

Alternative Diesel Fuels Characterization in Non-Evaporating and Evaporating Conditions for Diesel Engines

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ABSTRACT

This paper reports the study of the effects of alternative diesel fuel and the impact for the air-fuel mixture preparation. The injection process characterization has been carried out in a non-evaporative high-density environment in order to measure the fuel injection rate and the spatial and temporal distribution of the fuel. The injection and vaporization processes have been characterized in an optically accessible single cylinder Common Rail diesel engine representing evaporative conditions similar to the real engine.

The tests have been performed by means of a Bosch second generation common rail solenoid-driven fuel injection system with a 7-holes nozzle, flow number 440 cc/30s @100bar, 148deg cone opening angle (minisac type). Double injection strategy (pilot+main) has been implemented on the ECUs corresponding to operative running conditions of the commercial EURO 5 diesel engine. First and second generation biodiesel, like Soybean Methyl Ester (SME) and Gas To Liquid (GTL), have been used and their behaviour has been compared to the reference diesel fuel. Images of evolving fuel, acquired in non-evaporative conditions and in the combustion chamber of the optical diesel engine, have been processed extracting the main parameters of the jet evolution. The different characteristics of the investigated fuels have produced differences in spray global performances in terms of penetrations and cone-angles. Different spatial distributions of the liquid fuel in the chamber have been assessed by the analysis of the luminous intensity along the jet direction. Finally, a comparison of the tip penetration in both evaporative and non evaporative systems has been carried out.

INTRODUCTION

Alternative fuels for diesel engines are becoming important due to the decrease of petroleum reservoirs and the increase of environment pollution problems [1, 2]. The biodiesel is an alternative diesel fuel derived from the transesterification of vegetable oils with simple alcohols to give the corresponding mono-alkyl esters and generally indicated with acronym FAME, Fatty-Acid Methyl Esters [3]. The biodiesel is technically competitive with conventional petroleum-derived diesel fuel and requires virtually no changes in the fuel distribution infrastructure. For this reason and its biodegradability, the use of biodiesel is considered a good alternative to fossil fuels [4, 5]. There is evidence that biodiesel, fuelling the engine, can have a strong impact on performances and pollutant emissions [6,7,8]. In particular, the last generation electronically controlled diesel engines using biodiesel have shown a decrease in the emission of particulate matter and unburned hydrocarbons [6,7,8]. Vice versa, although many researches show a slight increase in NOx emissions when using biodiesel fuel, some works showing different effects have been found. Some of them found NOx increases only in certain operating conditions; some others did not find differences between diesel and biodiesel fuels, and others found decreases in NOx emissions when using biodiesel as well. [8].

The feedstock used for the biodiesels production interferes with the human food chain, and the production costs are very high. These are the two main problems of the first generation biodiesel. For this reason, researchers are making considerable efforts in the development of an alternative production path, leading to the so-called second generation of biodiesel. Usually, the biodiesel is indicated with xTL, where x is the specific source feedstock and TL (to Liquid) highlights the final liquid state of the fuel. This source can be

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either renewable Biomass (BTL) or fossil fuels, as natural Gas (GTL) or Coal (CTL). Anyway, regardless the source, the xTL production process involves the Fischer-Tropsch synthesis of the syngas produced from feedstock. From the diesel engine fuelling point of view, a significant important difference between 1st and 2nd generations of biodiesel lies in their chemical composition. The 1st generation is essentially a blend of methyl-esters while the 2nd are paraffin hydrocarbons [9]. It seems that there is a potential to reduce gaseous and smoke emissions using biodiesel blends, when an engine and its auxiliary systems (fuel injection, EGR) have been optimized for the specific blend.

Injection process of biodiesels influences the atomization and dispersion of the fuel in the combustion chamber. Consequently, the combustion process and the exhaust emissions depend on the mixture preparation during the ignition delay. Researchers worldwide reported the relationship between these processes and chemical characteristics of the fuel/biofuels or their blends studied in quiescent vessel optically accessible [10, 11].

