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The study on injection parameters of selected alternative fuels used in diesel engines

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Abstract. The paper presents selected results concerning fuel charging and spraying process for selected alternative fuels, including regular diesel fuel, rape oil, FAME, blends of these fuels in various proportions, and blends of rape oil with diesel fuel. Examination of the process included the fuel charge measurements. To this end, a set-up for examination of Common Rail-type injection systems was used constructed on the basis of Bosch EPS-815 test bench, from which the high-pressure pump drive system was adopted. For tests concerning the spraying process, a visualisation chamber with constant volume was utilised. The fuel spray development was registered with the use of VisioScope (AVL).

1. Introduction

The course of fuel injection process in diesel engines has a decisive effect on the combustion process and as a consequence, on other engine parameters, both operating and environment-related [3,5,10]. Values of the parameters are affected by numerous factors, from design and precision of manufacturing the injector as such, to physicochemical properties of fuels which can be subject to significant variation, even within a short period of time, due to temperature changes resulting in changeable density and viscosity [2–5].

Bearing in mind complexity of fuel spraying processes it is rather unlikely that the theory of fuel spraying will make any significant progress in the nearest future. It can be assumed therefore that the dimensional analysis will be still used in this field of research.

A large potential as far as the fuel spraying process assessment is concerned is currently offered by visualisation tests consisting in direct watching the involved phenomena. Tests of the type are in general classified as vision- and laser-based. Within each of the categories, different recording techniques are distinguished, characterised with different degree of complexity and possibility of combining several methods into one [5,7,9]. Visualisation studies allow to watch the injection process and its irregularities, facilitating the design the injection apparatus and combustion system in a way making the processes occurring in the engine more effective which ultimately leads to improvement of operating and environmental parameters of the combustion engine. Indeed, the use of the visualisation set-up does not allow to reproduce identically the conditions prevailing in the engine combustion chamber, but under certain assumptions it can be stated that there exists a relationship between tests results concerning structure of sprays obtained in extra-engine environment and actual shape of spray in a combustion

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chamber. An additional benefit derived from extra-engine tests is the possibility to carry them out at a relatively low cost, especially in studies requiring a large number of engine-based tests.
The paper presents results of tests concerning fuel charging and spraying process for selected alternative fuels.

2. Research set-up and methodology

To determine charge quantities and geometries of sprays, a test set-up for examination of Common Rail-type injection system was used constructed on the base of Bosch EPS 815 test bench from which the high-pressure pump drive was utilised. Such set-up allows to test a number of different liquid fuel types [1, 4, 5]. A view and a schematic diagram of the set-up is shown in Figure 1. Basic component systems of the set-up include:

- low-pressure circuit,
- high-pressure circuit,
- controller,
- supervising computer.

Figure 1. An overview of the set-up used for visualisation studies

The low-pressure system was mounted in a mobile structure together with components of the fuel cooling system and flowmeters (Figure 2).
The high-pressure system was situated on the test bench which was used to drive the high-pressure pump. The system comprises: high-pressure pump, fuel rail, injectors (mounted in the visualisation chamber), and high-pressure lines.
The pump transfers fuel to the rail where the fuel pressure value is measured used further to control pressure modulators in the pump and the rail. From the rail, the fuel is fed to injector which injects it to a visualisation chamber equipped with a stroboscopic lighting system and designed specifically to be included in the set-up. The process of spray development of the fuel injected into the chamber was recorded by means of VisioScope visualisation system (AVL). To record high-speed courses, a data acquisition system based on measuring card AT-MIO-16E-1 (National Instruments) was used [5].
The VisioScope system combined with a high-speed courses acquisition system controlled by crank angle encoder 365C (AVL), allows to record the spray development with angular resolution in pump shaft rotation (PSR) of 0.1 deg. Pulses from the encoder were also used as signals triggering the

electronic injector controller. In this case, angular resolution was 720 pulses per full rotation which ensured high precision of injection timing [1, 5].

