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Biodiesel from saturated and monounsaturated fatty acid methyl esters and their influence over noise and air pollution

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ABSTRACT

A combined analysis of exhaust and noise emissions of an three-cylinder direct injection diesel engine running on palm oil methyl esters (PME) and olive pomace oil methyl esters (OPME), both blended with diesel fuel in different proportions, is proposed to evaluate their suitability as partial substitute to fossil fuels. Moreover, engine sound quality (derived from the use of these fuels) based on loudness and roughness metrics has been analyzed. A strong correlation between sound pressure maximum level and loudness was found. Although it was observed that both parameters improved with the use of both set of blends, PME blends depicted the best behavior. In terms of roughness, OPME blends achieved the maximum attenuation. In addition, roughness attenuation was found to be more meaningful than loudness when the blends were used. Considering the exhaust emissions tests, it was observed that the use of both sets of fatty acid methyl ester blends allows a significant reduction of CO emissions. Moreover, lower NO exhaust emissions were produced when PME blends were used instead of OPME blends or diesel fuel. NO_x emissions were lower when PME blends were used instead of OPME blends, though diesel fuel depicts the lowest values. In general terms, it may be concluded that saturated fatty acid methyl esters produce biodiesel with a positive influence over air and noise emissions.

1. Introduction

Nowadays, the reduction of greenhouse gas (GHG) emissions is one of the most important targets for vehicle manufacturers. The "ecological conscience" of consumers, besides the fact that about one-third of the vehicles sold in Europe and United States are diesel-powered [1] are leading the scientific community to search for a new generation of fuels for diesel engines. To contribute to an effective reduction of GHG and to promote cleaner transport, the European Directive 2009/28/EC establishes that the share of energy from renewable sources in the transport sector must amount to at least 10% of final energy consumption in the sector by 2020. In this context, biofuels need to meet certain criteria to be considered a cleaner option, including sustainability. In particular, biodiesel has received wide attention as a replacement for diesel fuel because it is biodegradable, nontoxic and environmentally less contaminant, being compatible with conventional diesel fuel. Also, it can be blended in any proportion with fossil-based diesel fuel to create a stable biodiesel blend [2]. Biodiesel is obtained from different vegetable oils or animal fats through their transesterification with an alcohol and a catalyst. The usual feedstocks for biodiesel production are rapeseed, soybean, palm, sunflower and other oleaginous plants. The use of palm oil biodiesel, also known as palm oil methyl ester (PME), is increasing due its low cost and productivity. Biodiesel from palm oil is characterized by a high level of saturated fatty acids and shows excellent combustion properties, such as cetane number and high calorific value, despite its poor cold properties or high kinematic viscosity. In recent studies [2–4] it has been observed that biodiesel from triglycerides with high concentration of monounsaturated fatty acids (such as rapeseed oil or olive pomace oil) may have optimal characteristics in regard to chemical and physical properties. Olive pomace oil is the residual oil that remains in the olive fruit pulp, once virgin olive oil has been extracted. It cannot be described as olive oil due to its poor organoleptic properties, but it provides high-quality biodiesel [5].

On the other hand, the European Directive 2002/49/EC aims to provide a common approach that intends to avoid, prevent or reduce on a prioritized basis, the harmful effects, including annoyance, due to exposure to environmental noise. Generally, the radiated noise from diesel engines can be broken down into mechanical noise and combustion noise, as shown in Fig. 1. Combustion noise is separated into direct combustion noise (directly proportional to the combustion gas pressure) and indirect combustion noise (proportional to rotational forces as well as combustion-induced piston side forces) [6,7]. When combustion takes place, a

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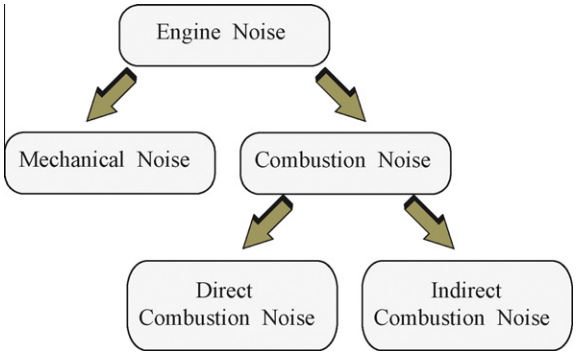

Fig. 1. Engine noise contributions.

sudden pressure rise is produced causing the vibration of the engine block, which in turn radiates air-borne noise. The block vibration is caused by pressure forces exerted directly by the gas and the mechanical forces associated with piston slap, bearing clearances and friction. Pressure forces strongly depend on the combustion process, which is mainly dominated by the fuel-burning velocity. In addition, this velocity is controlled by the injection rate [8]. The excitation source, pressure and mechanical forces of combustion noise are characterized by in-cylinder pressure; the system response is associated with the vibration of the block wall and the radiated noise is the final effect of such vibration [9,10]. As shown in Fig. 2, combustion noise, which is audible in the vehicle, is associated with the vibration of the block wall, while the radiated noise is the final effect of such vibration. It is transferred to the passenger as annoying noise in a frequency range between 800 Hz and 4000 Hz [11]. It is important to mention that engine performance, also related to combustion and hence to exhaust emissions, is a result of fuel properties, including molecular composition and structure, cetane number and viscosity [12–14].

