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Investigation of the effects of butanol addition on safflower biodiesel usage as fuel in a generator diesel engine

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ABSTRACT

As our world demands more and more energy and fossil fuel resources are running out, searches on finding alternative fuels in internal combustion engines are increasing. Alcohols and biofuels obtained from oils can be used as alternative diesel fuels. The present work investigated the effects of *n*-butanol addition to safflower biodiesel usage in a diesel engine used for driving an electrical power generator. Safflower biodiesel was obtained by using transesterification method. Binary blends of butanol-biodiesel and ternary blends of ultra-low sulfur diesel-biodiesel–butanol were contained 5%, 10%, and 20% butanol in volume basis. The tests were carried out on a four-cylinder, four-strokes, and direct-injection diesel engine at half load operation with stable engine speed of 1500 rpm. Experimental test results on combustion characteristics, emission and performance of the fuels were investigated. According to test results, formation of heat release rates and in-cylinder pressure curves were considerably similar and total heat transfer, average gas temperature and mass fraction burned were slightly changed. The ternary blends showed lower emission and increased brake thermal efficiency up to 1.5%. Besides, average mass fuel consumption was increased up to 5% and brake specific fuel consumption up to 6%. For the other fuels, emission and brake thermal efficiency were deteriorated.

1. Introduction

The energy demand is mostly supplied from petroleum based fuels. Currently, 80% of the energy consumed in the world is derived from fossil fuels and 58% of this consumption is used in transportation sector. While the usage is enormous, it is predicted that petroleum resources will be run out in the near future. However, exhaust gas emissions from engines cause permanent damages on the atmosphere leading serious health problems of human [1,2]. The researches have paid attention for finding alternative fuels for a long time that can be replaced with petroleum based fuels. Alcohols seem one of promising candidate that can be used in engines owing to its extensive resource and renewable nature [3,4].

Despite diesel engines are widely used, their efficiencies can just be as high as up to 40%. However, there are some methods that aimed to increase the efficiency of internal combustion (IC) engines. These methods are required some alterations either on fuel type or engine system. Replacing the base fuel or fuel addition is one way to increase efficiency [5,6]. Alternative fuels are desired to be less harmful effects on environment along with lesser fuel consumption and plenty of raw material in order to substitute diesel fuels. Apart from these, high engine performance should be taken from the fuel with current fuel systems without causing any damage on engine parts [7]. Correspondingly, any major engine modification is not required for biodiesel usage in diesel engines [8].

Safflower oil was selected for biodiesel production which it has plenty plant resources in Turkey. The root of safflower plant grows subterrestrial and the root length can be up to 100–150 cm dependence on soil characteristic while the plant length can be 30–100 cm. The weight of a thousand safflower seed is 35–40 g and the rate of seed/shell is 50%. The seed with shell is included 20–25% oil while seed without shell has 45% of oil content [9]. The researches in the literature related to safflower biodiesel usage were taken into consideration. According to these researches, pure safflower biodiesel was generally showed lower carbon monoxide (*CO*), carbon dioxide (CO_2), hydrocarbon (*HC*), particulate matter (*PM*) emission values in comparison with diesel fuel while nitrogen oxide (NO_X) emissions were significantly observed higher. However; engine torque, power, mean effective pressure and efficiency values were reduced [10–17].

Alcohols can both be used in engines as an additive or a single-fuel. Alcohols are more expensive than petroleum based fuels. Therefore, its usage was limited in IC engines in the past. But nowadays, as it is predicted that petroleum based fuels are running out, researches consider that alcohols as potential fuel that can be replaced with petroleum

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based fuels in engines. Accordingly, many countries have made legal regulations to encourage alcohol usage in engines and also provide various incentives for its usage [18,19]. Butanol is an alcohol and is obtained by biomass fermentation and it has carbon hydrate compounds in its structure [18,20]. The chemical formula of butanol is C_4H_9OH which consists of 4 carbons, 10 hydrogens and 1 oxygen molecule. Butanol also has 4 isomers which these are *n*-butanol (*1-butanol*) $CH_3CH_2CH_2CH_2OH$ (*normal butanol*), 2-butanol $CH_3CH_2CHOHCH_3$ (*sec-butanol*), i-butanol $(CH_3)_2CH_2CHOH$ (*isobutanol*), and *t*-butanol $(CH_3)_3COH$ (*tert-butanol*). These four isomers have the same chemical formula and the same heating value but combustion properties of each isomer are different due to different molecular structure. Besides, molecular mass and closed formula are similar, solubility of each isomer is different [20]. In this work, *n*-butanol isomer was used for the experimental test blends.

Butanol has low viscosity and it was selected with the aim of reducing viscosity of biodiesel while biodiesel has high viscosity value as shown in previously published reports in the literature. However, it is thought that alcohols and biodiesel will give good results in combustion, emissions and performance while alcohols and biodiesel have low emissions and can both work without any modification in engine and can be blended with diesel fuel. The test fuels consisted of diesel, safflower and biodiesel blends and the maximum amount of butanol was determined 20% in volume basis. The effect of butanol on combustion, performance and emission were investigated.

2. Material and methods

2.1. Biodiesel production from safflower oil

Vegetable oils have higher viscosity values. Therefore, a range of heat and chemical processes are subjected in order to reduce the viscosity of vegetable oils. Transesterification is one of most common method for viscosity reduction and was implemented for safflower oil in this work [21]. Transesterification processes for safflower biodiesel are illustrated in Figs. 1–3.

Safflower oil was obtained from a commercial company. Firstly, safflower oil was heated up to 120 °C with a stirring in the closed vessel in order to eliminate the water possibly contained in the oil (Fig. 1) and at this stage, by doing this, the mixture was also prevented to produce glycerin during chemical processing. When the temperature was approximately reached to 120 °C, the mixture was left to cool down in the room conditions. After cooling process, oil was heated up to 50–55 °C again. At this temperature, 400 ml methyl alcohol and 15 g KOH catalyzer for 1250 ml oil were added to the mixture in constant temperature. The reaction was maintained for 1 h.

Oil was waited one day in the room condition after the reaction. As a result of this process, a layer of glycerol was collapsed in the bottom which has higher viscosity (Fig. 2). The glycerol layer was gathered from the homogeneous mixture by a funnel. Then the same amount of pure water was added to the mixture which is called the washing process and heated up to 120 °C. After the mixture temperature exceeded 120 °C, the added water was fully evaporated from the mixture. After this process, the pure biodiesel was obtained.

The washing process took approximately 6–7 h. Thus, with this process, both pure biodiesel was obtained and the sediments in the early mixture were collapsed and eliminated (Fig. 3). Seven different blends were prepared in volume basis and Table 1 shows both the proportions and the names of the blends. Table 2 shows physical and chemical properties of the test fuels.

2.2. Experimental setup

The experiments were performed on a 4-cylinder, 4-stokes, water-cooled diesel engine with 17 kW maximum brake power. The technical specifications of the test engine are given in Table 3. All the test blends were prepared previously and sent to the fuel tank during the experiments. Fuel consumption was measured with an electronic precision scale and a stopwatch. Engine tests were conducted at the brake mean effective pressures (*BMEP*) of 2.78 bar and at the same engine speed of 1500 rpm. The combustion data were taken by a piezoelectric

Fig. 1. Mixing process of safflower oil and methyl alcohol.

Fig. 2. Collapse of glycerol in the mixture.