Quantitative Optical Measurements of Soot Evolution in Diesel Sprays in a Constant Volume Chamber with Different Fuel Composition

O. Margari, K. Boulouchos

Aerothermochemistry and Combustion Systems Laboratory, ETH - Swiss Federal Institute of Technology, Zürich, Switzerland

E-mail: margari@lav.mavt.ethz.ch
Telephone: +(41) 44 632 77 85
Fax: +(41) 44 632 12 55

Abstract. In this work a detailed study of the emissions produced by direct injection Diesel engines is presented. An analysis of the combustion processes needed to characterize soot formation and oxidation processes using non-intrusive optical methods. In order to achieve this goal, an experimental investigation carried out in a high temperature-high pressure combustion chamber, at the Aerothermochemistry and Combustion Systems laboratory (LAV) at the ETH Zürich. The formation of soot particles in a diesel spray flame is investigated, using optical measurement techniques, with the aim to provide data to validate and to improve simulation tools.

Analysis based on the acquired pressure signals and the flame light emission is performed to identify relationships between combustion and particulate formation. The formation of particulate matter (PM) emissions is investigated using two different optical techniques: the two-color pyrometer, which measures the flame temperature and the KL factor, and the Back Diffused Laser (BDL) technique. The latter provides the KL-factor, based on the extinction theory. The pyrometer technique uses series of calibration and additional light extinction measurements complement the pyrometry measurements.

A statistical analysis has been carried out, acquiring a set of 60 images under the same conditions at the same recording time, using both optical techniques. This analysis has shown that the measured temperature has a relative fluctuation up to 1%, while the KL-factor up to 10% (figure 1). Further analysis has shown that these values do not change considerably when data sets with a lower number of images (10 and 20) are considered**.**

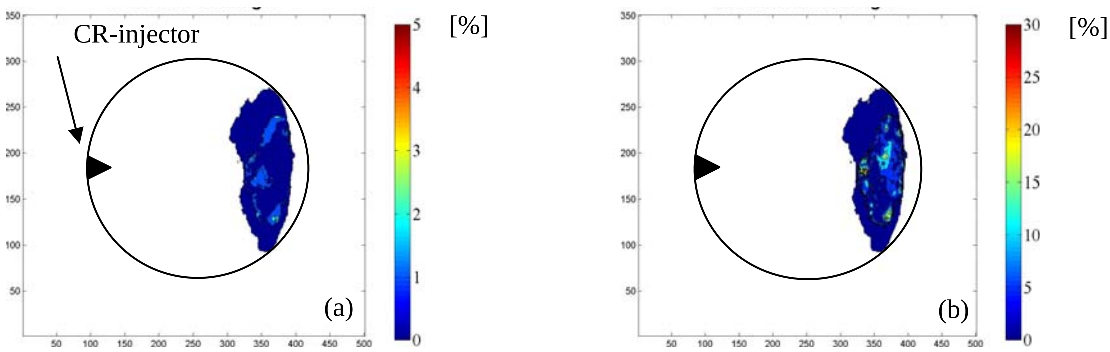


Figure 1: (a) standard deviation of temperature and (b) standard deviation of KL-factor over 60 images at p_{cell}=40bar, T_{cell}=790K, p_{inj}=1300bar, t_{inj}=3.0ms, at 2.9ms after start of injecion

The influence of fuel properties on the soot formation and oxidation processes were investigated using five different fuels: diesel, two blends (25% and 50% by mass) with an oxygenated diesel additive (Butylal) and two water-diesel emulsions (13% and 25% water by mass). To ensure a representative comparison of the fuels, the temperature and the pressure of the cell were held constant at 790K and 60bar, respectively. Furthermore, the injection pressure was maintained at 500bar, and the injection duration was adjusted, based on the lower heating value of each fuel, so that the injected energy contest remains constant.

