Introduction to Combustion in Diesel Engines

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Lecture Outline

- Diesel Engine Working Principle
- Difference between Gasoline and Diesel engine
- Diffusion Combustion
- Sprays
- Emissions (The Diesel Dilemma)
- New strategies and technolgies



Working Principle: 4-stroke

1. Induction

Pure air is drawn into the cylinder

2. Compression

The air is compressed to high temperature and pressure

3. Power Stroke

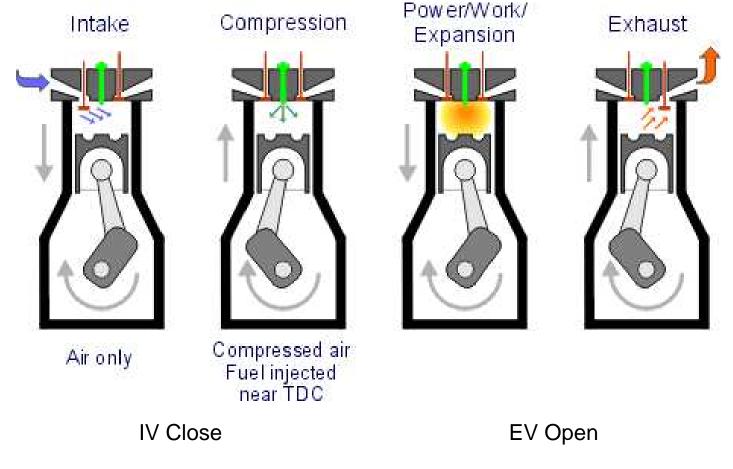
Around TDC fuel is injected, which self-ignites and burns, further increasing pressure and therby forcing the piston down.

