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DETERMINATION OF COMMON RAIL INJECTOR FLOW CHARACTERISTICS WITH THE USE OF DIESEL AND BIODIESEL FUELS

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Abstract

One of the most important requirements in the design of diesel combustion systems is to reduce emissions of harmful chemical compounds contained in exhaust gases. Solution to this problem is sought by the use of advanced engine injection systems and accurate control of mixture formation inside a cylinder via split fuel injection. The differences in physical characteristics between traditional and alternative fuels can affect fuel metering, especially at short injection durations. Thus, the aim of the current study was to identify dynamic flow parameters of the Common Rail injector with the use of different fuels. The study involved Diesel available in retail and biodiesel fuel obtained by methyl esterification of fatty acids. Measurements were performed on a test stand designed for determination of injectors and injection pumps characteristics. Studies were carried out changing the following parameters: injection pressure in the range of 30-180 MPa, injection time in the range of 200-1600 microseconds. Each fuel was tested at temperature 40 and 60°C. The obtained test results showed that injection of different fuels provided variable amounts of fuel injected at short injection durations, which can affect mixture formation process as well as combustion. Effect of the dose of the injected fuel has a viscosity of used fuel.

Keywords: *fuel, oils & lubrication, engines, injector, biodiesel*

1. Introduction

Nowadays there is a tendency to reduce toxic components in gases exhausted emitted by diesel engines. It is associated with new requirements concerning the emission of harmful substances into the environment [4]. Besides the composition of fuel, a significant impact on the emission of toxic components in the combustion ignition engine has an injection system and the way of creating a fuel-air mixture. Therefore, the forming of the jet, atomization and combustion of the mixture in the cylinder are affected. In order to achieve a better atomization and precision of an injection, high injection pressures up to about 300 MPa are applied [10]. High pressures of diesel engine injection systems and the velocity of fuel in the injectors' channels of the order of 500 m/s lead to the formation of turbulent flow and cavitation. As a result of cavitation the flow efficiency can be reduced. Furthermore, implosion of cavitation bubbles within the hole of the injector causes an erosion of material injector and, consequently, its damage [6, 16]. However, the positive effects of cavitation in the injectors were also reported. Cavitation improves the fuel spray degradation, increased turbulence, spray cone angle and velocity at the outlet of the injector [17, 18]. Main parameters characterizing the process of fuel injection are the mass flow rate and the total amount of fuel injected into the workspace [8]. Both of these parameters depend mainly on injection pressure, the injector opening time and the characteristics of the fuel flow through the injector [5]. The real flow of fuel through the injector is described by the effective area through which the medium flows at a constant and effective velocity and density.

Construction of modern fuel injection systems in diesel engines over the years have been adapted to the diesel produced from crude oil. The chemical composition of diesel was determined by feedstocks for the preparation them and thus the physicochemical properties, especially the density, viscosity, fractional composition, surface tension. They have a significant impact on the parameters of the flow of diesel fuel in the injection process and the quality and course of the entire combustion process [11, 21]. Introduce changes in the composition of diesel fuel by adding biodiesel, usually higher methyl esters of fatty acids, resulting in changes in its physicochemical properties [11, 13]. Should be emphasized that for the production of biodiesel may be used diametrically opposite vegetable oils or animal fats. They may be edible and inedible raw materials, from dedicated production but also production waste [2, 3, 9, 10, 22]. Conducting research with the use of biodiesel is required to identify its origin or determine the composition of individual FAME, which is confirmed by the work [2, 7, 25]. The composition of FAME will have a significant impact on the level of emission of the main toxic components of diesel engines, NO_X and particulates [12, 14, 23]. May be noted that the hydrocarbons contained in the fuel oil have higher diverse of molecular weight and chemical structure than the fatty acid esters. Regardless of the source of biodiesel in them composition can be divided into 3 to 5 of esters of relatively high molecular weight (C16, C18 and C20), the content of which ranges from 80 to up to 92% by weight [7, 22]. This chemical composition determines the density, viscosity, fractional composition and other physical and chemical parameters with significant importance for the flow process of common rail systems [1, 24]. A large range of pressure and injection time, and the ability to divide fuel dose in the common rail systems arises a question, what impact has the biodiesel fuel on flow characteristics of the injector, especially at low pressures and short opening durations [1, 11, 19, 21]. Thus, the aim of this study is to determine the characteristics of the injector flow rate using diesel and biodiesel.

