e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage: http://ijaet.academicpaper.org

Original Research Article

An Experimental Study on Performance and Emissions of a Single Cylinder Direct Injection Diesel Engine with *crambe abyssinica* and *crambe orientalis* biodiesels

hosted by Turkish JournalPark ACADEMIC

Ayhan Uyaroğlu

Selçuk University Cihanbeyli Vocational High School, Konya, Turkey

ARTICLE INFO

* Corresponding author
ayhan.uyaroglu@selcuk.edu.tr

Received: October 30, 2018
Accepted: December 16, 2018

Published by Editorial Board Members of IJAET

ABSTRACT

As an alternative fuel of diesel engines, the interest in biodiesel fuels is rising due to some useful features. This interest leads to an increase in the diversity of studies. In recent years, studies about the crops that can grow in non-arable lands and produce nonedible oils were increased. In this work, performance and emissions of biodiesel production from *crambe abyssinica* and *crambe orientalis* oils were studied. The purpose of this paper was to examine the performance and emissions of *crambe* biodiesels and diesel fuel in 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 (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa). *Crambe abyssinica* biodiesel and *crambe orientalis* biodiesel were expressed as CAME B100 and COME B100 respectively. The brake specific fuel consumption (BSFC), carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbon (THC), nitrogen oxide (NOx) and smoke emissions results obtained from the experimental study were compared with No. 2 diesel fuel. Achieved results suggest us that *crambe* biodiesels can preferred for diesel engines. Since environmental effects and energy requirement become more important, the interest of the crops that can grow unsuitable lands has increased.

Keywords: Inedible oils, Biodiesel, *Crambe abyysinica, Crambe orientalis,* Exhaust emissions

1. Introduction

According to modern history of petroleum, refining of paraffin from crude oil began the middle of the 19th century. Petroleum was initially used for illumination with limited demand, but towards the end of the 19th century, discovery of automobiles increased the demand of petroleum. Ever since, petroleum demand increases growing. As a matter of fact, request of petroleum cannot cover due to economic, geopolitical, geostrategic and regional challenges. To cope with these issues alternative and renewable energy sources can be a solution. Alternative and renewable energy sources can also reduce foreign dependency. When considered from this point of view biofuels are local fuel sources. Gasoline and diesel fuel are conventional fuels for internal combustion engines. In other respects, liquefied petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG), biodiesel, bio-alcohol are the other fuels for internal combustion engines. Vegetable oils are mostly preferred for biodiesel production than animal fats. The biodiesel obtained from inedible vegetable oil became important. Because the biodiesel produced from edible vegetable oil causes the rise of vegetable oil price. Biodiesel refers to the fuel obtained as a result of chemical reaction with oil, alcohol, catalyst and heat. At the end of the transesterification, glycerin is come out of as a by-product. Some of biodiesel characteristics are renewable, safe, non-toxic and biodegradable in water (98% biodegrades in just a few weeks), it contains less sulfur compounds and has a high flash point (>130°C) [1]. While the biodiesel generally decreases exhaust emissions like CO, HC, and soot owing to its oxygen content, that it has a negative effect on NOx (total nitrogen oxides) emission and engine performance [2].

As a chemical definition, methyl ester is called when methanol used for biodiesel production. Ethyl ester is expressed in case of using ethanol for biodiesel production. If the physical and chemical properties and performance of methyl ester and ethyl ester compare, these can be said; ethyl and methyl esters have almost nearly the same calorific value, the viscosity of ethyl esters is slightly higher than methyl ester, but cloud and pour points of ethyl ethers are slightly lower than methyl esters, methyl esters generated slightly higher power and torque in engine tests. Ethyl esters preferences to methyl esters due to lower smoke opacity, lower exhaust temperatures and lower pour point. On the other hand, ethyl esters tended to have more injector coking than the methyl esters [3].

