Optical Investigation of Spray Combustion Under Diesel Like Conditions

Subtask 1.2C

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Outlines

- Introduction
- Investigation Techniques: LDV, Spray Imaging and Two Color Method
- Measurements and Results
- Conclusion

Introduction

Subtask 1.2C aims to investigate the in-cylinder air fuel mixture formation and combustion of direct injection engines by optical techniques.

In the past we reported many results obtained using LDV, PDA as well as PIV.

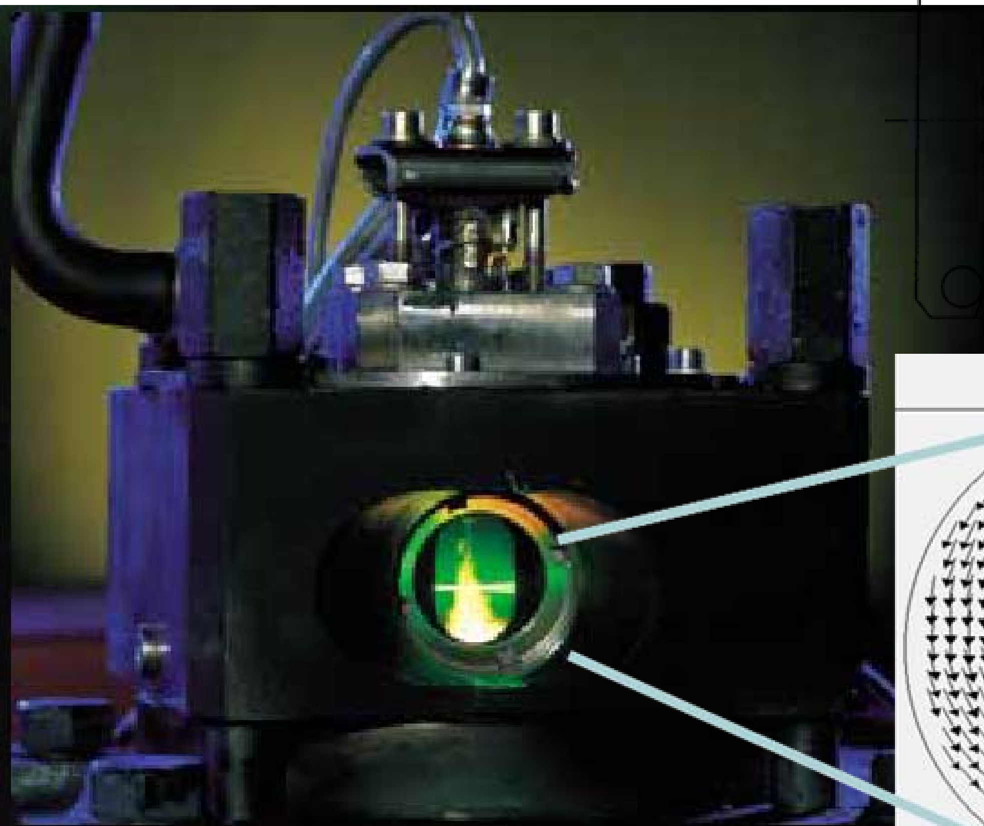
Now we are reporting results obtained using LDV, Spray Imaging and Two Color Method.

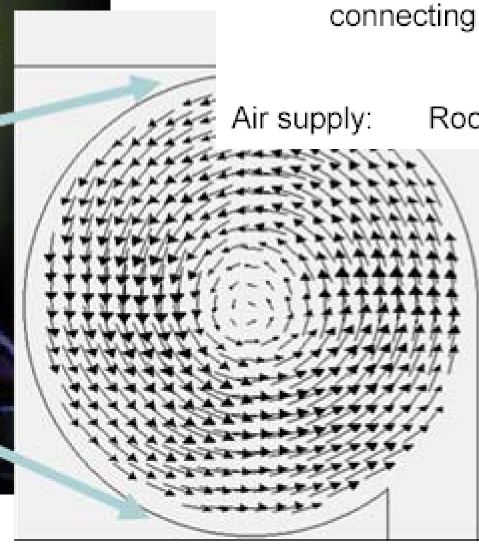
Consiglio Nazionale delle Ricerche

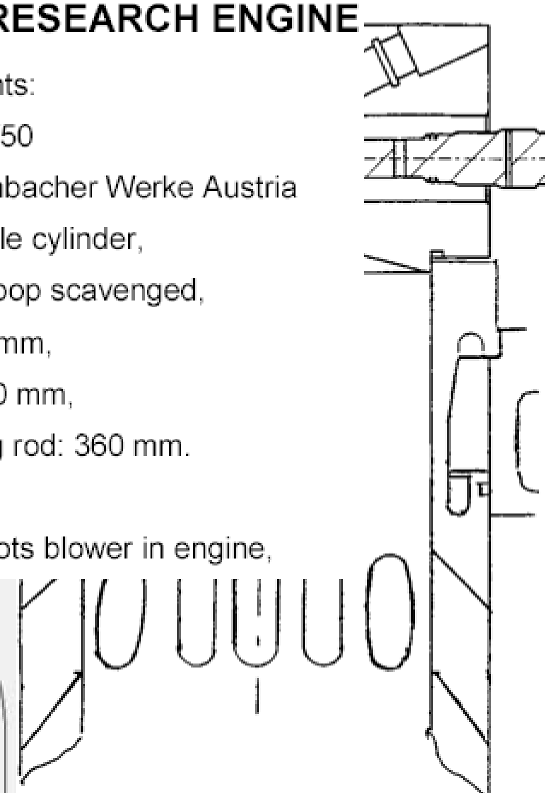
Spray Combustion Investigation

Optical Engine

The High Swirl Spray Diesel Engine







1.1 SPRAY RESEARCH ENGINE

Engine components:

Base engine: JW50

Manufacturer: Jenbacher Werke Austria

JW50 single cylinder,

2-stroke, loop scavenged,

bore: 150 mm,

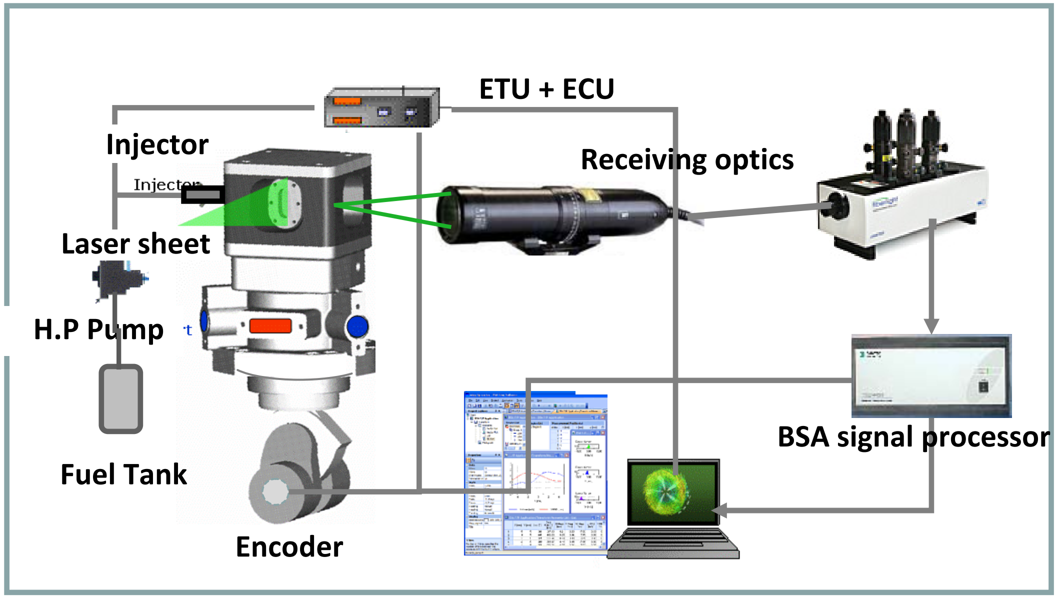
stroke: 170 mm,

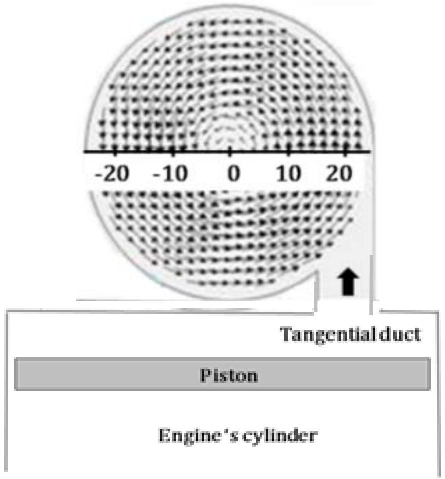
connecting rod: 360 mm.

