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Influence of diesel fuel blended with biodiesel produced from waste cooking oil on diesel engine performance

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HIGHLIGHTS

- Proper properties of blended fuels are achieved at 30% WCOME in the mixture.
- In-cylinder pressure data depends partially on the WCOME blending ratio.
- The best fuel economy is achieved at 10% WCOME.
- Best emission characteristics are attained at WCOME blending ratio 30–50%.

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ABSTRACT

Biodiesel from edible waste cooking oil (waste cooking oil methyl ester – WCOME) has been produced via trans-esterification process. The effect of various fuel blends containing the conventional diesel fuel and the produced WCOME on diesel engine performance has been evaluated experimentally. The study investigated the effect of WCOME blending ratio on viscosity and sooting propensity of the biodiesel–diesel fuel mixture. The engine performance has been expressed in terms of the in-cylinder pressure data as well as the engine mechanical and environmental aspects measured at engine rated speed (1500 rpm) and different engine loads. The main results of the current work showed that, the location and value of the in-cylinder peak pressure depends mainly on the engine load and the biodiesel blending ratio. The best value of Brake Specific Energy Consumption (BSEC) is attained at blended fuel containing 20% WCOME (B20) where the maximum brake thermal efficiency is also observed. While there was a range of blending ratio from B20 to B50 throughout the best engine environmental behavior is attained. Results indicated that, the use of neat biodiesel fuel (B100) at different engine loads leads to an increase of BSEC by about 8%, an increase of engine smoke opacity by about 15%, a decrease of NO_x emissions by about 10% with slight decrease of CO emissions and a decrease of the unburned hydrocarbons by about 15%. The most recommended WCOME biodiesel blending ratios vary from 30% to 50% for better engine performance and emission characteristics. In this recommended blending ratios, the engine performance provides the following results in comparison with the corresponding values for neat fuel around 10% higher BSFC, insignificant change in η_{bth}, around 3% higher BSEC, and 2% lower T_{Exh}, while the corresponding engine emissions include 25% lower CO, 20% lower UHC, 6% lower NO_x, and 20% higher smoke opacity.

1. Introduction

The progressively rise of conventional petroleum fuels prices as well as the high strengthened requirements of the current environmental norms to reduce the atmospheric pollution levels are becoming great challenges to scientist and researchers all over the world. These problems can be partially solved by the use of renewable energy resources. One of these resources is the use of vegetable oils that may be edible or non-edible. No doubt, the use of non-edible oils will be more valuable to overcome social problems related to food crises and debate of food versus fuel. This human waste (commonly called waste cooking oils) can be considered as the cheapest biodiesel feedstock as the raw (waste) oil price is very low in comparison with new edible/non-edible oils.

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Moreover its recycling as an energy resource should be the best disposal way.

The main problem that prevents the direct use of the waste cooking oils in different combustion systems is their high viscosity, which is several times higher than that of the conventional fossil fuels. This fact is owing to their large molecular mass and chemical structure [1]. The fuel viscosity affects the behavior of fuel system performance as well as the fuel atomization and spray characteristics. The high viscosity leads to the formation of larger droplets, poorer vaporization, and narrower injection spray angle. This will lead to an overall worsening of fuel atomization and so the combustion efficiency will be reduced with higher toxic emissions [2]. To reduce oil viscosity, different processes, based on chemical pre-treatment process (as pyrolysis – thermal cracking, and trans-esterification), should be performed to produce biodiesel fuel. The most commonly used method for converting heavy viscous oils into biodiesel is the trans-esterification process of raw oils [3,4]. In this process, fats or oil are reacted with an alcohol to form esters and glycerol in the existence of a chemical catalyst to form glycerol and (methyl or ethyl) esters. This process is commonly assessed in terms of product yield and product viscosity. The trans-esterification process depends mainly on different parameters ([5–8]); including (i) alcohol molar ratio which is theoretically 3 moles of alcohol for 1 mole of triglycerides but actually more value is used depending on the type and the quality of waste oil, (ii) reaction time required to complete the oil conversion into biodiesel without reversible reactions or soap formation, (iii) reaction temperature which is conducted close to the boiling point of methanol (60–65 °C) at atmospheric pressure, (iv) catalyst type and concentration which may be alkalis, acids, or enzymes (alkalis as sodium hydroxide and potassium hydroxide are the most used) with catalyst concentration ranges from 0.5% to 1% by weight to provide esters with yield from 94% to 99%, and (v) the agitation speed or mixing intensity which enhances the contact between oil and alcohol on catalyst surface.

It is noticed from the literature review that, the recommended values of any of the previous parameters depends mainly on the origin of the oil feedstock and its specification. For example the cited data for the optimum preparation conditions for biodiesel production from waste cooking oil are varied as observed in Table 1. This variation of results force to carry out a detailed study to attain the suitable preparation conditions for our waste cooking oil.

