RESEARCH ARTICLE | MARCH 11 2024

Effect of tire pyrolysis oil, crude palm biodiesel and engine speed on engine performance

Norrizam Jaat; Amir Khalid ✉; Syabillah Sulaiman; Muhamad Asri Azizul; Norirda Mohamed; Hamidon Salleh; Azahari Razali; Norshuhaila Mohamed Sunar; Rifqi Irzuan Abdul Jalal

AIP Conf. Proc. 2998, 060012 (2024)
https://doi.org/10.1063/5.0188302

Effect of Tire Pyrolysis Oil, Crude Palm Biodiesel and Engine Speed on Engine Performance

Norrizam Jaat[1,a)], Amir Khalid[1,2 b)], Syabillah Sulaiman[1,c)], Muhamad Asri Azizul[1,d)], Norirda Mohamed[1,e)], Hamidon Salleh[2,f)], Azahari Razali[2,g)], Norshuhaila Mohamed Sunar[3,h)] , Rifqi Irzuan Abdul Jalal[4,i)]

[1]*Centre of Automotive and Powertrain Technology,*
Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, Pagoh Education Hub, Johor 84600, Malaysia
[2]*Centre for Energy and Industrial Environment Studies,*
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor, Malaysia
[3]*Faculty of Engineering Technology,*
Universiti Tun Hussein Onn Malaysia, Pagoh Education Hub, Johor 84600, Malaysia
[4]*Universiti Kuala Lumpur Malaysia France Institute, Seksyen 14, Jalan Teras Jernang,*
43650 Bandar Baru Bangi, Selangor

[b)] *Corresponding author: amirk@uthm.edu.my,*
[a)] *norrizam@uthm.edu.my,* [c)] *syabillah@uthm.edu.my,* [d)] *mdasri@uthm.edu.my,* [e)] *norirda@uthm.edu.my,*
[f)] *hamidon@uthm.edu.my,* [g)] *azahari@uthm.edu.my,* [h)] *shuhaila@uthm.edu.my,* [i)] *rifqi@unikl.edu.my*

Abstract. Diesel combustion engine which the air is compressed to a sufficiently high temperature used to ignite diesel fuel injected into cylinder, where ignition, burning combustion and expansion actuate a piston. Due to limited resources of fossil fuel, the new alternative fuel is rise and now biodiesel became attention in the automotive industries sector. The purpose of this research is to investigate the effect of tire pyrolysis oil, crude palm biodiesel and engine speed on engine performance. Two cylinders four strokes cycle, air cooled, compression ignition was used to conduct this experiment. Then, the data was collected by PC based software from the experiment to show its performance. This engine experiment done by using blended biodiesel from blended tire pyrolysis oi l (TPO) that is TPO20 and TPO25 and also standard diesel (STD). Next the experiment also had done run using blended biodiesel from blended crude palm oil (CPO) which was CPO10 and CPO15 and also standard diesel (STD). The engine were done run at different speed for 1200rpm, 1400rpm, 1600rpm, 1800rpm and 2000rpm. The results of the engine performance were compared in different calculations which were brake power, torque, brake specific fuel consumption, brake thermal efficiency and the exhaust gas temperature. The development of the biodiesel technology will give an alternative fuel for the diesel engine user in order for them to do their daily routine.

Keywords : Biodiesel, Pyrolysis Oil, Crude Palm, Engine Speed, Engine Performance

INTRODUCTION

In the new era globalization, the combustion and engine technology across the world is getting improved and will keep improving in order to help every human in solving every problem that occurred [1-5]. Due to advance technology, the number of vehicles and engines keep growing in order to improve the satisfaction of the people. Nowadays, heavy duty trucks are one of important transportation to transport things from one place to another especially for factory. As we know that, most of heavy duty trucks are using diesel engine type [6-10]. The

The 5th International Conference on Automotive Innovation and Green Energy Vehicle
AIP Conf. Proc. 2998, 060012-1–060012-11; https://doi.org/10.1063/5.0188302
Published by AIP Publishing. 978-0-7354-4793-6/$30.00

technology keeps growing towards the modern world but the energy resources used in the vehicles and engines are very limited and it keep decreasing with the increasing of the technology. The numbers of vehicles are keeping increasing on the road and vehicles with diesel engine type are causing more pollution to the environment due to its emission using combustion engine [11].

The alternative fuels used to overcome the unpredicted increasing price of petroleum are by using biodiesel fuel which is a type of renewable of fuel. The biodiesel fuel is an alternative fuel and produce with similar to ‘fossil’ diesel characteristics. Biodiesel can be produced from straight vegetable oil, animal oil or fats, tallow and waste cooking oil [12-15]. There are many benefits of biodiesel fuel which is very efficient cause by low of emissions and better performance of the engine. Other than that, biodiesel fuel can be described as ‘carbon neutral’ and produces no net output of carbon in the form of carbon dioxide. This scenario due to the effect occurs because when the oil crop grows it absorbs the same amount of carbon dioxide as is released when the fuel is combusted. Thus, biodiesel is not harmful, have better biodegradability, no absence of sulphur, odourless smell and oxygen content which is normally not obtained in fuel [11-13]. The research conducted is to study the effect and the advantages of blended diesel fuel and the engine speed on engine performance.

