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Experimental investigation of pistacia lentiscus biodiesel as a fuel for direct injection diesel engine

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ABSTRACT

Biodiesel is currently seen as an interesting substitute for diesel fuel due to the continuing depletion of petroleum reserves and the environment pollution emerging from exhaust emissions. The present work is an experimental study conducted on a DI diesel engine running with either pistacia lentiscus (PL) biodiesel or its blends with conventional diesel fuel. PL biodiesel is obtained by converting PL seed oil via a single-step homogenous alkali catalyzed transesterification process. The PL biodiesel physicochemical properties, which are measured via standard methods, are similar to those of diesel fuel. A single cylinder, naturally aspirated DI diesel engine is operated at 1500 rpm with either PL biodiesel or its blends with diesel fuel for several ratios (50, 30 and 5 by v%) and engine load conditions. The combustion parameters, performance and pollutant emissions of PL biodiesel and its blends are compared with those of diesel fuel. The results show that the thermal efficiency is 3% higher for PL biodiesel than for diesel fuel. The emission levels of carbon monoxide (CO), unburned hydrocarbon (HC) and particulate matter are considerably reduced at full engine load (around 25%, 45% and 17% respectively). On the other hand, the brake specific fuel consumption (BSFC) and the nitrogen oxide (NOx) emissions increase (around 10% and 4% respectively).

1. Introduction

During the past two decades, the rapid demographic expansion, the development and industrialization of modern manufactories and the expansion of the transport means led to a vertiginous rise of the world demand in the limited fossil energy. At the same time, environmental degradation, which is mainly due to pollutant emissions, has pushed researchers to find a new renewable and clean energy source to substitute for petroleum. For internal combustion engines, an alternative is to use biofuels in liquid form such as biodiesel [1–3] and bio-ethanol [4,5] or in gaseous form such as hydrogen and biogas [6,7].

Non-edible vegetable oils such as polanga, karanja, eucalyptus and jatropha curcas oils are becoming a promising source to produce a fuel for diesel engine, commonly referred to as "biodiesel" [8–11]. Transesterification is the most commonly used process to convert vegetable oil to biodiesel and improve its properties (high viscosity and poor volatility) for use in diesel engines without any hardware modification [12]. The transesterification process consists of a catalyzed chemical reaction involving vegetable oil and an alcohol which produces esters (biodiesel) and glycerol [11]. Alcohol to fuel ratio, reaction temperature and time, catalyst type and stirring speed rate have been studied to improve the transesterification process [2,13]. Generally, the use of biodiesel in a diesel engine leads to an increase in BSFC mainly due to the lower calorific value. Additionally, a considerable decrease in the emissions of HC, CO and particulate matter are reported. However, a slight increase in NOx emissions is observed [12,14]. This result may be explained by the biodiesel low aromatic content and the presence of oxygen in the compounds [15]. In addition, biodiesel has good ignition ability in the engine due to its higher cetane number than for diesel fuel [16,17].

The pistacia lentiscus is an evergreen tree of the *Anacardiaceae* family which produces bright red globose berries. This species can reach a height of 3 m and may be found in arid and semi-arid areas of Mediterranean countries such as Algeria, Tunisia, Morocco, France, Turkey, Spain, Italy and Greece [18–23]. In Algeria, pistacia lentiscus trees extend over a large geographical area ranging from the littoral to the arid areas [19,24,25]. The oil extracted from the fruits and leaves has traditionally been used in folk medicine since the ancient Greeks. PL has a good chance of being profitable as it grows with abundance in soils of marginal fertility and needs less water than many other crops. Regardless of

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Table 1
Properties of diesel fuel and PL biodiesel.

Properties	ASTM standard method	PL biodiesel	Diesel	EN14214
Density at 15 °C (kg/m^3)	D4052-91	860	840	860–900
Kinematic viscosity at 40 °C (mm^2/s)	D445	3.44	3.2	3.5–5.0
Gross heating value (MJ/kg)	D2015-85	40.00	45.00	–
Cetane number	D613	53.94	49	51 min
Flash point (°C)	D93-94	168	55	101 min
Acid value (mg_{KOH}/g)	D664	0.187	–	0.5 max
Elementary composition				
Carbon content (wt.%)	–	76.17	86	–
Hydrogen content (wt.%)	–	13.93	14	–
Oxygen content (wt.%)	–	09.90	0	–
Fatty acid composition				
Palmitic acid (wt.%)	–	13.93	–	–
Oleic acid (wt.%)	–	47.02	–	–
Linoleic acid (wt.%)	–	29.56	–	–
Linolenic acid (wt.%)	–	4.85	–	–

the PL region, the fruit is found to have high oil content (from 32% to 60%) [19,26,27]. No previous works seem to consider using PL oil for diesel-like fuel preparation although the factors mentioned above make PL oil an attractive source for biodiesel production.

