International Journal of Marine Engineering Innovation and Research, Vol. 9(1), March. 2024. 135-145
(pISSN: 2541-5972, eISSN: 2548-1479)

Experimental Study of Plastic Waste Fuel in Diesel Engine to Overcome Fuel Shortage Towards a Green Economy Facing IMO Tier III Standards

Sutrisno[1], Hadi Prasutiyon [2], Alif Rizky Saputro[3]

(Received: 10 February 2024 / Revised: 16 February 2024 /Accepted: 9 March 2024)

Abstract**— Ships generally use diesel engines as propulsion to produce energy from the combustion process. The fuel used on ships uses diesel oil, but its use can result in marine environmental pollution. Marine environmental pollution is currently a national issue that must be addressed immediately, where the International Maritime Organization (IMO) in MARPOL Annex VI TIER III limits the content of exhaust emissions. This research is to analyze the effect on engine performance and emissions, especially NOx produced by diesel engines, then compare NOx emission data with IMO TIER III standards. This research uses an experimental method by mixing two fuels with the composition B0 (pure plastic waste), B1 (80% - 20%), B2 (70% - 30%). After conducting research the effective result is B1 fuel. Because trendline graphs are quite optimal for use on diesel engines. The power produced by B1 is 1.36 KW to 2.12 KW. SFC B1 produces 431.35 g/kWh to 352.61 g/kWh. For efficiency, B1 produces 19.3% to 23.6%. For torque, bmep, and fc produce values that are directly proportional to engine speed. The results of the NOx emissions test were obtained for each type of fuel composition, B0 was 174 gr/kWh – 185gr/kWh, B1 was 182gr/kWh – 218gr/kWh and B2 was 198gr/kWh – 224gr/kWh. This meets the MARPOL Annex TIER III standards.**

Keywords— Plastic Waste , Plastic Pyrolysis , Diesel Engine , Performance, Emissions i NOx.

I. INTRODUCTION

Energy is one of the most important parts of human life because almost all human activities always require energy, but in recent years energy has become a very important issue in the world. Fossil energy, especially petroleum, is the main energy source and source of foreign exchange for oil-producing countries [1]. However, petroleum reserves in the world are limited because petroleum is a non-renewable natural resource. Exploration of new oil sources must be closely monitored, while human needs for energy are increasing in line with the rate of economic growth and population growth [2]. Plastic waste is a problem for many countries because plastic cannot decompose in nature, so waste must be recycled [14]. Because the amount of plastic waste produced is higher than the amount recycled, it causes a lot of plastic to accumulate [3]. Therefore, research needs to be carried out to overcome the above problems, namely by making alternative energy by utilizing plastic waste into diesel fuel which can be used in diesel engines

Examining the performance of diesel engines using a combination of pyrolysis oil derived from plastic waste and biodiesel as an alternative fuel [4]. The aim of this study is to reduce plastic waste while producing hydrocarbon products with high economic value [15]. The findings suggest that pyrolysis oil from plastic waste can effectively be utilized in diesel engines [5]. The performance of a 4-cylinder diesel engine using plastic waste oil was evaluated by applying loads from an electric motor dynamometer [6]. The results of blending pyrolysis oil from plastic waste with biodiesel indicate that torque, power, BMEP (Brake Mean Effective Pressure), BSFC (Brake Specific Fuel Consumption), and thermal efficiency are comparable to those of biodiesel fuel [7].

Furthermore, governmental initiatives to address petroleum limitations often lack comprehensive solutions [16]. While the government restricts specific diesel fuels for motor vehicles produced before 2008 and encourages the use of Solar Dex for newer vehicles, policies should consider environmental and health factors alongside economic considerations [8]. Analyzed various parameters such as calorific value, flash point, ash content, moisture content, and composition analysis of the fuel product [9]. This research aimed to investigate the influence of temperature and time on the pyrolysis process to determine the optimal conditions for plastic waste [10]. The results indicated that the composition analysis revealed the highest percentage of $C_{12}H_{24}$ at 41.9%. Temperature was identified as the most significant influencing factor, affecting the reaction rate constant according to the Arrhenius equation, with an activation energy value of 10,106.77 kJ/mol [11].

In addition, a similar study analyzed the mixture of plastic waste pyrolysis oil with Solar Dex fuel to determine its cetane number and flash point. The study found that varying the blend ratios affected the flash point

Sutrisno, Department of Marine Engineering, Universitas Hang Tuah Surabaya, Indonesia.
E-mail: sutrisno@hangtuah.ac.id
Hadi Prasutiyon, Department of Marine Engineering, Universitas Hang Tuah Surabaya, Indonesia.
E-mail: hadi.prasutiyon@hangtuah.ac.id
Alif Rizky Saputro, Department of Marine Engineering, Universitas Hang Tuah Surabaya, Indonesia.
E-mail: alifrizky2526@gmail.com

and cetane number, indicating the potential impact on engine performance and emissions [12]. As previous research focused solely on flash point and cetane number determination, this study aims to investigate the effect of using plastic waste fuel with Solar Dex on NOx emissions in diesel engines complying with IMO TIER III standards [13]. By examining the emissions with three fuel mixture variations (B0, B1, and B2), this study will provide insights into the influence of plastic waste mixtures on diesel engine exhaust gases.

