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Effect of the use of olive–pomace oil biodiesel/diesel fuel blends in a compression ignition engine: Preliminary exergy analysis

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ABSTRACT

Although biodiesel is among the most studied biofuels for diesel engines, it is usually produced from edible oils, which gives way to controversy between the use of land for fuel and food. For this reason, residues like olive–pomace oil are considered alternative raw materials to produce biodiesel that do not compete with the food industry. To gain knowledge about the implications of its use, olive–pomace oil methyl ester, straight and blended with diesel fuel, was evaluated as fuel in a direct injection diesel engine Perkins AD 3-152 and compared to the use of fossil diesel fuel. Performance curves were analyzed at full load and different speed settings. To perform the exergy balance of the tested fuels, the operating conditions corresponding to maximum engine power values were considered. It was found that the tested fuels offer similar performance parameters. When straight biodiesel was used instead of diesel fuel, maximum engine power decreased to 5.6%, while fuel consumption increased up to 7%. However, taking into consideration the Second Law of the Thermodynamics, the exergy efficiency and unitary exergetic cost reached during the operation of the engine under maximum power condition for the assessed fuels do not display significant differences. Based on the exergy results, it may be concluded that olive–pomace oil biodiesel and its blends with diesel fuel may substitute the use of diesel fuel in compression ignition engines without any exergy cost increment.

1. Introduction

There are numerous research works focused on the evaluation of internal combustion engines (ICE) running on different biofuels, many of them limited to the determination of engine operating parameters to establish a comparison between diesel fuel and biodiesel [1–3] and vegetable oils [4], while other authors have assessed the influence of fuel properties on engine behavior [5]. Based on experimental tests, some researchers have performed energy analysis, namely thermal balance, applying the First Law of the Thermodynamics, to study the behavior of the engine running on different fuels [6–9]. But when Second Law of the Thermodynamics is taken into consideration, the conventional energy analysis is enriched with the calculation of the true thermodynamic value of usable energy, as thermodynamic inefficiencies and process losses are stated [10].

The concept of exergy is extremely useful for this purpose, as the main advantage of the exergy analysis consists on the possibility of determining the value of the irreversibilities associated to the process. In this sense, this analysis reveals the destruction of exergy in different systems and associated exergy efficiency of the processes [11,12]. An exergy analysis identifies the components of a system that generate major destruction of exergy, besides the processes that cause it. Although this research line has been applied to in-cylinder processes [13–15], nowadays, studies are focused on engine operation under different applications and technical modifications that can alter their operation when different fuels (including those of renewable nature) are used. In this sense, Caton [16] studied the implications of the use of several alcohols, carbon monoxide and hydrogen on a spark-ignition engine. Although the thermal efficiency was alike for all fuels considering the same operating conditions, the Second Law showed different destruction of exergy during the combustion process between the fuels [8,16]. Considering spark ignition engines, Sezer and Bilgin [17] stated that peak values for Second-Law efficiencies are around 0.9

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equivalence ratios and beyond this value there is no further contribution to work output.

As destruction of exergy is always present, thermoeconomics quantification is of special interest. Temir and Bilge [18] applied exergy and thermoeconomic analyses to a gas ICE-based tri-generation installation used for the production of electric power, heat and cool. Using this method, system exergies and exergy destruction, in addition to the investment and operational costs allowed the determination of the corresponding thermoeconomics costs. A similar study was developed by Abusoglu and Kanoglu [19] in an ICE-based co-generation system.

Other works have been focused on the evaluation of ICE operated with different biofuels and the comparison with fossil fuel at different experimental conditions. Canakci and Hosoz [20] performed energy and exergy analyses of a turbocharged 4-cylinder diesel engine running on two types of biodiesel, diesel fuel and their mixtures. Results under both First and Second Laws of the Thermodynamics points of view showed similar behavior between biodiesel and diesel fuel. Azoumah et al. [21] evaluated the operation of an ICE using straight cotton and palm oils and their blends with diesel fuel. Exergy analysis helped to determine the optimum engine load considering each alternative fuel.

Also, fundamental parameters of engine combustion and heat transfer process can be found from the Second Law of the Thermodynamics approach (including losses and exergy destruction). This procedure takes into consideration the exergy of the fuel, based on its elementary composition. In this sense, two fuels depicting same Low Heating Value (*LHV*), but showing differences in composition, may show variations in their chemical exergy. Moreover, biodiesel properties, i.e. cetane number and *LHV* fluctuate with the oil fatty acid composition, influencing both combustion process and engine performance. Other properties, like viscosity and density, may modify the fuel–air mixture formation into the cylinder, thus influencing combustion efficiency. In sum, although biodiesel must be forced to meet international quality standards, exergy evaluation of the fuel through the engine is also needed. Exergy analysis provides the tool to evaluate the influence of the fuel.