2. Theory of injection

The main parameters that characterize the process of fuel injection are the mass flow rate and the total amount of fuel injected into the cylinder [8]. Both these parameters depend mainly on injection pressure, injector opening time, as well as the characteristics of the fuel flow through the injector [5]. The amount of injected fuel into the cylinder with electromagnetic injector depends mainly on the injector opening duration. Despite the fact that the duration of injector opening depends on the electrical signal, in order to determine a real (effective) injection time the injector opening delay should be taken into account.

Effective injection time can be obtained based on the characteristic of the flow injector, as shown in Fig. 1. After determining the linear range of the injector and the equation of a linear function, the delay of opening of the injector needle is calculated on the basis of the effective time of fuel injection.

The flow coefficient *C* through the nozzle of the injector is calculated from the equation (1):

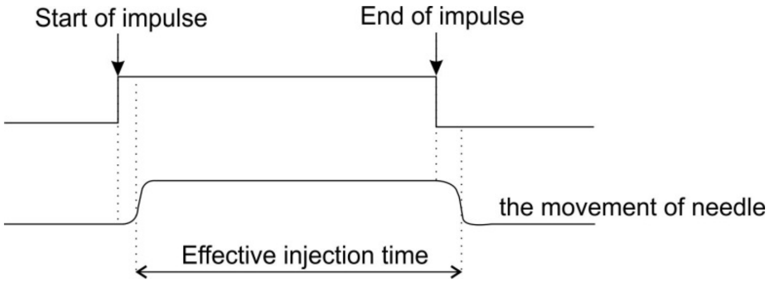

Fig. 1. Course of injection

$$C = \frac{u_t}{A_i \cdot \sqrt{\frac{2\Delta p}{\rho_F}}}, \tag{1}$$

where u_t is theoretical maximum velocity at the outlet of the nozzle, A_i is the cross sectional area at the outlet of the nozzle, Δp is the difference between the injection pressure and back pressure, whereas the symbol ρ_F is described the fuel density.

3. Experimental test stand

The research was carried out using a test stand designed for determination of injectors and injection pumps characteristics occurring in the Common Rail system. It is made of steel frame on which are mounted all necessary brackets and devices. The fuel pump is driven by an asynchronous three-phase motor, inverter-controlled by a toothed belt [15].

Test stand allows controlling and making measurements in an automated way. Main parameters of the test stand are specified in Tab. 1.

Tab. 1. Main parameters of the test stand

Technical parameters:	
Power supply	3x400V /50Hz
Max power	6 kW
Drive engine power	4 kW
Power of fuel heater	900 W
Settings:	
Engine speed	100-2000 rpm
Fuel temperature	20-60°C
Measurement range:	
Rotation speed	50-4000 rpm
Fuel pressure	0-0.2 MPa
Fuel temperature	0-100°C

4. Experimental conditions

The examinations were carried out using two fuels. Each fuel was tested in temperature: 40°C and 60°C. The study involved wide range of injection pressures, from 30 to 180 MPa. The injection time for each tested pressure was changed between 200 and 1600 microseconds. Were studied: Diesel available in retail, and biodiesel fuel obtained based on the transesterification of rapeseed oil using a homogeneous catalyst in the form of KOH. The composition of the various methyl esters were determined in accordance with PN-EN 14103 (Tab. 2), due to the significant impact of different types of esters on the physicochemical property of fuel, which is confirmed by the work [12, 23]. The density of fuel determined by the hydrometer in accordance with PN-EN

ISO 3675 at 15, 30, 40, 50, 60°C. Kinematic viscosity of studied fuels were determined by capillary according to PN-EN ISO 3104 at temperatures of 30, 50 and 60°C.Main parameters of the tested fuels are specified in Tab. 3. Both the fuel meet the standards respectively PN-EN 590 for diesel fuel and PN-EN 14214 for biodiesel.

Tab. 2. Biodiesel composition of fatty acid methyl esters

Common name of fattyacide methyl ester	Carbon no.: double bond no.	Percent composition of oil
Palmitic	C16:0	0.40
Palmitoleic	C16:1	4.52
Stearic	C18:0	1.59
Oleic	C18:1	61.95
Linoleic	C18:2	18.26
Linolenic	C18:3	9.81
Arachidic	C20:0	0.58
Eicosenoic	C20:1	1.45
Others		1.44

Tab. 3. Main parameters of the tested fuels

Fuel property	BIO 1	Diesel
Density @ 15°C (kg/m^3)	879.0	843.2
Density @ 30°C (kg/m^3)	868.9	832.3
Density @ 40°C (kg/m^3)	862.2	825.1
Density @ 50°C (kg/m^3)	855.4	817.8
Density @ 60°C (kg/m^3)	848.7	810.6
Viscosity @ 30°C (mm^2/s)	5.41	3.63
Viscosity @ 40°C (mm^2/s)	4.36	2.95
Viscosity @ 50°C (mm^2/s)	3.57	2.47
Viscosity @ 60°C (mm^2/s)	3.01	2.10

Measurements were performed on a Common Rail system electromagnetic injector Bosch with number 0445110647B004. After completing of examination of each fuel, whole fuel system was flushed and filled with another type fuel.