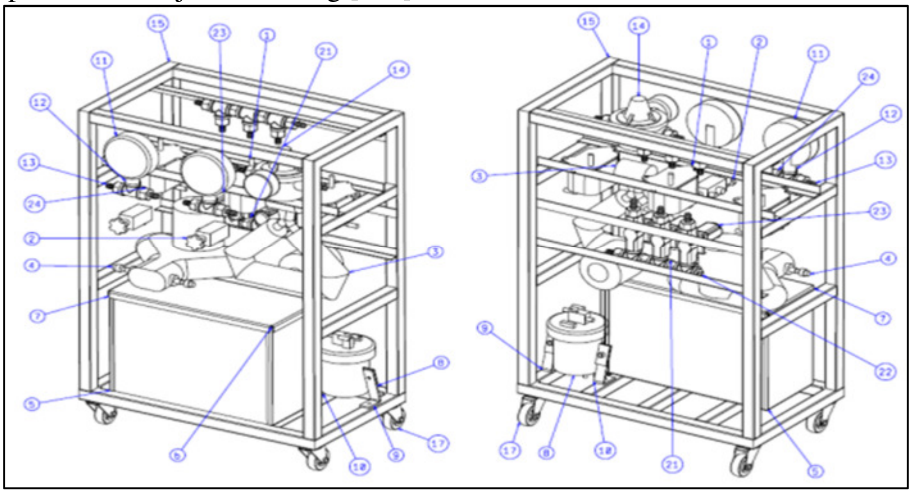

Figure 2. Arrangement of the injection system low-pressure components: 1 — fuel cooler; 2 — regulation valve; 3 — CMF 025 flowmeter; 4 — CMF 010 flowmeter; 5 — fuel tank; 6 — fuel pump; 7 — tank cover; 8 — fuel filter; 9, 10 — fuel filter brackets; 11 — manometer; 12 — T-connection; 13 — elastic line terminal; 14 — water pressure reducer with manometer; 15 — frame; 17 — mobile frame wheel; 21 — union piece, 22 — plug; 23 — solenoid valve; 24 — elastic line terminal

A view of the test chamber used to determine the injected fuel charge is presented in Figure 3, whereas the visualisation chamber is shown in Figure 4.

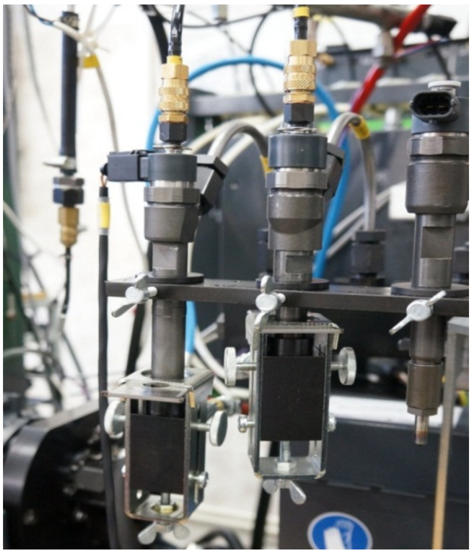

Figure 3. A view of injectors mounted in test chambers [1]

The research set-up, in combination with the visualisation system and a high-speed courses measuring system, allowed to carry out examination of the injection process as well as measure and record the following parameters:

- injected fuel charge,
- overflow quantity from injector,
- fuel density,

- fuel temperature at different points of the system,
- pressure in the fuel rail,
- parameters of injector controlling signal,
- high-speed courses of:
  - pressure downstream the fuel rail and in injector line upstream the injector,
  - injector needle lift (with the use of injector with needle lift sensor),
  - injector controlling signals,
  - injector voltage and current;
- spray macrostructure (by recording the process of its development) which allows to determine:
  - actual injection start and end time,
  - spray tip penetration and spray cone angle.