THE IMPLEMENTATION OF BIODIESEL

Biodiesel has become of one a source of alternative fuel and a part of renewable energy that contribute as a substitution fuel and as a key of renewable energy sources. The biodiesel is an alternative fuel for diesel engine, it is becoming increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines [13]. The used cooking oils are used as raw material, adaption of continuous trans esterification process and recovery of high quality glycerol. The utilization of liquid fuels such as biodiesel produced from used cooking oil by transesterification process represents one of the most promising options in order to produce biodiesel. On the other hand, biodiesel is found to be the best substitute for petro-diesel for not only because of its comparable calorific value but also for its own several advantages of biodiesel. The advantages are low toxic emissions, biodegradability which are renewable, high flash point excellent lubricity and environmental compatibility [14]. Moreover, biodiesel has been promoted and it is using a long term renewable energy sources which has potential to address net emission of carbon dioxide to the atmosphere, security concerns and the fluctuating prices of fossil fuel.

On the other hand, the quality standards of the biodiesel are continuously updated due to the evolution of compression ignition engine, ever stricter emission standards, reevaluation of the eligibility of feedstock used for the production of biodiesel, and others [15-17]. Furthermore, the currents standards for regulating the quality for biodiesel on the market are according to the factors from different region which are include the characteristic of the existing diesel fuel standards, the predominance of the types of diesel engines most common in the region, the emissions regulations governing those engines, the development stage and the climatic properties of the region where it is been produced, the purpose and motivation for the use of the biodiesel. In table 1 shows the list of most important biodiesel quality standards in every country or region around the world [15].

TABLE 1. Biodiesel Standards for every different region [15]

Country/Area	Specification	Title
EU	EN 14213	Heating fuels- Fatty acid methyl esters (FAME) – Requirement and test methods
EU	EN14214	EN 14214 Automotive fuels – Fatty acid methyl esters (FAME) for diesel engines
U.S.	ASTM D 6751	ASTM D6751 – 11a Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate fuels
Australia		Fuel Standard (Biodiesel) Determination 2003
Brazil	ANP 42	Brazilian Biodiesel Standard (Agência Nacional do Petróleo)
India	IS 15607	Bio-diesel (B100) blend stock for diesel fuel – Specification
Japan	JASO M360	Automotive fuel – Fatty acid methyl ester (FAME) as blend stock

TYRE PYROLYSIS OIL

During 2015, the European tyre and rubber manufactures association have estimated that production of tyres annually are 1.5billion approximately with the generation of used tyres was estimated approximately 17 million tonnes worldwide [16]. There are three main components of car's tyres used worldwide which are metal (21.5 wt %), textile (5.5%) and vulcanized rubber (78 wt %). On the other hand, the vulcanized rubber fractions of used in the manufacture of tyres are for the solid waste industry due to the physiochemical properties. Furthermore, the tyre waste is serious environmental problem as they causes or serves as breading sites for mosquitoes and rodents and lead to large fire hazards.

Other than that, tyres are difficult to deteriorate, pollute various ecosystems and causing damage to plant and wildlife. The disposal of scrap tires is a growing problem worldwide. Since the tires waste are artificial polymer and also not biodegradable material so it is considered as serious pollution problems. To overcome this problem, Pyrolysis is a thermochemical alternative to treating vulcanized rubber for the recovery of valuable products. Besides, Pyrolysis represents an environmental friendly and effective way, in order to transform solid waste into fuels, with acceptable chemical and physical properties, for the use in the internal combustion engine.

The Tyre Pyrolysis Oil (TPO) was made by pyrolysis of waste tyres at 500˚C and the process produces gaseous, liquid (condensate) and solid fractions. In addition, pyrolysis occurs in the absence of oxygen, with a hydrocarbon gas, carbon black and steel wire, as by products [17]. The Tyre Pyrolysis Oil (TPO) can be used for power generation including the internal and external combustion in industry and as fuel in automotive engines, serving as unconventional fuel alternative, to the petroleum derivatives. The tire pyrolysis not only for the environmental and sustainability benefits but also to contribute economically to generate cheaper fuels, if the process is deployed on a large scale.

OIL PALM

Malaysia is one of the largest producers of Elaeis guineensis palm oil in the world thus resulting in the dry matter yield of OPS is 0.938 tonnes per ha per year and the energy potentially available from the biomass is 19.50 per ha per year. One tremendous source for biomass is palm oil industry. To produce biofuel, the palm oil itself is considered as a promising candidate. Other than producing palm oil, the industry also generates a huge quantity of residues (dry and wet) which can be processed to produce biofuels as well. In fact, the produced oil only contributes to 10 % of total biomass generated from plantations. Moreover, during the palm oil production the biomass is generated, together with the amount of waste cooking oil is generated as the increasing rate of cooking oil consumption worldwide which could trigger complex problems if not handled carefully.

