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Original Article

Investigation of Performance Characteristics of Plastic Pyrolysis Oil and Crude Palm Oil Fuel on Diesel Engine

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Abstract - *Nowadays, with the increment of fossil fuel engines, there have been facing the downside of a fuel problem, and the survival of those engines has been vulnerable. The dependency on a single source which is a fossil fuel is a worrying issue because the fossil fuel is limited and takes millions of years to produce. In this paper, the performance of the alternative fuels on a diesel engine is analyzed and compared with the standard diesel to determine its compatibility with the diesel engine without any modification. The research study of the performance of plastic pyrolysis oil and crude palm oil blended with diesel at a different concentration which is 20% and 25%, on automotive 4 stroke diesel engine test system were illustrated in this paper. The brake power engine, thermal brake efficiency, brake specific fuel consumption, and exhaust temperature of the blended fuels are recorded and analyzed. The value of brake-specific consumption decreases as the concentration of the pyrolysis oil increases while thermal brake efficiency is increased. The blended fuels recorded lower brake thermal efficiency, brake-specific fuel consumption, and higher exhaust gas temperature compared to standard diesel fuel. In the aspect of performance of the diesel engine, the uses of crude palm oil and plastic pyrolysis oil are usable and applicable.*

Keywords — *Diesel, Pyrolysis, Biodiesel, Mechanical, Engine.*

I. INTRODUCTION

As a developing country, the demands for energy resources have increased each year. Fossil fuels have become the highest demand for many countries, including Malaysia [1-4]. It is important not to depend on a single source since the source is limited and non-renewable. Fossil fuel is formed by the dead and decaying plants and animals that happened millions of years ago. Depending too much on these sources can lead to over-extraction of fossil fuel, and it will be reduced significantly. Furthermore, the demand for diesel keeps growing, but the amount of fossil diesel keeps decreasing in the amount. Researchers keep finding another source in order to fulfill the demand for energy resources, thus reducing the dependency on fossil fuels [5-8].

Despite the advantages of alternative fuels such as biodiesel, this type of fuel that have their own unique fuel properties have their own challenges because usually, this type of fuel has high octane numbers, and its viscosity is also high compared to standard diesel [8-10]. All of these elements of the alternative fuels can bring different outcomes on the performance characteristic of the diesel engine. With analysis and improvement of the biodiesel fuels were vital to cut back the reliance on diesel oil. It's a necessity that different fuels ought to be produced from domestic supplies and ideally sustainable supplies. The alternate fuels, aside from sustainable, will be needed to help in reducing the emission exhausted, and plenty of researchers according that the performances of biodiesel fuels are comparable with standard diesel oil. Many advanced European countries have begun to implement biodiesel fuels as a primary fuel instead of standard diesel oil [11-12].

The diesel engine was invented in 1982 by Rudolf Diesel. At initial, he designed his engine to be powered by the coal dust as fuel and some other fuels such as vegetable oil which is peanut oil [13-15]. This peanut oil as fuel was invented and exhibited at the 1900 Paris Exposition and the 1911 World's Fair in Paris. Then later, he invented a compression-ignition engine that uses diesel as fuels that can be produced by various sources such as petroleum, which is the common, biomass, animal fat, biogas, coal liquefaction, and natural gas [2]. The diesel fuel is still being used till now, although many countries started to use another alternative fuel after developing worry of the earth and the impact of ozone harming substances likewise had accumulated an ever-increasing number of the utilization of vegetable oils [3,15-16].