Air supply: Roots blower in engine,

The engine is equipped with a circular optical access (50 mm diameter) on one side of the combustion chamber and a rectangular one at 90° used for the laser illumination input.

Optical Layout of LDV



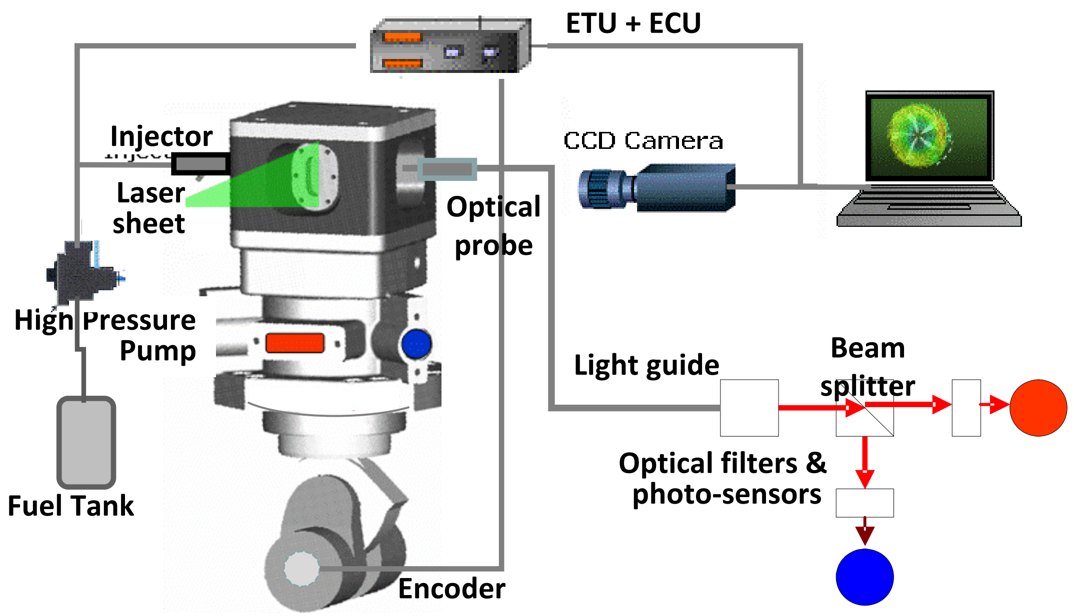


LDV measurements have been carried out along the main diameter at half depth of the combustion chamber.

Air flow measurements were taken using as seeder a small amount of fuel injected (3-4 mg/str) at 60° cad btdc

A 5 hole, 0.13 mm diameter and 150° spray angle, micro-sac nozzle was used

Optical Layout of Spray Imaging and Two Color Measurements

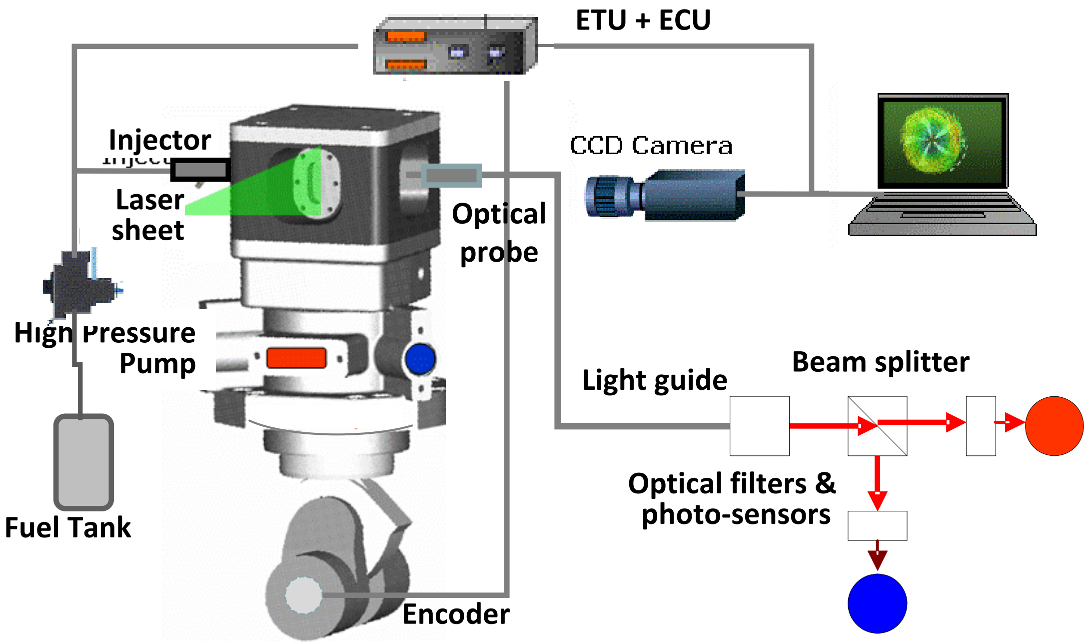


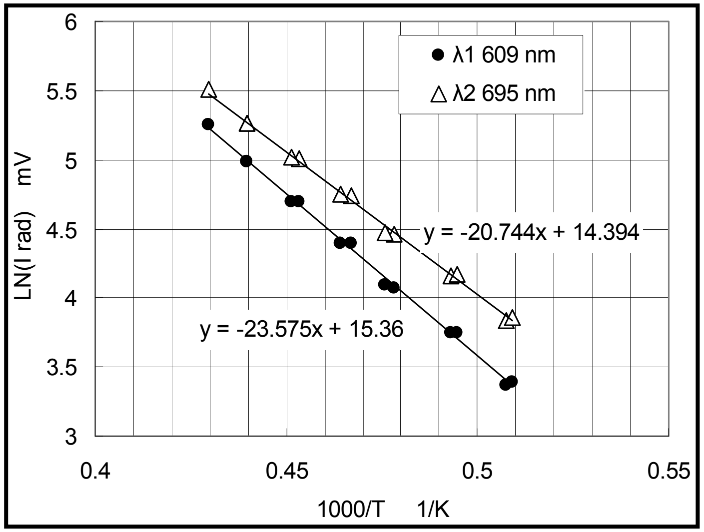
The optical probe (observation field limited to a circle of 3 mm) is attached to the side wall of the swirl chamber.

The radiation from the luminous flame in the cylinder travels through the quartz window, reaches the light guide and is acquired at 1° cad by a fast acquisition system.

The current configuration of the optical holder allowed continuous data acquisition over ten minutes with a little soot contamination on the quartz window surface.

Optical Layout of Spray Imaging and Two Color Measurements





The light is split in two directions and sent through a wide band pass filter to a silicon photodiode with a response frequency of 10 KHz.

A black body furnace (maximum temperature of 2500K) was used to calibrate the correlation between the apparent temperature and the detector output at two wavelengths (609 and 695 nm). Data plots lie on a single straight line at each wavelength.

Test Conditions

Tests were made at engine speed of 500 rpm.

EGR rate, fuel injection pressure (Pinj) and start of injection (SOI) were varied as in the table.

All test were performed at the same amount of injected fuel of 35 mg/stroke being able to preserve the optical sensor from soot contamination.

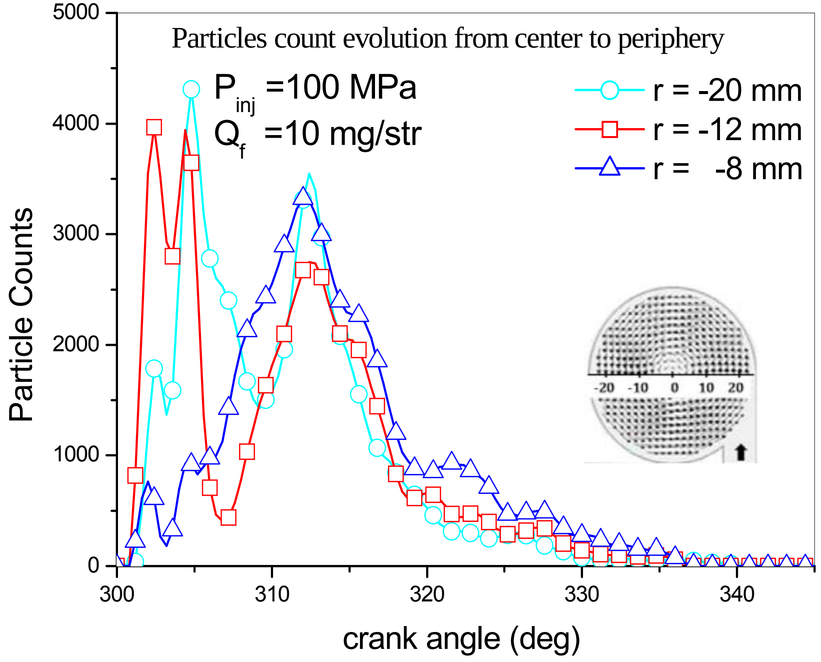
KL factor and the flame temperature were determined.