5. Experimental results

As a result of the measurements were received values of individual injections given in mm^3 for each inflicted parameters. Results of the measurements were collected automatically by the measuring system installed on the test stand. Graphs 2a-d presents results of the measurements of tested fuels. It can be seen that the fuel dose curves are similar, regardless of the temperature. Can be distinguished range of small non-linear increments of the fuel dose depending on pressure and the opening time of the injector and the extent of linear growth. For biodiesel at pressures below, 40 MPa and the opening time of less than 600 microseconds were measured a small fuel dose, significantly lower than for diesel.

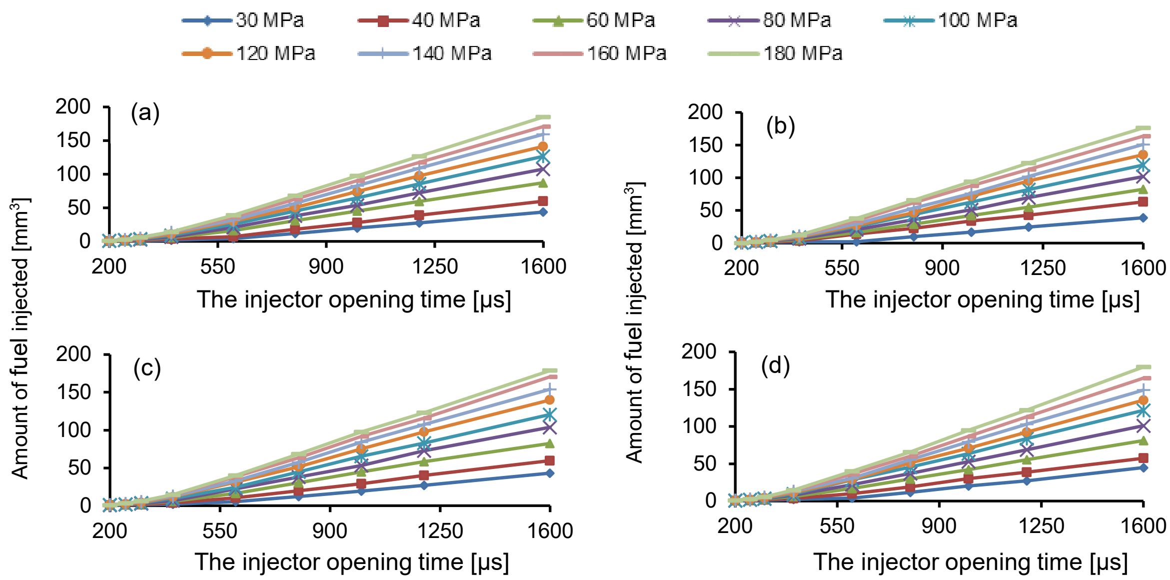

Fig. 2. Amount of fuel injected with: (a) Biodiesel at 40°C, (b) Diesel at 40°C, (c) Biodiesel at 60°C, (d) Diesel at 60°C

6. Identification of flow coefficient

Based on the values of individual injections effective time of the injection has been specified as a difference between a specified time of injection and the value of the point of intersection of the x-axis of the line describing the trend line course of injection. Effective injection time was used to determine the volume flow rate as a ratio of the fuel volume injected on the test stand and mentioned effective time. Identified flow coefficient is directly proportional to the volume flow rate of injected fuel and inversely proportional to the square root of the ratio between the value of twice the product of the differential pressure upstream and downstream of the injector and the value of density of the tested fuels. Determined values of the flow coefficient were presented in Fig. 3a, 3b.

