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EXPERIMENTAL SPRAY STUDY WITH USAGE OF ALTERNATIVE FUELS

EKSPERIMANTALNA ŠTUDIJA RAZVOJA CURKA ALTERNATIVNIH GORIV

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Abstract

This paper presents an experimental investigation of the development of alternative fuel sprays. Injection process characteristics were measured with a Friedmann-Maier injection system test bench using different fuel blends. The spray was injected into the pressurised chamber at 40 or 60 bars and filmed with a high-speed camera. The image acquisition and processing system was developed in order to determine the spray-cone angle and the penetration length during different injection regimes. The results obtained from the experimental study show that differences in the chemical and physical characteristics of the alternative fuel blends used influence the spray characteristics (spray cone angle and penetration length). For wider usage of alternative fuels, further investigations need to be made.

Povzetek

Članek predstavlja eksperimentalno analizo razvoja curka alternativnih goriv. Karakteristike vbrizgavanja so bile izmerjene na napravi za izvenvozilsko testiranje tlačilk Friedmann-Maier, ob uporabi različnih mešanic goriv. Vbrizgavanje curka v namensko tlačno komoro, s tlakom 40 ali 60 barov, je bilo posneto s hitro kamero. Za lažjo določitev dolžine in kota curka je bila razvita posebna metoda obdelave slik, posnetih s hitro kamero. Rezultati študije so pokazali, da kemijske in fizikalne lastnosti uporabljenih alternativnih goriv vplivajo na karakteristike vbrizganega curka (kot in dolžina). Za širšo uporabo alternativnih goriv, so potrebne nadaljnje raziskave.

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1 INTRODUCTION

The attention given to alternative fuels (biodiesel, bioethanol) derived from vegetable oils or animal fats has increased, because they represent alternative and clean fuels for compression ignition engines. It is well-known that biodiesels can be used in diesel engines as blended forms with conventional diesel fuel, without modifications to the engine. In addition, biodiesel can be used as an appropriate method to reduce polluting emissions from the engine. Therefore, it is necessary to analyse the influence between the mixing ratio of alternative fuels and their influence on engine emissions. Furthermore, the atomisation characteristics of different alternative fuels (such as spray-tip penetration and mean droplet size) play a decisive role in engine performance. In combination with the different physical properties of the analysed fuels, all influencing factors increase the complexity of the spray phenomena. Therefore, such spray is the subject of intensive experimental studies.

Ramadhas et al., [9], studied correlations between the physical properties of biodiesels and their combustion characteristics. They concluded that biodiesel-blended fuels can be used as alternative fuels for diesel engines without modification and even that pure biodiesel can be used for diesel engines with some minor modifications. Lang et al., [6], showed that, on a foundational level, biodiesels have properties compatible with those of conventional diesels. To study the effect of the high viscosity of biodiesels on spray characteristics, Grimaldi and Postrioti, [4], compared the process of spray development between conventional diesel and biodiesels, using a common-rail injection system. Their results indicated that the spray tip penetrations increase in accordance with the increase in the mixing ratios of the biodiesels. The main reason for this is the fact that biodiesels are barely atomised in comparison to conventional diesel, due to biodiesels' high surface tension. Despite these efforts, the fuel atomisation and combustion characteristics of alternative fuels have not yet been fully investigated. In particular, research on the correlations of fuel atomisation and combustion performance of the alternative fuels and its blends is needed. In this study, an experimental method for the determination of spray tip penetration and spray length was developed and used for measurements. Injection process characteristics, such as injection pressure, nozzle needle lift, injection rate, and the volume of injected fuel, were recorded simultaneously on a Friedmann-Maier fuel injection systems test bench.

