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The Effects of Using Diesel-Citronella Fuel Blend on The Emission and Fuel Consumption for Single-Cylinder Diesel Engine

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ABSTRACT

The emissions generated from vehicle engines are one of the problems of global warming worldwide. Conventional oil depletion globally has encouraged various researchers to look for alternative fuel solutions as a substitute for petroleum. Various studies on additive fuels have also studied and most of the fuels have shown perfect results. In this experiment, citronella oil blended into pure diesel fuel to investigate emissions and fuel consumption in a single-cylinder diesel engine. Citronella oil used for diesel fuel blends as much as 0.5%. This test carried out on a single-cylinder engine with three loads (25%, 50% and 75%) and different engine speeds. The results of experiments with diesel-citronella fuel show CO_2 emissions lower than pure diesel. Reduction of CO_2 emissions from the diesel-citronella mixture for engine loads 25% (0.4%), 50% (0.8%) and 75% (1.9%), respectively. While diesel-citronella fuel blend consumption is higher than pure diesel for each engine load and all speeds tested. Overall diesel-citronella mixed fuel for all tests showed better results compared to pure diesel.

Keywords:
Emission; diesel engine; fuel consumption; single-cylinder; citronella

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1. Introduction

Automotive vehicles that have produced exhaust emissions are one of the causes of global warming. The most vital contribution is the reduction of CO_2 emissions from global warming by using various bioenergy-based fuels that can mix into conventional fuels [1,2]. The use of alcohol as a fuel or additive for diesel engines has widely applied. France and Germany first used alcohols such as ethanol as engine fuel in 1894. Alternative fuels from ethanol had a high amount of octane. Ethanol can be produced from renewable sources such as starch, sugar cane and corn [3,4]. Ethanol fuel experiments for the first diesel engines were carried out in the 1970s and 1980s in South Africa and the US [5]. High latent heat in ethanol is an advantage that can reduce the filling temperature so that high solids can be produced with increased volumetric efficiency [6]. However, low cetane numbers and poor ignition quality and lower adiabatic fire temperatures are disadvantages of ethanol.

Technology in diesel engines today has demanded to improve the quality of the fuel used. Strategies to improve the quality of fuel can be done by reformulating diesel fuel and adding fuel additives [7–10]. Alcohol-based additives are currently widely used for combustion of diesel engines [11–13] However, this has the potential to cause the release of compounds which are very dangerous to the resulting emissions [14–16]. Investigations regarding organic fuel additives to improve the quality of fuels for diesel engines have been discussed [17–20]. The production of natural fuel additives provides many benefits, especially in improving the quality of combustion of diesel engines. This natural product for additive fuel production is quite widely available in nature and the price is relatively low and easy to obtain [21–23].

Furthermore, citronella oil which used as an additive for diesel fuel used as combustion of diesel engines has been reported [21,24,25]. The use of citronella oil as a diesel fuel additive to improve thermal efficiency and reduce NOx emissions, exhaust gas temperatures, and fuel consumption has also been studied [24,26–29]. The oil citronella-ethanol mixture fuel is perfect for applying to diesel engines. Ethanol with a mixture of citronella oil can produce high combustion pressure, heat release rate, brake specific fuel consumption, and brake thermal efficiency rather than using diesel fuel. However, CO_2 and NOx emissions are higher, but smoke production and hydrocarbon emissions decrease [30–32].

Chemical components contained in the citronella oil has similarities with citronella oil, where citronella oil is dominated by central compounds, while citronella oil contains several compounds, namely citronella and geraniol [33–36]. The structure of lemongrass oil is more oxygenated functional which expected to be very effective in reducing the strength of van der Waals interactions between the hydrocarbon chains of diesel fuel. Besides, efficient improvements have more potential to be reduced to combustion with diesel fuel. The citronella oil has not found in publications for vehicle fuel. Availability of the citronella oil is still very minimal and the price is too high compared to other additive oils such as alcohol [37–39].

The experiments using various fuel additives for diesel engines have been carried out. Citronella oil has excellent quality to be used as diesel fuel additives. Chemical compounds found in citronella oil are almost similar to alcohol. However, citronella oil has a higher price than alcohol. The main objective of this study is to analyse emissions and consumption of fuels operated on diesel engines. The experiments carried out at three different loads and five engine speeds. Also, the temperature of the crackpot from the combustion of diesel-citronella was analysed.

2. Material and Methodology

The citronella oil was isolated from Cymbopogon nardus leaves from Gunung Halu region of Indonesia by steam distillation without any chemical treatment. Diesel fuel used in this study was pure diesel type Euro2 from Malaysia. The citronella oil blended diesel fuel of 0.5% was prepared by mixing 30 mL of the citronella oil with diesel fuel for total 3000 mL at 700 rpm for 15 min using digital overhead stirrer IKA RW20. Hereafter, the D and DC fuels noted as diesel and citronella-diesel blend, respectively.

Chemical composition of the D and DC fuels were observed by gas chromatography-mass spectrometry (GCMS-Shimadzu P5050). Physical properties such as density, viscosity, etc. were determined using instruments listed in Table 1 following ASTM standard.

Table 1
Specification for fuel and ASTM standard

Properties	Equipment's	ASTM
Density (kg/m^3)	Analytical balancer, GH-252	D1298
Viscosity (mm	Viscometer, GD-265D	D445
Aniline point	Automatic aniline point, K10290	D611
API gravity	Hydrometer	D1297
Cetane number	Cetane number analyser, TP-131	D2699

In this work, a certified diesel engine model YANMAR TF120M engine was set-up in the Automotive Laboratory of Faculty of Mechanical Engineering of University Malaysia Pahang (UMP). The research diesel engine consists of a single-cylinder, four strokes, water-cooled, and natural aspirated direct injection (DI) diesel engine. The engine is a type where the fuel injected at 17^{o}CA before top dead center (BTDC) in the test engine. The specification details of the engine listed in Table 2.