Malaysia's total energy demand rose from 1,243.7 petajoules in 2000 to 2,217.9 petajoules in 2010, as shown in Table 1. Petroleum products (from crude oil) were the main demand in 2000 at 65.9%, followed by electricity (using gas, coal, and oil) at 17.7%, natural gas at 13.0%, and coal and coke at 3.4%. Compared to 2010, dependence on crude oil and petroleum products has decreased by 4.0 %, while dependence on coal and coke has increased by 1.2 %, indicating progress in government efforts to reduce overall dependence on a single source and develop renewable energy [4]. Compared to other sources, biomass appears to have great potential as a source of renewable energy. Using biomass as an energy source could help reduce waste and minimize dependence on non-renewable energy, thereby minimizing environmental degradation. Table 2 below shows the value of Malaysia's waste composition, and it states that increasing trend year by year [5-6]. This problem can be solved by transforming this waste into biomass energy such as plastic pyrolysis oil (PPO) and tire pyrolysis oil (TPO). Biodiesel is non-dangerous, biodegradable, and sustainable diesel fuel and can be utilized perfectly or mixed with oil diesel fills. Among other biomass types, oil palm waste is a major contributor to Malaysia's energy production since Malaysia is one of the. As the world's leading palm oil producer, the plantation area currently covers approximately 5 million hectares. Only 10 % of the oil palm is produced, and others are transforming into waste in the oil palm mill.

Table 1: Malaysia Final Commercial Energy Demand (200-2017) [4]

Source	Ave. energy demand (Petajoules)			Percentages of total (%)			Average annual growth rate (%)	
	2000	2005	2010	2000	2005	2010	8th MP*	9th MP*
Petroleum Product	820.0	1023.1	1372.9	65.9	62.7	61.9	4.5	6.1
Natural Gas	161.8	246.6	350.0	13.0	15.1	15.8	8.8	7.3
Electricity	220.4	310.0	420.0	17.7	19.0	18.9	7.1	6.3
Coal & Coke	41.5	52.0	75.0	3.4	3.2	3.4	4.6	7.6
Total	1243.7	1631.7	2217.9	100.0	100.0	100.0	5.0	6.3

MP* = Malaysian Plan

Table 2: Malaysia's Waste Composition

Waste Composition	1975	1980	1985	1990	1995	2000	2005
Organic	63.7	54.4	48.3	48.4	45.7	43.2	44.8
Paper	7.0	8.0	23.6	8.9	9.0	23.7	16
Plastic	2.5	0.4	9.4	3.0	3.9	11.2	15
Glass	2.5	0.4	4.0	3.0	3.9	3.2	3.0
Metal	6.4	2.2	5.9	4.6	5.1	4.2	3.3
Textiles	1.3	2.2	NA	NA	2.1	1.5	2.8
Wood	6.5	1.8	NA	NA	NA	0.7	6.7
Others	0.9	0.3	8.8	32.1	4.3	12.3	8.4

II. STANDARD BIODIESEL SPECIFICATION AND PROPERTIES

There are two biodiesel standards mostly used in Malaysia which are European Biodiesel Standard (EN 14214) and the B100 Blend Stock for Distillate Fuels (ASTM D6751) Standard Specification for Biodiesel Fuel. The standard implication was to let the researcher who would like to study biodiesel know the standard of the fuel to be used and the content of the blended diesel fuel in this standard. Biodiesel fuel properties have been measured based on density, heating value, viscosity, flash point and pour point, water content, and carbon residue that have a greater impact on engine performance and emissions. Table 3 shows the European Biodiesel Standard (EN 14214), and Table 4 shows the B100 Blend Stock for Distillate Fuels Standard Specification (ASTM D6751).

Table 3: European Standard for Biodiesel (EN 14214)

Property	Unit	Limits		Test method
		Minimum	Maximum	
Ester content	% (m m^{-1})	96.5	-	pr EN 14103
Density at 15°C	kg m^{-3}	860	900	EN ISO 3675 EN ISO 12185
Viscosity at 40°C	mm^2 s^{-1}	3.5	5.0	EN ISO 3104
Flash point	°C	120	-	ISO/CD 3679
Carbon residue (on 10% distillation residue)	% (m m^{-1})	-	0.3	EN ISO 10370
Acid value	mg KOH g^{-1}	-	0.5	pr EN 14104
Cetane index	-	51.0	-	EN ISO 5165
Sulphur content	mg kg^{-1}	-	10	-
Sulphated ash content	% (m m^{-1})	-	0.02	ISO 3987
Water content	mg kg^{-1}	-	500	EN ISO 12937
Total contamination	mg kg^{-1}	-	24	EN 12662
Copper strip corrosion (3 hr at 50°C)	Rating	1	-	EN ISO 2160
Oxidation stability, 110°C	hr	6.0	-	pr EN 14112
Iodine value	-	-	120	pr EN 14111
Linolenic acid methyl ester	% (m m^{-1})	-	12	pr EN 14103
Polyunsaturated (≥4 double bonds) methyl esters	% (m m^{-1})	-	1	-
Methanol content	% (m m^{-1})	-	0.2	pr EN 14110
Monoglyceride content	% (m m^{-1})	-	0.8	pr EN 14105
Diglyceride content	% (m m^{-1})	-	0.2	pr EN 14105
Triglyceride content	% (m m^{-1})	-	0.2	pr EN 14105
Free glycerol	% (m m^{-1})	-	0.02	pr EN 14105 pr EN 14106
Total glycerol	% (m m^{-1})	-	0.25	pr EN14105
Alkaline content (Na + K)	mg kg^{-1}	-	5	pr EN 14108 pr EN 14109
Phosphorus content	mg kg^{-1}	-	10	pr EN14107

