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Evaluation of Exhaust Emissions of Diesel Engine Using Pyrolysis Waste Plastic Fuel

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Abstract

Increase number of vehicles is one of the causes of increasing air pollution. In addition, plastic waste is a type of inorganic waste that has long decomposed, plastic waste can be recycled into fuel oil. But each type of fuel has characteristic properties, this affects the exhaust emissions resulting from the combustion process. The purpose of this study is to determine the exhaust gas emissions (CO, HC, CO_2) from Single Cylinder R175A diesel engines with the three kind of fuel such as 100% plastic fuel, dexlite, and a mixed of plastic fuel and dexlite with a ratio of 30% plastic fuel: 70% dexlite (PO30), 50% plastic fuel: 50% dexlite (PO50) and 70% plastic fuel: 30% dexlite (PO70). The results obtained are that carbon monoxide (CO) exhaust emissions increase with increasing engine speed, vice versa hydrocarbon (HC) emissions decrease with increasing engine speed. The use of plastic fuel produces the lowest carbon dioxide (CO_2) emissions.

Keywords: *Exhaust emissions, fuel, plastic fuel, dexlite, diesel engine*

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INTRODUCTION

The increase number of motor vehicles is one of the causes of increased air pollution and traffic congestion. The increase number of motor vehicles has resulted in increased emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxide (NO), and dust. Motor vehicles contribute to the largest source of air pollution in Indonesia. According to data from the Ministry of Communications of the Republic of Indonesia, 60% of the pollution is caused by the use of fossil fuel of cars and motorcycles. According to the Air

Pollution Emission Inventory calculations carried out by the Ministry of Environment, the largest sources of pollution in Indonesia are PM2.5 pollutants, NOx and CO from the vehicle or transport sector. The second contributor is the processing industry, sulphur dioxide (SO_2) pollutants. The main source of air pollution is the transport sector, mainly for NO_x (72.40%), CO (96.36%), PM_{10} (57.99%), and PM2.5 (67.03%). The processing sector is the second largest source of pollutant for SO_2 (61.96%), NOx (11.49%), PM10, (33.9%) and PM2,5 (26.81%) [1]. Therefore, there needs to be a solution to reduce the level of pollution.

Plastic waste is one of the kinds of inorganic garbage that is not easily broken down in the soil and takes 50 to 80 million years to decompose [2]. Facing this situation, efforts are needed to combat plastic garbage, by limiting the use of plastic and recycling plastic. Plastic waste can be recycled in several ways, one of which can be converted into fuel. Given that oil fuel is now an affordable and expensive energy source, the conversion of plastic waste into fuel is done using the pyrolysis method. Research on plastic fuel testing in Indonesia is still very minimal, especially the research on exhaust gas emissions on diesel engines. Our research is carried out analyzing the emissions of waste gases of one-cylinder diesel engines using the plastic fuel produced by Integrated Waste Management Industry (IPST ASARI) in Cilegon City with pyrolysis method.

The performance and emission research on diesel engines with a mixture of plastic fuels carried out by Ganesh et al., [3] is testing with plastics fuel levels of 25%, 50%, 75%, and 100%. Each test is performed at an engine speed of 1500 rpm for a variety of load conditions namely 25%, 50, 75% and 100%. The results of this study are that the specific fuel consumption obtained from plastic fuels is slightly higher compared to diesel fuels, proving that plastic fuel with a diesel fuel mix is suitable for a particular engine and can be used as an alternative fuel, higher NO_x emissions for all plastic fuel mixtures than diesel, more hydrocarbon emissions from low-load to high-load conditions, but the mixture has 75% less emissions compared with the other mixture [4]. The results of a study using plastic fuel operated at 2500 rpm with different torque loading conditions of 30, 50, 70, 90, and 110 N-m. showed that carbon-containing gas emissions were visible in low load conditions as well as NOx increased with the addition of plastic oil fuel, but produced a lower smoke index because of the smaller aromatic compounds [5].