The heat release rate calculation (figure 2a), carried out using WEG (a combustion analysis software developed at the LAV) and the recorded cylinder pressure, has shown that the that the peak values for diesel and both water-diesel emulsions appear at a similar time after the start of injection (ASOI) and have similar values. Using butylal blends (25% and 50%) the peak heat release rate appears earlier. From the heat release rate it is observed that the ignition delay gets shorter, when blends of oxygenated diesel additives are used. In all cases, high oscillation of the ROHR is observed after 4ms. Pressure waves propagation and reflection within the cell walls might be the explanation of this phenomenon.

Pyrometer results have shown that the mean temperature (the average temperature of the flame cross section) of the soot cloud decreases as a function of the fuel in the following order: diesel, butylal-diesel 25%, butylal-diesel 50%, water-diesel emulsions 13% and 25% (figure 3b). Both the mean KL-factor (the average KL-factor over the flame cross section) and its integral (the sum of the KL-factor over the flame cross section) show the same trend (figure 3c-d). An explanation can be given by the different chemical compositions of the fuels. Butylal contains oxygen and has higher cetane number (CN) compared to diesel. The high concentrations of oxygen in the mixture allow for better soot oxidation. Emulsions contain water that influences the flame temperature and the ignition delay. The cooling effect of the evaporation of the water depends on the quantity injected in the chamber. Usually, the droplet evaporation of the water generates a secondary atomization, promoting the fuel air mixing.

It is observed that the particulate emissions are reduced by using water-diesel emulsions and oxygenated additives in diesel fuel. These results are used to complement the spray and combustion data for the validation of soot formation and oxidation models used in diesel engine combustion modeling.