Table 2
Detail of engine specifications

Description	Specification
Engine model	YANMAR TF120M
Engine type	Horizontal single-cylinder 4-stroke diesel engine
Fuel injection type	Direct injection
Bore × Stroke (mm)	92 × 96
Displacement (L)	0.638
Injection timing	17° BTDC
Fuel injection pump	Bosch
Injection pressure (kg/cm^2)	200
Compression ratio	17:7
Continuous output (HP)	7.82 kW at 2400 rpm
Rated output (HP)	8.94 kW at 2400 rpm
Cooling system	Water-cooled (radiator type)
Cooling water capacity (L)	2.3

The engine fuel system consists of one tank which has one valve for diesel (D) and diesel citronella (DC) to flow into a diesel engine during the engine test. A hydraulic dynamometer was connected to the engine to adjust and measure the engine speed and control the loads. The combustion parameters investigated in this study included fuel consumption, intake airflow, the exhaust temperature and gas parameters (CO_2 and NO emissions). The schematic of the test engine with the necessary accessory shown in Figure 1. The parameters measured and analysed in this experiment were combustion characteristics and exhaust emission which had been carried out at different engine loads (25%, 50%, and 75%) and different speeds (1200 rpm, 1500 rpm, 1800 rpm, 2100 rpm, and 2400 rpm). Before the start of the experiment, the engine was operated with tested fuels until the temperature engine oil reaches 70°C at a constant speed to warm up the engine to reach engine stability. Data were recorded by the installed data-acquisition system (DAQ) after achieving the steady-state condition. For each of the tested fuels, all data was filed after the engine stabilised at the given operating condition.

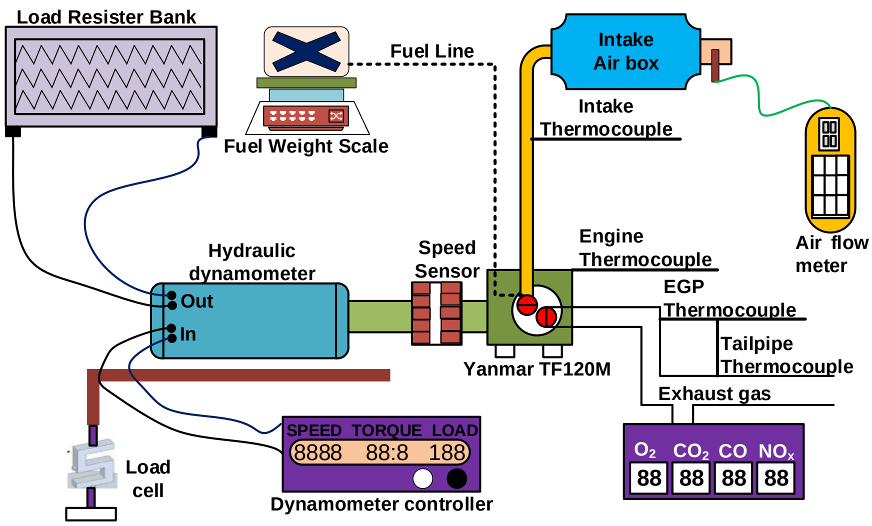

Fig. 1. Schematic diagram of single cylinder diesel engine

A KANE gas analyser was used to conduct the analyses of the NOx, CO, CO_2, and O_2 as shown in Figure 2. Lists the specifications of the A KANE shown in Table 3 Before the experiment is carried out, the company first calibrates the gas analysis to ensure accuracy in the measurement of the exhaust gas. Each after completing the zero test is calibrated with fresh air to adjust and further ensure the accuracy and consistency of data measurements. Measurements are made after the engine is run for approximately five minutes using gasoline fuel every after completing the test. Furthermore, for the next test, the fuel is replaced with the prepared fuel.

Table 3
Specifications of automotive emission analyser

Exhaust gas	Measurements range	Measurement Resolution
NOx	0–5000ppm	+/- 5% or 25 ppm
CO	0–21%	+/-5% or 0.06% volume^{-1}
CO_2	0–16%	+/-5% or 0.5% volume^{-1}
O_2	0–35%	+/- 5% or 20 ppm

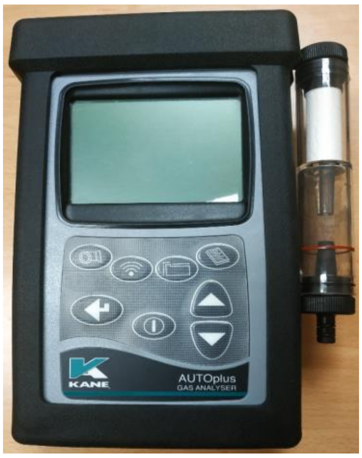

Fig. 2. Automotive emission analyse

3. Results and Discussion

Table 4 summarises the physical properties of the pure diesel and diesel-citronella blended fuel. In particular, the addition of citronella oil decreases the cetane number, gravity and aniline point of pure diesel fuel due to a modification of interaction distance between hydrocarbon molecules, consequently, reduces the volume. On the other hand, the viscosity of pure diesel decreased with the addition of citronella oil as a result of the increase in the mass of the molecules at specific volume, thus reduces the liquid velocity: the lower viscosity, the more comfortable in the fuel combustion. Furthermore, fuel with high aromatic compounds contents will readily dissolve in aniline. Citronella oil has a high content of aromatic compounds; thus, the addition of citronella oil will increase the aromaticity of pure diesel. The higher aromaticity in the fuel, but lower the aniline point. The high aromaticity, in contrast, leads to engine damage. The minimum limit for the aniline point must be above 40^{o}C. The results showed that the physical properties of diesel fuel and citronella blended diesel fuel in an excellent agreement to standard specification.

