Numerical study on the effects of using different concentrations of FAME blends on the spray structure of the injection process

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Abstract. The present paper takes a closer look at the injection process characteristics for different conditions when there are used different FAME blends. Using a numerical approach, this work highlights the main implications and differences in terms of geometry, structure, and physical parameters of the injected fuel spray, when alternating the used fuels. In this attempt, AVL FIRE was used as simulation software solution giving the chance to alternate the used fuels and furthermore to create a direct link between the fuel properties, internal flowing, and jet spray characteristics. Because of the environmental and economic reasons, there are a growing tendency of using biofuel blends in increasing concentrations, as ample consumption of commercial fuels. As the physical properties of the Fatty Acid Methyl Ester fuels are very different compared with conventional diesel fuel, we expect that the fuel blends between them will show different behaviors in terms of internal nozzle flowing and thus it will generate different injection characteristics, being closely related with the biofuel concentration. The main objective of this paper is to set a dependency between the used fuels, nozzle geometry, and injection parameters that should be adapted, to meet the emissions standards and to obtain a properly burning.

1. Introduction

In our days, the usage of biofuels is considered to be a potential solution for green gas produced by worldwide transportation systems. It also seems to offer an alternative for the dependency on fossil fuels. Because of this, biofuels gained fast popularity, and in almost every region, the law requires the commercialization of fuel blends instead of pure diesel fuel. Having a similar density but higher viscosity and surface tension, compared with the conventional diesel, the behavior of biofuels into the fuel system and specially into injection processes are closely studied by the researchers.

In one of the studies, Seoksu Moon[1] aims to investigate the spray dynamic spray structure, using biodiesel fuel. For a better understanding, he decided to highlight the results by making a comparison between the dynamic structure of the biodiesel and conventional fuel sprays obtained from a single and multi-hole diesel injectors and using a synchrotron X-ray velocimetry technique. The results showed that the high viscosity and density of biodiesel decreased the injection velocity compared to conventional fuels, but this behavior was less significant for the multi-hole injector. For the case of single-hole injector, the usage of biodiesel led to a slowed flow breakup and increased the intact core area, because of the lower velocity decay rate. This behavior was not recognised at the multi-hole injector, where the flow breakup and the velocity decay rate along the spray core appeared unchanged, regardless of the used fuel.

Focused on internal flow characteristics of the fuel, the paper of Moon et al. compared in nozzle needle movement of biodiesel and diesel injected fuels from a single hole diesel injector.[2] Their observation includes that when the biofuels are used, because of their higher viscosity, the needle movement and the outlet nozzle flow velocity is slowed down, modifying the process timing and structure of the spray. Kuti et al.[3] put their focus on the droplet size distribution, entertained air mass and macroscopic spray structure of the jet spray, obtained by alternating the conventional diesel fuel, with biodiesel. They observe that, for the cases when were used biodiesel fuels, the resulted jet spray had a narrower spread angle and was characterised by larger droplet size, longer penetration distance and was capable of entertaining less air. Those results are assumed to be the direct consequences of higher viscosity and surface tension of biodiesel fuel.

In their paper, F.J. Salvador et al.[4] defined a numerical approach for spray characteristics determination. To highlight the effect of biofuel usage on the internal flow and further on the jet spray, they decided to simulate the injection process using the same parameters but switching between conventional diesel fuel with soybean oil. The parameters variation allowed to investigate two different situations in terms of inner flow: two-phase flow (cavitation presence) and one phase flow (no cavitation). The comparison between injection processes, in each situation, was made with the propose of following main parameters, as mass flow, momentum flux, sufficient velocity at the outlet, and cavitation/cavitation intensity. The pressure drop was defined as the difference between the injection pressure and back pressure. When the injected mass flow in relation with pressure drop was determined for each fuel, they conclude that due to its higher density, biofuel injects more fuel at the same time. Big differences between fuels were also found at reaching the critical cavitation conditions (CCC), and it was observed that the cavitation phenomena developed more quickly and were more intense at the diesel fuel. It is believed that, because of the increased viscosity and surface tension, the biodiesel tends to inhibit cavitation phenomena. It's well known that the air-fuel mixing process is better when the sufficient injection velocity is higher and also when there is a wide cone spread angle. However, when the injection process is obtained using soybean oil, both of those factors are smaller, generating a more compact spray jet capable of longer penetration distance and the air-fuel mixing is worst.