Crambe abyssinica is inedible oil because of its erucic acid content, and its oil content is around 35%. As a member of brassicaceae family, *crambe abyssinica* having high tolerance to drought conditions and has a short cycle (between 90-100 days), it is durable to pests and diseases. It has good compatibility to warm and cold land [4]. *Crambe* species grow naturally in Turkey that is not cultivated: *C.orientalis* L., distributed in central Anatolia, eastern Anatolia and southeastern Anatolia, *C.tataria* Sebeok in central Anatolia and *C.maritima* L. in north-northeastern Anatolia [5]. These three species are perennial crops. *C.hispanica* is an annual crop found in the Mersin Anamur region in Turkey [6]. *Crambe orientalis* dehulled seed oil content is 26% [5]. *Crambe orientalis* is perennial crops that not cultivated.

The goal of this experimental study is to investigate of a single cylinder diesel injection engine performance and emissions fueled with biodiesel obtained from *crambe abyssinica* oil and *crambe orientalis* oil with 2200 1/min fixed engine speed and at four different engine loads.

2. Material and methods

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 were provided from Merck. While transesterification of raw *crambe orientalis* oil in pre-test had become gelling. The efficiency of the methyl ester in refined oil is 93-98% and the yield of crude oil is 67-86% [7]. So that two-step transesterification was chosen for raw *crambe orientalis* oil. In acid esterification of *crambe orientalis*, 100 g of oil, 20 g of methanol and 1 g of H_2SO_4 were heated to about 50°C, and stirred at 600 rpm for 1 h. The reaction mixture was then poured into a separation funnel and allowed to settle for 2-3 hours. The top phase included excess alcohol, sulfuric acid and impurities. The bottom phase was poured into a glass beaker and washed with distilled hot sodium bicarbonate solution at 85°C and the pH was adjusted to pH 7. Sodium bicarbonate solution was used to reduce the acidity of oil and reduces the need for an alkali catalyst. Then, the mixture was transferred to a separation funnel and settled for 1 day. The bicarbonate solution in the bottom phase was removed by means of the separating funnel. After the product was obtained from the first step, it was heated above 110°C for 20 minutes to remove any water. The transesterification parameters of *crambe orientalis* oil was applied 17 g of methanol for 100 g of oil, 0.42 g of NaOH as the catalyst and a reaction time of 60 min at 57°C and transesterification yield 96.5%. *Crambe abyssinica* oil was purchased from

Elementis Specialities Company by the name of Fancor Abyssinian Oil. The transesterification parameters of *crambe abyssinica* oil was applied as 6:1 Methanol to oil molar ratio with NaOH catalyst 0.40 g (w/w), 57°C reaction temperature, and 60 minutes reaction time and transesterification yield 96.2%. 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 fuels have shown in Table 1.

Table 1. Fuel properties [8]

Properties	CAME	COME	Diesel
Density (15°C) kg/m^3	880.22	882.7	841.75
Kinematic viscosity (40°C) mm^2/s	6.498	6.431	3.354
Flash point °C	190 *	181,5	-
Cold Filter Plugging Point (CFPP) °C	-	5	-
Cetane number	-	58.4	53,1
Pour point °C	-	-12	-
Calorific value MJ/kg	41.98 *	40.64	-
Water content mg/kg	453.58	356,36	-

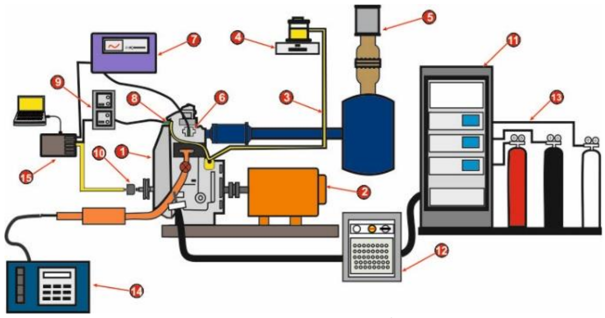
The four-stroke, naturally aspirated, single-cylinder direct injection diesel engine specifications were shown in Table 2. The experiments were conducted at four different engine loads (BMEP, 0.12 MPa, 0.24 MPa, 0.36 MPa and 0.48 MPa) and 2200 rpm engine speed. The experiments were carried out at this rpm as the maximum motor torque was at 2200 rpm. 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 fuels as COME and CAME were tested in the experiments and the results were compared with conventional No. 2 diesel fuel operation. Test rig was shown in Figure 1.