Experimental data on the basic characteristics of palm oil biodiesel and diesel fuel. Due to its high content of long chain, highly saturated methyl esters, POB's most critical property is its high cloud point [19-21]. At the temperature of 16, POB begins to form crystals. These crystals can plug filters and fuel lines at about 12℃. These defective cold flow properties of POB limit their use as neat fuel or in rich biodiesel mixtures in cold climates or during the winter season. POB is denser, slightly more viscous and has a smaller boiling interval than diesel fuel, indicating similar boiling points for fatty acid methyl esters in biodiesel. Meanwhile, diesel fuel consists of a wide range of hydrocarbons with varying volatility. Despite having a lower boiling point, biodiesel is denser than the diesel fuel. Because of the presence of oxygen in the methyl ester molecules, POB has a gross heating value lower than diesel fuel. Due to the higher POB density, this difference in heating values, expressed as energy per unit mass, is slightly reduced when reported as energy per unit volume. The calculated cetane index for POB is higher than for diesel fuel as a result of these differences; this is in line with the trend reported by several researchers for both cetane and CCI numbers. [15-20]. The development of the four cylinder modeling in one-dimensional simulation for four-stroke direct-injection (DI) diesel engine was used for this experiment [20]. The engine parameters or detail of the engine used are shown in Table 2.

The investigations of the performance and emissions produced by different type of blended fuel have been investigated by researchers throughout many years. The researched has shown that the development of the alternative fuel has gaining a lot of eyes of the world on the replacement or reducing the usage of fossil fuel for the future [21].

TABLE 2. Diesel Engine Specification

Parameter	Value
Bore (mm)	82.7
Stroke (mm)	93
Compression ratio	22.4
Displacement (cc)	500
Number of Cylinder	4
Connecting Rod Length (mm)	150
Piston Pin Offset (mm	1
Intake Valve Open (°CA)	351
Intake Valve Close	-96
Exhaust Valve Open	125
Exhaust Valve Close	398

TEST FUELS

In this study, standard diesel (STD), blended TPO20 and blended TPO25 were chosen as fuel test. The diesel for TPO20 was blended with 20% of TPO with 80% standard diesel fuel. Moreover, for the TPO25 also was blended with 25% of TPO with 75% of standard diesel fuel. This to show the effect on the engine performance of the speed using different percentage of blended TPO.

The blended diesels were mostly to all type of diesel fuel and can be used in for all type of diesel engine vehicle. The blended diesel will help in air pollution reduction of the unburned hydrocarbon and carbon monoxide. Furthermore, the blended diesel may produce low levels of carbon dioxide as compared to standard diesel fuels.

BLENDING PROCESS

The TPO20 are 20% of TPO and 80% of diesel fuel while for TPO25 is 25% from TPO and 75% of standard diesel fuel. The blending process is followed to the amount that has been decided. The effect of blended diesel on speed of engine performance can be seen from the process according the amount that had been decided. The blending machines were operated at temperature of 60°C. On the other hand, the mixture of two different blended fuel were stirred for an hour at temperature of 70°C. Besides, the speed of rotating blade was maintained at 270 rpm until finished the blended process. In order to maintain the temperature of the blending process, the water jackets were used around the blended machine. Figure 1 below shows the schematic diagram of blending process.

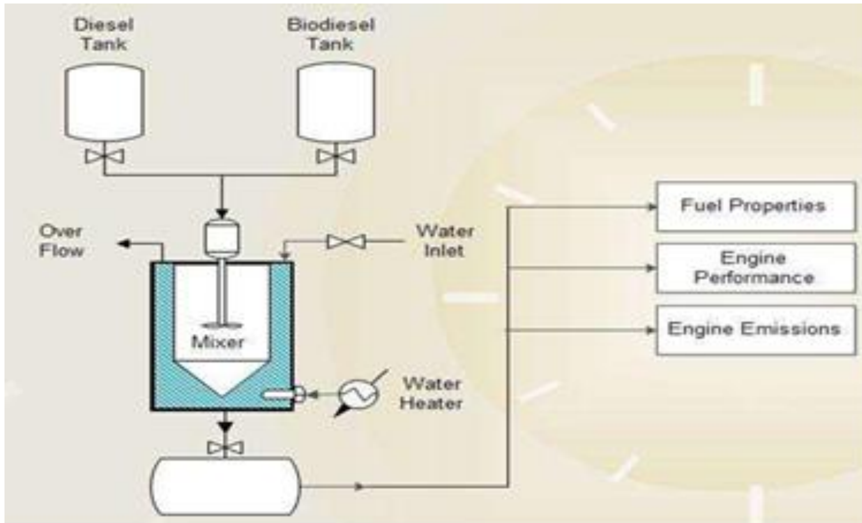

FIGURE 1. Schematic diagram for blending process

EXPERIMENTAL SETUP

The equipment of the experimental for the chassis dynamometer, fuel flow meter, fuel tank, AC motor, motor control panel, were shown in Figure 3. In order to avoid any malfunction, the conditions of the equipment were checked before the machine run. Other than that, the all the equipment were used to measure the engine performance that was installed to the panel and the date obtained were shown on the software. The names of each equipment are shown in Table 4 and the engine experimental set up are shown in Figure 2.