Source: European Committee for Standardization (CEN) (2003).

Table 4: B100 Blend Stock for Distillate Fuels Standard Specification (ASTM D6751).

Property	Unit	Grade S15 Limits	Grade S500 Limits	Test method
Kinematic viscosity at 40°C	$mm^2 s^{-1}$	1.9-6.0	1.9-6.0	ASTM D445
Flash point (closed cup)	°C	130.0 min	130.0 min	ASTM D93
Sulphur content	% mass (ppm)	0.0015 max (15)	0.05 max (500)	ASTM D5453
Carbon residue (on 100% distillation residue)	% mass	0.050 max	0.050 max	ASTM D4530
Acid number	mg KOH g^{-1}	0.80 max	0.8 max	ASTM D664
Cloud point	°C	Report*	Report*	ASTM D2500
Cetane number	-	47 min	47 min	ASTM D613
Sulphated ash content	% mass	0.020 max	0.020 max	ASTM D874
Water and sediment	% volume	0.050 max	0.050 max	ASTM D1796
Copper strip corrosion (3 hr at 50°C)	rating	No. 3 max	No. 3 max	ASTM D130
Free glycerol	% mass	0.020	0.020	ASTM D6584
Total glycerol	% mass	0.240	0.240	ASTM D6584
Phosphorus	% mass	0.001 max	0.001 max	ASTM D4951
Distillation temperature (90% recovered)	°C	360 max	360 max	ASTM D1160

Note: * The cloud point of biodiesel is generally higher than that of petroleum-based diesel fuel and should be taken into consideration when blending.

Source: ASTM International (2003).

III. METHODOLOGY

To make sure this project runs smoothly according to the timeframe that has been set, the flowchart is made as shown in Figure 1 below, and the project starts with identifying and preparing all the types of equipment and materials needed to accomplish the objectives. For this project, the equipment needed is such as fuel blending machine, test diesel engine, emission test machine, and others, while for the materials is such as standard diesel, plastic pyrolysis oil, crude palm oil, and so on. Next, all the fuels, which are the plastic pyrolysis oil and crude palm oil, are blended into CPO20, CPO25, PPO20, and PPO25 before it tested in the test diesel engine. In the engine performance testing process, each fuel is tested on the diesel engine at a different speed to measure its emission production and engine. The value of torque, brake thermal efficiency, exhaust temperature, and brake specific fuel consumption (BSFC) was measured. Then, the experimental result will be analyzed in order to investigate the performance of each fuel.

