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Quaternary blends of diesel, biodiesel, higher alcohols and vegetable oil in a compression ignition engine

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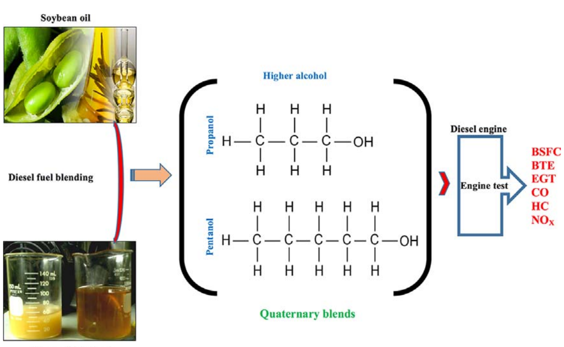
GRAPHICAL ABSTRACT



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ABSTRACT

Vegetable oils, biodiesel and alcohols are important alternative fuel resources for diesel engines. Prominent fuels of the three types include: soybean oil which has efficient amount of productivity, biodiesel made of waste oils which do not affect food security and alcohols with high number of carbons. There is potential to use quaternary blends of diesel fuel, waste oil methyl ester, soybean oil and higher alcohols, such as propanol and pentanol, in diesel engines for the purpose of increasing the use of biofuels and decreasing fossil fuel consumption. In this work, diesel fuel (D) was mixed with biodiesel (B), and biodiesel-vegetable oil (VO)-alcohol blends using the higher alcohols of propanol (Pro) and pentanol (Pen). Test fuel blends of DB (50 vol% D-50 vol% B), DBVOPro (40 vol% D-40 vol% B-10 vol% VO-10 vol% Pro), DBVOPen (40 vol% D-40 vol% B-10 vol% VO-10 vol% Pen) were prepared through the splash blending method and tested in a diesel engine. The key fuel properties such as density, lower heating value, viscosity and cetane number were measured. Engine performance and exhaust emission tests of the blends were carried out on a four-cylinder, four-cycle diesel engine generator at various loads (0, 3, 6, 9 kW) with fixed engine speed of 1800 rpm. According to engine test results, mean brake specific fuel consumptions (BSFCs) of DBVOPro increased compared to DB and DBVOPen at all engine loads. As compared to DB blend, DBVOPro presented the best mean oxides of nitrogen (NO_x) with a reduction of 11.9%. However, formation of carbon monoxide (CO) and hydrocarbon (HC) emissions have been increased with the addition of each of the higher alcohol to DB.

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1. Introduction

Energy is one of the most important topics in the world within the current century and into the future, where especially for those countries that are energy-dependent and export crude oil, they will face important energy problems. In order to solve this problem, local resources, as much as possible, must be used for energy production [1,2]. In addition, it is important to increase energy efficiency, the variety of alternative energy resources, and sustainability. Energy resources are consumed very quickly in industrialized countries and countries like the United State (US) search for new alternative, renewable energy resources to replace fossil fuels [2–4].

As the number of vehicles around the world increases, use of alternative fuels in internal combustion engines has become as a necessity [3]. Both the European Union (EU) and the US have adopted new initiatives for the use of biofuels in vehicles, in order to reduce emissions and decrease the dependency on fossil fuels [5]. Vegetable oils (bio-oil) and biodiesel made of various vegetable oils as well as animal fat and bioalcohols are the main alternative fuels for use in internal combustion engines. Vegetable oils and biodiesel are compatible with diesel engines while bioalcohols can be used in both spark ignition and compression ignition engines [6–8]. However, diesel engines are more popular because of their higher efficiency and less fuel consumption. Thus, it is important to focus on all three alternative fuel resources of bio-oils, biodiesel and bioalcohols for new opportunities.

Vegetable oils has been tested in diesel engines for many years [1–3]. Soybean oil (also known as soy-oil) is the most widely used oil in the US and throughout the world. Soybeans are the dominant oilseed in the US, accounting for about 90% of US oilseed production. Especially the highest produced oils regionally are modified using various methods (microemulsion and transesterification e.g.) to be used as alternative fuels [6]. Straight use of neat vegetable oils is limited in internal combustion engines because of their high viscosities and densities, and this limitation has led to the use of biodiesel which has relatively better fuel properties [7]. However, the high production cost of biodiesel, its relatively high viscosity as compared to diesel, poor cold flow properties and high NO_x emissions are important parameters to limit the use of biodiesel, as well [8–10]. In addition, it is very well-known that edible oils which are used for biodiesel production adversely affect food security. Thus, non-edible oils are recommended for production of biodiesel which would be used as an alternative fuel in diesel engines. Also, waste vegetable oils are suitable for biodiesel production as they have no affect on food security [10–13]. Although alcohols cannot be used directly in diesel engines, some of their fuel properties make them suitable additives for diesel and biodiesel [14]. Thus, in order to reduce the disadvantages of biodiesel, diesel-biodiesel or vegetable oil mixtures are blended with alcohols or similar additives [15–22]. The EU has taken initiatives to increase and target the use of biofuels in diesel engines as much as 20% by the year 2020 [23]. To reach this important target, it is necessary to investigate almost every alternative fuel resource in combustion engines. With this purpose in mind, bioalcohols have become important alternatives and additives [24–27].