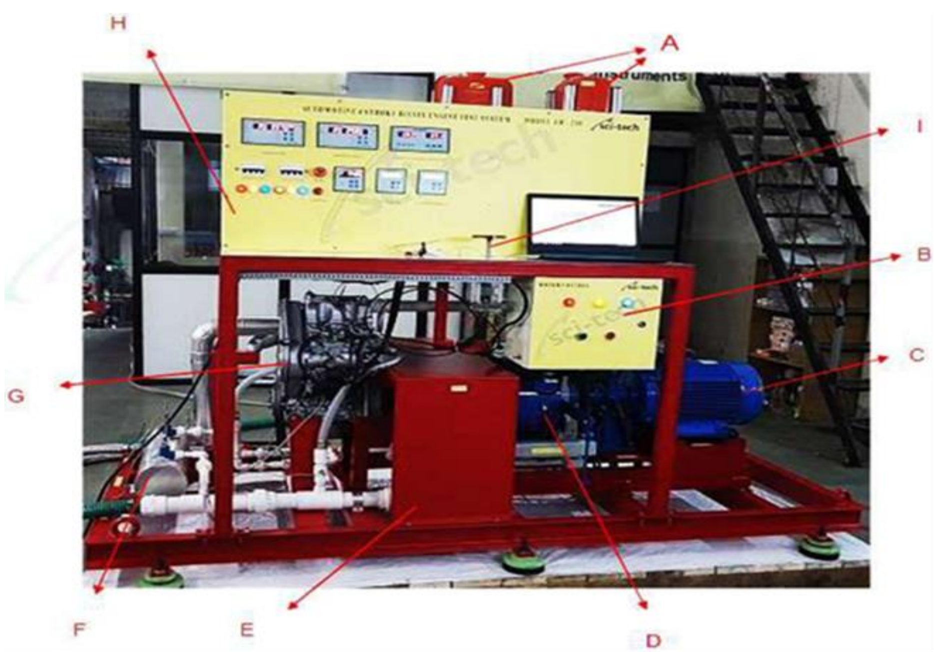

FIGURE 2. Engine Experimental Set Up

The description of the equipment used which has been installed to the panel was shown in Table 3. Besides, the description was to help to identify the name of the panel easily and can be manage well. Dynamometer and diesel engine are the main components of the panel. The fuel tank for this panel was on the top of the panel which it consists of two tanks as shown in Figure 1. Moreover, the panel will used laptop that will help that connect with the panel via USB cable to record the data while running the experiment.

TABLE 3. The description of the equipment**.**

Symbol	Description
A	Diesel tank
B	Motor control panel
C	AC motor
D	Dynamometer
E	Shaft guard
F	Calorimeter
G	Diesel engine
H	Control panel
I	Accelerator wheel

RESULTS AND DISCUSSION

These chapters are going to be analyzed and discussed on all knowledge obtained from the experiment which has been done. In line with the experiments, there were 5 type of fuels which are standard diesel (STD), TPO20, TPO 25, CPO10 and CPO15 were used. On the other hand, the performances of these 5 types of fuel were test with different engine speed which are 1200, 1400, 1600, 1800 and 2000 rpm. The experiment was carried in Automotive Laboratory for performance test. The parameters that have been tested for the performance test, the terms that were considered are torque, brake power, brake specific fuel consumption (BSFC), brake thermal efficiency and exhaust gas temperature. All the data were collected and observed using the graph obtained so that can be identify the different between these 5 types of fuel.

THE EFFECT OF BLENDED DIESEL AND ENGINE SPEED ON PERFORMANCE

For the performance tests, the data for all 5 types of fuels which are standard diesel (STD), blended 20% of tire pyrolysis with standard diesel (TPO20), blended 25% of tire pyrolysis with standard diesel (TPO25), blended 10% of crude palm oil with standard diesel (CPO10), and blended 15% of crude palm oil with standard diesel (CPO15) have been recorded include torque, brake power, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature.

Figures 3 shows the effect of blended TPO and CPO ratio on the engine performance. The engine performance of all the five fuels are measured using the parameters that have been decided that are the engine torque, engine brake power, brake thermal efficiency (BTE), brake specific fuel consumption(BSFC)and also exhaust temperature. All the performance parameters are measure against the speed that has been decided that are 1200rpm, 1400rpm, 1600rpm, 1800rpm and 2000rpm.