2 EXPERIMENTAL DETAILS

2.1 Injection System Characteristics

Injection characteristics were measured on the Friedmann-Maier type 12 H 100-h fuel injection system test bench, Kegl, [5]. A conventional fuel system with a high pressure pump (Bosch PES6A95D410LS2542) was used. A one-hole injection nozzle with a diameter of 0.68 mm (Bosch DLL25S834) was mounted into system. For the injection pressure measurement, a piezo-resistive sensor (Kistler, type 6227) was used. The nozzle's needle lift was measured using an inductive sensor. All the data was acquired and processed by a program written in LabVIEW 2012.

2.2 Experimental setup

The measurement system consisted of a pressure chamber and two subsystems. Subsystem 1 was used for pressure setup and Subsystem 2 for spray injection (Figure 1). In Subsystem 1, a M51/M52 reduction valve was mounted. The purpose of the reduction valve was pressure reduction and regulation in the combustion chamber. A pressure of 40 or 60 bars was set by using an inert gas (N_2) in order to achieve the conditions that usually appear in combustion engines. Subsystem 2 includes a BOSCH type PES 6A 95D 410 LS 2542 pump, with six injection nozzles (type BOSCH DLL 25S834) placed on the Friedmann-Maier fuel injection system in order to enable changing the rotation speed of the pump. One of the nozzles was connected with the pressure chamber, using the high pressure tube. The spray that was injected into the pressure chamber was recorded with a high-speed camera.

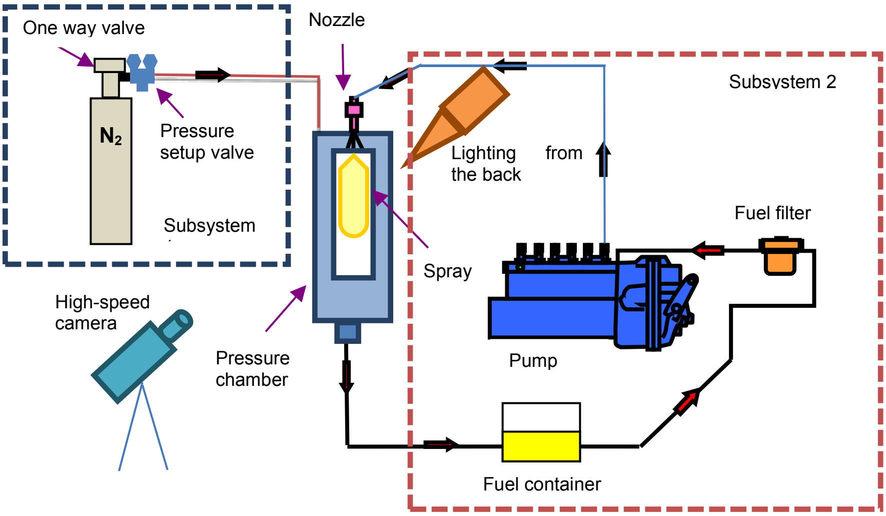


Figure 1: *Graphic presentation of experimental setup*

Figure 2: *Experimental setup – pressure chamber and Friedmann & Maier fuel injection system*

2.3 Image acquisition system

The developing spray was filmed with a Fastec HiSpec 4 high-speed digital camera (Figure 3). The camera was placed at a distance of 1.7 m from the fuel spray. A resolution of 128 × 332 pixels at a frame-rate of 18,499 frames per second (fps) was used. The camera was triggered with electric pulse that was recorded together with pressures p_1 and p_2, needle lift and the signal of TDC (top dead centre).

Figure 3: *High-speed camera Fastec HiSpec4*

3 VISUALISATION METHOD FOR FLOW ANALYSIS IN THE LABVIEW PROGRAM

In general, the camera and lightning give good results (image quality) when there is little or no fog (small particles) in the chamber. This condition is met when the rotation speed of the pump and the injection pressures are consequently low. Higher pump rotating speed results in a higher number of cycles and a generally higher amount of fuel injected per cycle at a higher pressure. Higher pressure results in better fuel distribution and, combined with higher quantity of fuel injected per time unit, increases the quantity of fog. During the test, it was observed that the movement of the fog cloud is much slower than the fuel injection. The idea to improve visual quality of the images is based on the presumption that the shape of the fog cloud remains the same during the injection. An additional issue that can be addressed with this approach is illumination in homogeneity or spots on the chamber window. A raw image just before the injection started is presented in Figure 4. Figure 5 was taken just before needle closure.

