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Original Research Article

Impacts of biodiesel blends with organic-based manganese additive on performance and emission characteristics of a single cylinder diesel engine

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Abstract

Biodiesel production from waste frying oil as a fuel can help the recycling and contributing to the economy. Transesterification reaction is preferred, it is not because the most common technique, it is one of the most efficient ways for the biodiesel production. The transesterification parameters of waste frying oil were applied as 6:1 Methanol to oil molar ratio with NaOH catalyst 0.4 g (w/w), 57°C reaction temperature, and 60 minutes reaction time and transesterification yield 88.5%. In this study, the effect of biodiesel blends with the organic-based manganese additive on performance and exhaust emissions of a single-cylinder, four-stroke, direct injected diesel engine with air cooling system at 2200 1/min fixed engine speed and with four different engine loads was experimentally investigated. The engine loads are (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa), and at the beginning of the tests, the engine was warmed with No. 2 diesel fuel. The oil and inlet air temperatures were kept at 85 ±2 °C and 25 ±1 °C, respectively. The testing fuels used in the experiments were composed of waste frying oil biodiesel blended with the No. 2 diesel fuel volumetrically with the ratio of 20, 40 and 60, respectively. The results obtained from the experimental study were compared with No. 2 diesel fuel. The effects of blends on CO, THC, NOx and smoke were investigated by emission tests. Additionally, brake specific fuel consumption of test fuels was examined. By virtue of the environmental effects, biodiesel production from waste frying oil has been become significant.

Keywords: Biodiesel; Additives; Engine performance; Exhaust emissions.

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1. Introduction

Vegetable oil can be an acceptable an alternative fuel to petroleum based fuel for diesel engines due to renewable energy source, biodegradable and non-toxic fuel. New or used vegetable oil and animal fat are sources of biodiesel. Biodiesel production methods are classified as direct use and blending, microemulsification, pyrolysis, and transesterification, among these, transesterification is an attractive and widely accepted technique [1]. Biodiesel is generated by chemical reaction from vegetable oil, animal fats and waste frying oils with an alcohol such as methyl alcohol and a catalyst, generally a strong base like sodium hydroxide or potassium hydroxide. This new chemical compounds named methyl esters [2]. The purpose of the transesterification process is to lower the viscosity of the vegetable oil [1]. Biodiesel has some advantages such as more favorable combustion emission profile, low emissions of carbon monoxide, particulate matter, and unburned hydrocarbons by comparison with the petroleum-based diesel. Moreover, biodiesel has a relatively high flash point, which makes it less volatile and safer to transport and handle than petroleum diesel. Biodiesel provides lubricating properties that can reduce engine wear and extend engine life [3]. Additionally, biodiesel is superior to conventional diesel with regards to its sulphur content, aromatic content and flash point. Biodiesel is essentially non-aromatic and sulphur free while conventional diesel can include up to 500 ppm SO_2 and 20–40 wt% aromatic compounds [4]. On the other hand, biodiesel fuels have disadvantages such as having poor storage stability, cold flow properties, inferior spray characteristics and lower heat content [1].

Biodiesel production from waste frying oil has an advantage due to of its low cost. While Encinar et al. stated that the waste frying oil is estimated to be about half the price of virgin oil [3], Phan et al. reported that the price of waste cooking oils (WCO) is 2–3 times cheaper than virgin vegetable oils. Consequently, the total manufacturing cost of biodiesel can be significantly reduced [4]. The fact remains that using waste frying oil for biodiesel production can help to solve of its disposal problems. Furthermore, rising population triggers the vegetable oil consumption so that the vegetable oil is considered an effective source of biodiesel production.

Using fuel additives improve combustion efficiency and decrease pollutant emissions. Among the additives, metallic based compounds have been used as combustion catalyst for hydrocarbon fuels. As stated in the literature that the metal base additives promote complete and more efficient combustion in the diesel engines and gas turbines, resulting in increased power, improved fuel economy and radically reduced exhaust emissions such as particulate matter, CO and HC. In addition, the additives decrease formation of particulates in cylinders and exhaust systems [5].