Table 4
Physical characteristics of diesel fuel and bio-additives fuel blends

Physical characteristic	Units	Limits	D	DC
Density	g/mL, 25°C		0.84	0.84
Density	g/mL, 60°F	0.82-0.87	0.85	0.85
Viscosity	cSt	1.6-5.8	5.21	5.19
Aniline point	°F	>129.6	192.60	185.40
API gravity	API		34.43	34.33
Cetane number	-	<40	66.32	63.64

3.1 CO_2 Emission

CO_2 emissions for the entire trial showed lower results for diesel-citronella mixed fuels compared to pure diesel. At the highest engine load 25% emission for diesel-citronella at 1.3% and speed of 2100 rpm. For engine loads, 50% of the highest CO_2 emissions recorded at 2400 rpm of 1.1% on diesel-citronella fuel. As for pure diesel, the highest CO_2 emissions are obtained at an engine speed of 2100 rpm shown in Figure 3. As for the engine load of 75%, the diesel-citronella mixture also shows lower results than pure diesel. The use of diesel- citronella fuel tested produces the highest CO_2 emissions by 1.1% lower than using pure diesel by 1.7% for a 50% engine load. When the testing engine combustion using diesel-citronella fuel produces CO_2 emissions of 0.9% lower than pure diesel fuel 1.2% for 25% load. Meanwhile, when the engine load reaches 75% of CO_2 emissions generated when using diesel-citronella fuel is also lower than pure diesel respectively of 0.92% and 2.1% when the engine speed is 1800 rpm as shown as in Figure 3. The overall results of experiments conducted that CO_2 emissions produced by diesel-citronella mixture fuels showed lower results. However, citronella oil has a higher price than other fuel additives. The use of citronella for mixtures and fuel additives for engine combustion is still complicated to find in the literature. Although the use of lemongrass oil is perfect for reducing emissions, however, the price is still too high for fuel. Investigation of emissions on diesel engines has been carried out with a variety of different fuels [40–42]. However, the emission results shown in several previous studies have resulted in higher emissions than in this article.