Figure 4*: Image before injection*

Figure 5: *Image at maximal injection*

When comparing images on Figures 4 and 5, all abovementioned issues (illumination inhomogeneity-edges, fog cloud and spots) can be observed. Grayscale values of both images were stored in a 2D matrix, and Figure 4 was subtracted from Figure 5. The image is presented in Figure 6. The homogeneous background can be noted on Figure 6.

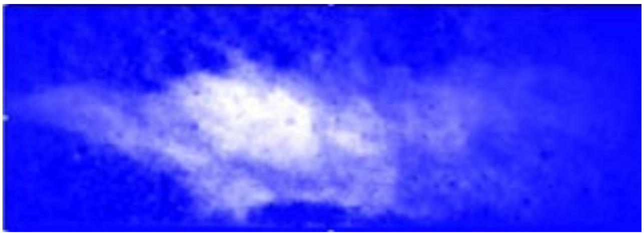


Figure 6: *Subtracted image*

Furthermore, it is possible to perform a histogram analysis of this image and establish the border value for the background and to set up the maximum greyscale value to extract the greyscale interval with the highest interest, as presented on Figure 7.

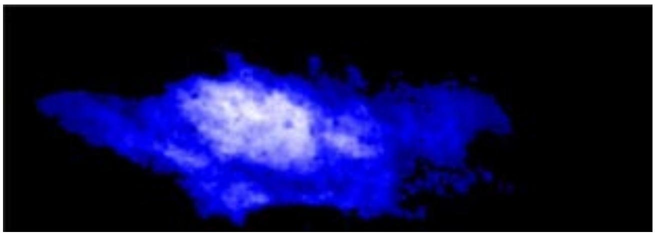


Figure 7: *Subtracted image-reduced interval*

The images presented on Figures 4–7 are stored in a 2D matrix from which it is possible to extract single raw/column. The whole image presented in Figure 7 was sliced perpendicular to the spray propagation. An example is shown in Figure 8.

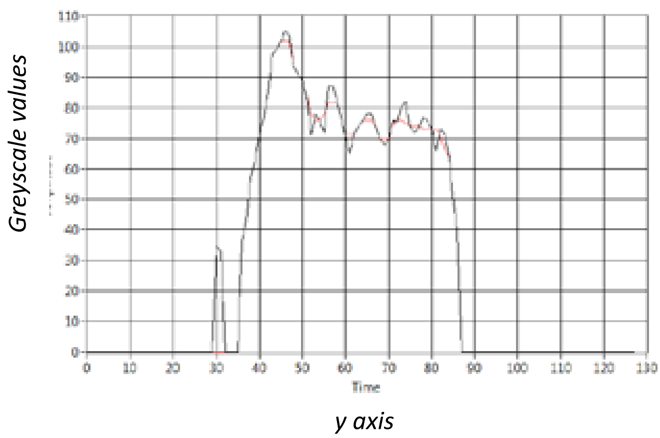


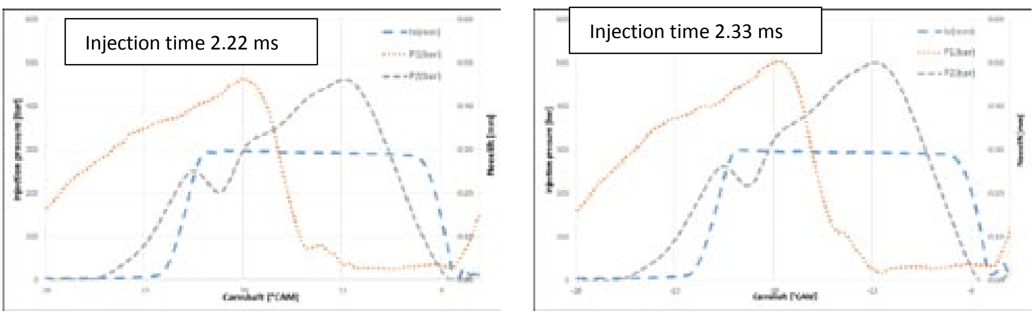
Figure 8: *Slice at 1/3 of spray length*

