Jurnal Dinamika Vokasional Teknik Mesin
Vol. 8, No. 1, April 2023, pp. 12-20
https://journal.uny.ac.id/index.php/dynamika/issue/view/58504
ISSN: 2548-7590, DOI: 10.21831/dinamika.v8i1.58504

The performance test of diesel engine with a combination of biodiesel and pyrolysis

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Article Info

Article history:

Received February 9, 2023
Revised February 23, 2023
Accepted April 30, 2023
Published April 30, 2023

Keywords:

Diesel engine
Mass balance
Performance
Polyethylene
Pyrolysis

ABSTRACT

The need for fuels is increasing and almost entirely derived from fossil fuels. The one of technology to reduce fossil fuel consumption is the pyrolysis method. Pyrolysis is defined as a chemical degradation reaction caused by heat in the absence of oxygen. Pyrolysis of plastic waste into liquid fuels, using a batch reactor, is set at a temperature of 450ºC. This study was conducted to determine plastic waste pyrolytic oil properties of LDPE50 %+ Other50 % blend, such as specific gravity, kinematic viscosity, pour point, water content, and ash content. The results of mass balance calculations produce 43,41 %wt liquid, 5,0 %wt solid, and 51,59 %wt gas. The results showed that the value of specific gravity was 0.881, kinematic viscosity 1.162 mm^2s, pour point of -12ºC, water content 0.8 %vol, and ash content 0.062 %wt. Diesel engine performance which uses a mixture of fuel from a result of pyrolysis process of (5 %vol and 10%vol) and biodiesel (90 %vol and 80 %vol) are tested to the Engine Test Bed Nissan Diesel SD22 Series. The results showed that the maximum torque at 1800 rpm is 122.919 Nm, which has the same value as mixed plastic waste pyrolytic oil 10 %vol to 100 % biodiesel. Maximum power at 2500 rpm is 30.3259 kW, which has the same value as mixed plastic waste pyrolytic oil 10 %vol to 100 % biodiesel.

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INTRODUCTION

Plastic is the most frequently used material. Gradually plastic has left the role of wood, metal, and aggregate, because plastic is light, easy to shape into the desired shape, cheap, strong, anti-rust, and can be colored or transparent. In addition, the production process is cheap. But plastic is also not heat resistant, and easily damaged in low-temperature conditions. Various types of plastics provide alternative choices about the manufacturing process and its uses.

Plastics can be classified into several types including *Polyethylene Thereptalate* (PET), *Polyethylene* (PE), *Polyprophylene* (PP), *Polystyrene* (PS), *Polyvinyl Chloride* (PVC), *Other*. The use of plastic must be in accordance with the procedure. Waste processing becomes very important because of the large number of packaging production using materials from plastic. However, to process it, the right way is required so as not to cause adverse impacts on the environment.

Plastic is a macromolecule formed through a polymerization process, by combining several molecules through a chemical process that is the merging of several simple molecules into larger molecules (Liestiono et al., 2017).

The processing of plastic waste carried out so far by the community is by burning them where this method can damage the environment and smoke from burning plastic can harm human health because the smoke contains carcinogenic compounds such as *polychloro dibenzodioxins* and *polychlorodibenzo furan* (Anom & Lombok, 2020). Therefore, it is necessary to treat plastic waste that is more environmentally friendly and does not harm human health. Many waste treatments (solid, liquid, and gas) produce residues such as dust or other residues that require further handling. The waste that is formed often becomes a problem because it falls into the dangerous category.

Pyrolysis is an alternative technology as a source of hydrocarbons. Various pyrolysis techniques were developed not only for the conversion of polymeric materials into beneficial hydrocarbons but also used for the synthesis of biomass-based hydrocarbons. Besides its renewable resources, pyrolysis technology can be developed in a wide variety of methods leading to clean technology and having aspects of utilizing natural resources.

