

# Evaluation of Performance and Emission Characteristics of Biodiesel Fuel Produced from Rapeseed Oil

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**Abstract:** The objective of the present study is to examine and compare the performance and emission characteristic of two biodiesel fuels produced from rapeseed oil via transesterification method. Tested biodiesel fuels (ROME (Rapeseed Oil Methyl Ester) and ROEE (Rapeseed Oil Ethyl Ester)) were selected based on their properties obtained from an optimization of transesterification conditions. A Yanmar diesel engine has led to evaluating their performance parameters such as fuel consumption rate, exhaust gas temperature and emission characteristic corresponding to nitrogen oxides ( $\text{NO}_x$ ), carbone monoxide (CO) and carbon dioxide ( $\text{CO}_2$ ). A comparative analysis was carried out using normal diesel fuel tested in same experimental conditions. Fuel consumption rate was measured by observing the volumetric rate from the fuel tank of the engine supported by stopwatch. The exhaust gas temperature and emission characteristic were measured simultaneously by using a testo 350 flue gas analyzer. According to the results, biodiesel fuels showed a higher fuel consumption rate and exhaust gas temperature under an increase of engine speed. They also exhibited lower  $\text{NO}_x$  emission with a slight rise in CO and  $\text{CO}_2$  emission compared to mineral diesel fuel. ROME exhibited low emission gas compared to ROEE and mineral diesel. It can be evaluated as a promising alternative fuel for diesel engine.

**Key words:** Biodiesel, transesterification reaction, rapeseed oil, diesel engine, emission characteristics.

## Nomenclature

ROME	Rapeseed Oil Methyl Ester (biodiesel obtained from rapeseed oil by using methanol)
ROEE	Rapeseed Oil Ethyl Ester (biodiesel obtained from rapeseed oil by using ethanol)
HHV	Higher Heating Value
ISO	International Organization for Standardization
ATSM	American Society for Testing and Materials
FGT	Flue Gas Temperature
$\text{NO}_x$	Nitrogen Oxides
NO	Nitric Oxide
$\text{NO}_2$	Nitrogen Dioxide
CO	Carbone Monoxide
$\text{CO}_2$	Carbone Dioxide

## 1. Introduction

Diesel engine constitutes the most cost effective internal combustion engine used in engineering machinery for power generation [1]. A vast majority of

these engines are engaged in transportation (road, railway, naval, etc.) and electricity generation. This gives rise to their important role in the global economy moving [2]. Fossil fuels are commonly used to run diesel engine due to its high thermal efficiency. The energy generated from the combustion of these fuels leads to an excellent engine performances. However, they simultaneously generate harmful emission gas such as  $\text{CO}_2$  (carbon dioxide), CO (carbon oxide),  $\text{NO}_x$  (nitrogen oxides), and PM (particular matters) which threat the sustainability of our ecosystem by environmental pollution and global warming [3-5]. Besides, the high energy demand combined with the limited petroleum reserves leads to the fast depletion of fossil fuels with expectation about 40 years [6].

These are key factors that motivated research and development for alternative diesel fuel with maximum efficiency and minimum environmental pollutions criteria. In this context, biodiesel can be considered as

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the most feasible options thanks to its renewability and compliance with fuel standard [7, 8]. It can be obtained from biological sources such as vegetable oil, animal fat, algae and recycling cooking oil. These raw materials contain triglycerides molecules which are converted into fatty acid alkyl ester (biodiesel) by using a specific reaction called transesterification. This is a chemical process involving triglycerides with alcohol in the presence of a catalyst to yield biodiesel and glycerol as by-product [9-13]. The properties of the biodiesel depend strongly on this reaction and are strictly checked before its use in diesel engine. Nevertheless, the incomplete combustion of biodiesel in diesel engine releases harmful gas through the atmosphere. Among them, CO, CO<sub>2</sub>, and NO<sub>x</sub> are widely emitted. These emission gases are generally analyzed and compared to those from normal diesel in order to evaluate the viability of the synthesized biodiesel. In this line of investigation, many researches considered that CO emissions are reduced when diesel engine is fueled by pure biodiesel [14-16]. Experiments was carried out by Kalligeros et al. [17] and Usta et al. [18] to estimate the emission characteristic of biodiesel fuels produced from sunflower oil and tobacco seed oil respectively. Their results reveal that a low CO emission was noticed from produced fuels [17, 18]. Many alcohol types are used in biodiesel production (methanol, ethanol, etc.). Their nature can influence the CO emission. Particularly, biodiesel based methyl esters emitted less CO compared to those based on ethyl esters [19]. On the other hand, biodiesel fuels are considered to emit low CO<sub>2</sub> compared to mineral diesel with 50%-80% reduction in CO<sub>2</sub> emissions [20]. In fact, biodiesels are lower-carbon fuels and have lower elemental carbon-to-hydrogen ratio than diesel [21, 22]. However, in some case, CO<sub>2</sub> emissions from them are found more important compared to normal diesel fuels. This can be explained by the high combustion efficiency of diesel fuels [23, 24]. As for NO<sub>x</sub> emission, some investigations found out an increase of this gas when using biodiesel to fuel diesel engine.