The aim of the study is to perform experimentally parametric tests of a single cylinder diesel injection engine performance and emissions fueled with biodiesel obtained from waste frying oil with 5µmol/l organic based manganese fuel additive with 2200 1/min fixed engine speed and at four different engine loads.

2. MATERIAL AND METHODS

2.1. Fuel description

The origin of the waste frying oil is sunflower oil, that was collected from a Turkish restaurant and filtered from solid impurities. The used oil was transesterified using methanol in the presence of NaOH. Biodiesel production was carried out using a batch reactor system as schematically shown in Fig. 1. The transesterification parameters of waste frying oil were applied as 6:1 Methanol to oil molar ratio with NaOH catalyst 0.4 g (w/w), 57°C reaction temperature, and 60 minutes reaction time and transesterification yield 88.5%. After the alkali transesterification reaction was completed, the mixture was left in separating funnel for

8-10 hours for gravity separation of the methyl esters and glycerol. The heavier glycerin settled at the bottom and was removed; the remaining sample was washed with hot distilled water (about 85°C) several times until the wash water became clear. After washing, the biodiesel was heated up 110°C for 20 minutes to remove any remaining water. Biodiesel blends of waste frying oil methyl ester (WFOME) were prepared in different proportions by volume basis like B20-B40-B60. The organic based manganese was added to B20-B40-B60 blends at the rate of 5µmol/l.

Chemical properties were determined for both of used fuels according to European Fatty Acids Methyl Ester (FAME) standard draft (EN 14214), as shown in Table 1.

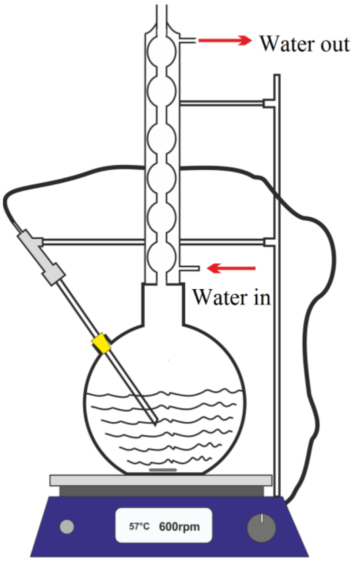

Figure 1. Schematic diagram of the batch reactor used for biodiesel production

Table 1. Some properties of the test fuels

Property	**WFOME-Mn**	**Diesel fuel**
Density at 15 °C (kg/m^3)	888.81	841.75
Kinematic viscosity at 40 °C (mm^2/s)	4.702	3.354
Sulphur (mg/kg)	2.3	-
Water content (mg/kg)	483.19	-

2.2. The Engine Specifications

The experiments were conducted on a four-stroke, naturally aspirated, single-cylinder direct injection diesel engine. The specification of the test engine is shown in Table 2. The experiments were conducted at four different engine loads (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa) and 2200 rpm engine speed. At the beginning of the tests, the engine was warmed with No. 2 diesel fuel. The oil and inlet air temperatures were kept at 85 ±2 °C and 25 ±1 °C, respectively, Biodiesel blends containing 20%, 40% and 60% proportions by volume were tested in the experiments and the results were compared with conventional No. 2 diesel fuel operation.

Table 2. Test engine specifications

Make/model	**Antor/6LD400**
Engine type	DI-diesel engine, natural aspirated, air cooled
Cylinder number	1
Bore x stroke (mm)	86 × 68
Displacement (cm3)	395
Compression ratio	18:1
Maximum power (kW)	5.4 @ 3000 rpm
Maximum torque (Nm)	19.6 @ 2200 rpm
Combustion chamber geometry	ω type
Fuel injection system	PF jerk-type fuel pump
Injection nozzle	0.24 mm × 4 holes × 160°
Nozzle opening pressure (bar)	180
Fuel delivery advance angle (°CA)	28 BTDC
Valve timings IVO/IVC (°CA)	7.5 BTDC/25.5 ABDC
EVO/EVC (°CA)	21 BBDC/3 ATDC

2.3. Measurements of exhaust gas emissions

Exhaust gas emissions were measured using environment SA-EGAS 2M gas analyzer that specifications were given in the Table 3. The EGAS 2M gas analyzer measures THC emissions with Heated Flame Ionization Detection (HFID) analyzer, NOx with heated chemiluminescence (CLA) analyzer and CO/CO_2 with a Non-Dispersive Infrared Sensor (NDIR).

