

THE EFFECT OF VARIOUS VEGETABLE OILS ON POLLUTANT EMISSIONS OF BIODIESEL BLENDS WITH GASOIL IN A FURNACE

by

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In this paper the effect of various vegetable oils on pollutant emissions of biodiesel blends with gasoil in a furnace is studied experimentally. The exhaust gas temperature and emissions of CO, NO_x, and SO₂ are measured by an R-type thermocouple and TESTO 350-XL gas analyzer, respectively. The oil of soybean, sunflower, canola, and corn are used in transesterification process of biodiesel. The results show that maximum of temperature, NO_x emission and SO₂ emission are achieved for the combustion of sunflower methyl ester and corn methyl ester blends with gasoil in contrast with combustion of soybean methyl ester and canola methyl ester blends with gasoil. Also the minimum of CO emission is reached for combustion of these fuels.

Key words: *biodiesel, furnace, gasoil, pollutant emissions, vegetable oil*

Introduction

Shortage of fossil fuel resources and its disadvantages such as environmental pollution, global warming has led countries to use renewable fuels like biodiesel. Biodiesel is a biodegradable fuel which can be produced from all kind of vegetable oils and animal fats through transesterification process [1]. It is non-toxic, free of sulfur, and aromatics [2]. Its flash point is higher than common diesel fuel which makes it safer to handle and store [3]. Besides its advantages, biodiesel has its own drawbacks. For example it has higher viscosity, lower volatility and lower heating value than diesel fuel. A great deal of studies is done on biodiesel production, performance, and emissions in transportation and non-transportation applications [4-8]. The summary of [4-8] show that a decrease may occur in most pollutant such as CO, SO₂, and NO_x. However, the effect of biodiesel on NO_x emission has remained uncertain. A study on the combustion of biodiesel in a furnace by Batey [2] showed that that B20 released less smoke numbers in comparison with diesel fuel. Combustion and emissions of soybean biodiesel in a residential heating equipment have been investigated in [3, 8-11]. Their results showed that blends of diesel fuel and biodiesel fuel emitted lower amounts of NO_x in comparison with pure diesel fuel. Ng and

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Gan [12] studied the combustion of palm oil methyl ester in a boiler. They evaluated the trends of NO_x and CO with various equivalence ratios and fuel pressures. They also represented an optimized equivalence ratio for each fuel pressure for optimum combustion process with lowest emissions. A study by Lee *et al.* [13] showed that biodiesel has lower emissions of NO_x and CO comparing with diesel fuel. Valaningham *et al.* [5] examined the combustion performance of 20 vol.% of soybean methyl ester in residential heating equipment. They reported that SO_2 and NO_x emission was less for B20 blend. Baghdar Hosseini *et al.* [14] investigated on the pollutant emission of diesel fuel and biodiesel blends. Their study showed that biodiesel can lower some pollutant such as CO, CO_2 and particulate matter emissions while NO_x emission would increase in comparison with diesel fuel. They also studied the effect of swirl number on pollutants from biodiesel combustion. Their results showed that the exhaust gas temperature and NO_x were increased with increase of biodiesel in fuel blend while CO was decreased in various swirl numbers. Ghorbani *et al.* [15], Ghorbani and Bazooyar [16], and Bazooyar *et al.* [17] performed some experiments in a water cooled boiler with different blends of biodiesel from B0 to B100. They verified the trends of all emissions with various fuel pressures and air fuel ratios. Their results showed that all emissions reduce except NO_x for all fuel pressures. However, NO_x emission decreases for some fuel pressures.

The main objective of this work is to study the effect of various vegetable oil on pollutant emissions of biodiesel blends with gasoil in a furnace. The results of this study are expected to provide some insights into understanding the correlation between various biodiesel oils and exhaust gas temperature and pollutant emissions.