Nevertheless, Utlu and Kocak [25] and Hansen et al. [26] have noticed a decreasing trend of this gas from their researches. Some reasons are given to explain the complexity of NO<sub>x</sub> emission. Many researchers believe that the oxygen content in biodiesel is responsible for this tendency of high NO<sub>x</sub> emission. However, Lapuerta et al. [27] found that the oxygen content in biodiesel has no influence on NO<sub>x</sub> emission. Recent studies still show an effective reduction of these harmful gases when using biodiesel as an alternative to diesel fuels [28-30].

Therefore, consideration must be taken regarding fuels quality of biodiesel for better estimation of these emission gases. This quality characteristic is expressed by the fuels' properties of biodiesel which can be controlled by the transesterification process. Thus, the objective of this present study is to investigate the engine performance and emission characteristics of two biodiesel samples (ROME (Rapeseed Oil Methyl Ester) and ROEE (Rapeseed Oil Ethyl Ester)) obtained from rapeseed oil by transesterification reaction. Data obtained are analyzed to evaluate their quality as alternative for regular diesel and to confirm the efficiency of transesterification strategy used.

## 2. Materials and Method

### 2.1 Fuel Properties

Biodiesels used in this study were obtained from rapeseed oil by transesterification process. The reaction involved methanol and ethanol to produce ROME and ROEE, respectively. The transesterification conditions were optimized based on the variation of the molar ratio of alcohol to rapeseed oil and alcohol type while other reaction parameters were kept constant. Each fuel produced was tested for compliance with ASTM (American Society for Testing and Materials) standards for density, viscosity and high heating value then compared to those of mineral diesels. From this optimization process, the optimal transesterification reaction conditions which give the best fuel properties were found to be an alcohol/oil molar ratio of 18:1, 1%

of potassium hydroxide as catalyst, 30 min of reaction time, 60 °C of reaction temperature and stirring speed of 650 rpm. ROME and ROEE produced with these conditions present good fuel properties where ROME gives the best results. Both of them were used in the engine test. Mineral diesel was also tested in same condition to provide comparative data. Properties of these tested fuels are listed in Table 1, which are taken from the previous study [31].

## 2.2 Engine Test

Engine test was performed by using a Yanmar diesel engine TF70V-E model as shown in Fig. 1. Its specifications are given in Table 2.

Test was performed outdoors at ambient temperature of 32 °C and 29% of humidity. During each test, the engine was fully warmed up for 30 min prior to the

beginning of data collection. The engine power was adjusted by the engine speed varied for 1,000, 1,500 and 2,000 rpm. A digital tachometer HT-5500 was used to measure the engine speed. Between each test, the fuel tank was completely drained and rinsed several times with the fuel for the next test. Each experiment was repeated three times to calculate the mean values. All data are obtained after the engine has reached a steady operation. Fuel consumption rate was measured by observing the volumetric rate from the fuel tank supported by stopwatch. The exhaust gas temperature and emission characteristic from the biodiesel were analyzed simultaneously by using a testo 350 Flue gas analyzer made by TESTO, Inc (from Germany). The gas analyzer was connected to the end of engine's chimney as shown in the experimental set up (Fig. 2) and its specifications are given in Table 3.

