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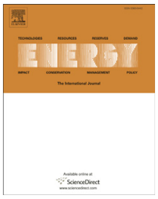

Evaluation of RME (rapeseed methyl ester) and mineral diesel fuels behaviour in quiescent vessel and EURO 5 engine

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ABSTRACT

Alternative diesel fuels for internal combustion engines have grown significantly in interest in the last decade. This is due to the potential benefits in pollutant emissions and particulate matter reduction. Nevertheless at possible increase in nitrogen oxide (NO_x), and almost certainly increase of fuel consumption have been observed.

In this paper, mineral diesel and RME (rapeseed methyl ester) fuels have been characterized in a non-evaporative spray chamber and in an optically-accessible single-cylinder engine using a Common Rail injector (8 holes, 148° cone opening angle and 480 cc/30s@10 MPa flow number) to measure the spatial fuel distribution, the temporal evolution and the vaporization–combustion processes. The injection process and mixture formation have been investigated at the Urban Driving Cycle ECE R15: 1500 rpm at 0.2 MPa of break mean effective pressure.

Characteristic parameters of the spray like penetration length and liquid fuel distribution have been analysed and they have been correlated with the exhaust gaseous and particulate matter emissions.

In the spray-analysis in non-evaporative conditions, short events (pilot) are mostly affected by asymmetries in the fuel distributions with noticeable standard deviations at low injected quantities. In the engine tests, the jets reached immediately the stabilization. A comparative analysis on the liquid phase of the spray, in non-evaporative and evaporative conditions, has permitted to investigate better the mixture formation. Its effect on pollutant emissions has been analysed for both fuels.

1. Introduction

In the last two decades the diesel engine has met the increasing demand of economy/performances of the powertrain conjugated with the legislative requirements of exhaust emission reduction, particularly focused on nitrogen oxides (NO_x) and PM (particulate matter). These results have been achieved thanks to the substantial progresses in the fuel injection equipments (Common Rail) and combustion managing that make large use of the electronic control. First (FAME (fatty acid methyl ester)) and second (Fischer-Tropsch) generation of alternative diesel fuels comply this challenge without any modification with the powertrain, coupling these potential emission reductions to the advantage of biodegradability/non-toxicity of the fuel and the global benefits on CO_2 cycle due to renewable fonts [1–3]. These fuels are generally referred as biodiesel for diesel engine applications and regulation permits mixtures up to 20% in volume to mineral diesel fuel.

However, some differences appear in the chemical-physical characteristics of biodiesels, with respect to the mineral diesel fuel, that affect the air-fuel mixture preparation and the combustion in the engine. The spray characteristics have been widely analysed to study the influence of injection pressure and cylinder backpressure on the fuel penetration [4–8]; moreover attempts in determining the fuel-bulk and droplet fragmentation have been carried out [9]. Some differences in the fuel injection rate have been found resulting biodiesel quantities lower than mineral fuels. This has been related to the different density and viscosity of the fluids [10]. Finally, effects of biodiesels on the injection apparatus have been widely investigated to associate the deposit formation in the injector system to the quality and composition of the fuel [11,12]. These sediments have been observed inside the injector body, on the piston, on nozzle needle but, especially, in the spray-holes resulting in a reduced flow and dispersion modification of the

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injected fuel. These lead to loss of power and worst air-fuel mixture preparation with strong consequences on the pollutant emission [13,14].

The effects on the combustion process of pure biodiesels and their blends with mineral diesel at different percentages have been investigated both in quiescent vessels and in optically accessible engines. High-pressure, high-temperature test rigs simulated the diesel engine conditions at the injection time and they have been used to study the behaviour of the liquid and vapour phases and the fuels properties effects [15–17]. In particular, the continuous penetration of the liquid phase has been related to the density, viscosity, and surface tension; while the droplet parts are mainly influenced by the fuel volatility [15]. Investigations on the penetration of the liquid- and vapour-phases inside diesel engines have been carried out on pure biodiesel and blends at diverse percentages [16] as well as for single components fuels [17] where a relationship between chemical-physical properties and spray evolution has been attempted.

In this paper, mineral diesel and RME (rapeseed methyl ester) fuels have been characterized both in a quiescent non-evaporative rig and in an optically-accessible single-cylinder engine. A pilot + main strategy has been explored with a slight increase of the main duration for the RME condition to compensate its lower heating value. The Urban Driving Cycle ECE R15: 1500 rpm at 0.2 MPa of BMEP has been simulated. A comparison between the liquid spatial distributions of the 8 jets has been performed in order to extract information about the air-fuel mixture and the pollutant emissions.