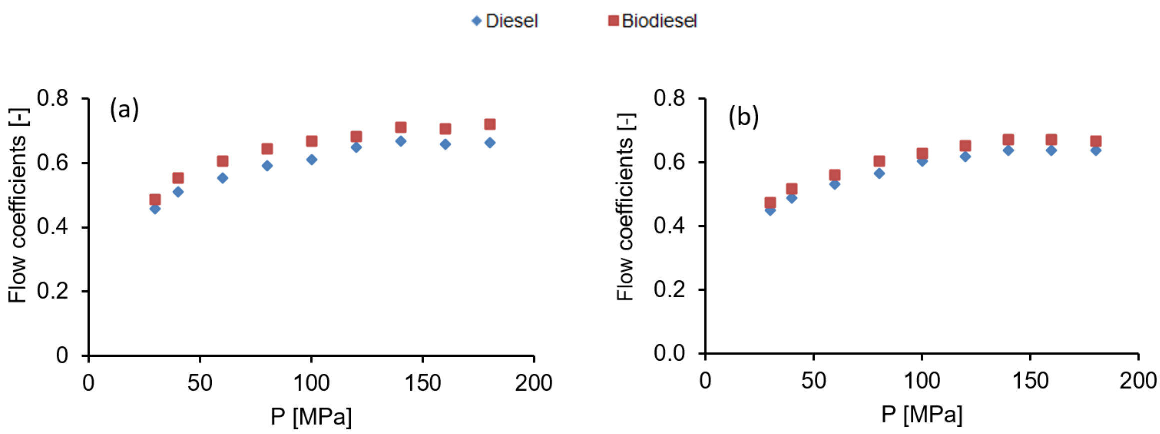

Fig. 3. Comparison of the flow coefficients of Diesel and Biodiesel at: (a) 40°C and (b) 60°C

Calculated for biodiesel, both at 40°C, and for 60°C, flow rate has a value much lower than the coefficient for diesel engines. Wherein the coefficients for both fuels increases to the injection pressure of 140 MPa, and above reaches the values at the same level as confirmed by studies Soma et al [22]. The differences between the values of flow rate for both fuels at temperatures of 40°C and 60°C do not change with the pressure rise. However, at a higher temperature differences are smaller. This is connected primarily with the fuel kinematic viscosity at a given temperature. The differences between the values of viscosity at 40°C and 60°C are lower. It was also concluded that value of kinematic viscosity for a tested biodiesel at 60°C (2.95 mm^2/s) is close to the viscosity of diesel at 40°C (3.01 mm^2/s). Therefore, fuel flow rates of the two fuels are comparable at given temperatures, as shown in Fig. 4.

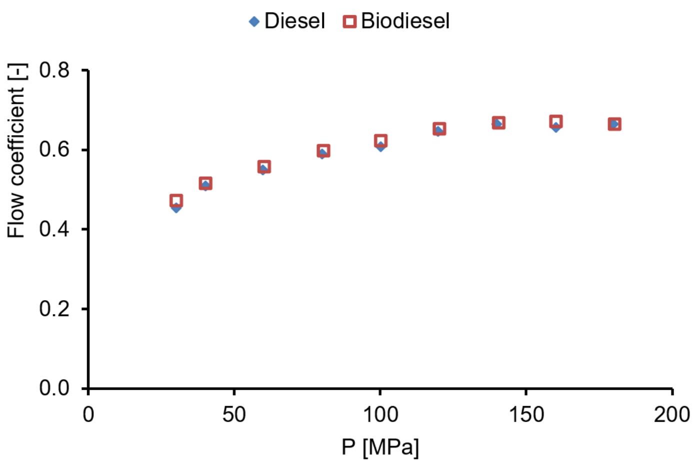

Fig. 4. Comparison of the flow coefficients of Diesel at 40°C and Biodiesel at 60°C

Comparing flow rates at different temperatures and at similar kinematic viscosity, values were obtained both fuels similar factor. It follows from this that the kinematic viscosity of the fuel has a significant influence on the course of injection. It was also found that the chemical composition has minimal impact on the value of the flow coefficient. Studies should be carried out for biodiesel from rapeseed oil, but from other sources, or derived from other plant materials in order to verify that the composition FAME does not affect the flow rate. It can be assumed that the fuel composition, its density and other physical and chemical parameters will affect the formation of air-fuel mixture, ignition delay, the process of liberation of heat, or emission of toxic compounds.

7. Conclusions

Common rail fuel injection systems, allow, on the one hand on the precise control of fuel dose, its division, the other for the construction of research equipment allows the determination of flow rates and their analysis. It should be emphasized that the common rail injection systems were designed to fuel produced on the basis of crude oil. Entering the bio-additives for diesel is important for the fuel dose control process. The study showed that the most important for the process of fuel injection is the kinematic viscosity of the fuel.

Were found considerable differences in the coefficients for the flow of diesel and biodiesel at the same temperatures and explicit dependence of the pressure rise. Whereas for the tested biodiesel raising the temperature from 40 to 60°C reduces the viscosity to a level appropriate for the operation of diesel at 40°C, which is confirmed by comparing the flow rate to the temperatures.

The obtained test results showed that injection of different fuels provided variable amounts of fuel injected at short injection durations, which can affect mixture formation process as well as combustion. Effect of the dose of the injected fuel has a viscosity of used fuel.

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