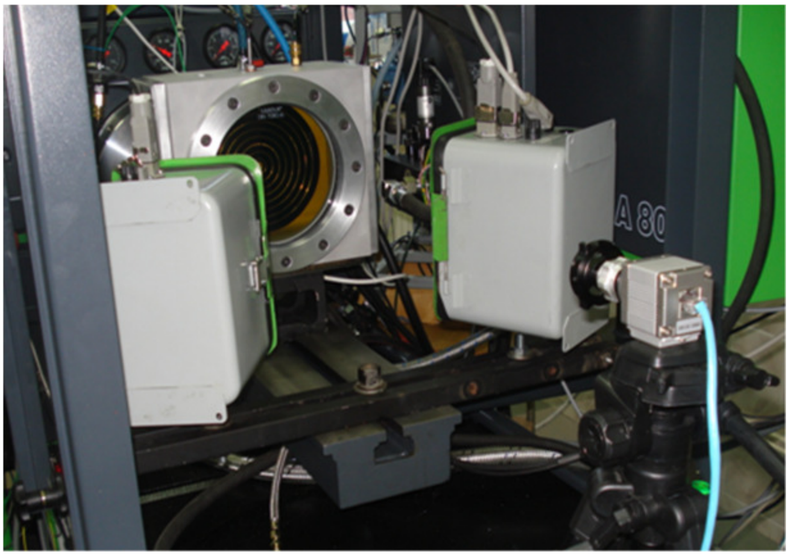

Figure 4. A view of the visualisation chamber with stroboscopic lighting system mounted on the test bench [4,5]

The program of tests realised on the research set-up equipped with visualisation chamber and a motion-picture camera for recording development of the spray was carried out in the following sequence:

- filling the system with the tested fuel,
- mounting the injector (W219 Bosch-type injector 0445120219) in the test chamber:
  - heating the injector and the fuel up to temperature (40 ± 2) °C,
  - checking fuel output for selected measuring points,
  - removing the injector from the test chamber;
- mounting the same injector in the visualisation chamber, and then carrying out the fuel spraying tests for the following settings: pump rotation speed 800 rpm corresponding to engine speed of 1600 rpm, injection pressure 100 MPa, and injection duration times 1800 μs and 2600 μs,
- removing the tested fuel from the system after completion of the test.

According to the assumed research program, the following fuels were subject to analysis: ONH (diesel fuel); B100 (rapeseed methyl ester); B50 (a blend of diesel fuel with an addition of 50% FAME), OR40 (a blend of diesel fuel with an addition of 40% of rape oil); and OR80 (a blend containing 80% of rape oil and 20% of diesel fuel).

Recorded motion pictures illustrating the courses of spray development allowed to determine their macrostructure, in this case represented by the spray tip penetration and spray cone angle.

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3. Research results

As a result of the performed tests, a number of data files were obtained from which the average fuel charge value was calculated at each of the measuring points. Figure 5 shows results of measurements of the injected fuel charge as a function of injection duration for the pressure in fuel rail amounting to 100 MPa. The results indicate that the relationship of fuel charge changes versus the injection duration is a proportional one.

Visualisation tests were carried out in accordance with the adopted programme. For selected fuels, motion pictures were recorded illustrating the course of spray development of fuel injected to the visualisation chamber based on which, with the use of VisioScope software (AVL), spray cone angles and spray tip penetration were estimated. The injection start was determined as the angle corresponding to the image preceding this in which a fuel jet flowing out from any of the spraying nozzle could be observed. The spray tip penetration was determined at the moment corresponding to rotation of the pump shaft by 4 deg counting from the actual injection start. At such point, the tip penetration was determined for each spray separately and the average spray tip penetration value was calculated (Figures. 9 and 10). In a similar way, the spray cone angle was determined (Figures. 11 and 12). Selected photographs visualising the fuel spraying are shown in Figures. 6–8.