Based on the background of the problem above, several problems can be drawn including:

a. How to convert plastic waste into fuel.
b. To find out the influence pyrolysis of plastic waste fuel on diesel motor performance.
c. To determine whether the NOx emission content of a mixture of two fuels meets IMO MARRPOL annex VI TIER III standards or not.

II. METHOD

Testing steps

1. Prepare tool and material.
2. The diesel motor is started and warmed up with zero load, after it is deemed sufficient, performance testing is carried out for all parameters by setting the motor rotation starting from 1600 rpm, 1800 rpm and 2000 rpm, and the exhaust gas is also recorded regarding the emission content.
3. The test uses fuel from pyrolysis of plastic waste and dex diesel
4. Meanwhile, loading is carried out at 2000 kW
5. Use appropriate instruments and measuring tools during testing.
6. During testing, the required measurement data is recorded.
7. The results of the test are recorded and tabled.
8. Testing is complete and the diesel engine is turned off

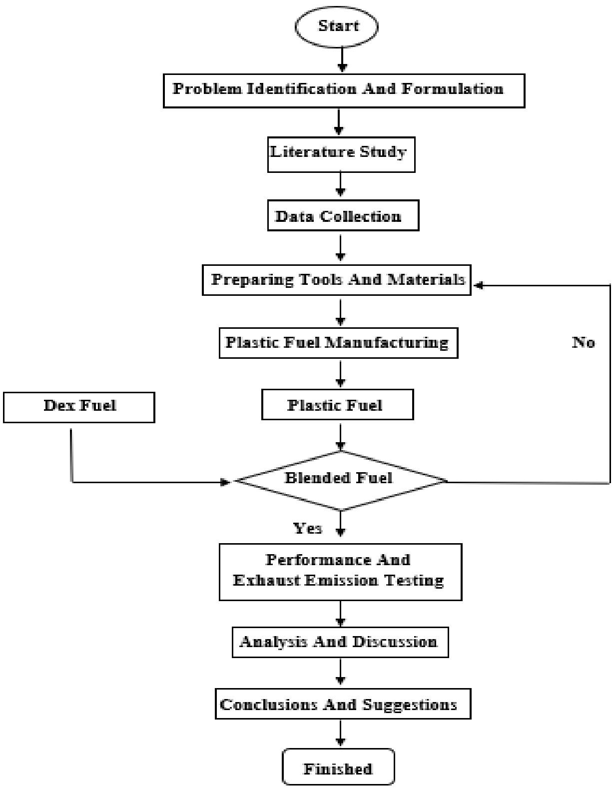

Figure. 1. Research flow diagram

III. RESULTS AND DISCUSSION

Properties of Fuel from Plastic Waste Pyrolysis

In research regarding exhaust gas analysis in diesel dex fuel mixtures using raw materials in the form of plastic waste collected from landfills, then to determine the quality, properties testing is carried out. In this research, properties testing was carried out at DBAL's Chemical and Materials Main Laboratory (LABINKIMAT), Benteng Station No.11, Ujung, Kec. Semampir East Java 60155 on 03 November 2023 to 10 November 2023. The test results are explained in table 1.

TABLE 1.
FUEL PROPERTY TEST RESULTS FROM PYROLYSIS OF PLASTIC WASTE

No	Parameter	Method	Technical specifications		Results
			Min	Max	
1.	Specific gravity (15 °C) kg/m ^{3}	ASTM D1298	815	860	786
2.	Color	ASTM D1500	-	3.0	2.5
3.	Flash point °C	ASTM D 93	52	-	54
4.	Visc. Kint at cSt 40 °C	ASTM D 445	2	6.0	3,398
5.	Water & Sediment Content % Vol	ASTM D1796	-	0.05	<0.05
6.	Sulfur Content % Wt	Sulfur meter	-	0.35	0.007
7.	*Distillation* 90%vol °C	ASTM D86	-	360	300
8.	*Cetane Index*	ASTM D613	45	-	62

Analysis of Fuel Characteristics Test Results resulting from pyrolysis of plastic waste, Fuel Characteristics Test Results resulting from pyrolysis of plastic waste

From the results of the fuel characteristics test resulting from pyrolysis of the three other types of fuel, the cetane number or cetane index meets the weight, namely 62. For the specific gravity of the fuel, it does not meet the specified standard characteristics, namely 815-860 Kg/m3, the test results show a figure of 786 Kg /m 3 . The resulting color of 2.5 still meets the quality standards for dexlite and biodiesel fuel, but does not meet the Pertamina Dex standard. This also applies to the resulting flash point of 54. The resulting viscosity meets the three fuel loads, namely 3,398 mm 2 /s. The water and sediment content produced by this fuel meets the standard, namely <0.05% m/m. The sulfur content of this raw material still meets the standard, namely 0.007% m/m. The resulting distillation still meets the requirements, namely 300 C. So based on the results of the analysis above and based on information from the lab test results at LABINKIMAT on November 9-15, the pyrolysis fuel still meets the existing specifications.