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/CO2 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 2. Test engine specifications

Specifications	Descriptions
Make/model	Antor/6LD400
Engine type	DI-diesel engine, natural aspirated, air cooled
Cylinder number	1
Bore x stroke, mm	86x68
Displacement, cm^3	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



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 (N2, O2, H2/He) and span gases (C3H8, CO2, CO, O2) 14- Smoke meter 15- Data acquisition card

Figure 1. Schematic diagram of the experiment set-up

3. Results and Discussion

3.1. Brake specific fuel consumption (BSFC)

Fuel efficiency of internal combustion engine is very important due to environmental and economic reasons. To get more power with less fuel is the main purpose in engine design. Thus and so, the less emission emits to the atmosphere. Biodiesel fuels have higher BSFC values. This increment stems from lower heating value and higher density of biodiesel than diesel fuel [9]. From the Figure 2, it can be seen that COME B100 shows higher BFSC than

CAME B100 because of the higher density as mentioned before. The maximum difference with COME B100 of 16.5% occurred at 0.36 MPa engine load.

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%	Accuracy 0.1%
	0-99.99 m^{-1}	0.01 m^{-1}

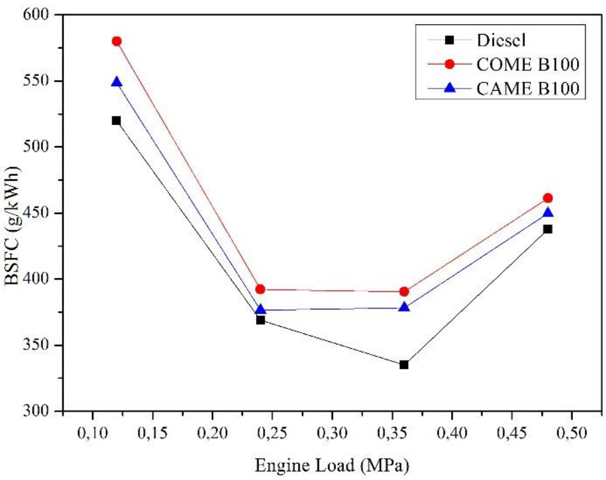


Figure 2. Brake specific fuel consumption variations of tested fuels

3.2. Exhaust gas emissions

Since the diesel engines always operate with excess air, CO emissions from diesel engine are low. But what CO emission formation occurs due to insufficient oxygen amount in the combustion chamber [2]. The reason of the diminishment in CO emissions of biodiesel, it is thought to higher cetane number and oxygen content of biodiesel [10]. From the Figure 3, it is observed that CO emissions gradually increase by virtue of the rising engine load. This increasement originates from the increasing fuel amount that entering the combustion chamber. CAME B100 was given better results than COME B100.

HC itself is a fuel that exposes as an emission in combustion of rich or lean mixture. HC emissions derive from the uncompleted combustion of fuel vapour in the cylinder engine as well [11]. Figure 4, illustrates the THC emissions of tested fuels. When we look at the Figure 4, it can be seen that biodiesel fuels have lower THC emissions.