The research activity described in this paper is part of a wider study that involves fuel injection both in cold spray bomb investigations and in single-cylinder engine in order to assess the various biodiesel types on combustion behaviour (including performance, specific fuel consumption, GHG and pollutant emissions). Optical diagnostics based on imaging have been applied both in high-pressure optically accessible quiescent vessel for non-evaporating investigation and in the combustion chamber of a DI diesel engine for evaporating/combustion conditions using two pure biofuels, Soybean Methyl Ester (SME) and Gas To Liquid (GTL). Injection rates have been measured for all the used fuel and the defined injection strategies. The diesel engine has been optically accessible through quartz windows and equipped with multivalve head of real engine. The fuel penetration, spray atomization, air/fuel mixing and cone angle have been analyzed in non evaporating and evaporating conditions for multi injection strategies performed with last generation Common Rail (CR) high pressure injection system and typical of new generation Euro 5 diesel engines.

EXPERIMENTAL APPARATUS

The effects on the injection process of the physical and chemical properties of a commercial diesel and two alternative diesel fuels are the main objective of the present study. The injection process characterization has been carried out under non evaporative conditions injecting the fuel within stagnant inert gas in a high-pressure optically-accessible cylindrical vessel in order to measure the spatial and temporal distribution of the fuel. Moreover, the injection process has been studied in an optically accessible single cylinder Common Rail diesel engine representing evaporative

conditions similar to the real engine. The selected engine working condition has been extracted from the ECU map of a commercial EURO 5 engine. It is the low load condition 1500 rpm, 2 bar break average effective pressure (BMEP) and 50 MPa of injection pressure. The implemented injection strategy consisted of pilot + main pulse and has been fixed for all fuels. A Bosch second-generation common rail system has been used to inject the fuel through a CRI2.2 injector with 7-holes nozzles, 440 cc/30s @100bar flow number, 148 deg cone opening angle (minisac type). First generation of biodiesel, Soybean Methyl Ether (SME), and second one, Gas To Liquid (GTL), have been used and their behaviours have been compared to the reference diesel fuel. A comparison of chemical properties of mineral diesel fuel, first and second generation of biodiesel is reported in [Table 1](#).

Table 1. Chemical and physical properties of mineral fuel and first and second generation biofuels

Feature	Method	Diesel	GTL	SME
Density @ 15 °C [kg/m ³]	EN ISO 12185	840.1	777.5	884.4
Viscosity a 40 °C [mm ² /s]	EN ISO 3104	3.141	2.547	3.958
Oxydation Thermal Stability a 110°C h	EN 14112	-	-	7.9
Oxydation stability [g/m ³]	EN ISO 12205	0.1	0.8	1.2
Lubricity a 60 °C [micron]	EN ISO 12156-1	-	235	174
Cetane Number	EN ISO 5165	51.8	73.9	48
Net Heat Value [MJ/kg]	ASTM D3338	43.1	43.53	37.25
Distillation [°C]	EN ISO 3405			
°C IBP			203.1	320
°C 10% vol.			230.3	332.1
°C 50% vol.		280.1	265.9	335
°C 90% vol.		338.1	305.8	341.2
°C 95% vol.			312.2	345.6
°C FBP		362	317.3	-
%vol Recovered 250°C			32.3	-
%vol Recovered 300°C			84.9	-
%vol Recovered 350°C			-	97
%vol Residual/Loss			2.2	0.5/0.3
Carbon [%, m/m]	5991	86.5	84.3	78.4
Hydrogen [%, m/m]	5991	13.5	14.4	11
Nitrogen [%, m/m]	5991	-	1.3	0.2
Oxygen [%, m/m]	5991	-	0	10.4

Non-evaporative experimental setup

The experimental activity implied the measurement of instantaneous fuel injection rates on suitable test rig and the spatial-temporal evolution of the jets sprayed from the nozzle in a spray bomb.

A Programmable Electronic Control Unit (PECU) controlled the injection apparatus, thus enabling to set the strategies in terms of pulse number and timing. Fast electronic drivers in the PECU allowed setting precise and stable injections like the one involving small fuel quantities in multiple injections. The high pressure pump supplying the fuel to the CR has been driven by a variable speed electric motor while a heat exchange system on the hydraulic circuit has been adopted to keep a constant fuel temperature in the tank, $(21 \pm 1 \text{ }^{\circ}\text{C})$.

