A COMPARISON OF SPRAY PROPERTIES FOR MODEL FUEL AND STANDARD DIESEL USING SEVERAL OPTICAL METHODS

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ABSTRACT

Many experiments are carried out using a model fuel, for instance for measurement technique reasons. These data are usually transferred to situations where standard diesel fuel is used. The objective of this work is to characterize the liquid and vapour phase penetration of two different diesel fuels, one two-component model fuel, IDEA (70% *n*-decane and 30% α-methylnaphthalene) and one standard diesel fuel (Swedish Environmental Class I), when injected into air with density corresponding to early injections up to self ignition conditions in diesel engines. The experimental study was carried out in the high-pressure, high-temperature (HP/HT) spray rig at Chalmers, which was pressurized in the range of 4 to 85 bar and with temperature ranging from 400 to 800 K. A common-rail injection system with a single hole nozzle was used. Several optical methods (Schlieren, Shadowgraph, LIF (Laser Induced Fluorescence) and Mie-scattering) were used together or separately which allow a comparison of the output. Phase Doppler Anemometry (PDA) was used for the two fuels as a complement to the planar methods. Results from measurements show that there are differences in liquid penetration, fuel vaporization and droplet distribution in between the fuels and relatively good agreement between the methods.

1 INTRODUCTION

Experimental research using diesel fuels like commercial diesel or a model fuel containing one or more components can be preformed with many different purposes like investigation of spray behaviour or the dynamics of fuel systems using different injection strategies, to make comparisons of measurement techniques or to create data bases that could be used to validate numerical simulations. It might also be necessary to transform data or information obtained from these experiments into situations where suitable experiments or measurements can not be performed.

The objective of this work is to characterize the liquid and the vapour phase penetration of two different diesel fuels, one two-component model fuel, called IDEA (70% *n*-decane and 30% α-methylnaphthalene), and one standard diesel fuel (Swedish Environmental Class I) when injected into air with a density corresponding to different conditions in a diesel engine during the compression stroke, and by using several optical methods in combination comparing the behaviour of the two fuels.

2 EXPERIMENTAL SETUP

The experimental study used mainly Mie-scattering and Laser Induced Fluorescence, LIF, with which it is possible to capture the liquid and vapour penetration simultaneously. Complementary optical methods used were Schlieren and Shadowgraph imaging and direct imaging with an AVL Visioscope system. Measurements of droplet properties were performed with a Phase Doppler Particle Analyzer from TSI/Aerometrics. The measurements were made for two cases corresponding to non-evaporating and evaporating conditions.

2.1 Spray rig and fuel system

The experiments were carried out in Chalmers high-pressure high-temperature (HP/HT) spray rig equipped with a common rail fuel injector system. Two single-hole nozzles with different diameter, 0.15 mm and 0.19 mm, were used. Pressure and temperature in the spray rig were in the range of 4 to 85 bar and 400 to 800 K respectively.

The fuels used were two, a standard diesel and a two component model fuel (IDEA), and the properties of the standard diesel and the components of the two components of the IDEA fuel is seen in Table 1.

Optical access for the different methods was possible by using two different pressure vessels, one with three windows suitable for the PDA measurements, and one with four windows for all other measurements. The spray rig is adjustable along the axial direction of the injector which makes it possible to observe the entire spray, see Figure 1.