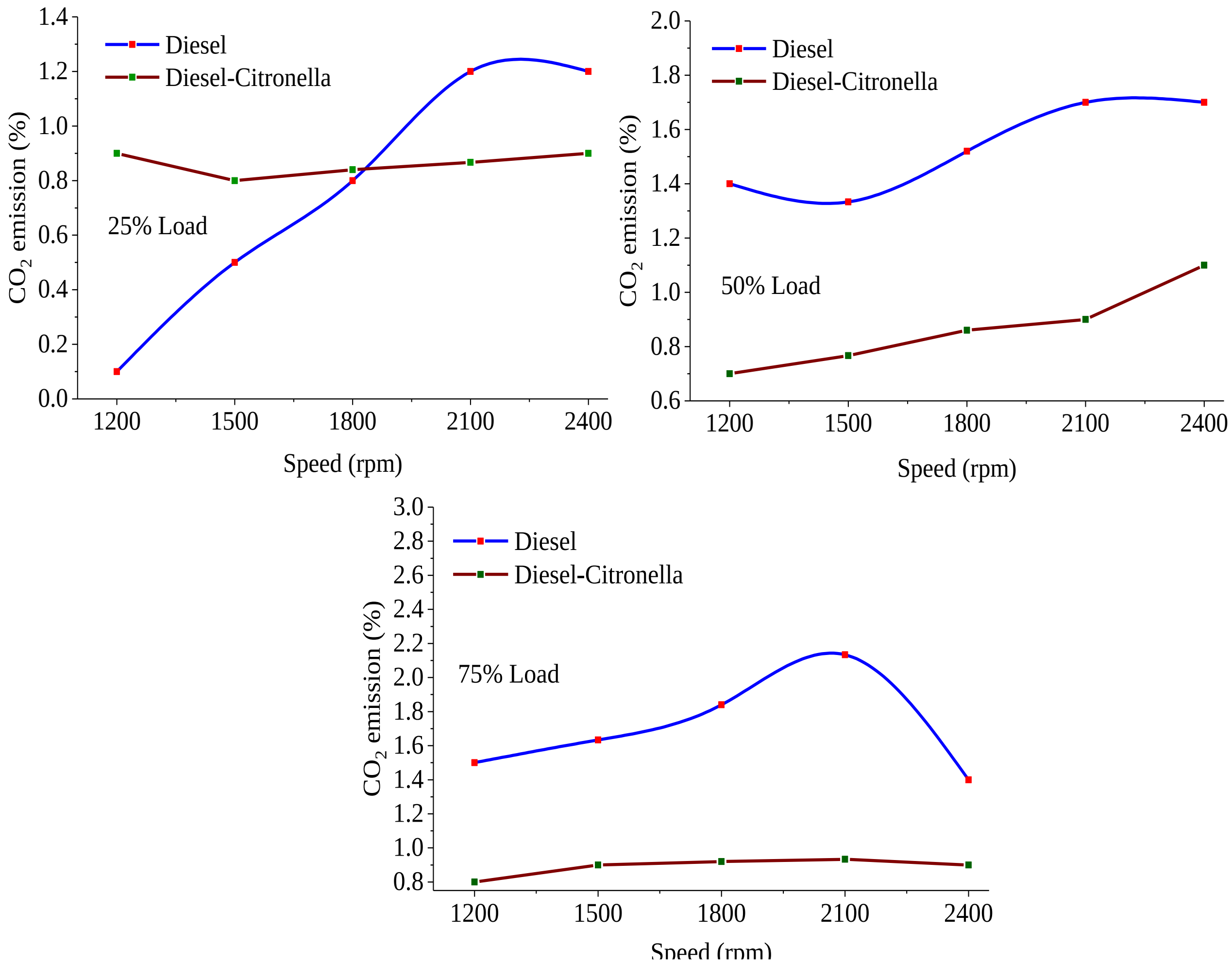

Fig. 3. Effect of CO_2 emission for different speed and load

3.2 CO Emission

The experiments carried out on single-cylinder diesel engines with diesel fuel and compared with diesel-citronella mixed fuels have been completed. CO emissions at a 25% load for a diesel-citronella fuel mixture show a slight decrease as engine speed increases. While pure diesel fuel shows an increase of up to 2100 rpm. From the overall results of trials conducted that the diesel-citronella fuel mixture decreased for an engine load of 25% shown in Figure 4. Whereas for an engine load reaching 50%, CO emissions from burning a diesel-citronella fuel mixture did not show an increase or decrease. While diesel fuel shows a significant increase from 1200 engine speed to 2100 rpm shown in Figure 4.

Experiments carried out at 75% engine load that CO emissions from diesel-citronella mixed fuels decreased significantly. While experiments with diesel fuel showed a slight increase. The maximum CO emission results for diesel-citronella fuel mixture at 75% engine load is 0.04% at 1200 rpm speed and decreases to 0.01% at engine speed 2400 rpm as shown in Figure 4. While some studies that have been carried out by several researchers regarding previous CO emissions with different mixed fuels show higher results than in this study [43,44].