Diesel Engine Performance Calculations

The results of the tests that have been carried out produce these data which can be calculated using a certain formula to determine the Power, Torque, Fuel Consumption, Bmep, Sfoc, and Thermal Efficiency of a mixture of two fuels with the composition B0, B1, B2 on the performance of diesel motors at Table 2 is the result of calculating diesel motor performance which is calculated using a predetermined formula.
Table 2, Calculation results of diesel engine performance on pure plastic waste fuel (B0)

TABLE 2.
CALCULATION RESULTS OF DIESEL ENGINE PERFORMANCE ON PURE PLASTIC WASTE FUEL (B0)

100% PLASTIC PYROLYSIS FUEL									
Engine Speed		Voltage (Volt)	Current (A)	Power (kW)	Generator Torque (Nm)	BMEP (bar)	FC (kg/h)	SFC (gr/Kwh)	Thermal Eff (%)
(rpm) Control	(rpm) Actual								
1600	1609	160	7,39	1,38	8,21	2,09	0,53	386,06	21,6
1800	1812	189	8,03	1,78	9,36	2,38	0,60	339,17	24,5
2000	2010	211	8,53	2,11	10,01	2,55	0,76	363,29	22,9

TABLE 3.
CALCULATION RESULTS OF DIESEL ENGINE PERFORMANCE ON 80% PLASTIC WASTE FUEL + 20% DEX DIESEL (B1)

80% WASTE PLASTIC FUEL + 20% DIESEL DEX									
Engine Speed		Voltage (Volt)	Current (A)	Power (kW)	Generator Torque (Nm)	BMEP (bar)	FC (kg/h)	SFC (gr/Kwh)	Thermal Eff (%)
(rpm) Control	(rpm) Actual								
1600	1607	159	7,32	1,36	8,09	2,06	0,59	431,35	19,3
1800	1816	191	8,07	1,80	9,48	2,41	0,71	394,69	21,1
2000	2014	212	8,54	2,12	10,05	2,56	0,75	352,61	23,6

TABLE 4.
CALCULATION RESULTS OF DIESEL ENGINE PERFORMANCE ON 70% PLASTIC WASTE FUEL + 30% DEX DIESEL (B2)

70% WASTE PLASTIC FUEL + 30% DIESEL DEX									
Engine Speed		Voltage (Volt)	Current (A)	Power (kW)	Generator Torque (Nm)	BMEP (bar)	FC (kg/h)	SFC (gr/Kwh)	Thermal Eff (%)
(rpm) Control	(rpm) Actual								
1600	1610	162	7,34	1,39	8,25	2,10	0,55	395,34	21,1
1800	1809	193	8,06	1,82	9,61	2,45	0,65	357,44	23,3
2000	2012	214	8,55	2,14	10,16	2,59	0,80	371,86	22,4

Diesel Engine Performance Calculations

Diesel engine performance analysis can be carried out which includes Power, Torque, Bmep, Fuel Consumption, Specific Fuel Consumption , Thermal Efficiency. Matter This can show which type of fuel has quality and complies with quality standards in its use.

Effect of Using B0, B1 and B2 on Power

Power analysis of a diesel engine fueled by a mixture of plastic waste and dex diesel with the composition B0 (pure plastic waste), B1 (80% plastic waste + 20% dex diesel), B2 (70% plastic waste + 30% dex diesel) on rotational variations RPM 1600, 1800, 2000. It can be seen in figure 2.

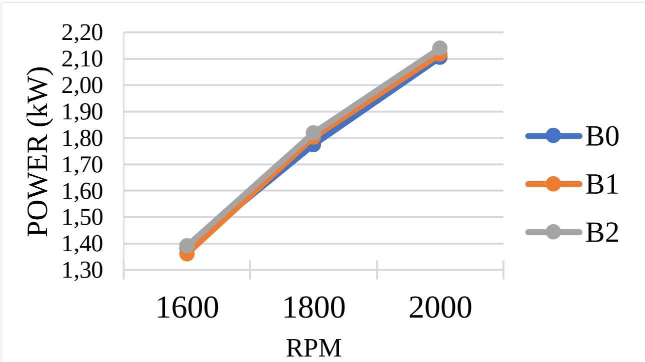

Figure. 2. Graph of the Effect of Engine Speed on Power and Fuel Composition

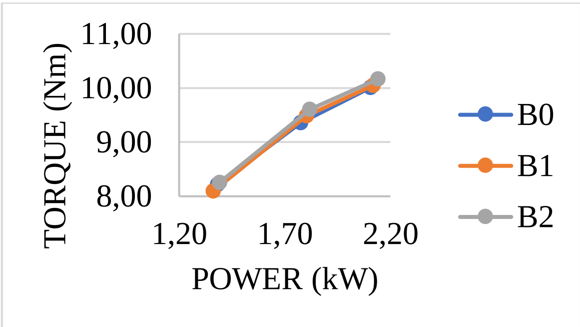

Figure. 3. Graph of the Effect of Power on Generator Torque with Fuel Variants

The graph above explains the relationship between power and torque. It can be seen in the picture that the graph experiences a constant increase for each type of fuel. B0 fuel with a power of 1.38 kW produces a generator torque of 8.2 Nm, B1 fuel with a power of 1.36 kW produces a generator torque of 8.09 Nm and B2 fuel with a power of 1.39 kW produces generator torque. of 8.25 Nm. From these results it can be concluded that the type of fuel does not affect the amount of power and generator torque because the difference in numbers is small

The Effect of Using B0, B1 and B2 on Fuel Consumption

Fuel Consumption or FC is a term used to measure the amount of fuel needed by an engine in a certain time. To measure the amount of FC requires data related to the mass of the fuel and the time required to calculate the fuel volume.