Experimental set-up

Combustion chamber and gas analyzer

The experimental study was performed on an atmospheric combustion chamber which was equipped with a liquid fuel burner of a nominal heating capacity of 70 kW. The length of this cylindrical furnace is 1800 mm and its diameter is 360 mm. It is made of steel AISI 316 and it is completely insulated. Exhaust gas exits through a 4 m high chimney. Two holes, after 90° insulated elbow, are considered to locate thermocouple and gas analyzer probe. On the rims of furnace some openings in different spaces from burner nozzle have been made for measuring temperature along the furnace. Temperature was measured with a K-type thermocouple. Fuel spray jet that is used in this fuel burner is Danfoss atomizer with nominal flow rate of $1.3125 \cdot 10^{-6} \text{ m}^3/\text{s}$ and 60° W-type of nozzle. The concentration of CO, CO_2 , SO_2 , NO_x , and excess air ratio were measured and determined with TESTO 350 XL gas analyzer. Figure 1 shows

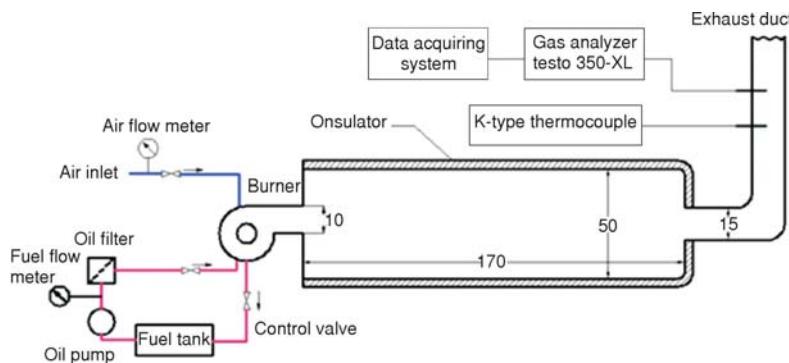


Figure 1. Schematic of the furnace

a schematic of the furnace and experimental set-up. List of measurement instruments and their specification are shown in tab. 1.

Table 1. List of measurement instruments and their specifications.

Instrument	Range	Resolution	Accuracy [%]
Hotek AM 4206 anemometer	0.4-25 m/s	0.1 m/s	±2
Satronic SOG960 oil flow meter	1-40 dm ³ /h	±0.01 dm ³ /h	±2.5
K-type thermocouple for exhaust gas temperature	0-1100 °C	±1°C	±0.75
O ₂ sensor	0-25%	±0.1%	±0.2
CO ₂ sensor	0-20%	±0.1%	±2
CO sensor	0-10,000 ppm	±1 ppm	±2
SO ₂ sensor	0-5000 ppm	±1 ppm	±2
NO sensor	0-3000 ppm	±1 ppm	±2
NO ₂ sensor	0-500 ppm	±0.1 ppm	±2

Biodiesel production

Gasoil and biodiesel blends are used in the experiments. Biodiesels were produced, in the Combustion and Fuel Laboratory of Islamic Azad University in Mashhad, India, with four different kinds of oils by alkali-catalyzed transesterification process. In this process, methanol is mixed with NAOH alkali catalyst. Physical properties of the fuels provided by Research Institute of Petroleum Industry are summarized in tab. 2. In this table CME 1, CME 2, SME 1, and SME 2 refer to canola methyl ester, corn methyl ester, sunflower methyl ester, and soybean methyl ester, respectively. The blends of biodiesel and gasoil are prepared by mixing different volumetric proportions of the two fuels. For example, number 40 in B40 represents the volume percentage of biodiesel in the mixture. Therefore, B100 stands for pure biodiesel.

Table 2. Properties of pure biodiesel with various oils and gasoil

Property	Unit	ASTM standard	Gasoil	SME 1	SME 2	CME 1	CME 2
Density at 15 °C	g/cm ³	D4052	0.815	0.9	0.9022	0.8820	0.88
Kinematic viscosity at 40 °C	Cst	D445	2.45	2.74	3.6	3.46	4.79
Low heating value	MJ/kg	D240	42.5	37.6	37.9	38.72	38.7
Flash point	°C	D93	61	109	269	171	147
Cloud point	°C	D2500	-4	-2	-0.5	-1	-3.2
Carbon		D5291	85.05	76.3	76.7	77.2	77
Hydrogen	%	D5291	14.9	12.2	11.7	11.8	12.5
Oxygen		Oxygen analyser	0	11.5	11.6	11	10.5
Sulphur		D5453	0.05	0	0	0	0