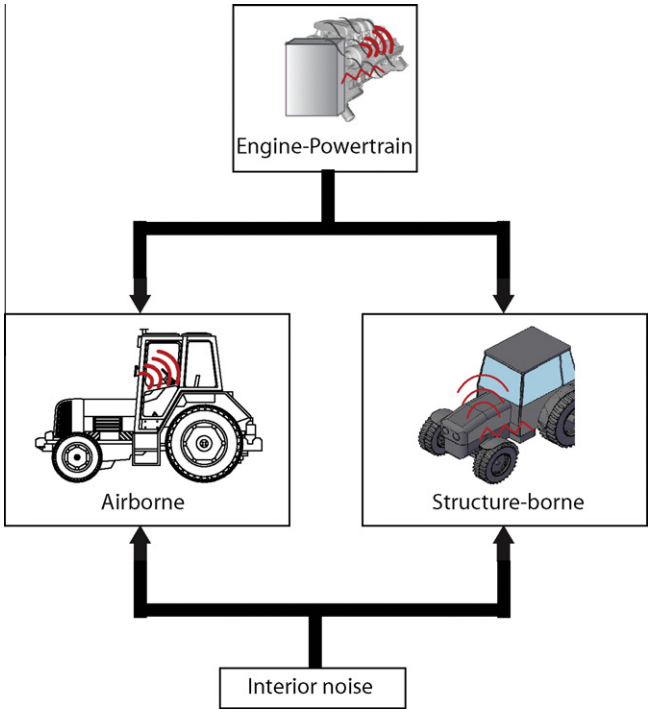

Fig. 2. Transfer path of combustion noise in a vehicle.

Therefore, it is important to achieve the reduction both exhaust emissions and combustion noise when different fuels are used.

In this paper, to evaluate the suitability of low and high saturation degree biodiesel blends as partial fossil fuel substitutes, a combined analysis of exhaust and noise emissions of a diesel engine fueled with palm oil methyl ester and olive pomace oil methyl ester (OPME) is proposed. Moreover, sound quality based on loudness and roughness metrics has been considered, besides other important parameters.

2. Experimental procedure

2.1. Materials and experimental set-up

Both methyl esters of olive–pomace oil and palm oil were produced by alkaline transesterification and further purification processes as described by Pinzi et al. [15]. Olive pomace oil (OPO) was acquired from KOIPESOL (Sevilla, Spain) and palm oil (PO) that was purchased from Quimics Dalmau (Barcelona, Spain). KOH and methanol were the catalyst and alcohol used during the transesterification to produce biodiesel, respectively. KOH pellets [85%p.a.CODEX(USP_NF)] and methanol ACS–ISO were acquired from PANREAC (Barcelona, Spain). Fatty acid composition of OPME and PME were analyzed following the EU standard EN14103 and glycerides content was determined following EN14105 standard. The most important chemical and physical properties of OPME, PME and no. 2 diesel fuel were analyzed following the EU Standard EN14214 and EN 590, respectively.

Biodiesel blends of 20% and 50% (v/v) of OPME with diesel fuel (OPME20 and OPME50) and 20% and 50% (v/v) of PME with diesel fuel (PME20 and PME50) were tested in a diesel engine test bench. Exhaust and noise emissions were analyzed in a direct injection three-cylinder 2500 cm^3 diesel engine Perkins AD 3-152 2500, with a maximum torque of 162.8 Nm at 1300 rpm and a maximum engine power of 44 kW at 2132 rpm (DIN 6270-A). To simulate the actual driving conditions, an electric Froment testing device (model XT200) dynamometer was used. The engine dynamometer has a maximum engine power of 136 ± 1.44 kW of accuracy at 100% of the engine speed (reported by the National Institute of Agricultural Engineering, UK), as described by Dorado et al. [16]. The engine speed was measured and monitored electronically to the nearest 5 rpm. Fuel consumption was measured using a Froment electronic fuel flow monitor (FM502), as described by Dorado et al. [16]. Also, atmospheric condition data were collected to correct the engine power following the SAE standard J1349 (revised August 2004). A portable Testo 350-S exhaust emissions monitor was used for measuring and recording the exhaust emissions values.

The noise radiated by the engine was recorded using a GRAS prepolarized free-field half-inch microphone placed at 1 m off the engine at a height of 1.5 m. It was calibrated before each test by means of a B&K calibrator model 4231. A Soundbook instrumentation series, consisting of a portable and multi-channel meter, was utilized as the measuring device, including the software package Samurai v1.7 from SINUS Messtechnik GmbH (Germany) for data collection. Matlab R2008a from MathWorks Inc. (USA) was used for post processing all recorded measurements. The acquisition of noise signals was performed at a sampling frequency of 2.56 kHz with a frequency resolution of 1.56 Hz. All recordings were carried out following ISO 362-1:2007.

Several engine operating conditions were tailored after the '8-mode cycle' for engine dynamometer operation. The emission test plan adapted to diesel engine Perkins AD 3-152 is shown in Table 1. Each parameter was measured and recorded, during the last 3 min of each running step, although each mode cycle was held for 10 min until exhaust emissions were stabilized and maintained.