The study entitled Engine Fuel Production from Waste plastic Pyrolysis (WPO) and Performance Evaluation in a CI engine with Diesel Blend tested using diesel fuel and mixture B10, B20, B30 and B40. All experiments with different fuel comparisons were carried out at a constant engine turnover of 1500 rpm as well as variable engine loads. The loads vary between 2 kg, 4 kg, 6 kg, 8 kg, 10 kg and 12 kg. The results of the research were that the use of fuel mixed with plastic waste oil in diesel engines resulted in improved engine performance and exhaust gas emissions. The mixture of plastic oil with diesel is safe to use up to 40% of the mixture without losing energy. The addition of plastic waste oil results in a significant reduction in exhaust gas emissions, carbon monoxide decreases as the load increases, and carbon dioxide increases in connection with the increased load for all the mixtures [6].

In addition, the research conducted by Jatadhara et al. [7] analysed the performance and emission parameters of diesel engines using plastic fuel. The engines used in this experiment were four-cylinder engine, direct injection, water-cooled turbocharger, 17:1 compression ratio with 68 kW of identification power. The tests were carried out at 1500 rpm engines and four different loads of 25%, 50%, 75% and 100% of identifying power. The result of the experiments that have been conducted is that NO_x emissions increase as the load increases, then hydrocarbon emissions rise as the mixture of plastic fuels grows, and carbon monoxide emissions decrease as the charge increases.

Waste Plastic Fuel

Plastic waste is one type of inorganic garbage that takes a long time to decompose in the soil and takes 50 to 80 million years to disintegrate. According to data from the Indonesian Plastic Industry Association (INAPLAS) and the Central Statistical Agency (BPS), plastic waste in Indonesia reaches 64 million tonnes/year, of which 3.2 million tonnes are plastic waste thrown into the sea. Therefore, it is necessary to manage plastic waste by limiting the use of plastic until it is recycled.

Plastic waste can be recycled in a variety of ways, one of which is converted to oil fuel (WPO). Given that petroleum fuel is now an affordable and expensive energy source, therefore, recycling is done by turning plastic waste into fuel, given that the plastic raw material comes from natural oil derivatives, then the plastic can be transformed back into hydrocarbons as a basic energy material. Plastics can be grouped into two types: thermoplastic and thermosetting. Thermoplastic is a plastic that, if heated to a certain temperature, will melt and can be re-formed into the desired shape. Based on two groups of properties, thermoplastics are the type that can be recycled [8].

Pyrolysis is the process of decomposing materials at high temperatures without air or with limited air volume. This process uses high temperature and low pressure. Plastic waste pyrolysis is the process of decomposing organic compounds contained in plastics through heating with little or no oxygen, where the raw material can undergo chemical decomposition into gases, oils and residues such as candles and coals. The specifications of waste plastic fuel used are shown in Table 1.

ASTM D 445 Standard Fuel Characteristics is a method used to determine the kinematic viscosity of liquid petroleum products, both transparent and blurred, by measuring the flow time of the volume of liquid under gravity through the calibration of the glass capillary viscometer. The following is a table of the viscosity values of the test results carried out by the Chemical Engineering Operations Laboratory of Sultan Ageng Tirtayasa University. Viscosity is a measure of the rigidity of a fluid or fluid, burning in a combustion chamber affects a high viscosity value. The higher the viscose value, the more imperfect the process of spraying the fuel. This occurs because the fuel released from the

Table 1. Specification of Waste Plastic Fuel

Specification	Unit	Result	Method
Cetane number	-	49,2	ASTM D 613
Specific Gravity	-	0,7943	ASTM D 1298
Flash point	Deg C	2	IP 170
Pour point	Deg C	27	ASTM D 97
Lubricity	Micron	145	ASTM D 6079
Sulfur	Ppm	56	ASTM D 4294
Analine point	Deg C	76,9	ASTM D 611

(**Source:** Industrial Waste Management (IPST ASARI), Cilegon City) (2021) [9]

Table 2. Viscosity of experimental fuel

No.	Fuels	Viscosity (mm^2/s)	Method
1.	Dexlite	6,97	ASTM D 445
2.	PO30	6,04	ASTM D 445
3.	PO50	5,87	ASTM D 445
4.	PO70	5,65	ASTM D 445
5.	PO100	4,62	ASTM D 445

Table 3. Specific Gravity of experimental fuel

Fuels	Specific Gravity (at 60/60°F)	Method
Dexlite	0,8450	ASTM D 1298
PO30	0,8365	ASTM D 4052
PO50	0,8269	ASTM D 4052
PO70	0,8169	ASTM D 4052
PO100	0,7943	ASTM D 1298

(**Source:** Laboratory of Fuel Characteristics and its product LEMIGAS) [10]

Table 4. Cetane Index and Cetane Number

Fuels	Cetane Index	Cetane Number
Dexlite	48	51
PO30	52,64	50,46
PO50	53,39	50,1
PO70	52,04	49,74
PO100	-	49,2

nozzle is too thick that the size of the droplet at the time of spray becomes inconsistent. If the spraying process is not even then there will be imperfect combustion. If imperfection continues, exhaust gas emissions can increase. Table 2 shows the viscosity of three kinds of fuel.