**Table 1 Properties of the test fuels.**

Samples	Density (15 °C; g/mL)	Kinematic viscosity (40 °C; mm <sup>2</sup> /s; 15 s <sup>-1</sup> )	High heating value (MJ/kg)
ROME	0.865	3.49	40.81
ROEE	0.853	4.50	39.94
Diesel	0.806	2.50	45.44

**Table 2 Diesel engine specification.**

Engine model	TF70V-E
Engine type	4-stroke diesel engine
Maximum output	5.5 kW/2,600 min <sup>-1</sup>
Continuous rate output	4.8 kW/2,600 min <sup>-1</sup>
Total stroke volume	0.382 L

**Table 3 Gas analyzer specifications.**

Measurement item	Measurement range	Resolution
CO <sub>2</sub>	0-25 vol.%	0.01 vol.%
CO, H <sub>2</sub> -compensated	0-10,000 ppm	1 ppm
NO	0-4,000 ppm	1 ppm
NO <sub>2</sub>	0-500 ppm	0.1 ppm
SO <sub>2</sub>	0-5,000 ppm	1 ppm
H <sub>2</sub> S	0-300 ppm	0.1 ppm
CO <sub>2</sub> -(IR)	0-50 vol.%	0.01 vol.% (0~25 vol.%) 0.1 vol.% (> 25 vol.%)
	Natural gas: 100-40,000 ppm	
HC	Propane: 100-21,000 ppm Butane: 100-18,000 ppm	10 ppm 10 ppm 10 ppm
K-type (NCr-N)	-200~1,370 °C	0.1 °C
S-type (Pt10Rh-Pt)	0~1,760 °C	1 °C

### 3. Results and Discussion

#### 3.1 Effect of Biodiesel on Fuel Consumption Rate

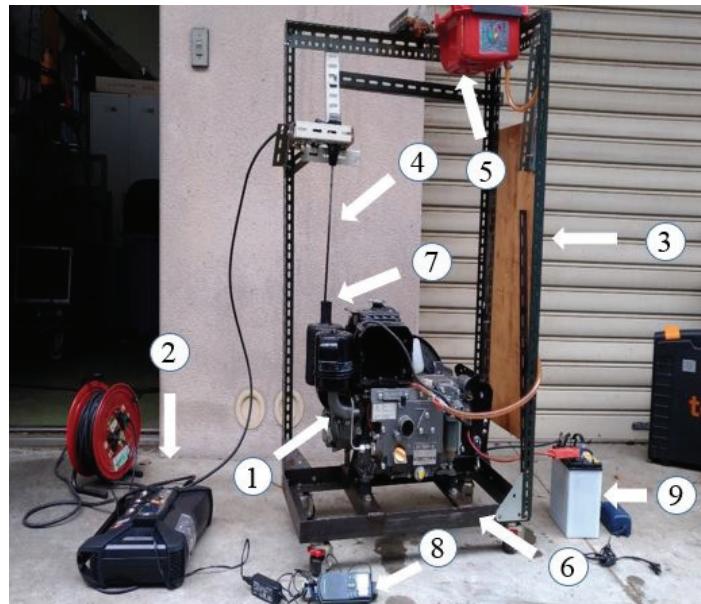
Fuel consumption rate is a parameter used to estimate the long-term viability of fuel during engine operation. Fig. 3 shows the evolution of fuel consumption rate of fuels with the variation of engine speed. It can be seen that for any tested fuel, the fuel consumption rate increases with the increase of engine speed. In fact, when the engine speed is increased the friction horsepower increased according to the drop in the mechanical efficiency to maintain a fixed torque output thus leading to more fuel consumption [32]. By using biodiesel fuels, the engine fuel consumption rate is higher compared to when using mineral diesel. This difference can be explained by the low energy content of biodiesel compared to normal diesel (Table 1) [33, 34].

As the result, a larger amount of biodiesel fuel must be supplied to the engine to attain the same engine power output as that of conventional diesel. At low and medium engine speed (1,000 and 1,500 rpm), the fuel consumption rate of ROEE is slightly higher than that of ROME because of the slight differences in their fuels properties. However, at high engine speed this

difference disappeared as shown in Fig. 3.