2. Test conditions and procedures

The injection process characterization has been carried out under both non-evaporative and evaporative environments to analyse the effects that the fluid density and viscosity of biodiesels-diesel fuels have on spray formation, mixing, and pollutants emissions. The delivering fuel rate and the spatial and temporal distribution of the liquid for non-evaporative conditions have been carried out in a test rig composed of a flow rate meter and a quiescent high-pressure optically accessible vessel, respectively. The evaporative phase has been studied in an optically accessible single-cylinder diesel engine working in real engine-like conditions.

2.1. Non-evaporative conditions

Diesel and RME fuels have been used to characterize the injection process in non-evaporative quiescent vessel. Fuel injection rates as well as spatial and temporal distribution of the fluid have been measured. The main physical/chemical characteristics of the two fuels are reported in Table 1.

The parameters mainly affecting the injection and spray formation are the density, viscosity and distillation curve. It is worthwhile to note that the RME has higher density and viscosity value than diesel fuel, parameters that influence the spray behaviour. The tests have been performed on a Bosch second generation common rail solenoid-driven fuel injection system by using a Bosch minisac-type injector (8 × 480 cc/30sx148°). The nozzle diameter is 0.136 mm and the length/diameter ratio is 5.29. The injection strategy is the same used in the single-cylinder engine and it has been taken from the calibration of real engine. It consists of a train of pilot + main injections at the injection pressure of 62.0 MPa. This is a typical Euro 5 engine condition at 1500 rpm and 0.2 MPa of BMEP (break mean effective pressure) and it is one of the most frequent point of the Urban Driving Cycle ECE R15 cycle. The optimization of this operating point on the real engine for biodiesel has produced an increase of the main pulse duration due to its lower energy content with respect to the diesel [18]. To achieve equivalent power output, the main pulse of RME is 20 μs longer than the diesel one. A PECU (programmable ECU) has managed the injection apparatus enabling to set the strategies in terms of pulse number and timing. Fast electronic drivers in the PECU allowed setting precise and stable injections for large as well as small fuel quantities like pilot ones. The high pressure pump supplying the fuel has been driven by a variable speed electric motor while a heat exchange system on the hydraulic circuit has been adopted to keep constant the fuel temperature in the tank (40 ± 1 °C). Further details as the sketch of the experimental apparatus, the injection flow rate bench and the high pressure vessel are reported in Ref. [19].

Table 1
Physical-chemical properties of diesel and RME fuels.

Feature	Method	Diesel	RME
Density @ 15 °C [kg/m^3]	EN ISO 12185	840.1	883
Viscosity @ 40 °C [mm^2/s]	EN ISO 3104	3.141	4.254
Oxidation stability [g/m^3]	EN ISO 12205	0.1	0.8
Lubricity @ 60 °C [micron]	EN ISO 12156-1	–	188
Cetane number	EN ISO 5165	51.8	52.3
Low heating value [MJ/kg]	ASTM D3338	43.1	37.34
Distillation [°C]	IBP	184.8	322
[°C]	10% vol.	221.9	33.2
[°C]	50% vol.	276.1	337
[°C]	90% vol.	329.1	343.3
[°C]	95% vol.	344.9	347
[°C]	FBP	358.3	360
Carbon [%, m/m]	ASTM D5291	86.5	78.5
Hydrogen [%, mm]	ASTM D5291	13.5	10.8
Nitrogen [%, m/m]	ASTM D5291	–	0.2
Oxygen [%, m/m]	ASTM D5291	–	10.5

The global behaviour of the fuels has been studied by an AVL injection meter for collecting the fuel injection rates and the analysis of the spray images collected by a flash/CCD (charge coupled device) system synchronized with the injection command. More details of the technique and procedures are reported in Ref. [19].

2.1.1. Fuel injection rate

Fuel injection rates have been measured by an AVL meter working on the “Bosch pipeline” principle [20]. The pressure increase, produced by the fuel injected through the nozzle in an adapted chamber, is registered by a GM12D – AVL piezoquartz transducer. The signal is proportional to the fuel rate through a relationship with geometrical parameters of the device and chemical-physical properties of the fluid. The time resolution of the fuel rate is less than 1 μs. The measured injected fuel has been compared with the weight one collected at the Bosch tube discharge and measured by a precision balance. The experimental setup is completed by electronic devices for managing the injections both in terms of starting and synchronization with the acquiring instruments. The data storage is a four channels oscilloscope Tektronix TDS 684 B, 1 GHz bandwidth. Further details on the injection rate measures procedure have been reported in Ref. [19].

2.1.2. Spray evolution setup

The spatial and temporal evolution of the injected fuel has been studied processing the images of the sprays captured at different time from the SOI (start of injection) in an optically-accessible quiescent vessel at ambient temperature and filled with gas at densities typical of the engine at the injection time. Taking into account that the main controlling factor of the sprays development in non-evaporative conditions is the density of the gas [21], SF$_6$ (sulphur hexafluoride) (density 6.2 kg/m^3) has been used for safety reasons permitting to reach the desired densities at pressures lower