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Effects of Multi-Variant Biofuel on Engine Performance and Exhaust Emission of DDF Engine System

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Abstract – *This paper presents an investigation on the effect of multi-variant biofuel towards engine performance parameter and emission characteristic, using mix of diesel dual fuel (DDF) engine of different blend biodiesel (B5-DDF and B10-DDF) of palm oil and coconut oil in comparison to pure diesel, diesel-biodiesel (B5 and B10). This experiment was conducted with variable speed between 1400-2700 rpm at an interval of 400rpm. The collected data for engine performance showed that B5-DDF coconut oil produced the highest torque, but the brake specific fuel consumption was reduced as compared to diesel with 36% and 28.02%, respectively. In case of engine emission, lower emission of CO_2 was recorded by B5-DDF coconut oil. B10 palm oil emitted low emission of CO compared to other fuels. Significant reduction of NO_x concentration was recorded for B5-DDF palm oil compared to other fuel. It can be concluded that, diesel engine with some modifications can be used as engine DDF, which has beneficial effects both in terms of emission reduction and performance as alternative fuel.*

Keywords: Renewable Energy, Biodiesel, Diesel Dual Fuel, Engine Performance, Exhaust Emission

1.0 INTRODUCTION

Recently, a demand for energy has increased rapidly as consequence of rapid development and growth of world population [1, 2]. In 1980 to 2010, the global primary fuel consumption has grown from 6630 to 12,002.4 million tons of oil equivalent (mtoe). International Energy Agency predicts that by 2030, the global energy consumption will increase up to 53%, in which 87% of energy consumption is mainly from fossil fuels, comprising 33.75% of crude oil, coal 29.62% and natural gas 23.81%.1 In year 2000, transportation sector is the largest consumer of energy demand with roughly 41% out of total energy demand at 29.70 (mtoe) [3].

Currently, diesel engine is the most widely used as it has low fuel consumption and better efficiency [4]. However, fossil fuels cause major environmental pollutant emissions such as particulate matter, carbon monoxide (CO), nitrogen oxide (NO_x) and carbon dioxide (CO_2) which affect human health. Besides, fossil fuels also confront energy crisis due to depletion of resources [5]. Hence it is crucial to develop alternative fuels and also to cope with pollutant emissions [1]. Biofuel is an alternative fuel promising to replace fossil fuel in the transition phase towards cleaner transportation energy sources. Biodiesel is one of the most available biofuels, and nowadays Malaysia focuses more on the use of biodiesel, as the country is rich with oil palm trees, and is the second largest producer of palm oil after Indonesia [6]. Biodiesel is defined by American Society for Testing and Materials (ASTM) as fuel of monoalkyl esters of long-chain fatty acids derived from vegetables oils or animal fats, designated B100 [7]. Biodiesel is produced through process of transesterification, by which the triglycerides are reacted with alcohols, in the presence of catalyst, to produce fatty acid alkyl ester [7]. Biodiesel is promising as alternative fuel due to several advantages such as able to reduce environmental impact, reduce adverse impact on human health and easy to produce from readily available sources and safe to handle [1,5]. Unfortunately, biodiesel production faces several issues such as limited land, food versus fuel war and deforestation [8].

In order to be more environmental friendly, compressed natural gas (CNG) has been proposed as fuel in diesel engine. CNG is natural gas, made up primarily of methane and principally consists 90% in natural gas. CNG has some substantial benefits such as when burnt, it produces virtually insignificant SO_x and relatively little NO_x; the main constituents of acid rain and substantially less CO_2 [9]. Besides, the main component in natural gas, methane, reduces the risk of explosion when leakage occurs [10]. In addition, it enables engine to operate smoothly, has lower fuel cost and is non-toxic.

Dual fuel engine, which utilizes both diesel and gaseous fuels, basically mixes gaseous fuel with air by direct mixing in the intake manifold or through injection directly in the engine cylinder. The injection of small amounts of diesel fuels into the mixture is as ignition source for subsequent flame propagation [9]. Dual fuel engine uses both types of combustion which are compression-ignition (CI) and spark-ignition (SI) [9]. According to Sahoo et al [9]. CI engines (diesel engines) compress air at pressure and temperature at which the injected liquid fuel fires easily and burns progressively after ignition, whereas, SI engines (Otto engines) operate by compressing the mixture of air and vaporized fuel (high octane index) in the carburetor (equipment in a car engine that mixes petrol and air) under its ignition point and then fired. Dual engine is named diesel dual fuel engine (DDF) if diesel is used as the pilot fuel [11].

The advantage of DDF engine is that it can operate using gaseous fuel either with diesel pilot or on diesel fuel alone. This operation makes dual-fuel engines particularly attractive in vehicles application, especially when travel distance is a concern because of the lack of CNG refuelling facilities [12]. Secondly, diesel engine can be converted to dual fuel engine even without removing the original cylinder head. The conversion is also not as complicated as opposed to converting a diesel engine into spark-ignited CNG operation, thus reducing the capital cost and time for conversion [12]. Besides, dual-fuel engine is an effective technique as it can use CNG efficiently and reduce exhaust emission from diesel engines effectively [12].

Lots of research works on fuel natural gas-diesel and biodiesel-diesel have been carried out so far. However, the data on diesel-biodiesel-natural gas in engine performance and emissions are still limited. Hence, DDF engine system performance and emission fuelled by diesel-biodiesel-natural gas have become an increasing interest. The main purpose of the present study is to investigate the effect of multi-variant biofuel towards engine performance and emission of DDF engine system.

