Jurnal Tribologi
Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

Performance analysis of biodiesel engine by addition of HHO gas as a secondary fuel

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KEYWORDS

Biodiesel
HHO gas
Diesel engine
Performance
Emission

ABSTRACT

Biodiesel, an alternative fuel similar to fossil-based diesel, has the advantages of carbon-neutral, high flash point and emit no carbon dioxide (CO_2). HHO gas has been introduced to the automotive industry as a new energy source, a fuel supplement in an internal combustion engine (IC). This paper presents the performance and emissions of diesel engines powered by biodiesel with HHO gas as a fuel supplement. The biodiesel used is a mixture of biodiesel B20 and B30. The effect of adding HHO gas on biodiesel fuel is evaluated on engine performance and emissions before and after using HHO gas as a secondary fuel. The results show an increase in engine performance on the B20 is 14% and on the B30 is 14.63%. The observation on smoke produce of the tailpipe exhaust also drastically improved. Based on the results above, that the addition of HHO gas supplements to biodiesel fuel has a positive effect on improving engine performance and reducing emissions that are very significant so that it can improve environmental aspects when compared to the use of biodiesel without HHO gas.

Received 11 July 2020; received in revised form 19 August 2020; accepted 8 September 2020.
To cite this article: Sudrajat et al. (2020). Performance analysis of biodiesel engine by addition of HHO gas as a secondary fuel. Jurnal Tribologi 26, pp.120-134.

1.0 INTRODUCTION

The rapid development of the world automotive industry has triggered an increasing demand for fossil fuels. Meanwhile, global warming that occurs one of which is caused by the incomplete combustion process in internal combustion engines producing hazardous element such as carbon monoxide (CO), sulfur oxides (SOx) and nitrogen oxides (NOx), which are harmful not only to human health but also damaging the environment. To meet the above fuel requirement, most still depend on fossil fuels, while supplies are running low and world oil prices are rising. This condition encourages various energy experts to develop the energy that is more environmentally friendly.

The use of biodiesel fuels can help shift traditional fossil fuel users and efforts to reduce greenhouse gas emissions, diversify transportation fuels, promote renewable energy because biodiesel fuels are fuels derived from vegetable oils or animal fats through esterification or transesterification reactions. with alcohol, such as methanol and ethanol (Sawangkeaw et al., 2012). Apart from the depletion of crude oil reserves and the increasing concern of the world community on greenhouse gas emissions, which is a problem of global warming, prompting calls for global adoption of an energy economy that refers to the use of renewable energy. This gives motivation and interest to the generation of liquid biofuel users as an alternative to clean and sustainable fuels such as biodiesel, which has potential as a substitute for diesel fuel (Johari et al., 2015). As a renewable energy source, biodiesel is known to have superior quality than fossil diesel fuels, including biodegradability, higher flash points, cetane numbers, lubrication, and less greenhouse gas emissions such as CO, HC, and particles. Several studies have shown that diesel engines powered by palm oil have lower emissions of white smoke, hydrocarbons, sulfur oxides, and carbon monoxide (Yusop et al., 2018).

1.1 Effect of HHO on Biodiesel Fuel

The use of biodiesel blends with HHO gas supplements will have an impact on engine performance and emissions. In general, research on the use of pure biodiesel fuels or mixtures of them shows a decrease in emissions of hydrocarbons, carbon monoxide, and other particles when compared to the use of conventional diesel fuels, although emissions such as nitrogen oxides and carbon dioxide increase. Many studies have been conducted that lead to the refinement of HHO generators as HHO gas generators, even exceeding the standard value from Faraday's calculations. H_2 water-based gas is more useful for human needs in using energy because H_2 can be obtained from water whose sources are relatively abundant everywhere. So, it can be said that H_2 is an abundant and inexpensive source of future energy. Based on recent research that the use of hydrogen gas is widely used by the public as a fuel supplement in internal combustion engines for vehicles.

1.2 Effect of Biodiesel on Engine Performance

The process of biodiesel production through the chemical reaction of vegetable oils or animal fats with alcohol (Yusuf et al., 2011), using a catalyst can separate mono-alkyl-esters and glycerin from biodiesel (Kuss et al., 2015). In the transesterification reaction, three moles of alcohol react with one mole of triglycerides (Vedaraman et al., 2011). Research on vegetable oil has been carried out since several decades ago, including palm oil, soybean oil, cottonseed oil, castor oil, and others. The use of vegetable oil was first considered a new era when diesel engines were developed. Rudolf Diesel (1858-1913), the inventor of the diesel engine, had tested peanut oil as a diesel engine fuel (Issariyakul et al., 2014).

The characteristics of biodiesel fuel are needed to determine the suitability of engine performance, engine component life, and exhaust emissions as an environmentally friendly indicator (Karmakar et al., 2018). Important properties of biodiesel fuels include ignition quality, ease of starting, mix ratio of air and fuel, quality of exhaust emissions, and engine heating value (Barabas et al., 2011).