The data was fed into the LabView subprogram Gaussian Peak Fit.vi, and the amplitude was observed. When it fell too low (0), the program stopped and returned the maximum spray length and the spray angle at one third of the maximal spray length.

4 RESULTS AND DISCUSSIONS

4.1 Injection process characteristics

The injection characteristics (injection pressure p_1 and p_2, injection time and needle lift) at different camshaft rotational speeds for diesel and biodiesel fuel were measured. The two diagrams in Figure 9 show that the injection pressure curves are similar for both fuels, but the maximal injection pressure was 40 bars higher in the case of biodiesel. The needle lift curves show that the injection was advanced and the injection time was longer when using biodiesel. The differences were the consequence of the fuels' physical properties, such as the speed of sound, viscosity and density.



Diesel Biodiesel

Figure 9: *Diesel and Biodiesel injection pressure characteristics at 1100 rpm*

4.2 Recorded signals

The acquisition system recorded the signals for injection pressure p_1 and p_2, needle lift, TDC and trigger signal (Figure 10). The sampling rate for pressures p_1 and p_2 and needle lift were simultaneously 100 kHz.

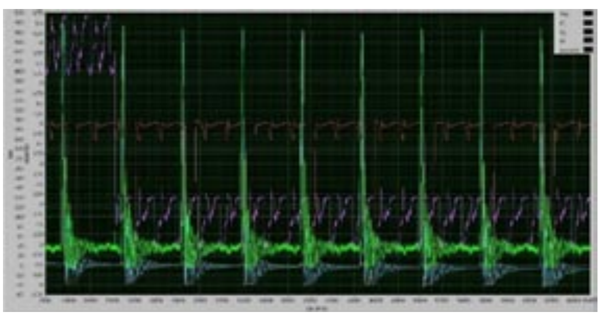


Figure 10: *Recorded signals in program LabVIEW*

4.3 Spray development

Based on the images of the spray visualisation, we have determined main spray developments of interest, for different fuel blends and pressure in chamber, shown on Figures 11–14. The images show the spray development in different camshaft rotational angles. Figure 11b represents the starting point of injection time (needle slowly starts to open), and Figure 11f represents the full development of spray.

For each spray development, two images are shown. The left one on Figure11b represents the image recorded with a high-speed camera, and the right one represents the image analyses with the visualisation method. Comparison of the experimental results shows substantial accordance in the spray development as well as in its shape (spray angle and penetration). The difference in angle and spray length between the alternative fuels is less than 10% (Tables 1 and 2).