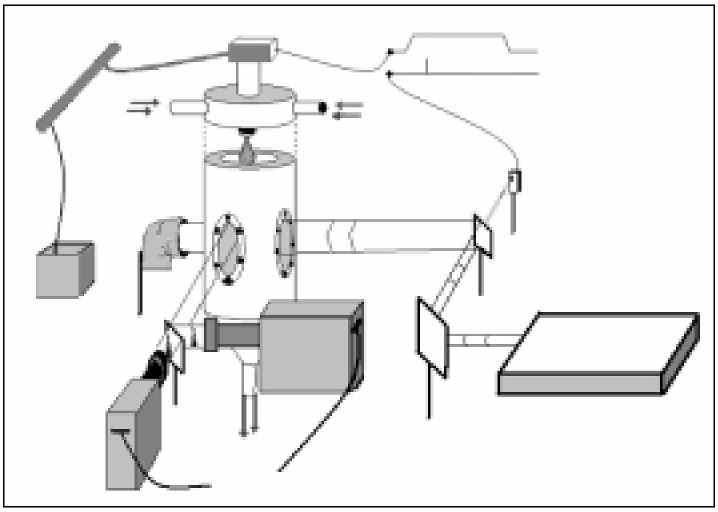

Figure 1 Schematic setup of the Chalmers HP/HT spray rig

Table 1 Properties of fuel used in experiments

Main physical data		**Fuel - Components**		
Property	**Unit**	Standard Diesel Swedish Environmental Class 1	*n*-decane $C_{10}H_{22}$	α-methylnaphthalene $C_{11}H_{10}$
Density	[kg/m^3]	836.8 @ 15 °C	730	1020
Kinematics viscosity	[mm^2/s]	2.58 @ 40 °C	1.2758 @ 20 °C	3.2658 @ 20 °C
Surface tension	[N/m]	26.0*10^{-3}	23.8*10^{-3}	40*10^{-3}
Boiling point	[K]	465 – 637	447.3	517.8
Cetane number	[-]	51.8	77	0
Vapour pressure	[Pa]		133	6.1

2.2 Optical methods

Several optical methods (Schlieren, Shadowgraph, LIF (Laser Induced Fluorescence) and Mie-scattering) were used together or separately which allow a comparison of the output. Phase Doppler Anemometry (PDA) and direct photography were used as a complement to the planar methods.

Mie-scattering and Laser Induced Fluorescence. The light of the pulsed Nd:YAG laser (wavelength 266 nm) was set up to give a laser sheet with a height of 48 mm and a width of 0.8 mm. The laser pulse had an intensity of 60 mJ and length of 12 ns. As shown in Figure 1, the laser sheet passes through the window and continues into the spray where the α-methylnaphthalene in the vaporized fuel absorbs the light of this specific wavelength and emits light in the 355 nm range. Scattered and fluoresced light thereafter passes a beam splitter where one of the two intensified CCD cameras uses a band pass filter ranging between 265±25 nm for the Mie-scattered light and the other a high-pass filter, UG1, for the fluoresced light from the α-methylnaphthalene

Schlieren and Shadowgraph. In these experiments the Nd:YAG laser was set up with a wavelength of 532 nm. The laser beam was expanded and parallelized using spherical lenses. The Schlieren method will obtain information on transparent media with refractive index gradients in the spray. When the Shadowgraph method is used will light that passes leaves a shadow of the liquid and vapour in the spray depending of the amount of absorbed light. In both cases is the light let trough projected on a low reflection paper screen and captured with an ICCD-camera.

Direct photography. During these experiments photographs of the spray were captured with digital photography equipment (AVL Visioscope). This includes a high resolution camera with short enough exposure time to make it possible to capture reliable information about the spray behaviour. The equipment is primarily used in combination with the Mie/LIF and Schlieren/Shadowgraph experiments to calibrate injection timing and trig signals for the control and acquisition units. However, the images were also used to estimate the liquid penetration of the injected fuel.

Phase Doppler Anemometry. Measurements of droplet properties were done with equipment from TSI/Aerometrics giving diameters and velocities in two directions. The measurements were also used to investigate the penetration of the non-evaporating spray. Droplet measurements were carried out along the spray axis in steps of 5 mm. The radial coordinates during the sampling were chosen in order to get a high sampling frequency which could be a problem close to the centre-line of the spray.

3 IMAGE ANALYSIS

The image analysis focuses on the Mie and LIF measurements in order to get the penetration length of the injected fuel. Data from the other optical methods is compared to the Mie/LIF as a complement. In general the pictures captured from the different cameras are stored as different binary files, and thereafter processed in MATLAB.