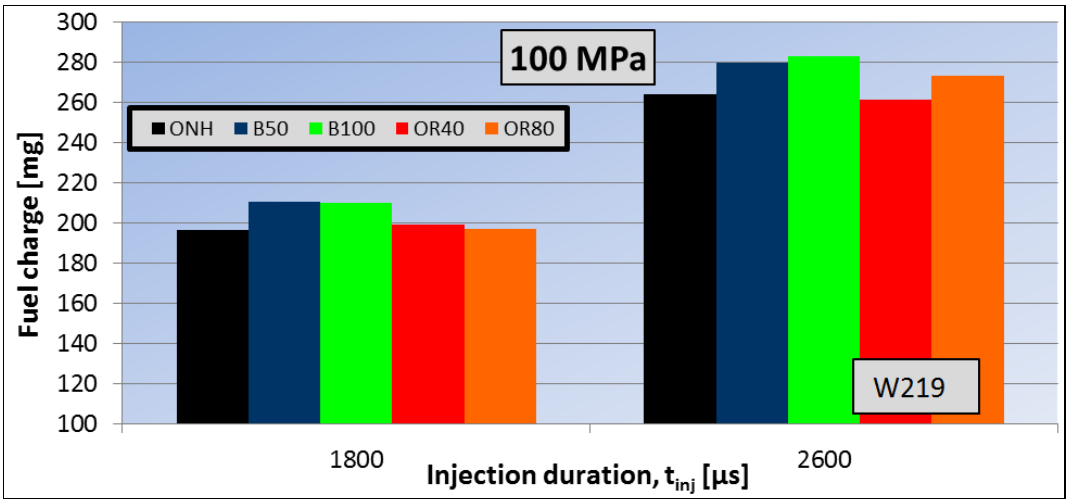

Figure 5. A summary of W219 injector deliveries depending on the injection duration for the injection pressure of 100 MPa

After visualisation tests concerning in recording views of sprayed fuel tests for all adopted measuring points and after analysis of the obtained results it has been found that the injection duration has no significant effect on the spray cone angle.

The presented results concerning the determined tip penetrations and cone angles represent average values over for all sprays (number of holes in the spray nozzle).

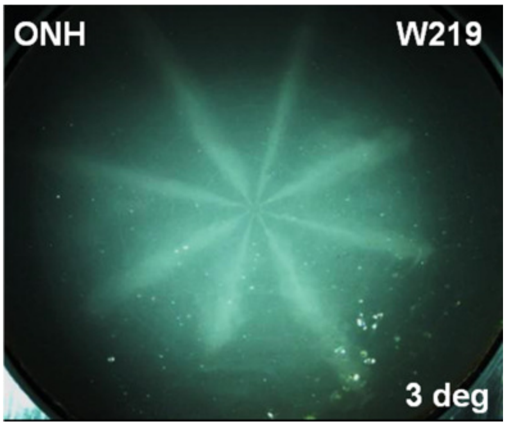

Figure 6. Spraying of ONH fuel (3 deg after injection start)

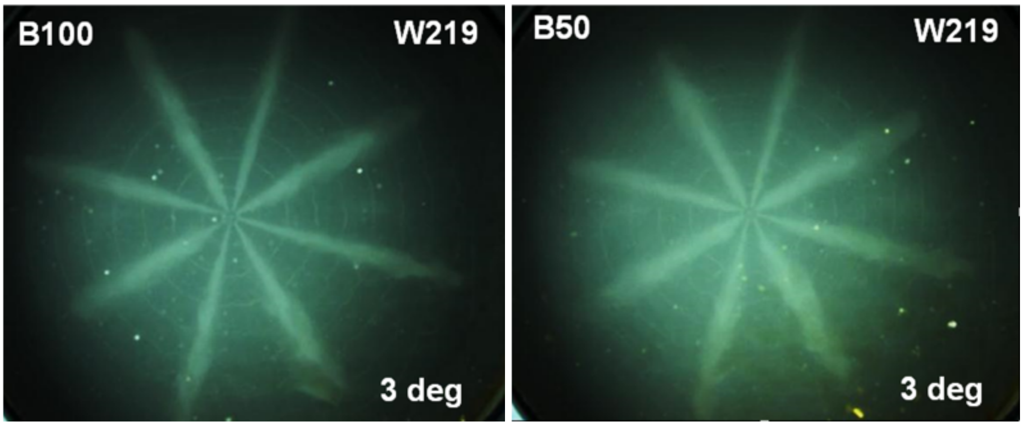

Fig. 7. Spraying of B100 and B50 fuel (3 deg after injection start)