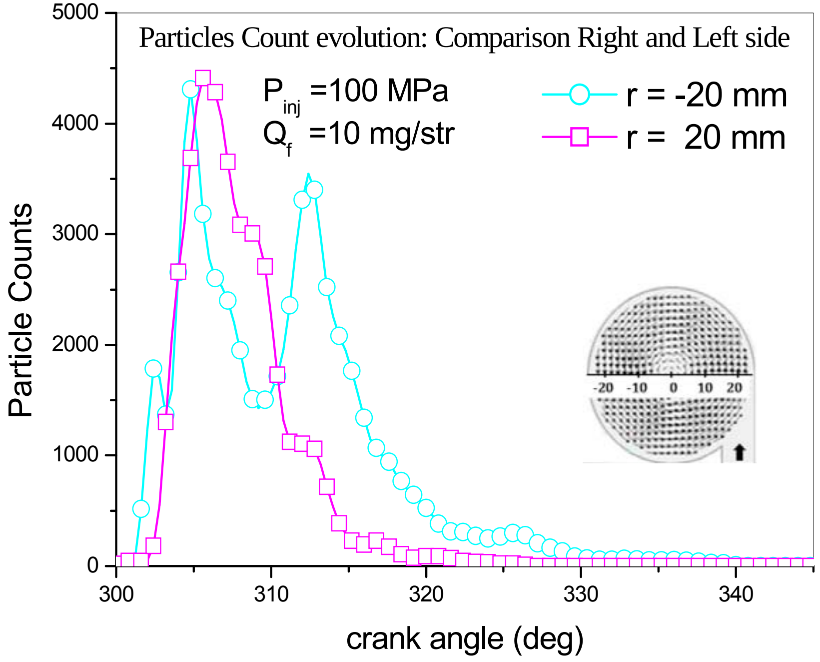
#	P_{inj} [MPa]	Δt_{inj} [ms]	SOI [btdc]	EGR %	O_2 [%]	A/F
1	100	1.015	10	0	20	50,5
2	100	1.015	10	40	16	45.0
3	100	1.015	10	45	15.1	39.6
4	100	1.015	10	50	14.1	35.0
5	100	1.015	5	50	14.1	36.8
6	100	1.015	6	50	14.1	37.1
7	100	1.015	7	50	14.1	37.2
8	100	1.015	10	60	13.5	33.0
9	110	0.895	10	60	13.5	33.4
10	120	0.820	10	60	13.5	34.0