AVL 4000 DiSmoke opacity meter specifications were shown in Table 4. AVL 4000 DiSmoke opacity meter is partial flow meter, which have 0.1 m^{-1} sensibility and range of 0–99.99 m^{-1}.

Table 3. Technical specifications of exhaust gas analyzers

Analyzer	**GRAPHITE 52M**	**TOPAZA 32M**	**MIR 2M**
Measuring compound	THC (wet)	NO-NOx (wet)	CO-CO_2-O_2 (dry)
Measurement principle	HFID	HCLD	NDIR Paramagnetic
Linearity	<1%	<1%	<1%
Measurement rate	0-10/30000 ppm	0-10/10000 ppm	0-500/10000 ppm (CO) 0-1/20% (CO_2) 0-5/25% (O_2)
Lower detectable limit	0.05 ppm (0-10 ppm range)	0.1 ppm (0-10 ppm range)	<2% (FSO)
Response time (T90 s)	<1.5 s	<2 s	<2 s

Table 4. Technical specifications of opacimeter

Analyzer	**AVL DiSmoke 4000**	
Measurement principle	Partial flow opacimeter	
Measurement range	Opacity	K value
Accuracy	0-100%	Accuray 0.1%
	0-99.99 m^{-1}	0.01 m^{-1}

2.4. Testing procedure

The experiments were conducted at four different engine loads (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa) and 2200 rpm engine speed. At the beginning of the tests, the engine was warmed with No. 2 diesel fuel. The oil and inlet air temperatures were kept at 85 ±2 °C and 25 ±1 °C, respectively, Biodiesel blends containing 20%, 40% and 60% proportions by volume were tested in the experiments and the results were compared with conventional No. 2 diesel fuel operation.

3. RESULTS and DISCUSSION

3.1. Brake specific fuel consumption (BSFC)

Brake specific fuel consumption refers to the efficiency of a combustion engine which burns fuel and produces rotational power. Fig. 2. shows the variation of BSFC of test fuels. Biodiesel blends have higher brake specific fuel consumption values at all engine loads. BSFC increases as biodiesel blend ratio increases. This increase causes the lower calorific value of biodiesel fuels [6] and the relatively higher density compared with diesel fuel [7]. In order to maintain the same power output, more fuel is required [8]. In addition, conventional jerk fuel pump systems, fuel metering is made volumetrically so that an increase of mass based flow rate in the same fuel volume is due to the higher density of biodiesel. Furthermore, internal leakage in the pump could be decreased by using more viscous biodiesel fuels. Thus, pertaining to specific fuel consumption, more fuel mass flow rate is required to provide the same engine output due to lower energy content of biodiesel and this explains the higher specific fuel consumption [9]. The maximum BSFC increase of 23.95% in B60 biodiesel occurs at 0.48 MPa engine load.

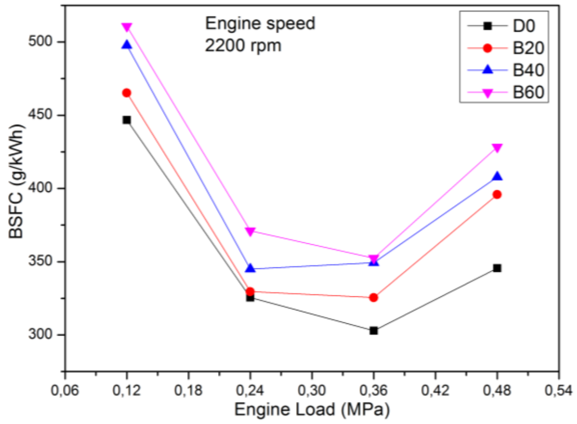

Figure 2. Effects of biodiesel addition and engine load on brake specific fuel consumption