Alcohols are clean fuels due to hydroxyl (OH) in their molecular structures. They can be mixed with diesel fuel and other organic component (vegetable oil and biodiesel) which can be used to increase their phase stability at low temperatures [28]. In addition, low viscosity and density of alcohols allow vegetable oils to be used in diesel engines and have increased the use of microemulsion over transesterification because of easiness and lower cost [29–33]. But, lower cetane numbers of alcohols limit their concentrations in diesel engines [34,35]. Especially methanol (CH_3OH) and ethanol (C_2H_5OH), are not good alternative fuels because of their low cetane numbers [36–38]. However, the number of carbons in alcohols affects overall fuel properties. As the number of carbons increases (higher alcohols), alcohols can be mixed with organic molecules more easily and also reach higher cetane numbers and heat of combustion. Thus, higher alcohols have better potential to mix with diesel than lower alcohols [39].

One of the higher alcohols, n-butanol (C_4H_9OH) has frequently been used and tested in diesel engines in recent years and evaluated as a blend with diesel-biodiesel mixtures [35–38]. However, there are a very limited number of investigations with regards to the use of propanol (C_3H_7OH) and pentanol ($C_5H_{11}OH$) in diesel engines and these studies included only blends with diesel or biodiesel. Balamurugan et al. [39] investigated the effects of propanol-diesel and n-butanol-diesel blends on engine performance and emission characteristics of a single cylinder diesel engine under 5 different engine loads (20%, 40%, 60%, 80%, and 100%). Diesel was blended with 4% and 8% propanol and n-butanol by volume. Test results showed that 4% butanol increased 1.579% of the brake thermal efficiency (BTE) at 80% load. Use of 4% propanol increased smoke density by 12.891% but decreased NO_x emission by 6.098%. Li et al. [40] studied the combustion and emission characteristics of a diesel engine fueled with pentanol/diesel and pentanol/biodiesel/diesel blends. Their results indicated that simultaneous reduction in soot and NO_x emissions occurred at only low-partial loads, while NO_x emissions increased at high loads as compared to diesel fuel operation.

Use of the blends of vegetable oil, biodiesel and bioalcohols can increase biofuel consumption in diesel engines while decreasing diesel fuel consumption. This would also allow one to overcome some of the disadvantages of using neat vegetable oils or biodiesel. Yilmaz et al. [41] used a two-cylinder diesel engine and evaluated diesel-biodiesel-vegetable oil-alcohol blends to investigate engine performance and emission characteristics. Blends consisted of 5% alcohol (ethanol, methanol, butanol), 5% vegetable oil, 20% biodiesel and 70% diesel. Vegetable oil-biodiesel-alcohol-diesel blends increased HC and CO emissions while decreasing NO_x emissions as compared to diesel, and it was noted that vegetable oil improved the lubricity. Rakopoulos et al. [42,43] used cotton oil and its methyl ester in the same study because of the high volume of cotton oil in Greece. Studies included the performance and emission characteristics of a 4-cylinder diesel engine running diesel-cotton oil, diesel-alcohol and diesel-biodiesel blends.

Results based on the limited number of studies with regards to vegetable oils, biodiesel and bioalcohols show that vegetable oils of high production and potential depending on local conditions can be alternative resources such as soybean oil to be used with diesel and to make biodiesel which would increase the percentage of biofuel input in diesel engines. The purpose of this work is to investigate and compare the engine performance and emission characteristics of a diesel engine running on various quaternary blends of diesel, biodiesel, vegetable oil and higher alcohols which could potentially serve as a future generation alternative fuel. With that purpose in mind, 40% diesel, 40% waste oil methyl ester, 10% soybean oil and 10% higher alcohol of propanol or pentanol by volume were blended, and the fuels of DBVOPro and DBVOPen were prepared. Engine emission and performance results of these fuels were compared to those of diesel and diesel-waste oil methyl ester blends.

2. Experimental procedure and specifications

The experiments were performed using an Onan DJC type, indirect injected, four-cylinder diesel engine generator (Fig. 1). Further general information for this generator can be found in Table 1. AN EMS 5002 exhaust gas analyzer was used to measure the emissions. The analyzer provided a CO_2 range of 0–20 vol% with a resolution of 0.1 vol%, an O2 range of 0–25 vol% with a resolution of 0.01 vol%, a NO range of 0–5000 ppm with a resolution of 1 ppm, a CO range of 0–10 vol% with a resolution of 0.01 vol%, and an HC measurement range of 0–2000 ppm with a resolution of 1 ppm. BAR 97 Low gas was used during the calibration procedure of the EMS 5002 exhaust gas analyzer. While testing, the calibration procedure was repeated regularly. The engine ran on neat diesel for at least ten minutes prior to switching to an auxiliary fuel