The main thing in determining engine performance is the average effective power when braking (Break Mean Effective, Power-BMEP) specific fuel consumption during braking (Break Specific Fuel Consumption-BSFC), and Thermal Efficiency when braking (Break Thermal Efficiency-BTE). BMEP is defined as the average pressure which, when applied uniformly to the piston at each power step, will produce measurable power output while braking the specific fuel consumption (BSFC) of the engine is a measure of fuel consumption under certain working conditions (Crolla et al., 2011). Many studies have indicated an increase in BSFC and a reduction in BMEP when using biodiesel and its blends compared to diesel oil (Chattopadhyay et al., 2013) reported that a higher BSFC when using biodiesel compared to neat diesel, and BSFC increased when the mix ratio increased, while BMEP was lower than mineral diesel. Higher BSFC for biodiesel is due to higher density than diesel oil, which indicates that the fuel injection pump gives more mass of fuel to the engine for the same output power.

Brake thermal efficiency is defined as to break the power of a heat engine as a function of the thermal input from the fuel. It is used to determine how well an engine converts the heat from fuel to mechanical energy. Nalgundwar et al. (2016) showed the thermal brake efficiency for biodiesel is nearly the same as diesel fuel for lower blends of diesel. However, the brake thermal efficiency increases as the blending percentage of biodiesel increase beyond 30% by volume. The increase is contributed by the high oxygen content of biodiesel, resulting in good combustion of fuel.

1.3 Effect of Biodiesel on Emission

Internal combustion engines are the main source that contributes to decreasing air quality throughout the world. Emissions from diesel engine exhaust gases contain gas and particulate pollutants, including unburned hydrocarbons (HC), nitrogen oxides (NOx), carbon dioxide CO_2, carbon monoxide (CO), and other particles including sulfur dioxide (SO_2) (McCormick, 2016). In general, research on the use of pure biodiesel fuels or mixtures shows a decrease in emissions of hydrocarbons, carbon monoxide, and other particles when compared to the use of conventional diesel fuels. However, emissions such as nitrogen oxides and carbon dioxide are increasing. The B20 biodiesel mixture is the most optimal mixture ratio based on engine performance and emissions, where HC and CO emissions are reduced by 28% and 30%, respectively, compared to conventional diesel oil (Vedaraman et al., 2011).

1.4 HHO Gas Implementation in ICE Engine

One effort to overcome the energy crisis is to get new energy as an alternative fuel. A hydrogen is a new form of energy. The technology used to obtain hydrogen gas through water electrolysis (H_2O) is more profitable because of the unlimited availability of raw materials. The concept of HHO generators is a technology that converts water into HHO gas molecules. HHO generators generally consist of three important components: electrodes, catalyst solutions, and electric currents (Usmani, 2016.). Electrodes are connected to the flow of electric current to pass through the catalyst solution and work to decompose the catalyst solution or liquid compound (Bhardwaj et al., 2014). Through this process, a mixture enriched with hydrogen and oxygen or Oxy-

Hydrogen bonded together molecularly and magnetically will be produced in the form of HHO or Brown gas (Kumar et al., 2014).

Water-based hydrogen production is very beneficial for environmental preservation and the availability of abundant raw materials, making water electrolysis is the only hydrogen-producing process from water (Miller et al., 2016). Hydrogen is classified as new energy that becomes the most promising transportation fuel candidate in the future. Various vehicle tests that use fuel cells sourced from hydrogen have begun to shed light on the fact that there was a massive increase in hydrogen (Kalamaras et al., 2013). Much research has been done to apply HHO gas to vehicles so that ICE engines can be supplied with HHO gas fuel from HHO generators as HHO gas producers through the process of water electrolysis (Joshi et al., 2015). The rate of formation of HHO gas and the volume of gas released directly depends on the concentration of the electrolyte, the electric current and the contact area between the electrode and the catalyst solution (Kumar et al., 2013).

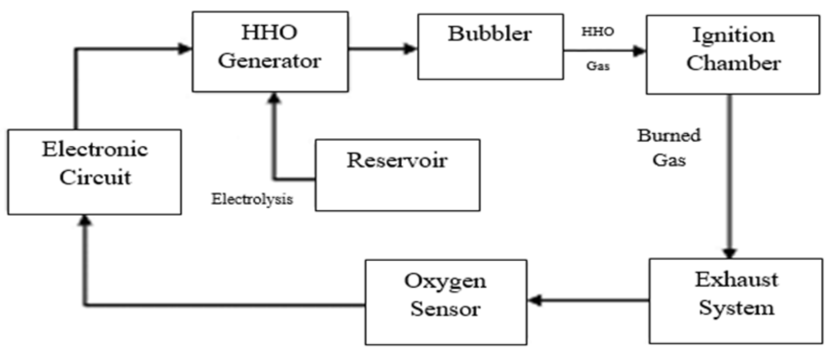

Figure 1: Block Schematic Diagram of HHO generator Integration with IC Engine.

2.0 EXPERIMENTAL PROCEDURE

In this research, diesel engine testing with alternative biodiesel B20 and B30 has been carried out using HHO gas as a fuel supplement in an internal combustion engine. The water electrolysis process takes place on an HHO generator designed for a 12 Volt DC input voltage with a maximum HHO gas output of 500 ml/min.