Refined olive oil is dehydrated in special ovens that may be working at temperatures above 1000 °C, which causes the appearance of benzopyrenes in large quantities. This is the case of olive–pomace oil. The International Agency for Research on Cancer (IARC) classifies benzopyrenes like substances probably carcinogenic to humans. To avoid benzopyrenes formation, thus converting olive–pomace oil in edible oil, the process must follow a strict vacuum and use specific absorbent materials, which makes more expensive olive–pomace oil extraction. With the expected reduction of olive oil price, linked to the future reduction of subsidies, it can be economically converted into potential oil for biodiesel production. Besides, it has a high content of oleic acid that presents excellent characteristics with regard to fuel ignition quality and fuel stability, according to the standard EN 14214 [22]. Although, many vegetable oils are used for biodiesel production [23], the use of biodiesel from olive–pomace oil (also known as *orujo*) as fuel for compression ignition engines from the exergy point of view, has not been studied.

In the present work, to gain knowledge about the implications of its use, the behavior of a diesel engine running on olive–pomace oil biodiesel, diesel fuel and their mixtures, has been evaluated from the exergy point of view. ICE constitutes a thermal system in which exergy analysis included in the thermodynamic study of the engine operation may provide interesting information referred to the evaluation of different alternative fuels. The quantification of exergy efficiency for each alternative is considered key parameter for the selection of the most viable fuel [24].

2. Materials and methods

2.1. 1. Fuels description

Oil was purchased from KOIPE (SOS Cuétara, Madrid, Spain). Properties are depicted in Table 1. Reaction conditions to produce biodiesel were selected from previous kinetic studies [25,26]. Olive–pomace oil transesterification was performed in a stirred tank reactor at 60 °C using a solution of 1.2% KOH and 30% methanol (wt reagent/wt oil), equivalent to 8.6:1 (molar ratio), after 40 min of vigorous stirring. Reaction was then stopped and settled to decant. To remove the alcohol and catalyst residues from biodiesel, the ester phase was washed with the aid of distilled water [27].

Fatty acid methyl ester (FAME) conversion was analyzed using a gas chromatograph equipped with flame ionization detector (GC–FID) model Clarus 500 from Perkin–Elmer (Shelton, Connecticut, USA) and following the UNE EN 14103 standard. A SGE capillary column, 30 m length, 0.32 mm inner diameter and 0.25 μm film, maximum temperature 250 °C was used. Fatty acid composition besides some properties of biodiesel and generic No. 2 diesel fuel are shown in Table 2.

Olive pomace oil methyl ester (B100) and its blends with diesel fuel, i.e. 20% biodiesel/80% diesel fuel (B20), 50% biodiesel/50% diesel fuel (B50) and 80% biodiesel/20% diesel fuel (B80) blends, were used to carry out performance tests in a diesel engine. Results were compared to those obtained by the use of straight diesel fuel in the same engine.

2.2. Tests equipment

The 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 N m at 1300 min^{-1} and the maximum engine power was 34 kW at 2250 min^{-1} (DIN 6270-A). The engine was reconditioned to original specifications. The injection type was a DPA–CAV distributor and the injection pressure was 18.74 MPa.

The engine 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 in [28,29]. The fuel was metered by a positive displacement gear type sensor, by means of a Froment Electronic Fuel Flow Monitor (FM502), placed in the fuel line between the tank and the engine fuel filter. The return fuel from the engine was circulated back into the engine supply line, as described in [28,29]. The engine speed was measured by the Froment testing device and monitored electronically to the nearest 5 min^{-1}. Atmospheric conditions were collected to correct the brake specific fuel consumption and engine power, following the SAE standard J1349 (revised August 2004).

2.3. Engine performance tests

The performance curves were conducted at maximum load and speed settings. A first baseline test was run with straight No. 2

Table 1
Olive–pomace oil properties.

Property	Unit	Olive–pomace oil
Density (15 °C)	kg/m^3	908
Kinematic viscosity (40 °C)	mm^2/s	46.27
Acid value	mg KOH/g	0.6
Iodine number	g I_2/100 g	99.8
Gross heating value	MJ/kg	40.49