ACADEMIC PLATFORM

Academic Platform Journal of Engineering and Science

journal homepage: http://apjes.com/

Investigations of Effects of Density and Viscosity of Diesel and Biodiesel Fuels on NOx and other Emission Formations

*[1]Gökhan TÜCCAR(0000-0003-3041-299X), [2]Erdi TOSUN(0000-0001-5733-2047), [3]Erinç ULUDAMAR(0000-0001-5247-5057)

[(1)]Adana Science and Technology University, Faculty of Engineering, Mechanical Engineering Department, Adana, gtuccar@adanabtu.edu.tr

[(2)]Çukurova University, Faculty of Engineering and Architecture, Mechanical Engineering Department, Adana, etosun@cu.edu.tr

[(3)]Adana Science and Technology University, Faculty of Engineering, Automotive Engineering Department, Adana, euludamar@adanabtu.edu.tr

Received Date: 26.12.2017 Accepted Date: 31.05.2018

Abstract

In the present study, effects of fuel properties; such as viscosity and density of different biodiesels on engine exhaust emissions were investigated. Sunflower, corn and canola oils were used as raw materials of biodiesel fuels which were produced via transesterification method. In experiments, pure biodiesels were used as test fuels and diesel was used as reference fuel. The results indicated that viscosity and density of biodiesel fuels went up with a higher proportion of biodiesel. Engine experiments, which were conducted on a Mitsubishi Canter 4D34-2A, four-stroke, four-cylinder diesel engine indicated that carbon monoxide (CO) emission reduced with the utilization of fuels that have higher viscosity and density. On the other hand, carbon dioxide (CO_2) and nitrogen oxide (NOx) emission had opposite trend. Both emission values were increased with higher biodiesel ratios.

Keywords: Biodiesel, density, emission, viscosity

1. INTRODUCTION

Energy demand which is rapidly growing with industrialization, forces developed and developing countries to import crude oil. Dependently, a considerable amount of domestic income is spent on importing of oil. For instance, crude oil consumption in our country climbed above 30 million tons per year in last years and this situation causes external dependency of Turkey to increase up to 70% with regard to energy issue [1].

With energy demand in the rapidly industrialized world, oil consumption is also growing inevitably and it causes oil prices to increase. Furthermore, emission gases released by combustion of petroleum-based fuels constitute greenhouse effect and they cause global warming. It is known that 73% of produced CO_2 is originated from fossil-based fuels nowadays [2]. In addition, it is predicted that petroleum reserves are limited sources and they will be depleted in near future [3-6]. The studies which focus on a search of a candidate to petroleum products revealed that vegetable oils can be used with close performance to diesel fuel in compression ignition engines.

Use of biodiesel in diesel engines is firstly suggested by Rudolf Diesel in 1900s but cheap petroleum prices cause a decrease of attention to biodiesel [7]. Nevertheless, the importance of biodiesel has been gradually increasing with energy crises occurred in the 1970s.

Nowadays, the most important environmental problem is global warming caused by greenhouse effect. Beside increments in use of coal and petroleum fossil fuels, a decrease of vegetation has an effect of a rapid increase in the amount of CO_2 in the atmosphere. Increasing of chlorofluorocarbons, hydrocarbons, methane, NOx and SOx which are produced by combustion are also accelerating greenhouse effect as well as CO_2. The greenhouse effect cause melting of glaciers and dependently rising of sea levels, warming globally and changes in climate. Reduction of emissions as unburned hydrocarbons (UHC), carbon monoxide (CO) and particulate matter (PM) can be provided with the use of biodiesel. Despite these reductions, there are studies which report an increase, decrease or no change in NOx emissions [8-9].
Zhang and Van Gerpen [10] have explored the use of soybean biodiesel and diesel mixtures on a modified, turbocharged, four-cylinder, direct-injection diesel engine, They discovered that the mixtures provide similar combustion properties compared to diesel fuel. Radwan et al. [11] investigated the effect of equivalence ratio, ignition temperature, ignition pressure, and ignition delay time of jojoba methyl ester. They reported that jojoba methyl ester has a lower ignition delay time, higher ignition temperature

*Corresponding Author: Adana Science and Technology University, Faculty of Engineering, Mechanical Engineering Department, Adana, gtuccar@adanabtu.edu.tr

Doi: 10.21541/apjes.371015

and higher ignition pressure [11]. Combustion properties of the waste cooking oil are investigated by Yu et al. [12] on a direct injection diesel engine. Tashtoush et al. [13] have reported the combustion performance of ethyl esters of waste vegetable oil.