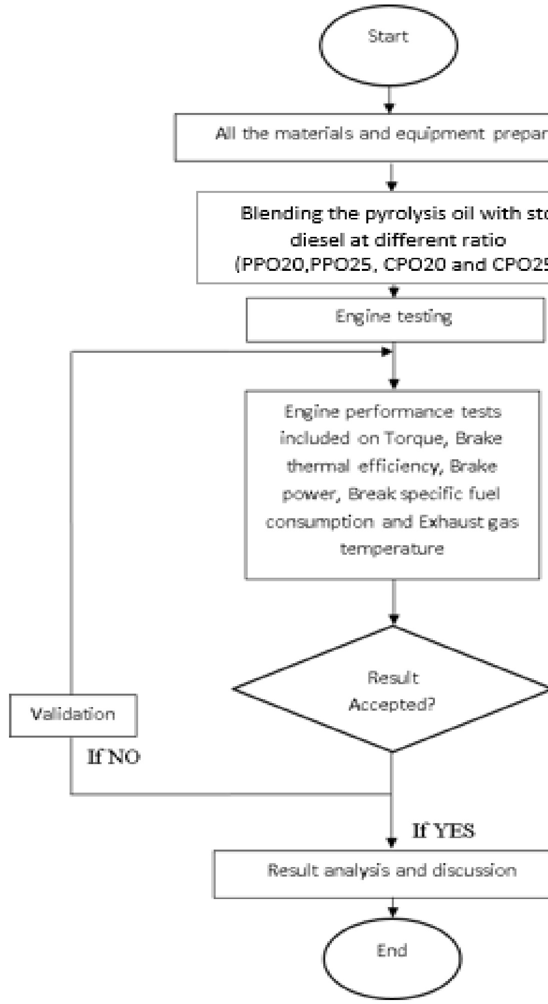

Fig. 1 Flowchart of the project

For the test engine, we use a Double Cylinder Four Stroke Diesel Engine. The specification of the diesel engine can be observed in Table 5.

Table 5: Test engine specifications

Maker	Tata
Model	TATA 275 IDI Diesel
Type	Air-cooled, compression ignition
Compression ratio	21:1
No. of cyl.	Two
No. of stroke	Four
Max. Power outp.	16 HP at 3200 rpm
Max. Torque	38 Nm at 2000rpm
Displacement	702 cm^3
Bore	75mm
Stroke	79.5mm
Method of starter	Asynchronous motor

An Eddy Current Dynamometer has been used in this experiment. The purpose of this dynamometer is to collect the data based on the engine performance and operating parameters such as brake power, brake specific fuel consumption (BSFC), brake the r male efficiencies (BTE), torque, and also engine speed. The specifications of this dynamometer are shown the Table6.

Table 6: Specifications of Eddy Current Dynamometer

Model	TMEC-20
Cooling	Water
Type	Eddy current
Load Measurement method	Strain gauge
Max. power	15 BHP
Cooling Water Flow rate	~14 – 15 lit/min
Min. water pressure	~ 1.6 bar

IV. RESULTS AND DISCUSSIONS

Based on the experiment, all results obtained will be analyzed and discussed in this chapter. The experiment used two types of alternative fuels (Plastic Pyrolysis oil and Crude Palm Oil) with different ratios (20% and 25%) and standard diesel. To achieve the objective, the test engine is run with those fuels at 0% load at a different speed which RPM being 1200, 1400, 1600, 1800, and 2000. The test engine's output (torque, brake power, fuel flow rate, and so on) are recorded as results and will be analyzed to investigate the effect of the alternative fuels on the engine performance of the diesel engine.

A. Effect of Engine Speed towards Engine Performance

Figure 2 shows that the effects of engine speed on the engine performance for the standard diesel, PPO20, PPO25, CPO20, and CPO25. All fuels were run in a diesel engine with different speeds (which RPM are 1200, 1400, 1600, 1800, and 2000.) Figure 2 also shows that the value of torque and brake power is directly proportional to the engine speed. It shows that as the engine speed is increasing, those two values also increase for all types of fuels. This is because as the speed of the engine is increases and the force value also increases; thus, the value of torque and brake power also increases.

For brake-specific fuel consumption (BSFC), it shows the inversely proportional trends towards the engine speed for all types of fuels. The lowest BSFC for PPO 20, PPO25, CPO20, CPO25 and standard diesel is at 2000 rpm which are 0.636, 0.557, 0.549, 0.565 and 0.344 while the highest value is at 1200 rpm engine speed which are 1.191, 0.849, 1.235, 1.235 and 0.900.

Therefore, for the thermal brake efficiency (BTE), it shows the directly proportional trend towards the engine speed for all types of fuels. At1200 rpm of engine speed, all fuels show that the thermal brake efficiency of all fuels are quite similar, and not much difference in value, but as the engine speed is increase, the value of the BTE is also increasing, and the value of the BTE started shows the difference in value between all fuels. The BTE recorded the highest value at 2000rpm for PPO20, PPO25, CPO20, CPO25, and standard diesel are 3.35, 4.71, 3.37, 3.14, and 3.45.

