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A comparative study of almond and palm oils as two bio-diesel fuels for diesel engine in terms of emissions and performance

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HIGHLIGHTS

- Engine performance fueled with almond and palm oil biodiesels was investigated.
- This study provides options for new valuable use for an existing crops.
- Almond biodiesel resulted in improved engine performance compared to palm oil biodiesel.
- Almond biodiesel produced lower emissions in the exhaust gas of the engine tested.
- Almond oil could be effective as an alternative fuel for diesel engines.

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ABSTRACT

This study was initiated to investigate the various performance parameters and emissions of a single cylinder diesel engine operating on almond biodiesel and compare them to the performance and emissions when the engine is operated on palm oil biodiesel and 'baseline' diesel fuel through laboratory measurements. Different fuel blends containing 0%, 10%, 30% and 50% on volume basis of almond biodiesel with diesel fuel were tested. Another fuel blends consist of 0%, 10%, 30% and 50% on volume basis of palm oil biodiesel in a palm biodiesel–diesel fuel were also tested. The influence of these blends on emissions and some performance parameters under various load conditions were inspected. Compared to the results obtained using palm oil biodiesel, almond biodiesel resulted in improved performance over the load range considered as indicated by lower brake specific fuel consumption, higher thermal efficiency, and higher exhaust gas temperature. In terms of emissions, almond biodiesel resulted in lower carbon monoxide (CO), oxides of nitrogen (NO_x), total particulate and unburned fuel emissions in the exhaust gas.

1. Introduction

Current energy policies are greatly reliant on fossil energy. Fossil fuels are the greatest energy source among all energy resources. The major part of energy requirements in the world is provided thorough fossil fuels such as petroleum, natural gas, oil and coal. Due to resource limitations, it is expected that the rising demand and diminishing supply will affect global fuel prices dramatically. The declining reserve of fossil fuels, and more importantly, the high fuel prices have strongly motivated the search for alternative engine fuels. For diesel engines, a great deal of research effort has been oriented toward using biodiesel as an alternative fuel for land, transport and power generation.

The use of diesel engines reduces emissions and improves fuel consumptions [1]. Diesel machines are widely used in heavy-duty applications especially in construction and farming sectors. Accordingly, the rate of reduction of diesel fuel is the greatest among gasoline fuels, which subsequently results in the greater price of diesel fuel than other gasoline fuels due to increased demand. Additionally, the growing concern about environmental pollution since the 1990s has boosted the interest in substitute fuels. This has led to extended efforts and financial supports for research studies in energy management and conservation. Recently, the issues of steadily rising fuel prices, declining oil storage and air contamination have resulted in the investigation of fossil fuel substitutes. The increase in greenhouse gases such as CO_2 which is causing climate change and global warming coupled with the fossil fuels decreasing reserves as well as increasing prices of fuel have robustly boosted the interest in making use of biodiesel for power generation. The term "Biodiesel" refers to Fatty acid methyl esters. These esters are often created from animal fats or extracted

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from vegetables, and have acceptable capabilities to be used in diesel engines. Because diesel fuel and vegetable oils have close cetane numbers, biodiesel made from vegetable oils might be used in current diesel engines after minor alterations [2–4].

Regarding diesel engines, several studies have investigated the use of vegetable oils as substitute fuels [5–9]. Some of these research studies [10–13] reveal that usually there is little harm caused to engines due to issues such as lubricating oil thickening, injector coking, and gum formation ring sticking. The non-volatility and excessive stickiness of pure vegetable oils are the major causes of these problems [14]. Blending vegetable oils with diesel in different proportions lessens those problems to some extent.

Because biofuels are made from renewable sources, developing the technology to produce them now may contribute to a better fuel supply and can be more sustainable. However, there are many questions and issues, which needs to be tackled before a reliable and adequate supply of biofuel can be guaranteed. The biodiesel produced from palm oil is defined as the palm oil methyl ester also known as palm oil biodiesel. Few studies related the combustion diagnosis of diesel engines operating with palm biodiesel can be found in the literature [15–19]. But, to the best of the author's knowledge, no investigations were done on the employment of almond oil as a substitute for diesel fuel. Therefore, this study provides options for new valuable use for an existing crop. Almonds (Prunus dulcis) are believed to be the most widely spread among tree nuts all over the world, and is top of the list in tree nut output. Almonds are widely produced in areas characterized by a Mediterranean climate [20], including many countries in the Mediterranean, all Middle East countries, and some countries in the Southern Hemisphere. The biggest producer of almonds in the world is the United States, specifically California. As a result, almond oil is mostly produced in these countries [21].

Diesel engines are one main source of environmental pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and partly burned (or burned) hydrocarbons (HC) organic compounds [22–25]. Such emissions have always been a critical issue in the pollution of air [26–28]. Engine exhaust emissions usually contain nitrogen oxides. As Lapuerta et al. [29] showed in their review paper, biodiesel exhibits an increase in NO_x concentration compared to diesel and only a few studies showed a percentage drop off in NO_x concentration [30,31].