Specific Gravity (SG) is the comparison of the weight of such a petroleum fuel at a given volume with the water weight at a certain volume, with the mass of the water at the same volume and measured at a temperature of 60^0 F, or the ratio of the weights of a type of oil at a standard thermometer with those of a water type. The methods used for the specific gravity testing are ASTM D 1298 and ASTMD 4052. The Specific Gravity (SG) testing was carried out in the Lab of Physical Properties in the LEMIGAS. Table 3 is the results of the test of SG fuel.

Table 4 is the results of the calculation of the cetane index and cetane numbers on the fuel used in this study. The cetane number indicates the speed of injection of fuel into the combustion chamber to burn directly. The lower the cetane number, the lower the quality of combustion because it requires a higher flame temperature.

The calorie value is used to determine the amount of heat energy produced by each fuel unit when it is completely burned, where the energy value generated by combustion is proportional to the caloric value. The higher the calorific value, the less fuel is consumed. The Table 5 is show a table of net calorie values for dexlite, PO30, PO50, PO70 and PO100 fuels. The table shows that the higher the net calorific value due to the higher plastic fuel mixture. This explains that the plastic content in the fuel increases the NCV value of the fuel and effect to the fuel consumption.

Table 5. Calorific Value

Fuels	Specific Gravity 60/60 °F	NCV
Dexlite	0,8450	11,65 kWh/kg
PO30	0,8365	11,69 kWh/kg
PO50	0,8269	11,74 kWh/kg
PO70	0,8169	11,80 kWh/kg
PO100	0,7943	11,93 kWh/kg

RESEARCH METHODOLOGY

The research was carried out in the Engine Laboratory of the Department of Mechanical Engineering of Sultan Ageng Tirtayasa University. There are five different fuels used in this study: dexlite, 30% plastic fuel: 70% dexlite (PO30), 50% plastic fuel: 50% dexlite (PO50), 70% plastic fuel: 30% dexlite (PO70) and 100% plastic fuel. (PO100). Figure 1 show the experimental setup of engine test. The data was obtained by testing a single-cylinder diesel engine with variations in engine speeds of 1200 rpm, 1600 rpm and 2000 rpm with a fixed load of 1000 W lamp. Exhaust emissions taken from the exhaust pipe by using the gas analyzer type Hesbon.