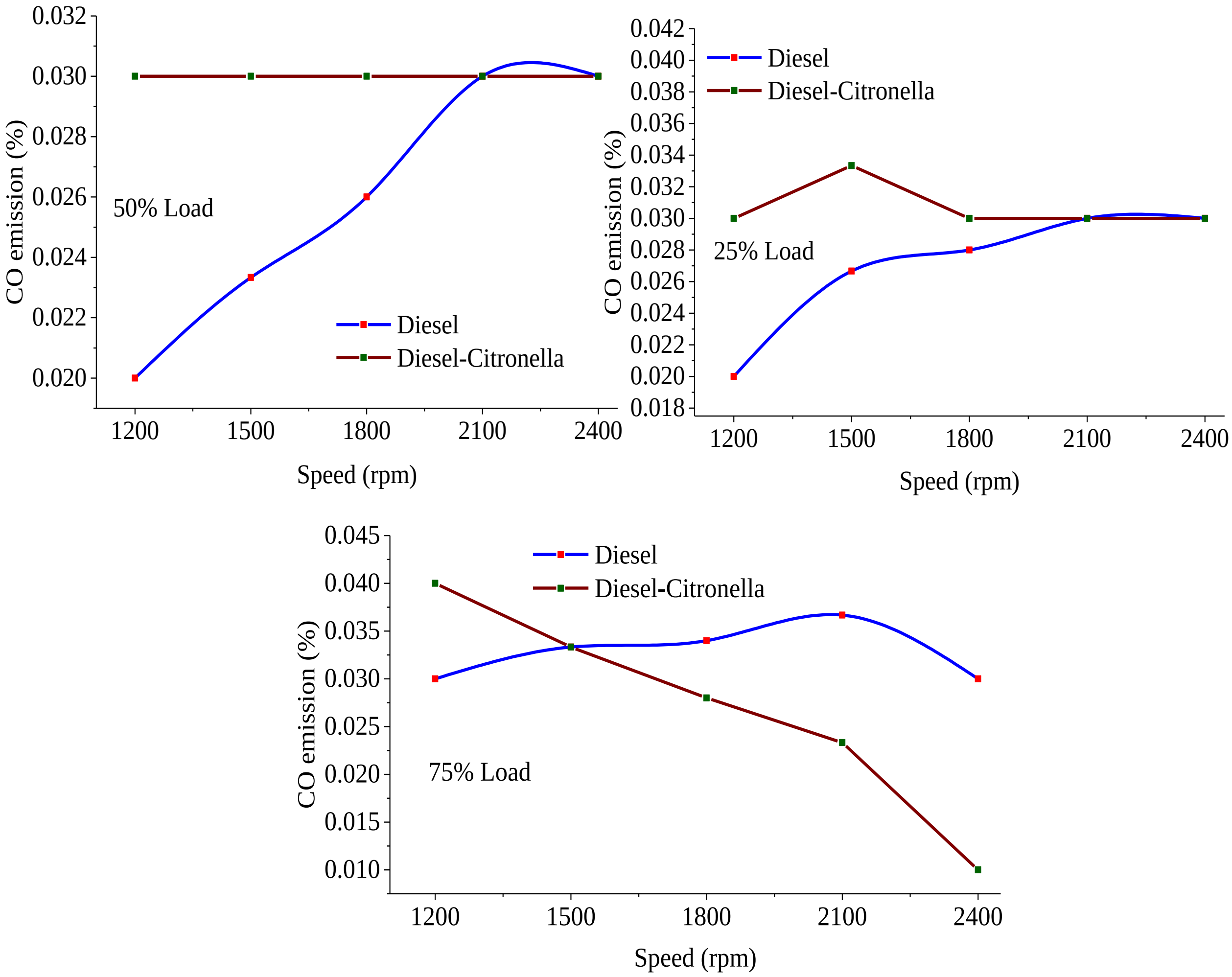

Fig. 4. Effect of CO emission for different speed and load

3.3 O_2 Emission

Figure 5 is the result of an analysis of O_2 emissions tested with the use of diesel fuel and diesel-citronella fuel mixture. The combustion engine results when using diesel-citronella fuel produces O2 emissions 19.32% lower than pure diesel 20.91% at 2,100 rpm engine speed and 25% load. However, when the engine speed increased to reach 2400 rpm the use of diesel-citronella O_2 mixture fuel produced was higher than pure diesel fuel of 19.33% and 18.92%, respectively. When testing the engine using diesel-citronella fuel with a load of 50% the highest O_2 emissions generated at an engine speed of 1200 rpm of 19.65%. While the use of pure diesel O_2 emissions produced by 18.37% lower than diesel-citronella. The combustion results of diesel-citronella when the engine load is 75% produces O_2 emissions of 19.56% higher than the use of pure diesel of 18.30% at an engine speed of 1200 rpm shown in Figure 5. However, trials of combustion of engines with diesel fuel showed a very significant reduction. The use of diesel-citronella mixed fuel slowed slightly. Citronella oil shows excellent results for blends and diesel fuel additives. However, the high price is an obstacle so it is very minimal to use for fuel mix, especially for motor vehicles. While the results of several previous studies using various fuel mixes showed higher results [44,45].

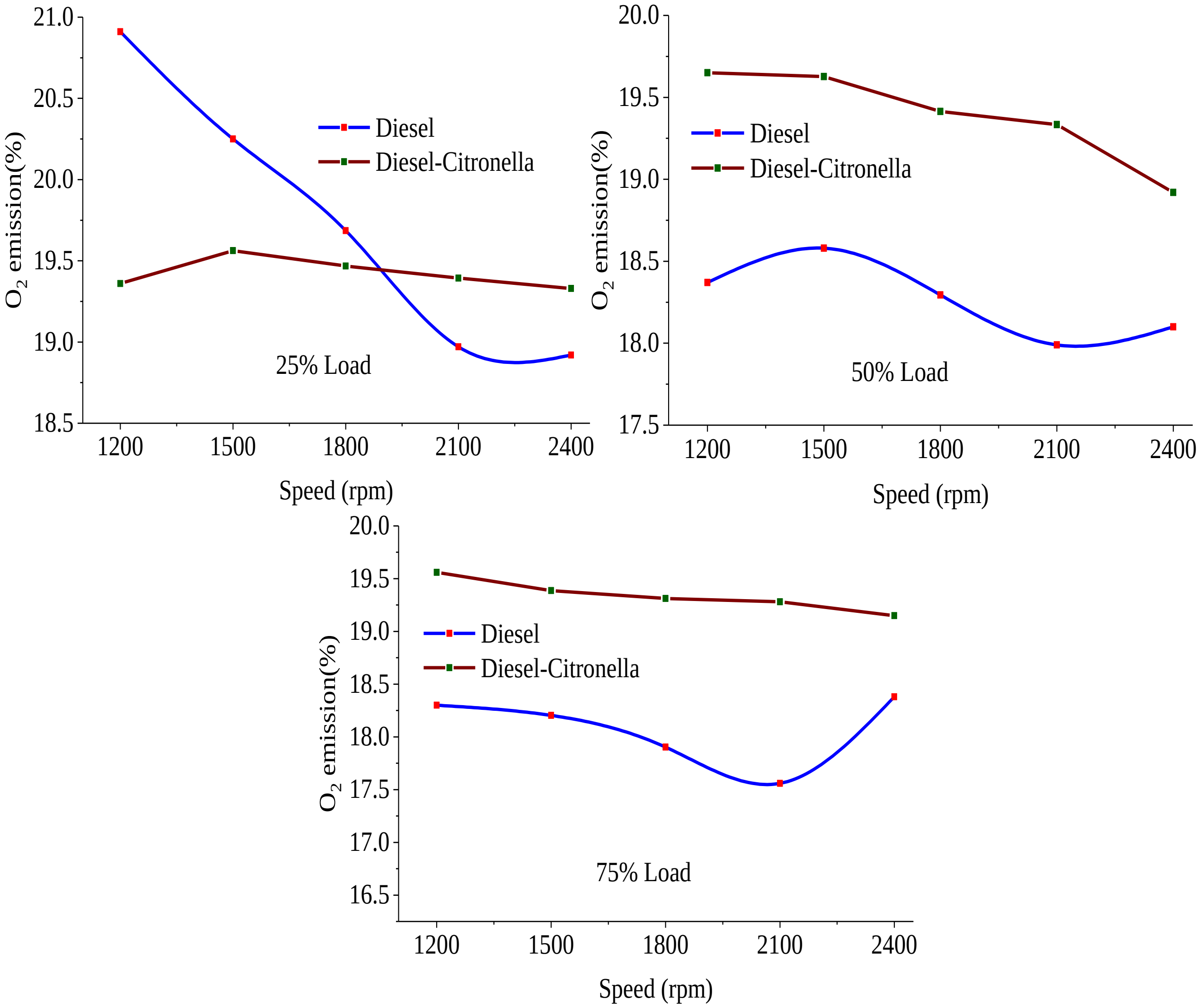

Fig. 5. Effect of O_2 emission for different speed and load

3.4 NOx Emission

Analysis of NOx emissions carried out by testing diesel fuel, and diesel-citronella fuel mixture shows lower results than pure diesel. The maximum NOx emission at engine load is 25% by 93 ppm. These are shows a decrease from 93 ppm at 1200 rpm to 53 ppm at 2400 rpm. While for diesel fuel, it increased from 5 ppm at 1200 rpm to 94 ppm at 2100 rpm and decreased by 74 ppm at 2400 rpm, as shown in Figure 6. The results of trials conducted at 50% engine load showed the same thing at a 25% engine load. Diesel-citronella blend fuel shows lower results than pure diesel fuel. The diesel-citronella mixture fuel increases when engine speed increases. While for diesel fuel is decreasing, however, the value generated from diesel fuel is shown in Figure 6.