3.1 Mie-scattering and LIF

The signals captured from the scattered and fluoresced light have different signal to noise ratios and are therefore treated differently in the image analysis. A typical example thereof is shown in Figure 2 where the strong signal to the right represent the LIF-picture of the spray, which not requires any special treatment before capturing the length or the angle of the spray, the Mie signal on the other and seams to require some data processing. In this case one can suspect that there might be some minor slugs or formations of droplets that might be scattering a relatively weak signal due to the absorption of light in the gaseous fuel at the periphery of the spray were the laser sheet enters. A first step in the image analysis is to cut of the strongest signal in order to amplify the weak signals relatively to the background, see Figure 3. Finally, as shown in Figure 4, one can add the processed image of the Mie-scattered light with the LIF image for capturing the wanted data like the spray length.

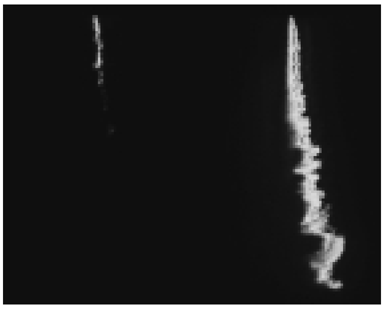

Figure 2 Raw Mie and LIF

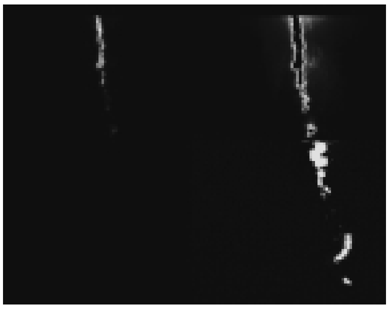

Figure 3 Mie, raw and modified

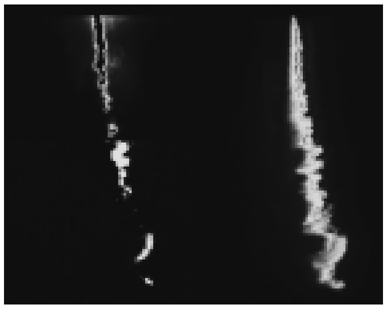

Figure 4 Modified Mie and LIF

3.2 Schlieren and shadowgraphy

Starting with the captured lengths from the Mie/LIF measurements of the IDEA-fuel one can more easily interpret and calculate the liquid and vapour penetration of the two fuels from the Schlieren and Shadowgraph experiments. Due to the rather diffuse edges of the spray, see Figure 5, there must be some definition of how to define what is spray and what is background. One way to do this for Schlieren images is to average a couple of images just by adding them together and look for the point where the curve of the signal intersect with a threshold set to 10 % of the maximum value, Figure 6. Penetration obtained from the Shadowgraph pictures are calculated in a similar way by finding a disruption in the signal from the shadowed light exemplified in Figure 7 and Figure 8.

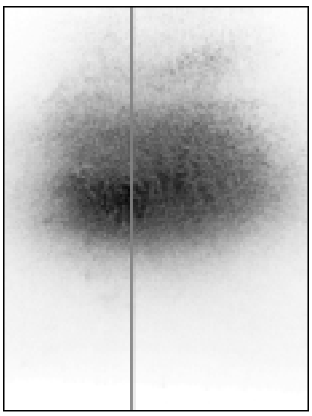

Figure 5 Schlieren image of a spray with line showing where the signal is captured

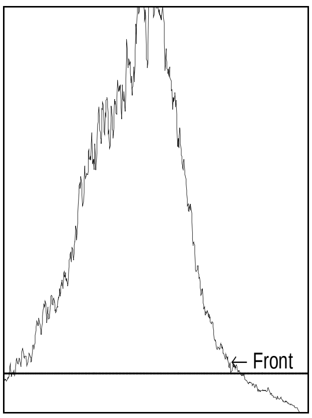

Figure 6 Signal from a Schlieren image with threshold defining the front of the spray

