Analysis of spray structure characteristics

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Abstract. The paper deals with numerical and experimental analyses of mixture formation and combustion processes in diesel engines. Numerical simulations are quick, accurate and cost efficient and are good compensation to experiments, which are usually longer lasting and more expensive. Numerical analyses were made using the computation fluid dynamic (CFD) program FIRE and 1D simulation program AVL Hydsim. In the present paper the influence of different mixtures of commercial diesel fuel, D2, with biodiesel fuel B100 has been studied. Numerical analysis results are compared to the experimental observations of the two-phase flow available from the literature and to the experimental measurements made in our laboratory.

Experiments were made on 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. The penetration length and the spray cone angle of injected fuel were measured by taking photos.

Experimental results were compared with numerical results from FIRE and Hydsim. Due to the limited options in the experimental measurements, only the needle lift, spray cone angle, and penetration length of spray were compared. A comparison of the Sauter mean diameter has been done between both numerical programs FIRE (3D) and Hydsim.

The results obtained from numerical simulations agree well with experimental results and confirm possible use of biofuels in diesel engines.

Introduction

Global atmosphere pollution has become a serious problem of today. The emissions from the combustion of fossil fuels contribute a notable part to this pollution. Biodiesel fuels, an alternative for petroleum fuel, are the acid esters of triglycerides that originate from vegetable or animal sources. This renewable source significantly reduces exhaust emissions. While biodiesel fuel has similar physical properties, no major engine modifications are necessary. Nevertheless, the differences in physical properties may result in spray anomalies causing an unnecessary increase of pollutive emissions. Fuels with a higher density and viscosity show shorter penetration lengths and greater spray cone angles [4–8]. Applicative research based on the fundamental knowledge of two-phase flows is used for the investigations of the fuel spray characteristics in individual industrial devices. They result in numerous empirical correlations, which are common in today’s practice and deliver important data for the development of spray mathematical models.

Experimental details

For simulating spray formations, fuel physical properties and necessary injection characteristics were measured. Experiments were made on injection system test bend Friedmann-Maier Type 12 H 100-h. This type of test bend allows measurements of the needle lift, injection pressure and injection rate, at three different camshaft speeds (550, 800 and 1100 rpm) at full load. Injection characteristics at 1100 rpm for diesel and biodiesel fuel are shown in Figures 1 and 2.

