Numerical and experimental research of spray characteristics

L. Lešnik[1], B. Vajda[2], Z. Žunič[3] and B. Kegl[4]

[1] Luka Lešnik, University of Maribor, Faculty of mechanical engineering, Engine research Laboratory, Smetanova ulica 17, SI-2000 Maribor, Slovenia, luka.lesnik@uni-mb.si

[2] Blaž Vajda, University of Maribor, Faculty of mechanical engineering, Engine research Laboratory, Smetanova ulica 17, SI-2000 Maribor, Slovenia

[3] Dr. Zoran Žunič, AVL-AST d.o.o., Trg Leona Štuklja 5, SI-2000 Maribor, Slovenia

[4] Dr. Breda Kegl, University of Maribor, Faculty of mechanical engineering, Engine research Laboratory, Smetanova ulica 17, SI-2000 Maribor, Slovenia

Abstract. The paper focuses on experimental and numerical analysis of biofuels in injection systems of heavy duty engines. Addressed are various mixtures of commercial diesel fuel, D2, with biodiesel fuel, B100, (D2, B25, B50, B75 and B100). All simulations and experimental measurements were made for various speeds of pump crank shaft and at various engine loads.

The experiments were performed on the injection system test bed Friedmann-Maier type 12 H 100-h. This type of test bed allows for measurements of the needle lift and the amount of injected fuel. Furthermore, penetration length of injected fuel and spray cone angle has also been measured by taking photos of the spray at various levels of spray formation.

Experimental results for various percentages of biodiesel fuel mixed with diesel fuel were compared to each other to identify the variations in spray characteristics and to confirm possible use of biofuels in diesel engines. The same comparisons were made for the results obtained from numerical simulations, which were made by the 1D simulation program AVL Hydsim. The compared quantities were: needle lift, spray cone angle and penetration length of the spray. The results from numerical simulations agreed well with experimental data and confirm possible use of biofuels in diesel engines.

Introduction

Biofuels offer good replacement for commercial fuels. One of the most appropriate biofuel for use in commercial diesel engines is biodiesel, because it has chemical and physical properties which are very similar to mineral diesel and therefore is very suitable for use in commercial diesel engine [1]. Its combustion in diesel engines produces less HC and smoke emissions at all operating regimes and reduces exhaust gas temperature and CO emission at higher load [2]. Biodiesel has also negative consequences and the unfavorable one is that it contributes to increase of NOx emissions which are caused by advantage of needle lift. Commercial engines are developed to operate with mineral diesel fuel and not with biodiesel fuel or its blends with neat diesel fuel. For use of biodiesel in these engines we need to investigate how biodiesel influence on engine operating condition. Our research presented in this paper focuses on experimental and numerical analysis of biodiesel and its mixtures with neat diesel fuel on mechanical M injection systems of heavy duty engines.

Fuels

The fuels under consideration are neat mineral diesel, D2, conforming to European standards EN 590, neat biodiesel, B100, from rapeseed which was produced in Pinus, Slovenia and confirm to European standard EN 14214, and their blends, BXX, where XX denotes the vol % of neat biodiesel in blend (e.g. B25 consist of 25% of biodiesel and 75% of mineral diesel). All tested fuels do not contain any additives for winter conditions. Some properties of mineral diesel and biodiesel are given in Table 1.

Table 1. Properties of Biodiesel and Diesel Fuel

fuel	D2	B100
kinematic viscosity at 40 °C (mm^2/s)	2.776	4.477
surface tension at 40 °C (N/m)	0.0252	0.0265
lower calorific value (*MJ/kg*)	42.91	42.36
flashpoint (°C)	66.0	138.5

As we see from Figure 1 biodiesel fuel has higher values of kinematic viscosity and surface tension. Fuel properties have influence on injection characteristics and on response of injection system. For properties determination of tested fuels we use recommendations from reference [2]. Results are presented in Figure 1 and were introduced in Hydsim.

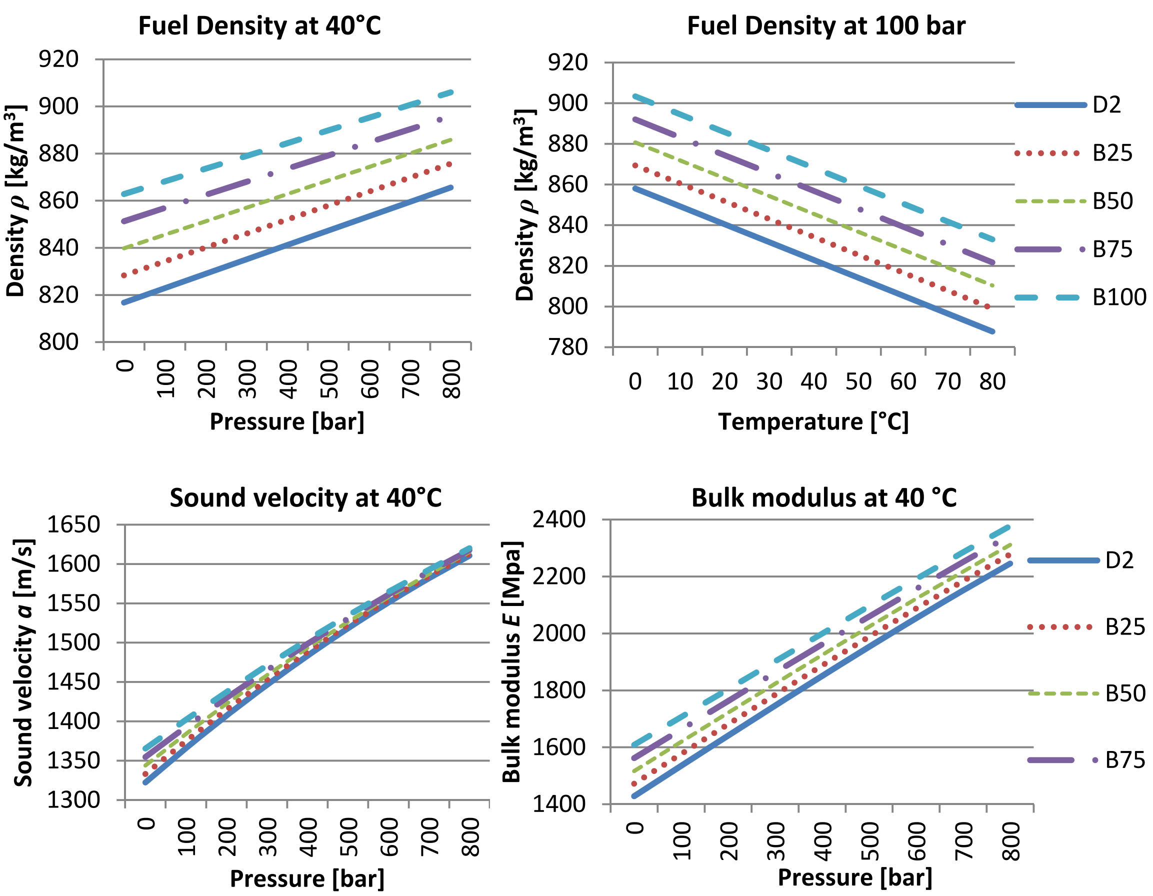

Figure 1: Properties of used fuels

Experiment

All experiments were made on Friedmann Maier typ 12 H 100-h test bench. This type of test bench allows us to measure needle lift, pressure in different points in high pressure fuel lines and amount of injected fuel per cycle. Test bench was fully instrumented in order to measure basic parameter characteristic of system operation. To be able to monitor and to measure penetration length and spray angle we designed and added to test bench an injection chamber in which we have injected fuels at different working areas (pressure in chamber was 0.1 MPa). To capture spray development, length and angle at different stages we have used Phantom v.4.1 high speed camera. Camera was synchronized with PC and data were monitored with program made in LabVIEW. In experiment we measured needle lift, spray penetration length and spray cone angle. All experiments were made for different pump crankshaft speeds and for different engine loads. To capture whole engine operating regimes we decided for three pump crank shaft speeds, 1100rpm, 800rpm and 500rpm, and for 100% and 50% engine load. The fuel injection system used in this research is mechanically controlled fuel injection system with wall distribution (M system), which consists of a jerk pump, high pressure tube and injector with one hole. The specifications of injection system are presented in Figure 3. The results from measurements and high speed camera are shown in Fig. 3. [7]

Table 2: Injection system specifications

pump type	Bosch PES 6A 95D 410 LS 2542
pump plunger (diameter / lift)	9.5 mm /8 mm
fuel pipe (length / diameter)	1024 mm / 1.8 mm
nozzle hole diameter	0.68 mm
needle lift (maximal)	0.3 mm
needle opening pressure	175 bar

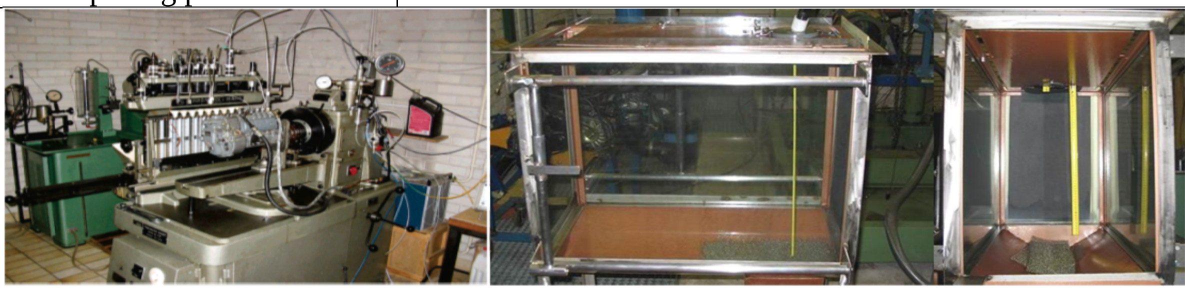

Figure 2: Friedmann Maier test bench (left hand side) and injection chamber [7]

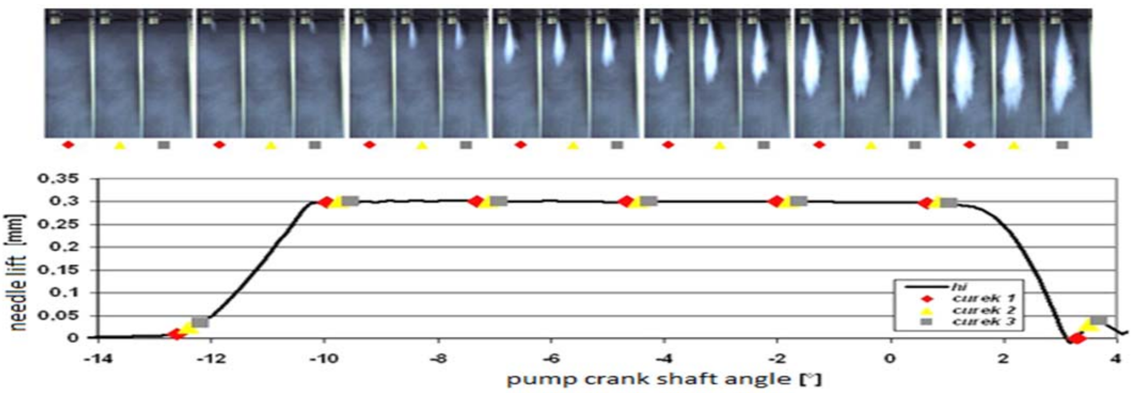

Figure 3: Result from measurements and photos made with high speed camera [7]

Numerical simulations

To be able to investigate different fuels at different operating conditions we need to make significant number of experiments which are expensive. Therefore we used numerical programs which are cost efficient and can give us good results if we make accurate settings of simulations parameters. In our study we made numerical simulations in 1D AVL program Hydsim, which was developed for dynamic analyses of hydraulic systems. In program we first made model of present injection system. For all parts of injection system we first need to insert geometrical data. Then we set up simulation parameters and operating conditions (crankshaft angel and load).

Results

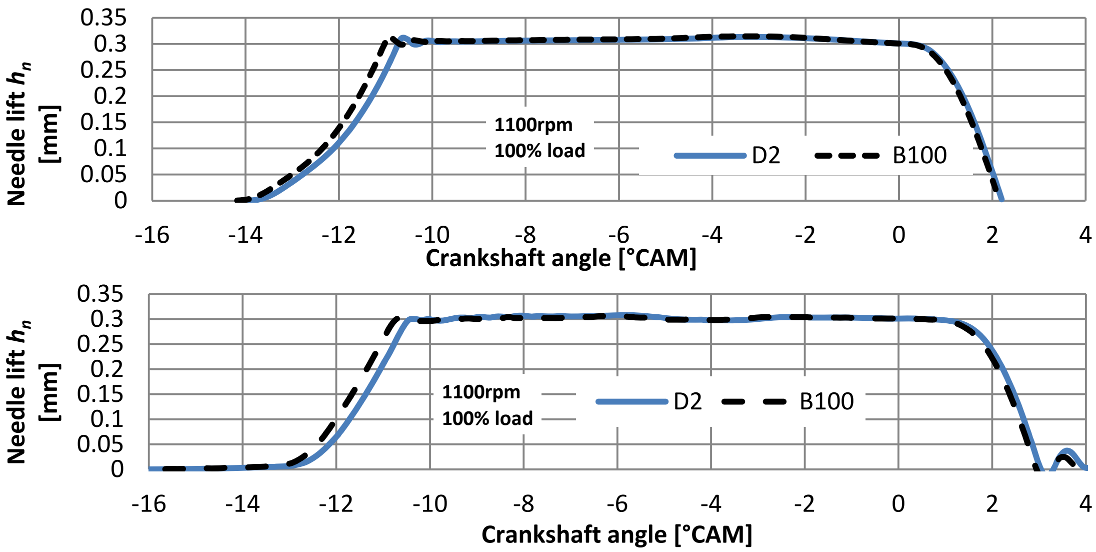

Figure 4: Numerical (upper) and experimental (lower) results for needle lift

As we see from upper two graphs in Fig. 4 needle lift is earlier when using biodiesel. For better transparency we only show results for D2 and B100, the result for other fuels follow this trend. Earlier needle lift beneficially influences injection duration which is presented in Figure 5.

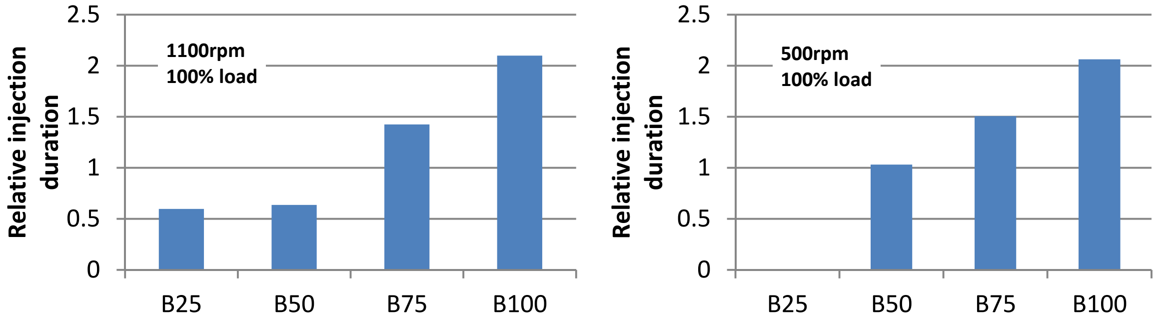

Figure 5: Influence of biodiesel content on relative injection duration (left experiment)

From Fig. 5 we can see how biodiesel content influence on increase of relative injection duration which is advanced when we are adding biodiesel to mineral diesel fuel (Fig. 4). In Fig. 5 are presented results from numerical and experimental analyses for different crankshaft rotation which show that relative injection duration increase in all operating conditions. If injection time is increased we can conclude that injected amount of fuel per cycle will be increased too. Comparison of amount of injected fuel is made only for numerical simulations.

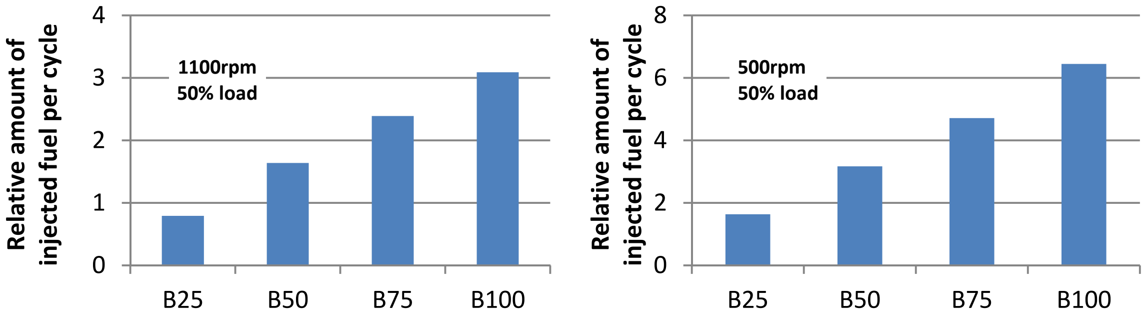

Figure 6: Influence of biodiesel content on relative amount of injected fuel (simulations)

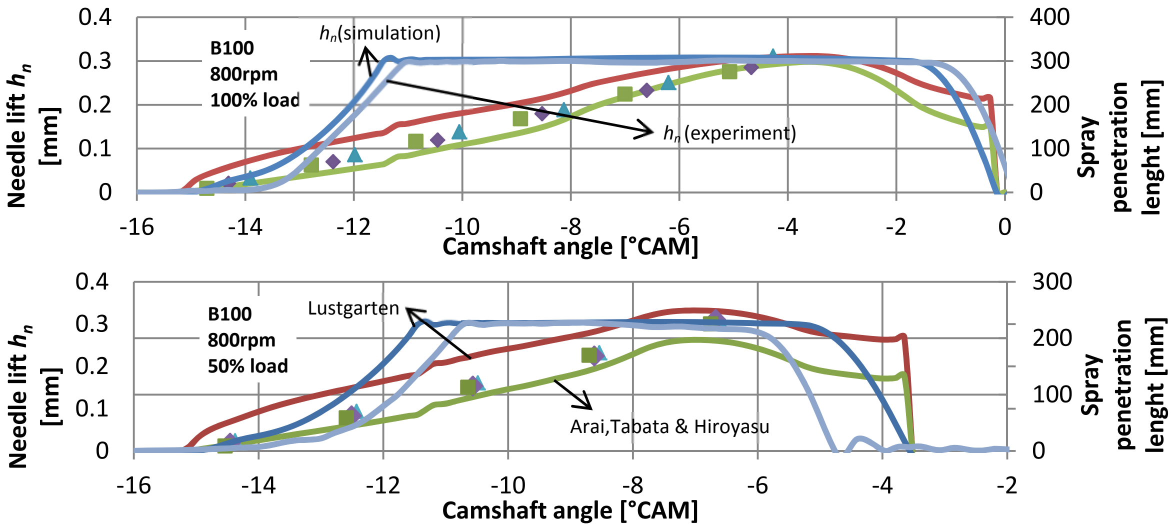

Figure 7: Needle lift (simulation/experiment) vs. penetration length (simulation/experiment)

In Figure 7 we have comparison of needle lift and penetration length which was measured in experiment (symbols) and calculated in simulations with two different calculations models (Lustgarten - red line and Arai, Tabata & Hiroyasu - green line). In Figure 8 we can see how biodiesel content influences on spray penetration length which is increased when adding biodiesel to mineral diesel.