Experimental results

In this study, the effect of various vegetable oil on pollutant emissions of biodiesel blends with gasoil in a furnace is investigated. Biodiesels are made from sunflower, corn, soy-

bean, and canola vegetables oils with alkali catalyzer and methanol alcohol. The concentration of CO, CO₂, NO_x, and SO₂ are recorded. All the experiments are conducted three times at consistent performance conditions in order to reduce uncertainties. In every case, the average of three measurements is presented. The trends of experimental data obtained from measurements on different days are in good agreement, which demonstrates the reliability of the combustion apparatus.

Effect of various vegetable oil on pollutant emissions of biodiesel blends with gasoil

The main difference between pure biodiesel and gasoil is oxygen content, *i. e.*, biodiesel contains 10-12 wt. % oxygen. As it can be seen from fig. 2 the furnace temperature increases for higher content of biodiesel in the blend. This behavior may be attributed to the oxygen content of biodiesel that leads to an enhanced combustion and higher temperatures. This behavior intense when higher amount of biodiesel is used in mixtures. It also shows that the maximum temperature is obtained for combustion of CME2 in both fuel blends.

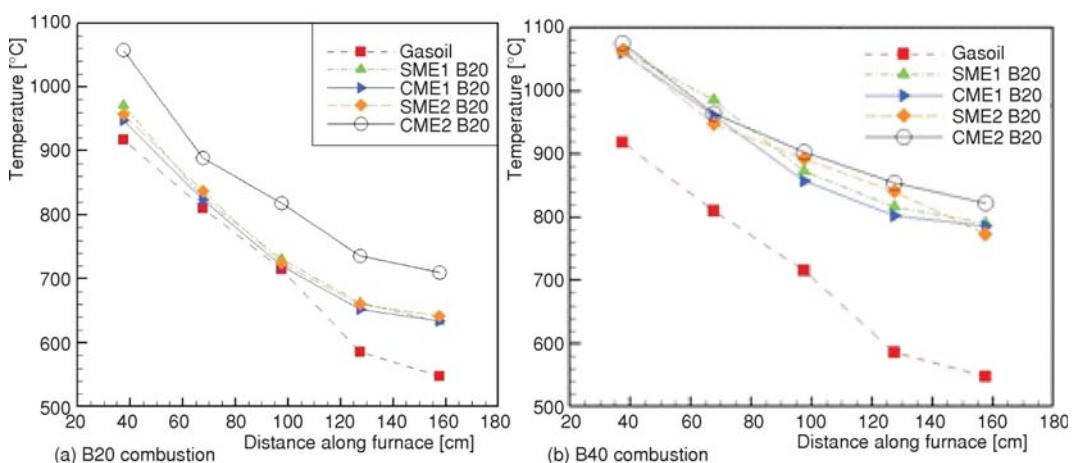


Figure 2. The effect of various vegetable oil on temperature for B20 and B40

The CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete CO is fully converted to CO₂, but if the combustion is incomplete, due to shortage of air or low temperature in the furnace, CO will be formed. Figure 3 demonstrates the trend of CO emissions of B20 and B40 combustion at various excess air (EA). As it can be seen, lower CO emission is achieved for the combustion of CME1 and SME2. It can also be observed that the minimum amount of CO is produced for the higher EA where the combustion is almost complete. For lower EA values, insufficient O₂ content of the combustion gives a rise to the level of CO emission. These figures also demonstrate the correlation between CO emission and biodiesel content in fuel blends at different percentage of EA. It can be seen that CO emission is decreased with increasing all kind of methyl esters fraction in the biodiesel blends. The arguments made for exhaust gas temperature are equally valid here. Lowering CO emission implies the positive effect of oxygen content in biodiesel. As O₂ concentration in the fuel blends rises, the combustion process is more complete.