The trans-esterification does not give any information about the environmental behavior of the received biodiesel upon its combustion. This behavior can be attained with a simple combustion process to determine the fuel sooting propensity. This is an important indicator for the compression ignition engines where the reduction of soot reduces the radiation heat losses from the engine and the soot contaminants in the exhaust system [12]. Thus, the soot reduction has valuable environmental and economic impacts [12]. Soot is mainly formed from the fuel combustion by diffusion mode due to poor fuel atomization and poor fuel–air mixing.

The easiest way to determine the liquid fuel sooting tendency due to diffusion combustion is to measure the maximum flame height at which the soot is just appeared or as commonly called by measuring the smoke point. In accordance with ASTMD1322 [13], the smoke point is measured by the use of specific wick-fed lamp. The smoke points of heavily sooting compounds are short, and easy to identify. This is due to the low flow rate associated with a smoke point of this height, leading to a stable flame with well-defined edges [14]. Even the wick lamp does not give accurate results for soot in diesel engines (where sooting tendency depends on fuel as well as on operating mode), it can provide a qualitative assessment of the relative sooting propensity of different fuels; the more the value of the smoke point, the lower the fuel sooting tendency and so the cleaner the fuel combustion [15]. Another parameter can be used to determine the sooting propensity of fuel based on the measured smoke point and the fuel molecular weight called Threshold Sooting Tendency (TSI) [15]. It is noticed that [16] TSI does not account the effect of oxygen atoms in fuel structure, and so inconsistent results are received for the sooting propensity of oxygenated fuels when TSI is used and compared with the corresponding literature data. To overcome these discrepancies another index called Oxygen Extended Sooting Index (OESI) is presented by Barrientos et al. [16]. OESI is a relation between the smoke point and the stoichiometric air volume required for the flame and so this index is suitable for both oxygenated and non-oxygenated fuels. As seen both indices (TSI and OESI) are not determined directly from experiments but they are related to the measured smoke point, so it will be better to use directly the values of the measured smoke point to quantify fuel sooting propensity and so overcome additional uncertainty in the used relation.

Due to the high viscosity of biodiesel compared with that of conventional diesel fuel, biodiesel is usually used as a blend with the diesel fuel. In this case, the blending ratio of the biodiesel into diesel has a great effect on the combustion characteristics of biodiesel–diesel mixture. Therefore, the effect of the blending ratio on the mixture sooting propensity should be determined. The sooting propensity of biodiesel–diesel with blending ratios up to 25% has been studied and the results showed that at low blending ratios, the smoke point is increased linearly with the increase of biofuel fraction [17]. From this study, B20 (20% biodiesel) could be considered as the optimum blending ratio for combustion application from the soot and emission points of view [17]. The sooting characteristics of ethanol–diesel blends B30 and B50 has been compared to those of a diesel in a diffusion flames under various injection and ambient conditions [18]. The results of this comparison showed that, increasing ethanol blending ratio enhances the soot reduction potential and B30 suppresses the soot formation near the flame lift-off location promoting the soot oxidation process. This soot reduction potential of B30 became larger with the increase of injection pressure, but insignificant at high ambient temperatures [18]. Thus, it will be important to study the effect of the blending ratio on the smoke point and give more concern for the low blending ratios below 30%.

Graboski and McCormick [19] stated in their literature review, that the use of biodiesel either in neat or in blended form has remarkable positive effect on reducing the PM emissions, but the NO_x emissions are increased no matter the engine is two or four stroke engine especially for the most recommended blending ratio of 20% biodiesel at high engine loads. They pointed out that the reduction of PM is observed in all the literature, while not all oxygenated fuels provide an increase of NO_x emissions; literature accounts also a reduction of NO_x emissions, or no significant effect no matter the complexity or the sophistication of the applied test facility [20]. Xue et al. [21] stated from deep studied literature that major researchers (more than 85%) recorded a remarkable decrease in PM, CO, and UHC emissions, only among of them about 10% recorded an increase, while about 5% of them recorded similar values relative to the case when base diesel fuel is used. In regard of NO_x emissions, it is found that about 65% of collected studies reported an increase in NO_x emissions, about 29% reported a reduction in NO_x emissions, and about 6% reported similar NO_x emissions in comparison with the corresponding NO_x emissions when base petroleum fuel is used. A similar conclusion has been drawn in many literature reviews (as those presented by Shahir et al. [22], Lapuerta et al. [23], Boehman et al. [24], Mueller et al. [25], and Sun et al. [26]) regarding the influence of biodiesel on NO_x emissions as there is no a single factor responsible for NO_x effects, but there are numerous factors each has its own relative importance according to the engine technology, operating conditions,