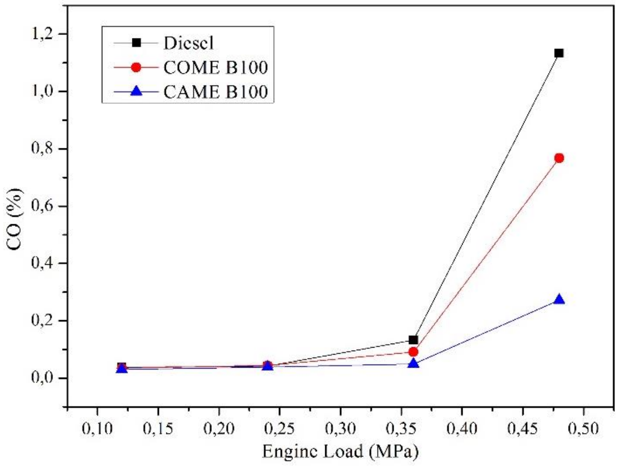


Figure 3. CO variations of tested fuels

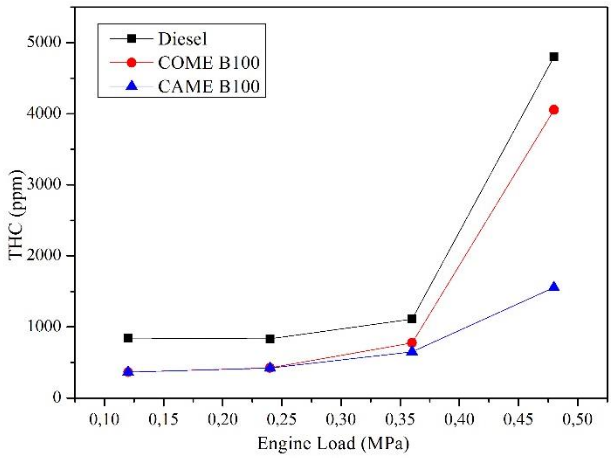


Figure 4. THC variations of tested fuels

This reduction may be referred to oxygen content in biodiesel which provides the react with the hydrocarbons present in fuel. The higher oxygen in combustion region, the combustion is more completely [11, 12]. The maximum decrease of THC of about 68% was taken place with the CAME B100 at 0.48 MPa engine load.

While the carbon dioxide emission is held responsible for global warming, it indicates the fully combustion. In other words, carbon dioxide represents combustion efficiency. Due to global warming concern there have been so many researches. To minimize the global warming effects alternative fuels are used. Figure 5, depicts the CO_2 emission changing of tested fuels. Biodiesel, by the reason of lower carbon to hydrogen ratio, has lower CO_2 emissions in comparison to diesel fuel [13]. The maximum decrease of CO_2 of about 37% was come off with the CAME B100 at 0.48 MPa engine load.

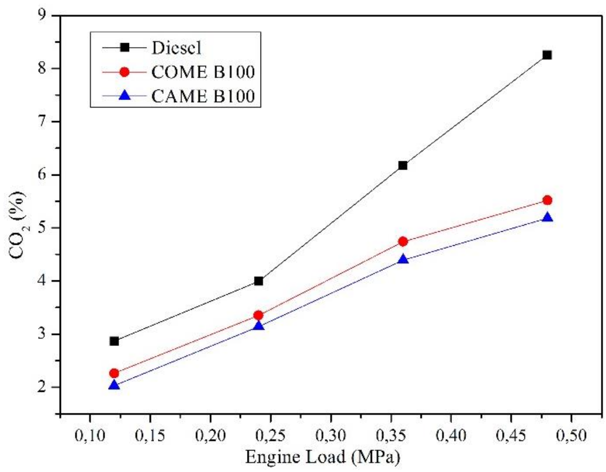


Figure 5. CO_2 variations of tested fuels

NOx emissions are air pollutant, as well as cause the acid rain. From this perspective, delimitation of NOx emission has become important. Therefore, NOx emission has decreased in the exhaust emission legislation. NOx formation can be three ways like; 1- Thermal NOx: Combustion at temperatures above the 1300°C forms, 2- Prompt NOx: During the combustion, in potential fuel-rich zones, can be formed with fuel and the molecular nitrogen in the air, 3- Fuel NOx: The reaction of the fuel that contain nitrogen with oxygen occurs NOx. [14]. In addition, NOx emission formation is impacted by the engine load, engine speed, density, homogeneity and air-fuel mixture [15]. Moreover, oxygen concentration, in-cylinder temperature and residence time for the reaction to take place also affects the NOx emission [16]. As the biodiesel is an oxygenated fuel, molecular oxygen content improves the combustion so that causes to higher NOx emission. EGR can be help to the decrease NOx emission [3]. From the Figure 6, biodiesels have higher NOx emissions compared to the diesel fuel. The maximum increase is developed by the CAN B100 of about 19% at the 0.48 MPa engine load.

