Fuel 95 (2012) 615–621

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Air and noise pollution of a diesel engine fueled with olive pomace oil methyl ester and petrodiesel blends

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ARTICLE INFO

Article history:
Received 13 October 2011
Received in revised form 1 November 2011
Accepted 2 November 2011
Available online 15 November 2011

Keywords:
Biodiesel
Sound quality
Performance
Air contamination
Acoustic pollution

ABSTRACT

Olive pomace oil derives from the oil left in the olive fruit pulp than remains after pressing extra virgin olive oil. To extract olive pomace oil, the pulp is treated with solvents. The resultant oil contains impurities and may undergo several heating and filtering processes to refine it to an acceptable standard. To make it satisfactory to consumers, it must be blended with virgin olive oil before use. Therefore, another uses for this oil could be soap production or its recycling to produce biodiesel. Exhaust emissions, noise and sound quality of a direct injection diesel engine fueled with olive pomace oil methyl ester (OPME) blends were studied at several steady-state engine operating conditions. Results showed that the higher the content of OPME in the blends, the lower the CO emissions, whereas NO_x increased, keeping fuel consumption constant. Moreover, it was found that cetane number exhibited a stronger effect over noise production than bulk modulus, whereas the reverse effect was found concerning NO_x emissions. Biodiesel blends reduced air and noise pollution, while improving sound quality. Therefore, the higher the percentage of biodiesel in blends, the lower the pollution emitted by the engine.

1. Introduction

The Directive 2009/28/EC of the European Parliament and the Council sets out a package of measures to reduce greenhouse gas emissions, energy savings and increased energy efficiency, while complying with the Kyoto Protocol of the United Nations Framework Convention on Climate Change and with further Community and international greenhouse gas emissions reduction commitments beyond 2012. Moreover, it includes a mandatory 10% minimum target to be achieved by each Member State for the share of biofuels in transport by 2020. In this sense, biodiesel is a good alternative for diesel fuel since it can be used in diesel engines without major modifications. Biodiesel, commonly known as fatty acid methyl esters (FAME), is produced through the transesterification of vegetable oils or animal fats.

A highly valuable oil that is mainly produced in Mediterranean countries, i.e. Greece, Spain, Italy, Tunisia, Portugal, Syria and Lebanon is olive oil. Once virgin olive oil has been extracted by pressing, there is still some oil that remains in the olive fruit pulp. To extract the so-called olive pomace oil, the pulp is treated with solvents. Although, olive pomace oil may be used for consumption, it cannot be described as olive oil. In fact, it has a more neutral flavor than virgin olive oil, making it undesirable among experts; however, it has the same fatty acid composition as regular olive oil. Therefore, another uses such as raw material to produce soap or its recycling for biodiesel production must be taken into consideration.

In recent studies, the relationship between the fatty acid composition of biodiesel and its chemical and physical properties has been determined [1]. Several authors have suggested that biodiesel with a high level of methyl oleate (or monounsaturated fatty acid) may have excellent characteristics in regard to ignition quality, fuel stability, flow properties at low temperature and iodine number (according to the European biodiesel standard EN14214) [1,2]. For this reason, olive pomace oil (that contains more than 75% wt. of oleic acid) should be a suitable raw material for biodiesel production, especially in the South of Europe where it is obtained as a secondary product in the virgin olive oil industry.

Although, biodiesel is an important option for alternative uses of olive pomace oil, it results imperative to study the pollution (air and noise emissions) produced from a diesel engine when it is fueled with olive pomace oil biodiesel compared to conventional diesel fuel. In this sense, many researches have addressed the suitability of the use of methyl esters of vegetable oils as fuel or additives to diesel fuel to reduce exhaust emissions, such as particulate matters (PMs) [3,4], carbon monoxide (CO) [5] or total hydrocarbons (THCs) [6]. However, using biodiesel, an increase of NO_x emissions has been observed [2,5,7–9].

Since noise is one of the most important environmental factors, which affects comfort and human health, it seems logical to

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doi:10.1016/j.fuel.2011.11.003

consider acoustic pollution in the same level of importance as air contamination. This is of special interest in protected landscapes, where flora and fauna need to be preserved from air and noise pollution that may imperil the ecosystem. Reduction of the ever-increasing noise levels in the environment may improve our quality of life. Vehicle noise, which constitutes about 40% of city environmental noise, has been considered in the past few decades, and vehicle noise control has accordingly become a very active research area. A large research effort related to sound quality (SQ) of vehicle has recently been conducted [10,11]. It has been found that the characteristics of a sound as it is perceived are not exactly the same as those of the sound being emitted. Traditionally, acoustic engineers have employed measuring units such as A-weighted decibels (dBA), which, in spite of showing a correlation with human perception, they simply give weight to the effects of the different components, specially in low frequency noise, using a family of curves defined in the International standard IEC 61672. In this sense, it neglects an important mechanism within the ear transduction of pressure fluctuations into signals to the brain, namely frequency masking. Understanding the basic anatomy of human hearing is vital to facilitate the fundamental psychoacoustic findings relevant to the perception of the sound [12]. By means of a study of the sound and psychoacoustic quality, a more than mathematical interpretation is made of the pressure signals in order to correlate the acoustic stimulus with the hearing sensation [13].