One of the most important points of avoiding emission formations is understanding of emission formation reasons. Therefore, investigations of effects on emission formation by determination of fuel properties of biodiesel fuels which are used as an alternative to diesel fuel in internal combustion engines are very important. Therefore, the aim of the study is investigation of the effects of biofuel fuel properties obtained from various oils on emissions.

2. MATERIAL AND METHODS

2.1. Biodiesel Production

Production of test fuels used in the project was performed in Çukurova University Automotive Engineering Department Fuel Analysis Laboratory.

Biodiesel production method used in this study is transesterification. Transesterification is a method that reacting of animal fats or vegetable oils with alcohol and catalyst to form glycerol and ester. The ratio of alcohol to triglyceride must be 3:1 in order to transesterification reaction to being completed stoichiometric. Practically, this ratio must be higher to obtain the maximum amount of product. Various types of catalysts are used to enhance reaction speed and products. The reaction can be catalyzed by alkaline, acids or enzymes. The chemical interaction of reaction was shown in Figure 1. One ester transforms to another ester in the transesterification reaction.

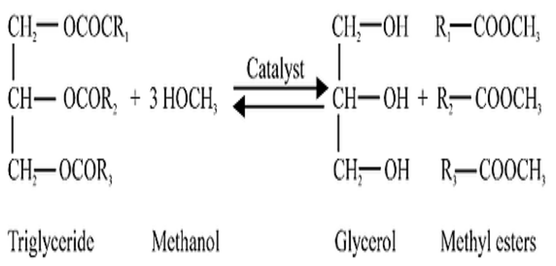

Figure 1. Transesterification reaction

Methanol which has 20% weight of oil and sodium hydroxide which has 1% weight of oil was mixed in a separate case by using a magnetic mixer and then, this mixture was mixed with oil which was heated up to 65 ^oC with 600 rpm for one hour and reaction occurred. The temperature was kept at 60 ^oC during the reaction. Then, the new blend was put in a separating funnel for one day and so, separation of biodiesel from glycerine phase was ensured. Lastly, obtained biodiesel was washed with warm water by three times, it was subjected to filtration process after drying at 105 ^oC for one hour (Figure 2).

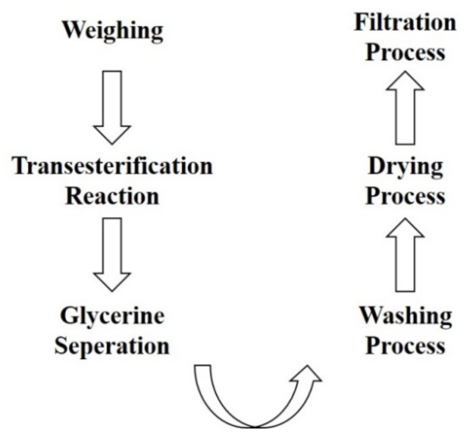

Figure 2. Biodiesel production steps

2.2. Measurements of Fuel Properties of Test Fuels

Fuel properties were determined in Çukurova University Fuel Analysis Laboratory. Tests were repeated 3 times and mean values of results were calculated. Fuel properties were analysed by, Zeltex ZX 440 NIR petroleum analyzer with an accuracy of ±0.5 for determining cetane number; Tanaka AKV-202 type automatic kinematics viscosity meter with an accuracy of ±0.01 mm^2/s for determining the viscosity; Kyoto Electronics DA-130 type density meter with an accuracy of ±0.001 g/cm^3 for density measurement, Tanaka APM-7 type flash point analyzer with an accuracy of ±0.5 ^oC for flash point measurement, IKA-Werke C2000 Calorimeter for heating value measurement.

2.3. Engine Tests

The engine used in performance tests is 4 stroke, 4 cylinders diesel engine. Technical specifications are given in Table 1 and schematic representation of the experimental setup is given in Figure 3. Experiments were conducted at full load conditions between the most common engine speed interval from 1200 to 2400 rpm, with an increment of 200 rpm. A hydraulic dynamometer which has a torque range of 0–1700 Nm and speed range of 0–7500 rpm was used to measure engine torque. Before starting the experiment, the engine was operated with the new fuel for sufficient time to clean out the remaining fuel from the previous experiment. Sealing of fuel unit of experimental set-up was checked before every experiment to be able to ensure accurate measurements. Then, the load cell was calibrated.