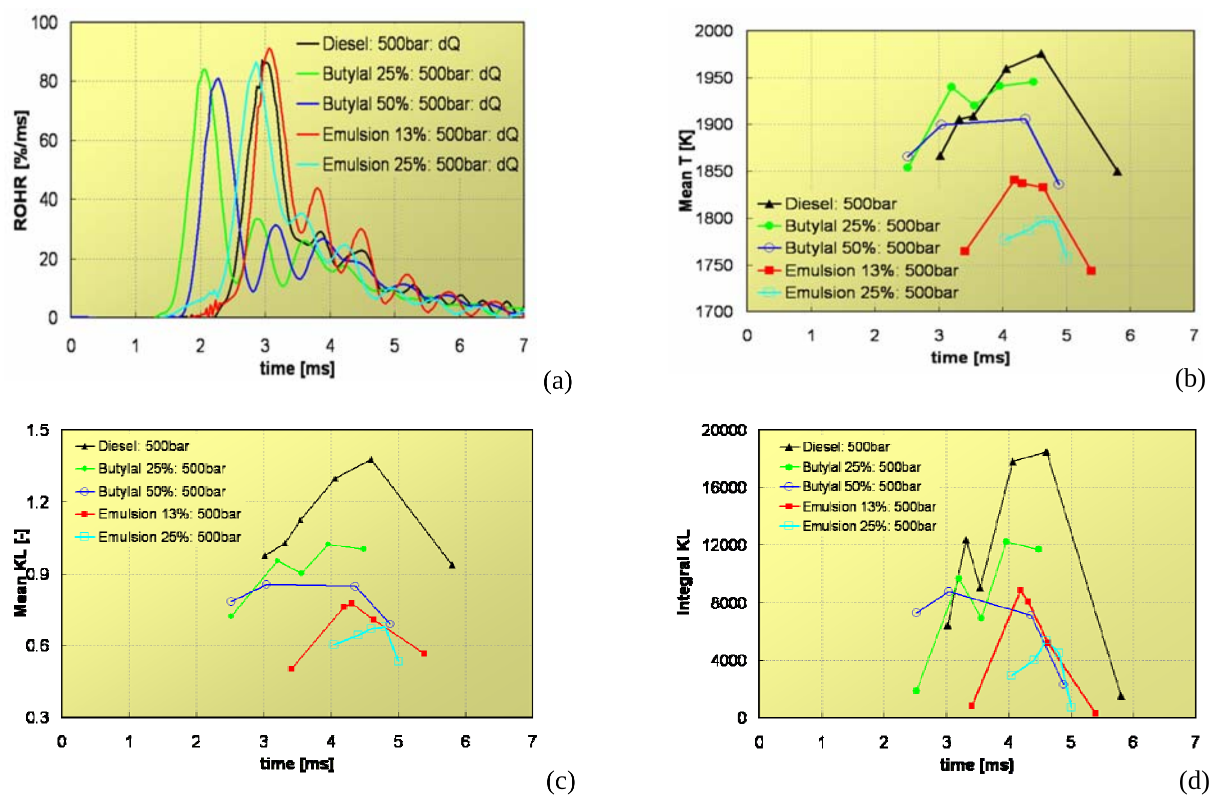


Figure 2: (a) heat release rate (b) mean soot temperature, (c) mean KL-factor and (d) integral of the KL-factor versus the time after start of injection (measured by pyrometry) for diesel, butylal-diesel blends 25% and 50%, and water-diesel emulsion, at p_{cell}=60bar, T_{cell}=790K, p_{inj}=500bar, with a constant injected energy contest

Ourania Margari
Konstantinos Boulouchos

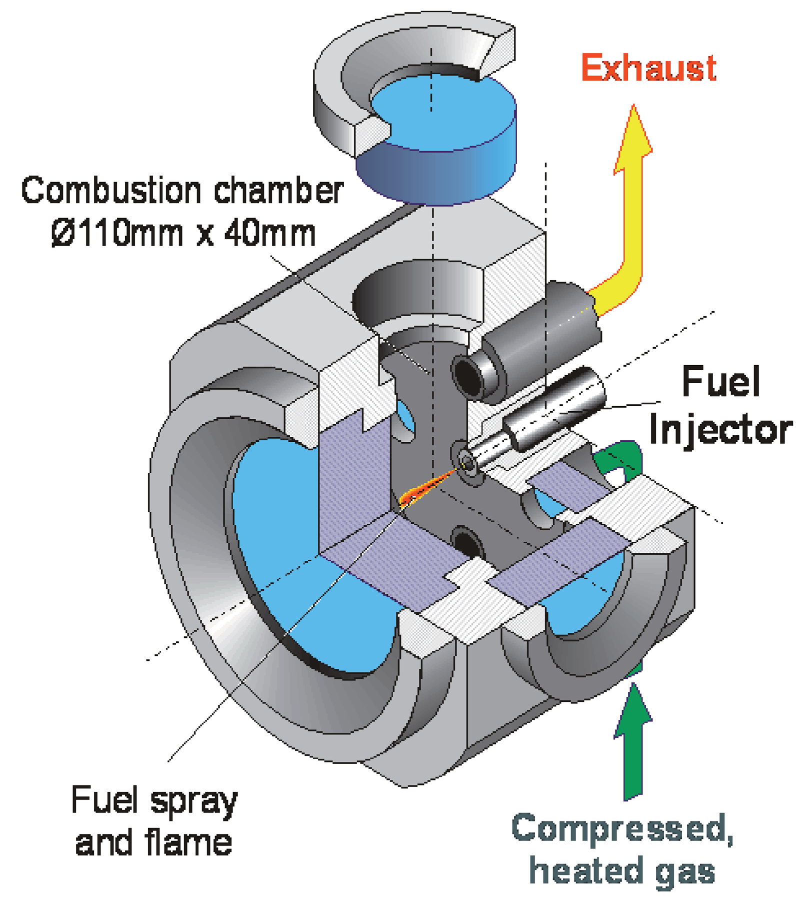
Optical Spray Measurement

LAV
Laboratorium für Aerothermochemie und Verbrennungssysteme
Aerothermochemistry and Combustion Systems Laboratory

Optical Measurements of Soot Evolution in Diesel Sprays in a Constant Volume Chamber with Different Fuel Compositions

High Temperature - High Pressure Cell

The aim of this project is the study of the emission levels produced by the direct injection Diesel engines. An analysis of the combustion processes is needed to comprehend soot formation and oxidation processes by non-intrusive optical methods. Optical measurement techniques are used at a constant volume combustion chamber with the aim to validate and improve simulation tools.