Pyrolysis is the process of decomposition of a material that requires a high temperature and is continuous in the absence of oxygen. This process is often called devolatization. The pyrolysis process produces fuel products in the form of liquids, solids, and gases as well as some other substances. Another product is methane. In general, the pyrolysis process takes place at temperatures above 300^{o}C within 5 – 7 hours. However, this process is highly dependent on raw materials.

Pyrolysis of plastic waste in its application to society needs to be developed on an industrial scale in Indonesia. Research is conducted to determine the economic potential of the products produced and knowledge about their quality. Each landfill has a content percentage and various types of plastic waste mixture. Therefore, before the waste is processed, first it should be grouped based on its type.

Biodiesel is an environmentally friendly fuel derived from a combination of biodiesel with diesel fuel. Diesel fuel is derived from fossils that cannot be renewed. Biodiesel emerges as one of the alternative energies.

The purpose of this study is to determine the performance of diesel engines using a combination of biodiesel and pyrolysis oil and to recognize the characteristics of pyrolysis oil. It is hoped that with this data we can determine the process of processing plastic waste that is more environmentally friendly and in accordance with the needs of the type of petroleum substitute fuel that we want.

METHOD

This research uses a pyrolysis reactor device, thermometer, scale water pump, oil reservoir, stopwatch, and testing machine. The plastic material used is LDPE (*Low-Density Polyethylene*) and *Other* (Code 7) plastic waste types. While as the catalyst, natural catalyst is used. The research tools and materials are shown in Figure 1 and Figure 2.

Description :
1. Pyrolysis Reactor
2. Catalitic Reactor
3. Condensor
4. Oil Reservoir
5. Flare Pipe
6. Temperature Control

Figure 1. Scheme of Research Tools

Figure 2. LDPE Plastics, Other Plastic, and Natural Zeolite

The first research process carried out was to prepare *Low-Density Polyethylene* and *Other* plastic materials. Waste is obtained from waste collectors in the Piyungan area of Yogyakarta. The waste is then chopped to make it easier to put into the reactor tube. The pyrolysis method works using an electric heater to raise the temperature to 450°C.

Products flowing from the reactor to the condenser are in the form of liquids and gas. If the gas in the flare pipe is reduced and the liquid oil in the pipe that goes to the reservoir is no longer dripping, the pyrolysis process can be stopped. The mass amount of Gas can be calculated by subtracting the mass of the liquid plus the mass of the solid. Liquid products are tested in a laboratory to find out their characteristics. Liquid testing is carried out in the laboratory to determine the characteristics of fuels including *Specific Grafity* (SG), *Kinematic* viscosity, flash point, pour point, cloud point, water, and ash content.

Table 1. Specifications of Diesel Engine Used

Brand	:	*Nissan Diesel SD22 Series*
Compression Comparison	:	22 : 1
Displacement	:	2164 cc
Cooler	:	Water
Cylinder diameter	:	83 mm
Piston stroke length	:	100 mm
Number of cylinders	:	4 cylinders

In the next stage, the pyrolysis oil is tested on Nissan *Diesel SD22 Series* diesel engine. The oil put into the diesel engine is mixed with biodiesel in the ratio of 5% pyrolysis oil and 95% biodiesel and 10% pyrolysis oil and 90% biodiesel. After the oil is put into the diesel engine, the engine performance can be seen starting from the torque, power, BMEP, BTE, and BSFC in the diesel engine. Table 1 indicates the specifications of the diesel engine that is used.

RESULTS AND DISCUSSION

Plastic Waste Pyrolysis Oil

This study shows that the pyrolysis process of 50% LDPE and 50% *Other* plastic mixture at a temperature of 450°C using a natural zeolite catalyst, gives the highest gas percentage result compared to liquids and solids, as shown in Figure 3. The high level of this gas production is likely due to the presence of impurities that are carried into the cracking process, the ineffectiveness of the condensation process due to the lack of surface area of the condenser, or the regulation of cooling water temperature that is not optimal.