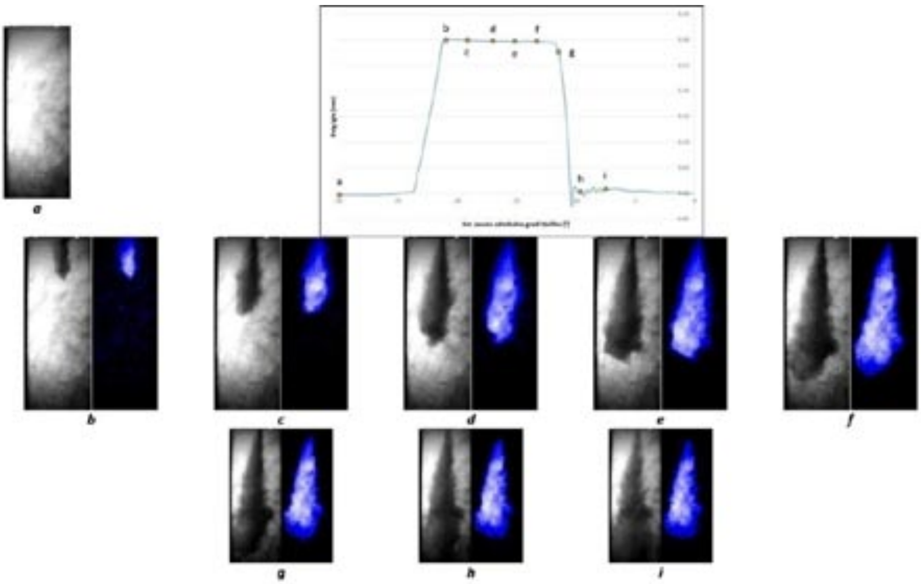


Figure 11: *Spray development measured with high-speed camera and LabVIEW (B100, 800 rpm, 40 bars)*

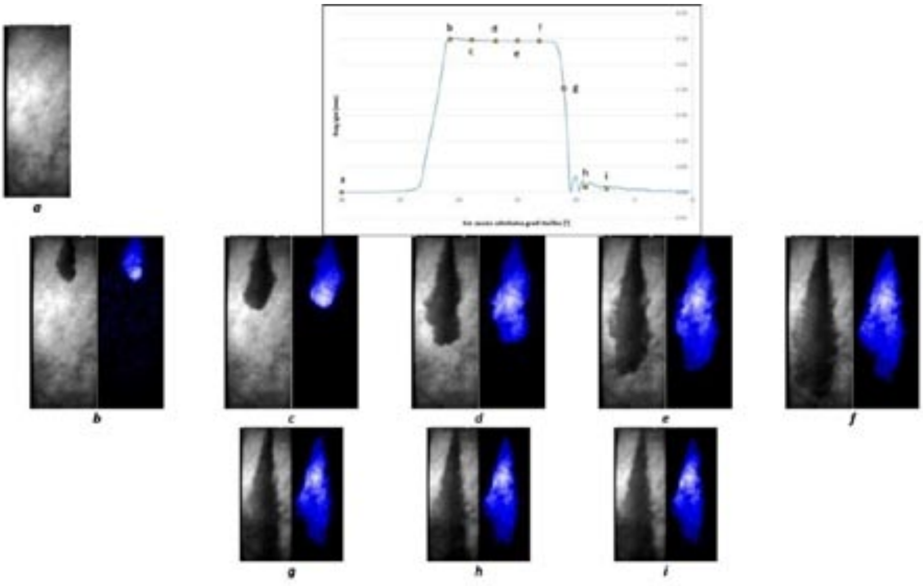


Figure 12: *Spray development measured with high-speed camera and LabVIEW (D2, 800 rpm, 40 bars)*