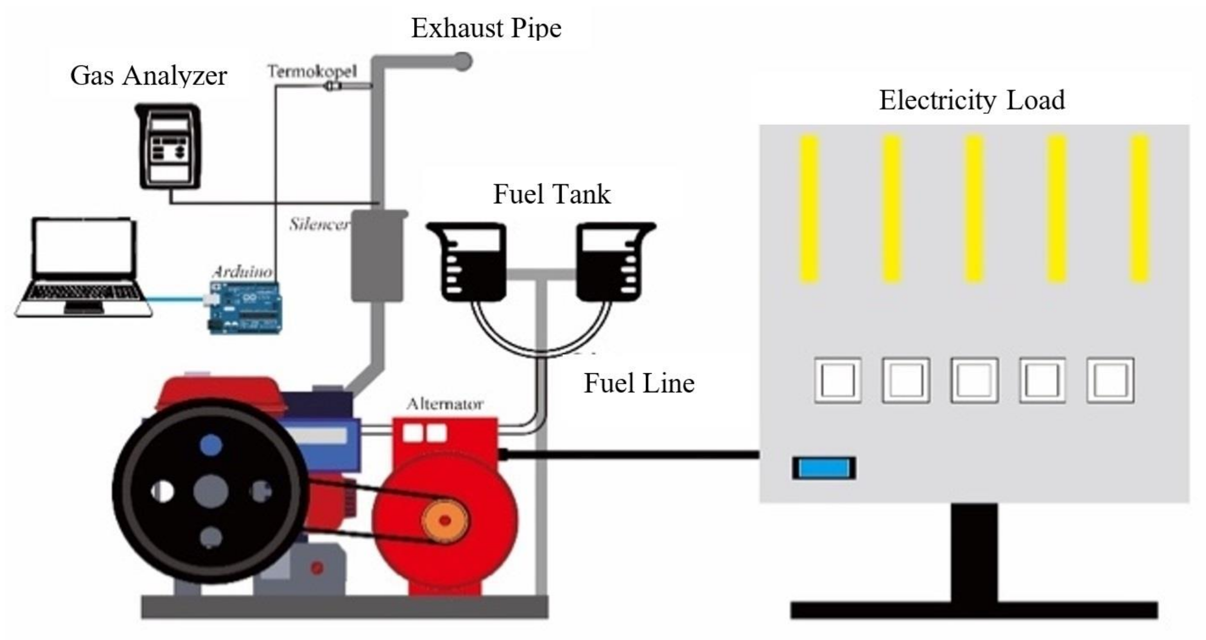

Figure 1. Schematic Diagram of Research

Table 6. Diesel Engine Specification

Items	
Brand	DONGFENG
Type	R175A
Engine Type	Horizontal, 4 stroke, Water Cooled
Combustion System	Direct Injection
Number of Cylinder	1 cylinder
Diameter x Length	75 x 80 mm
Volume Cylinder	353 cc
Max Power	7.0 Hp / 2600 rpm
Power Rate	6.5 Hp / 2600 rpm
Lubrication Tank Cap	2 Liter
Fuel	HSD
Lubrication	SAE 40 CC/CD
Lubrication System	Pressure / Inject
Cooling System	Hoper
Dimention	38 x 57 x 55 cm
Weight	77 Kg

The data collection process was done fifteen times, where there are five different types of fuels: dexlite fuels, PO30, PO50, PO70 and PO100 with variables rpm 1200, 1600 and 2000 on each of the fuels used. During the process of data collection by observing the display on the gas analyzer until the number is stable. Then after data collection with the gas analyser is calibrated for 120 seconds the objective to remove the remaining air that is in the gas analyzer. The specifications of the diesel engine utilized in this study can be found in Table 6.

RESULTS AND DISCUSSIONS

The experimental data of exhaust emissions from diesel engine using plastic fuel was examined. Figure 2 above shows that the temperature of the exhaust gas increases as the speed of the engine increases. Moreover, the decreased of viscosity of fuel that injected into the combustion chamber of diesel was give effect to the increased of exhaust temperature. The temperature inside cylinder is comparatively higher for PO100 due to lowest viscosity and poor atomization causes for delayed combustion, the temperature of exhaust gases is more high compared to other fuel. From the above data it can be conclu-