3.2. Exhaust gas emissions

The variation of CO emissions is shown in Fig. 3. CO emission is originated from incomplete combustion due to insufficient oxygen content. CO emission greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO, and emissions increase almost linearly with the deviation from the stoichiometry [10]. CO emission increases with increasing engine speed, by virtue of the increase in air/fuel ratio related to the reduction in volumetric efficiency and increase in fuel consumption associated with the increase in engine speed [8]. Feedstock of biodiesel influences the CO emissions and it decreased with the increase of chain length. Higher oxygen content leads to complete combustion and thus CO emission reduced. Thus, CO emission decreased with the increase of cetane number of biodiesel, engine load and engine speed [11]. Lowest CO emission occurred at 0.24 MPa engine load of 34.01% with B20 blend.

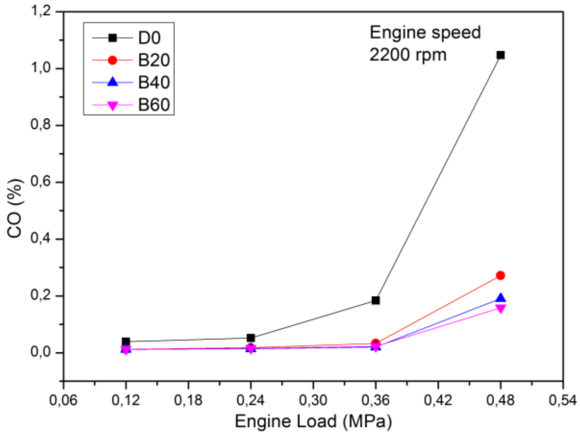

Figure 3. Effects of biodiesel addition and engine load on CO emissions

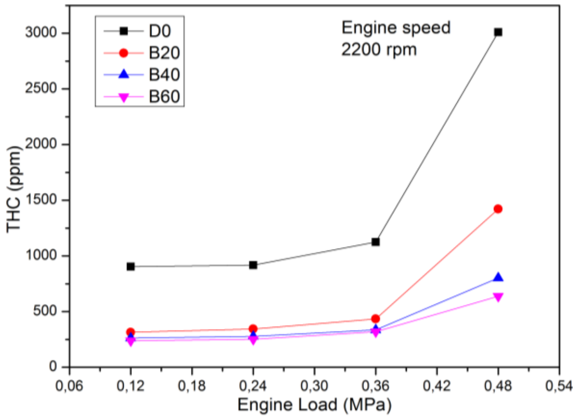

Figure 4. Effects of biodiesel addition and engine load on THC emissions

Basically, hydrocarbons are originated from incomplete combustion, decreasing of combustion temperature and lack of oxygen [12]. The increase in hydrocarbons shows that the efficiency of the diesel engine is reduced as well [13]. It is observed in Fig.4. HC emission decreased as the percentages of biodiesel in the blends increased. Decreasing of HC emission is due to higher oxygen content [11, 13, and 14] and cetane number of biodiesel [11, 14]. Higher oxygen content leads to complete combustion of fuel and higher cetane number leads to reduce burning delay which reduce unburned hydrocarbon [11, 14]. HC emission also reduced with the increase in chain length [11]. The biggest THC emission difference occurs in 0.48 MPa engine load with the B60 blend.