4. Exhaust

The hot gas is released to the surrounding

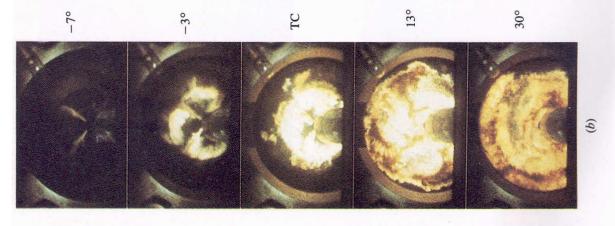


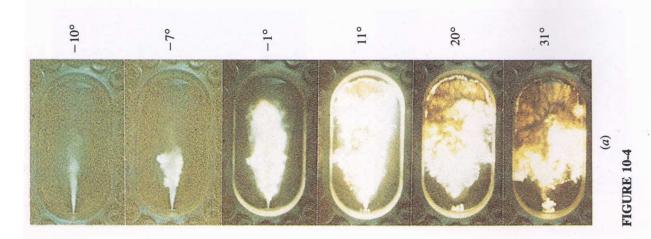
Working Principle: 4-stroke





Diesel Spray Combustion

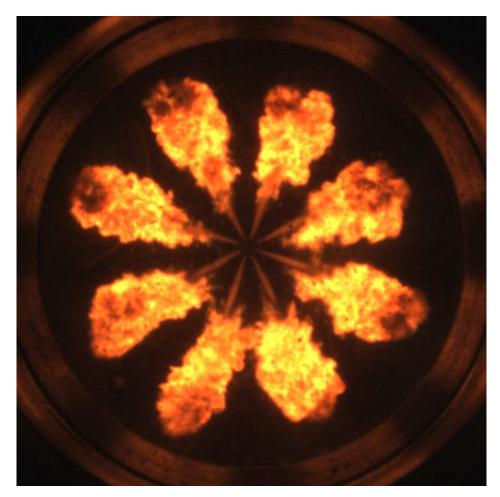




Conditions: T=1000K, p=100 bar



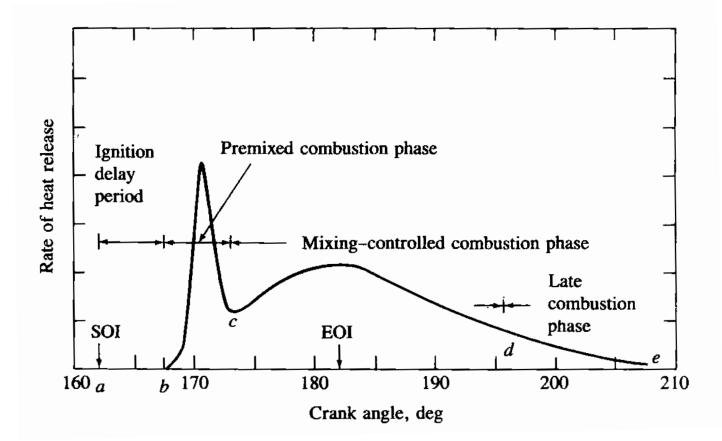
Diesel Engine Combustion



Clear lift-off and sooty flame (A. Cronhjort, Scania)



Rate of Heat Release



Typical evolution of the heat release for Diesel combustion



Diesel vs. Otto Engine

The main difference between the Diesel and Otto engine is:

The burning of the fuel.

- In a Gasoline engine the air/fuel mixture enters the cylinder and creates a stoichiometric homogeneous mixture, which is ignited and the flame travels from the spark and outwards to the liner.
- In the Diesel air enters the cylinder, fuel is injected, self-ignites and burns with a diffusion type of combustion



Diesel vs. Otto Engine II Otto Engine drawbacks

- Since the mixture always must be stoichiometric it is necessary to reduce the amount of air that is drawn into the cylinder if we reduce the fuel amount.
- Throttling is thus necessary at low loads, which takes power from the engine.
- Due to the fuel/air mixture it is necessary to lower the compression ratio to avoid it from self-igniting (knock).



Diesel vs. Otto Engine III

The Diesel has:

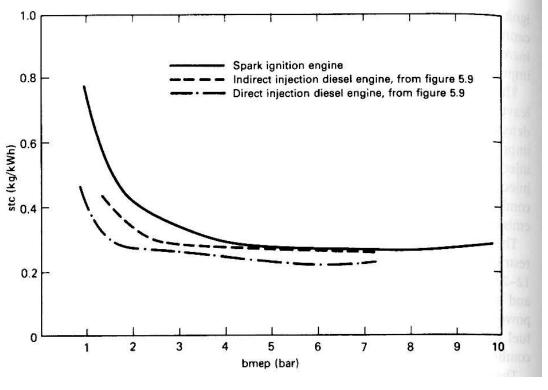
- higher compression ratio higher thermodynamic efficiency, no knock
- no throttle

no pumping losses, power \sim fuel

- combustion is always lean lower heat losses, higher efficiency
- more flexibility about choice of fuel



Diesel vs. Otto Engine IV

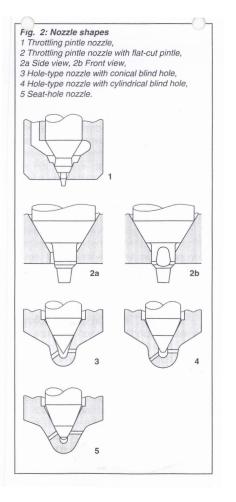


Specific Fuel Consumption as function of load for Diesel and Otto.

Otto engines have higher pump-losses at low loads, which leads to higher sfc.



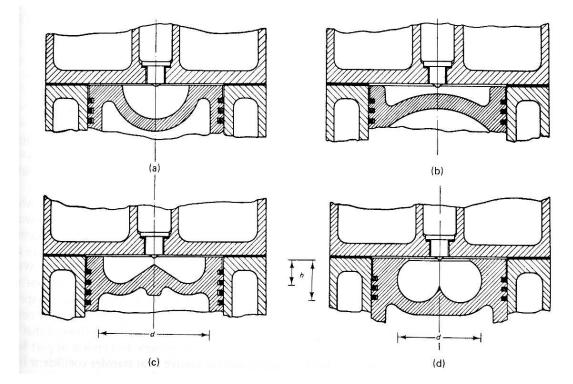
Different Nozzle Examples



The most important part of the Diesel engine is the fuel injector. Recent development has lead to increasing fuel injection pressure and reduction in the orifice diameter.



Bowl Shapes



Each system requires a different, suitable, injection system/strategy Swirling engines have 'problems' at high rpms.

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The Greenhouse Effect

There is only one way to reduce the CO₂ and that is by reducing the fuel consumption.

 $Fuel + O_2 \rightarrow CO_2 + H_2O$

From the carbon dioxide point of view, the Diesel engine is therefore more attractive than the Otto engine since it is more efficient.



Notes on Diffusion Combustion

Two important parameters in gasoline engines (premixed combustion) are

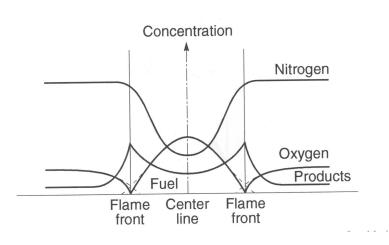
- flame speed
- fuel/air equivalence ratio

These are not relevant for diesel engines(diffusion flames), since the burning of the fuel does not propagate through the air and there is always excess of air.



Nature of a Diffusion Flame

Since fuel and air are initially separated, the nature of combustion is very different from premixed combustion.



- combustion will always be on the most favourable place, i.e. stoichiometric conditions.
- this will lead to very high temperatures



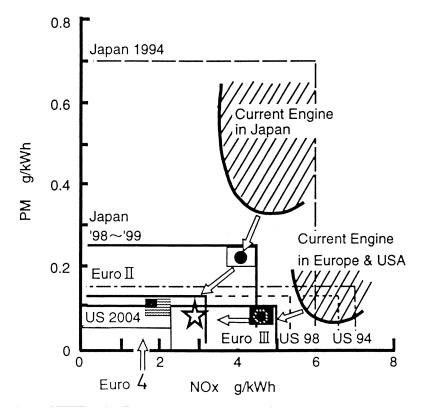
Diffusion Flame Emissions

- Soot
- NO and NO₂ (collectively reffered to as NO_x)
- (CO₂)

These are the only emmisions affected by legislation and, hence, the only ones of interest.



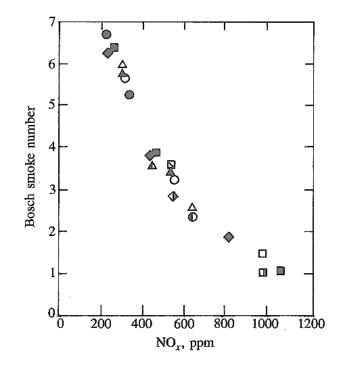
Emissions Legislations



It is very unlikely that these conditions can be met without any type of aftertreatment.



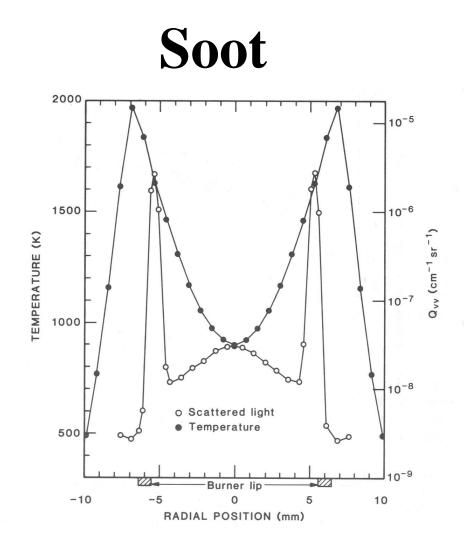
The Diesel Dilemma



Reducing the soot increase the NO_x and reducing NO_x leads to more soot. Both the soot reduction and NO_x formation increase with increasing temperature and oxygen concentration.

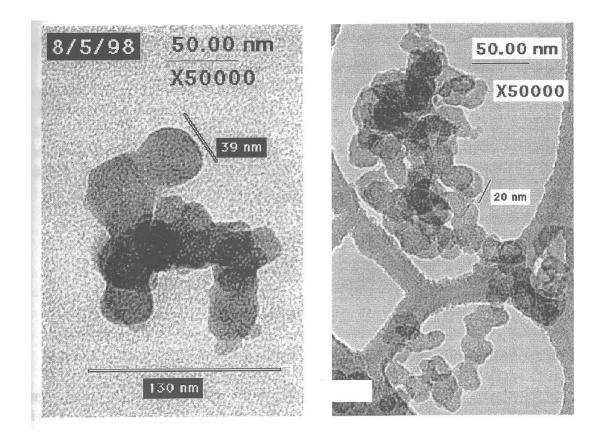
So the choice is: use oxygen to reduce soot or increase NO_x .





Soot is formed when the temperature is 'high enough' and the mixture is 'rich enough'

Soot Particles



The soot particles decrease in size as the fuel injection pressure increase. Very dangerous to your lungs.



Lung Absorption

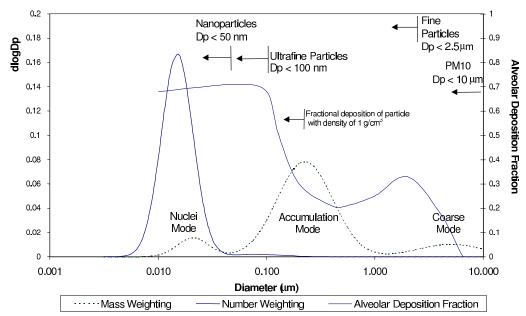


Figure 3. - Typical engine exhaust size distribution both mass and number weightings are shown (Kittelson, 1998a).

Diesel engines produce soot particles in the nano range.

Typical athmospheric dust is in the PM10 range (size < 10μ m)



NO_x

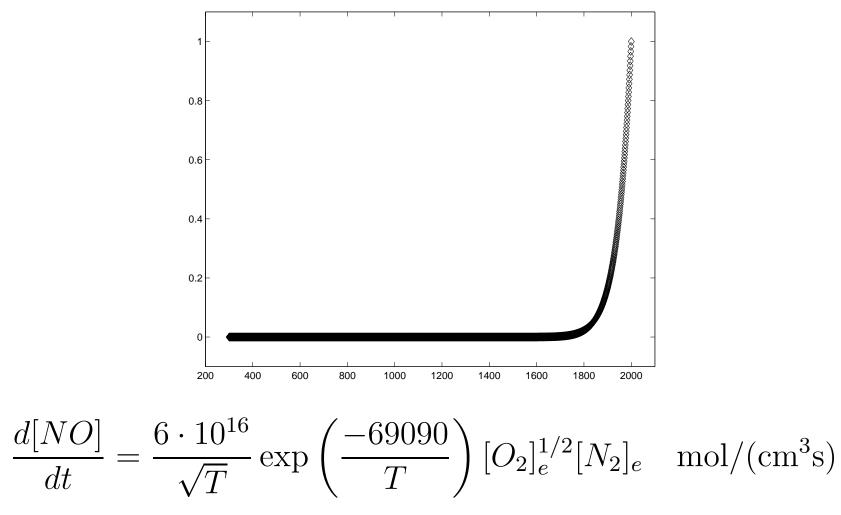
For diffusion flames almost all of the NO_x is thermal. Described by the Zeldovich mechanism

$$N_2 + O \rightleftharpoons NO + N$$
$$N + O_2 \rightleftharpoons NO + O$$
$$(N + OH \rightleftharpoons NO + H)$$

(Easy to remember if you think 'Zeldovich's wife' - NO NO NO NOH, and you have the right hand side)



Thermal NO_x production rate





The Liquid Spray

Diesel injector

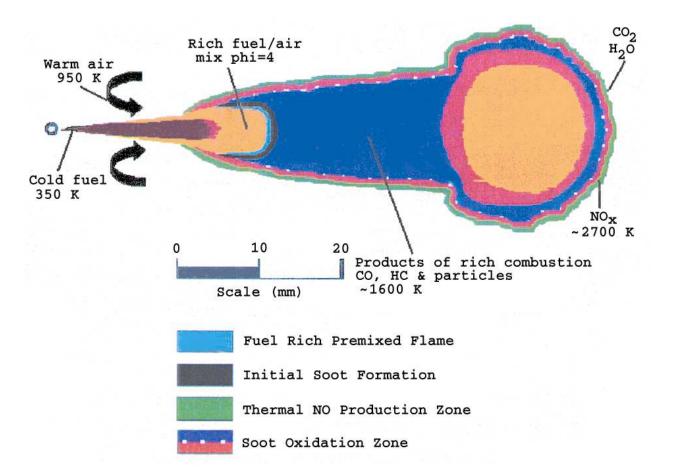
- injectopn pressure 1000-2400 bar
- drop diameter <10 μ m
- velocity > 400-500 m/s

It is a very influencial and the most important factor for emission formation.

Alot of research has gone into investigating elliptical holes, conical holes and hole configurations.



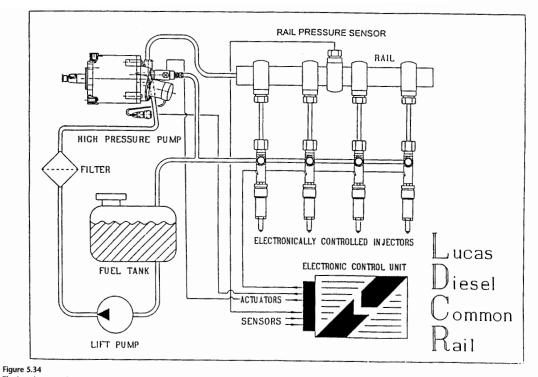
The Lift-off Effect



It has been shown that increasing lift-off allows for reduction of both soot and NO_x .



New Technologies

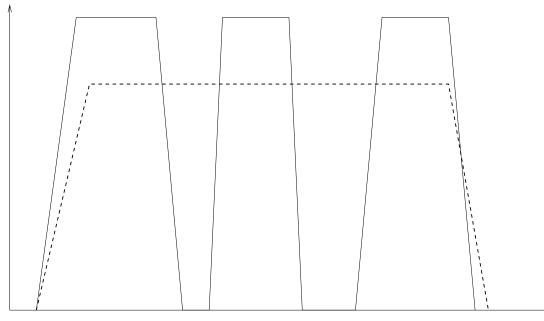


The key elements of a common rail injection system (courtesy of Lucas Diesel Systems).

Injection pressure is constantly increasing



New Technologies II

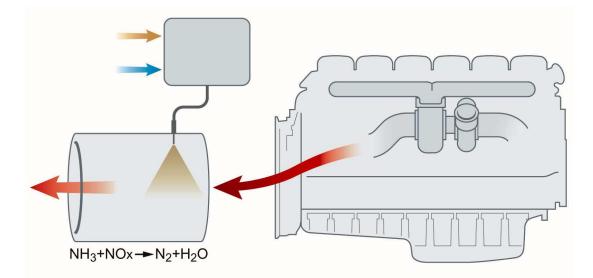


The common rail allows for multiple injections and rate shaping.

The idea is that we dont want to inject fuel in the already rich and hot regions.



SCR (Selective Catalytic Reduction)



Inject Urea (decomposes to ammonia) in the exhaust to remove the NO_x

(Will require Ammonia exhaust legislations)



Questions?



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