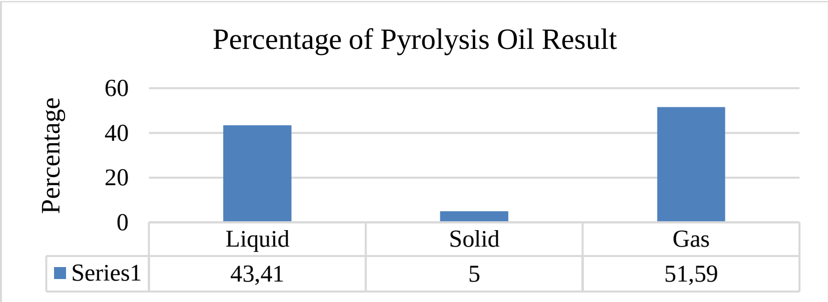


Figure 3. Mass Balance Chart

Another study using natural zeolite catalysts affects the distribution of pyrolysis products. Natural zeolite catalysts used to process PET and PP plastics are able to produce gas products that are more dominant than solid and liquid products (Anggono et al., 2020). The test results of pyrolysis oil properties of mixed LDPE and *Other* can be seen in Table 2 below.

Table 2. Properties of Pyrolysis Oil and Biodiesel

Properties	Unit	Biodiesel	LDPE 50% + *Other* 50%
Specific Gravity	-	0,8445	0,8474
Viscosity	mm^2/s	4,012	1,421
Flash Point	°C	*)	*)
Pour Point	°C	3	12
Cloud Point	°C	**)	**)
Water Content	% vol.	Detected	0,6
Ash Content	% wt	0,076	0,056

*) At a temperature of 10°C, it already ignites
**) Cloud Point can't be observed, for example: dark colors

The viscosity of plastic waste pyrolysis oil has properties that tend to be close to biodiesel (Wardhana & Saptoadi, 2016). Viscosity is a measure of fluid resistance to flow or internal friction (Istiadi, 2011). Viscosity is the main characteristic of biodiesel because this can affect the fuel injection working system. High viscosity leads to the low atomization of the fogging process and lack of accuracy of the fuel injector in the engine. The viscosity of oil from processing plastic waste is smaller than that of diesel. The results of research on plastic waste oil have a low kinematic viscosity value, causing oil to flow faster than biodiesel so that for the same cross-sectional area and fluid thrust, the process of supplying plastic waste oil from the fuel tank to the combustion chamber will be faster. The reason is that the lower the viscosity, the smaller the friction value between the fluid and the surface.

Plastic waste oil and biodiesel can already ignite at a temperature of 10°C. The flash point of plastic pyrolysis waste oil is still far below the flame temperature of biodiesel (55°C). The flash point is related to the safety of distribution and storage, which means that the oil from the pyrolysis of plastic can be easily burned.

The cloud point is the temperature at which the *paraffin wax* crystal first appears as a cloud at the base of the test tube if the fuel is cooled under certain conditions. The cloud point can be used as an indicator of the paraffin content in petroleum products. In general, the pour point and cloud point of pyrolysis oil are higher than biodiesel.

The pour point is the temperature at which the amount of *wax* produced by the solution is sufficient for the formation of *gel* from the fuel which at the lowest temperature the fuel is able to flow (Istiadi, 2011). Compared with biodiesel, pyrolysis oil has a higher pour point. The low pour point is very suitable for machines operating in cold places. The lower pour point allows fuel to be able to flow from the tank to the combustion chamber well (Pratama & Saptoadi, 2014).

Specific gravity (S_g) is the ratio between the density of fluid and water at a given temperature (Munson et al., 2003). *The specific gravity (S_g)* of plastic waste pyrolysis is higher than that of biodiesel. The increase in the value of Sg is beneficial because the higher the Sg, the fuel can be accommodated in a room or a tank with the same volume will be greater. Viscosity is a measure of fluid resistance to flow or internal friction (Istiadi, 2011). Viscosity is a major property of biodiesel because it can affect fuel injection operations.