#### 3.2 Effect of Biodiesel on FGT (Flue Gas Temperature)

The FGT or exhaust gas temperature gives an indication about the combustion temperature. Its variation can influence the amount of exhausted pollutants from the burning fuel [35]. From Fig. 4, there is an increase in FGT with increase of engine speed for all fuels. In fact, diesel engine usually consumes more fuels to maintain a constant torque output when its speed is increased. Consequently, this releases more heat and hence increases the FGT [36]. Most of works of the literature stated that higher FGT is obtained when using biodiesel compared to other diesel fuel [37]. However, lower values are recorded for ROME during the experiment (Fig. 4). This can be attributed to the fact that, compared to mineral diesel, ROME exhibits higher latent heat of vaporization and lower heating value. Thus, more heat is needed for ROME vaporization, while the energy released by this biodiesel is lower than from the same mass of mineral diesel. As the result, the low FGT values for ROME can be considered as acceptable [38].



**Fig. 1 Photographic view of the experimental setup (1: Yanmar Diesel Engine TF70V-E; 2: Testo 350 Flue gas analyser; 3: fuel consumption measurement system; 4: flue gas probe; 5: fuel tank; 6: engine support; 7: engine chimney; 8: digital Tachometer; 9: battery).**

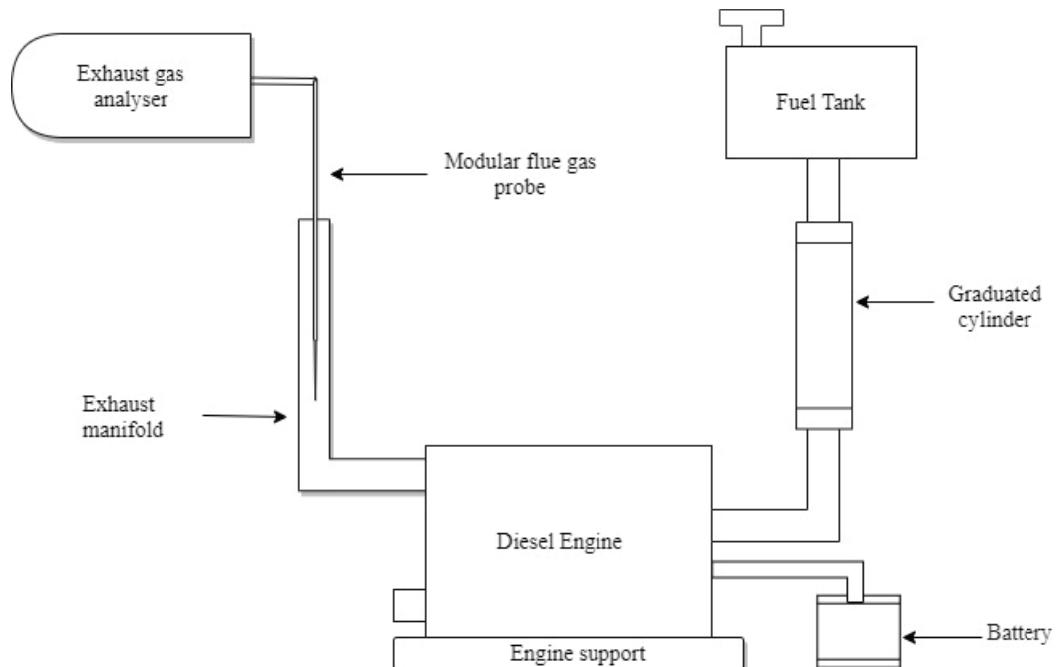


Fig. 2 Schematic diagram of experimental for engine test.