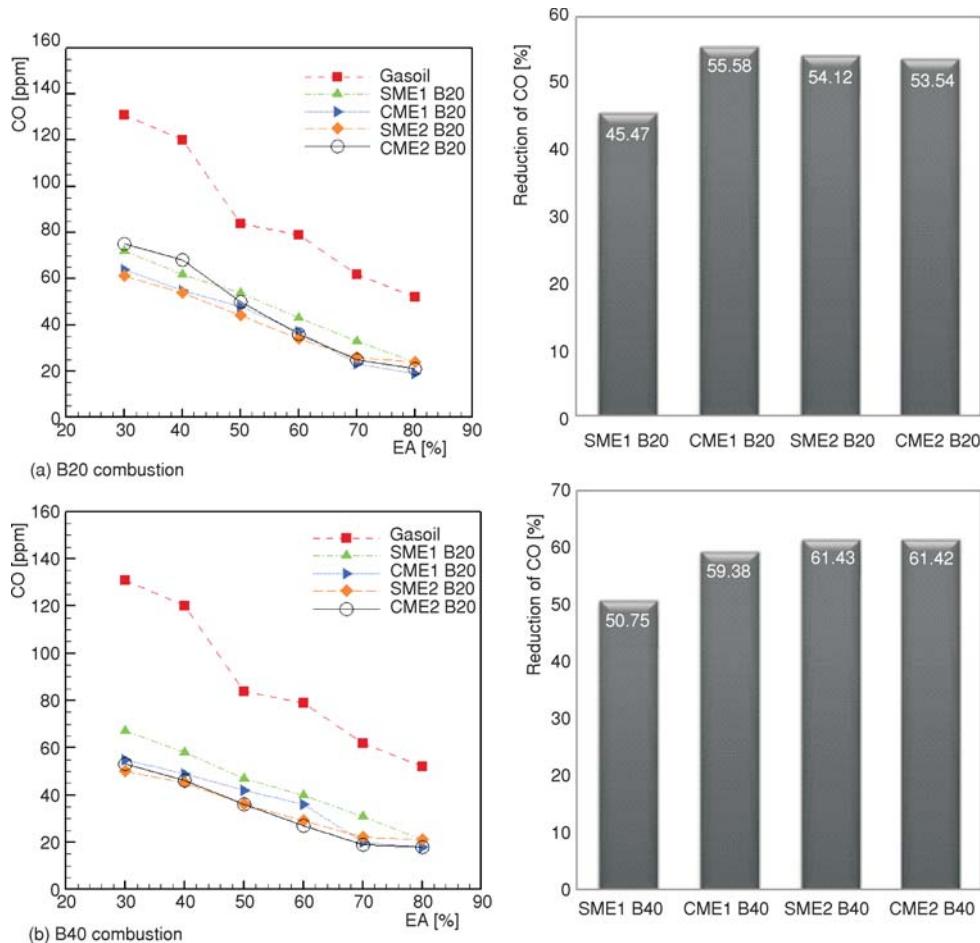


Figure 3. The effect of various vegetable oil on CO emission for B20 and B40

Figure 4 shows the effect of various vegetable oils on NO_x emission for B20 and B40 combustion. As it can be seen, maximum emission of NO_x is reached for the combustion of CME1, SME1, and CME2. Maximum level of NO_x emission is reached at lower range of EA for B20 and B40 mixtures. It can also be seen that the trend of NO_x emission like exhaust gas temperature is decreasing. Generally, NO_x production is dependent on two factors. The first factor is high temperature and the other, is the excess oxygen. The maximum level of NO_x and exhaust gas temperature is observed for 30% to 40% of EA values. The level of NO_x emission decreases with the increase of EA and it might be as a result of higher amount of oxygen which leads to reduction in exhaust gas temperature.

The SO_2 concentration trends of B20 and B40 combustion for different vegetable oil is illustrated in fig. 5. It shows that minimum SO_2 emission is achieved for the combustion of SME2 and CME1 for B20 and B40 fuel blends, respectively. The SO_2 emission decreases with the increase of EA value. At higher EA, SO_2 concentration reduces because of dilution with EA. Gasoil generally contains sulfur which forms sulfur oxides during the combustion. Whereas, pure biodiesel has null sulfur content and biodiesel fuel blends have proportionally lower sulfur