2.1 Implementation Fuel on the Engine

Two biodiesel blends were used in this study, one of palm oil (PME) and the second of rapeseed oil origin (RME). The two oils were blended in fossil diesel (base fuel), which was a typical market diesel fuel already containing an unknown biodiesel fraction, ranging from 1 to 2.5 vol.%. The base fuel was blended with the two biodiesels at a ratio of 10 vol.%, thus bringing the total ratio of biodiesel in the final fuels within the range of 11–12.5 vol.%. Only the PME blend was used for the engine tests, while both the PME and RME blends were used for the vehicle testing. The fuels were prepared by splash blending just before the initiation of the measurement campaign. The cetane number was found well above the specification limit (51 min) for the base diesel and the two biodiesel blends tested. All fuels tested were found to comply with the EN 590 specifications.

2.2 Experiment Set-up

In this experiment, the performance and emission characteristics of two types of biodiesel, B20, and B30 were tested on a single air-cooled four-cylinder direct injection diesel engine named LAUNTOP supplied by KHENG SUN. The application of this machine is mainly for powering agricultural equipment such as water pumps and generators. Detailed technical engine specifications are given in Table 1, while the set–up experiments and schematic diagrams are shown in Figure 2 and Figure 3.

Table 1: Engine specifications.

MODEL	Diesel 170FA
Bore*stroke (mm) / (inch)	70 × 57 / 2.76 × 2.24
Displacement (cc) / (cu.in.)	219 / 13.36
Engine speed (rpm)	3000 - 3600
Maximum output (kw) /(hp)	2.8 / 3.8
Continuous output (kw)/ (hp)	2.5 / 3.4
Mean effective pressure (kpa)	425
Power take off	Crankshaft or Camshaft (Camshaft PTO rpm is 1 / 2)
Starting system	Recoil or Recoil / Electric
Fuel tank capacity (L) / (us.gal)	2.5 / 0.66
Lube oil capacity (L) / (us.gal)	0.75 / 0.20
Dimensions L*W*H (mm) / (inch)	332 × 392 × 416 / 13.0 × 15.4 × 16.3
Net weight (Recoil) (kg) / (lbs)	27 / 59.5
Cooling type	Force air cooled system

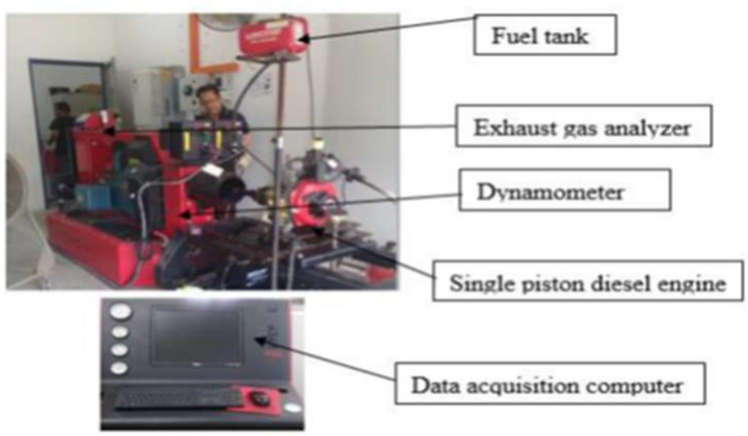

Figure 2: Engine Dyno set-up.

The process of determining fuel performance is carried out by connecting the engine to the Dynomite Engine Dynamometer. At the same time, the exhaust gas emissions are measured with a 5002 model exhaust gas analyzer. Calibrated (K) type thermocouple probes are used for temperature measurements at different experimental settings, including air intake manifolds and exhaust gases. Crankshaft rotation speed is measured using a speed tachometer. Two fuel tanks with a capacity of 10 liters are installed to store fuel on the rear side of the panel in the highest position. One burette with a stopcock and two-way valve is mounted on the front side of the panel for measuring fuel flow and choosing between diesel and biodiesel fuels. The experiment was carried out by varying the engine load from zero to full load by maintaining a constant rated speed of 1500 rpm during the experiment. All equipment is calibrated according to the specifications of each manufacturer before carrying out testing.