In internal combustion engine NOx formation highly based on the concentration of oxygen, the temperature inside the cylinder, the residence time for the reaction to take place and the equivalence ratio. The main reason of increasing NOx emissions in biodiesel fuels related to (i) faster burn rate as well as advanced start of combustion, (ii) low radiation heat transfer, (iii) variable adiabatic flame temperature [11]. Oxygen content of biodiesel fuel leads to better combustion of biodiesel fuels and as a consequence, the combustion temperature increases so that results in the excessive NOx emission [11,15]. In addition, the different physical properties of biodiesel such as viscosity, density, bulk modulus, speed of sound, can cause advancing of the injection timing in the pump-line-nozzle fuel systems [9]. On the other hand, NOx emissions increment with decrease in mean carbon chain length and increase in unsaturation. Increase in NOx emissions with increase in iodine number iodine number is closely connected to density, compressibility and cetane number [16]. It can be clearly seen from Fig.5. highest NOx emission occurred at 0.48 MPa engine load of 7.24% with B60 blend.

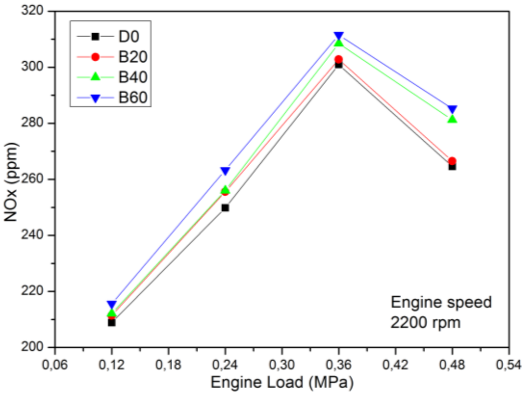

Figure 5. Effects of biodiesel addition and engine load on NOx emissions

The variation of smoke emissions for biodiesel blends and neat diesel for different engine loads can be seen in Fig. 6. According to Fig. 6. lower smoke emission of biodiesel blends occurred than that of diesel fuel at all engine loads. Principally PM is the opacity of exhaust gas measured [6]. As the engine load increases the air/fuel ratio decreases due to high fuel injection rate, which results in higher smoke emission [11]. In fact, reduction in smoke emissions of biodiesel fuel is depending on the oxygen and sulphur content of biodiesel and lower aromaticity [9]. The higher oxygen content of biodiesel provided more oxygen for combustion and soot oxidation [16]. Keskin et. al. reported that biodiesel with metallic based additives has lower smoke opacity than biodiesel with no additives [6].

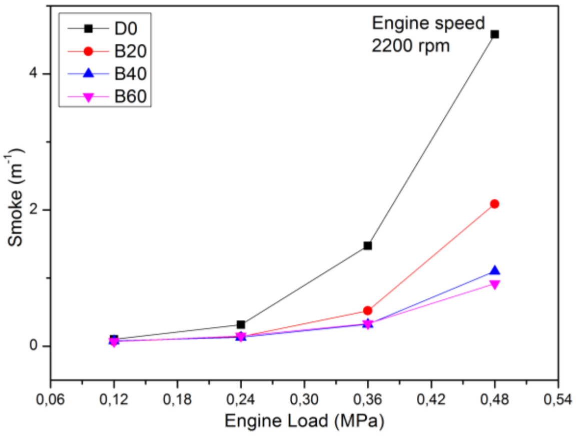

Figure 6. Effects of biodiesel addition and engine load on smoke emissions

4. CONCLUSION

Using waste frying oil as an alternative diesel fuel can help the recycling and contributing to the economy. On the other hand, low sulphur and aromatic contents are advantages of biodiesel fuels that can help reduction of the emissions. Additionally, lower price of waste frying oil is another advantage. The performance and emission characteristics of diesel fuel and biodiesel derived from waste frying oil and its blends of B20, B40 and B60 were compared at four different engine loads (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa) and 2200 rpm engine speed in a single cylinder diesel engine. As can be seen in the emission test graphs; CO, THC and smoke emissions of biodiesel blends are lower than diesel fuel, but NOx emission of biodiesel blends is slightly higher compared to diesel fuel. Even though biodiesel blends have higher NOx emission, by means of lower CO, THC and smoke emissions levels, biodiesel fuels are most suitable fuel for diesel engines. Furthermore, NOx emission can be reduced by selective catalytic reduction (SCR) system.

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