# Detailed Analysis of Mixture and Combustion of Diesel Jets by Laser Induced Fluorescence Techniques

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The evolution of Diesel engines in the last decades has been driven by the stringent pollution legislation and increasing environmental concern. In this context the Diesel engine appears like a very good candidate due to its naturally high efficiency. However, in order to further reduce engine out pollutant and green house gases to the required limits, a detailed study of the fuel-air mixing and combustion processes is necessary. An investigation of those processes by Laser Induced Fluorescence (LIF) techniques is presented. The mixing process is studied by tracer LIF, enabling a statistical analysis of the mixture structure and of the effect of injection parameters. The combustion process is studied by simultaneous formaldehyde, Poly-Aromatic-Hydrocarbons (PAH) and OH LIF, giving access to detailed information on the combustion process. A strong coupling is observed between the two processes.

## Introduction

High Pressure Direct Injection (HPDI) has established itself as a proven technology which allows the efficient reduction of engine-out emissions in DI Diesel engines. But although HPDI is becoming a standard, the consequences of this new technology on mixing and combustion processes inside the combustion chamber have yet to be further understood because the physical phenomena involved are extremely complex, in particular since the two processes occur on overlapping time scales and therefore a strong coupling is happening.

For a detailed investigation of the physical processes occurring in the combustion chamber, optical diagnostics are the best candidates since they are the only way to obtain two dimensional quantitative measurements inside the combustion chamber. Various techniques are available for the study of mixing[1,2] and combustion processes[3], each one having its advantages and limitations. Among them, Laser Induced Fluorescence (LIF) is a complete and powerful tool giving access to detailed qualitative and quantitative information on the mixing and combustion processes. Examples of application of these techniques are presented here.

## Mixing process

Tracer LIF is appropriate for the study of the mixing process since it can provide two-dimensional quantitative information appropriate for statistical analysis. The first step of the application of tracer LIF to the measurement of fuel distribution in the jet is to develop a method to obtain normalized fuel mass concentration fields. In ref.[4] such a methodology was developed based on the knowledge of the injected mass at a given instant and taking into account laser sheet profile shape, beam steering effect corrections, and the effect of temperature on the LIF signal. The resulting fuel mass concentration field is illustrated in Figure 1 for a set of injection conditions.

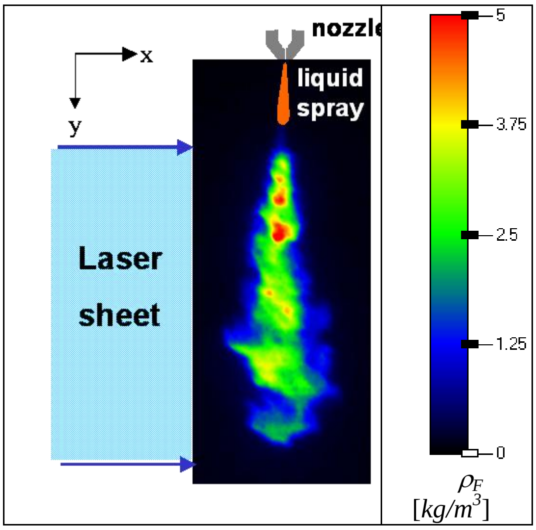


*Figure 1 : Schematics of tracer LIF images configuration and palette connecting image colors and fuel mass concentrations.*

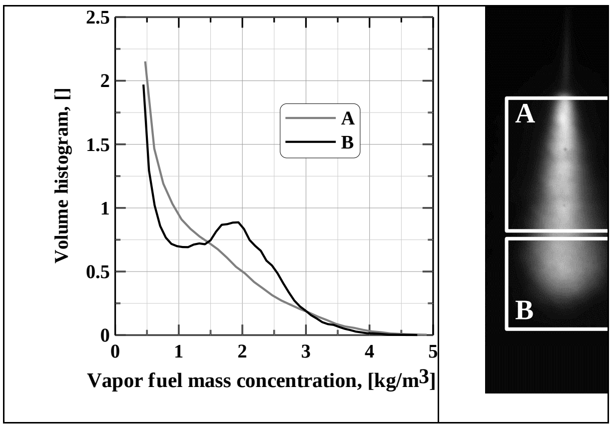


*Figure 2 : Comparison of statistical fuel distribution (volume histograms) obtained in the mixing zone (A) and the stagnation zone (B) (left), and illustration of the zone locations (right).*

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A statistical analysis of the mixture fields obtained by tracer LIF was carried out and is illustrated in Figure 2. It showed that the Diesel jet mixture can be separated in two distinctive zones: the mixing zone on the upstream sides, where air entrainment due to shear turbulence dominates the jet dynamic, and the stagnation zone at the tip where the jet pushes away the dense surrounding gases. The latter is characterized by a lower mixing rate since small scales turbulence are missing.

Such analysis was then carried out to investigate the effect on the mixing process of different injection parameters such as injection pressure (illustrated in Figure 3), nozzle hole diameter, injection duration.