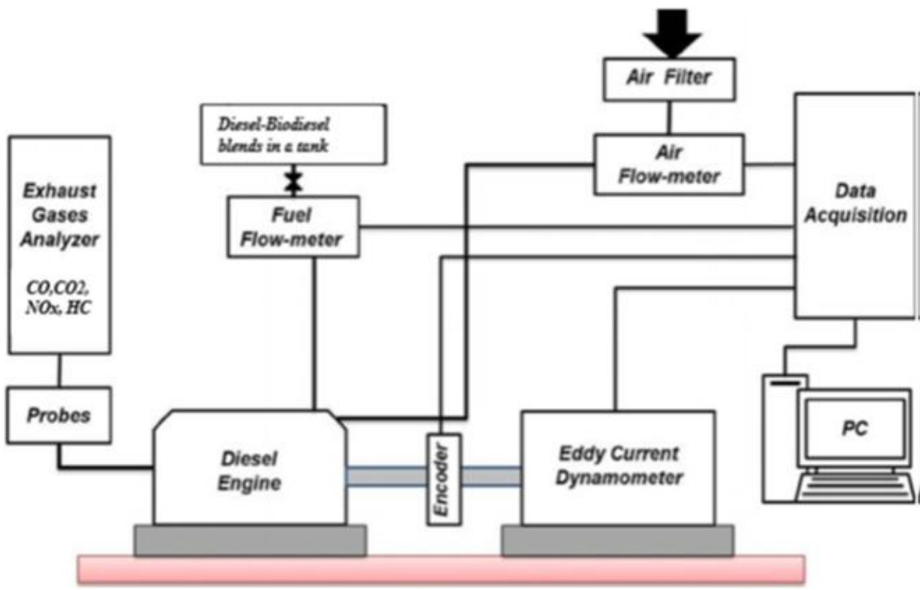

Figure 3: Schematic diagram of the experimental set-up.

2.3 Experimental Procedure

Sweep test and step tests were carried out to determine both the performance and emission characteristics of each fuel. Before conducting a new test for each fuel, the fuel tank was drained of its previous fuel used for testing and the tank was flashed with the next test fuel. After flashing, the tank was filled with the test fuel. After that, the engine was run for about 15 minutes before the test runs for actual data collection. This is to ensure that the engine is circulating only the test fuel and also ensuring that data is collected when the engine is running at an optimum temperature.

During the sweep test, the engine speed started from 2000rpm and finished at 3000 rpm with full throttle opening, while during the step test, the engine speed started at 2000 rpm and ended at 3500 rpm, with a step increment of 250 rpm. In both cases, the measured parameters that were measured and recorded to determine the engine performance of each biodiesel blend were power (hp) and torque (Nm). Emission was measured by the exhaust gas analyzer of model 5002, where exhaust gas samples were transferred from the exhaust tail to the analyzer by inserting a probe at the end of the exhaust pipe. All data were collected and stored using the engine dynamometer data acquisition.

2.4 Measurement Results

Performance and torque measurements and emissions are carried out on each type of biodiesel, namely B20 and B30, with different speeds of 2,000 to 3,000 rpm. The measurement results can be seen in the table below.

Table 2: Engine performance and torque measurement for B20.

Without HHO			With HHO		
RPM	**Horsepower (Hp)**	**Torque (N-m)**	**RPM**	**Horsepower (Hp)**	**Torque (N-m)**
2510	1.26	3.5	2515	1.462	4.1

Table 3: Engine performance and torque measurement for B30.

Without HHO			With HHO		
RPM	**Horsepower (Hp)**	**Torque (N-m)**	**RPM**	**Horsepower (Hp)**	**Torque (N-m)**
2540	1.476	3.9	2540	1.460	4.0

Table 4: Emission measurement for B20.

Without HHO					With HHO				
RPM	**CO_2**	**CO**	**NOx**	**Hc**	**RPM**	**CO_2**	**CO**	**NOx**	**HC**
2485	3.9	4.65	69	1570	2485	1.7	1.25	65	519

Table 5: Emission measurement for B30.

Without HHO					With HHO				
RPM	**CO_2**	**CO**	**NOx**	**Hc**	**RPM**	**CO_2**	**CO**	**NOx**	**HC**
2702	4.3	4.24	66	1234	2702	2.0	2.16	37	662

Table 6: Comparison of Emission measurement for B20 and B30.

B20					B30				
RPM	**CO_2**	**CO**	**NOx**	**Hc**	**RPM**	**CO_2**	**CO**	**NOx**	**HC**
2702	4.3	4.24	66	1234	2702	2.0	2.16	37	662

3.0 RESULTS AND DISCUSSION

Implementation of B20 and B30 fuels in internal combustion engines (ICE) with the addition of HHO gas as a supplement has been carried out with conditions before and after the addition of HHO gas. Data analysis of measurement results is carried out to determine the performance and emissions.

Performance analysis was carried out at different speeds from 2000 to 3000 rpm to test with B20 biodiesel and B30 biodiesel fuels. The results of this test show the engine power and torque for each use of B20 and B30 biodiesel fuels. Emission analysis was carried out at different speeds ranging from 2000 to 3000 rpm for the sweep test, ranging from 2000 to 3500 rpm for the step test. CO_2, CO, NOx, and HC emissions were measured for all tested fuels and the values are presented below.

3.1 Engine Performance

The performance parameters in this study are described as changes in power (hp) and torque (Nm) measured at rotation speeds of 2000 to 3000 rpm using biodiesel fuel with the addition of HHO gas and without the addition of HHO gas. These two parameters are plotted to compare engine performance from the use of B20 and B30 fuels with the addition of HHO gas and without the addition of HHO gas.

3.1.1 Engine Power and Torque for B20

Variations in power and torque output with engine speed and B20 biodiesel fuel with the addition of HHO gas and without the addition of HHO gas can be seen in Figure 4.