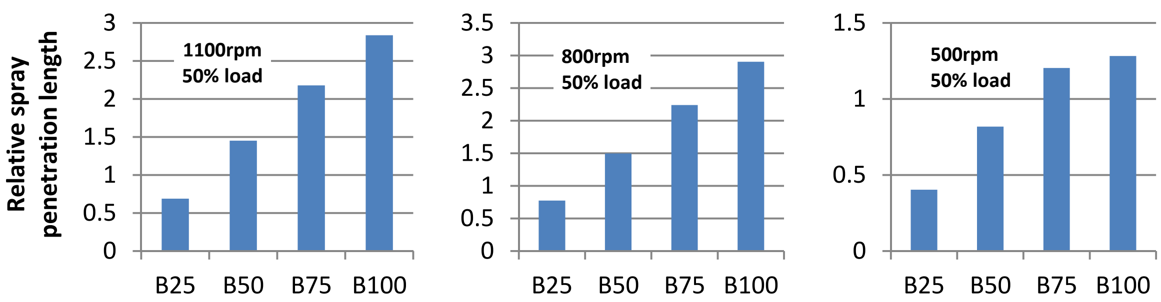

Figure 8: Influence of biodiesel content on relative spray penetration length

The extension of spray penetration length coincides with results in [3]. Furthermore we made comparison of Sauter mean diameter which was calculated in Hydsim program with Elktob model.

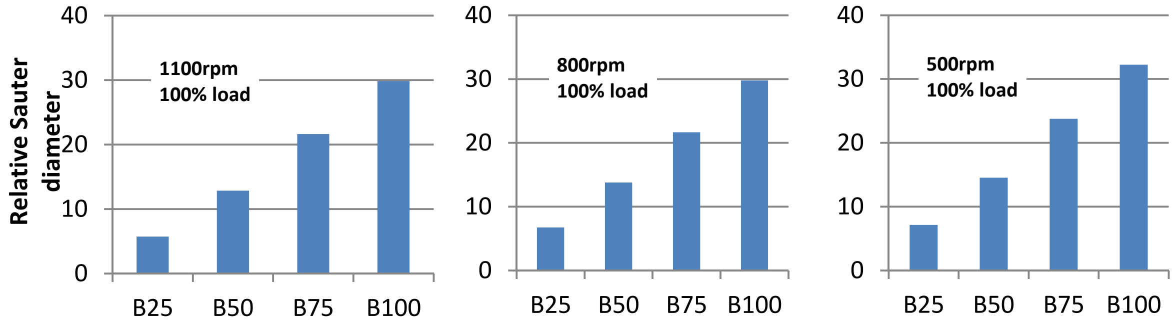

Figure 9: Influence of biodiesel content on relative Sauter mean diameter

The results for Sauter mean diameter are in good agreement with results in reference [3].

Conclusions

Difference in physical and chemical properties of biodiesel influence on spray characteristic in mechanically controlled injection system. Main reason for that is higher viscosity and bulk module of biodiesel and leads to an earlier needle lift. Advance in needle lift give us smaller injection delays but increase pressure in cylinder and as consequence increase of NOx emissions. This can be controlled by moving injection start closer to top dead center of piston. All results from analyses show that by adding biodiesel to diesel fuel we get slighter differences in injection characteristics. From that we can conclude that biodiesel is suitable for usage in commercial diesel engines but to get optimal operating conditions and exhaust gas emissions some modification on engine should be made.

Acknowledgment

This work was supported by Slovenian Research Agency (ARRS). We also wish to thank AVL LIST GmbH for their support by providing the AVL-AST software programs FIRE and Hydsim which were use in our research.

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