Based on the calculation of calorific value using a bomb calorimeter, the calorific value of pyrolysis oil combination of LDPE 50% and *Other* 50% is 42.37 KJ/Kg, while the biodiesel calorific value is at 45.22 KJ/Kg. The calorific value graph is presented as shown in Figure 4. The cause of low calorific value is the percentage of high amounts of polystyrene and *Other*. Polystyrene increases the pyrolization rate to form a shorter C chain.

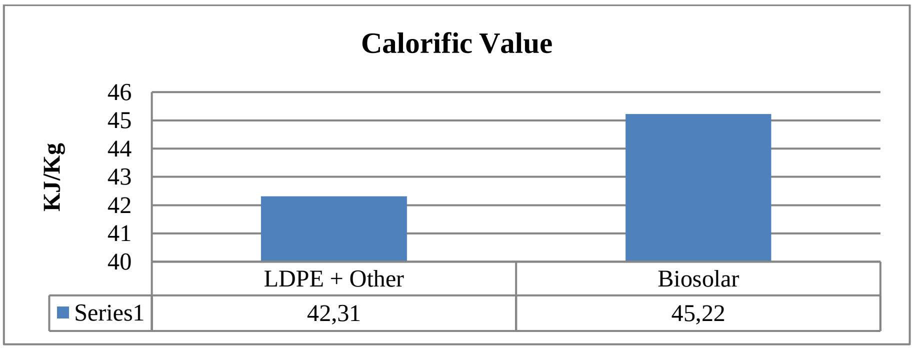


Figure 4. LDPE Calorific Value: Other and Biodiesel

The next test is GCMS (*Gas Chromatography Mass Spectroscopy*). GCMS is used to analyze compounds in the sample. GCMS is carried out to determine the amount and content of hydrocarbon elements. As in Figure 5, the GCMS results showed that in the combination of LDPE 50% + *Other* 50% the highest percentage of atomic number is C_{20} by 12.09%.

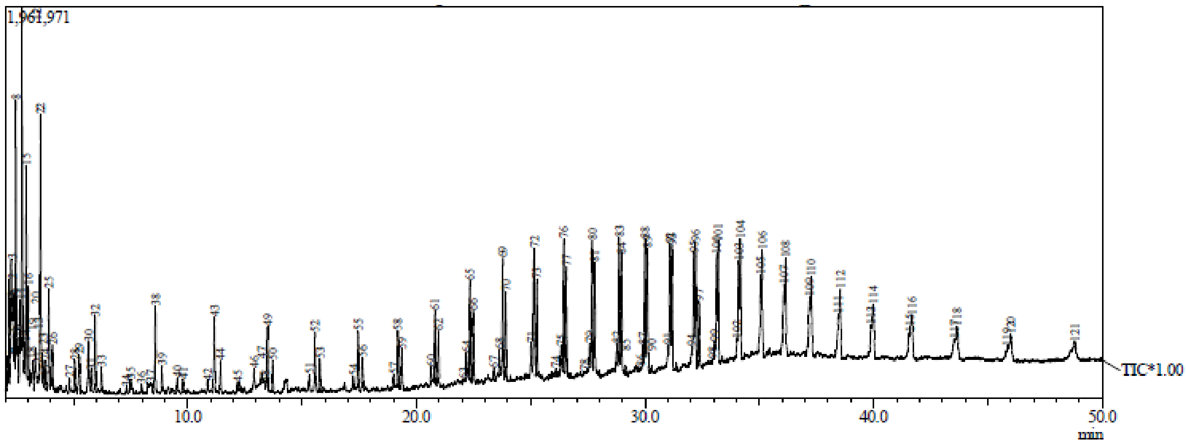
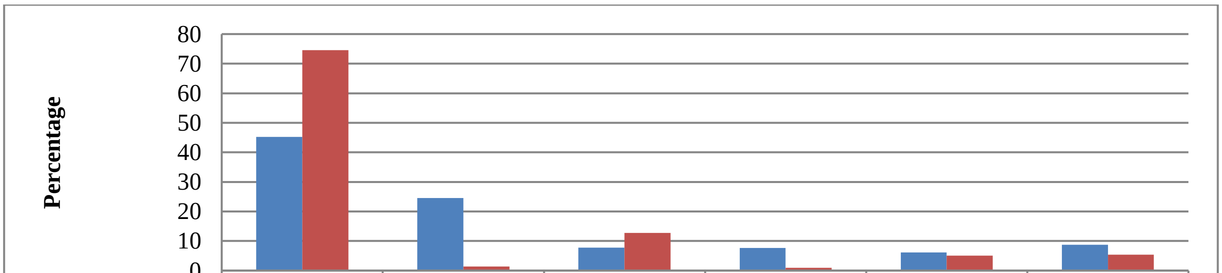