The value of the gas temperature increase as the engine speed is the increases for all types of fuels. Figure 2 shows the highest gas temperature is at 2000 rpm for PPO20, PPO25, CPO20, CPO25, and standard diesel, which are 163℃, 167℃,156℃,165℃, and 154℃, while the lowest gas temperature is at the 1200rpm for all fuels type which are 86℃,89℃,106℃,87℃, and 82℃,

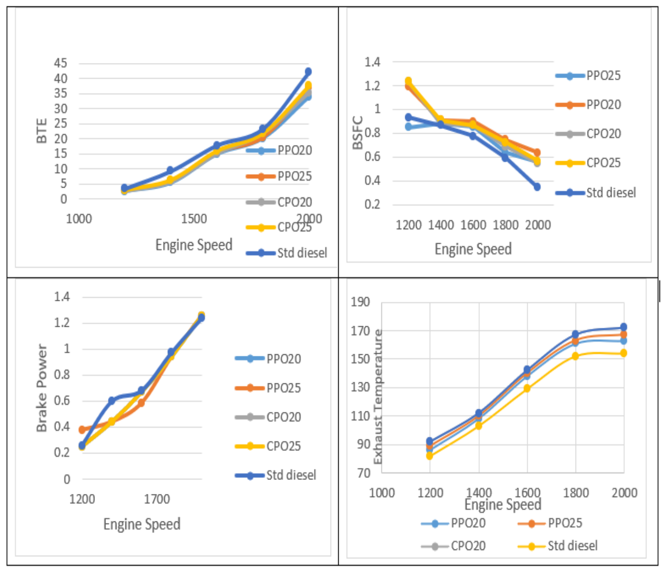

Fig. 2Brake Power, BTE, BSFC, and EGTagainst Engine Speed

B. Effect of Fuel Blending Ratio towards Diesel Engine Performance

The fuels with different blending ratios, PPO20, PPO25, CPO20, and CPO25, are used in a diesel engine to investigate the relationship between the concentration of the pyrolysis oil and the performance of the diesel engine. To achieve that, each fuel is tested out at the test diesel engine, and data at set engine speed are collected to calculate the value of engine torque, brake power, exhaust temperature, thermal brake efficiency (BTE), and brake specific fuel (BSFC) as shown in Figure 3.

As shown in Figure 3, the value of brake power and torque for both blended fuels have no significant differences when the blending ratio of the fuels is increasing. This shows that there is no effect on fuel properties if the difference of blended ratio is only 5%. The value of the brake power for both blended fuels is increase as the engine speed is increase.

Figure 3 also shows that the value of brake-specific consumption for both blended fuels at 20% (PPO20, CPO20) is higher than the blended fuels at 25% (PPO25, CPO25). This is because of several factors, and one of them is the lower calorific value of plastic pyrolysis oil and crude pyrolysis oil compared to standard diesel. By increasing the concentration of plastic pyrolysis oil and crude palm oil in the blended fuels, it will affect the fuel properties, thus resulting in the high value of brake specific consumption compared with the standard diesel.

Based on Figure 3 shows that the value of the thermal brake efficiency (BTE) is directly proportional to the percentage of the blended fuel. As explained before, an increasing percentage of the blended fuels will affect the properties of the fuels that result in the higher value of BTE. Exhaust gas temperature (EGT) increased for all types of blended fuels as the concentration of the pyrolysis oil is increased, shown in Figure 3.