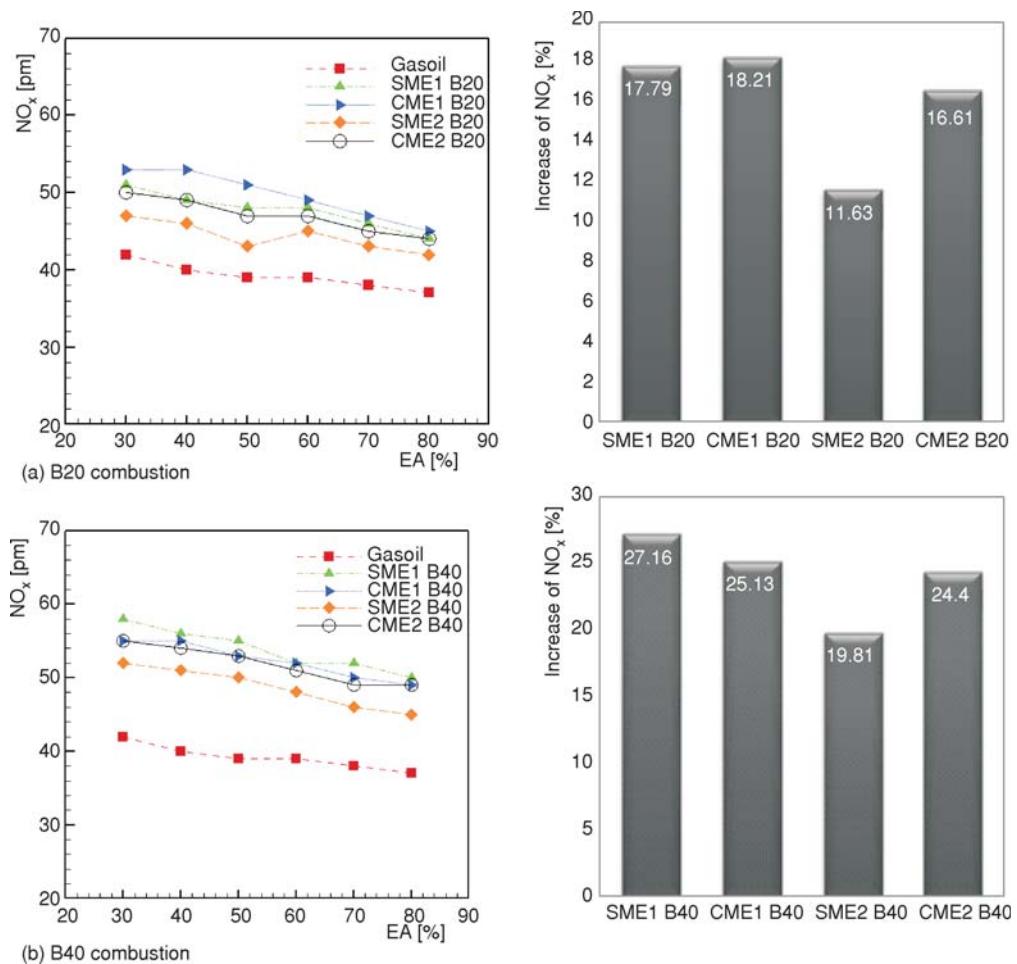


Figure 4. The effect of various vegetable oil on NO_x emission for B20 and B40

content compared to pure gasoil. It can be seen from fig. 5 that combustion of B20 blend, which contains more gasoil than B40 blend, emits more SO₂ pollutant.

Conclusions

In this study the effects of different kinds of vegetable oil methyl esters and EA on pollutant emissions of biodiesel combustion is investigated. The following conclusions can be drawn from experimental results:

- The furnace temperature increases around 1100 °C with increase of biodiesel content in fuel blend because of oxygen availability of biodiesel.
- The CO emission decrease up to 60% with increase of all kind of methyl esters fraction in fuel blend because of positive effect of oxygen content in biodiesel.
- The SO₂ emission decrease with increase of all kind of methyl ester fraction in fuel blend because of null sulfur content of pure biodiesel.
- The most reduction of SO₂ is achieved for combustion of SME2 B20 blend and CME1 B40 blend, around 62% and 37.5%, respectively.