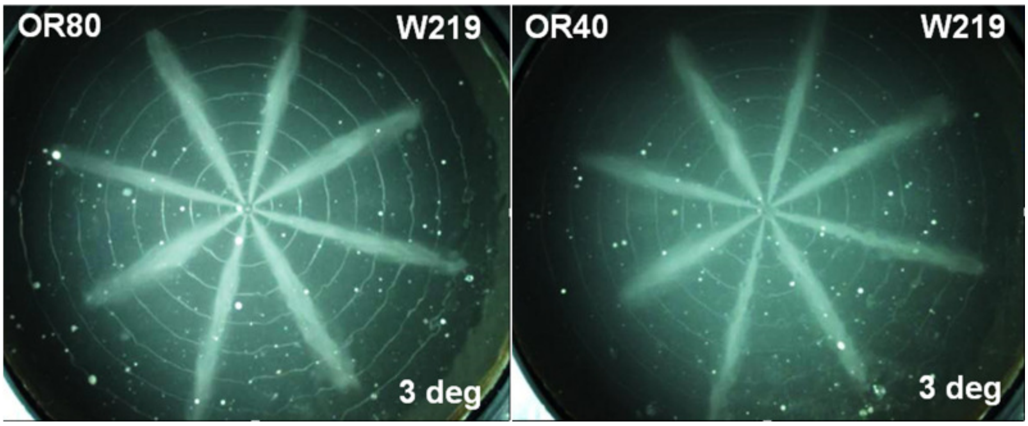

Figure 8. Spraying of OR80 and OR40 fuel (3 deg after injection start)

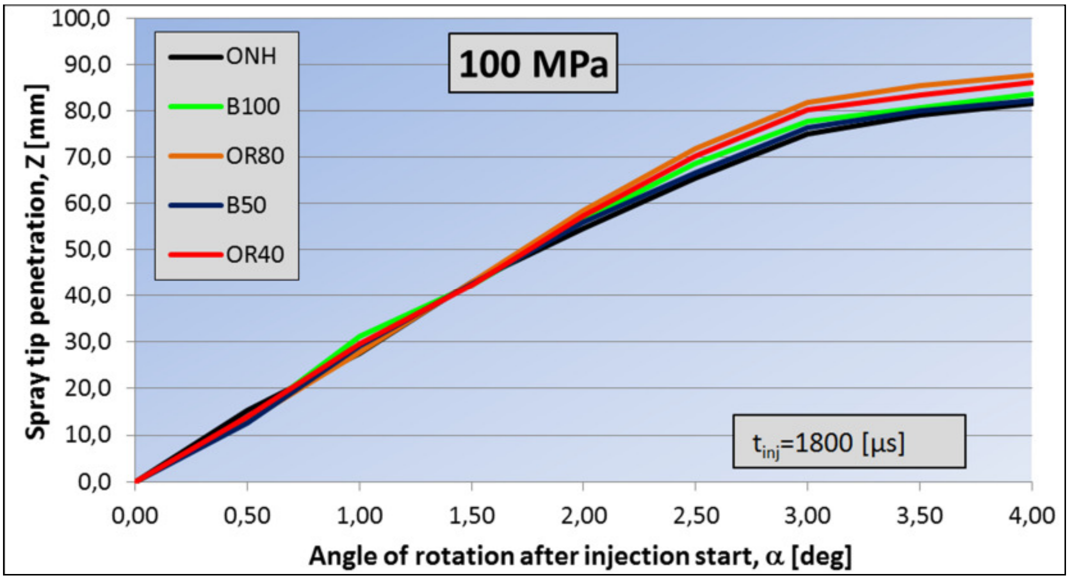

Figure 9. A comparison of average spray tip penetrations for examined fuels for W219 injector (p_{inj} = 100 MPa, t_{inj} = 1800 μs)

