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Impact of biodiesel fuel on cold starting of automotive direct injection diesel engines

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ABSTRACT

The use of biodiesel fuels in diesel engines is gaining attention as a promising solution to control CO_2 emissions. Great research efforts have been carried out to identify the impact of biodiesel physical and chemical properties on engine systems and processes. Most of these investigations were performed in warm conditions, but the suitability of biodiesel for starting the engine at under-zero ambient temperatures has not widely evaluated. The surface tension and the viscosity of biodiesel fuels are higher compared to those of standard diesel and, in cold conditions, these differences become critical since the injection fuel rate is largely affected and consequently the combustion process can be deteriorated. In order to improve its flow characteristics at cold temperatures and make them more suitable for low temperatures operation, additives are used in biodiesel fuels. In this paper the suitability of different biodiesel fuels, with and without additives, for cold starting of DI (direct injection) diesel engines has been evaluated. The results have shown that the engine start-ability with pure biodiesel fuels can be largely deteriorated. However, using diesel/biodiesel blends the start-ability of the engine can be recovered with the additional benefit of reducing the opacity peak of the exhaust gases.

1. Introduction

Nowadays, petroleum-based fuels are obtained from limited reserves, and thus the search for other fuel resources is crucial in order to attend the worldwide demand of energy. In particular, biodiesel blends have emerged in the last years as an alternative fuel for transportation. According to the European Commission, even though the current high production cost of the renewable energies, bio-fuels are now probably the most promising way to reduce the fossil fuel dependence of transport vehicles powered by diesel engines [1].

Bio-fuels, which are obtained from vegetable oil resources, appear to be an excellent substitute for fossil fuel, because their production is simple, they are biodegradable, nontoxic, recyclable, benzene-free and cleaner than fossil fuels [2–4]. Due to their miscibility with the standard diesel fuel, it can be used either pure or in blends [5]. Additionally, bio-fuels have an excellent lubricity and its use does not require considerable modifications in the engine hardware.

In addition, this alternative fuel allows a significant reduction of pollutant emissions of diesel engines, most notably of CO_2 (carbon dioxide). In comparison with the standard diesel fuel, the use of biodiesel blends can produce reductions of 78% of net CO_2 emissions, due to the carbon neutral cycle of such fuels [6]. In this cycle, the CO_2 released into the atmosphere, when the biodiesel fuel burns, is recycled by growing plants, which are later converted into fuel. Since the sulfur and the aromatic content of biodiesel fuels are negligible while their O_2 (oxygen) concentration is substantially high [7], significant reductions of SO_2 (sulfur dioxide), soot, CO (carbon monoxide) and UHC (unburned hydrocarbons) can be achieved [8–10].

Due to their higher Cetane number, a shorter ID (ignition delay) is produced and hence the formation of NO_x (nitrogen oxides) during combustion is usually increased [11,12]. Since the heat value of biofuels is lower than that of standard diesel fuel, the BSFC (brake specific fuel consumption) of diesel engines increases while the thermal efficiency is scarcely affected [13–15].

The suitability of bio-fuels for controlling CO and UHC emissions at high idling operating conditions has been also confirmed. In fact, the higher the biodiesel percentage in biodiesel/diesel blends, the lower the CO and UHC emission levels, while NO_x emissions remain constant or even decrease slightly for biodiesel ratios up to 5%, and tend to increase for ratios above 5% [16].

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Nomenclature

Abbreviations

BSFC	brake specific fuel consumption
CFPP	cold filter plugging point
CO	carbon monoxide
CO_2	carbon dioxide
DI	direct injection
ECE	Economic Commission for Europe
ECU	electronic control unit
EGR	exhaust gas recirculation
ELR	European Load Response
FIS	fuel injection system
ID	ignition delay
NO_x	nitrogen oxides
O_2	oxygen
SAE	Society of Automotive Engineers
SO_2	sulfur dioxide
UHC	unburned hydrocarbons
VGT	variable geometry turbocharger

The major drawbacks of bio-fuels are associated with their effects on engine operation. Indeed, the use of such a fuel can cause clogging of the fuel lines and injector coking. Moreover, due to the higher surface tension and viscosity of biodiesel fuels, the hydraulic behavior of the injector can be affected and consequently an adequate atomization before the combustion process is hardly achieved [17]. As a consequence, on one hand carbon deposits can be promoted and the sticking of piston rings can be produced as well [18,19]; on the other hand, the lack of atomization has a negative impact on the vaporization process, and consequently on the auto-ignition of the fuel. Since misfiring is frequently produced in those conditions, in particular, this issue is harmful for the start-ability of engines under below-zero ambient temperatures. Under these unfavorable conditions, the increase of the oil viscosity [20] and the decrease of battery performance cause very low cranking speeds and quite high blow-by levels [21,22] and, additionally, fuel-air mixing is hindered due to the weak air motion [23].