While the engine load reaches 75% diesel-citronella mixture fuel shows very maximum results and is lower than pure diesel fuel. Maximum NOx emissions for pure diesel fuel are 297 ppm compared to 117 ppm when using diesel-citronella mixed fuels show in Figure 6. With these results, it is clear that citronella oil best used as a fuel additive or a mixture of diesel fuel for combustion in a single-cylinder diesel engine.

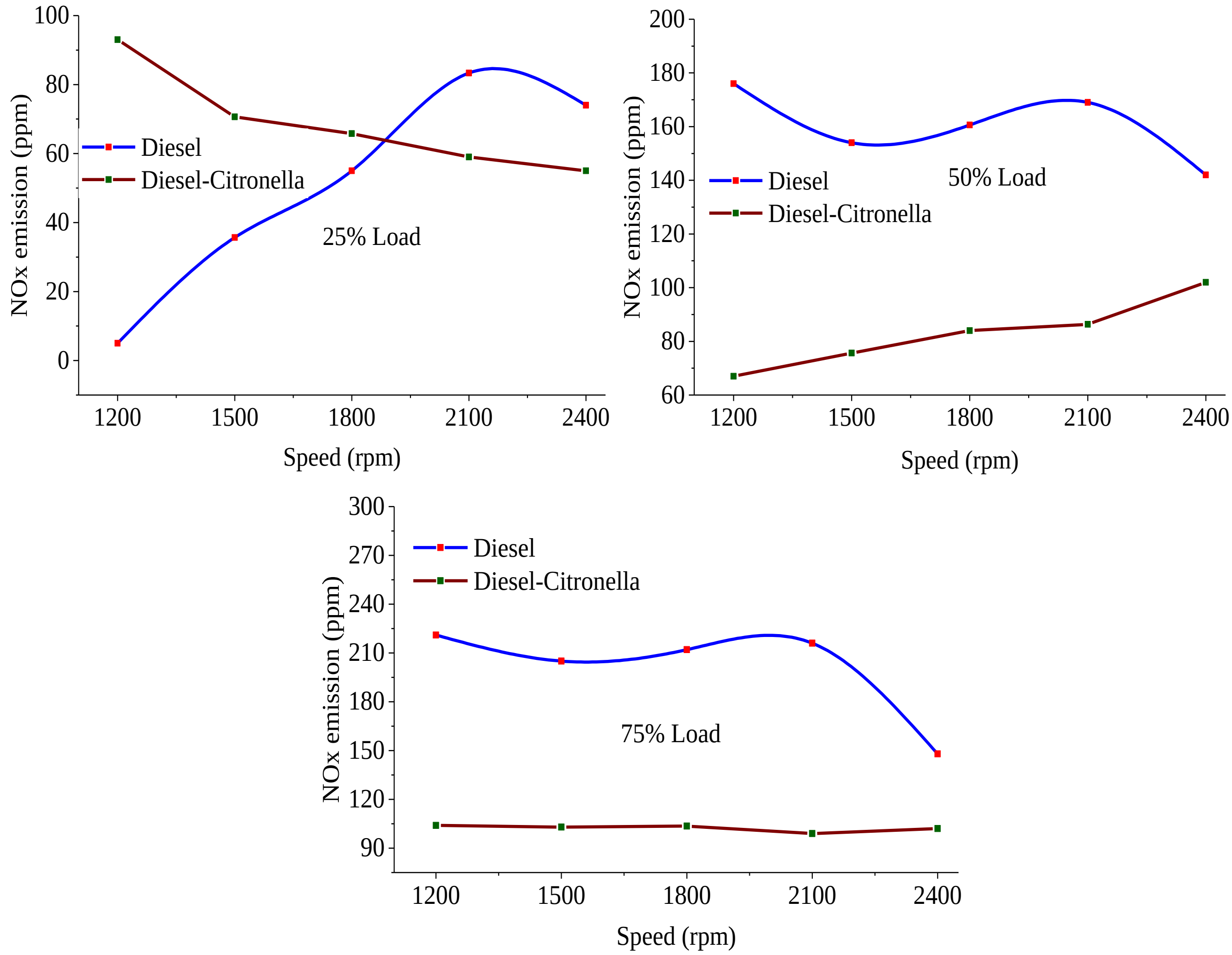

Fig. 6. Effect of NOx emission for different speed and load

3.5 Fuel Consumption

The diesel-citronella blend fuel shows better results for emissions produced by combustion of diesel engines. However, if you look at the fuel consumption needed in this test that the diesel-citronella mixture is slightly higher than pure diesel. However, the height of this fuel consumption is not very significant, as shown in Figure 7. Maximum fuel consumption when using diesel-citronella mixture is 0.2727 g/s for a 25% engine load. While the maximum fuel consumption for diesel in testing with the same engine load of 25% is 0.2693 g/s lower by 0.0034 g/s.

As for engine load, 50% of fuel consumption spent on pure diesel of 0.357 g/s versus 0.369 g/s shown in Figure 6. While for engine loads reaching 75% of fuel consumption required for diesel-citronella mix of 0.502 g/s compared to pure diesel at 0.4507 g/s. Overall results of experiments conducted that the fuel consumption for diesel-citronella is slightly higher than for pure diesel.