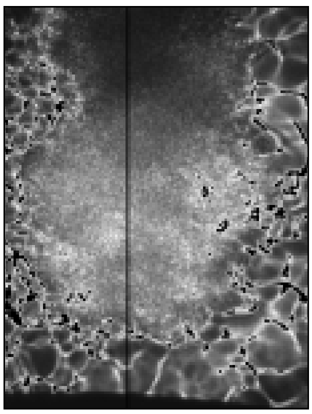

Figure 7 Shadowgraph image a spray with line showing where the signal is captured

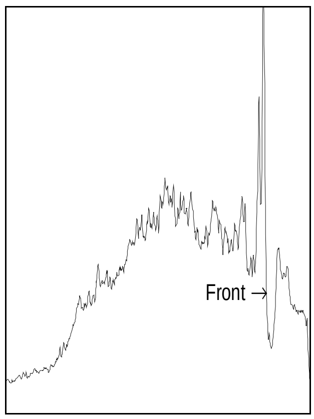

Figure 8 Signal from a Shadowgraph image with a disruption defining the front of the spray

3.3 Direct photography

A negative of a photograph captured with the AVL equipment showing the reflected flash light from the liquid in the spray is shown in Figure 9. The line indicates where the cut are located that are used for identification of thresholds when to interpret and calculate penetration length. Values from the line are plotted in Figure 10 showing a small increase where the front of the liquid are defined.

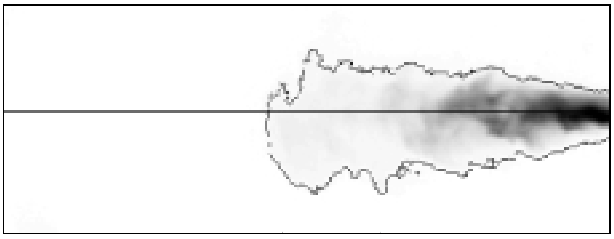

Figure 9 Photograph of liquid in a spray with a line indicating where signal is captured

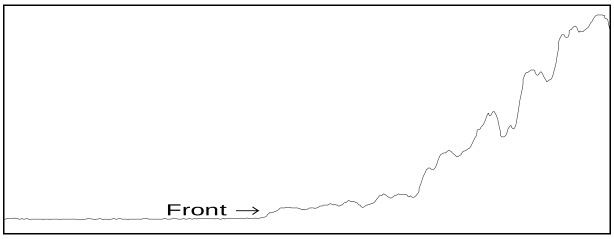

Figure 10 Signal from a photography with threshold defining the front of visible liquid in a spray

4 RESULTS

4.1 Non-evaporating conditions

Data from PDA-measurements with low air temperature and low pressure are shown in Figure 11 and Figure 12 where it can be seen that the IDEA fuel penetrates faster and also that the droplets of the IDEA fuel in general are larger. One can notice that the injected fuels seem to penetrate with a similar behaviour even if density of air and fuels differs, shown in Figure 13.

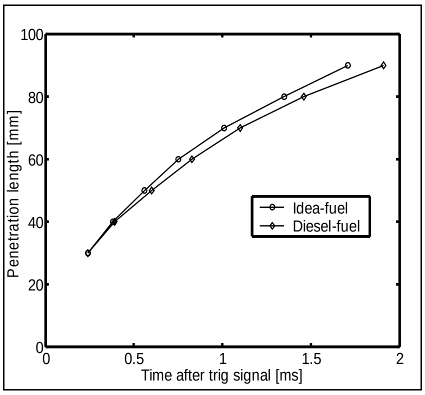

Figure 11 Droplet penetration for diesel and IDEA fuel from PDA measurements. Spray rig pressure 16 bar, injection pressure 1350 bar and air temperature 393 K.