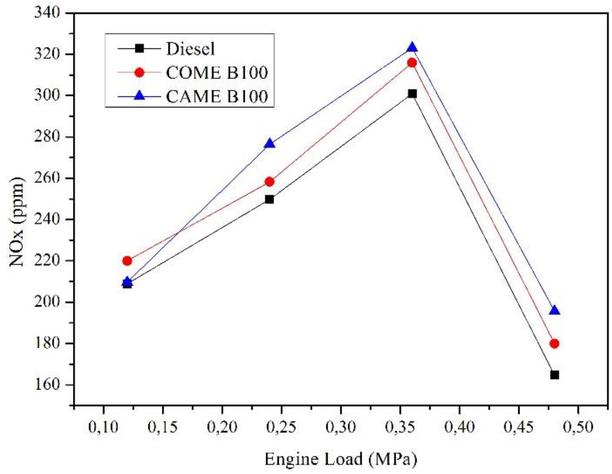


Figure 6. NOx variations of tested fuels

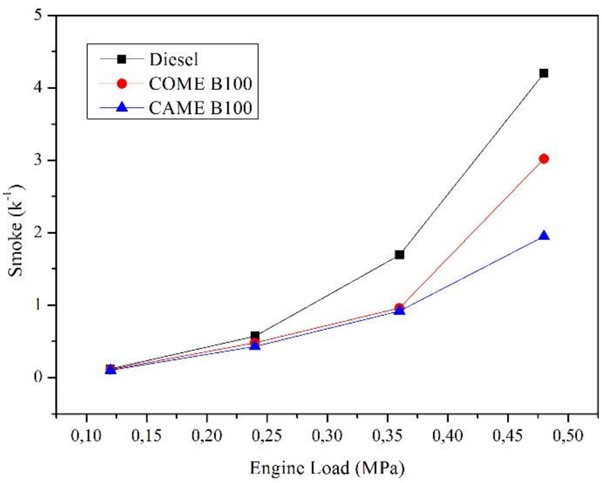


Figure 7. Smoke variations of tested fuels

Smoke emission is only inherence to the diesel engine until EURO V emission standards. But then, in EURO V and EURO VI emission standards, it also includes gasoline engines which have direct injection engines. Smoke formation is caused by the partial reaction of carbon content in the liquid fuel and incomplete combustion of hydrocarbon fuel [17]. Soot is not only produced in the diffusion combustion but also overly rich premixed combustion [18]. Biodiesel fuels have lower smoke emissions due to oxygen content [17, 19] and lower carbon content [17]. Oxygen bound in biodiesel allow for the more complete combustion even in the regions of the fuel-rich diffusion flames so that leads to the decreasing of the smoke emission [17, 19]. According to the Figure 7, the maximum decrease of smoke emission of about 53% was come off with the CAME B100 at 0.48 MPa engine load.

4. Conclusion

In this study, performance and emission characteristics of *crambe absyssinica* and crambe orientalis biodiesels were compared to diesel fuel 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 end of the study the following results can be deduced.

1- BSFC of biodiesel was slightly higher than diesel fuel due to lower heating value and higher density.

2- Lower CO emissions of biodiesel fuels were found because of the high cetane number and oxygen content.

3- HC emissions of biodiesel fuels were low by the reason of the presence of oxygen.

4- CO_2 emissions of biodiesel fuels were decreased than the diesel fuel by virtue of the lower carbon to hydrogen ratio. Biodiesel fuels can help to reduce carbon footprint.

5- In terms of the NOx emissions, biodiesel fuels have slightly higher owing to the oxygenated fuels.

6- Lower smoke emissions of biodiesel fuels were obtained thanks to the oxygen bound.

7- Biodiesel production from *crambe* oils can be important due to have the feature of its nonedible oils.

5. References

1. Vyas, A. P., Verma, J. L., & Subrahmanyam, N. (2010). A review on FAME production processes. Fuel, 89(1), 1-9.

2. Örs, İ., Kahraman, A., & Ciniviz, M. (2017). Performance, emission, and combustion analysis of a compression ignition engine using biofuel blends. Thermal Science, 21(1B), 511-522.