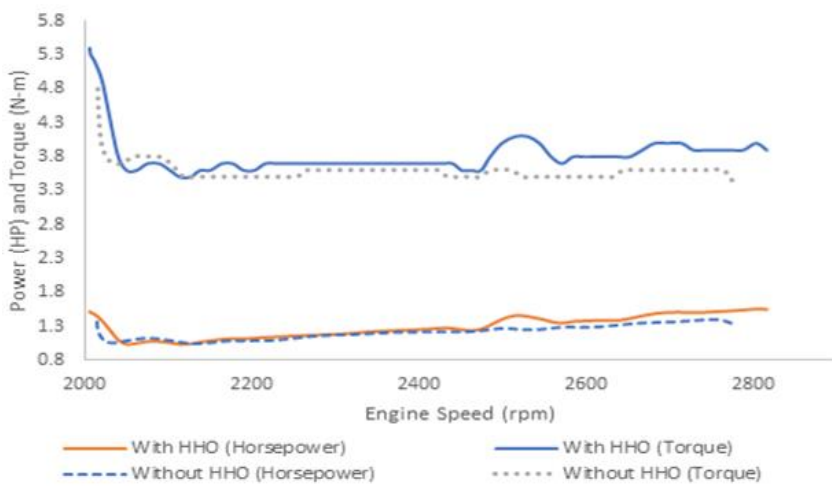

Figure 4: Engine power and torque for B20 with and without HHO gas.

From Figure 4, there are differences in output performance both in power and torque with the use of biodiesel fuel with and without additional HHO gas. For proper visualization and analysis, the graph is divided into two parts, where the bottom graph shows the relationship of speed to power and illustrates machines with the addition of the HHO gas painted in red. In contrast, machines without HHO gas are painted in intermittent blue. The graph shows a slight difference in power values due to too much oxygen content, so the combustion process requires more fuel.

3.1.2 Engine Power and Torque for B30

Variations in power and torque output with engine speed and B30 biodiesel fuel with the addition of HHO gas and without the addition of HHO gas can be seen in Figure 5.

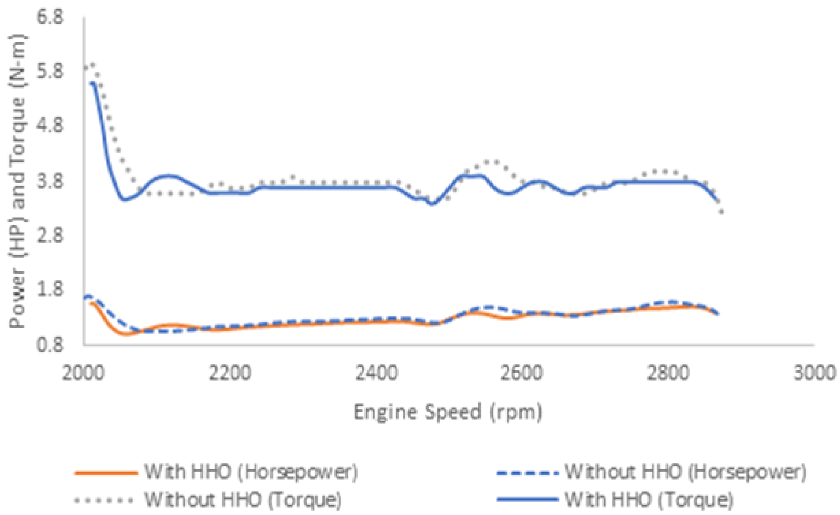

Figure 6: Engine power and torque f or B30 with and without HHO gas.

3.2 Emission Test B20

In this experiment, it was noted that CO_2, CO, NOx and HC emissions resulting from the combustion process of B20 biodiesel fuel without the addition of HHO gas were higher than the emissions that occur in the process of burning biodiesel fuel with the addition of HHO gas. The addition of HHO gas in this process encourages complete combustion. Emission analysis is carried out at different speeds from 2000 to 3000 rpm. Tests of CO_2, CO, NOx, and HC emissions are measured for B20 body-fuel with HHO gas, whose results are presented below.

3.2.1 CO_2 Emission

The results of CO_2 emissions using B20 biodiesel fuel with HHO gas are presented in Figure 7.

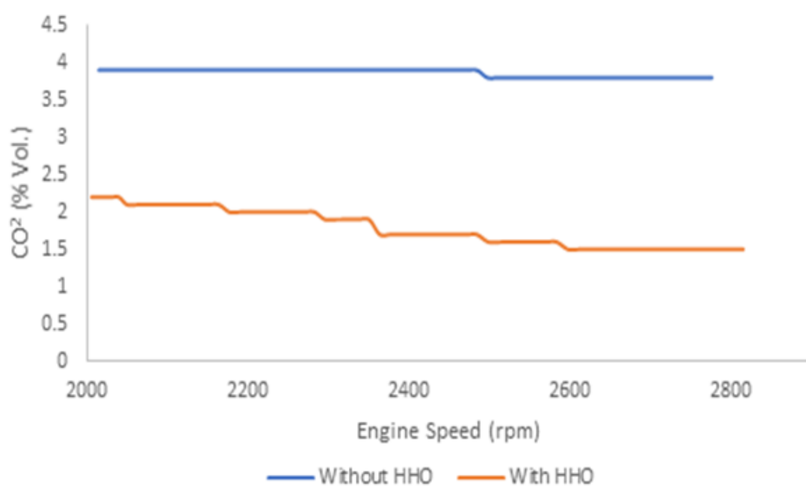

Figure 7: CO2 emissions using B20 biodiesel fuel with HHO gas.