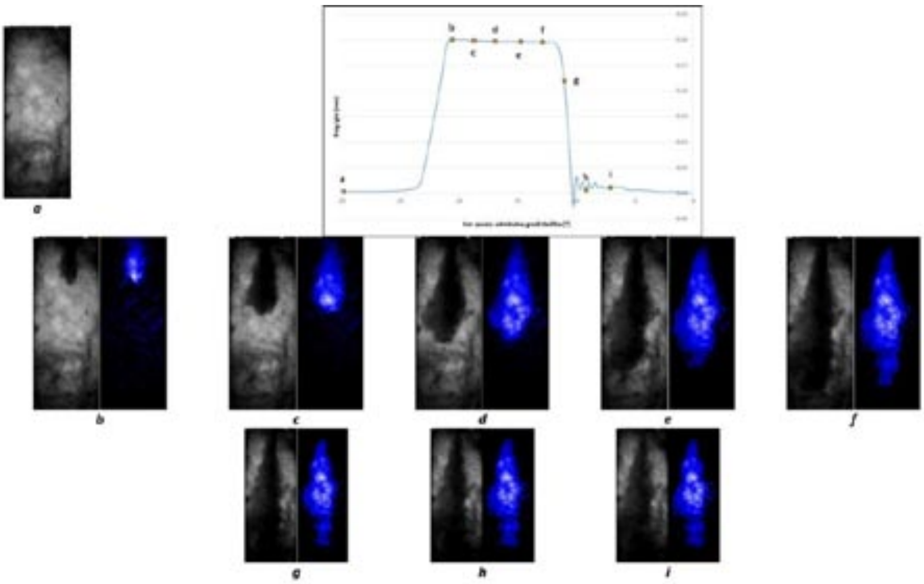


Figure 13: *Spray development measured with high-speed camera and LabVIEW (D50B50, 800 rpm, 40 bars)*

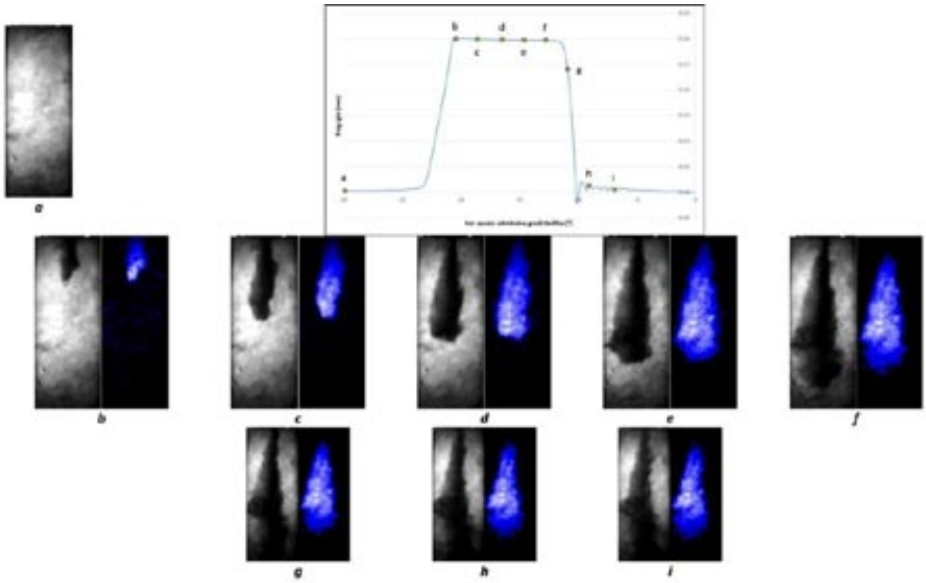


Figure 14: *Spray development measured with high-speed camera and LabVIEW (D85E15, 800 rpm, 40 bars)*

Table 1: *Spray development length for different alternative fuels*

Fuel	*D2*	*B100*	*D50B50*	*D85E15*
Length [mm]	71.56	72.09	65.42	69.42

Table 2: *Spray development angle for different alternative fuels*

Fuel	*D2*	*B100*	*D50B50*	*D85E15*
Angle [°]	30.51	29.12	30.32	26.4

5 CONCLUSION

The visualisation method for the determination of spray characteristics described in this paper presents the procedure for the reliable determination of spray length and angle. This study showed that it is possible to use alternative fuels in diesel engines without modifications, but this is limited to older fuel injection systems. The comparison of spray cone angle and length showed that the alternative fuels have similar spray development and characteristics as the standard diesel fuel. In particular:

- the results showed minor differences in spray cone angle,
- spray length at different camshaft rotational speeds has shown some differences, which are caused by the different densities of the used fuels (B100 ρ=875 [kg/m^3]; D2 ρ=825 [kg/m^3]; D50B50 ρ=852 [kg/m^3]; D85E15 ρ=822 [kg/m^3]),
- injection time for different fuel blends showed minor differences,

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- the injection pressures p1 and p2 shows differences between them and indicate the importance of further experimental investigations.

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