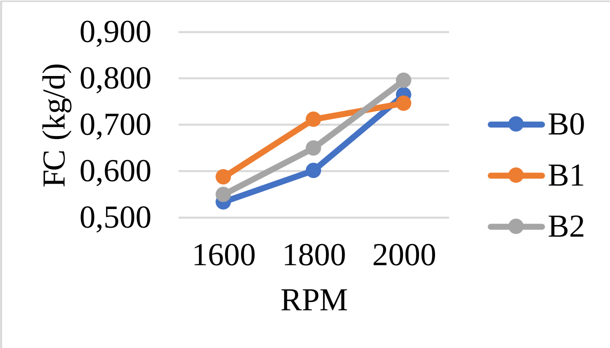

Figure 4. Graph of the Effect of Engine Speed on *Fuel Consumption* **(FC) with Fuel Composition**

The graph above shows the effect of engine speed on the FC value or fuel requirements used by the engine. The image shows a graphic pattern of increase in each type of fuel. At an engine speed of 1600 rpm, B0 fuel requires an FC of 0.53 kg/h and B1 fuel requires an FC of 0.58 kg/h, then B2 fuel requires an FC of 0.54 kg/h. These results explain that the type of fuel significantly influences the FC value because the difference in numbers varies, but the engine speed influences the FC value.

The Effect of Using B0, B1, and B2 on *Specific Fuel Consumption*

Specific fuel usage is defined as fuel usage per unit time (hour) to produce each unit of power (kW). The following are the test results regarding specific fuel usage on the engine speed and power produced.

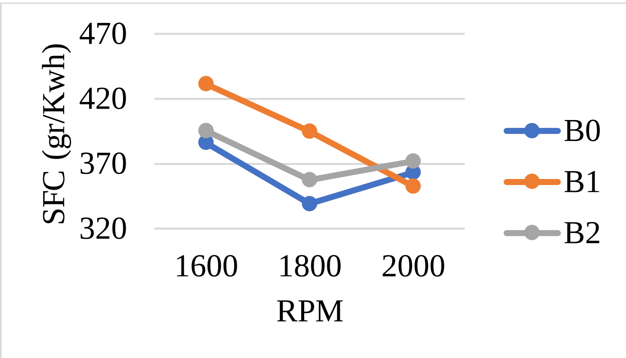

Figure 5. Graph of the Effect of Power on *Specific Fuel Consumption* **(SFC) With Various Types of Fuel**

Chart above shows the effect of power on the SFC value or specific fuel consumption used by the engine. The graph shows an irregular pattern for each type of fuel. B0 fuel with a power of 1.38 kW requires an SFC of 386.05 g/Kwh and decreases then increases as the power increases. B1 fuel with a power of 1.36 kW requires an SFC of 431.35 g/Kwh and decreases as the engine speed increases. B2 fuel with a power of 1.39 kW requires an SFC of 395.34 g/Kwh and decreases then increases as the engine speed increases. These results explain that the type of fuel influences the use of specific fuel on power.

Effect of Using B0, B1, and B2 Power Influence on Thermal Efficiency

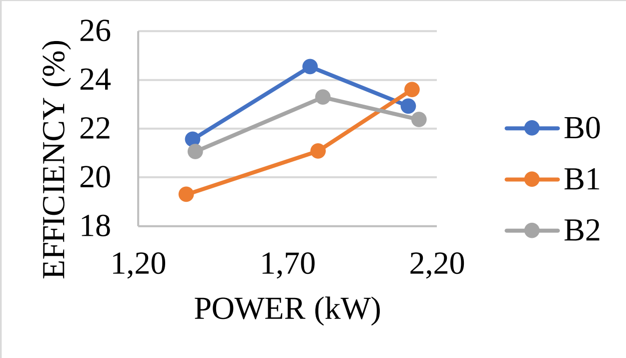

Figure 6. Graph of the Effect of Power on Thermal

Efficiency By Fuel Composition

The graph above shows the effect of power on thermal efficiency for each type of fuel . For example, B0 fuel at 1600 rpm rotation with a power of 1.38 kW has a thermal efficiency of 21.56%, while B1 fuel at 1600 rpm rotation with a power of 1.36 kW has a thermal efficiency of 19.30% and for fuel B2 at 1600 rpm with a power of 1.39 kW has a thermal efficiency of 21.05%. The results of this data explain that the types of fuel, even with the same parameters, have different thermal efficiencies.

