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The Effects of Biodiesel Obtained from Inedible Oils on the Emissions

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Abstract: Environmental effects and economic conditions have led researchers to find alternative energy sources so that the interest of biodiesel production from inedible oils is continue to rise due to its low price. Using raw vegetable oil as fuel cannot be evaluated possible due to several unfavorable effects. Thanks to the transesterification reaction raw vegetable oil viscosity can be reduced. This study is aimed to investigation of emissions of B100 waste frying oil methyl ester and B100 *crambe abyssinica* oil methyl ester. Experimental tests were conducted to 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. 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 results obtained from the experimental study were compared with No. 2 diesel fuel. The effects of fuels on CO, THC, NOx and smoke emissions were investigated. Brake specific fuel consumption of test fuels was also examined. According to the obtained results, B100 fuels can be used as an alternative fuel in a diesel engine.

Keywords: Inedible oil, *Crambe abyysinica*, Waste frying oil, Engine performance, Exhaust emissions

Introduction

Industry and transportation are the most energy consuming sectors in the world. Furthermore, this consumption is increasing in proportion to the development of the countries. Transportation refers to the movement of person and ware from pillar to post. Increasing population and level of welfare causes increasing need for transportation, to meet this need more fuel will be consumed. Biofuels seem to good economically and environmentally option to satisfy this need. Biodiesel fuel is the definition of biological origin fuel that derived from plant oil and animal fat. Biodiesel production components are oil, alcohol, catalyst and heat. Methanol is usually used as alcohol for biodiesel production. Sodium hydroxide and potassium hydroxide are the base catalysts that use for base transesterification frequently.

1.5 million tons of vegetable oil using with the aim of food in Turkey, about 150.000 tons of that vegetable oil are generating waste oil (Anonymous, 2018). Using waste frying oil for biodiesel production can help to solve disposal problems. Kumar et al. have shown worldwide waste edible oil production at Table 1. Waste cooking oil can be thought the source of biodiesel production potentially.

Tabel 1. Worldwide waste edible oil production (Kumar, Sushma, Chandrasagar, Raju, & Devi, 2017).

Country	Estimated waste cooking oil
USA	1,00,00,000 gallons/day
Canada	1,35,000 tons/year
E.U.	7,00,000 - 10,00,000 tons/year
UK	2,00,000 tons/year
China	45,00,000 tons/year
Malaysia	5,00,000 tons/year
Taiwan	70,000 tons/year
Japan	4,50,000 - 5,70,000 tons/year
India	90,00,000 tons/year

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Biodiesel obtained from inedible oil prefers due to low price. Soo-Young No reviewed inedible vegetable oils in his article. Those inedible vegetable oils are : Jatropha, karanja, mahua, linseed, ruberseed, cottonseed, neem, camelina, putranjiva, tobacco, polanga, cardoon, deccan hemp, castor, jojoba, moringa, poon, koroch seed, desert date, eruca sativa gars, see mango, pilu, crambe, syringa, milkweed, field pennycress, stillingia, radish Ethiopian mustard, tomato seed, kusum, cuphea, camellia, paradise, cuphea, treminalia, michelia champaca, garcinia indica, zanthoxylum bungeanum (No, 2011). Since the inedible vegetable oil crops have a large variety so that offer more options as an alternative fuel product. On the other hand, the plants that have drought and cold tolerant and can grow in nonarable land become popular. According to Falasca et al. crambe abyssinica is promissory crop for Argentina due to tolerance to draught and frost and it can be harvested at 90 days (Falasca, Flores, Lamas, Carballo, & Anschau, 2010). In this respect, *crambe abyysinica* plant is become important.

With respect to the emissions, biodiesel fuels are the center of interest. According the literature; researchers have stated that using biodiesel the NOx emission increases, but HC, CO and PM emissions decrease compared to diesel fuel (Verma & Sharma, 2015).

The aim of the study is to investigate of the effects of biodiesel obtained from waste frying oil and crambe abyssinica oil on the emissions on a single cylinder diesel injection engine with 2200 1/min fixed engine speed and at four different engine loads.