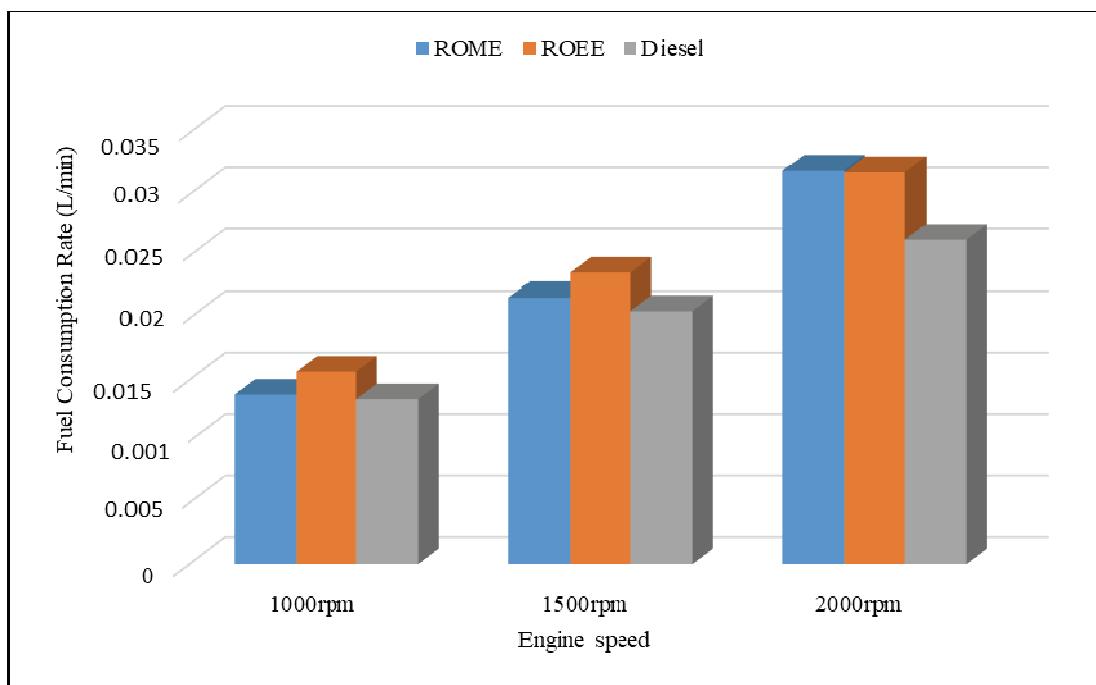
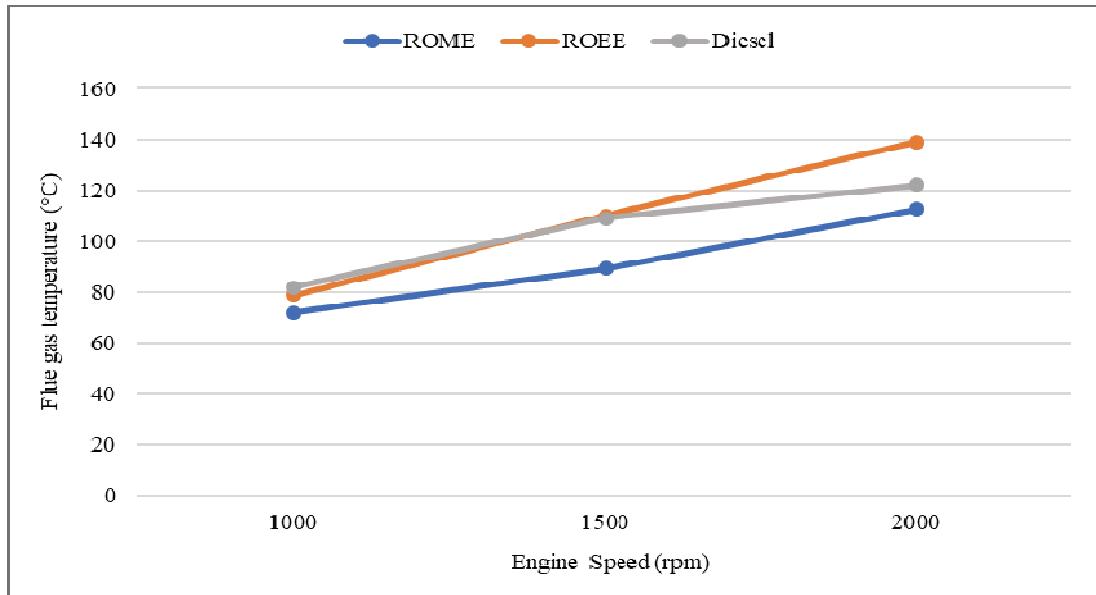


Fig. 3 Fuel consumption rate.



**Fig. 4 FGT from diesel engine using biodiesel and diesel fuel under varied speed.**

### 3.3 Effect of Biodiesel on $\text{NO}_x$ Emission

Nitrogen oxides ( $\text{NO}_x$ ) are the most significant environmental pollutants emitted from a diesel engine. In the presence of sunlight, it reacts with atmospheric oxygen to form a ground-level ozone which is the major smog component. Furthermore, in the presence of water,  $\text{NO}_x$  gas reacts with oxygen to form acid raining which directly affects human health (lung cancer) and threatens certain ecosystems [39, 40].