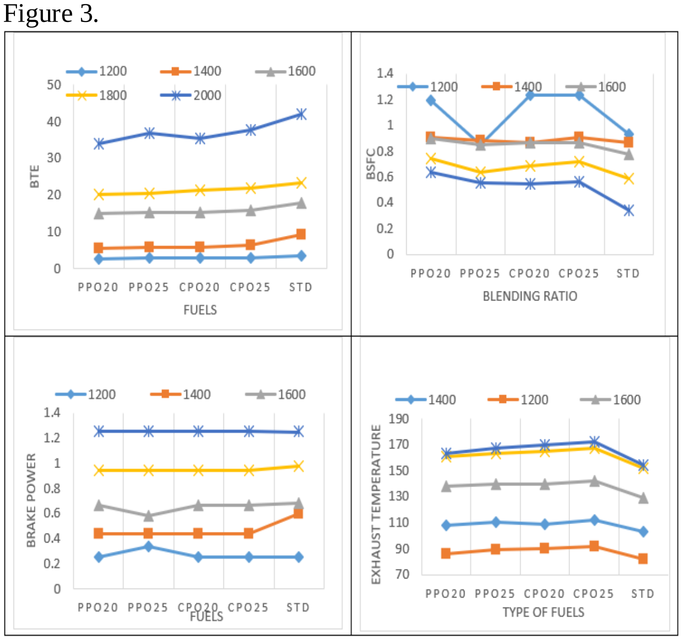

Fig. 3 Brake Power, BTE, BSFC, and EGT against Type of Fuel

C. The Comparison of Blended fuels with Standard types of diesel towards the diesel engine performance

Figure 4 shows variant brake-specific fuel consumption (BSFC) against brake power for blended fuels and standard diesel. It shows that the blended fuels (PPO20, PPO25, CPO20, and CPO25) have higher brake-specific fuel consumption than the standard diesel. This is caused by the calorific value of the plastic pyrolysis oil, and crude palm oil is lower than standard diesel. Calorific value is the energy contained in fuel or food, determined by the measurement of the heat produced by the combustion of a specified quantity. Typically, this is measured in joules per kilogram. The graphs also show the increasing pattern of brake-specific fuel consumption of blended fuels proportional to the percentage of the blended fuels. These are caused by the lower calorific value of plastic pyrolysis oil and crude palm oil compared to standard diesel, and increasing the percentage of pyrolysis oil will affect the calorific fuel value. Lower calorific value causes the test diesel engine to consume more fuel to develop the same amount of power. Even though the standard diesel has a lower BSFC value compared to blended fuels, the values are only have slightly different and still acceptable. Thus, in terms of fuel consumption, both blended fuels (PPO and CPO) are applicable to be used in a diesel engine without modification.

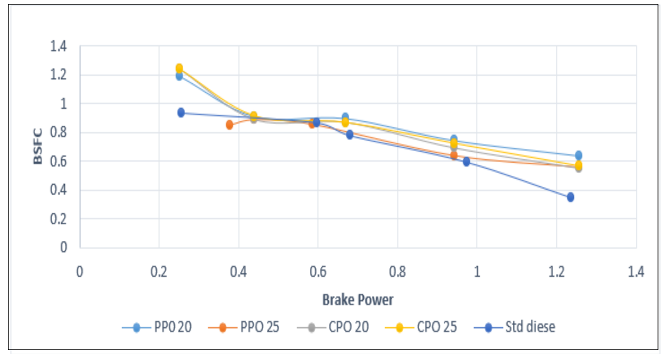

Fig. 4 Brake Power against BSFC

Based on the variation of the brake power and thermal efficiency as shown in Figure 5. The value of thermal efficiency for blended fuels (PPO20, PPO25, CPO20, and CPO25) are comparable to standard diesel oil even though the standard diesel offers the higher efficiency of the brake thermal efficiency compared to blended fuels who offers slightly lower efficiency. Thermal efficiency is an indicator to investigate the performance of engines on converting the heat energy into work. Thermal efficiency can be affected by several factors such as heating value, fuel density, and fuel viscosity. The standard diesel offers the highest thermal efficiency at 2000 rpm, which is 42.07 %, while the PPO20, PPO25, CPO20, and CPO25 offer 33.97 %, 36.97%, 35.41%, and 37.63% at the same engine speed. The drop value of BTE for blended fuels is due to the properties of the fuel itself, which is higher density, higher viscosity, the lower calorific value that resulted in poor combustion characteristics and poor volatility of the blended fuels compared to standard diesel fuel.