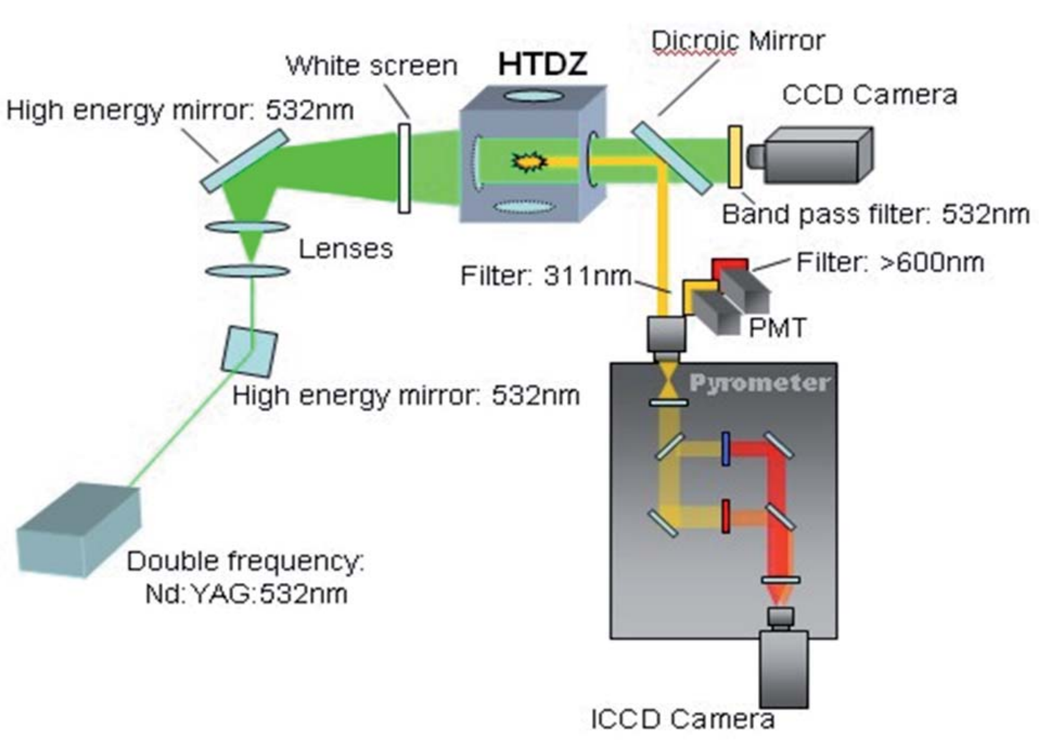


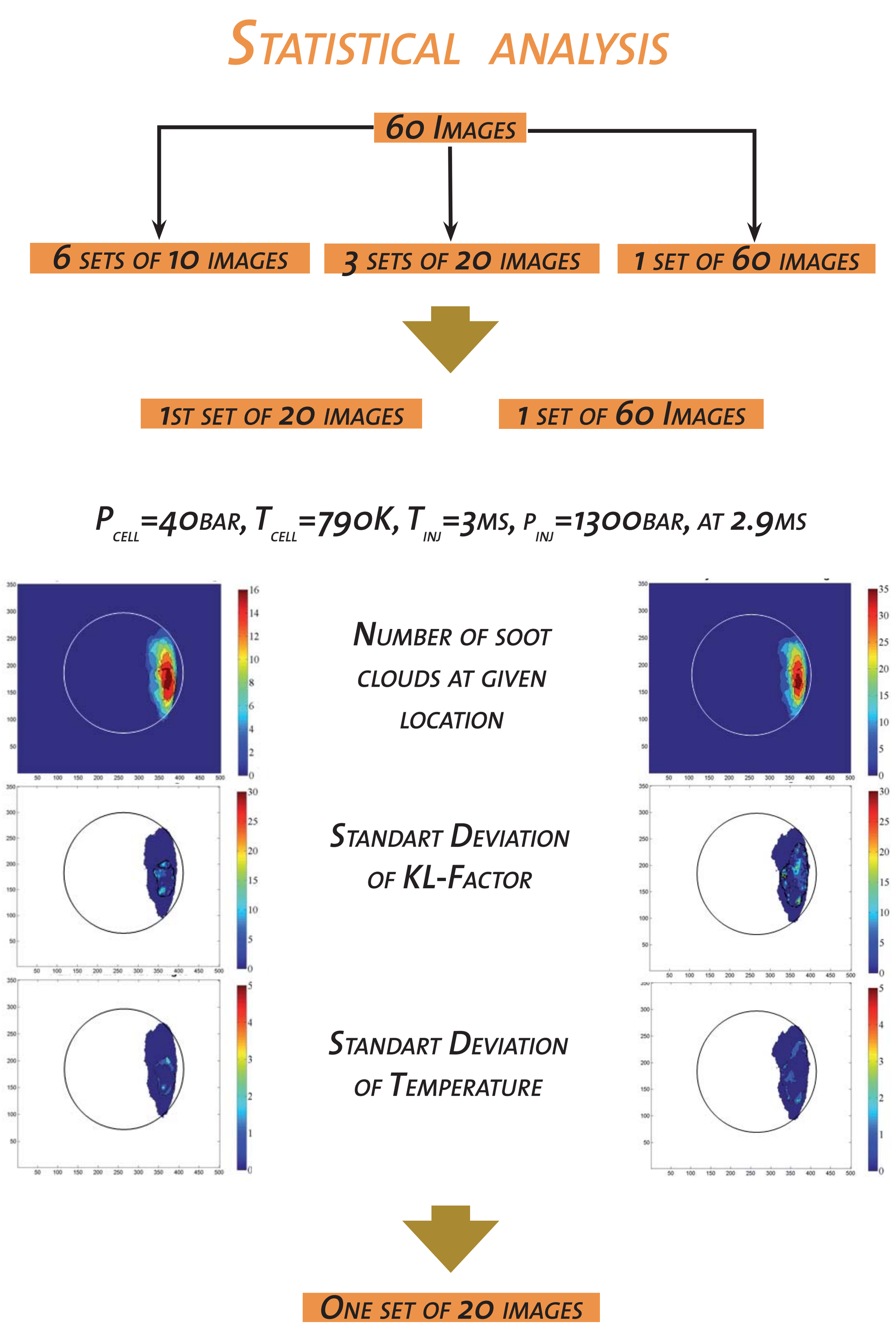
- constant volume: ~ 0.4l
- optical access: 4 sapphire window
- p_{cell} < 80 bar (before combustion)
- p_{cell} < 250 bar (after combustion)
- T_{cell} < 800 K (before combustion)
- Very high global λ
- Injection system: flexible (CR type)
- 200 bar < p_{inj} < 1500 bar
- t_{inj} > 0.3 ms