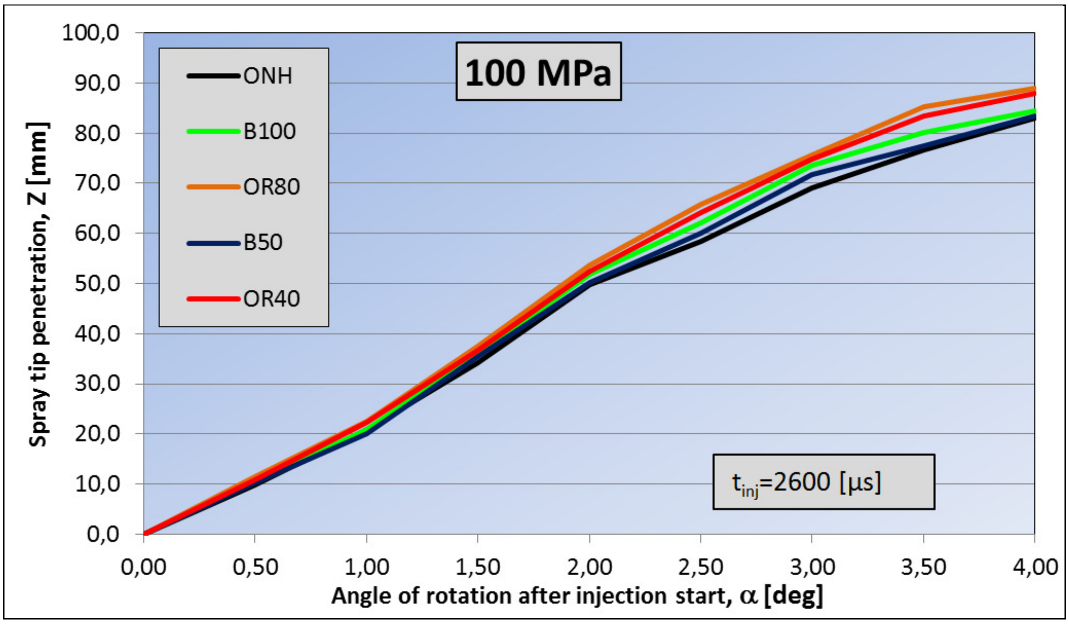

Figure 10. A comparison of average spray tip penetrations for examined fuels for W219 injector (p_{inj} =100 MPa, t_{inj} = 2600 μs)

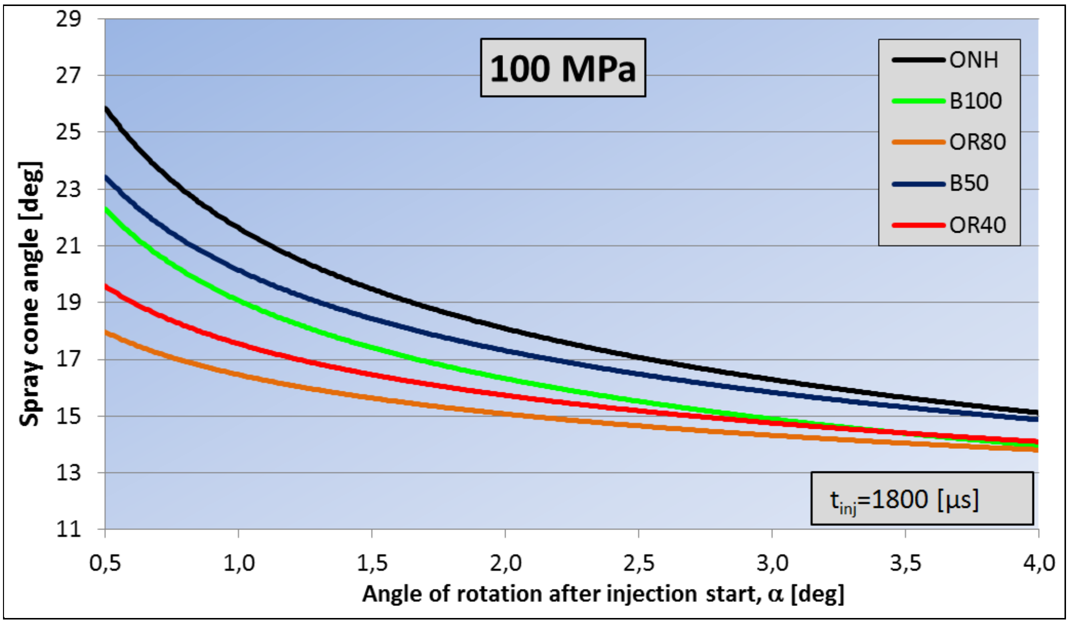

Figure 11. A comparison of average spray cone angles for W219 injector (p_{inj} =100 MPa, t_{inj} = 1800 µs)

After visualisation tests consisting in recording patterns of sprays at all measuring points and after analysis of the obtained data it has been found that the injection duration has no significant effect on the spray cone angle.

The presented results of determined tip penetrations and cone angles represent values averaged over all sprays generated by the injector.