2. Method and simulation

As was already presented, changing the conventional diesel fuel with biofuels have a significant impact on the injection process. To obtain good burning performance, the conclusions of the studies shown that a couple of adjustments of the conventional injection system needs to be implemented for the cases of usage biofuels blends. Those adjustments are close related to the study cases and tend to be different at every change of used fuel, the thing that generates a real effort and represents a big challenge for developers.

However, modern computing techniques gives a potential helping hand in many study cases [5]. Using the numerical methods, it's possible to predict very close the behavior of the injection process and further the burning characteristics. One of the best software solutions used on a large scale in the automotive industry is represented by CFD Software AVL FIRE. AVL ESE DIESEL module allows computing the flow and jet spray using different types of fuel blends in different conditions. In our case of study, the conventional Diesel and B7 (Diesel and Biodiesel-7% blend) was taken into consideration, and several numerical simulations were done alternating those fuels, to monitories few parameters, as output velocity, dissipation rate, turbulence velocity, etc. Also, in this attempt, the effects of temperature variations were taken into consideration, at following values: 0, 40, and 80^{0}C.

The precise geometry of the injector nozzle was needed and used as a boundary condition. The injector that was taken as a reference is BL 76 S2 R, and the specifications were provided by the manufacturer. Both Diesel and B7 are widely used commercial fuels, and their properties were toked from official data of marketed fuels. The numerical simulation for injection event time is set at 0.005 sec. The cylinder inner diameter was set at 70 mm, and the mesh for this volume was generated automatically.

For time and calculation capabilities reasons and because the injector has one single hole, the computational domain was split and considered one-quarter of the hole domain.

Table 1 The boundary conditions

Injector	Type	Sac
	Hole number	1
	Hole diameter	0.17 mm
	Hole length	1.1 mm
	k- factor	0
Diesel	Density (300 K)	0.78 kg/l
	Liquid viscosity (300 K)	0.002 N-s/m^2
	Surface tension (300 K)	0.02 N/m
	Heat of vaporization (300 K)	385 kJ/kg
B7	Density (300 K)	0.86 kg/l
	Liquid viscosity (300 K)	0.0065
	Surface tension (300 K)	0.025 N/m
	Heat of vaporization(300 K)	360 kJ/kg
Environmental parameters	Environmental gas	air
	Environmental pressure	atmospheric

3. Results and discussions

One of the very first parameters that can be monitored at the injected spray and it's capableof characterizing the inner fuel flow is the particle distribution and particle size. To have more complex behavior, it was chosen to implement also a temperature variation, for both fuels. In the following images will be presented the simulation results in terms of those aspects:

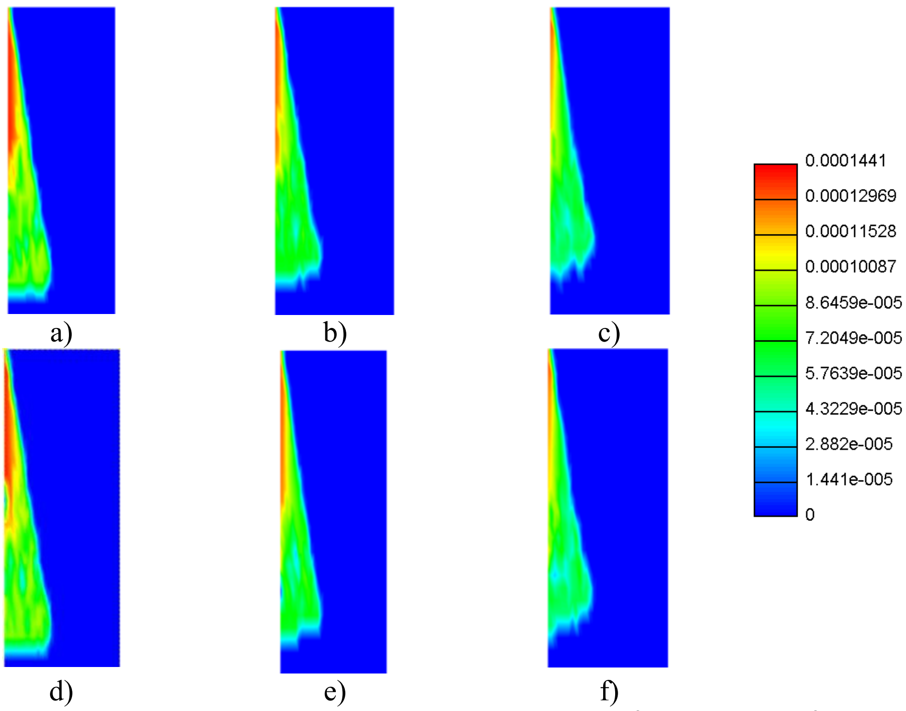

Figure 1. Sauter Mean Diameter (SMD) for a) B7 at 0^{0}C, b) B7 at 40^{0}C, c) B7 at 80^{0}C, d) D at 0^{0}C, e) D at 40^{0}C, f) D at 80^{0}C