2-Dimensional Optical Techniques

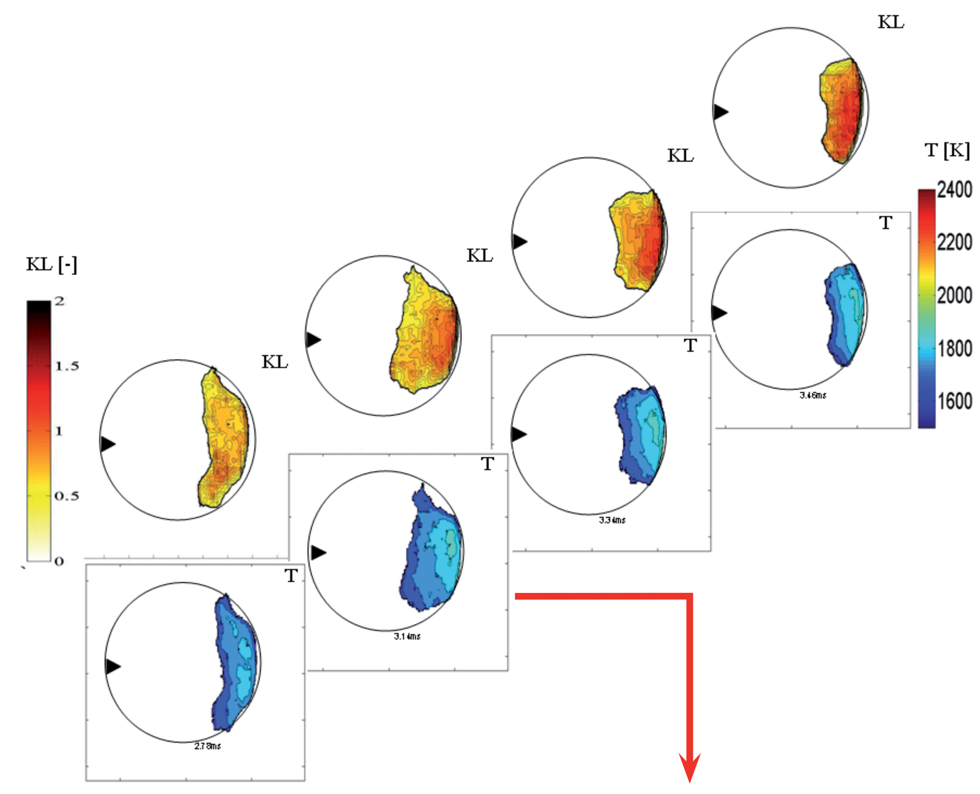
- Back Diffusion Laser (BDL) technique
- the pyrometry
- light detection by PMTs
- Record of cylinder pressure

These techniques are used for the study of soot formation and oxidation in similar diesel conditions. With both techniques the KL-factor of the cross section of the flame is calculated.

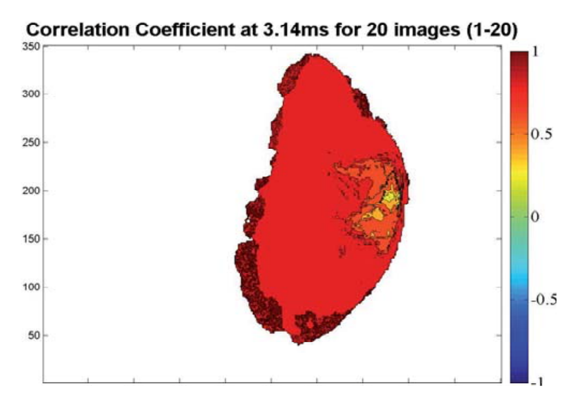




The statistical analysis has shown that a record of 20 images are is appropriate and sufficient for the study of the soot formation and oxidation in the constant volume combustion chamber.



p_{cell}=60 bar,
T_{cell}=790K,
T_{inj}=3 ms,
p_{inj}=900 bar



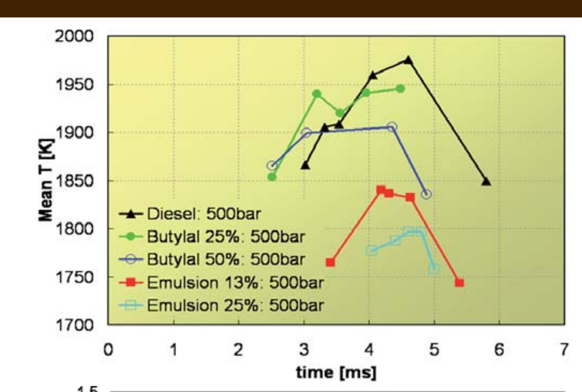
Results

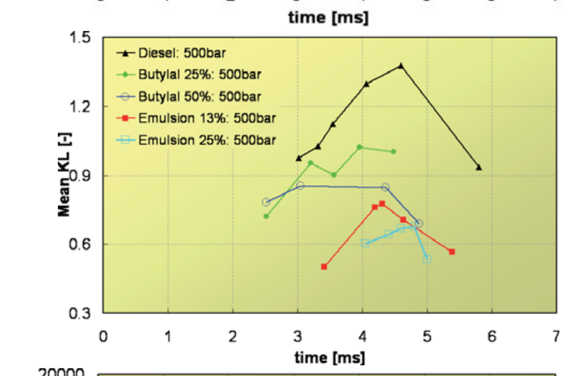
Fuels: Diesel, Diesel-Butylal blends 25% & 50%, Water-Diesel Emulsions 13% & 25%