Measurements and Results

LDV Measurements Particle Count

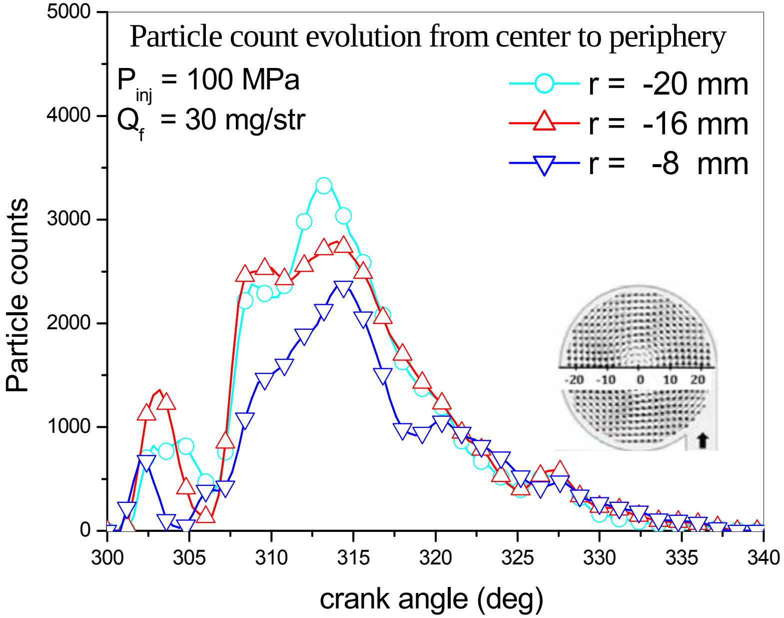
Spray Images from SOI = 60° CAD BTDC

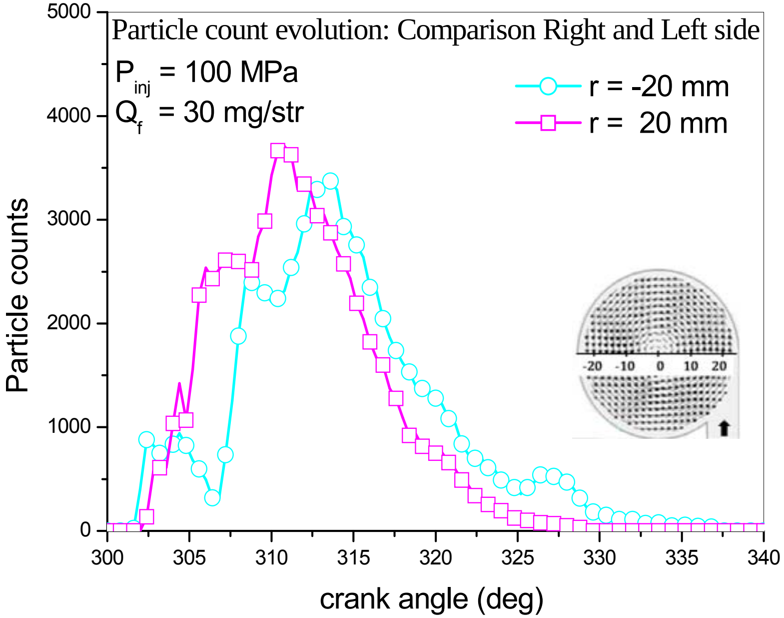




LDV Measurements Particle Count

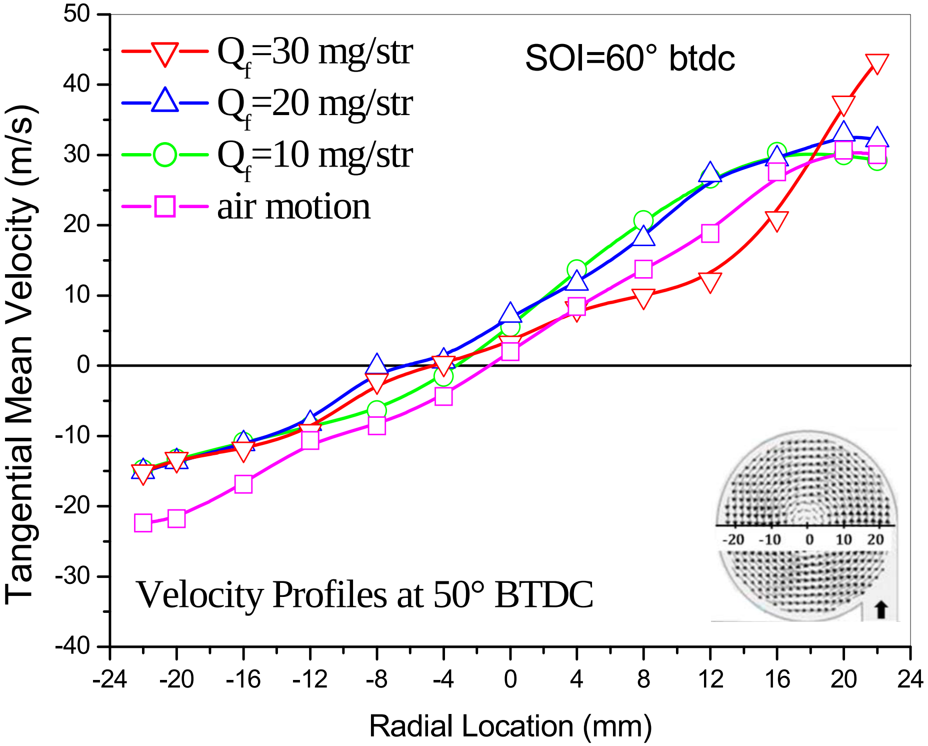
Spray Images from SOI = 60° CAD BTDC





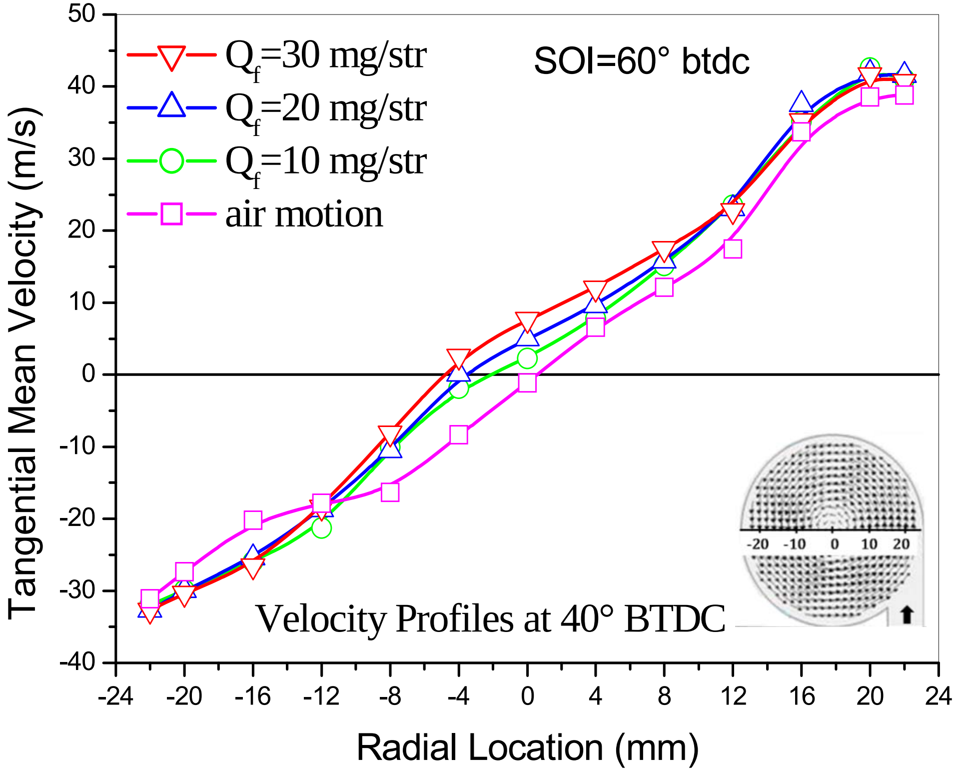
LDV Measurements at 50° CAD BTDC

Spray Images from SOI = 60° CAD BTDC



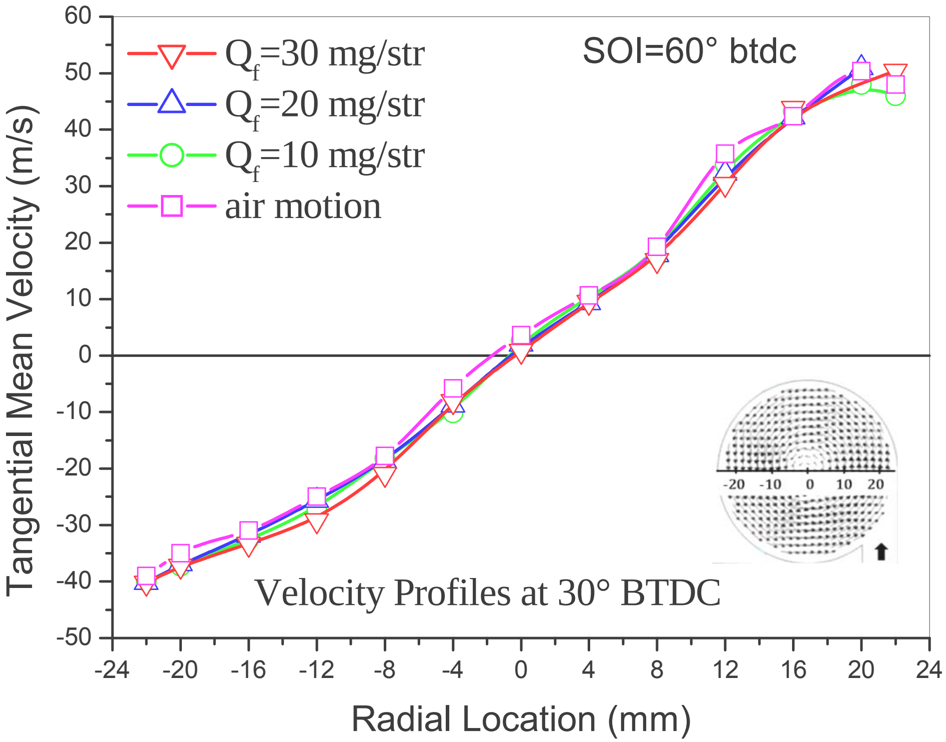
LDV Measurements at 40° CAD BTDC

Spray Images from SOI = 60° CAD BTDC



LDV Measurements at 30° CAD BTDC

Spray Images from SOI = 60° CAD BTDC

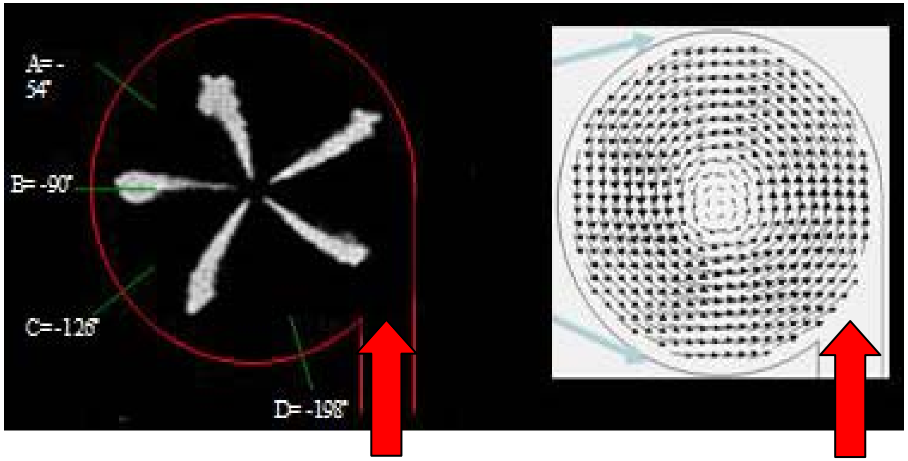


Spray Imaging

2D Images were collected by a high resolution CCD camera to follow the spray evolution.

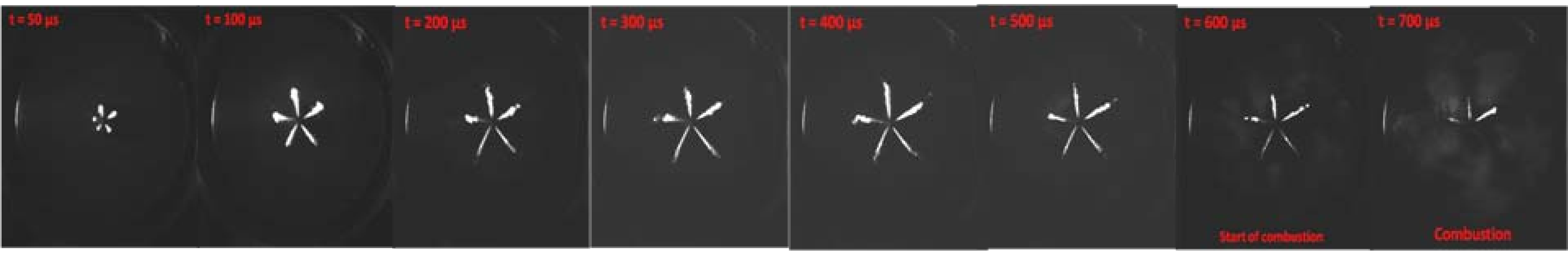
The picture shows the swirling four jets coming from the injector located on the back of the combustion chamber.

The air flow, generated by the tangential duct, is forced by the piston into the combustion chamber making available a counter clockwise swirl flow with the rotation axis coincident to the symmetry axis of the combustion chamber.