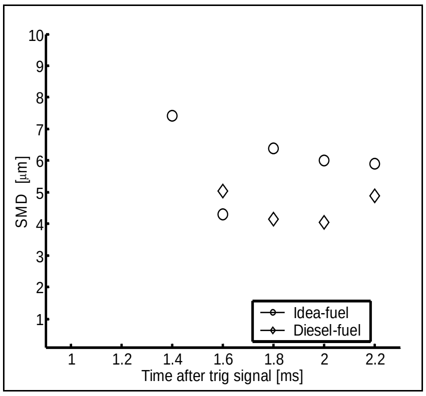

Figure 12 Sauter Mean Diameter from PDA measurements on diesel and IDEA fuel 90 mm downstream. Spray rig pressure 16 bar, injection pressure 1350 bar and air temperature 393 K.

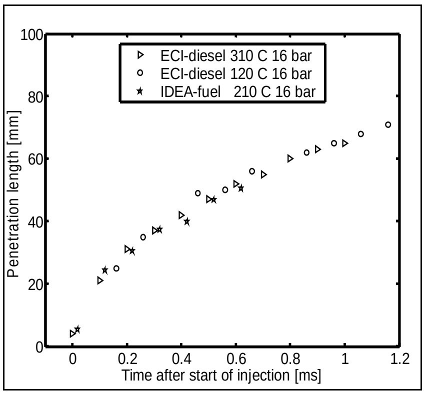

Figure 13 Liquid penetration from Mie measurements on diesel and IDEA fuel. Spray rig pressure 16 bar and injection pressure 1350 bar.

4.2 Evaporating conditions

Calculated penetrations lengths from Schlieren measurements at conditions with slightly increased backpressure and with a temperature just below to ignition temperature are plotted in Figure 14 and showing that the vaporised IDEA-fuel seems to penetrate a little bit faster than the vaporised diesel fuel. Fuel penetration calculated from Shadowgraph measurements showing similar behaviour as penetrations from Schlieren measurements, see Figure 15. Figure 16 shows the calculated liquid penetration of visible droplets of IDEA and diesel fuel captured with AVL's direct photograph equipment. From the same pictures is the core of the spray captured and shown in Figure 17.

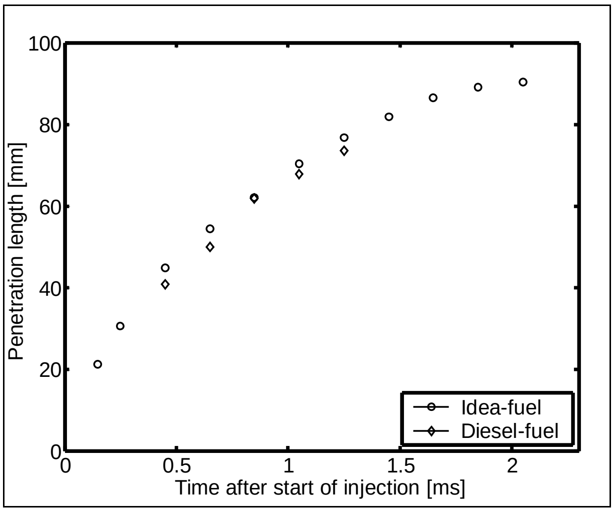

Figure 14 Vapour penetration from Schlieren measurements on diesel and IDEA fuel. Spray rig pressure 24 bar, injection pressure 1350 bar and air temperature 713 K.

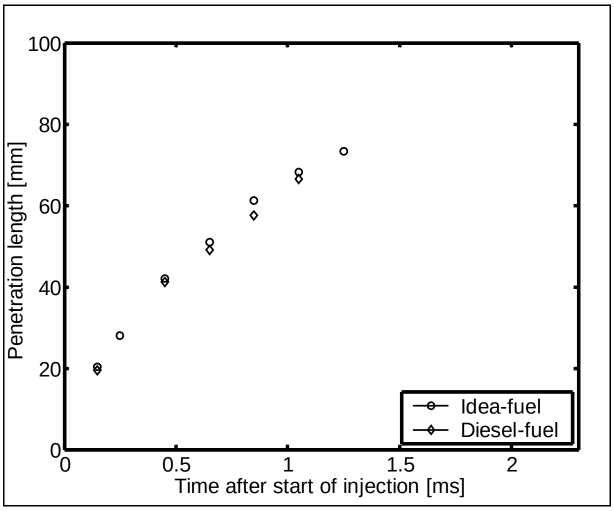

Figure 15 Liquid penetration from Shadowgraph measurements on diesel and IDEA fuel. Spray rig pressure 24 bar, injection pressure 1350 bar and air temperature 713 K.

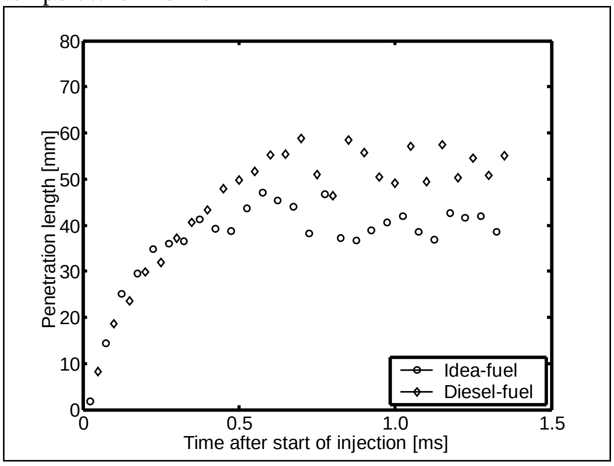

Figure 16 Liquid droplet penetration calculated from direct photographing on diesel and IDEA fuel. Spray rig pressure 44 bar, injection pressure 1350 bar and air temperature 773 K.

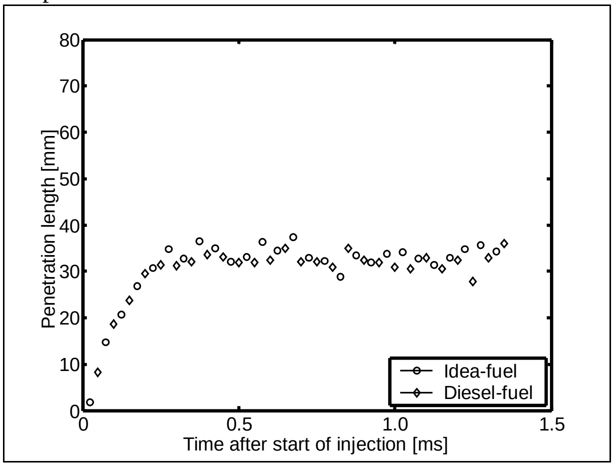

Figure 17 Liquid core penetration calculated from direct photographing on diesel and IDEA fuel. Spray rig pressure 44 bar, injection pressure 1350 bar and air temperature 773 K.

5 DISCUSSIONS AND CONCLUSIONS

Results from the Mie-scattering measurements shown in Figure 13 shows that the two fuels have a similar behaviour looking at the liquid penetration but when comparing the penetration of droplets, see Figure 11, there are a minor difference not only the penetration rate but also the size of the droplets, see Figure 12. When increasing the temperature one can see that the vapour penetration between the fuels differs up to 10 % during the injection, see Figure 14. This difference, see Figure 15, was also seen when using the Shadowgraph method, indicating that there is liquid fuel present at the front of the spray. The presence of liquid fuel was also seen in Mie/LIF experiments on IDEA fuel [1]. Differences in liquid penetration between the fuels is also shown by using direct photographing methods on the two fuels, see Figure 16. Results from the direct photographing method also indicates that the liquid core penetration is quite similar between the fuels and also constant in length, see Figure 17. This is also observed in Mie/LIF experiments on IDEA fuel [1] and by others [2, 3].

By combining several optical methods can the behaviour of different fuels be studied and characterised with good agreement between the results. There might be some physical properties that have to be more investigated and taking care of like how the fuel properties affect the dynamics of two different fuels [4].

6 REFERENCES

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