$\text{NO}_x$  emission profile of different tested fuels is shown in Fig. 5. It was found that the amount of  $\text{NO}_x$  released from fuels decreases when engine speed is increased. This is generally due to the shorter residence time available for  $\text{NO}_x$  formation, which may be the result of an increase both in the volumetric efficiency and flow velocity of the reactant mixture specifically at higher engine speed [41-43]. At low and medium engine speed, diesel fuel and ROEE produced maximum  $\text{NO}_x$  compared to ROME. This can be attributable to their higher FGT compared to ROME fuel. However, at high engine speed (2,000 rpm),  $\text{NO}_x$  emission from ROEE fuel becomes slightly higher than other tested fuels. This coincided to its highest FGT. So, the variation of  $\text{NO}_x$  is proportional to the FGT and is influenced by the nature of the fuel.

Generally,  $\text{NO}_x$  emission includes NO and nitrogen  $\text{NO}_2$ . However, NO is the predominant oxide of nitrogen generated from the engine combustion. It contributes to ozone formation and it is considered as non-toxic gas by itself but it can threaten infants and sensitive individual [40, 44]. Fig. 6 shows the  $\text{NO}/\text{NO}_x$  ratio of the fuels under varied engine speed. The ratio follows a decreasing trend when engine speed is increased. This illustrates lower NO emission for all fuels but more reduced when using biodiesel at low engine speed.

### 3.4 Effect of Biodiesel on CO and $\text{CO}_2$ Emission

Carbone monoxide (CO) is a poisonous gas generated by incomplete combustion process during diesel engine operation. This exhaust gas has severe effect on human health especially when it is breathed into the lungs [45]. In the presence of sufficient oxygen, it can be oxidized to  $\text{CO}_2$ , which has a negative effect on the global warming [46, 47]. Emission characteristics of CO and  $\text{CO}_2$  from biodiesel and diesel fuel are depicted in Figs. 7 and 8, respectively. It can be seen that, CO emission from ROEE is continuously higher than other fuels and remains practically constant for any engine speed. This confirms that biodiesel based methyl esters emitted less CO compared to those based on ethyl esters [48].

Meanwhile, the trends of CO emission from ROME and diesel are constantly unstable with the variation of engine speed. In fact, when substituting diesel fuel with biodiesel many factors may influence significantly the variation of CO emission. Generally a decrease trend in CO emission is more evident even though some studies have found that CO emission from biodiesel is higher than of pure diesel fuel [49, 50]. Even so, at low engine speed, CO emission from biodiesel fuels is higher compared to diesel fuel. This could be partly due to the poor atomization conditions influenced by the higher viscosity of biodiesel and the low FGT which leads to

the high CO emission [51]. At medium engine speed, CO emission from ROME decreases and becomes the lowest compared to other fuels. In this case, it could be said that the molecular oxygen present in biodiesel, combined with the engine conditions at medium speed can be an ideal condition in the burning fuel at stoichiometric air-fuel mixture. This leads to a complete combustion of ROME and hence lowers its CO emission [23]. However, similar trend is not recorded from ROEE. The reason can probably come from the differences noticed in fuel properties of these two biodiesels.