In addition, Figure 3 shows the engine performance shows the torque of the different type of fuel versus the engine speed. From the graph obtained, it shows that the STD diesel has the higher torque as compared to the other blended fuel. The different torque obtained may cause by the viscosity and density in all blended fuel properties. However, STD diesel fuel shows some higher torque values than blended diesel since diesel fuel has higher heating value than blended diesel. On the next figure shows the relationship between the brake power and engine speed. The engine performance shows that the brake power of STD has higher value compared to the TPO and CPO blended diesel. This means that the STD fuel has better completed combustion of oxygenated fuel. The lower brake power for TPO and CPO blended diesel can be due to their respective lower heating values.

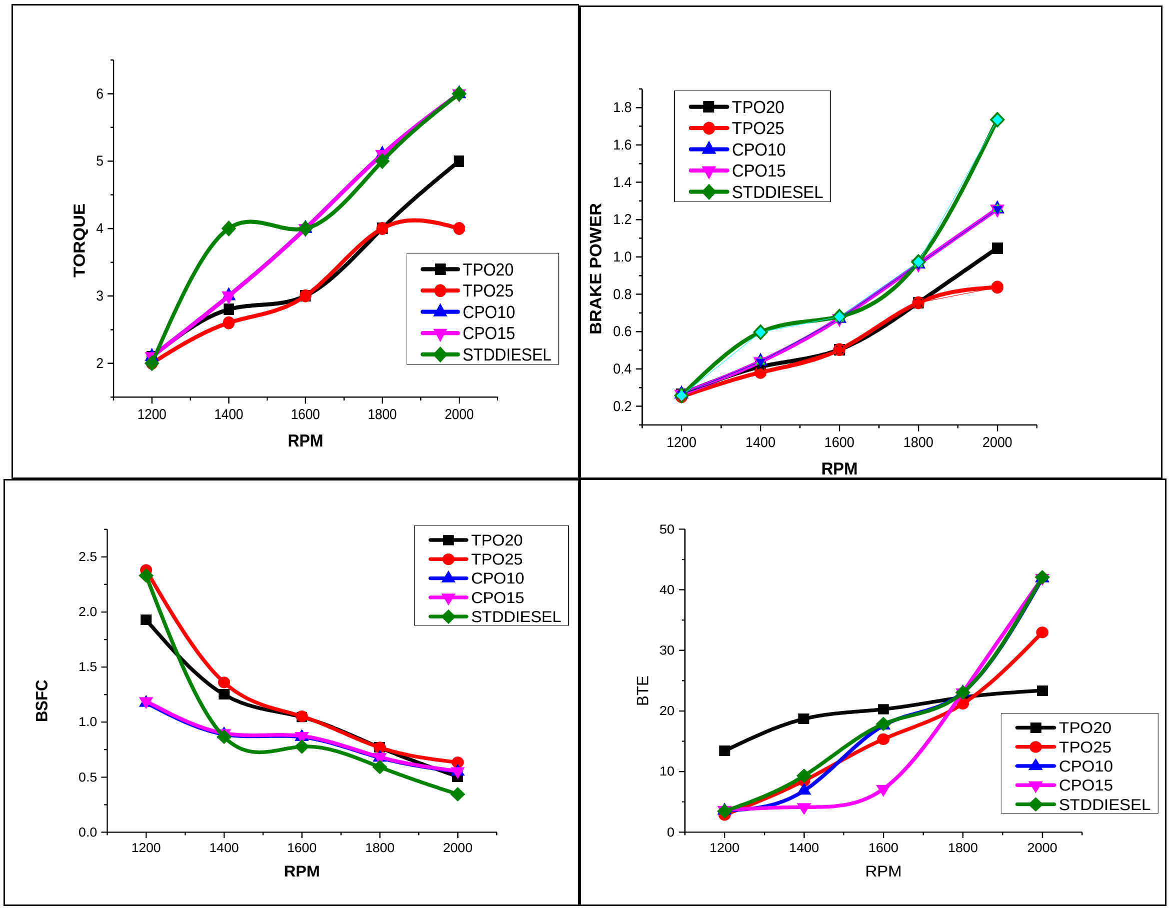

FIGURE 3. Effect of engine speed of alternative fuel on engine performance

In addition, Figure 3 the standard diesel (STD) has the lowest brake specific fuel consumption (BSFC) compared to the other blended which are TPO and CPO when reached the engine speed at 1400 rpm to 2000rpm. The lowest value for BSFC of the STD Diesel was 0.344 kg/kW.hr at the speed of 2000 rpm. Meanwhile, for TPO20, TPO25, CPO10 and CPO15 were 0.505, 0.633, 0.549 and 0.553 kg/kW.hr respectively at 2000rpm. For the blended diesel, heating value is found slightly higher than STD diesel fuel. This may be attributed to the lower heating value and higher density of the blends. It is also known that biodiesel contains oxygen content, which results in the lower heating value. Plus, the changes in BSFC were due to lower calorific value, higher viscosity and density of biodiesel in comparison with diesel fuel. As the density of biodiesel was higher than that of diesel fuel, which means the same fuel consumption on volume basis resulted in higher specific fuel consumption in case of biodiesel.