Figure 5. *Chromatogram* Results (121 *peaks*) Pyrolysis Oil of PE 50% + *Other* 50%

The pyrolysis oil combination of LDPE 50% + *Other* 50% contains the highest percentage of *paraffin*. Low aniline points result from a high percentage of *aromatics*. A high aniline point results from the percentage of *paraffin*. The aniline point between *paraffin* and *olefin* is produced by *napthane* and *olefins*. *Paraffin* has the best combustion, on the contrary *aromatic* is the worst. *Aromatic* compounds if burned produce a reddish and even blackish flame and more smoke.



	Parafin	Olefin	Napthane	Aromatic	Acetylene	Other
LDPE + Other	45,18	24,55	7,8	7,62	6,15	8,7
Biosolar	74,51	1,38	12,75	0,97	5,03	5,36

Figure 6. PONA Charts of Pyrolysis Oil and Biodiesel

Diesel Engine Performance

Figure 7 shows a graph of the relationship between RPM and torque. From the results of the study, the maximum torque between LDPE + O 5% and 10% has the same value of 122.91 Nm. The data shows torque. This is because *the cetane number* in biodiesel fuel is different after being added to pyrolysis oil.

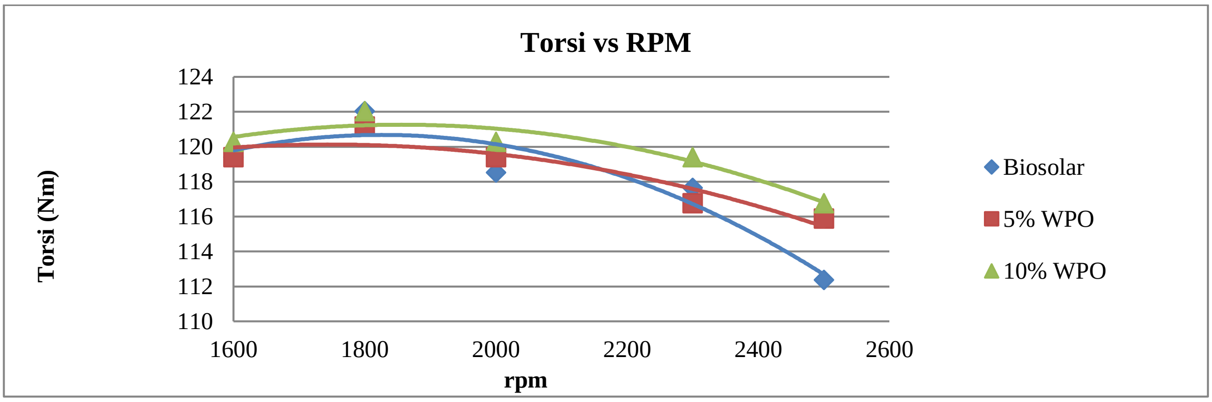


Figure 7. Graph of Torque as a Function of Engine Rotation

Figure 8 shows the effect of RPM with biodiesel and pyrolysis oil combination on power. The graph shows that the engine power will increase in proportion to the RPM speed. The higher the RPM the greater the power. Torque is very influential in determining the value of power because the value of torque is directly proportional to power, the greater the torque, the greater the power. The maximum torque value at 2500 rpm for biodiesel and pyrolysis oil combination of both 5 and 10% has the same value of 30.3259 kW.