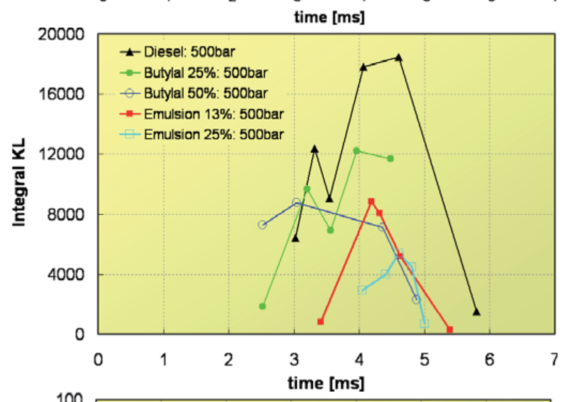
Operation Conditions: p_{cell}=60bar, T_{cell}=790K, T_{inj}=3ms, p_{inj}=900bar

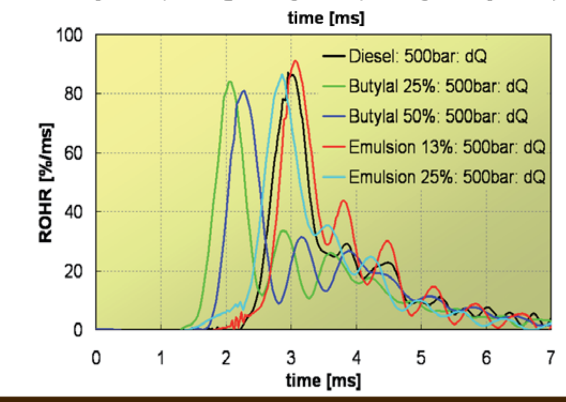
Constant load engine conditions: the injected fuel was adjusted, based on the Lower Heating Value (LHV) and the injection duration

- The mean temperature, the mean KL-factor and its integral (the sum of the KL-factor of the flame cross section) of the soot cloud decrease as a function of the fuel in the following order: diesel, butylal blends 25 & 50% and water-diesel emulsions 13 & 25%
- The rate of heat release shows that the peak values for diesel and both water-diesel emulsions appear at a similar time after the start of injection (ASOI) and have similar values. Using butylal blends (25% and 50%) the peak heat release rate appears earlier. It is observed that the ignition delay gets shorter, when blends of oxygenated diesel additives are used
- Chemical compositions of the fuels: Butylal contains oxygen and has higher cetane number (CN) compared to Diesel. The high concentrations of oxygen in the mixture allow for better soot oxidation. Emulsions contain water that influence the flame temperature and the ignition delay. The cooling effect of the evaporation of the water depends on the quantity injected in the chamber. Usually, the droplet evaporation of the water generates a secondary atomization, promoting the fuel air mixing.









Publications

[1] K. Boulouchos, O. Margari, A. Escher, G. Barroso, B. Schneider, S. Kunte: Optical Diagnostic on Diesel Sprays for the Validation of Computer Aided Simulation, 6. Internationales Symposium für Verbrennungsdiagnostik, Baden-Baden, June 2004

[2] B. Schneider, K. Boulouchos, B. Ineichen: Experimental Investigation into Diesel-Sprays under Evaporating and Non-Evaporating Conditions in a High Temperature and High Pressure Cell, 3rd Meeting of the Greek Section of the Combustion Institute, Patras, 7-8 November2003

[3] A. Bertola: Technologies for Lowest NOx and Particulate Matter Emissions in DI-Diesel Engine Coimbustion-Influence of Injection Parameters, EGR and Fuel Composition, Diss ETH No. 15373, 2003

Contacts
Ourania Margari margari@lav.mavt.ethz.ch
Prof. K. Boulouchos boulouchos@lav.mavt.ethz.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich