EFFECT OF FUEL QUALITY ON PROPERTIES OF A DIESEL SPRAY

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ABSTRACT

A large variety of diesel fuels were tested to verify if fuel has a considerable effect on the properties of diesel fuel sprays. Measurements were made with a fuel injection system from a medium speed diesel engine with output of 170 kW per cylinder. Maximum injection pressure in the tests was 120 MPa. The orifice in the nozzle was 0.37 mm in diameter. All the measurements were made at room temperature but at a high pressure in nitrogen atmosphere with a gas density of 39 kg/m^3.

The spray tip penetration and the width of the spray were analysed from images taken with a flash lamp and a CCD-camera with short exposure times. Droplet sizes in the spray were measured with a diffraction drop size analyzer at the edge of the spray where multiple scattering was not too severe. For most of the test fuels viscosity and density were kept constant as composition of the fuels was changed. In tota, 12 fuels was tested.

Fuel properties had no effect on the spray tip penetration, a small effect was observed in the spray width and even more in the droplet size. Analysis of the effect of single properties was difficult due to cross effects between fuel parameters. Mean spray angle was from 15 degrees to 24 degrees. Lowest spray angles were observed at low injection pressures and gas density and as the fuel viscosity, surface tension and initial boiling point were high.

INTRODUCTION

Properties of a diesel spray are known to be a function of orifice geometry, injection pressure, viscosity and density of fuel and density of gas based on literature and previous studies [1]. In this study the object was to look deeper into the effect of fuel properties on the characteristics of the spray. In addition to viscosity and density, the effect of surface tension and distillation were studied. Changes in the spray were not expected to be large as most properties of hydrocarbon fuels do not vary over a large range. That meant that all measurement had to be made at constant conditions, with great accuracy or at least repeatability, and the change in the composition of fuels had to be as large as possible. Measurements reported in [2], were a part of this study.

EXPERIMENTAL SET-UP

Measurements were made at an injection test rig for medium speed engines, at room temperature and at an elevated pressure. Density of the gas in the measurement chamber corresponded to that of a real engine at the time of injection. The measurement chamber was equipped with three windows for imaging and droplet sizing. The injection equipment was from a small medium speed engine, camshaft, injection pump, injection valve and nozzle (Figure 1). The camshaft was rotated with an electric motor driven by an AC inverter and was equipped with large flywheels to maintain steady rotational speed. The injection nozzle was modified. Nozzle orifices next to the measured one were plugged and orifices on the opposite side were drilled larger to maintain the same volume flow as in the original nozzle. Injection pressures for different fuels were adjusted to the same level using different rotational speeds and rack positions. Thus injection pressure was constant regardless of the fuel used such as in a common-rail injection system. Without adjustment the injection pressure had been lower with fuels with low viscosity and/or low density. Figure 2 presents the injection pressure in the engine and with two of the tested fuels.

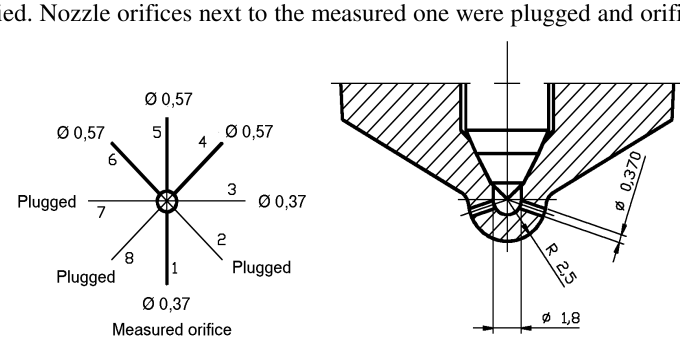

Figure 1 *Nozzle used in the measurements.*

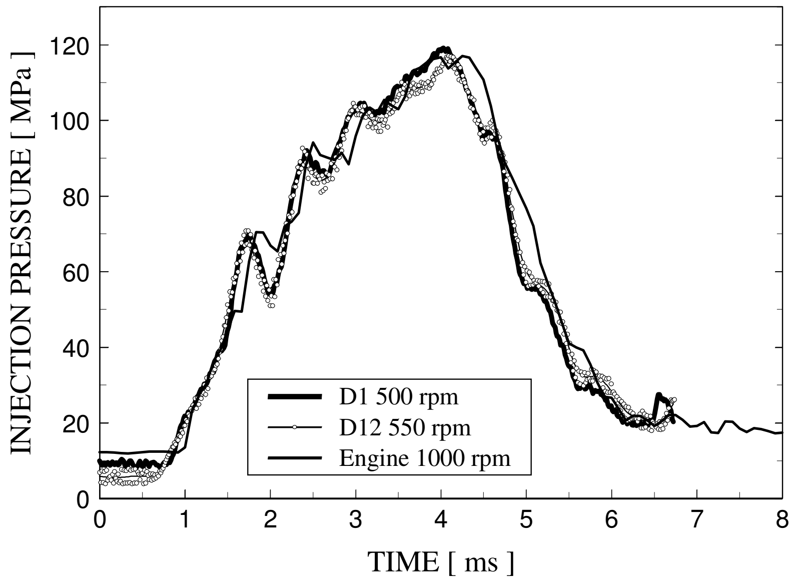

Figure 2 *Injection pressure in the engine and spray test rig.*

The measurement chamber was pressurised with nitrogen to maintain gas densities of 12, 20 or 39 kg/m^3. Gas was conducted on the windows to keep them clean and to the spray cutter. The spray cutter was used for measurements of droplet size to maintain multiple scattering at an acceptable level. The thickness of the cut slice of the spray was 2, 5 or 25 mm. In former measurements [3], the use of cutter blades was noticed to decrease measured droplet size. However, this error is small and is of no significance in comparative measurements.

The injection pressure, needle lift, and trigger pulse were measured with a high speed data acquisition system. The sampling interval of the measurements was 13.5 µs and the accuracy of the timing was 23.5 µs. Zero for timing was the moment when needle lift was 50 % of the maximum lift, which is later than the start of injection.

Imaging was performed using a black and white CCD-camera at a resolution of 1280x1024 pixels. The spray images were illuminated with a Xenon flash lamp using diffuse backlight. The flash duration was 0.5 µs to 2 µs depending on the power level. The spray tip penetration and the width of the spray was measured from CCD-images with an automated image analysis program. The background was subtracted from the images to get an image of plain spray as in Figure 3. The spray tip penetration was measured at five angles from which the highest value was selected. The width of the spray was measured at three distances, 2 mm, 39 mm and 62.5 mm from the orifice. The edge of the spray was determined to be at the point where the intensity of the light was decreased to a value of 40 % from that at centre of spray in the line histogram. Spray angle was then calculated from these values.

The droplet size measurement was made with a Malvern 2600 analyzer, but with a smaller than standard laser beam diameter of 4 mm. Measurements were made at a delay of 2 ms from the moment of 50 % needle lift, in a cross section at a distance of 62.5 mm from the orifice (169*d) at several points. Measurement points are presented in Figure 4.

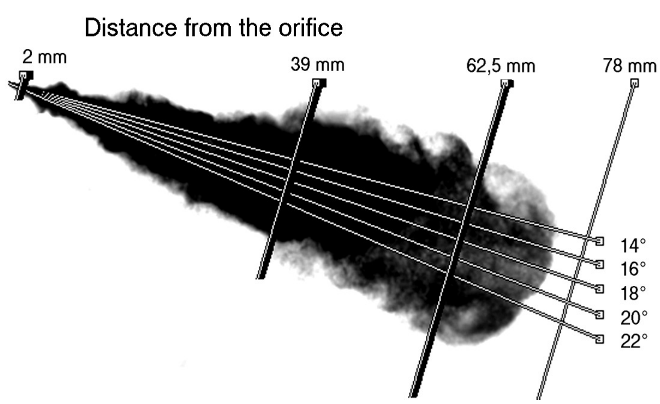

Figure 3 *Analysis of the spray tip penetration and width of the spray from the video images.*

FUELS

Reference fuel D1 was a diesel fuel normally used with small medium speed engines and its viscosity was higher than that of automotive fuels. Reference fuel D2 was a commercial automotive diesel fuel. The fuels were blended to obtain differences in viscosity, surface tension and distillation. Fuels D3 and D8 contained additives influencing the surface tension, D4 and D12 were paraffinic and D5 was aromatic/naphtenic in composition. D9 contains oxygen and fuel D10 was rapeseed methyl ester. Fuel D11 was a diesel/water emulsion. The accuracy of the viscosity and the density results of fuel D11 are more inaccurate, as the methods used were not suitable for an emulsion. Surface tension was measured at room temperature. Physical properties of the fuels are presented in Table 1. Compressibility of fuels may differ due to compositional changes, but no method was available for measurement. In the same table, the rotational speed used with the high pressure pump to maintain constant injection pressure level before the injection valve is given. The temperature of the fuel before the injection pump was kept at 23ºC ±2 ºC. The temperature increase in the high pressure pump was 5 ºC.

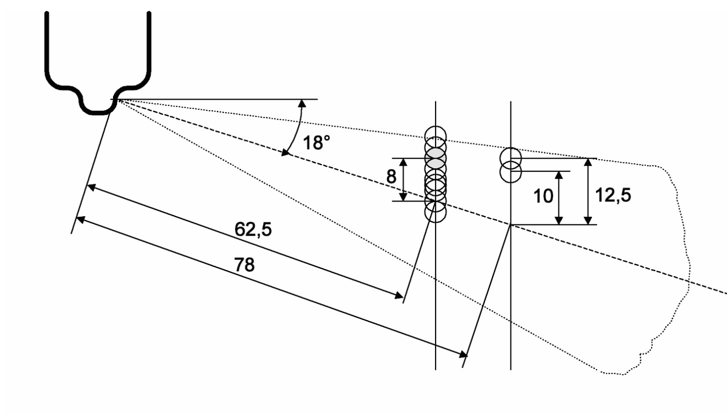

Figure 4 *Location of measurement volumesfort the droplet size measurement.*

Table 1 *Properties of fuels and rotational speed used compared to fuel D1. * Marked values are estimates.*

Fuel	Density at +15 °C ASTM D4052	Viscosity at +30 °C ASTM D445	Surface tension ASTM D971	Initial Boiling Point ASTM D86	Mid Boiling Point ASTM D86	Final Boiling Point ASTM D86	Rotational speed
	kg/m^3	mm^2/s	mN/m	°C	°C	°C	%
D1	858,8	8,04	30,4	208,2	322,0	379,8	100
D2	829,8	3,24	29,0	179,1	264,1	358,5	108
D3	829,6	3,28	25,0	185,3	261,0	360,5	108
D4	804,7	3,15	27,6	185,3	259,1	357,5	110
D5	866,8	2,08	29,9	136,7	275,2	372,0	108
D6	832,5	2,85	28,3	167,1	252,3	366,7	108
D7	820,3	2,40	28,0	168,4	233,4	352,6	110
D8	829,7	3,33	27,4	182,9	263,8	358,6	108
D9	834,7	3,09	28,6	186,2	259,3	357,9	108
D10	882,9	5,64	32,4	335*	339*	354*	100
D11	866,2*	> 6 *	30,0	100*	230*	358*	100
D12	816,3	2,46	28,3	198,0	236,7	303,5	110

RESULTS

The spray tip penetration was measured at intervals of 20 to 50 times for each fuel. At the start of injection the penetration accelerated as a paraboloid until a steady velocity was achieved, as can be seen in Figure 5. At a later time, the spray decelerated and the penetration velocity decreased relative to the square root of the time. In Figure 6, the spray tip penetrations of all 12 fuels are presented. As can be seen there was little difference between the penetrations of these fuels, in terms of measurement accuracy. The change in the velocity at the nozzle, due to variation in the density of the fuel, was not detectable.

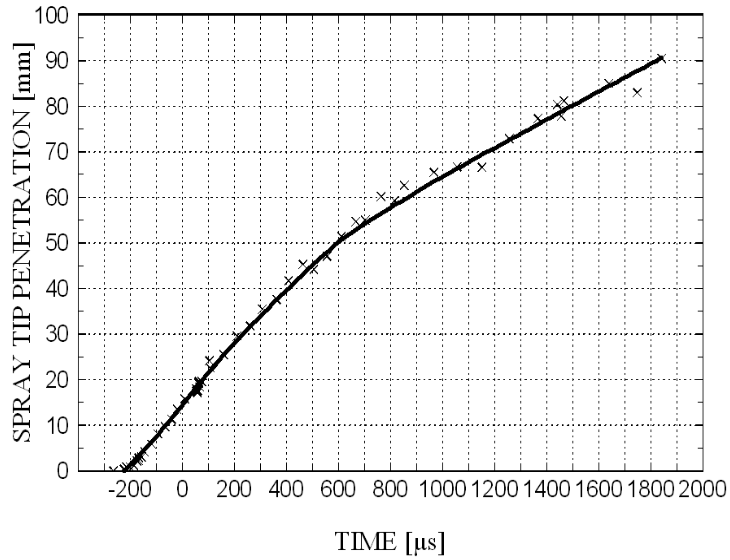

Figure 5 *Spray tip penetration as function of time with fuel D1, 500 rpm, gas density 39 kg/m^3 . Measured points and weighted least squares regression*

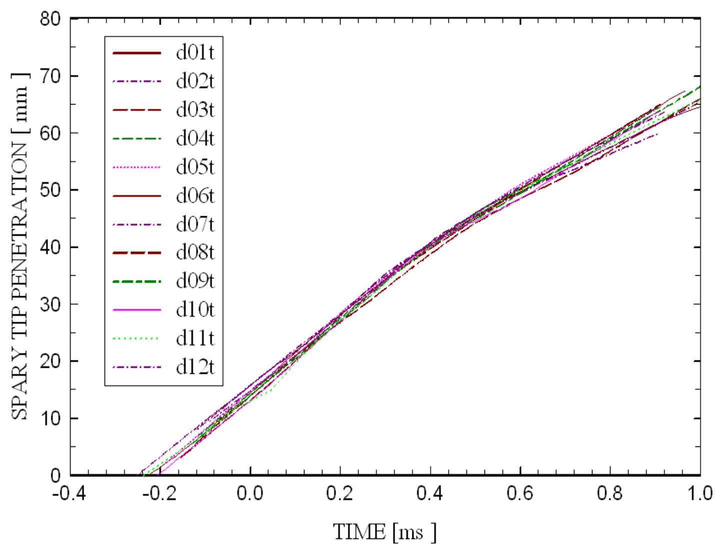

Figure 6 *Spray tip penetration of all tested fuels, 500 rpm, gas density 39 kg/m^3. Linesre present weighted least square regression.*

At the start of the injection the angle of the spray was very wide, up to 40°, but decreased fast to about 20° as injection pressure increased. At large distances from the orifice, the angle of the spray was at first small but increased to a steady value as the spray tip had passed the measurement point as can be seen from Figure 7. Spray angles with all 12 fuels are presented in Figure 8. The mean of all the measurements and the confidence interval of 95% was 21.1° ±0.9°. The quite large confidence interval is due to a large variation of the widths of the individual sprays. The final boiling point of the fuel had the most prominent effect on the spray width.

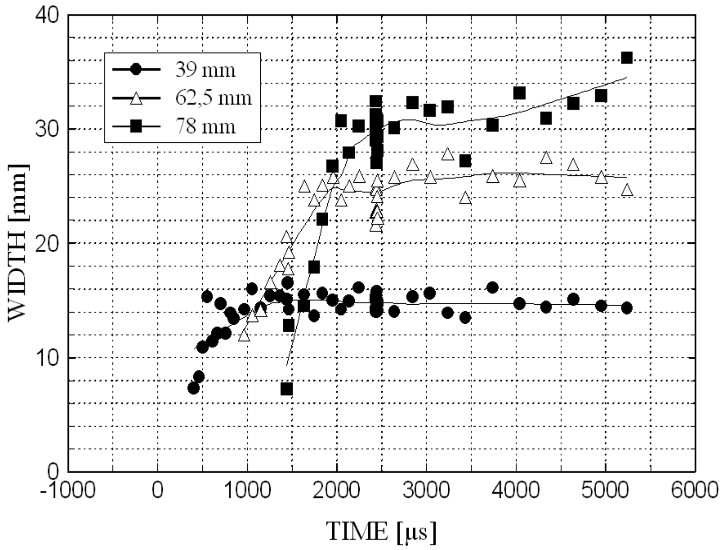

Figure 7 *Width of the spray as function of time with fuel D1.*

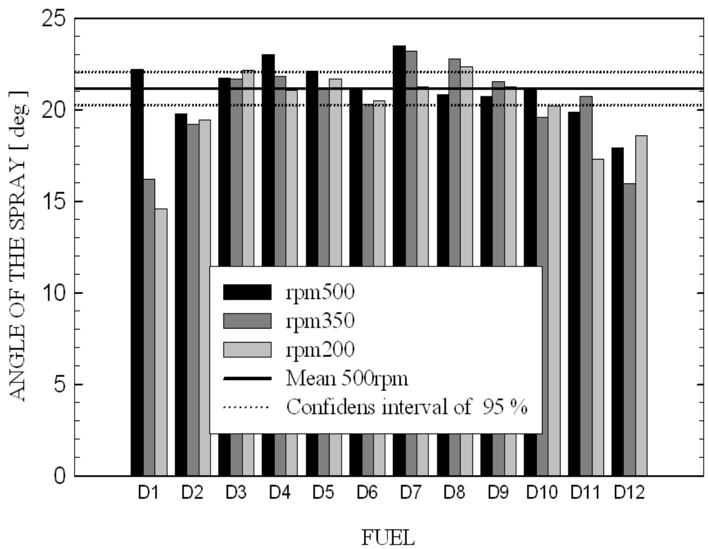

Figure 8 *Width of the spray, gas density 39 kg/m^3.*

Droplet size distribution was assumed to have Rosin-Ramler distribution and a corresponding analysis algorithm was used. The Rosin–Ramler distribution has been found suitable for diesel spray measurements in earlier studies [1]. At one measurement point, a droplet size of 4000 droplets was measured with image analysis and showed consistence with the Rosin-Ramler distribution function. Standard correction for multiple scattering was used [4]. The smallest scattering angles were ignored in the analysis due to disturbance caused by the windows and the turbulent flow. Droplet size measurement results are averages from 20 samples. Error due to the statistical variation was estimated to be ±10%. In addition to changes in droplet size this was due to disturbance from turbulent flow. Accuracy of droplet size measurement was estimated to be ±20 % in cases where the influence of the multiple scattering after correction was small, i.e. obscuration was less than 85 %. For obscuration values of 85% to 95%, error was estimated to be under 30 %.

Despite the use of cutters for the droplet size measurements, density of the spray was high and multiple scattering occurred in most of the cases. In the centre of the spray multiple scattering was too high for reliable results, although some of these results are presented in Figure 9. These results occur where the dimensionless distance from the centreline of the spray was less than 0.4. Dimensionless distance is defined as the distance of the centreline of the laser beam to the spray centreline divided by half of measured width of the spray at the same distance from the orifice.

CONCLUSIONS

Only slight changes in the spray tip penetration due to physical or chemical properties of the fuel with the tested 12 fuels were observed. However, measurable differences were detected in the angle of the spray. The lowest spray angles, 15°, occurred at low injection pressures and gas density and at higher levels of viscosity, surface tension and higher initial distillation point. At high injection pressures the narrowest spray was 18° and the widest spray was 22°. Change of the spray angle has a considerable effect on the combustion in small high pressure combustion chambers of diesel engines.

Droplet size was measured in the outer parts of the spray as in the centre parts the droplet size was under the measuring range, less than 6 µm. At a dimensionless distance of 0.7 from the centreline of the spray, droplet size was from 13 µm to 22 µm with different fuels. As expected the most significant correlation was found between viscosity and droplet size.

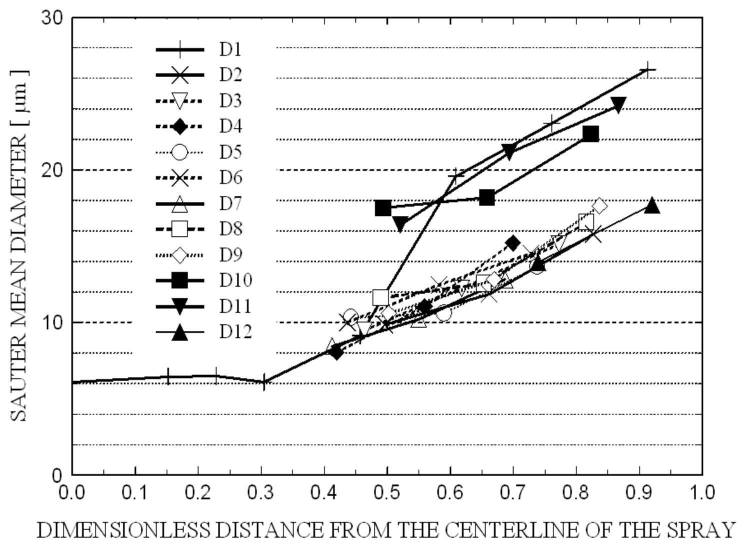

Figure 9 *Droplet size as function of dimensionless distance from the centreline of the spray in a diesel spray with different fuels, 500 rpm, gas density 39 kg/m^3 .*

ACKNOWLEDGEMENTS

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