Table 1. Technical specifications of the test engine

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Displacement	3907 cc

	Diesel	**Sunflower Biodiesel**	**Corn Biodiesel**	**Canola Biodiesel**	**Biodiesel Standards (EN 14214)**
Density (kg/l)	0.833	0.886	0.887	0.833	0.86-0.9
Cetane Number	56.46	44.5	42.2	46	>51
Viscosity (mm^2/s)	2.37	4.5	4.2	4.7	3.5-5
Heating Value (kJ/kg)	45850	39179	37376	38363	-
Flash Point (^oC)	58.5	>140	>140	120.5	>120

Bore	104 mm
Stroke	115 mm
Power	89 kW @ 3200 rpm
Torque	295 Nm @ 180 rpm
Cooling type	Water cooled
Weight	325kg

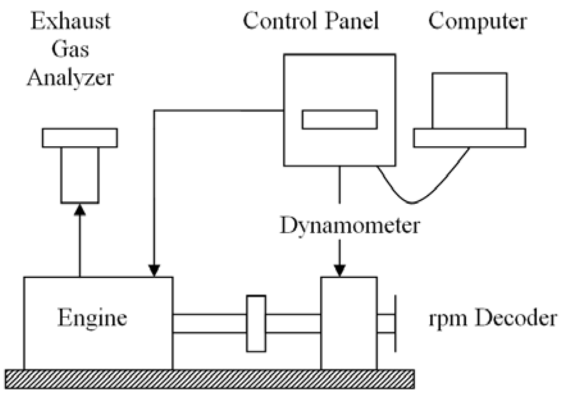

Figure 3. Schematic representation of the experimental setup

TESTO 350 XL gas analyzer was used to measure exhaust emissions. Emission data were collected with the help of a computer program which takes data at intervals of 2 s. The measurement accuracy of the gas analyzer is ±10 ppm for CO, 1% for CO_2 and ±1 ppm for NOx.

3. RESULTS AND DISCUSSIONS

3.1. Fuel Properties

The test results obtained to determine fuel properties of produced biodiesel fuels were given in Table 2. It is specified that all density and viscosity values of biodiesels are in the range of European Biodiesel Standards (EN 14214). Viscosity which is an important property for injection of fuel was measured at 40 ^oC and compared according to standards. Nevertheless, viscosity values can be very different for biodiesel produced from different oils and produced with different techniques. Higher density generally means higher viscosity. Flow resistance increases with higher viscosity. Cetane number is used for measuring combustion quality in diesel engines. Higher cetane number means the higher self-ignition tendency of fuel. Therefore, cetane number is an important property for diesel fuels. Low cetane numbers of test fuels were recorded. Mixing of test fuels with diesel fuel or usage of cetane improvers as an additive are suggested in order to eliminate this disadvantage.

Flash point is the minimum temperature that fuel releases vapor which is needed for ignitable mixture. This property is important for transportation and safety. High flash point means safe fuel. As seen in Table 2, the flash points of test fuels are in safe range.

Fuel analysis results

3.2. Emissions

There were some differences between emission values of different fuels used as seen in Figure 3, 4 and 5. While biodiesels which have higher density and viscosity values than diesel fuel cause to decrease in CO emission values, there is an increase in CO_2 and NO_X emission values. Table 3 shows the amount of increment or decrement percentage of emissions when different biodiesels were used instead of diesel fuel.

Table 3. Change in emissions (%) with respect to diesel fuel

	CO_2	**CO**	**NOx**
Sunflower	+17.95	-18.55	+33.43
Canola	+18.62	-24.76	+33.13
Corn	+15.69	-17.14	+27.69

Density is mass per unit volume. If a fuel has higher density than other, it means much more mass is entering into the combustion chamber for the same volume, since new generation diesel injectors which supply fuel into combustion chamber for power generation regulate the amount of fuel by volume, not by mass. Much more fuel entering into cylinder means an increase of emissions. The increment of CO_2 and NOx emission values with biodiesel use can be explained by this reason.

There is a reduction in CO emission with biodiesel usage. Since biodiesel has extra oxygen content, it gives less CO emissions (Figure 3). It is expected that reduction in CO emission due to extra oxygen cause to the conversion of CO to CO_2. The increment in CO_2 emission values can also be explained with the same reason (Figure 4). Biodiesel which has higher density will cause to have more oxygen and mass per unit volume. There are also many articles in the literature that report CO_2 increase and CO reduction with the use of biodiesel [14-17].