Other than that, the brake thermal efficiency shows that the STD diesel has the better efficiency as compared to other blended fuel which are TPO20, TPO25, CPO10 and CPO15 as shown Figure. Meanwhile, the engine speed at 1200rpm, all fuel shows that the brake thermal efficiency looks similar with not much different in values. When the engine speed reach up to 2000rpm, it shows different value of the brake thermal efficiency which the reading obtained for STD diesel was the highest at 42.07% while for the TPO 20, TPO25, CPO10 and CPO15 were 23.37%, 32.95%, 41.87% and 41.94% respectively. The higher viscosity leads to decreased atomization, fuel vaporization and combustion and hence the thermal efficiency of blended diesel is lower than that of diesel fuel.

For figure 4 shows the relationship between the exhaust gas temperature and the engine speed. As the engine speed increases, the value for exhaust gas temperature increases. The STD fuel has lower exhaust gas temperature with 82°C compare to the other blended fuel which are TPO20, TPO25, CPO10 and CPO15 at 1200rpm the temperature obtained were 84°C,76°C, 87°C and 85°C respectively. At engine speed 2000 rpm, STD fuel has the highest value of exhaust gas temperature which is 154°C while for TPO25 was the lowest which at 139°C. The exhaust gas temperature shows increase pattern as the engine speed increase. This may due to the complete combustion of the fuel in the engine.

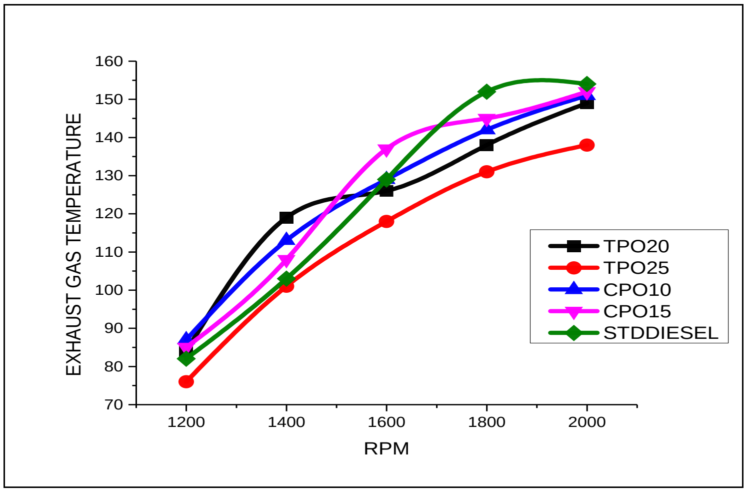

FIGURE 4. Exhaust gas temperature versus Engine speed

THE EFFECT OF BLENDING RATIO ON ENGINE PERFORMANCE.

The Figure 5 shows the effect of TPO and CPO blending ratio on the engine performance. The data analyses of this experiment were based on the standard diesel (STD), TPO20, TPO25, CPO10, and CPO15. All the five fuels were run in diesel engine with different engine speed which 1200, 1400, 1600, 1800 and 2000 rpm. Based on the Figure 4.6, the engine performance shows that the engine torque is decrease pattern in values as the engine speed increase. The STD fuel show higher torque value compare to the others two blending ratios with 6 Nm at engine speed 2000 rpm while CPO15 show the lowest value of torque at engine speed 2000 rpm.