Diesel Engine Performance Consequence Influence of Power on Break Mean Effective Pressure (BMEP)

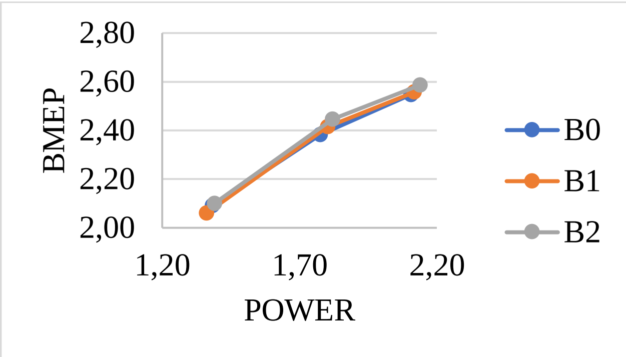

Figure 7. Graph of the Effect of Power on *Break Mean*

***Effective Pressure* (BMEP) with Various Types of Fuel**

The graph above shows the influence of power on BMEP for each type of fuel, where the graph experiences a constant increase for each type of fuel. At 1600 rpm, B0 fuel with a power of 1.38 kW has a BMEP of 2.09 bar, then B1 fuel with a power of 1.36 kW has a BMEP of 2.06 bar, then B2 fuel with a power of 1.39 kW has a BMEP of 2.10 bars. These results explain that the type of fuel does not affect the amount of power on BMEP, but BMEP tends to increase with increasing power.

Analysis of Exhaust Gas Emission Test Results

Based on the research and testing that has been carried out, the exhaust gas emission levels obtained are in the form of Carbon Dioxide (CO_2), Nitrogen Monoxide (NO), Nitrogen Dioxide (NO_2), Nitrogen Oxide (NOx), Nitrogen *Species* (NS), Nitrogen (N), Potassium (K) with varying engine rotation speeds, namely 1600 rpm, 1800 rpm and 2000 rpm. The results of this analysis are explained in table 5, table 6 and table 7 which show the results of measuring exhaust emissions using B0 fuel (100% pure plastic waste), B1 fuel (80% plastic waste + 20% dex diesel), fuel B2 (plastic waste 70% + diesel dex 30%).

TABLE 5.
RESULTS OF EMISSION CONTENT IN B0 FUEL

100% WASTE PLASTIC PURE FUEL							
Round (RPM)	CO (%vol)	NO (10^{-6})	NO_2 (10^{-6})	NOx Gr/kWh	Ns (%)	N (%)	K (m^{-1})
1600	1,68	157	41	198	3,4	1,7	0,08
1800	2,05	168	46	214	3,8	1,9	0,09
2000	2,2	188	36	224	2,3	2,3	0,11

TABLE 6.
RESULTS OF EMISSION CONTENT IN B1 FUEL

80% PLASTIC WASTE FUEL + 20% DIESEL DEX							
Round (RPM)	CO (%vol)	NO (10^{-6})	NO_2 (10^{-6})	NOx Gr/kWh	Ns (%)	N (%)	K (m^{-1})
1600	1,74	146	36	182	3,9	1,9	0,09
1800	1,91	142	35	177	4,1	2,1	0,1
2000	2,03	178	40	218	4,5	2,3	0,11

TABLE 7.
RESULTS OF EMISSION CONTENT IN B2 FUEL

70% PLASTIC WASTE FUEL + 30% DIESEL DEX							
Round (RPM)	CO (%vol)	NO (10^{-6})	NO_2 (10^{-6})	NOx Gr/kWh	Ns (%)	N (%)	K (m^{-1})
1600	1,58	150	25	174	3,8	1,9	0,09
1800	1,82	141	26	167	3,8	1,9	0,09
2000	2,15	160	24	185	4,4	2,2	0,1

Results of Analysis of Fuel Composition on CO_2 Content

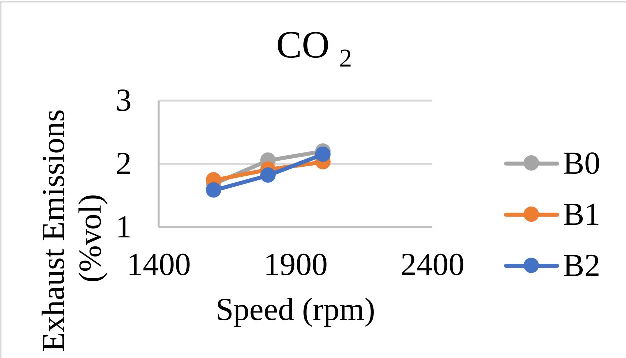

Figure 8. Graph of the Effect of Engine Speed and Fuel

Type on CO2 *output* with a load of 2000 kW

The graph above shows the CO2 gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel with a loading of 2000 kW. It can be seen in the graph that CO2 exhaust emissions have increased for each fuel. At 1800 rpm, B0 fuel exhaust gas emissions contain carbon dioxide (CO2) of 2.05 % vol and B1 fuel exhaust gas emissions contain CO2 of 1.91% vol, then B2 fuel exhaust gas emissions contain CO2 of 1.82 %vol. These results explain that the fuel mixture influences the content of $CO_{2\ \text{exhaust emissions}}$, where the more Dex diesel mixed with plastic waste fuel, the less $CO_{2\ \text{content}}$ in exhaust emissions.