It is also important to define the most appropriate set of metrics for each application. The International Standardization Organization (ISO) has generalized sound quality (SQ) methods into two classes. The first is the octave-band analysis (OBA) for linear and/or weighted sound power levels (SPLs). The second refers to more appropriate values based on the human sensation of loudness. Typically, the standard ISO 532 and further updated versions BS5727 and EN61260, which provide a graphic method for loudness calculation by means of third-octave bands, have been proven very useful for SQ design in automotive engineering in the areas of engine noise [14–16]. The most important metrics in sound quality evaluation of vehicle related sounds are Zwicker loudness, sharpness, roughness and fluctuation strength. Some researchers recommend loudness and roughness as the most important sound quality metrics for the evaluation of engine noise [10]. However, other authors indicate that roughness and fluctuation strength seem to correlate well with engine related noise [17]. Also, loudness and sharpness have been proposed to evaluate the sound quality in vehicles [18]. According to these researches, it seems that an established criterion for determining the best parameters to assess the sound quality of an engine is missing. The so-called just noticeable difference (JND) of amplitude and frequency, as well as duration changes of pure/complex tones or broad band noise, have been investigated for decades, but little is known regarding the JND of sound quality metrics in real noise [19,20].

The aim of this paper is to study the sound quality of a diesel engine fueled with olive pomace oil methyl ester (OPME) considering loudness, sharpness and roughness psychoacoustic metrics to evaluate the noise emission in a receptor position as a human being could listen it. The study includes the influence of the use of OPME as a fuel for diesel engines in some of the main exhaust emissions. Finally, noise and air pollution of a diesel engine fueled with OPME are assessed.

2. Materials and methods

2.1. Fuel description

OPME was produced after basic-catalyzed transesterification of olive pomace oil (OPO) that was acquired from KOIPESOL (Sevilla, 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). Transesterification and purification processes carried out to produce OPME have been previously described [21].

Fatty acids composition of OPME was analyzed following the EU standard EN14103, while glycerides content was determined following EN14105 standard. The most important chemical and physical properties of OPME and No. 2 diesel fuel were analyzed following the EU Standard EN14214 and EN590, respectively.

Pure diesel fuel and blends of 20% and 50% (v/v) of OPME and diesel fuel (OPME20 and OPME50, respectively) were tested in a direct injection diesel engine.

2.2. Description of the engine

Fuel tests were performed in a 2500 cm^3, three cylinder, four-stroke, water-cooled, 18.5:1 compression ratio, direct injection diesel engine Perkins AD 3-152. The maximum torque was 162.8 Nm at 1300 rpm and the maximum engine power was 44 kW at 2132 rpm (DIN 6270-A). The engine was not new but reconditioned to original specifications. In order to measure the emissions and brake-specific fuel consumption (*BSFC*) during operation, the actual driving conditions on the road were simulated on a dynamometer bench. The dynamometer was an electric Froment testing device (model XT200), with maximum engine power of 136 kW and ±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. [5]. The fuel was metered by a positive displacement gear type sensor, using a Froment Electronic Fuel Flow Monitor (FM502), as described by Dorado et al. [5]. The engine speed was measured by the Froment testing device and monitored electronically to the nearest 5 rpm. Atmospheric condition data were collected to correct the engine power following the SAE standard J1349 (revised August 2004).

2.3. Emission tests

Emission tests were carried out with a portable Testo 350-S exhaust emissions monitor. The engine test cycle was tailored after the '8-mode cycle' for engine dynamometer operation, according to ISO 8178–4. Emission test plan adapted to diesel engine Perkins AD 3-152 is shown in Table 1. Each running step was held for 10 min until exhaust emissions were stabilized and maintained while each parameter was measured and recorded, during the last 3 min of each running step. The following principles of calculation were used:

$$NO_x = NO + (NO_{2add} \times NO)$$

where NO_x is the nitrogen oxide value (ppm), NO is the measured nitrogen monoxide value (ppm) and NO_{2add} is the nitrogen addition factor.

$$uCO = CO \times \lambda$$

where uCO is the carbon monoxide undiluted (ppm), CO is the measured carbon monoxide value (ppm) and λ is the calculated air ratio defined like the relationship between the fuel-specific carbon dioxide value, CO_{2max} (ppm), and calculated carbon dioxide value, CO_2 (ppm).

For the conversion from ppm to mg/m^3, the following expressions were used:

$$CO(mg/m^3) = \frac{O_{2ref} - O_{2Bez}}{O_{2ref} - O_2} \times CO(ppm) \times 1.25$$

$$NO_x(mg/m^3) = \frac{O_{2ref} - O_{2Bez}}{O_{2ref} - O_2} \times NO_x(ppm) \times 2.05$$