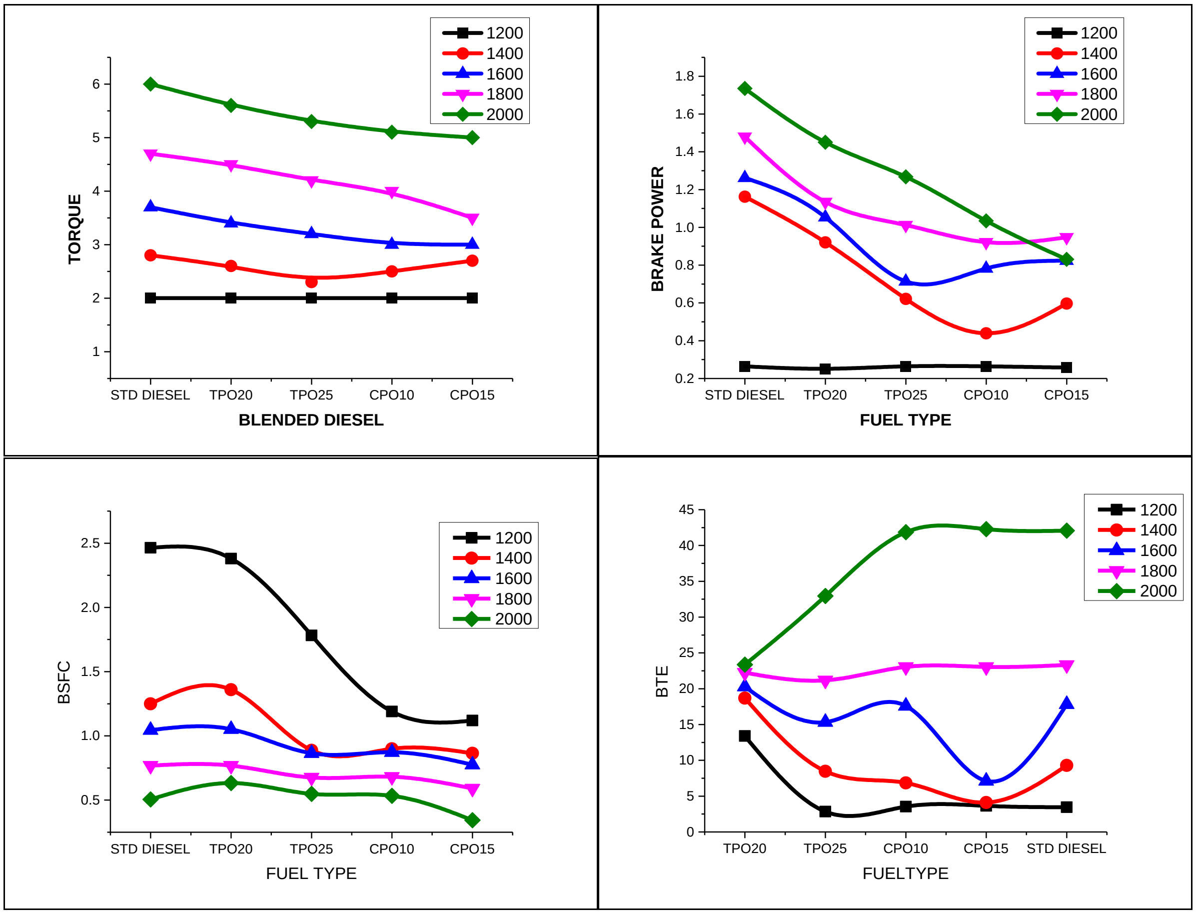

FIGURE 5. Effect of blending ratio on engine performance

Based on Figure 5 indicates the engine performance show that the brake power have decreasing pattern as the blending ratio of fuel increasing at certain engine speed. STD diesel shows the highest value of brake power as compared to TPO20, TPO25, CPO10 and CPO15. The decreasing value of brake power for the STD diesel, TPO and CPO were due to the density of the fuel which are TPO has the highest density and STD diesel has the lowest density. The engine performances also show the value of the brake specific fuel consumption (BSFC) in Figure 4.8. The lowest reading of BSFC is shown by the STD fuel. The lowest reading is 0.344 kg/kW.hr at the engine speed 2000 rpm while TPO25 shows the highest value of BSFC which at 0.633 kg/Kw.hr. The different of the BSFC of the STD diesel and blended diesel are due to difference in calorific value between the TPO and CPO.

Furthermore, the figure 5 shows the brake thermal efficiency affected by different blended diesel at different engine speed. As for the CPO15 shows that have the highest value obtained when at 2000rpm which is 42.29% as compared to other blended diesel and STD diesel. The changes of the brake thermal efficiency of the fuels were affected by properties of the TPO and CPO with different blended ratio such as viscosity, density and heating value.

CONCLUSION

The purpose of this experiment is to investigate the effect of TPO blended fuel and CPO blended fuel with different blending ratio on performance of a direct injection engine. The TPO and CPO were blended from the automotive and fuel laboratory. The testing fuels chosen for the experiment were Standard Diesel (STD), Tire pyrolysis oil (TPO20 and TPO25) and Crude palm oil (CPO1O and CPO15). The performances of the different type of blended fuel were tested based on the torque, brake power, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature.

The TPO and CPO blended fuel had different blending ratio used which were TPO20, TPO25, CPO10 and CPO15 were test at different engine speed at 1200, 1400, 1600, 1800 and 2000 rpm. The results from this investigation and researched are summarized as follow:

i. The trend for brake power produce by all TPO blended ratio was less than the STD diesel. This were achieved by oxygen content from the results of STD are better combustion and increase in the combustion chamber temperature than TPO.
ii. The torque value for all TPO was lower than diesel fuel. This was cause to the decrease in the calorific value of C and reduction of thermal efficiency.
iii. The CPO produced a lower maximum power of the engine was lower as compared to STD diesel due to lower calorific value.
iv. CPO has higher efficiency and better combustion as compared to STD diesel due to easier vaporization.
v. The different in properties of the blended diesel were affect the efficiency and combustion of the value for torque, brake power, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature.

The used of pyrolysis oil as the material for production blended diesel may cause the reduction of production cost for biodiesel and improve the quality of combustion together with the efficiency of fuel. The used of the alternative fuel may not only improve the quality of combustion but also improve the waste management.

ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Higher Education (MOHE) for supporting this research under the Fundamental Research Grant Scheme No. FRGS/1/2019/TK10/UTHM/02/10 Vot K224 and also Research Fund Universiti Tun Hussein Onn Malaysia (H802).

REFERENCES

1. Alexander Grande (2013), Heavy Duty Diesel Engines: Trucks and Buses, A Review on heavy vehicle and fuel used for the transportation, 35-55.
2. Andsaler, A.R., Khalid, A., Adila Abdullah, N.S., Sapit, A., Jaat, N., “The effect of nozzle diameter, injection pressure and ambient temperature on spray characteristics in diesel engine”, (2017) Journal of Physics: Conference Series, 822 (1), art. no. 012039.
3. Khalid, A., Azman, N., Zakaria, H., Manshoor, B., Zaman, I., Sapit, A., Leman, A.M., “Effects of storage duration on biodiesel properties derived from waste cooking oil”, (2014) Applied Mechanics and Materials, 554, pp. 494-499.
4. Abidin, S.F.Z., Rodzi, S.N.A.M., Khalid, A., Zahari, I., Jalal, R.I.A., Abas, M.A. (2021). Reducing fuel consumption of a passenger car towards energy efficient vehicle by using belted alternator startertechnology. (2021) International Journal of Engineering Trends and Technology, 69 (9), pp. 116-123.
5. Ishak, I.A., Ali, M.S.M., Sakri, F.M., Zulkifli, F.H., Darlis, N., Mahmudin, R., Abidin, S.F.Z., Azizul, M.A., Sulaiman, S., Samiran, N.A., Khalid, A. (2019). Aerodynamic characteristics around a generic train moving on different embankments under the influence of crosswind. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 61 (1), pp. 106-128.
6. Jaat, N., Khalid, A., Mustaffa, N., Zulkifli, F.H., Sunar, N.M., Nursal, R.S., Mohamad, M.A.H., Didane, D.,”Analysis of injection pressure and high ambient density of biodiesel spray using computational fluid dynamics”, (2019) CFD Letters, 11 (1), pp. 28-39.
7. Khalid, A., Mudin, A., Jaat, M., Mustaffa, N., Manshoor, B., Fawzi, M., Razali, M.A., Ngali, Z.,”Effects of biodiesel derived by waste cooking oil on fuel consumption and performance of diesel engine”, (2014) Applied Mechanics and Materials, 554, pp. 520-525.

8. Khalid, A., Suardi, M., Chin, R.Y.S., Amirnordin, S.H., "Effect of Biodiesel-water-air Derived from Biodiesel Crude Palm Oil Using Premix Injector and Mixture Formation in Burner Combustion", (2017) Energy Procedia, 111, pp. 877-884.
9. Jaat, N., Azizul, M.A., Khalid, A., Jais, M.H.A., Abidin, S.F.Z., Mustaffa, N., Ishak, I.A., Manshoor, B., Didane, D.H., Zahari, I. (2021). Investigation of Performance Characteristics of Plastic Pyrolysis Oil and Crude Palm Oil Fuel on Diesel Engine. International Journal of Engineering Trends and Technology, 69 (12), pp. 312-318.
10. Abidin, S.F.Z., Khalid, A., Zanalli, S., Zahari, I., Jalal, R.I.A., Abas, M.A., Koten, H. (2021). The effect of 48V mild hybrid technology on fuel consumption of a passenger car by using simulation cycle. Case Studies in Thermal Engineering, 28, art. no. 101492
11. Robert Liew, Nils Hooftman (2016), The Future Diesel Engine Technology, Environmental Analysis of Petrol, Diesel and Electric, Passenger Cars in a Belgian Urban Setting , 121-142
12. István Barabás and Ioan-Adrian Todoruţ, (2007), Biodiesel as an Alternative Fuel, 331-338.
13. Alemayehu Gashaw, Tewodros Getachew and AbileTeshita. (2014). A Review on Biodiesel Production as Alternative Fuel. Journal of Forest Products and Industries, 4(2), , 80-85.
14. Conley, S. P. (2006). What Is Biodiesel. Bio energy, 332-337.
15. Carsten Baumgarten, (2006) Mixture Formation in Internal Combustion Engines, Conventional Diesel Combustion, 226-229
16. Tanksali, P. A. (2013). Waste Plastic Pyrolysis. Waste Plastic Pyrolyzed Oil , 217.
17. Zainal, K. K. (2008). Biofuel from palm oil. Small Industrial Scale Pyrolysis of Oil Palm Shells and Characterizations of their Products, 251-258.
18. Singh, Y. F.-C. (2018). Decomposition of Used Tyre Rubber by Pyrolysis. Environment, 72.
19. Hossain, S. a. (2018). Performance and emission analysis of a diesel on Palm oil diesel. Conference on Energy and Power, 160.
20. Menetrez, M. Y. (2014). Meeting the renewable fuel standard. Biofuel Research Journal 4 , 110-112.
21. Kumar, P. (2017). Preparation of Biodiesel. International Journal of Pure and Applied Mathematics, 119.