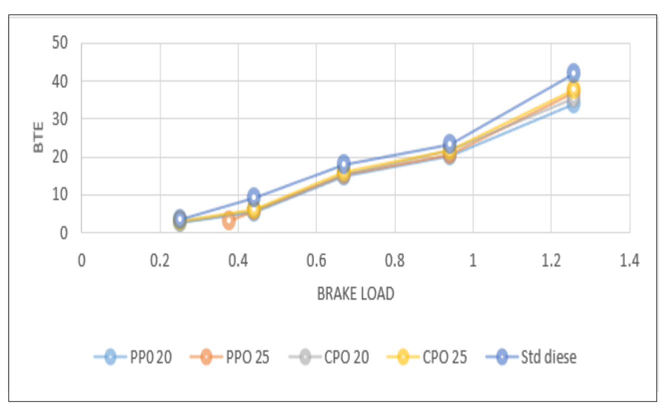

Fig. 5 BTEagainst Brake Load

When the value of the brake load of the engine is increased, the exhaust gas temperature (inlet) is also increased, shown in Figure 6. Maximum exhaust gas temperatures for all types of fuels were measured at 2000 rpm, while the lowest was at 1200 rpm. Both types of blended fuels recorded higher exhaust temperatures compared to standard diesel. The fuel type of PPO25 was recorded as the highest exhaust gas temperature (EGT), which is 167°C. The superheated flame produced from the ignition of the diesel in the combustion chamber creates pressure within the cylinder. This process can be affected by the properties of the fuel itself. In these case, the slow-burning properties of the fuels and the prolonged ignition delay period was the reason for those trends. High EGT can cause damage to engine part such as piston, cylinder heads, and causes havoc within the engine. However, even the blended fuels recorded higher exhaust temperature than the standard diesel, and it is fair to say that it was safe and applicable to be used in a diesel engine without any improvement and modification.

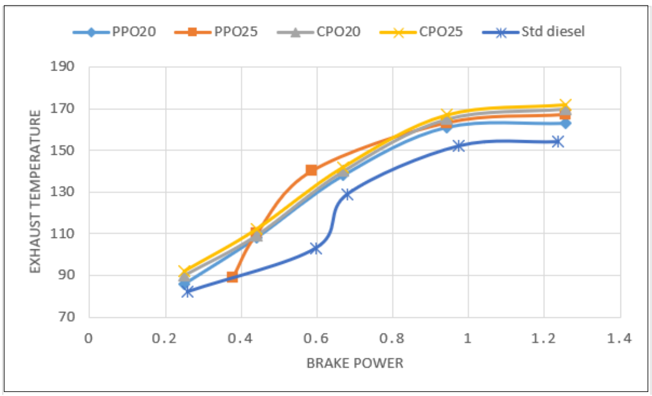

Fig. 6Brake Power againstEGT

V. CONCLUSIONS

A test diesel engine was run by using plastic pyrolysis oil blended (PPO20 and PPO25)with standard diesel fuel, crude palm oil blended(CPO20 and CPO25) with standard diesel fuel, and standard diesel. Performance of the test diesel engine was measured at RPM are 1200, 1400, 1600, 1800, and 2000. In addition, exhaust gas temperature (EGT), Brake specific fuel consumption (BSFC), and thermal brake efficiency (BTE) were recorded and compared with standard diesel fuel. Thus, the following conclusion can be listed as below:

1. When the mixing ratio increases, there is no obvious increase in the torque. This is because the calorific value of the raw pyrolysis oil is almost the same as the diesel fuel, which indicates that the heat value is not changed by mixing the pyrolysis oil with diesel fuel.
2. The value of thermal brake efficiency for blended fuels is found lower than the standard diesel due to poor combustion characteristics of the pyrolysis oil compared to standard diesel (higher density, higher viscosity, lower calorific value, and poor volatility of the blended fuels) compared to standard diesel fuel.
3. The blended fuels recorded higher exhaust gas temperature compared to diesel fuel for the entire engine load due to decreases in the thermal efficiency of blended fuels.

In the aspect of performance of the diesel engine, the uses of crude palm oil and plastic pyrolysis oil are usable and applicable. The government also should implement a policy to encourage entrepreneurs to transform waste into energy because it's not only profitable but also can reduce the pollution problem. By transforming waste into energy also can reduce the dependency on a single source which is a fossil fuel.

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