The fuel injection rate has been measured by an AVL Fuel Injection Gauge Rate System fitted on the Bosch tube inlet [12]. The fuel is injected in a small chamber, connected to a pipeline of constant section for the wave propagation, kept at constant pressure of 5.0 MPa for avoiding cavitations phenomena [12, 13]. An AVL GM12D pressure transducer collected the pressure variation due to the incoming fuel delivered from the nozzle. The pressure variation p is proportional to the injected quantity q according to the ratio

$$q = \frac{p \cdot A_{tube} \cdot 10^5}{a \cdot \rho}$$

here considering the fuel density ρ , the pipe inner section A_{tube} and the sound speed in the fuel a . The collected pressure signals in the gauge meter have been averaged on one hundred shots with dispersion less than 2%. The whole injected fuel per stroke is the integral of the instantaneous fuel rate over the total injection time [14]. The amount of injected fuel obtained has been successfully compared with the one pounded at the Bosch tube discharge by a precision balance.

The spatial and temporal evolution of the injected fuel have been measured by digital processing of spray images captured at different time from the start of injection in an optically-accessible quiescent vessel filled at engine-like gas densities. SF_6 gas (density 6.2 kg/m^3) has been used in the vessel at room temperature reaching the desired gas densities at lower pressures than air. Pressure of 0.28 MPa have been set in order to achieve a gas density of 17.5 kg/m^3 . The images of evolving jets have been captured by a VCO - CCD camera (1376×1040 pixels, 12 bit, $0.5 \text{ } \mu\text{s}$ shutter time) synchronized both with the injection system and a set of high intensity flashes. The camera has used a 95 mm macro lens for the pilot injection, while a 50 mm lens for the main pulse has allowed the acquisition of images with a field of view capable to cover the complete penetration of the sprays. Five images of consecutive injections have been acquired at each time-step. The stability and uniformity of the evolving sprays has made these conditions confident with a statistical evaluation on the spread of the parameters under study.

Analysis of the liquid fuel spray images has been carried out by image processing software: image acquisition, background

subtraction and filtering, edges determination, tip penetration and cone angle measures. A sketch of experimental apparatus for tests under non evaporative conditions and further details on the analysis procedure has been reported in [15].

Evaporative spray experimental setup

In order to study the spatial and temporal evolution of the fuel jets under the real pressure and temperature conditions a transparent diesel engine has been used. This could also help to provide important information about mixture formation and combustion start of the selected fuels. The optical single-cylinder engine used for optical diagnostics has been equipped with the head and injection system of the four-cylinder, 16 valves, 1.9l, GM standard production engine. The scheme of the engine and the experimental apparatus is shown in Fig. 1.

The optical engine uses a conventionally extended piston with a 46 mm diameter piston crown window which provides full view of the combustion bowl by locating an appropriate 45° UV-visible fixed mirror inside the extended piston. The window is made of UV-grade fused silica. To compensate for the slightly lower compression ratio typical of the optical engines and to match the in-cylinder conditions of the multi-cylinder engine tests, an external air compressor has been used to supply pressurized intake air. The air has been well filtered, dehumidified, and preheated. Moreover, a cooled EGR system has been used, and a pressure valve has been set in the exhaust pipe in order to ensure the correct operation of the burned gas recirculation system. More details about the specifications of the engine are reported in [16].

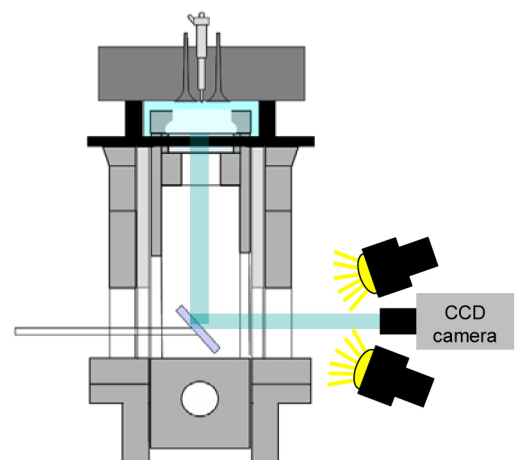


Fig. 1. Optical SC engine experimental setup

The engine has been equipped with the latest generation of common rail (CR) injection system operating with a maximum injection pressure of 180 MPa. The injector has been located centrally along the cylinder axis and provided with the seven holes nozzle. It was a CRI2.2 injector with the same geometric and flow rate characteristics as the one used