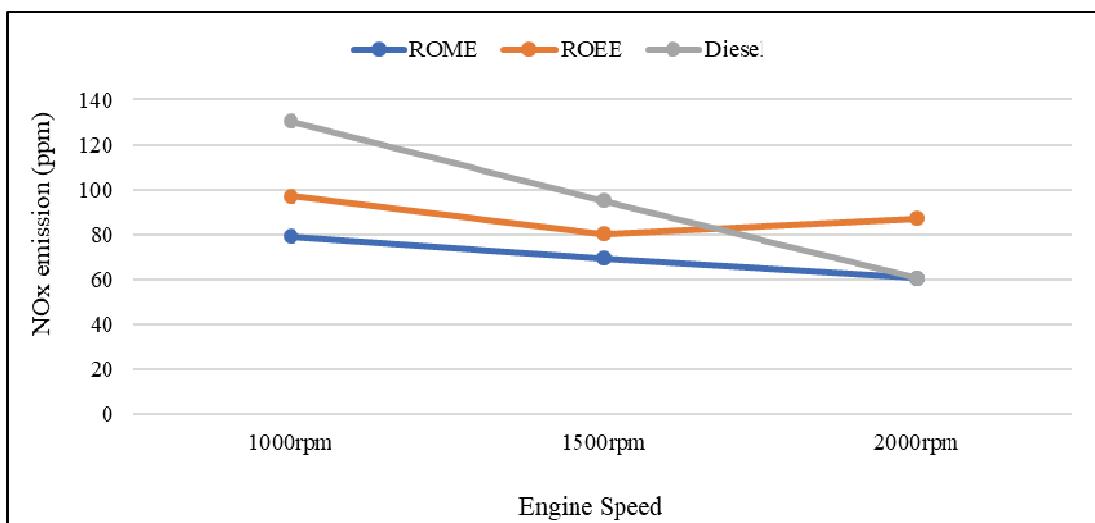


Fig. 5  $\text{NO}_x$  emission from diesel engine using biodiesel and diesel fuel under varied speed.

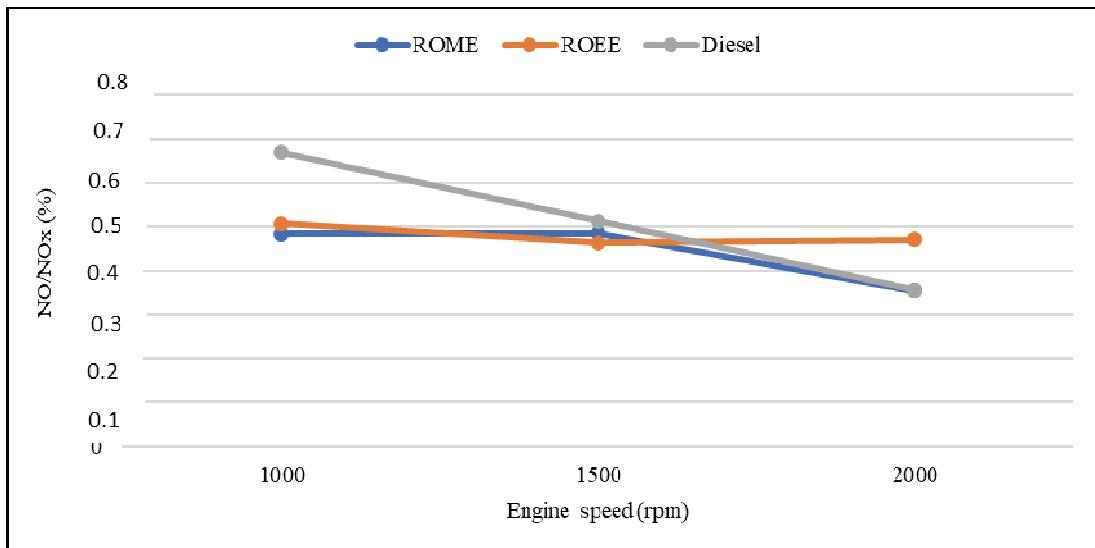


Fig. 6 NO/NO<sub>x</sub> ratio of biodiesel and diesel fuels under varied speed.