The present study is carried out using a single cylinder, direct injection Lister Petter diesel engine with transesterified PL oil or its blends with diesel fuel (containing 50%, 30% and 5% biodiesel by volume). The physicochemical properties of the obtained biodiesel are determined according to ASTM standard methods. The engine tests are conducted at constant speed (1500 rpm) and for different engine load conditions (25%, 50%, 75% and 100% of full engine load). The combustion parameters (cylinder pressure and temperature, ignition delay and heat release rate), engine performance (BSFC and brake thermal efficiency) and pollutant emissions (HC, CO, NOx and particulate) are evaluated and discussed.

2. Materials and methods

2.1. Biodiesel preparation

The red mature fruits of PL are collected in October from the Blida Mountains located in northern Algeria. The oil is extracted with n-hexane in a soxhlet apparatus with a 42% yield.

To prepare biodiesel from PL oil, a small-scale transesterification reaction is carried out in the laboratory condition, thus, the reaction inputs such as catalyst amount, molar ratio, reaction temperature and time are determined.

In this study, PL biodiesel is prepared using methanol to oil ratio of 6:1 with potassium hydroxide (KOH) as catalyst (1% of oil by weight). After solving KOH catalyst in methanol at room temperature, PL oil is added to the reaction tank to start the transesterification reaction. The mixture is agitated throughout 1 h at 50 °C. The mixture is then allowed to settle overnight. Once the separation is occurred, the glycerol layer is removed from the bottom of the flask and the biodiesel is washed with water in order to remove both excess alcohol and residual catalyst and then dried using calcium chloride ($CaCl_2$). These transesterification conditions yield 94% of fatty acid methyl ester (biodiesel).

A series of tests are performed to characterize the composition and properties of the produced biodiesel. The fatty acid composition, the elementary composition and the physicochemical properties of PL biodiesel are summarized in Table 1. It is shown that the biodiesel physicochemical properties are comparable to those of conventional diesel fuel, and are also within the limits prescribed by EN14214 European requirements.

2.2. Engine test facility and procedure

Engine tests are conducted on a single cylinder DI naturally aspirated air cooled Lister Petter (TS1) diesel engine at constant speed (1500 rpm). The engine specifications are given in Table 2. The engine is loaded with a dynamometer that converts the mechanical energy to the laboratory electrical network. The experimental set up scheme is presented in Fig. 1.

The test bench is equipped with both fast and slow acquisition systems that are used for control and signal acquisition. The first acquisition system (AVL Indiwin) which is for fast measurements mainly deals with fuel injection pressure, cylinder pressure as well as angular position of the crankshaft. The second data acquisition system controls the engine dynamometer and is used for the acquisition of low measurements (torque, air and fuel flow rate, engine speed, exhaust pollutant emissions, pressure and temperature in the collectors...). The details of the engine test bench are well explained in previous works [3,11,28]. The sensor types and their corresponding accuracies are presented in Table 3, where the uncertainty in the calculated results is performed according to the method described by Holman [3].

2.3. Test method and conditions

The steady state experimental investigation is performed with PL biodiesel and its blends with diesel fuel (50%, 30% and 5% by

Table 2
Lister Petter (TS1) engine specifications.

General details	Single cylinder, 4-Stroke, naturally aspirated, Air-cooled, direct injection, Compression Ignition
Bore × stroke	95.3 mm × 88.9 mm
Connecting rod length	165.3 mm
Compression ratio	18:1
Fuel injection timing	13° BTDC
Fuel injection pressure	240 bar
Rated power output	4.5 kW at1500 rpm
Orifices × diameter	4 × 0.25 mm
Piston type	Cylindrical bowl (diameter: 45 mm and depth: 15 mm)
IVO	36 °CA before TDC
IVC	69 °CA after BDC
EVO	76 °CA before BDC
EVC	32 °CA after TDC