The increase of power before and after adding pyrolysis oil is different. This is because the calorific value of each mixture is also different. The higher the calorific value, the better the combustion process. Therefore, the efficiency and the power which is produced will be higher.

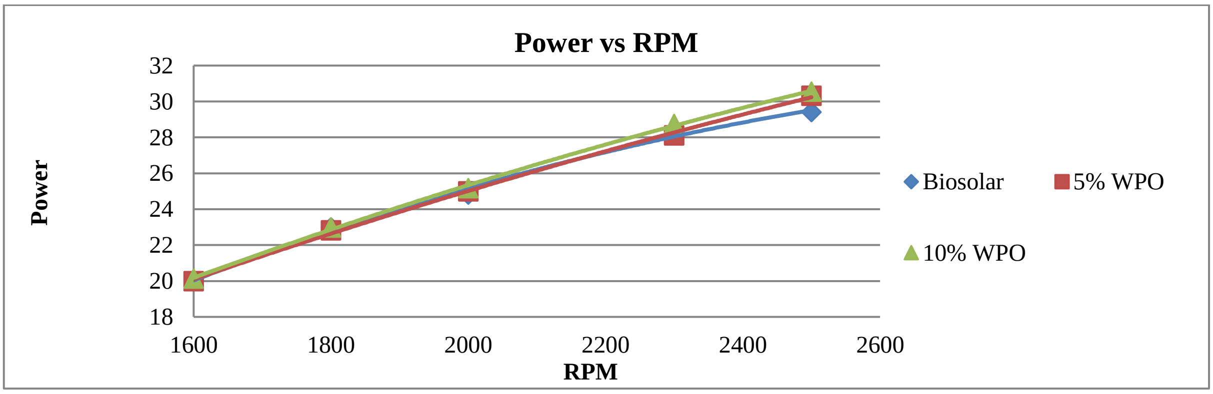


Figure 8. Graph of Power as a Function of Engine Rotation

Figure 9 shows a graph between engine speed and *Brake Mean Effective Pressure* (BMEP) with various variations of engine rotation. BMEP is the work produced by the cycle in the cylinder divided by the volume of the piston stroke. The graph that BMEP shows against the variation in engine rotation is almost the same as the torque graph because torque is closely related to engine power. From the chart, it can be seen that the highest BMEP is in the combination of pyrolysis oil and biodiesel 5% and 10%, which is 713,731 at 1800 rpm.

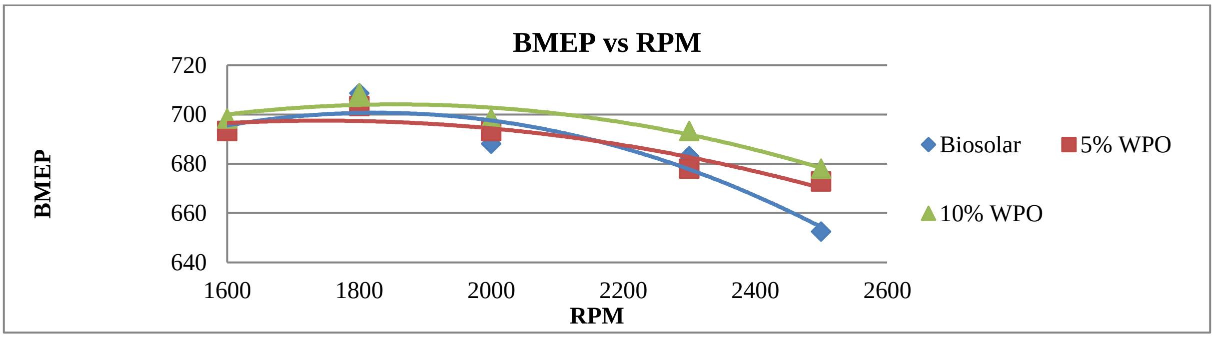


Figure 9. The Graph of BMEP as a Function of Engine Rotation

Figure 10 shows a graph of various variations in engine speed using biodiesel and the variations in the addition of pyrolysis oil to specific fuel consumption. From this data, the lowest SFC value is obtained from a combination of pyrolysis oil and Biodiesel 5% at 1600 rpm, which is 0.278 kg / kWh.