Spray Imaging

Spray images: 26 mg/stroke - Pinj = 100MPa – SOI = 60° CAD BTDC

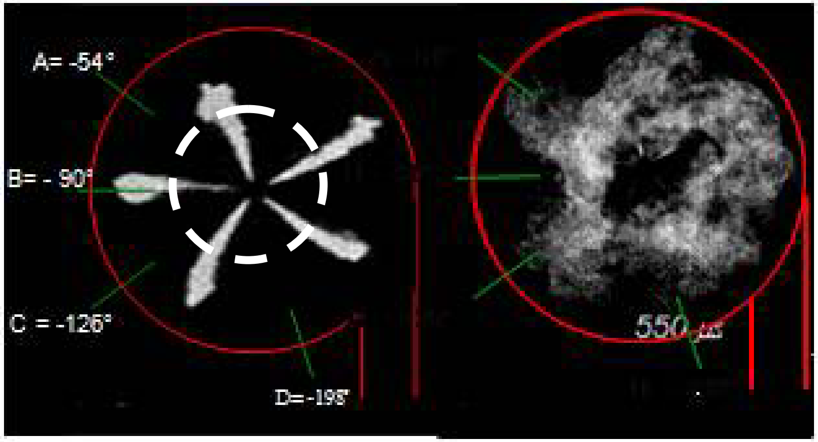


Two Color Measurements

To set the best location of the optical probe for T and KL estimation, measurements were performed at four angular locations at the same radial position of r=20 mm.: angular positions: 54°, 90°, 126° and 198° respectively.

Test conditions:

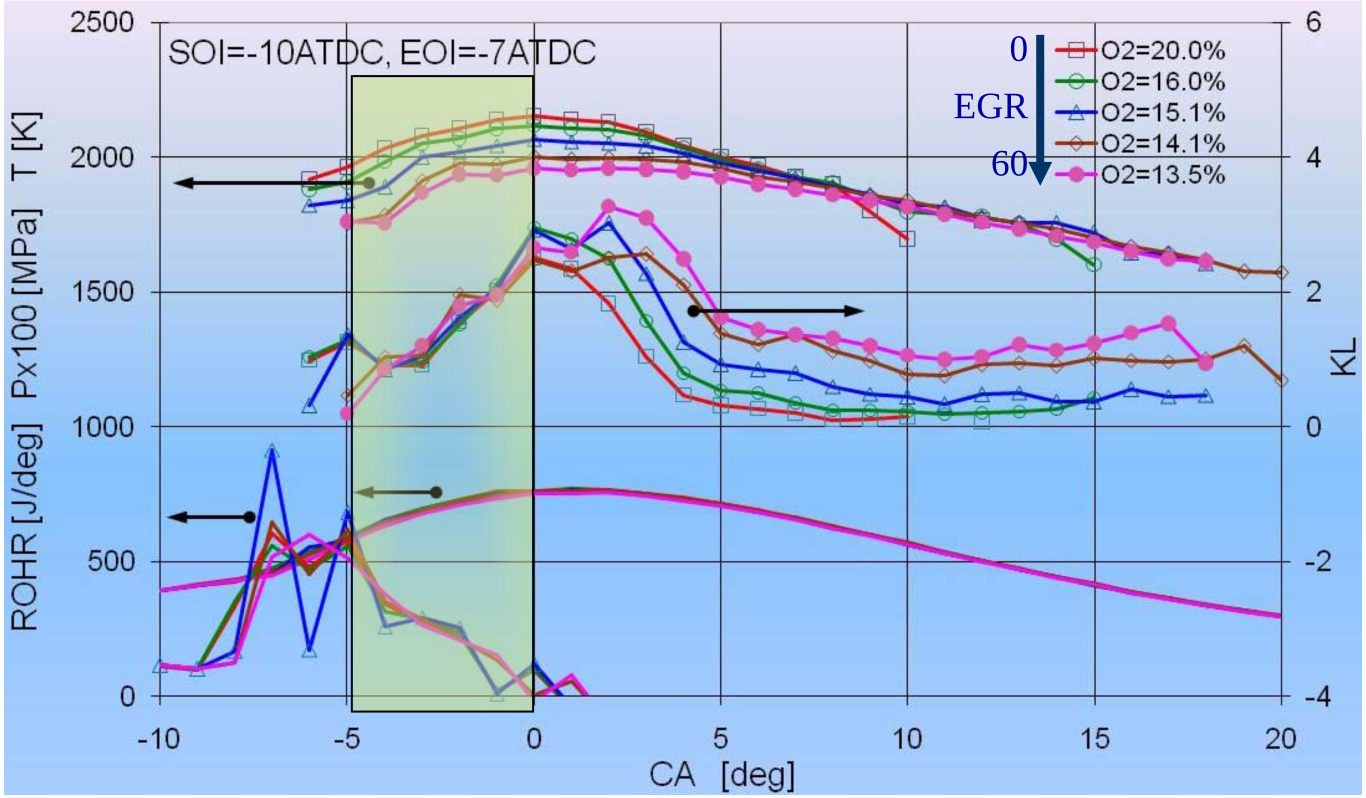
- Injection pressure: Pinj = 100 MPa
- Start of Injection: SOI = 10° btdc,
- Exhaust Gas Ricirculation: EGR from 0 to 60% [O2=20% to13.5%].



Images of sprays and combustion
SOI = 10° CAD BTDC - EGR=0

KL Factor Trend

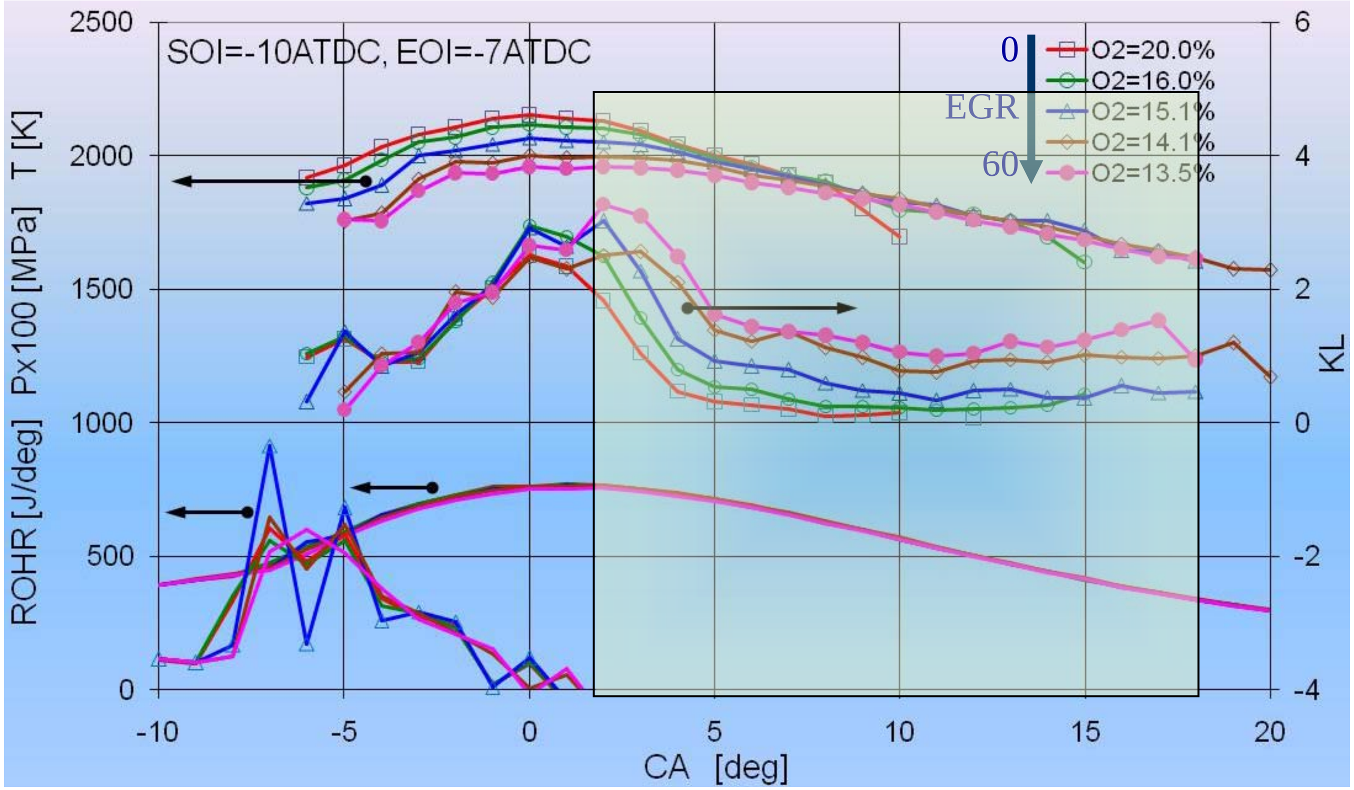
KL factor exhibits an overlapped trend during the initial stage (-5°CA to TDC) of combustion denoting a low effect of O2 concentration on soot formation process.