3. Çelikten, I., Koca, A., & Arslan, M. A. (2010). Comparison of performance and emissions of diesel fuel, rapeseed and soybean oil methyl esters injected at different pressures. Renewable Energy, 35(4), 814-820.

4. Rosa, H. A., Wazilewski, W. T., Secco, D., Chaves, L. I., Veloso, G., de Souza, S. N. M., & Santos, R. F. (2014). Biodiesel produced from crambe oil in Brazil—A study of performance and emissions in a diesel cycle engine generator. Renewable and Sustainable Energy Reviews, 38, 651-655.

5. Çömlekçioğlu, N., Karaman, S., & Ilçim, A. (2008). Oil composition and some morphological characters of Crambe orientalis var. orientalis and Crambe tataria var. tataria from Turkey. Natural product research, 22(6), 525-532.

6. Yildiztugay, E., Küçüködük, M., Özel, M., & ÖZDEMİR, C. (2009). A new record for the flora of Turkey: Crambe hispanica L.(Brasssicaceae). Turkish Journal of Botany, 33(3), 227-230.

7. Freedman, B. E. H. P., Pryde, E. H., & Mounts, T. L. (1984). Variables affecting the yields of fatty esters from transesterified vegetable oils. Journal of the American Oil Chemists Society, 61(10), 1638-1643.

8. Demirbas, A. (2008). Relationships derived from physical properties of vegetable oil and biodiesel fuels. Fuel, 87(8-9), 1743-1748.

9. Uyaroğlu, A., & Çelikten, İ. (2017). Impacts of biodiesel blends with organic-based manganese additive on performance and emission characteristics of a single cylinder diesel engine. International Journal of Automotive Engineering and Technologies, 6(4), 157-163.

10. Hazar, H., Uyar, M., Aydın, H., & Şap, E. (2016). The effects of apricots seed oil biodiesel with some additives on performance and emissions of a diesel engine. International Journal of Automotive Engineering and Technologies, 5(3), 102-114.

11. Das, M., Sarkar, M., Datta, A., & Santra, A. K. (2018). An experimental study on the combustion, performance and emission characteristics of a diesel engine fuelled with diesel-castor oil biodiesel blends. Renewable Energy, 119, 174-184.

12. Kahraman, A., Ciniviz, M., Örs, İ., & Oğuz, H. (2016). The Effect on Performance and Exhaust Emissions of Adding Cotton Oil Methyl Ester to Diesel Fuel. International Journal of Automotive Engineering and Technologies, 5(4), 148-154.

13. Tesfa, B., Gu, F., Mishra, R., & Ball, A. (2014). Emission characteristics of a CI engine running with a range of biodiesel feedstocks. Energies, 7(1), 334-350.

14. Clean Air Technology Center. (1999). Nitrogen Oxides (NOx): Why and How they are controlled.

15. Abedin, M. J., Kalam, M. A., Masjuki, H. H., Sabri, M. F. M., Rahman, S. A., Sanjid, A., & Fattah, I. R. (2016). Production of biodiesel from a non-edible source and study of its combustion, and emission characteristics: A comparative study with B5. Renewable Energy, 88, 20-29.

16. Balamurugan, T., Arun, A., & Sathishkumar, G. B. (2018). Biodiesel derived from corn oil–A fuel substitute for diesel. Renewable and Sustainable Energy Reviews, 94, 772-778.

17. How, H. G., Masjuki, H. H., Kalam, M. A., & Teoh, Y. H. (2014). An investigation of the engine performance, emissions and combustion characteristics of coconut biodiesel in a high-pressure common-rail diesel engine. Energy, 69, 749-759.

18. Zbarcea, O., Scarpete, D., & Vrabie, V. (2016). Environmental pollutions by diesel engine. Part II: a literature review regarding HC, CO, CO2 and soot emissions. Termonetica, suppliment, 65-69.

19. Lahane, S., & Subramanian, K. A. (2015). Effect of different percentages of biodiesel–diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine. Fuel, 139, 537-545.