3.2.2 CO Emission

The results of CO emissions using B20 biodiesel fuel with HHO gas are presented in Figure 8.

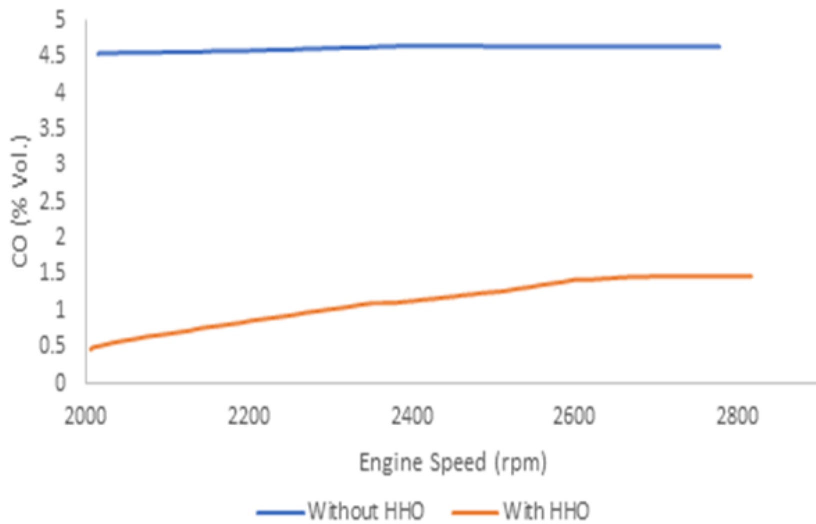

Figure 8: CO emissions using B20 biodiesel fuel with HHO gas.

3.2.3 NOx Emission

The results of NOx emissions using B20 biodiesel fuel with HHO gas are presented in Figure 9.

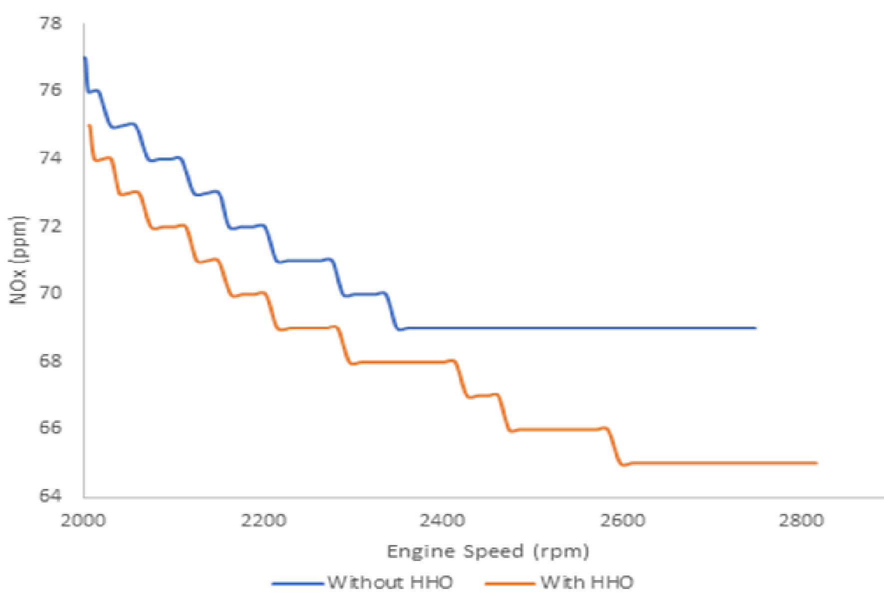

Figure 9: NOx emissions using B20 biodiesel fuel with HHO gas.

3.2.4 HC Emission

The results of HC emissions using B20 biodiesel fuel with HHO gas are presented in Figure 10.

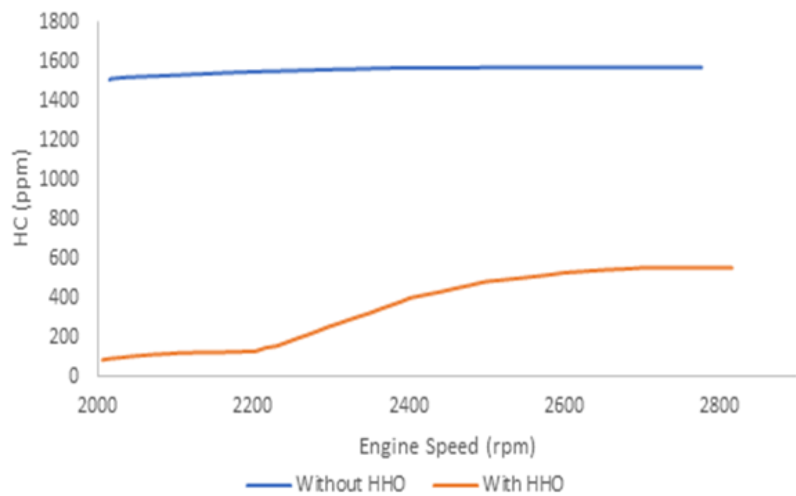

Figure 10: HC emissions using B20 biodiesel fuel with HHO gas.

