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Influence of fatty acid unsaturation degree over exhaust and noise emissions through biodiesel combustion

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HIGHLIGHTS

- Biodiesel chemical composition affects engine performance and emissions.
- Biodiesel/diesel fuel blends reduce the emissions of CO and noise.
- Biodiesel/diesel fuel blends improve the sound quality, although, NO_x increases.
- The higher the unsaturation degree the higher the NO_x and the lower the CO emissions.
- A linear correlation between fatty acid unsaturation degree and sound pressure level was found.

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ABSTRACT

Environmental concerns are driving the scientific community to search for alternative fuels to substitute fossil-based ones. In this context, biodiesel is the most extended alternative to fuel diesel engines due to its renewable nature. However, the chemical composition of the raw materials used to produce biodiesel is variable, thus providing a wide range of types of biodiesel showing diverse affinity to diesel engines. Moreover, depending on the fuel properties, engine exhaust and noise emissions may be affected. For these reasons, it is important to increase the knowledge about the implications of biodiesel chemical composition and properties over engine exhaust and noise emissions. An experimental study with vegetable oils (covering a wide range of fatty acids) to produce biodiesel has been carried out. Selected raw materials included high, medium and low saturated fatty acids, i.e. palm, sunflower, olive-pomace, coconut and linseed oil. Later, their methyl esters blended with diesel fuel were tested in a direct injection diesel engine. Effects of chemical properties of biodiesel on exhaust and noise emissions have been studied at several engine operating conditions. In general terms, results showed that the use of biodiesel/diesel fuel blends reduced the emissions of CO and noise, thus improving the sound quality, although, NO_x increased. Particularly, it was found that the higher the unsaturation degree the higher the emission of NO_x and the lower the CO emissions. A linear correlation between fatty acids unsaturation degree and sound pressure level was found at high engine power values. In sum, despite the increase on NO_x, the use of unsaturated biodiesel as partial diesel fuel substitute is recommended to improve CO emissions, besides engine sound quality, therefore making the engine sound more pleasant.

1. Introduction

Due to the increasing interest in environmental problems and also motivated by the European legislation, the reduction of noise and pollutant emissions is one of the main target for vehicle manufactures. During the last years and mainly due to their lower fuel consumption, compression ignition engine cars, commonly known as diesel vehicles, have increased their share in the European passenger car market, in detriment of spark ignition engine-based cars [1]. In fact, about one-third of the vehicles sold in the EU and the States are diesel powered. Moreover, diesel engines are also used in industrial activities, power generators and construction. However, provided that engines are fueled with fossil fuels, being highly responsible of the increase of hazardous pollutants to both humans and environment, alternatives to petroleum-based fuels are needed. Because it is produced from renewable sources and

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can be produced domestically, biodiesel has emerged as an alternative to petroleum diesel fuel [2,3].

Biodiesel consists in monoalkyl esters of long chain fatty acids derived from renewable feedstocks, such as vegetable oils, animal fats or microorganisms [4]. It is commonly composed of fatty acid methyl esters (FAMEs) that are usually prepared from triglycerides by transesterification with methanol. Biodiesel is an attractive alternative fuel for diesel engines because it can be used in its pure form or in any combination with diesel fuel to create a stable biodiesel blend.

When used in diesel engines, biodiesel usually exhibits combustion-related advantages, including reductions in carbon monoxide (CO), unburned hydrocarbon (UHC) and PM emissions [5]. The reduction of these emissions is mainly credited to the physicochemical properties of biodiesel, i.e. density, bulk modulus, cetane number and heat capacity, among many others.

However, there are also several combustion-related disadvantages, also due to biodiesel chemical composition. Owing higher oxygen content, FAME exhibits lower heating values than fossil diesel fuel. So, to achieve adequate engine power, an increase of the injection volume is needed [6]. This fact results in a larger biodiesel requirement to achieve the same brake power level as diesel fuel, resulting in higher specific fuel consumption. Moreover, many authors have found that for some operating conditions, biodiesel combustion emits more NO_x than conventional diesel fuel [7,8]. The reduction of NO_x exhaust emissions is one of the most important technical challenges facing biodiesel development, especially in view of the increasingly stricter exhaust emission regulations affecting diesel engines.

There are several raw materials being exploited commercially to produce biodiesel, mainly consisting of fatty oils derived from different oleaginous plants. Several studies have proved the influence of the chemical structure of the raw material on the physical and chemical properties of biodiesel [9–11], showing the crucial importance of the selection of the raw materials to produce biodiesel. It has been shown that the presence of saturated fatty acids in biodiesel improves combustion properties such as cetane number (*CN*) and lower calorific value (*LCV*), despite their poor cold-flow properties. Unsaturated, especially polyunsaturated fatty acid esters exhibit lower melting point (which is desirable for improved low-temperature properties) but also low cetane number and reduced oxidative stability, which are undesirable for a diesel fuel [11,12].