KL Factor Trend

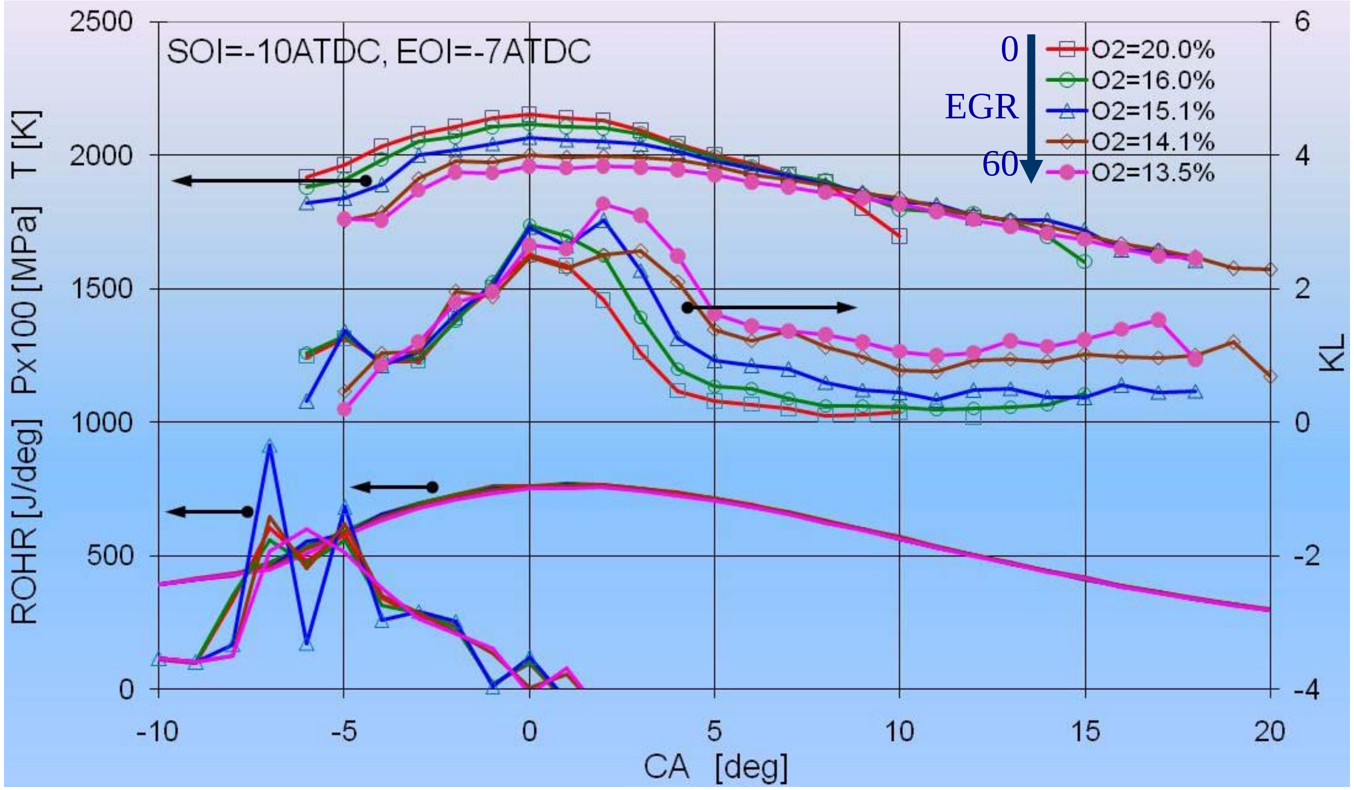
KL factor displays a peak corresponding to the crank angle at which the soot process switches from formation to oxidation.

The crank angle at which the KL factor gives a peak delays with the reduction of O2 concentration. After this peak, KL factor decreases with time. It shows a fast initial soot oxidation phase, followed by slow oxidation at the end of combustion.



KL Factor Trend

KL factor shows the highest peak at the lowest O2 concentration and the lowest for the highest O2 concentration. These observations lead to a conclusion that the O2 concentration in the intake charge slightly affects the formation while it strongly affects the oxidation.

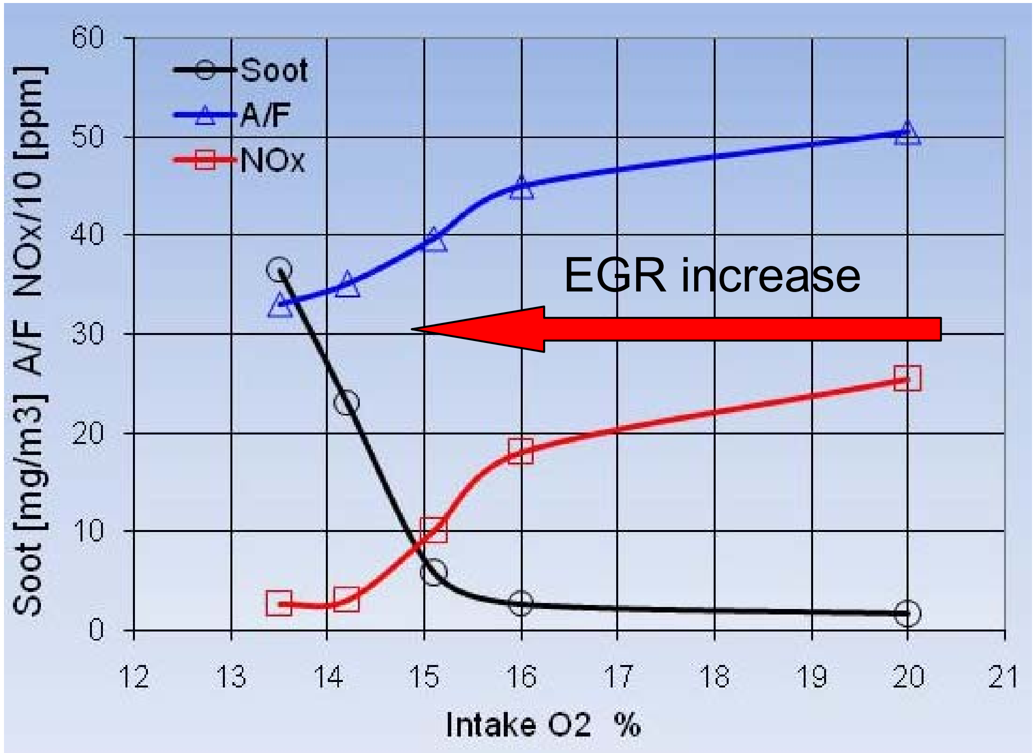


EGR Effect on Soot and NOx

The flame temperature decreases with the decrease in O2 concentration from 2200°K at O2=20% to 1880°K at O2=13.5%. This change corresponds to the change in NOx emissions at the exhaust.

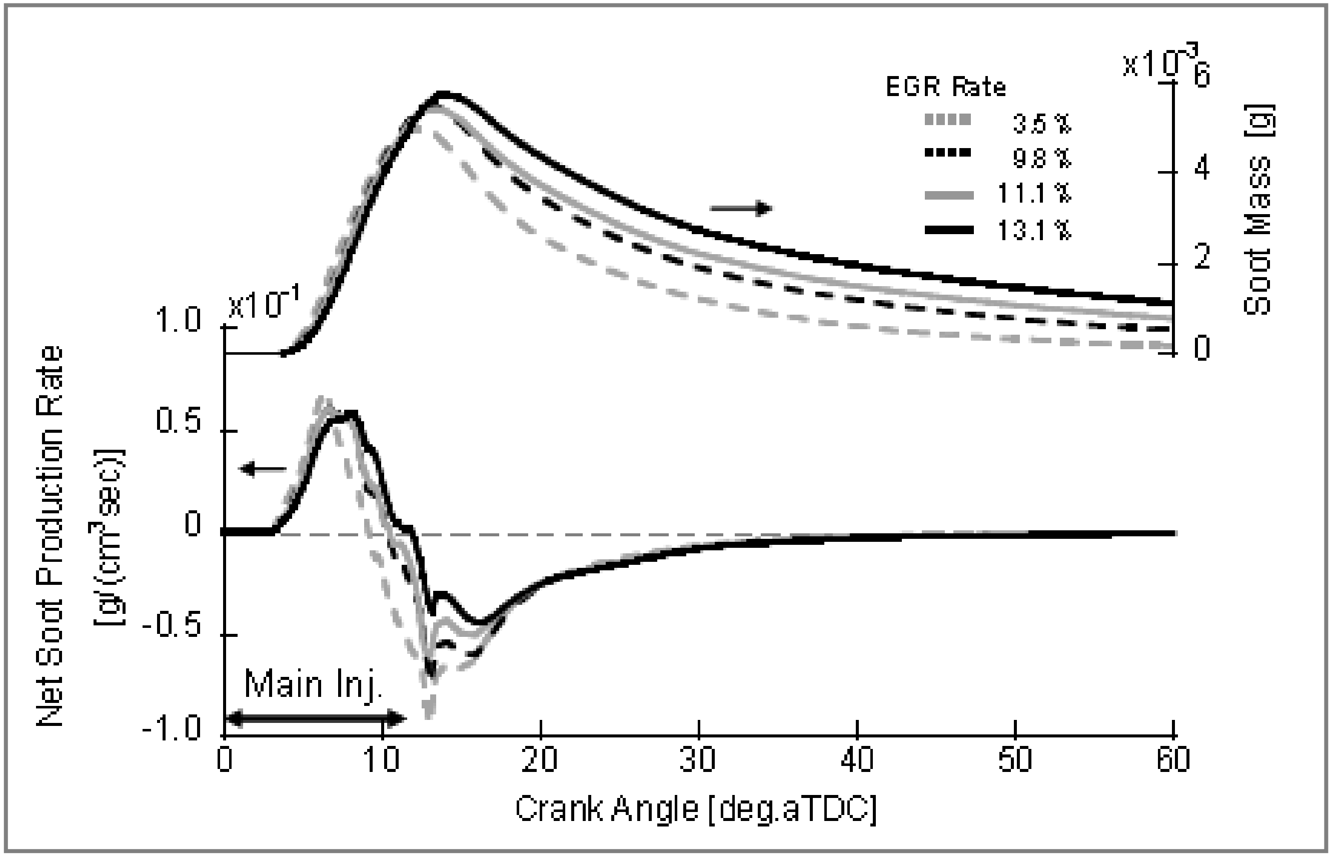
Effect of EGR rate on exhaust emissions of NOx and soot:

