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Investigation of the effects of steam injection on performance and emissions of a diesel engine fuelled with tobacco seed oil methyl ester

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ABSTRACT

Although biodiesel is renewable, nontoxic, biodegradable and has low emission profiles, the main drawback of using biodiesel in diesel engines is higher NO_x. In this study, steam injection has been used as a method to reduce NO_x emissions of a direct injection diesel engine fuelled with tobacco seed oil methyl ester (TSOME). The effects of 10% (S10) and 20% (S20) steam ratio have been investigated in terms of performance and emissions of a diesel engine fuelled with 20% (B20) TSOME. Steam is injected into the inlet manifold during inlet period. It is shown that steam injection into the engine fuelled with B20 fuel improved torque, effective power, effective efficiency and specific fuel consumption (SFC) decreased. Whilst S10 has been found optimum at the low engine speeds, S20 is optimum at the high speeds for the performance. However, S10 has been found as optimum for the exhaust emissions. At this injection ratio, both NO_x and smoke emissions decrease. As a result, steam injection is a found powerful tool for reducing NO_x emissions of the diesel engines running with biodiesel blend.

1. Introduction

Biofuels and their blends with fossil fuel that production and application have been commonly increased internationally have become significant energy resources over the last couple of decades [1,2]. Fatty acid methyl esters (FAME) appear to be the most popular as a potential alternative fuel for compression ignition engines [3–5]. It is the most suitable fuel in environmentally sensitive areas where environmental conditions must meet high standards [6,7]. The substitution of conventional diesel fuels with rapeseed oil methyl esters comprises already a commercial activity in many European countries. There are a lot of studies investigating the effects of engine performance and emission characteristics using different biodiesel blends [5–12]. However, the main drawback of the engines fuelled with biodiesel blends is NO_x emission.

Nowadays, water injection methods to reduce NO_x emissions have been promising methods which can accomplish both of these goals [13–15]. Four major practical means for introducing water into the combustion chamber have been reported in the literature: Fumigating water into the engine intake air, direct injection into the engine through separate injectors, in-line mixing of water and fuel and mixtures of stabilized fuel and water emulsions. Some researchers [8–10,16] have shown in their studies that it is possible to reduce NOx and smoke with no loss of power and efficiency by means of introducing water into the combustion chamber. Among the researchers, Tsukahara et al. [16] showed reduction of specific fuel consumption (SFC) could be possible with water emulsified diesel. Tsukahara et al. [16] explained the reason of improvements in SFC with the following main reasons: Formation of a finer spray due to rapid evaporation of water, more air entrained in the spray due to increasing momentum and penetrating force, suppression of thermal dissociation and decreasing in cooling loss due to a lower flame.

However, these methods mentioned above have some advantages and drawbacks. Emulsified fuel–water blends can be used as an alternative method and have been shown to reduce NO_x and particulate matter (PM) emissions. However, emulsified fuel blends tend to lower the combustion temperature indiscriminately. Lower temperatures too early in combustion can lead to increased ignition delay and engine noise. A more significant drawback to emulsified fuels is that the percentage of water is constant and cannot be changed for cold start or other transient operating conditions [11,17].

The fumigation technique has been shown to reduce NO_x emissions in DI diesel engines. However, some drawbacks have arisen. One of the drawbacks of this method is to require about twice amount of the liquid volume for the same reduction in NO_x when compared to DW injection. Another drawback is that water can contaminate with the oil and increase engine wear and condensing water in the manifold can increase corrosion side effects [8]. Corrosive side effects of water and stabilizing agent on metallic parts of an engine are

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not yet solved in the techniques of fumigation and emulsified fuel [8,13–15,17].

Direct water (DW) injection method has the advantage over fumigation and emulsified fuel as the liquid water is injected close to the flame and away from the wall [13]. DW injection allows the fuel–water ratio to be changed for cold start or different operating conditions unlike emulsified fuels. The water would have to be injected into the hot reaction zone inside the cylinder. This would require considerable injection distances for the water spray which can be hardly achieved [12].

Another method for controlling NO_x emissions is named as Electronic Controlled Steam Injection (ESI) system developed by Parlak et al. [17–20]. From the literature reviews, water injection inside the diesel engine has certain effects to reduce emissions and improve performance parameters. But, the water inside the cylinder causes corrosion. Steam injection is the preferred method recently, so as to reduce this negative effect in the internal combustion engines [17–20].

In the studies conducted by Parlak at al. optimum steam ratio was found as 20% in terms of performance and emission reduction. At full load conditions, it was found that effective power increased about 2.5%, specific fuel consumption (SFC) decreased to 5% especially in low speeds. The NO_x emissions decreased up to 33% [17–19].

The main drawback of the engine fuelled with biodiesel is higher NO_x emissions. Hence, it is important to eliminate these pollutant emissions during operations. In the literature, there is no study investigating the effects of steam injection on engine performance and NO_x emissions fuelled with biodiesel. This study investigates the effects of steam injection on NO_x emissions and engine performance of the engine fuelled with tobacco seed oil methyl ester.