3.3 Emission Test B30

In this experiment, it was noted that CO_2, CO, NOx and HC emissions resulting from the combustion process of B30 biodiesel fuel without the addition of HHO gas were higher than the emissions that occur in the process of burning biodiesel fuel with the addition of HHO gas. The addition of HHO gas in this process encourages complete combustion. Emission analysis is carried out at different speeds from 2000 to 3000 rpm. Tests of CO_2, CO, NOx, and HC emissions are measured for B30 body-fuel with HHO gas, whose results are presented below.

3.3.1 CO_2 Emission

The results of CO_2 emissions using B30 biodiesel fuel with HHO gas are presented in Figure 11.

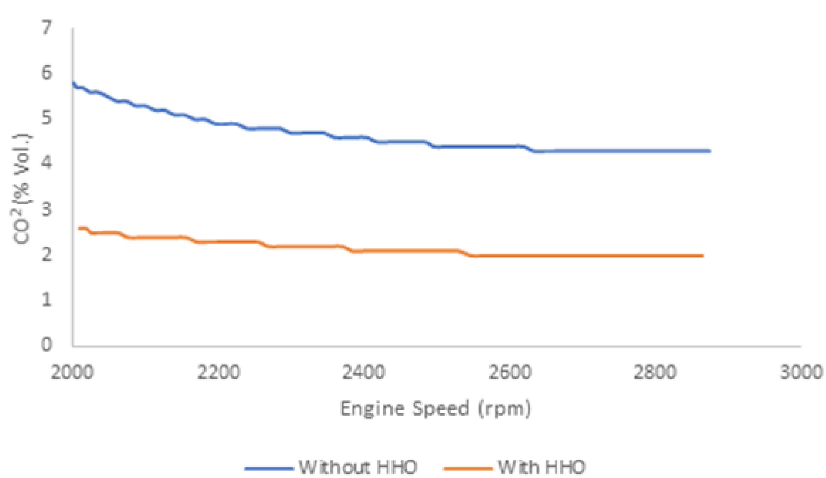

Figure 11: CO_2 emissions using B30 biodiesel fuel with HHO gas.

3.3.2 CO Emission

The results of CO emissions using B30 biodiesel fuel with HHO gas, are presented in Figure 12.

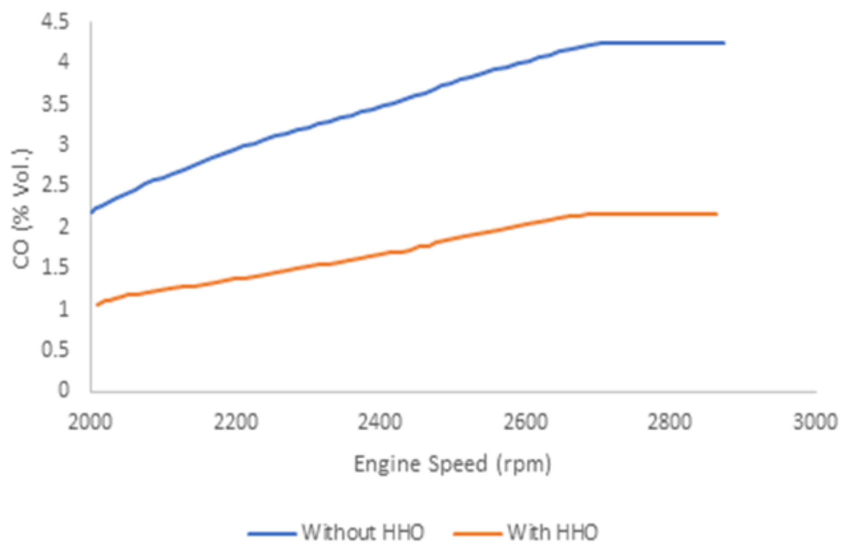

Figure 12: CO emissions using B30 biodiesel fuel with HHO gas.

3.3.3 NOx Emission

The results of NOx emissions using B30 biodiesel fuel with HHO gas are presented in Figure 13.