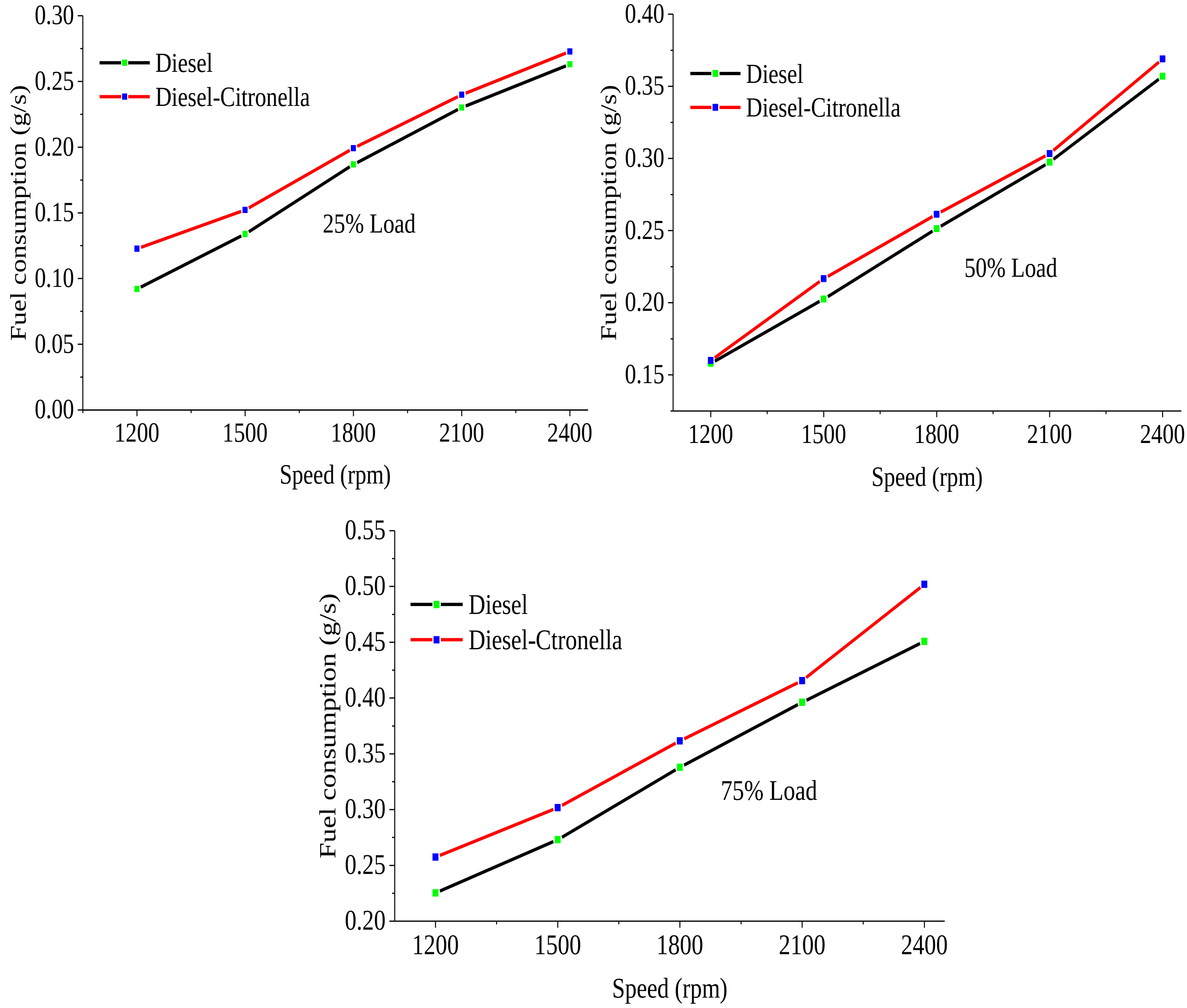

Fig. 7. Fuel consumption for different speed and load

3.6 Exhaust Temperature

The results of the analysis of exhaust gas temperatures from diesel engine experiments with different loads and engine speeds are shown in Figure 8. The results of the overall trials conducted showed that the mixture of diesel-citronella fuel is lower than pure diesel fuel. Exhaust gas temperature at the time of testing with a large engine 25% with an engine speed of 1200 rpm each of 160.41ºC for pure diesel is lower than the diesel-citronella mixture of 160.79ºC. However, when the engine speed is 2400 rpm, the exhaust gas temperature of the diesel-citronella211.93ºC fuel mixture is lower than that of pure diesel 211.93ºC. While at 50% engine load engine combustion using diesel-citronella fuel is lower than pure diesel for all engine speeds tested as shown as in Figure 8. The maximum exhaust gas temperature recorded at a 75% engine load for a diesel-citronella mixture of 367.3ºC when the engine speed reaches 2400 rpm. Experiments carried out using pure diesel fuel obtained higher exhaust gas temperatures than the diesel-citronella mixture. The highest exhaust gas temperature recorded at 75% engine load of 427.99°C for pure diesel fuel. The increase in exhaust gas temperature occurs when the load and engine speed increase, as shown in Figure 8.