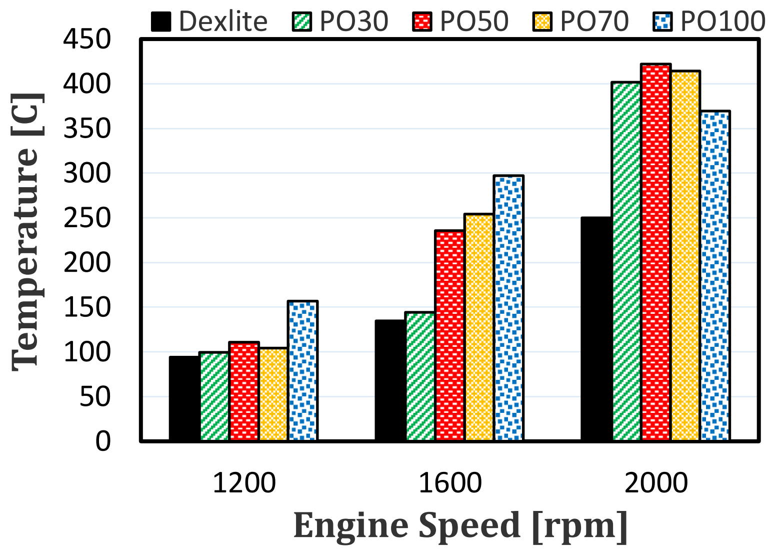

Figure 2. Graph of Exhaust Gas Temperature

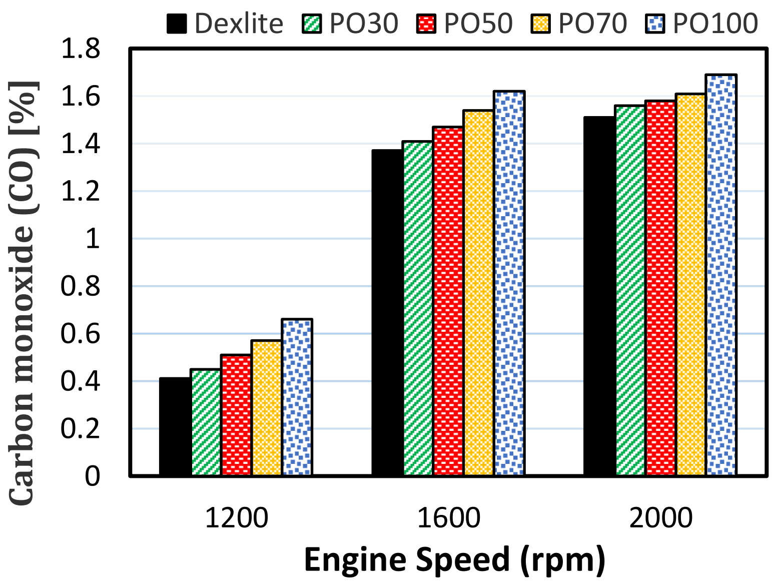

Figure 3. Graph of CO Emissions

ded also that the use of dexlite fuel results in a lower exhaust gas temperature compared to other plastic fuel uses. It shown the effect of carbon inside plastic fuel show the increased of exhaust gas temperature.

Based on Figure 3, it can be concluded that rpm has a strong influence on the CO emissions generated. Carbon monoxide (CO) emissions are caused by combustion in a fuel chamber that is deficient in oxygen and rich in fuel. The graph above shows an increase in carbon monoxide emissions as rpm increases for all experiments. While the highest carbon monoxide (CO) emissions are generated by all plastic fuel mixtures, this is due to insufficient time and inappropriate mixture of air-fuels that can lead to imperfect combustion and reduced amount of oxygen present in the burning chamber. The main cause of the increased carbon monoxide emissions in the plastic fuel mixture is because of the high amount of fuel injected into the burn chamber, which can be seen from high SFCs and low viscosity, resulting in higher emissions of carbon mon oxides (CO) [3]. Carbon monoxide (CO) is obtained by comparing fuel with unbalanced oxygen. The ratio of the carbon element (C) cannot bind to oxygen (O_2) and thus forms carbon monoxide gas (CO) from an imperfect combustion result. Increased rpm results in increased fuel demand, thereby reducing thermal efficiency and increasing CO emissions.