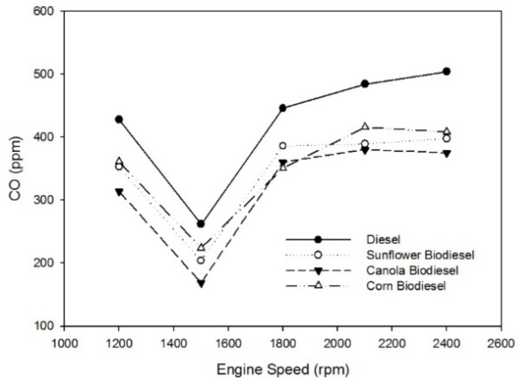

Figure 4. CO (ppm) emissions

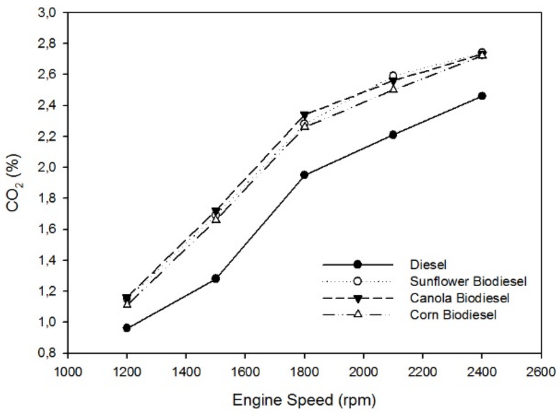

Figure 5. CO_2 (%) emissions

Viscosity is an important property of fuel which has effects on NO_X formation. NO_X formation occurs at temperatures above 1700 K since nitrogen and oxygen molecules are inert up to these temperatures [9]. NOx emission values tend to increase with increasing viscosity and density of the fuel. Since viscosity and density of biodiesel fuels are greater than diesel fuel, fuel leakage during injection is reduced with biodiesel utilization, as a result, increased combustion chamber pressure and advanced injection timing occurs [18]. The increase in NOx formation can be explained by these phenomena. Figure 5 shows NOx emissions of various biodiesels. The literature also recorded increase in NOx emissions with the use of biodiesel [19-23].

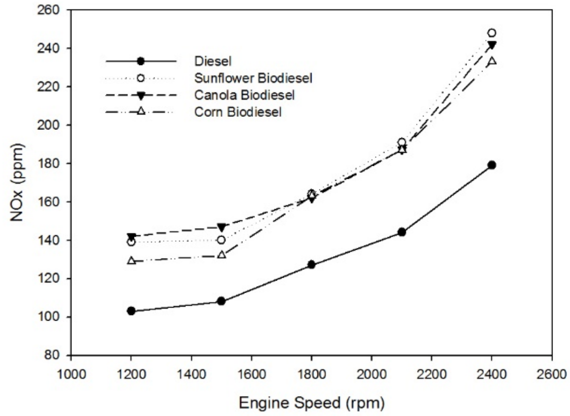

Figure 5. NO_X (ppm) emissions

4. CONCLUSIONS

In this study, the effects of fuel properties as viscosity and density to exhaust emissions were investigated. Biodiesels were produced from sunflower, corn and canola oil via transesterification method. Biodiesels have higher density and viscosity values with respect to diesel fuel. According to engine tests, reduction in CO and increase in CO_2 and NOx emissions were observed when biodiesel was used.

Biodiesel usage is important for our country which is dependent on other countries at the rate of 95% with regard to petroleum and petroleum-based fuels. Europa and developed countries encourage usage of biodiesel mixture at the rate of 20% with diesel fuel although pure biodiesel use both increase CO_2 and NO_X emissions and decrease engine performance. Therefore, both exterior dependency of our country will decrease and transfer existing reserves to the next generations by using efficiently energy sources which are totally renewable will be possible. On the other hand, it was observed that reduction in CO release in these studies along project.

5. ACKNOWLEDGMENTS

The authors are appreciated to Adana Science and Technology University for providing financial support. This work is supported financially by Adana Science and Technology University Scientific Research Office under contact no: MÜHDBF.MM.2015-13.

6. REFERENCES

[1] M. Akbalık, Ş. Kavcıoğlu, “Energy Sector Outlook in Turkey”, Dumlupınar Üniversitesi Sosyal Bilimler Dergisi, special issue, pp. 97-118, 2013.