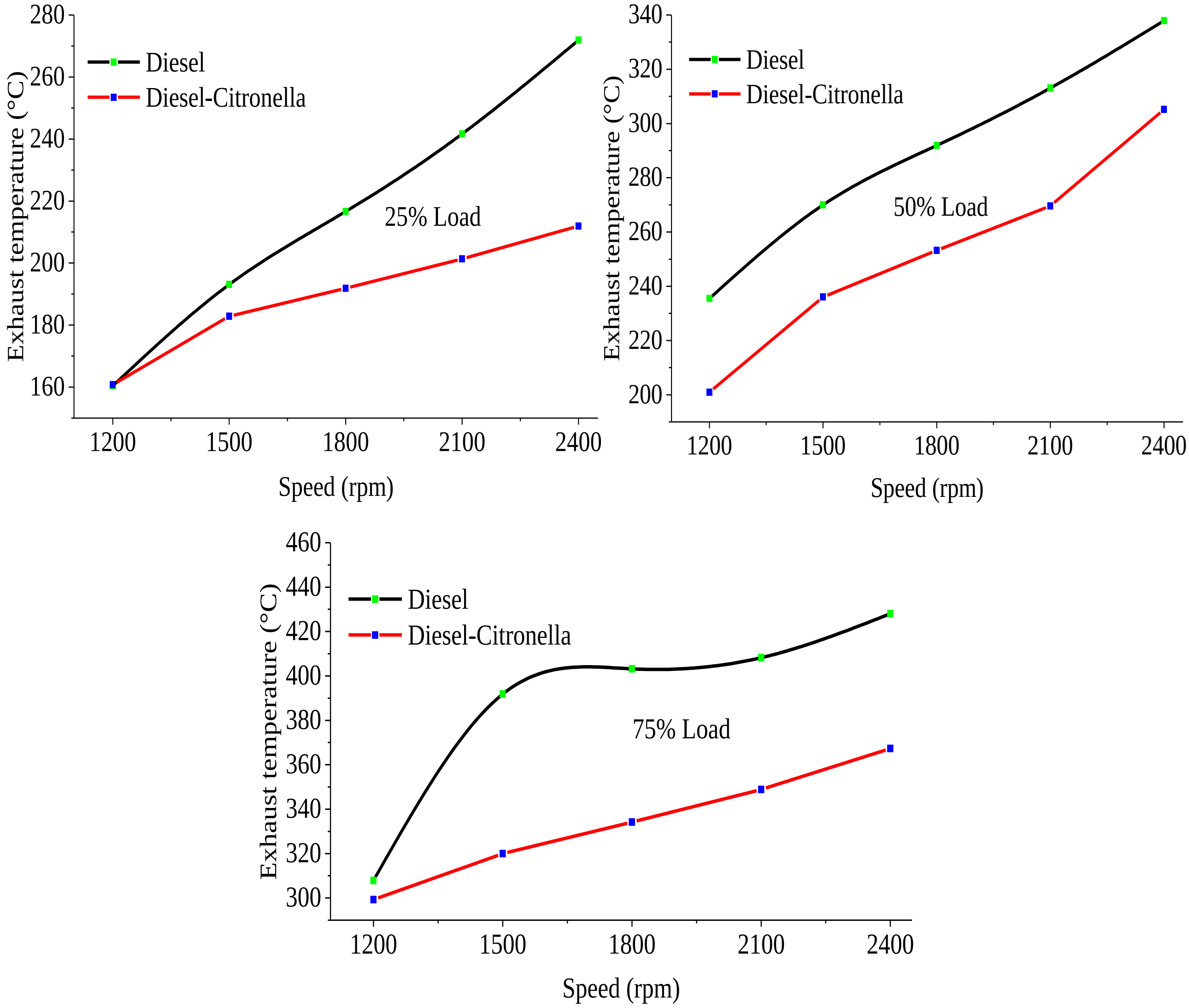

Fig. 8. Exhaust gas temperature for different speed and load

The results of the exhaust gas temperature with pure diesel fuel also increase when the load and engine speed increase. Investigation of the temperature of the exhaust gas in the engine has also been widely studied before [7,46,47]. The exhaust gas temperature in this study was lower with diesel-citronella mixture fuel. These are shows that citronella oil is excellent to use as fuel additives or a mixture into diesel engine fuel.

4. Conclusions

The experiments in this study have been completed with a single-cylinder diesel engine. The evaluation in this study accurately carried out on emissions and fuel consumption at 25%, 50% and 70% engine load and five different engine speeds. The use of a blended of oxygenated fuel at low concentrations (Citronella 0.5%) blends with pure diesel fuel. Subsequent mixed results were compared with pure diesel fuel and compared with the results of previous studies. The conclusions from the experimental results in this study can be described as follows

i. The results of CO_2 emissions for the entire trial conducted in the study showed that the diesel-citronella fuel mixture was lower than pure diesel.
ii. CO emissions have decreased significantly in diesel-citronella mixture fuels from 0.04% at 1200 rpm engine speed to 0.01% at 2400 rpm.
iii. The diesel-citronella fuel mixture tested in the study produced more stable O_2 emissions compared to pure diesel fuel.
iv. Test results using diesel-citronella mixture fuel at engine load reaches 2400 rpm showed a decrease of 40 ppm compared to 1200 rpm at 93 ppm. While pure diesel fuel has increased significantly from 5 ppm at 1200 rpm engine speed to 94 ppm at 2100 rpm.
v. The diesel-citronella mixture fuel consumption is higher than pure diesel for each engine load and all tested speeds (0.2727 g/s, 0.367 g/s and 0.502 g/s) compared to pure diesel (0.2693 g/s, 0.357 g/s and 0.4507 g/s).
vi. The results of exhaust gas temperature testing for pure diesel fuel and diesel-citronella mixture showed an increase when engine speed increased. However, overall trials conducted with diesel-citronella mixed fuels are lower than pure diesel.

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Conflicts of interest
There are no conflicts to declare. All authors declare that they have no known competing for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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