Materials and Methods

In this study, a flat-bottom flask was used as a laboratory scale reactor with a reflux condenser for the experimental tests, and Daihan MSH-20D Digital Precise Hotplate with temperature probe arrangements was used for heating the mixture in the flask. Shimadzu UW620H accuracy 0.001g electronic balance was used for scaling chemicals. All chemicals was provided from Merck. Waste frying oil was collected from a Turkish restaurant and filtered from solid impurities. The origin of the waste frying oil is sunflower oil. The used oil was transesterified using methanol in the presence of NaOH. The transesterification parameters of waste frying oil was 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%. *Crambe abyssinica* oil was purchased from Elementis Specialities Company by the name of Fancor Abyssinian Oil. The *crambe* oil was transesterified using methanol in the presence of KOH. The transesterification parameters of *crambe abyssinica* oil was applied as 6:1 Methanol to oil molar ratio with KOH catalyst 0.8 g (w/w), 57°C reaction temperature, and 60 minutes reaction time and transesterification yield 96.5%. 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. The properties of used fuels have shown in Table 2.

Table 2. Fuel properties used in tests

Properties	*Crambe* methyl ester	WFOME	Diesel fuel
Viscosity (cSt)	6.492	4.848	3.354
Density (g/L)	879.7	888.91	841.75
Sulfur (mg/kg)	1.3	1.5	-
Water content (mg/kg)	378.49	488.5	-
Cetane index	-	-	53.1

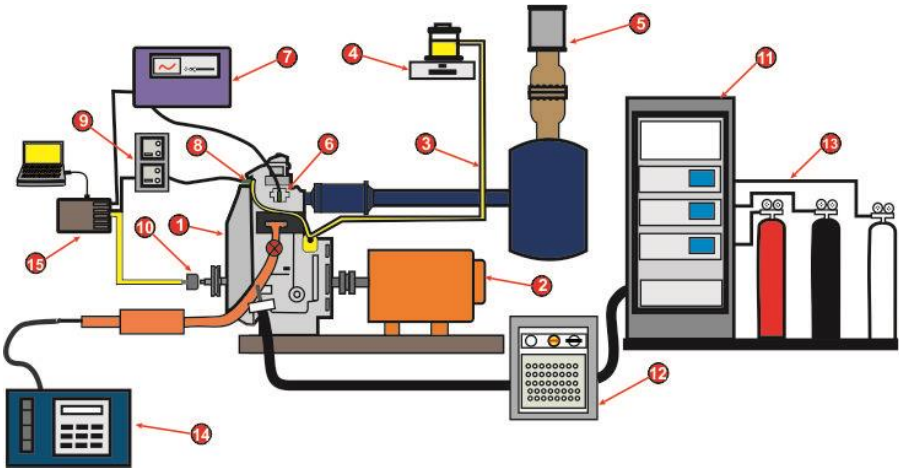

Figure 1. Test rig

1- Test engine 2- DC dynamometer 3- Diesel fuel line 4- Sensitive scale 5- Laminar flow meter 6- In-cylinder pressure sensor 7- Combustion analyzer 8- Diesel fuel line pressure sensor 9- Diesel fuel line pressure sensor amplifier 10- Encoder 11- Emission gas analyzer 12- Emission sampling system 13- Function gases (N_2, O_2, H_2/He) and span gases (C_3H_8, CO_2, CO, O_2) 14- Smoke meter 15- Data acquisition card

The test rig used in this study is shown in Fig. 1 and the specifications of the single cylinder diesel engine are given in Table 3. The engine was loaded with Cussons brand P8160 model DC type dynamometer measuring up to 10 kW at 4000 rpm. The inlet air flow rates were measured with Merriam brand Z50MC2-4F model laminar flow meter. The inlet air and the lubrication oil were measured using NiCr–Ni type thermocouples. The fuel consumption values were measured using an electronic balance with high precision. The engine torque was calculated from the force values acquired with a straingauge type load cell and the engine speeds were obtained with a magnetic collector type sensor. In order to minimize the variations of the inlet air temperature, PID (ENDA ETC. 9420) controlled air heater (Farnam Flow Torch 400) was used.

Table 3. General specifications of the Antor diesel engine

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

Exhaust gas emissions were measured using Environnement SA-EGAS 2M gas analyzer that specifications were given in the Table 4. The EGAS 2M gas analyzer measures THC emissions with Heated Flame Ionization Detection (HFID) analyzer, NOx with heated chemiluminescence (CLA) analyzer and CO/CO2 with a Non-Dispersive Infrared Sensor (NDIR).