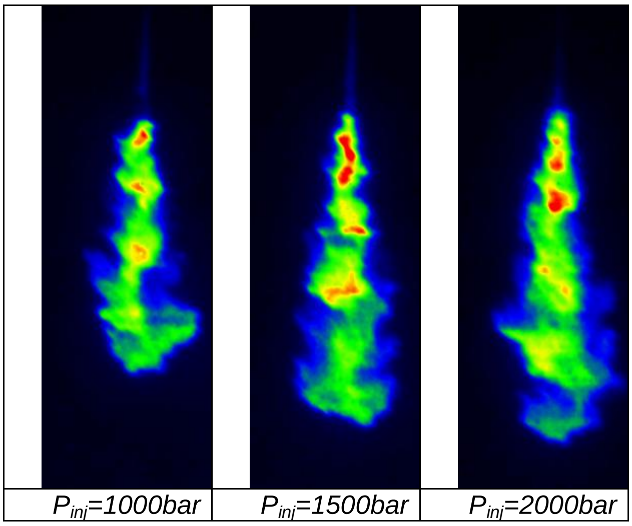


*Figure 3: Comparison of individual vapor fuel mass concentration fields obtained by LIF for different injection pressures.*

**Combustion process**

The combustion of Diesel jets is a complex process involving different steps from auto-ignition to the stabilization of a diffusion flame, and different regimes of combustion (premixed, diffusion, soot formation...).

In order to carry out a detailed analysis of the different combustion regions, a simultaneous formaldehyde, PAH and OH LIF technique was developed and applied to the Diesel jet configuration [5]. The technique allows to obtain simultaneous information on the different regions of the combustion zone: the low temperature zones with formaldehyde, the fuel-rich high temperature zones with PAH and the fuel-lean high temperature zones with OH.

Figure 4 shows a typical combined image obtained with this technique during the diffusion limited combustion. A detailed analysis of the structure of those images was carried out in order to identify the different regions of combustion and understand the evolution of the process, in particular the transition from premixed auto-ignition to diffusion controlled combustion.

The results were then synthesized by a conceptual model of Diesel jet combustion illustrated in Figure 5.

One important result that came out of those investigations is the clear connection between the mixture and combustion structures, as well as for the transition from auto-ignition to diffusion limited combustion than for the structure of the diffusion flame itself.

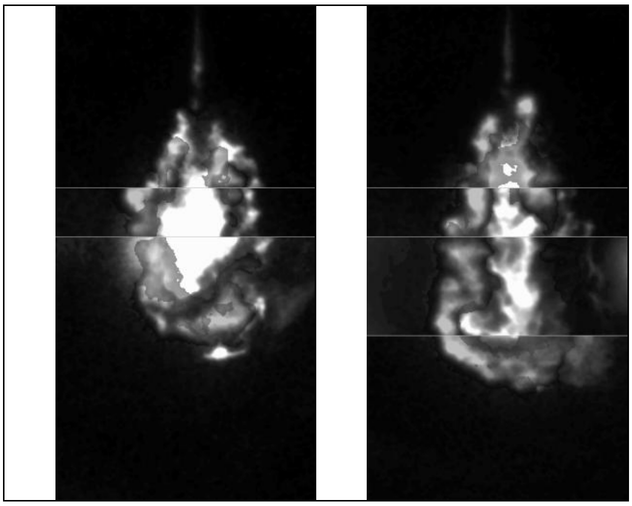

*Figure 4: Simultaneous OH and 355 LIF images during different stages of the diffusion-limited combustion phase. OH LIF in gray, formaldehyde and PAH LIF in white.*

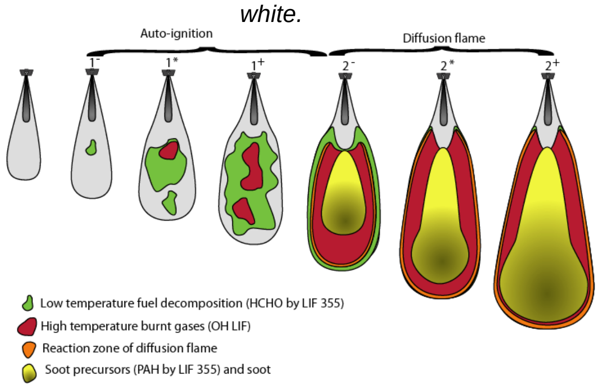


*Figure 5:Schematic for conceptual model of Diesel jet combustion.*

**Perspectives**

The study of mixture and combustion processes of Diesel jets by LIF clearly brought up the advantage of using such techniques for this kind of complex investigation. Furthermore, this kind of research can clearly benefit in the future from the improvement of LIF technique. Indeed in recent years, a lot of efforts has been made to obtain more quantitative information with LIF[6], in particular for measurements of temperature.

Also, it will be interesting in the future to use the LIF techniques presented here to study more complex configurations. For instance multiple injection strategies are a promising technology to further reduce engine out emission, and a more detailed analysis of the physical phenomena involved during those strategies will certainly help the optimization process of Diesel combustion systems towards cleaner engines.

## References


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