NOx 254 ppm	Soot 1.6 mg/m3	at O2=20.0%
NOx 26 ppm	Soot 36.4 mg/m3	at O2=13.5%,



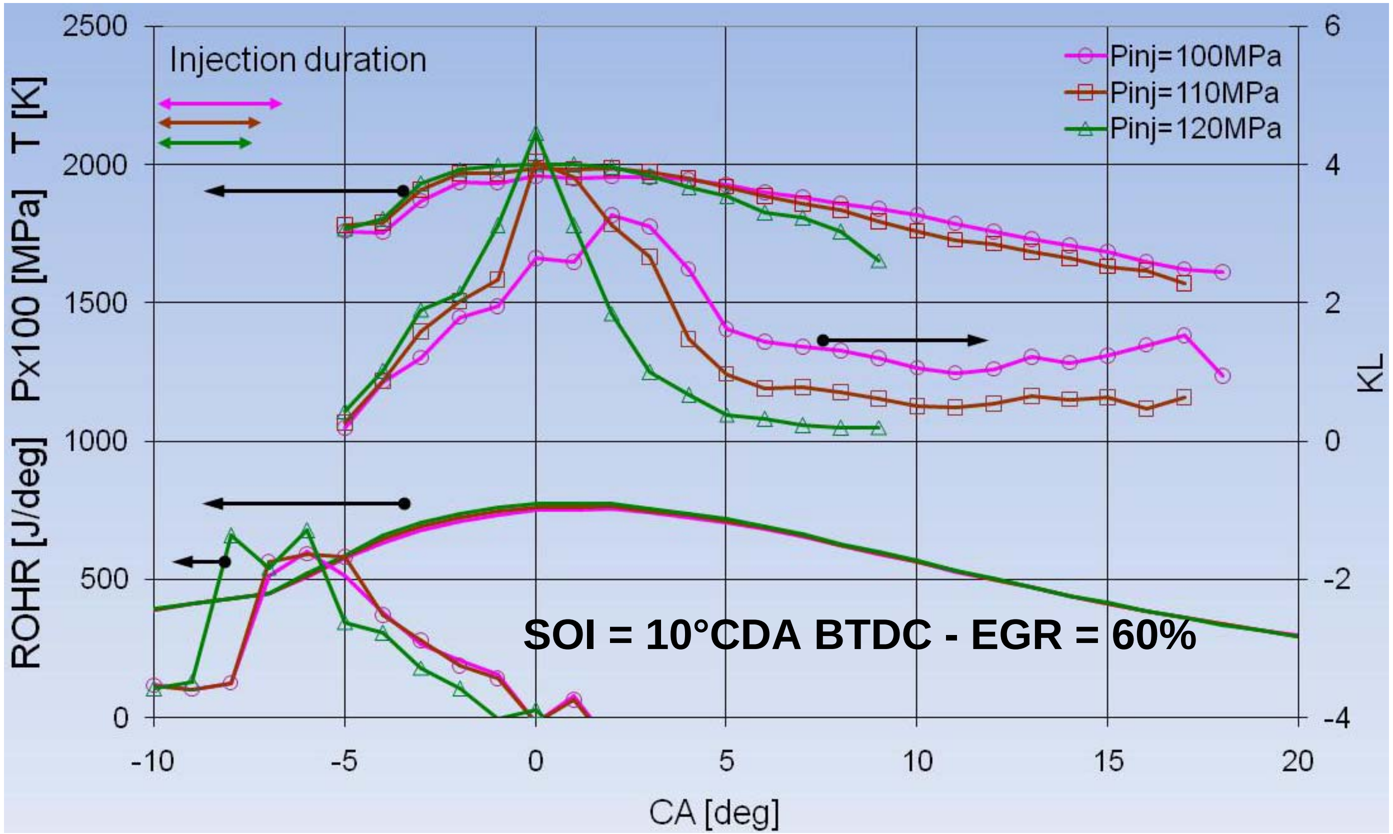
EGR Effect on Soot and NOx

Kaminawa et al. (I.J.E.R. 2008 Vol.9 No.4 pp.283-296) recently have reported a three-dimensional numerical study on the in-cylinder soot evolution in a three-liter common-rail diesel engine using a phenomenological soot model combined with detailed chemistry.



Injection Pressure Effect on T and KL

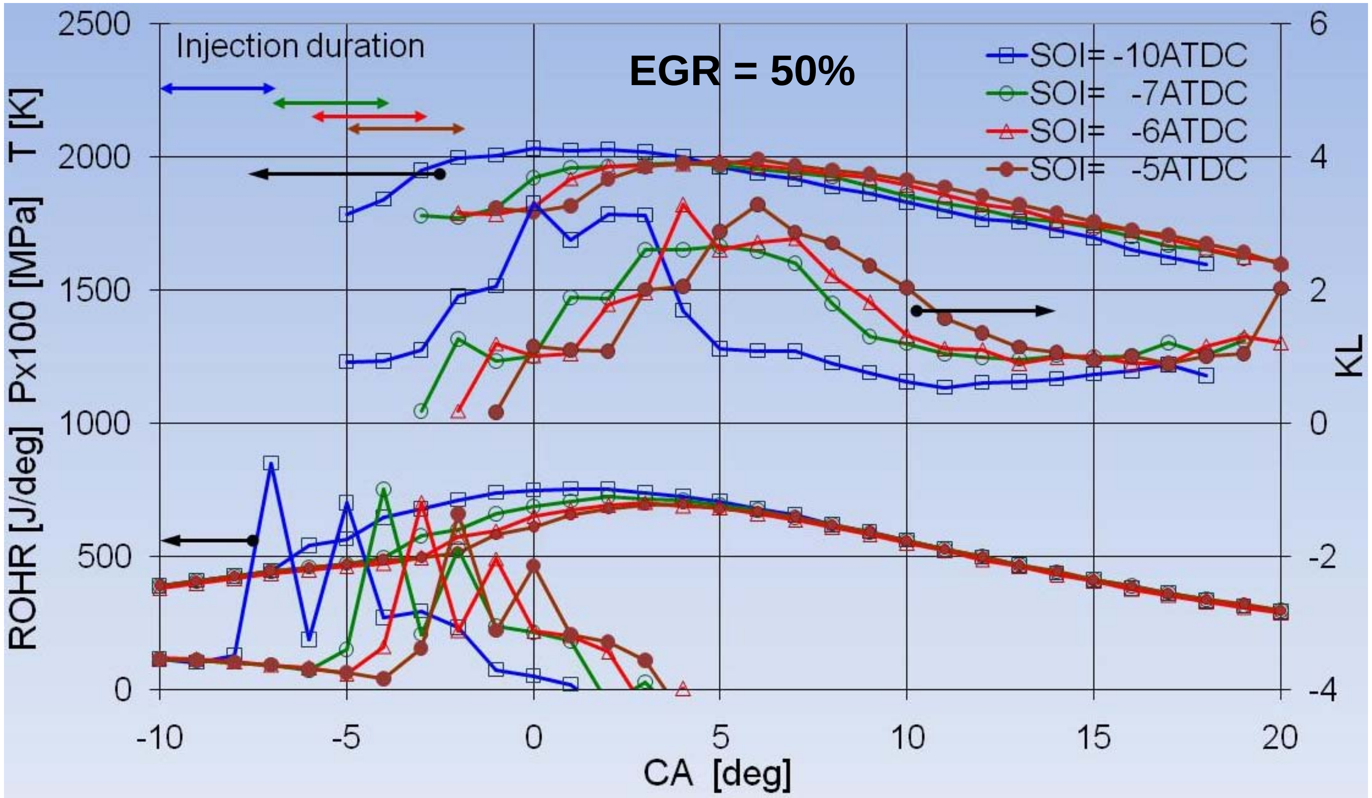
Increasing the injection pressure (100 to 120 MPa), the air fuel mixing improves and the ignition delay reduces as can be observed by looking at the heat release rate. Consequently, both soot formation and oxidation processes are faster and KL factor reduces .