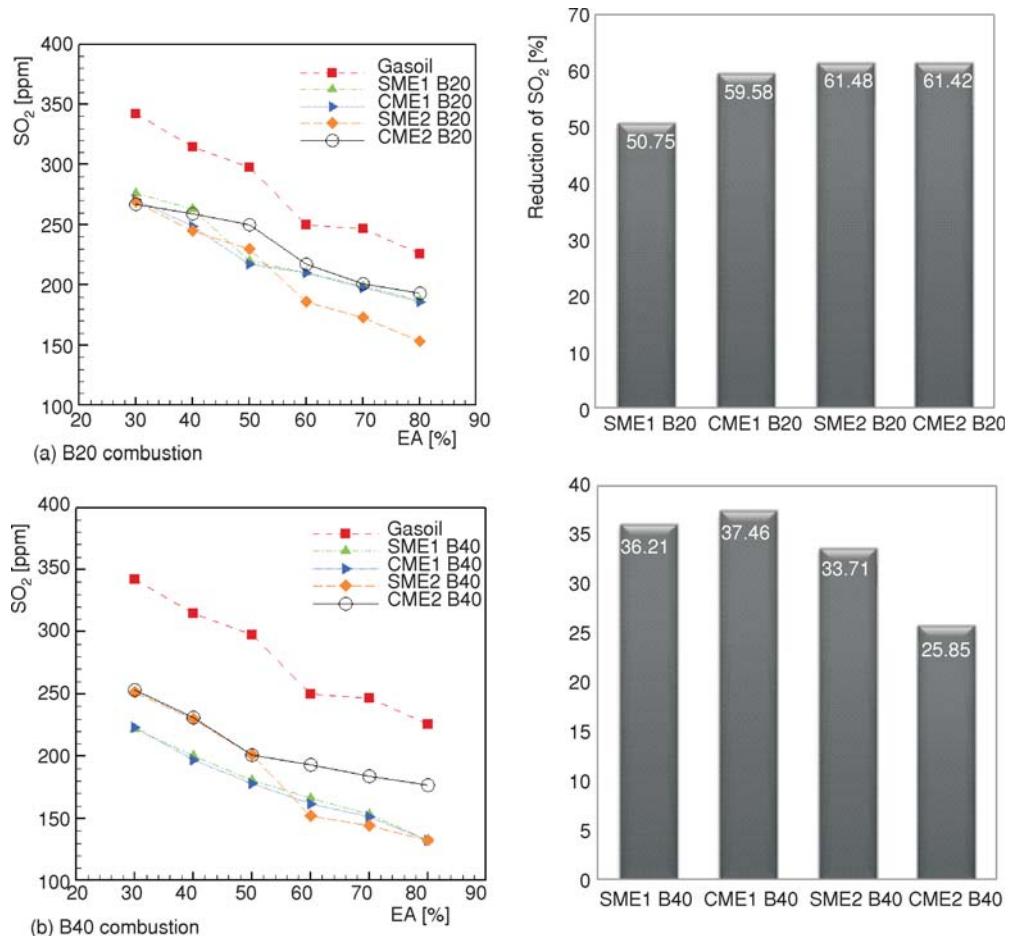


Figure 5. The effect of various vegetable oil on SO_2 emission for B20 and B40

- The maximum of temperature with value of about $1080\text{ }^{\circ}\text{C}$ and NO_x emission are achieved for the combustion of CME2.
- Maximum reduction of CO emission with about 55.58% and 61.43% is achieved for the combustion of CME1 B20 and SME2 B40 blend in contrast with pure gasoil combustion.
- Maximum increase of NO_x emission is reached for the combustion of CME1 B20 blend with 18.21% growth rate and SME1 B40 blend with 27.16% increase rate, in contrast with pure gasoil combustion.
- Maximum reduction of SO_2 emission is achieved for the combustion of SME2 B20 blend with about 61.5% and CME1 B40 blend with about 37.5%, in contrast with pure gasoil combustion.

Nomenclature

SME1 – sunflower methyl ester
 SME2 – soybean methyl ester
 CME1 – canola methyl ester

CME2 – corn methyl ester
 EA – excess air

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