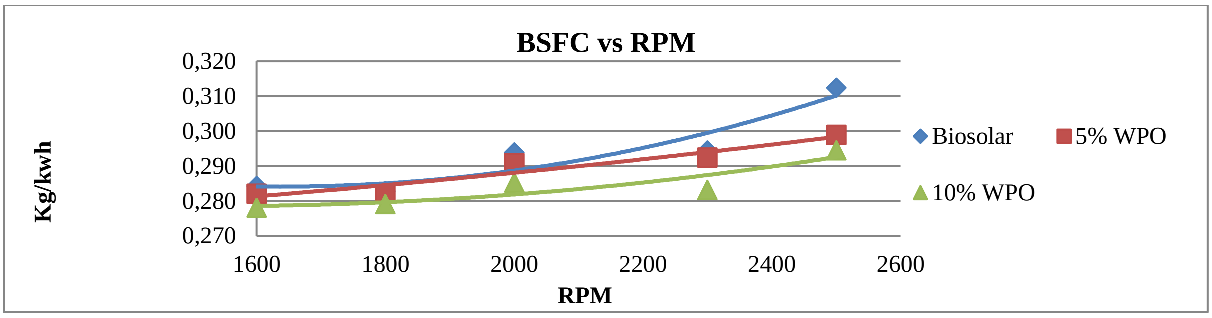
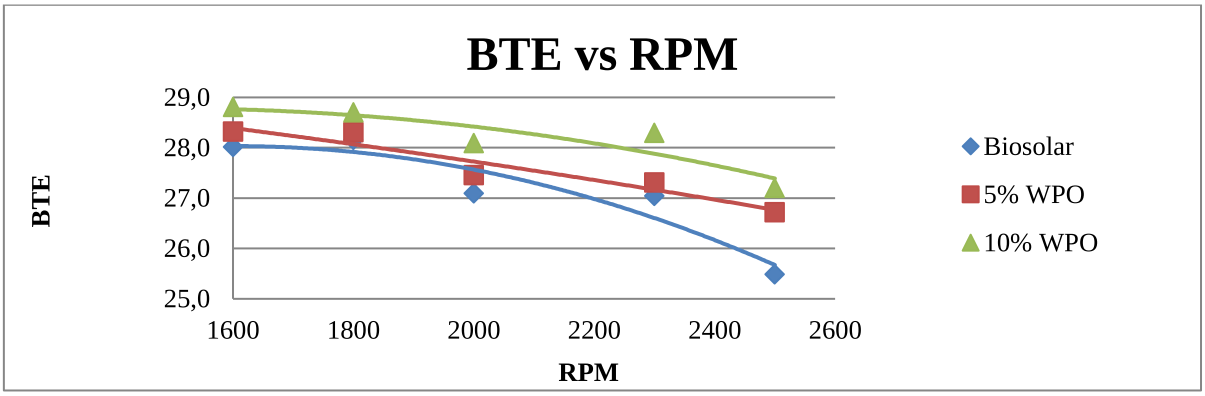


Figure 10. Graph of BSFC as a Function of Engine Rotation

Figure 11 shows the relationship between *Brake Thermal Efficiency* and engine rotation using a number of variations of fuel combination. From the data, it can be seen that the highest η_{bt} value is obtained from the biodiesel mixed with 20% WPO at 1600 rpm, which is 28.47%. This is because the calorific value of each fuel mixture is different, the higher the calorific value of a fuel, the combustion process will be more optimal or perfect so that the efficiency produced will be higher.



CONCLUSION

From this research, it can be concluded that pyrolysis product produces 43.41% liquid, 5% solid, and 51.59% gas. The Pyrolysis oil combination of LDPE 50% and *Other* 50% effect 100% biodiesel. The ideal combination fuel is a 5% mix.

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