Table 4. 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

AVL 4000 DiSmoke opacity meter specifications were shown in Table 5. 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 5. Technical specifications of opacimeter.

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

Results and Discussion

In internal combustion engine, the brake-specific fuel consumption (BSFC) is expressed the rate of fuel consumption divided by the power produced. That is to say, brake-specific fuel consumption indicates the efficiency of a combustion engine which burns fuel and generates rotational power. Brake-specific fuel consumption value of biodiesel fuels is higher than that of diesel fuel. The biggest difference of brake-specific consumption as %13.04 is occured at 0.36 MPa engine load with CAB100 biodiesel. This increment can originate from the lower heating value and higher density of biodiesel fuels by comparison with diesel fuel (Utlu & Koçak, 2008).

Since the diesel engines run higher A/F ratio, HC emissions of diesel engine are low. However, HC emissions can consist of unburned fuel due to insufficient air and temperature. HC emission of biodiesel fuels lower than diesel fuel. This reduction is derived from the oxygen content and fuel ignition quality of biodiesel fuels. Oxygen improves the combustion and higher cetane number shorten the ignition delay, thus progress the combustion (Bueno, Pereira, de Oliveira Pontes, de Luna, & Cavalcante Jr, 2017). As the engine load increases, HC emission of tested fuels increase due to more fuel entered into the cylinder. In terms of HC emission, CAB100 is shown better results comparison the WFOB100 and diesel fuel.

CO_2 emission is responsible for the global warming and using fossil fuel increases the global warming. On the other hand, biodiesel fuels generate lesser CO_2 emissions due to higher oxygen content in biodiesel (Samuel, Raj, Sreenivasulu, Rajasekhar, Edison, Saco, 2016) and lower carbon to hydrogen ratio (Xue, 2013). From the Figure 2, it is observed that CO_2 emissions of tested fuels have increased while engine load increasing.

If the carbon fuels are not burned completely, as a result of CO emission occurs. CO emission is poisonous to humans. CO emission of biodiesel fuels are lower than diesel fuel because of the oxygen content of biodiesel fuel. From the Figure 2, it can be seen that, CO emission of tested fuels increased by gradually as the engine load increases. Oxygen enhances complete combustion and thus decrease CO emission (Shirneshan, 2013).

Figure 2, depicts that, smoke emissions of tested fuels increased with the engine load proportionately. Biodiesel fuels have lower smoke emissions by reason of absence of aromatics, low C/H ratio and the oxygen content. Thanks to the oxygen content in the fuel, combustion improves even in locally rich zones. The lower carbon can produce the lower soot, absence of aromatics causes producing lower soot as well (Öner & Altun, 2009).

Figure 2, illustrates that, NOx variation of tested fuels. NOx emission of biodiesel fuels is slightly higher than diesel fuel. This rising can stem from oxygen content of biodiesel that makes leaner air/fuel ratio. Additionally, unsaturated fatty acids content in biodiesel can lead to the higher adiabatic flame temperatures, that resulting in higher NOx (Mofijur, Masjuki, Kalam, Atabani, Fattah, & Mobarak, 2014). Nevertheless, like viscosity, density, compressibility and sound velocity physical properties of biodiesel lead to advanced injection and so higher cetane number of biodiesel gives rise to advanced combustion with shorten ignition delay (Tesfa, Gu, Mishra, & Ball, 2014).