Results of Fuel Composition Analysis of NO Content

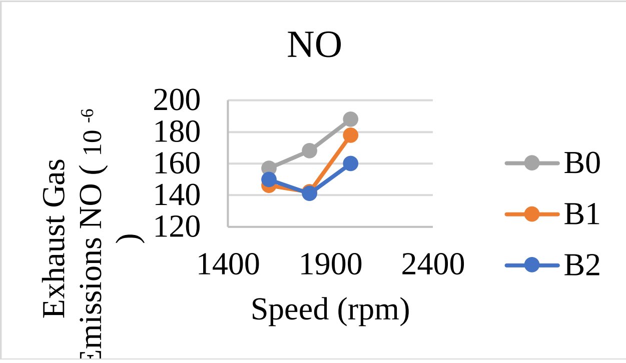

Figure 9. Graph of the Effect of Engine Speed and Fuel Type on NO *output* with a load of 2000 kW

The graph above shows the NO gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the graphic image of NO exhaust gas emissions experienced an irregular increase in each fuel. At 2000 rpm, B0 fuel exhaust gas emissions contain nitrogen monoxide (NO) of 188 (10^{-6}) and B1 fuel exhaust gas emissions contain NO of 178 (10^{-6}) then B2 fuel exhaust gas emissions contain NO of 160 (10^{-6}). These results explain that the fuel mixture influences the NO content of exhaust gas emissions, where the more Dex diesel mixed with plastic waste fuel, the less NO content in exhaust gas emissions.

Results of Fuel Composition Analysis of NO_2 Content

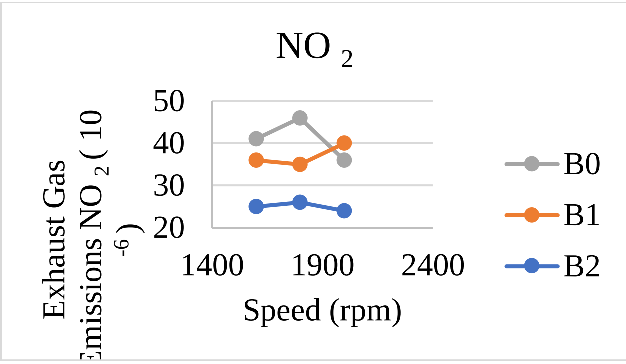

Figure 10. Graph of the Effect of Engine Speed and Fuel

Type on NO_2 *output* with a load of 2000 kW

The graph above shows the NO2 gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the picture are NO2 exhaust emissions has an irregular graphic pattern for each fuel. At 1600 rpm, exhaust gas emissions from B0 fuel contain nitrogen dioxide (NO2) of 41 (10^{-6}) and then increase and then decrease as engine speed increases. At 1600 rpm, exhaust gas emissions from B1 fuel contain NO2 of 36 (10^{-6}) then decrease and then increase as the engine speed increases. At an engine speed of 1600 rpm, exhaust gas emissions from B2 fuel contain NO2 of 25 (10^{-6}) and then increase and then decrease as the engine speed increases. These results explain that the fuel mixture influences the NO2 content of exhaust gas emissions, where the more Dex diesel mixed with plastic waste fuel, the less NO2 content in exhaust emissions.

Results of Fuel Composition Analysis of NO_X Content

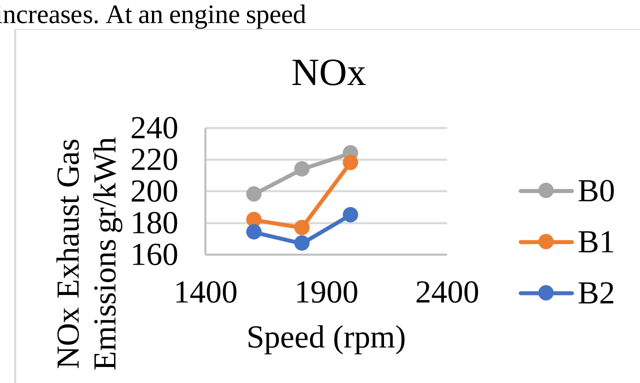

Figure 11. Graph of the Effect of Engine Speed and Fuel

Type on NOx *output* with a load of 2000 kW

The graph above shows the NOx gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the graphic image of NOx exhaust gas emissions experienced an irregular increase in each fuel. At 1600 rpm, exhaust gas emissions from B0 fuel contain nitrogen oxides (NOx) of 198 gr/kWh and exhaust emissions from B1 fuel contain NOx of 182 gr/kWh, then exhaust gas emissions from B2 fuel contain NOx of 174 gr/kWh. These results explain that the fuel mixture influences the NOx content of exhaust gas emissions, where the more Dex diesel fuel mixed with plastic waste fuel, the lower the NOx content in exhaust gas emissions.

Results of Fuel Composition Analysis of NS Content

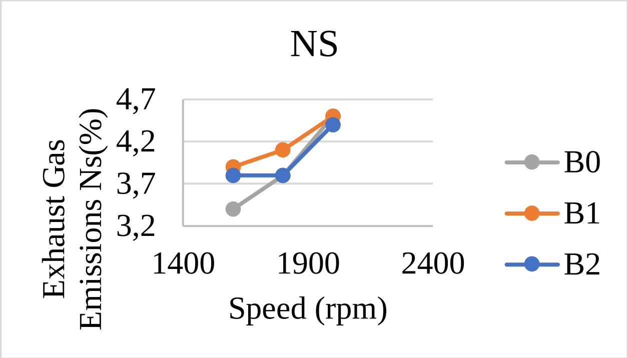

Figure 12. Graph of the Effect of Engine Speed and Fuel

Type on NS *output* with a load of 2000 kW

The graph above shows the Ns gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the graphic image of exhaust gas emissions Ns increases with each fuel. At 1600 rpm, B0 fuel exhaust gas emissions contain 3.4 % nitrogen species (Ns) , B1 fuel exhaust gas emissions contain 3.9% Ns, then B2 fuel exhaust gas emissions contain 3.8% Ns. These results explain that the fuel mixture influences the exhaust gas emission content Ns.