[2] E. Buyukkaya, “Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics”, Fuel, vol. 89, pp. 3099-3105, 2010.

[3] G. Tüccar, T. Özgür, K. Aydın, “Effect of diesel–microalgae biodiesel–butanol blends on performance and emissions of diesel engine”, Fuel, vol. 132, pp. 47-52, 2014.

[4] G. Tüccar, E. Tosun, T. Özgür, K. Aydın, "Diesel engine emissions and performance from blends of citrus sinensis biodiesel and diesel fuel", Fuel, vol. 132, pp. 7-11, 2014.
[5] K. Srithar, K. A. Balasubramanian, V. Pavendan, B. A. Kumar, "Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines", Journal of King Saud University Engineering Sciences, vol. 29, pp. 50-56, 2017.
[6] P. K. Sahoo, L. M. Das, "Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine", Fuel, vol. 88, pp. 994-999, 2009.
[7] A. N. Özsezen M. Çanakçı, C. Sayın, "Effects of Biodiesel from Used Frying Palm Oil on the Exhaust Emissions of an Indirect Injection (IDI) Diesel Engine", Energy & Fuels, vol. 22, pp. 2796-2804, 2008.
[8] C. Öner, Ş. Altun, "Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine", Applied Energy, vol. 86, pp. 2114-2120, 2009.
[9] S. K. Hoekman, C. Robbins, "Review of the effects of biodiesel on NOx emissions", Fuel Processing Technology, vol. 96, pp. 237-249, 2012.
[10]Yu Zhang, Jon H Van Gerpen. "Combustion Analysis of Esters of Soybean Oil in a Diesel Engine." SAE paper 960765.
[11]Dr Mohamed Y Selim, Radwan MS, Dandoush SK, Kader AMA. "Ignition delay period of Jojoba diesel engine fuel." SAE paper No. 972975
[12]Yu CW, Bari S, Ameen A. "A comparison of combustion characteristics of waste cooling oil with diesel as fuel in a direct injection diesel engine." Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering, vol.216, pp.237–243, 2002.
[13]Tashtoush Ghassan, Al-Widyan Mohamad I, Al-Shyoukh Ali O. "Combustion performance and emissions of ethyl ester of a waste vegetable oil in a watercooled furnace. Applied Thermal Engineering" vol.23, pp.285–93, 2003.
[14] Y. Ulusoy, Y. Tekin, M. Çetinkaya, F. Kapaosmanoglu. The engine tests of ˘ biodiesel from used frying oil. Energ Source Part A, vol. 26, pp.927–932,2004.
[15] A.S. Ramadhas, C. Muraleedharan, S. Jayaraj, "Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil." Renew Energ vol.30, pp.1789–1800, 2005.
[16]G. Fontaras, G., M. Karavalakis, Kousoulidou, T. Tzamkiozis, L. Ntziachristos, E. Bakeas, et al. "Effects of biodiesel on passenger car fuel consumption, regulated and non-regulated pollutant emissions over legislated and real-world driving cycles", Fuel, pp.1608–1617, vol.88, 2009.
[18]M. Canakci. "Performance and emissions characteristics of biodiesel from soybean oil". P I Mech Eng D-J Aut,vol.219, pp.915–922,2005.
[18]B. Kegl, "Numerical analysis of injection characteristics using biodiesel fuel", Fuel, vol. 85, pp. 2377-2387, 2006.
[19] M. Nabi, N. Hoque, "Biodiesel production from linseed oil and performance study of a diesel engine with diesel bio-diesel.", JME, vol. 39(1), pp.40–44, 2008.
[20] M. Nabi, M. Rahman, M. Akhter, "Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions.", Appl. Therm. Eng., vol. 29, pp.2265–2270, 2009.
[21] S. Ghai, L. Das, G. Babu, "Emissions and performance study with sunflower methyl ester as diesel engine fuel", J Eng. Appl. Sci., vol. 3(5), pp.75–80, 2008.
[22] H. Serin, Ş. Yıldızhan, "Influence of the compression ratio on the performance and emission characteristics of a VCR diesel engine fuelled with alcohol blended fuels." Eur. Mech. Sci., vol. 1(2), pp. 39–46, 2017.
[23] Ş. Yıldızhan, E. Uludamar, A. Çalık, G. Dede, M. Özcanlı "Fuel properties, performance and emission characterization of waste cooking oil (WCO) in a variable compression ratio (VCR) diesel engine" Eur. Mech. Sci., vol. 1(2), pp. 56–62, 2017.