Injection Timing Effect on T and KL

The most advanced injection timing increases the maximum flame temperature producing the lowest level of *KL* factors, during the final stage of combustion, as a result of the enhanced soot oxidation.

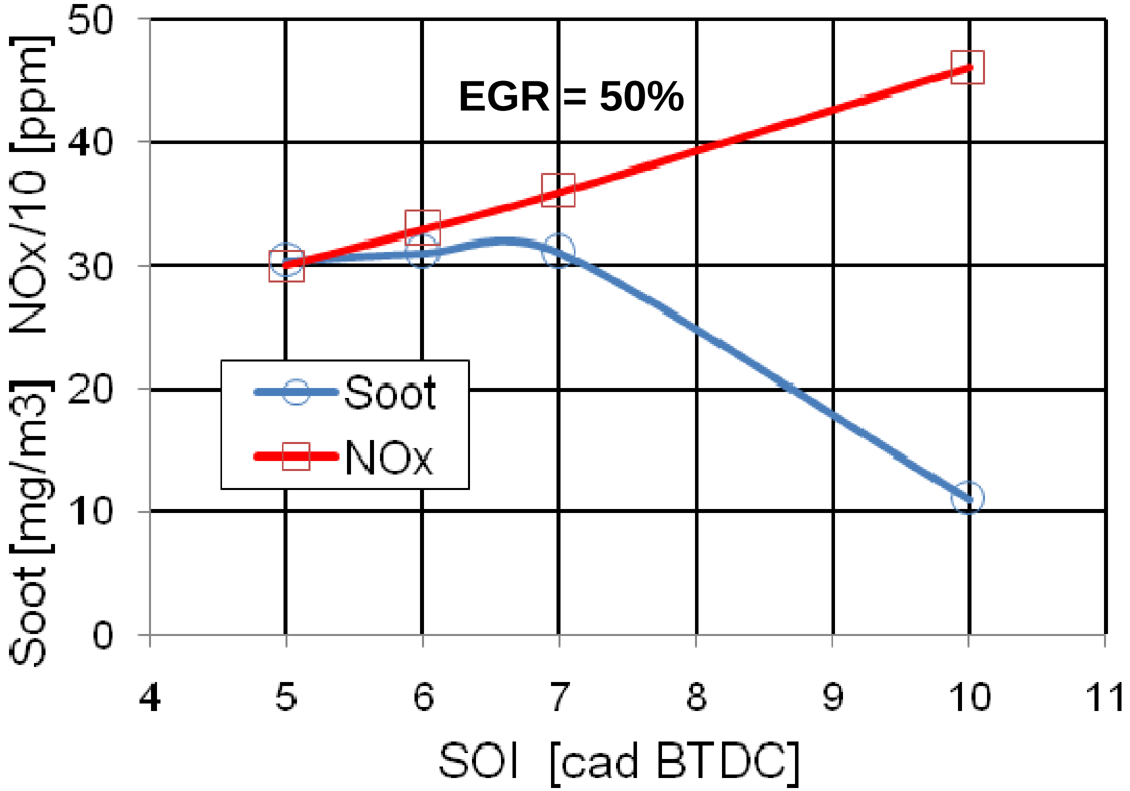
NOx reduces at retarded start of injection as consequence of reduced flame temperature.



Injection Timing Effect on T and KL

Effect of SOI on exhaust emissions of NOx and soot:

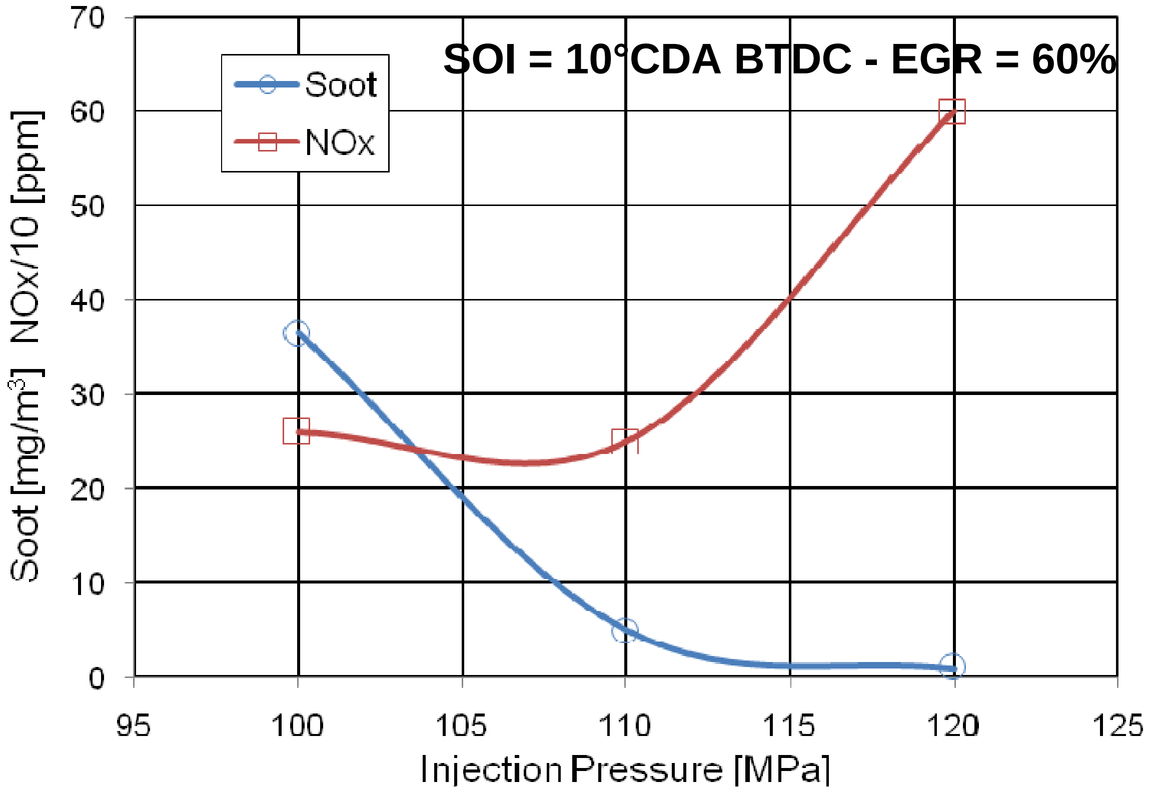
NOx 46 ppm Soot 11 mg/m3 at SOI=10 BTDC
NOx 30 ppm Soot 30 mg/m3 at SOI= 5 BTDC



Injection Pressure Effect Soot and NOx

Engine out soot emissions

36.4 mg/m3 at Pinj=100 MP
1.0 mg/m3 at Pinj=120 MPa



Conclusion

The two-color method has been applied to investigate the effects of engine parameters (EGR, Injection Pressure, SOI) on temporal variations of flame temperature and KL factor in a prototype optically accessible 2-stroke diesel engine equipped with a common rail injection system.

The swirl chamber of the engine has been set with a common rail, 5-hole solenoid injector, reproducing a combustion similar to that within direct injection diesel engines under high swirl conditions. Tests have been performed at constant engine speed and at the same amount of injected fuel.

Results of investigation support the following main conclusions:

- Reduced O2 concentration in the intake charge slightly affects soot formation but delays the start of soot oxidation.
- The highest peak of soot concentration is reached at the lowest O2 concentration.
- Both formation and oxidation rates increase with increased injection pressure, if the fuel amount remains constant.
- KL values in the later part of combustion interval show a good correlation to the exhaust soot emissions.