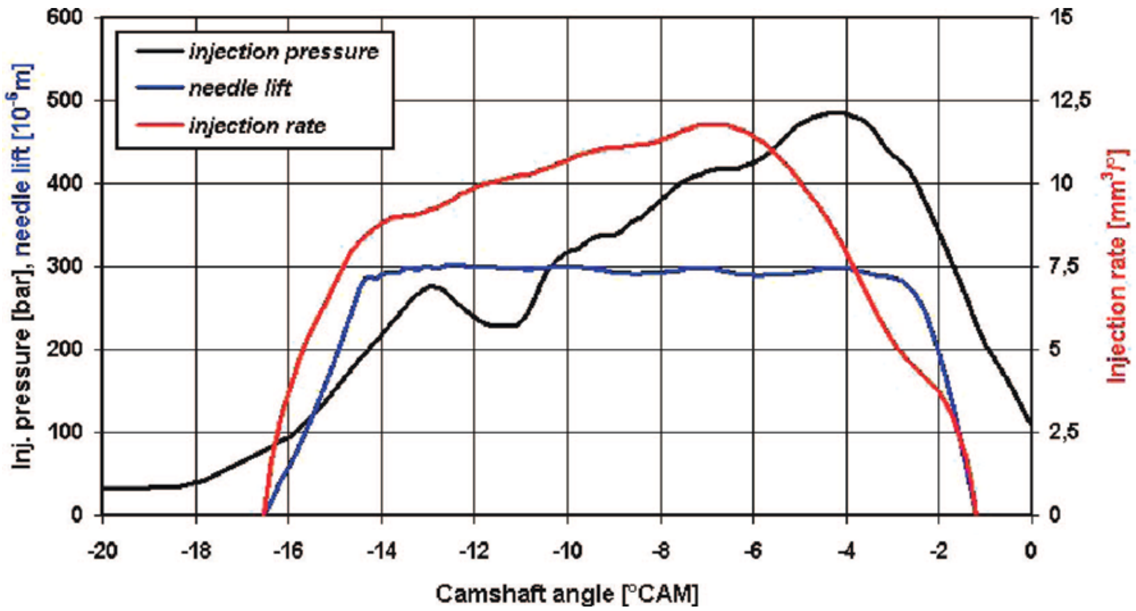

Figure 1: Diesel injection process characteristics at 1100 rpm

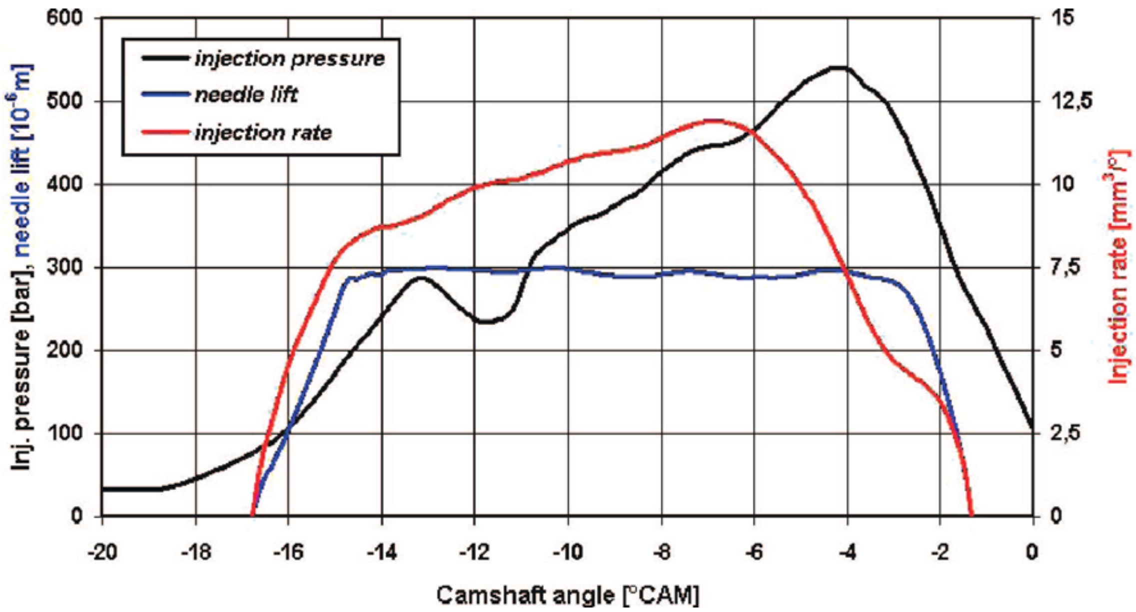

Figure 2: Biodiesel injection process characteristics at 1100 rpm

In order to validate numerical result, spray development was filmed using a high-speed camera.

Physical properties

The physical properties of commercial diesel fuel D2, biodiesel B100 and different mixtures of D2 with B100 have been studied. Fuel properties are given in Table 1.

Table 1: Fuel Density, Viscosity and Surface Tension at 30°C

fuel	density [kg/m^3]	viscosity [Pa s]	surface tension [N/m]
D2	825	2.7	0.0259
B50	848	3.55	0.0267
B100	875	4.8	0.0275

Spray development

The fuel spray was injected into the glass chamber at room temperature and atmospheric pressure [11]. For the spray filming, the high-speed digital camera Phantom v4.1 was used. Three consecutive spray developments for each fuel were filmed.

Numerical models

Numerical analyses were done by using the CFD program FIRE (spray) and 1D simulation program AVL Hydsim (needle lift…). The spray was simulated in FIRE using Euler-Lagrange approach, the calculations are based on a statistical method referred to as the discrete droplet method. Droplet parcels are introduced in the flow domain with initial conditions of position, size, velocity, temperature and number of particles in the parcels.

Results

Results shown follow the axial symmetry polyline. The position is presented in the Figure 3. All the results were taken at the same camshaft rotation angle 17.2°. It is assumed that the needle is fully opened at this time and the spray is fully developed.

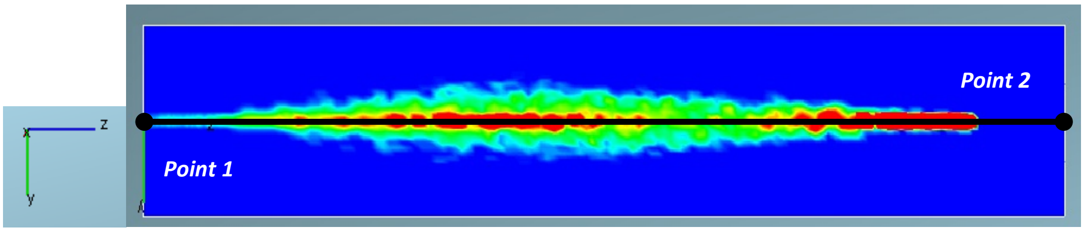

Figure 2: Position were the result are taken

Table 2: Spray penetration length (biodiesel and diesel)

fuel: biodiesel	camshaft speed [rpm]	
	500	**1100**
camera [cm]	30.6	33.8
simulation [cm]	29.9	34.8
difference[%]	-2.3	3.0

fuel: diesel	camshaft speed [rpm]	
	500	**1100**
camera [cm]	29.1	**32.5**
simulation [cm]	29.3	**30.7**
difference[%]	0.7	-5.5

The experimental and numerical results are almost identical for the spray penetration length. Comparison of the results in Table 2 shows how different type of fuel significantly influences the spray penetration length on a different camshaft rotation speed. When we compare the results for diesel fuel at camshaft speed 500 rpm the difference between experimental and numerical result is about 0.7 %, at camshaft speed 1100 rpm is -5.5 %. Usually the numerical results give higher values of penetration length than experimental ones. Comparison of result for biodiesel shows the opposite result to diesel. The differences are -2.3 % at 500 rpm and 3.0 % at 1100 rpm camshaft rotation speed. Comparison for biodiesel and diesel shows differences between them in results for different camshaft rotational speed, caused by different densities of used fuel (B100 ρ=875 [kg/m^3]; D2 ρ=825 [kg/m^3]).

Model parameters were inserted into the AVL Fire solver steering file and tested on the B100, D2 and on the blend of diesel and biodiesel B50 fuel at 1100 rpm and 800 rpm. Recorded spray development compared with simulation results is shown in Figure 3, 4 and 5 [11]. Comparison shows good accordance in the spray development as well as in its shape (spray angle and penetration). The difference between numerical and actual penetration is less than 5%. Spray simulation results for B50 confirm the adequacy of primary breakup parameter expressions for a used conventional injection system. In order to expand the application area, the injection system geometry parameters should be considered in the expressions.

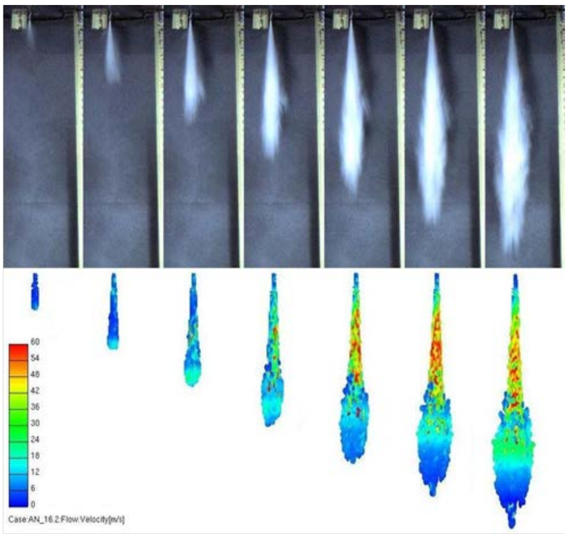

Figure 3: Spray development (D2, 1100 rpm)

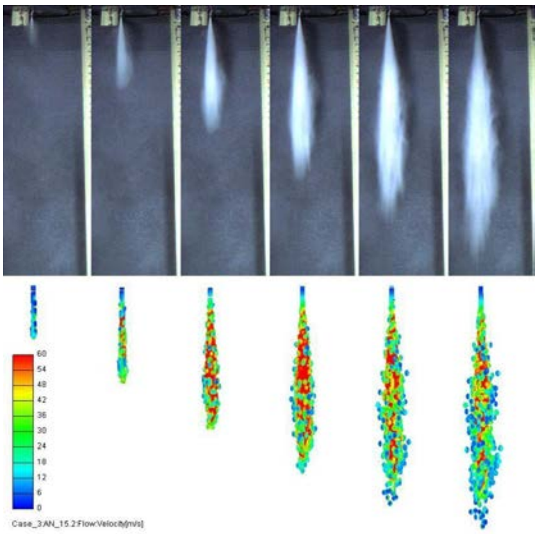

Figure 4: Spray development (B100, 1100 rpm)

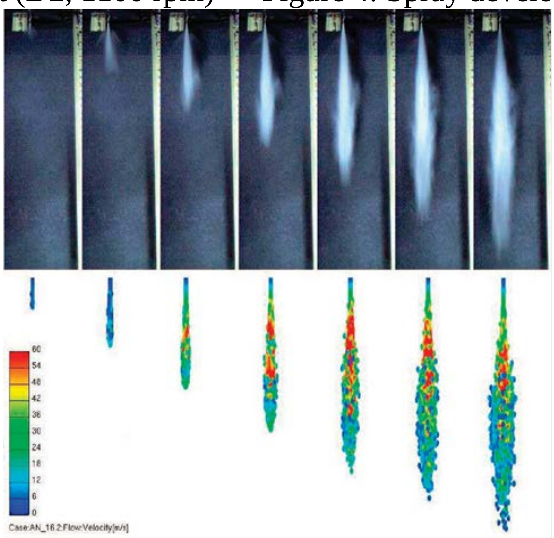

Figure 5: Spray development (B50, 800 rpm).