2. Material and methods

2.1. Determination of fatty acid composition

Fatty acid composition of tobacco seed oil was determined by means of GC (gas chromatography) analysis. A Hewlett Packard 5890 series II Gas Chromatograph, with a split–splitless injector and SP2340 type column 30 m long was used. Film thickness was 1.0 μm and the inside diameter was 0.53 mm. Also, the detector was a FID. An automatic sampler was attached to the HP 5890 GC to automate sample introduction. The sample (tobacco seed oil) injection amount was 0.5 mL/min. The temperature of the GC injector was 250 °C. Helium was used as a carrier gas. The split ratio was 1:50. The flame ionization detector temperature was 260 °C. The oven temperature was kept at 150 °C for 3 min. Afterwards, the oven was heated with heat ratio 10 °C/min to 225 °C. The oven temperature was constant for 15 min. The fatty acids of tobacco seed oil were identified and quantified using the AOAC 963.33 and AOAC963.22 methods. Gas chromatogram of tobacco seed oil (TSO), fatty acid composition of TSO and chemical formulas are shown in Fig. 1 and Table 1, respectively [21].

As can be seen from Table 1, the total saturated and unsaturated fatty acids inside the tobacco seed oil have been found to be 11.92% and 87.96% respectively. Whilst palmitic acid was most abundant (8.72%) amongst saturated fatty acids (Table 1), the major parts of unsaturated fatty acids were linoleic acid (75.58%) and oleic acid (11.24%). As reported in the present work, the amounts of unsaturated and saturated fatty acids are close to those reported by Giannelos et al. [22] (85.2% and14.8%), Mukhtar et al. [23] (87.36% and 12.64%) and Baydar et al. [24] (84.35% and 12.53%) [21]. The slight difference in the amounts of different fatty acids could be because of different species of tobacco (Nicotiana) used in the studies or different environmental or geographical conditions [21].

2.2. Production of TSOME

The tobacco plant is grown in 119 countries all over the world [25,26]. The leaves of the plant have been used in the production of cigarettes in the tobacco processing industries and are a commercial product. Hence, statistical information on tobacco harvesting area and leaf production is handily obtainable [25,26].

Tobacco seeds are a by-product of tobacco leaf production. Due to the fact that tobacco seed oil is a non-edible oil, it is not used as a commercial product in the food industry. Most of them are left unused in the fields, only a small amount of tobacco seeds have been collected from fields for next year production. [26].

To produce biodiesel, heterogeneous catalysts are stipulating for the transesterification reaction of vegetable oils [27]. Transesterification method was used for producing tobacco seed oil methyl ester (TSOME). The weight of the oil, alcohol and catalyst was measured by 0.0001 g sensitivity. Base catalyst was chosen because free fatty acid was found around 1% in the oil analyses. Reaction temperature, alcohol/oil molar rate, type and amount of catalyst, and reaction duration were chosen as parameters to find out the optimum conditions of reaction for TSO.

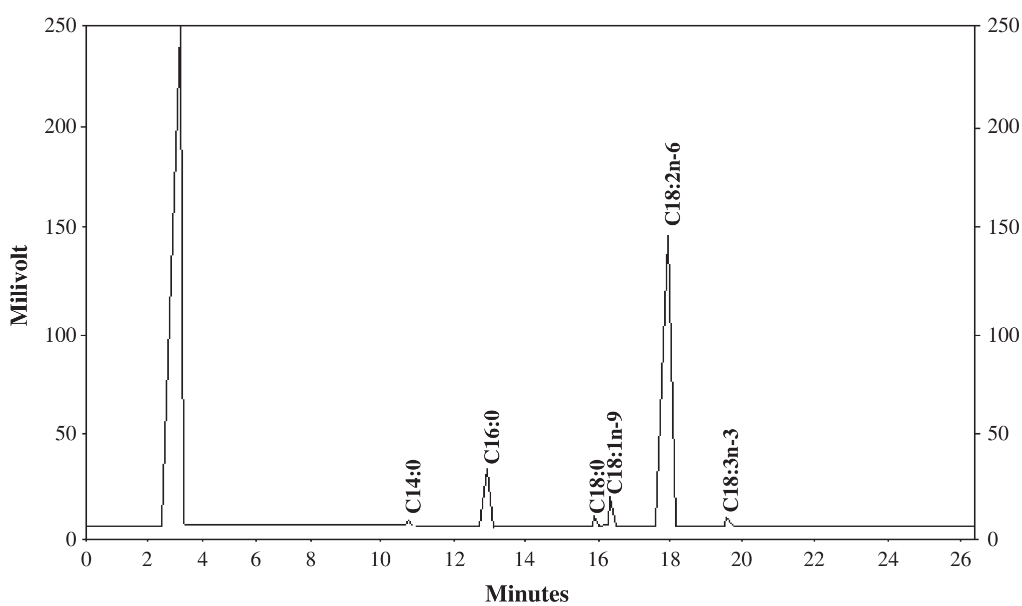

Fig. 1. Gas chromatogram of TSO [19].