It's not hard to observe that, once with the increasing of the fuel temperature, the particle medium diameter is drastically decreasing. Once with the decreasing dimensions of the particles, their kinetic energy is also declining and because of this, they are not capable of penetrating such long distances and in the end leading to a smaller spray tip penetration. However, this observation is valid for both fuels, but not in the same manner. Once with the increasing of the temperature, the density, and also the viscosity of the fuel is decreasing. This effect enhances the particles breaking and thus generating a more fragmented spray. When it's looking at fuels, it can be observed that at small temperatures, the fuel which has higher surface tension and viscosity (B7) has also at the core of the jet, bigger particles.

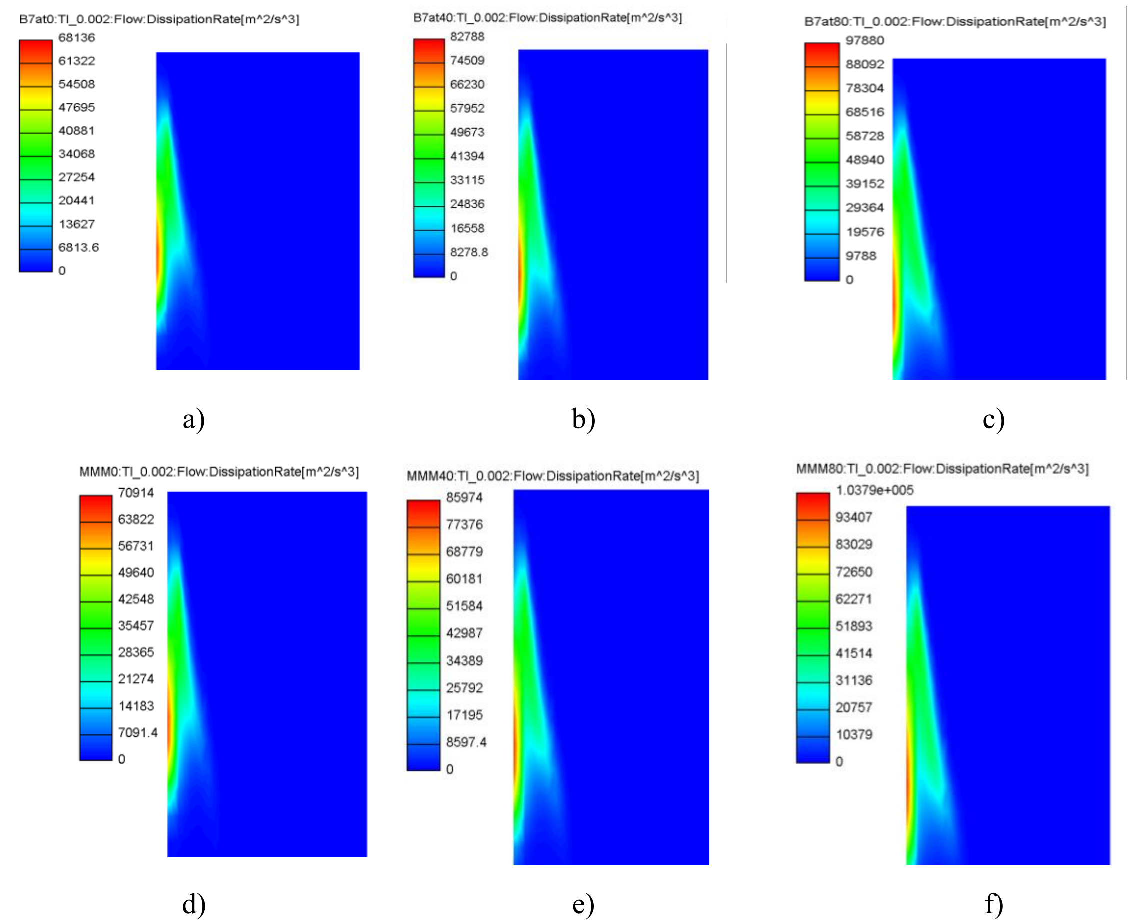

Figure 2. Dissipation rate for a) B7 at 0^0C, b) B7 at 40^0C, c) B7 at 80^0C, d) D at 0^0C, e) D at 40^0C, f) D at 80^0C

The second parameter that was analyzed is flowed dissipation rate. The shown results are easy to predict, taking into consideration the previous results of particle mean diameter. Once with the temperature is rising, because of the properties changes, the particle breakdown is amplified, and thus, the dissipation rate is increasing. Of course, this effect is more visible at fuels which have lower viscosity, surface tensio, and density properties. Because in our case, b7 and diesel fuels have very close properties, the differences in terms of flow dissipation rate are small. However, even those differences are enough to give us a conclusion, as follows: once with the increasing of the density and viscosity of the fuel (equivalent to an increase of biofuel concentration), the flow dissipation rate is decreasing, and furthe, generate a spray more compact which is capable to entrain less air. To be more obvious, the differences between those two fuels are represented also in the graph from figure 3. The output velocity of the fuels, in relation with temperature variation, is shown in figure 4. At the first sight, what can be conclude is that the velocity is increasing approximately linear and directly proportional with a temperature rising. Also can be mentioned that at every temperature value, the output velocity of the B7 fuel is lower than the diesel fuel. The explanation for this behavior is leading to the internal flow of each of the fuels. Because of the lower viscosity and surface tension, the critical cavitation conditions are reached more easily and this phenomenon is developing in more pronounced forms, for diesel fuel.

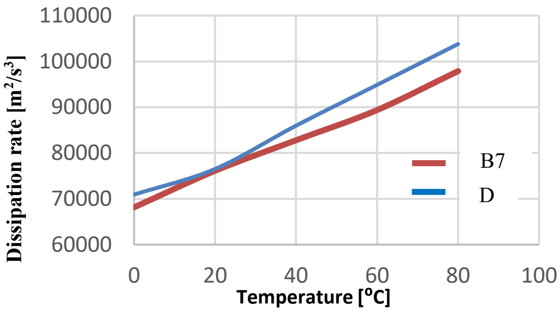

Figure 3. Dissipation rate of B7 and Diesel fuel, at different temperature values

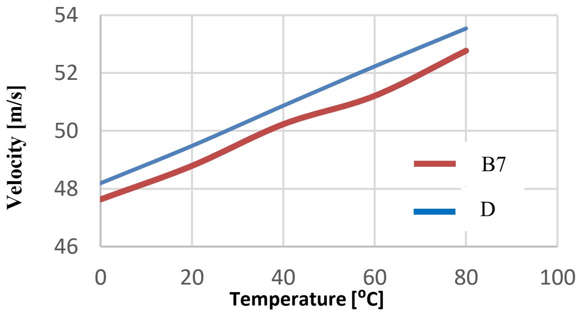

Figure 4. Output velocity of B7 and Diesel fuel, at different temperature values

4. Conclusions

Because there are many differences in terms of physical properties between the Diesel fuel and biofuel blends, several modifications should be implemented at injection systems in case of the fuel switch. For a better understanding and more accurate determination of the implications, the numerical approach remains one of the most convenient methods.

Conventional Diesel and B7 (Diesel+7%biofuel) were taken into consideration, at different temperature values: 0,40 and 80^{0}C. The fuel temperature increase leads to a decreasing mean particle diameter of the jet spray. It has also been observed that the penetration of the jet spray is decreasing once with the temperature of the fuels are rising, and this fact is believed that it's happening because smaller droplets lose their kinetic energy quicker and so, their travel distance is shorter.

Regarding the dissipation rate, this factor is more accentuate at conventional Diesel, because of the lower viscosity and surface tension properties. With the higher temperature, the viscosity of the fuels is decreasing, and particle breakdown phenomena are amplified, increasing the dissipation rate. Of course, the apparition and development of cavitation phenomena inside the nozzle have a significant effect on this factor. The outer fuel velocity was also measured, and the results showed that this parameter is increasing approximately linear and directly proportional with a temperature rising. At every temperature value, the output velocity of the B7 fuel was lower than the output velocity of Diesel, and this fact leads us to the cavitation phenomena which, mainly because it's physical properties, appears more often and develop itself in more intense phases, for this second-mentioned fuel.

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