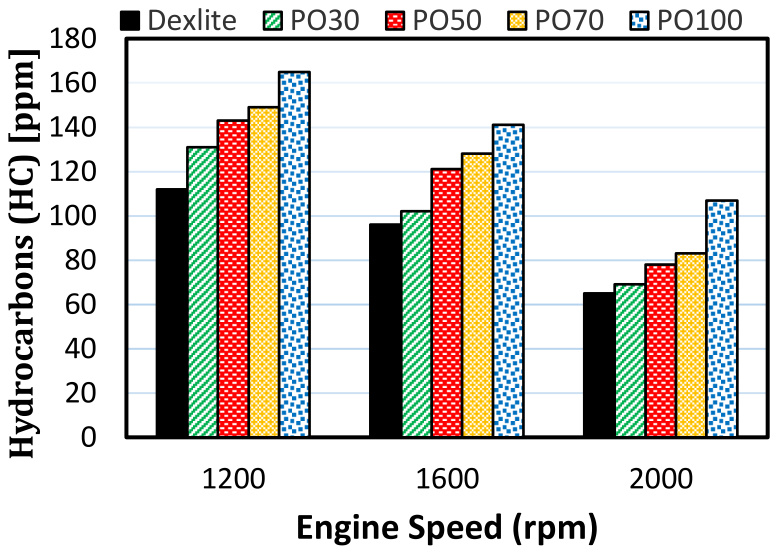

Figure 4. Graph of HC Emissions

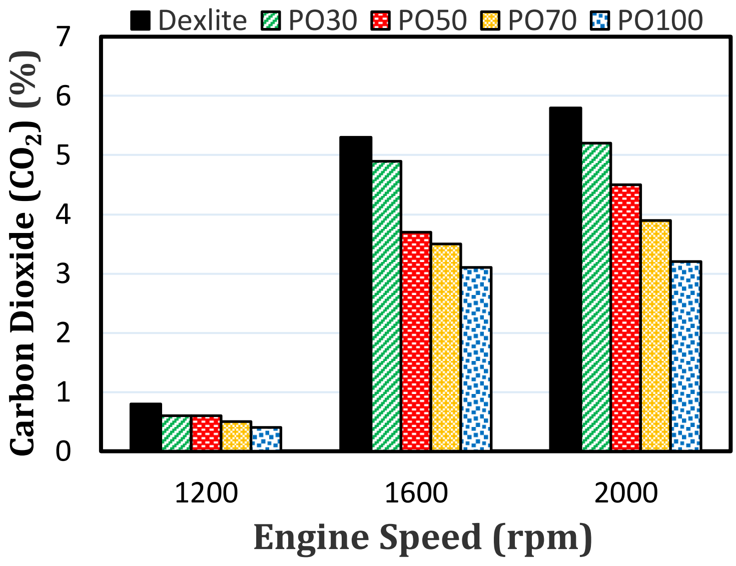

Figure 5. Graph of CO_2 Emissions

Hydrocarbon emissions (HC) are emission gases generated by non-combustion fuels. Figure 4 shows the increase in hydrocarbons (HC) as the mixture of plastic fuels increases, but the decrease in hydrogen (HC), as the speed of the engine increases (rpm). The increase is due to the low viscosity and also the low demonic number.

The main cause of increased of hydrocarbons (HC) can also be caused by the walls of the combustion chamber that are temperature low around the wall, the occurrence of misfiring. The presence of overlap intake valve (both valves open together) so that the hydrocarbon acts as a flushing gas and ignition delay is a factor that drives increased hydrocarbon emissions. Hydrocarbons will affect painful eyes, sore throats, lung diseases and even cause cancer. In addition to disturbing health, excessive hydrocarbon emissions can also cause photochemical smog. The higher the hydrocarbon emissions means that the engine power is decreasing and the fuel consumption is increasing.

Based on Figure 5 above, showing that carbon dioxide (CO_2) emissions increase as the rpm increases, the highest emissions of CO_2 are with the use of dexlite fuels. Carbon dioxide (CO_2) emissions are affected by air-fuel ratios, combustion failures, and engine performance problems. The highest carbon dioxide emissions are generated when the ideal air-fuel ratio. CO_2 emissions are heavily influenced by the viscosity of the fuel, a good combustion process occurring at the ideal Air Fuel Ratio (AFR). Under conditions of combustion of a mixture of plastic fuels where the viscosity of the mixed plastic fuel is lower than dexlite causes CO_2 emissions to decrease. The reaction that occurs in the combustion process is:

$$2C_{16}H_{34} + 49O_2 + N_2 \rightarrow 32CO_2 + 34H_2O + N_2 \text{ energy (heat)}$$

The burning reaction above is called perfect burning. The result of the combustion was only CO_2 and H_2O, whereas N_2 was originally contained in the air and entered the engine, but did not reacted. CO_2+H_2O+N_2 is a reaction resulting from a perfect combustion process to be later referred to as the perfect exhaust gas [11].

CONCLUSIONS

The research of exhaust emissions using plastic fuel in the single cylinder diesel engine is examined. The experimental results can be concluded that more mixture plastics and dexlite fuel show the high carbon monoxide (CO) emissions compare to the less of mixture plastic fuel by variable of engine speed. The highest CO emissions shown in the highest engine speed. The hydrocarbon (HC) emissions increase as increasing of the composition of plastic fuel mix, however the hydrocarbons (HCs) decrease as the engine speed. Moreover, the carbon dioxide (CO_2) emissions decrease gradually by increasing of plastics fuel mixture with dexlite. Lower CO_2 emissions are influenced also by lower viscosity of the fuel. The good fuel specifications are closely related to the quality of combustion in the combustion chamber which results in good diesel engine exhaust emissions.

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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