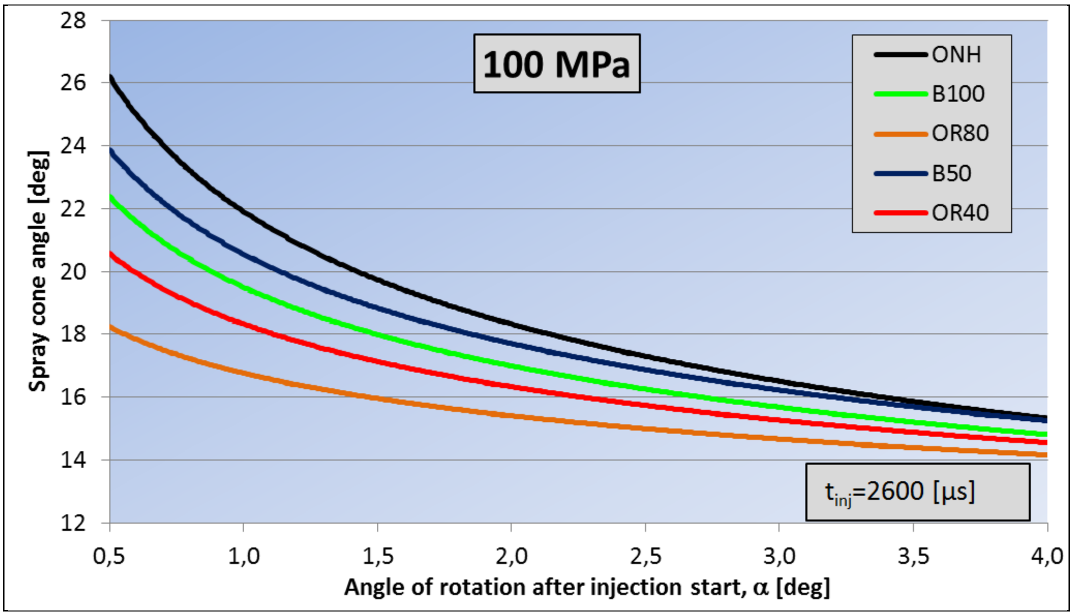

Figure 12. A comparison of average spray cone angles for examined fuels for W219 injector (p_{inj} =100 MPa, t_{inj} = 2600 µs)

Figures 9 and 10 present values of spray tip penetrations determined for the tested fuels. It follows from the graphs that the higher viscosity of fuel, the larger is the spray tip penetrations. Figs. 11 and 12, on which averaged values of spray cone angles characterising sprayed fuel for injection pressure 100 MPa and injection durations of 1800 µs and 2600 µs are presented, respectively, show a distinct differences in spray cone angles for different fuels. The main factor resulting in such differences is different viscosity of the fuels. Higher fuel viscosity disrupts the secondary disintegration of droplets [7, 10] – the spray becomes more compact and this in turn results in lower value of cone angle. For the fuel characterised with the largest viscosity (OR80), the cone angle was about 18 deg, while for the fuel with the lowest viscosity (ONH), the observed cone angle value was about 26 deg.

4. Conclusions

The undertaken visualisation studies were aimed at comparing geometries of sprays (the spray cone angle and the spray tip penetrations) for fuels characterised with various physicochemical properties and to propose a research methodology for examining the spraying process with the use of visualisation system.

Among different parameters characterising diesel engine fuels, those decisive for the jet spray cone angle and spray tip penetration include viscosity, surface tension and density (with increasing values of these quantities, the spray tip penetration and spray cone angle decreases), which was confirmed by the obtained research results. Fuels characterised with higher viscosity form more compact sprays which is a result of disrupted secondary disintegration of droplets (large drops are formed). As a result, this may lead to reaching the cylinder liner and piston head walls by sprays and consequential penetration of unburned fuel to the crank chamber. This in turn deteriorates lubrication properties of engine oil. Improper parameters of the spray macrostructure have a negative effect on the engine operation process resulting in, among other things, increased emissions of toxic exhaust gas components. Improvement of the process of spraying fuels characterised with large viscosity can be achieved by using injectors with smaller holes and a larger number of holes and increasing temperature of the injected fuel.

Although visualisation tests do not reproduce accurately conditions prevailing in the engine combustion chamber, it can be however claimed that, under determined assumptions, there exists certain correlation between structure of sprays in the extra-engine set-up and their actual shapes in the combustion chamber. Moreover, an essential advantage of extra-engine tests is the possibility to carry them out at relatively low cost.

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