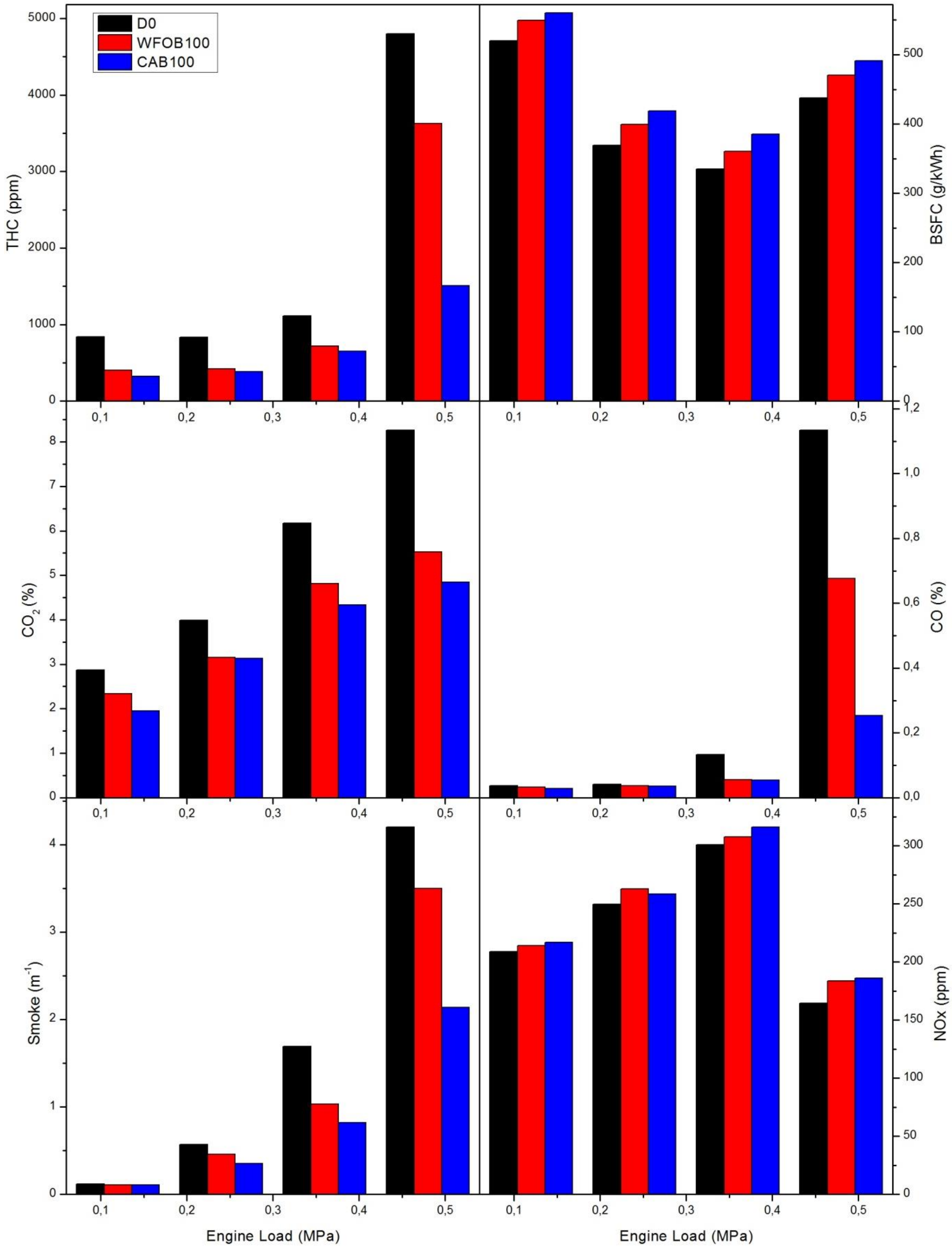

Figure 2. Variations of THC, CO, CO_2, NOx and smoke emissions and BSFC of tested fuels at different engine loads.

Conclusion

In this experimental study, the effects of waste frying oil biodiesel and *crambe abyssinica* biodiesel on emissions were investigated under four different engine loads (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa) and 2200 rpm engine speed. Based on the experimental results, the following major conclusions have been concluded. Biodiesel fuels have shown higher brake specific fuel consumption as it was expected due to lower calorific value of biodiesel. While the THC, CO, CO_2 and smoke emissions of biodiesel fuels have decreased, NOx emissions have increased. The presence of the oxygen in biodiesel fuel can help the reducing smoke emission whereas causes the increase in NOx emission. The most important component increasing the cost of biodiesel production is oil, so that inedible oil and waste frying oil due to low price can drop off the biodiesel production expenditure. At the same time, the interest in the crops that grow in non arable areas is rising, for this reason *crambe abyssinica* is promising crop for biodiesel production. Due to the similarity of fuel characteristics of biodiesel fuels and diesel fuel, biodiesel fuels can evaluate as an alternative and environmental friendly fuel.

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