Moreover, several studies have demonstrated that chemical and physical fuel properties influence the quality of engine combustion [13–15]. Besides, diesel engine combustion may be considered the most important source of noise in a vehicle. For these reasons, the study of the influence of the fuel chemical and physical properties over sound quality is needed [16]. Traditionally, despite Fast Fourier Transform (FFT) analysis, A-weighted sound pressure and effective perceived noise level have been recommended as noise methods, they are no effective to assess the quality of perceived sound. Moreover, reducing the emitted noise may not ensure a good sound quality, provided that human perception is a very complex mechanism and many factors influence the sound quality evaluation process. Nowadays, automotive manufactures have invested a lot of effort and money to improve the sound of their vehicles, being the acoustic features a vehicle sound signature. In fact, while the control of the overall noise is imperative to fulfil the current legislation, sound quality and comfort also play an essential role in the customers purchasing decision. Even very quiet noises that are not associated with quality or do not meet personal expectations become noticeable and are potential cause for customer complaints. Forthcoming legislation establishes an increase of the presence of biodiesel in fossil-based diesel fuel, which could modify the vibro-acoustic perception of the engine, initially conceived to run on straight diesel fuel. For these reasons, it is important to study the influence of the use of biodiesel, straight and blended with diesel fuel, in engine performance and emissions, to take them into consideration in the early design phase.

Furthermore, the ultimate advances in combustion technologies, conceived to further reduce NO_x or PM to comply with the European regulations without penalties, may affect this issue. The self-ignition of air–fuel mixture is the origin of the combustion noise, which produces an important sudden pressure increase giving rise to the well-known diesel knock [17]. Additionally, in-cylinder pressure forces are strongly dependent on the combustion process, which is mainly dominated by the fuel-burning rate. Moreover, for a given combustion system, the fuel-burning rate is controlled by the fuel injection rate. Although research has provided results about exhaust and noise emissions of a diesel engine fueled with biofuels [18–22], the influence of biodiesel on engine sound quality remains unknown.

The aim of this work is to study the influence of oleaginous feedstock fatty acid unsaturation degree used to produce biodiesel (in terms of physical and chemical properties of raw materials) on engine exhaust and noise emissions. A preliminary exhaust emission test of a direct injection diesel engine fueled with biodiesel produced from five different vegetable oils with fatty acids covering a wide range of saturation degree: sunflower oil (SFO), olive pomace oil (OPO), palm oil (PO), coconut oil (CO) and linseed oil (LO) will be carried out. Finally, the influence of the unsaturation degree over biodiesel sound quality will be reported.

2. Experimental procedure

2.1. Fuels properties

Biodiesel samples were produced after basic-catalyzed transesterification of five different vegetable oils showing a wide range of fatty-acid composition [23,24]. Table 1 shows the chemical composition, unsaturation degree (*UD*) and average chain length (*LC*) of the used vegetable oils. Sunflower and olive pomace oils were acquired from KOIPESOL (Sevilla, Spain), linseed oil was purchased from Guinama (Valencia, Spain), while palm and coconut oils were acquired from Quimics Dalmau (Barcelona, Spain).

KOH and methanol were the catalyst and alcohol used to produce biodiesel through transesterification, respectively. KOH pellets [85% p.a. CODEX (USP_NF)] and methanol ACS-ISO were acquired from PANREAC (Barcelona, Spain).

Yield on FAME (wt.%) and fatty acid composition of each fatty acid methyl ester sample were analyzed following the EU standard EN 14103. Coconut and palm oil methyl ester yields were analyzed using the modified EN 14103 (the initial oven temperature was raised from 150 °C to 220 °C at 5 °C/min, with this last temperature being held for 15 min) and using as internal standard methyl tridecanoate (C13:0) to make possible the separation of short-chain fatty acid esters (C12–C14) in the chromatogram [25]. A Perkin Elmer (Waltham, Massachusetts, USA) Clarus 500 chromatograph (GC) equipped with a flame ionization detector (FID) was used for gas chromatographic determinations. A 30 m × 0.25 mm Elite Wax Perkin Elmer capillary column (film thickness of 0.25 μm) was selected.

Each biodiesel was blended with no. 2 diesel fuel (20% and 50% vol/vol biodiesel/diesel fuel). Some fuel properties used during this analysis are depicted in Table 2.

Kinematic viscosity (μ) was measured with a Canon–Fenske capillary viscometer immersed in a constant temperature (40 °C) bath, following the European norm EN ISO 3104. High calorific value (*HCV*) analysis were carried out following the ASTM D240 standard, using an IKA (Staufen, Germany) Bomb Calorimeter, model