Therefore, while most of the properties of biodiesel are comparable to those of petroleum-based diesel fuel, the major challenge when using biodiesel as an alternative fuel for diesel engines is still the improvement of its low temperature flow characteristics. Typically, the biodiesel fuels will display higher cloud points and pour points, and this is a great handicap for biodiesel usage [24]. The pour point is the temperature at which a fuel can no longer be poured due to gel formation. Crystallization of the saturated fatty acid methyl ester components of biodiesel at cold ambient temperature causes fuel starvation and operability problems as solidified material clogs fuel lines and filters. With decreasing ambient temperature more solids form and material approaches the pour point. Furthermore, it is well established that the presence of a higher amount of saturated components increases the cloud point and pour point of biodiesel. Potential solutions to this problem include the use of specific additives or blending the given biodiesel with other fuels such as ethanol or kerosene. Specific improvers such as olefin-estercopolymers decrease by 33% the dynamic viscosity of soybean biodiesel even with very low contents of around 0.03% [25]. Blending the biodiesel with ethanol or kerosene at ratios up to 20% [26] also decreases by 30% the kinematic viscosity, improves the NO_x-soot trade-off compared to raw bio-diesel fuel, and promotes the atomization of the fuel, being an interesting option for solving the problem.

In this framework, the objective of this paper focuses on investigating experimentally the suitability of different biodiesel fuels, with and without additives, for keeping the engine start-ability at low temperature conditions similar to that obtained with standard diesel fuel. The most common parameter used to evaluate the cold performance of pure biodiesel or biodiesel blends is the so-called CFPP (Cold Filter Plugging Point), as observed in the European standard [27]. The Cold Filter Plugging Point is the temperature at which a fuel jams the filter due to the formation of agglomerates of crystals [28]. Additional fuel characteristics could be used for evaluating the effects on cold starting, such as viscosity, cetane number, ignition quality and many others, but considering that the CFPP is the unique parameter limited in the European standard, the study presented in this paper considers mainly this parameter and includes a detailed analysis about its feasibility to characterize the suitability of biodiesel fuels for cold starting of diesel engines.

This paper is organized into four main sections. First, a description of the experimental facilities used in the study is presented. In Section 4, the methodology used is detailed, whereas the parameters considered in order to characterize the start-ability of the engine are defined in Section 4. Following, in Section 5 the results obtained for the different fuels tested are discussed in detail. Finally, the conclusions extracted from this work are summarized.

2. Experimental configuration

2.1. Evaluated engine

The experiments were performed on a light-duty 4-cylinder Euro V turbocharged DI (direct injection) diesel engine, with a total displacement of 1.5 l and FIS (fuel injection system) with common rail. The engine coupled to the gear box was mounted on a test bench, so that the contribution of the gear box to the total load that the engine must overcome during the starting can be also considered in the tests. The specifications of both engine and FIS are summarized in Table 1.

2.2. Engine test rig

Cold starting tests have been performed in a climatic chamber where it is possible to control the ambient temperature from −30 up to 15 °C. Fig. 1 shows a diagram of the climatic chamber used. The humidity in the main chamber was controlled by a pre-chamber, which supplied cold dry air through depression wall valves. The engine bench was located in the main chamber. The fuel tank and the battery were also placed in the main chamber, so that both fuel and electrolyte temperatures were similar to those of the rest of fluids before the test began.

The soaking time required for maintaining stable temperatures in the engine fluids (oil, coolant, fuel and battery electrolyte) before

Table 1
Engine specifications.

Engine type	Direct-injection diesel engine
Fuel injection	Common rail
Turbocharger	Variable geometry turbine
Cylinders	4 in line
Swept volume (dm^3)	1.5
Bore (mm)	75
Stroke (mm)	80.5
Compression ratio	16:1
Max. power (kW)	65 (@ 3750 rpm)
Max. torque (Nm)	200 (@ 1900 rpm)