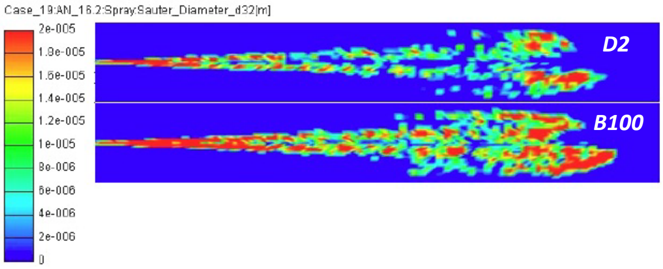

Figure 5: Sauter mean diameter in program FIRE (800 rpm)

Table 3: Comparison of Sauter mean diameter in programs FIRE and Hydsim (800 rpm)

biodiesel

Numerical program	Sauter mean diameter
FIRE [μm]	22.5
Hydsim[μm]	29.9
difference[%]	25

diesel

Numerical program	Sauter mean diameter
FIRE [μm]	21.6
Hydsim[μm]	23.0
difference[%]	7

As already stated the comparison of the Sauter mean diameter has been done only between both numerical programs FIRE (3D) and Hydsim (1D). Comparison of the results in Figure 5 and Table 3 show the differences between them and the importance of careful program selection. The differences in calculated values of the Sauter mean diameter were 25 % for biodiesel and 7 % for diesel fuel, where the CPU time for Hydsim was only 20 s while on the other side the CPU time for FIRE was 1 day.

Conclusion

Considering above-mentioned results the following conclusions could be made:

- the difference in the fuel's physical properties is reflected in the injection characteristics,
- higher density and bulk modulus result in the injection pressure increase (by biodiesel),
- higher fuel viscosity and surface tension, have no significant influence because of the large nozzle diameter; however for spray simulation purposes, just changing the fuel properties and injection process characteristics is not always enough and mathematical model influential parameters need tuning,
- the results obtained from experiments agree well with experimental results (spray length, cone angle…),
- comparison of the Sauter mean diameter of used numerical programs FIRE and Hydsim are comparable, however we recommend more simulations with additional parameters,
- it is very difficult to decide which program is better to use to predict the Sauter mean diameter, however we recommend more detailed experimental research so we can validate the numerical simulations,
- it is recommended to use numerical program FIRE for simulating spray characteristics, but Hydsim can also be used for fast estimations.

Acknowledgment

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References

[1] M. Graboski, R. L. McCormik: Combustion of fat and vegetableoil derived fuels in diesel engines, Prog. Energy Combust. Sci. 1998, 24, 125–164.

[2] D. Y. Z. Chang, J. H Van Grepen, I. Lee, L. A. Johnson, S. J. Hammnod, S. J. Marley: Fuel properties and emissions of soybean oil esters as diesel fuel, JAOSC 1996, 73 (11), 1549–1555.

[3] C. Y. Choi, G. R. Bower, R. D. Reitz, Effects of Biodiesel Blended Fuels and Multiple injections on D.I. Diesel Engine Emissions, SAE 970218, Society of Automotive Engineers: Warrendale, PA, 1997.

[4] S. Lee, D. Tanaka, J. Kusaka, Y. Daisho: Effects of diesel fuel characteristics on spray and combustion in a diesel engine, JSAE200224660, Japanese Society of Automotive Engineers: Tokyo, Japan, 2002.

[5] C. S. Lee, S. W. Park, S. I. Kwon: An Experimental Study on the Atomization and Combustion Characteristics of Biodiesel-Blended Fuels, Energy Fuels 2005, 19, 2201.

[6] Y. Wengiao: Computational modelling of nitrogen oxide Emissions from biodiesel based on accurate fuel properties, W. Yuan, PhD Dissertation, University of Illinois at Urbana–Champaign. Department of Agricultural and Biological Engineering, 2006.

[7] C. A. Allen: Prediction of biodiesel fuel atomization characteristics based on measured properties, PhD Dissertation, Dalhousie University - DALTECH, Halifax, Canada, 1998.

[8] K. Yamane, A. Ueta, Y. Shimamoto: Influence of Physical and Chemical Properties of Biodiesel Fuel on Injection, Combustion and Exhaust Emission Characteristics in a DI-CI Engine, The Fifth International Symposium on Diagnostics and Modeling of Combustion in IC Engines COMODIA, Nagoya, Japan, July 1–4, 2001.

[9] B. Kegl: Numerical analysis of injection characteristics using biodiesel fuel, Fuel 2006, 85, 2377–2387.

[10] AVL Fire Spray, version 2010, AVL LIST GmbH, Graz, 2010

[11] P. Pogorevc, B. Kegl, L. Škerget: Diesel and biodiesel fuel spray simulations, Energy & Fuels 2008, 22, 1266-1274