Results of Fuel Composition Analysis of N Content

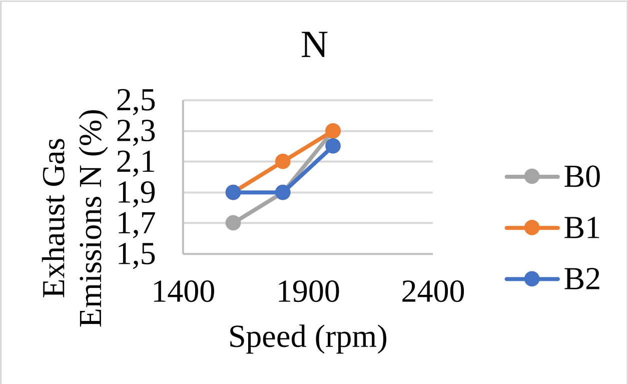

Figure 13. Graph of the Effect of Engine Speed and Fuel

Type on Nitrogen *output* with a load of 2000 kW

The graph above shows the N gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the graphic image of N exhaust gas emissions increases with each fuel. At 1600 rpm, B0 fuel exhaust gas emissions contain 1.7% nitrogen (N), B1 fuel exhaust gas emissions contain 1.9% N, then B2 fuel exhaust gas emissions contain 1.9% N. These results explain that the fuel mixture influences the N content of exhaust gas emissions, where the more Dex diesel mixed with plastic waste fuel, the less N content in exhaust gas emissions.

Results of Fuel Composition Analysis of K Content

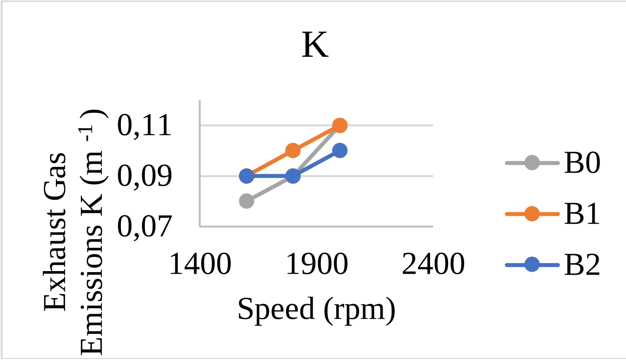

Figure 14. Graph of the Effect of Engine Speed and Fuel

Type on Potassium *output* with a load of 2000 kW

The graph above shows the K gas content in exhaust gas analysis research on a mixture of plastic waste fuel and dex diesel fuel with a loading of 2000 kW. Seen in the graphic image of exhaust gas emissions K increases with each fuel. At 1600 rpm, B0 fuel exhaust gas emissions contain potassium (K) of 0.08 m^{-1} and B1 fuel exhaust gas emissions contain K of 0.09 m^{-1} then B2 fuel exhaust gas emissions contain K of 0, 09 m^{-1}. These results explain that the fuel mixture influences the K content of exhaust gas emissions, where the more Dex diesel mixed with plastic waste fuel, the less K content in exhaust gas emissions.

Diesel Engine Performance Analysis Results on the Composition of B 0 , B1 and B2.

Based on the performance test results of diesel motors fueled by pyrolysis of plastic waste and a mixture of diesel dex with a predetermined composition, it can be seen from all the graphs on the *trendline* that B1 fuel is more optimal at high engine speeds of 2000 rpm. However, the highest power is in B2 , namely 2.14 kW with a difference between B1 fuel of 2.12 kW, B0 of 2.11 kW. For torque, B2 produces 10.16 Nm of torque with a difference between B1 of 10.05 Nm, and B0 with a difference of 10.01. The BMEP produced by B2 fuel is 2.59 bar, which is different from B1, 2.56 bar, and B0, 2.55. However, in terms of *Specific Fuel Consumption* and Thermal Efficiency, B1 fuel is superior to B0 and B2, the SFC results obtained by B1 were 352.61 gr /kWh with a difference from B0 of 363.29gr/kWh and a fairly large difference from B2 of 371.86. gr/kWh and superior Thermal Efficiency for B1 fuel, the resulting value is 23.6% with a difference between B0 of 22.9% and B2 with a difference of 22.4%.

With B0 fuel, the influence in terms of *Specific Fuel Consumption* is less effective for diesel motors because it is wasteful to use, this is because the fuel resulting from pyrolysis has a cetane number of 62 which is relatively high so that the fast combustion reaction makes the engine work to produce large amounts of power. For fuel consumption and thermal efficiency, B0 fuel is still below B1 fuel. Because the fuel resulting from the pyrolysis of plastic waste is still at the development stage, it is necessary to mix the fuel so that it is easier for people to use it.

NOx Emission analysis results for each composition B 0, B1 and B2.

The IMO MARRPOL annex VI regulations regarding emissions are written in several TIERs, one of which is TIER III which came into effect on January 1 2016, in TIER III the NOx emission limits are regulated. To determine whether the NOx emissions from the test results meet or exceed the limits as written in MARRPOL *annex* VI TIER III, a comparison is made between the NOx values from the test results and the NOx values set by MARRPOL *annex* VI.

