and pressure during the delay period.

<u>Injection quantity</u> – For a CI engine the air is not throttled so the load is varied by changing the amount of fuel injected.

Increasing the load (bmep) increases the residual gas and wall temperature which results in a higher charge temperature at injection which translates to a decrease in the ignition delay.

<u>Intake air temperature and pressure</u> – an increase in ether will result in a decrease in the ignition delay, an increase in the compression ratio has the same effect.