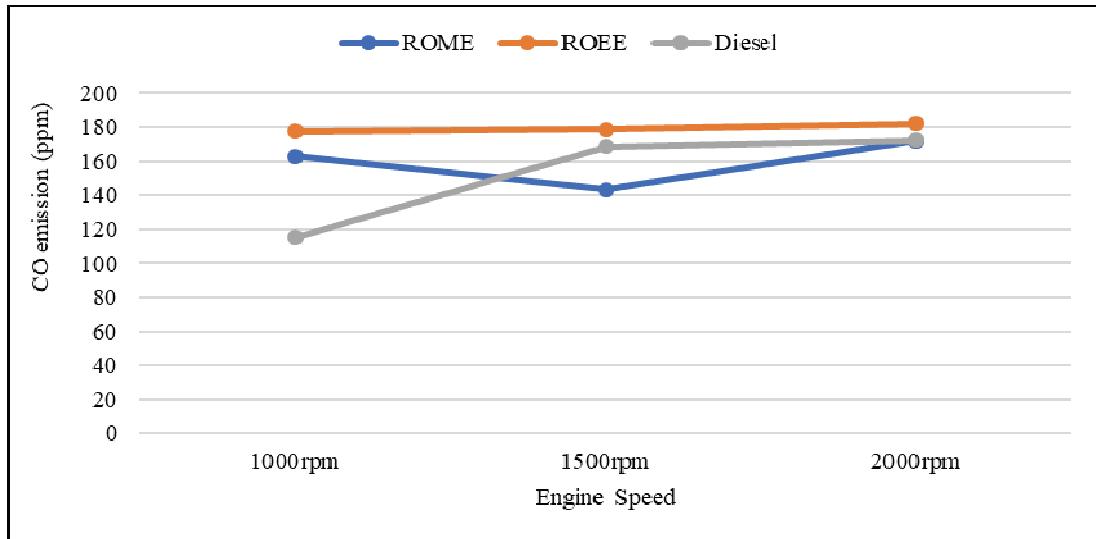


Fig. 7 CO emission from diesel engine using biodiesel and diesel fuel under varied speed.

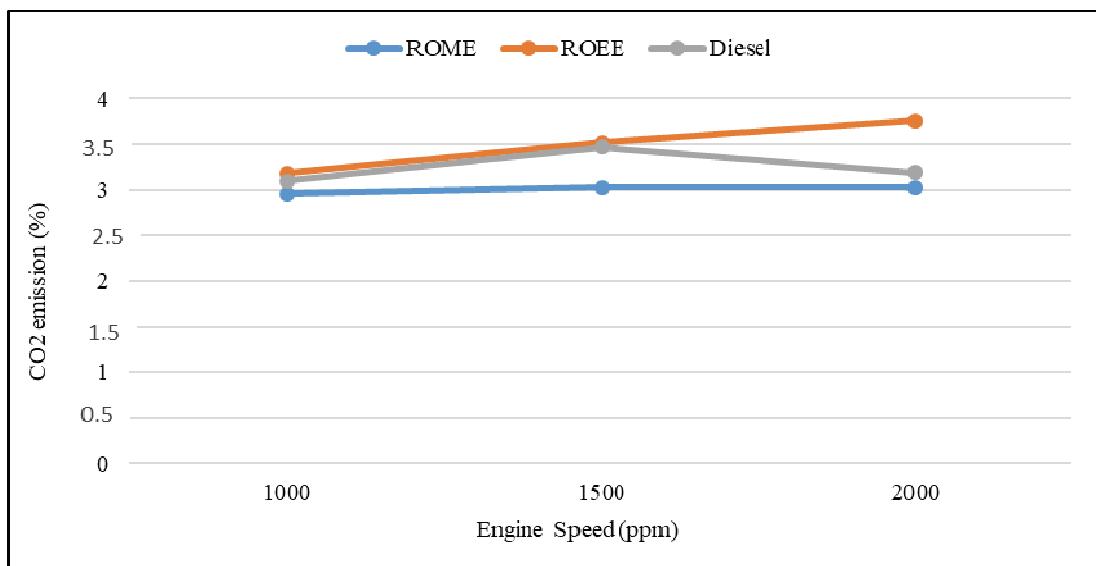


Fig. 8 CO<sub>2</sub> emission from diesel engine using biodiesel and diesel fuel under varied speed.

#### 4. Conclusion

This study was focused on the investigation of engine performance and emission characteristics of two types of biodiesel produced from rapeseed oil. Results have shown that for all fuels tested, there is an increase in fuel consumption rate and exhaust gas temperature when the engine speed is increased. The variation profile of these parameters was more significant for normal diesel compared to biodiesel fuels. Exhaust emission gases such as NO<sub>x</sub> and NO were reduced with the increase in engine speed in

contrary CO and CO<sub>2</sub> which were slightly increased. In comparison with diesel fuel, the biodiesel (ROME and ROEE) appeared to have higher fuel consumption rate because of their lower heating value and their oxygen content. ROME exhibited low emission gas compared to ROEE and mineral diesel as well. The results of this study proved that performance and exhaust emissions of a diesel engine using ROME and ROEE are reasonable. Thus, the optimization strategy used in the transesterification process is efficient to produce a quality biodiesel suitable for diesel engine.

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