The tests carried out were using the fuel variation method and engine rotation variations with direct loading, the load used was a lamp with a load of 2000 kW, and consisted of three variations of engine speed, namely 1600, 1800, 2000, on B0, B1, B2 fuel.

To limit the value of Nitrogen Oxide (NOx) in diesel engines, the IMO TIER III Standard is used where the NOx emission limit is 3.4 gr /kWh. In this study, the average NOx emissions in B0 fuel were 174 gr/kWh – 185 gr/kWh, B1 fuel was 182 gr/kWh – 218 gr/kWh and B2 fuel was 198 gr/kWh – 224 gr/ kWh, it can be said that there is no comparison for each fuel composition with NOx content because the difference in numbers is small. Therefore, NOx emissions for each type of fuel have met MARRPOL *annex* VI TIER III standards with a difference in figures that is far below the figures set by the IMO (International Maritime Organization).

IV. CONCLUSION

After conducting research on loading in the form of a 2000 kW lamp with variations in fuel and engine speed, it was discovered that the effective result was B1 fuel. Because of the data The research above on the graph on the trendline is quite optimal and effective to use on B1 fuel if used in diesel engines . The power produced by B1 is 1.36 kW to 2.12 kW. SFC B1 produces 431.35g/kWh to 352.61g/kWh. For efficiency, B1 produces 19.3% to 23.6%. For torque, bmep, and fc produce values that are directly proportional to engine speed.

The use of a mixture of plastic waste fuel and diesel dex will affect the content of exhaust emissions, one of which is Nitrogen Oxide (NOx), where the NOx emission limit is 3.4 gr /kWh. The research results showed that the average NOx emissions in B0 fuel were 174 gr/kWh – 185gr/kWh, B1 fuel was 182gr/kWh – 218gr/kWh and B2 fuel was 198gr/kWh – 224gr/kWh. So the NOx emissions for each type of fuel have met the Marpol Annex VI regulation 13 TIER III standards with a difference in figures that is far below the figures set by the IMO (International Maritime Organization).

AKNOWLEDGEMENTS

Thanks are expressed to all parties who have helped run this research, including; BLH District. WLingi, Blitar Regency, which has permitted the manufacture of fuel from plastic waste, and the Indonesian Navy's Chemical and Materials Main Laboratory which has permitted the property testing. and the ITS Surabaya Ship Engine Laboratory (MPP) which has permitted performance and emissions testing.

REFERENCES

[1] W.-K. Chen, Linear Networks and Systems.Belmont,CA: Wadsworth, 1993, pp. 123–135.
[2] Ain, AU (2020). Processing Plastic Waste into Fuel Oil. Banjarmasin: Lambung Mangkurat University Press, 2020.
[3] Ariadji, T. (2022). Ministry of Energy and Mineral Resources. Ministerial Regulation.
[4] Cappenberg, A.D. (2017). The Effect of Using Diesel, Biosolar and Pertamina Dex Fuel on the Performance of Single Cylinder Diesel Motors. Journal of Energy Conversion and Manufacturing.
[5] Eko Arif Syaefuddin, ZK (2012). Plastic Fuel Oil Mixture Testing. Journal of Mechanical Engineering,
[6] Julia Ascha Randis, A.R. (2021). processing plastic waste using the pyrolysis method into fuel oil. Chemurgy Journal,
[7] Nasrun, E.K. (2015). Processing Plastic Bag Waste into Fuel Using the Pyrolysis Process. Journal of Electrical Energy,
[8] Hadi Prasution, SF (2021). Ship Fuel. Pekalongan, Central Java: Pt. Nasya Expanding Management.
[9] Nursujianto, T. (2013). Diesel Motor Performance Using a Mixture of Oil from Pyrolysis of Plastic Waste and Biodiesel as an Alternative Fuel. Public Manuscripts.
[10] PINTO, F. (2018). Analysis of the Effect of Iodine Numbers on NOx Emissions in Diesel Motors Using Biodiesel Fuel from Waste Cooking Oil with IMO TIER III Standards. Marine Systems and Control Engineering.
[11] Saiful Irfan, HP (2018). Comparative Study of Diesel Engine Exhaust Emissions Using Diesel Fuel and Virgin Coconut Oil. Engineering Study Program, Surabaya Shipping Polytechnic.
[12] Silmi, F.A. (2021). Exhaust Gas Emission Test for Plastic Shredding Machines Using Diesel Fuel, Dexlite, and Pertamina Dex. DIII Mechanical Engineering Study Program, Harapan Bersama Polytechnic.
[13] Sugianto, E, (2023). The Effect Of Wave Length And Amplitude on The Hydrodynamic Characteristics of Waste Collection Vessels Using Computational Fluid Dynamics (CFD).
[14] Yusanto, TH (2023). Design and Performance Testing of a 3D Printed Mini DC Powered Pump for Microbubble Generator.
[15] Pertamina. (2023). Retrieved From Https://Onesolution.Pertamina.Com/Insight/Page/Ini-Dia-Jenis-Bahan-Bakar-Mesin-Diesel-Pertamina.
[16] Baroroh, I. (2023). Risk Evaluation of Ship Repair Delays with The Failure Modes and Effects Analysis (FMEA) Method.