This work aims to investigate the various performance parameters and emissions of a single cylinder diesel engine operating on almond biodiesel and compare them to the performance and emissions when the engine is operated on palm oil biodiesel and 'baseline' diesel fuel through laboratory measurements. No research was conducted in the literature to explore the possibilities of utilizing almond oil as an alternative source of diesel fuel. The production of almond biodiesel does not create a threat to edible almond supply. The global almond supply is growing at about 9% per year (estimated production 1,237,862 tons in 2014) while demand is growing at around 5–6% [32]. On the contrary, almond biodiesel could increase the demand for almond, which leads to an increase of almond production, and then raising food supply. Having the almond industry focusing on best practice and the development of optimal production techniques, together with the fact of largely mechanical nature of almond production will help the world to achieve higher levels of productivity.

2. Materials and methods

2.1. Transesterification of almond and palm oils

After peeling the almond seeds, they were dried at nearly 30 °C and then crushed in a blender. Powdered seeds were kept at 5 °C in polyethylene bags before analysis. The Bligh–Dyer method was used to extract almond oil [33]. Ground seeds were harmonized with a chloroform–methanol ($CHCl_3$/MeOH) mixture (1:1) and water. Two phases were obtained, aqueous layer (MeOH–water) and organic layer ($CHCl_3$). A rotary evaporator was used for evaporating off the solvent ($CHCl_3$) for the recovery of oil. A residual solvent was detached by oven drying for 1 h at 60 °C and flushing with 99.9% nitrogen. The transesterification of almond oil was performed as given by Hossain et al. [34] to ensure that it contains fewer impurities. On the other hand, samples of palm oil were collected from local market since it is extensively used locally as fryer oil. The transesterification of palm oil was performed as detailed by reference [35].

2.2. Properties of almond and palm biodiesels and their blends

The fuel selected for the base case study was a local commercially available diesel fuel. A laboratory preparation of blends of almond biodiesel and palm oil biodiesel with diesel fuel was performed to operate a diesel engine and to make measurements of emissions and performance parameters. The ratios of blends of almond biodiesel selected were 0% (base case study), 10%, 30%, and 50% on volume basis of almond biodiesel in an almond biodiesel–diesel fuel mixture. They are referred to as 0%A (0% almond biodiesel – 100% diesel fuel), 10%A (10% almond biodiesel – 90% diesel fuel), 30%A (30% almond biodiesel – 70% diesel fuel), and 50%A (50% almond biodiesel – 50% diesel fuel), respectively. The ratios of blends of palm oil biodiesel selected were 0% (base case study), 10%, 30%, and 50% on volume basis of palm oil biodiesel in a palm biodiesel–diesel fuel mixture. They are referred to as 0%P (0% palm oil biodiesel – 100% diesel fuel), 10%P (10% palm oil biodiesel – 90% diesel fuel), 30%P (30% palm oil biodiesel – 70% diesel fuel), and 50%P (50% palm oil biodiesel – 50% diesel fuel), respectively. These abbreviations are used throughout the current study.

The chemical and physical properties of pure biodiesel, ordinary diesel and biodiesel blends were experimentally determined since they directly affect parameters such as emissions, fuel droplet dimension and spray features. The experimental method was carried out according to the detailed procedures outlined by Kannan et al. [36]. The measured properties of diesel, biodiesel from almond oil, biodiesel from palm oil, and different ratios of their blends according to ASTM standard are shown in Table 1.

Density is an important property of fuel for compression ignition engines. It is worth noting that fuel density increases with the increase in the percentage of biodiesel in the blend. Preheating of biodiesel before injection could be done to overcome the problem of higher fuel density by taking advantage of the high temperature of the engine exhaust gas. The kinematic viscosity was measured for biodiesel from almond oil and palm oil and was found to be about 40% and 45% more than the kinematic viscosity of diesel respectively. A decrease in the blending percentage of both biodiesels reduced the kinematic viscosity of the mixture. The density and kinematic viscosity values of the palm oil diesel ratios are higher than their counter parts of the almond biodiesel. The shape of the fuel droplets and atomization are affected by the fuel viscosity. A higher viscosity of the fuel may cause starting problems and smoky exhaust. This requires higher spraying pressure to obtain the desired spray pattern inside the cylinder. In contrast, very low viscous fuel would prevent accurate metering of the fuel especially in older engines due to the leakage from piston walls of the injection pump [34]. Preheating of biodiesel before injection either in the fuel tank or in the fuel lines could be done to overcome the problem of higher viscosity of biodiesel oils by taking advantage of the high temperature of the engine exhaust gas. The heating value of the almond biodiesel and palm oil biodie-