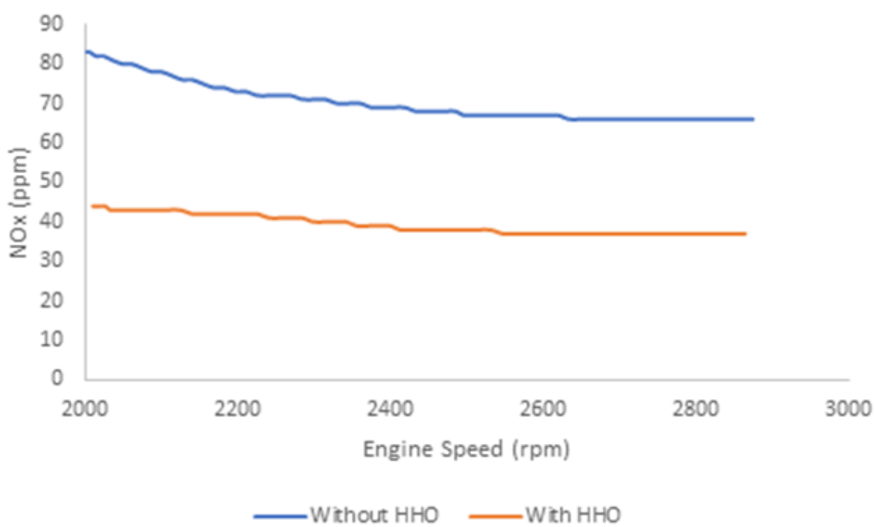

Figure 13: NOx emissions using B30 biodiesel fuel with HHO gas.

3.3.4 HC Emission

The results of HC emissions using B30 biodiesel fuel with HHO gas are presented in Figure 14.

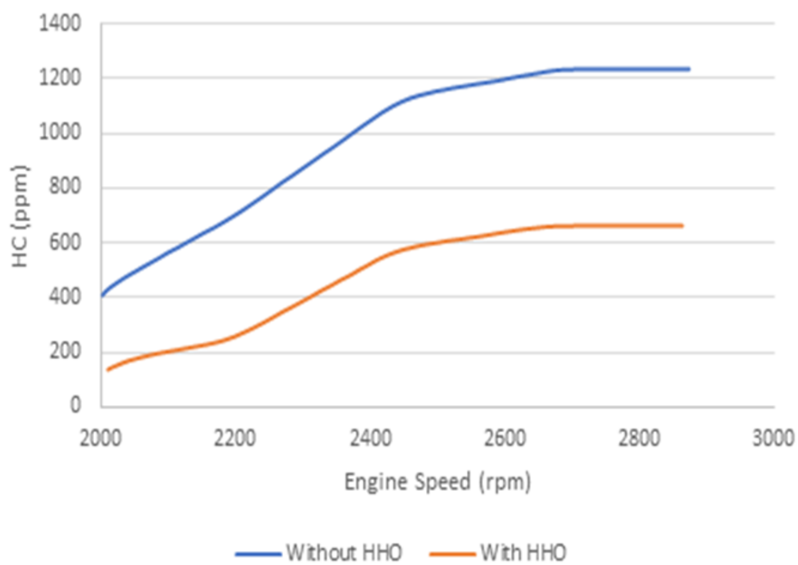

Figure 14: HC emissions using B30 biodiesel fuel with HHO gas.

4.0 CONCLUSIONS

Two different mixtures of palm methyl ester as B20 and B30 biodiesel fuels have been compared running on experimental tests by adding HHO gas to each type of biodiesel to investigate the effect of mixing ratio of biodiesel on engine performance and emissions. The tests of both types of biodiesel fuel with the addition of HHO gas and without the addition of HHO gas, B20 showed better engine performance and torque than the B30. However, the emissions test has almost the same value; B20 is 50.53% and B30 is 48%. Based on these conditions, it can be concluded as follows:

(a) The one-cylinder diesel engine used in this experiment is to determine the effect of a B20 and B30 diesel fuel mixture with the addition of HHO gas on engine performance and emissions. The torque and power parameters are measured with an engine dynamometer, while the emission analyzer measures the emission data. The experimental results show that engine performance with biodiesel blends is not linear with blends. However, B20 shows better torque performance and power output in sweep and step tests compared to B30.

(b) The use of B20 fuel with the addition of HHO gas shows a pretty good engine performance and torque at the same speed between 2000-3000 rpm, where the percentage value of engine performance increased by 13.81% and torque increased by 14.63%. In terms of emissions, the use of B20 with the addition of HHO gas shows better results than pure B20. The percentage value of the emissions shows CO_2 = 56.41%, CO = 73.11%, NOx = 5.8% and HC = 67% with an average reduction in emissions in B30 with additional HHO gas reaching 50.58%.

(c) The use of B30 fuel with the addition of HHO gas shows poor engine performance and torque at the same speed between 2000-3000 rpm, where the percentage of engine performance is 1,084% and torque is 2.5%. But in terms of emissions, the results are almost the same as B20 biodiesel fuel and there is little difference. The percentage of emissions shows CO2 = 53%, CO = 49%, NOx = 44% and HC = 46.35% with an average reduction in emissions in B30 with additional HHO gas reaching 48%.

ACKNOWLEDGEMENT

The authors gratefully acknowledge contributions made by the Green Tribology and Engine Performance (G-TriboE) research group, Universiti Teknikal Malaysia Melaka.

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