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1.1 Engine Performance

The performance of the engine can be determined through two parameters, which are torque and brake specific fuel consumption (BSFC). Torque can be defined as force acting at a distance, and it is an indicator of an engine ability to do work. Meanwhile, BSFC is a ratio between mass fuel consumption and brake effective power and for a given fuel. BSFC is a very important criterion in term of economy.

1.2Torque

Buyukkaya [13] showed that at higher speeds, the torque delivered by B5 fuel was higher, approximately 2 Nm on average than torque delivered by diesel fuel. The torque for other fuels such as B20, B70 and B100 were found decreasing, signifying that higher viscosity of biodiesel will lower the engine torque. Cetinkaya et al. [14] tested four stroke diesel engine using biodiesel fuel originated from used cooking oil. The torque obtained was 3-5% less than normal diesel fuel and lower specific heating value of biodiesel were the reasons for this difference. Lim et al. [3] tested dual fuel engine fuelled with diesel and natural gas. They reported that when percentage of CNG increased, torque and break power also increased. They also concluded that dual-fuel system can satisfy performance characteristic with 5% variation as compared to diesel engine.

In addition, torque and power of dual-fuel were found slightly higher than those of diesel. Damas [15] tested diesel dual fuel engine operational reliability and its environmental impacts using biodiesel fuelling. He reported that B5-DDF gave better results as it achieved highest value of torque and decreased to 16% at highest engine speed. Syazwan [16] conducted a research on emission and performance of direct fuel injection diesel engine fuelled with blend corn oil methyl ester with DDF (with variation of B5-DDF, B10-DDF, B15-DDF and B20-DDF). The result showed that, engine torque became higher at low speed compared with diesel-CNG, B20 and pure diesel. Investigation by Aizuddin [17] on direct fuel injection diesel engine fuelled with blend palm oil methyl ester with DDF (B5-DDF, B10-DDF, B15-DDF and B20-DDF) found that B20-DDF had higher engine torque than diesel-CNG, B20 and pure diesel at low speed, and the torque reduced at the top of engine speed. This was due to presence of CNG, where better combustion was achieved but causing high torque. The reduction in engine torque at high speed is very important to sure that the engine can carry heavy load and there is no extra force inside the cylinder that can cause engine burst at high speed.

1.3Brake specific fuel consumption (BSFC)

Buyukkaya [13] tested four-stroke, turbocharged direct injection diesel engine with neat rapeseed oil, with blends variation of 5%, 20% and 70%, and standard diesel fuel separately. BSFCs of B5, B20, B70 and B100 fuels were observed to be higher. This might be contributed to lower heating value of the B100. Nurun Nabi et al. [4] found BSFC values for biodiesel mixtures tended to be higher than those of neat diesel fuel when tested in 4-stroke, Direct Injection (DI) diesel engine with neat diesel and cottonseed seed oil methyl ester (B10, B20, B30, B40 and B50). The increasing values were a result of lower heating value of biodiesel mixtures. Papagiannakis and Hountalas [18] also tested four stroke diesel engines, where they found that the total brake specific fuel consumption for dual fuel operation was considerably higher at low load compared to normal diesel operation. Poor utilization of the gaseous fuel was mainly due to lower temperature. Wagemakers and Leemakers [19] tested conventional diesel in dual-fuel mode operation with additional gaseous fuels to the liquid

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diesel. The BSFC seemed to increase with natural gas content due to poor utilization of the gaseous fuel. Majid et al. [10] tested four-stroke CI engine, which was converted into a dual fuel engine with CNG-Diesel fuel, where they found that the specific diesel fuel consumption in dual fuel engine was lesser than a dedicated diesel engine because of substitution of CNG. During the dual mode, diesel was used for pilot injection, and thereafter CNG and diesel were combusted in the chamber simultaneously.

1.4Engine Emission

Engine emission can be determined through three parameters which are carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxide (NO_x). CO is produced when there is incomplete combustion. CO represents the lost chemical energy that is not fully utilized in the engine. Meanwhile, CO_2 is produced when complete combustion occurs. CO_2 is important to measure because it contributes to serious public health problems and plays major role in ozone formation. Lastly, nitrogen oxide is produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperature.

1.2Carbon Monoxide (CO) Emission

Da Silva et al. [20] reported that the addition of sunflower methyl ester in higher contents can contribute towards a decrease in CO concentration in the exhaust gases. This may be attributed to the higher oxygen content in the blend, which may promote a more efficient combustion. Nurun Nabi et al. [4] found that B30 can reduce CO emission by 24% compared to neat biodiesel. B30 helps releasing some extra oxygen contained in biodiesel molecule, and leads to complete combustion of the fuel and supplies the necessary oxygen to convert CO to CO_2. Papagiannakis and Hountalas [18] observed that under dual fuel operation, CO emission was significantly higher. At low load engine speed, carbon monoxide concentration under dual fuel decreased with the increase of engine load, as consequence of the improvement of gaseous fuel utilization. Hakim [21] studied on emissivity impact reduction via diesel dual fuel (DDF) sustainable engine. He found that the diesel alone emitted higher CO compared to dual-fuel operation. Simon Damas [15] concluded that pure diesel and B20 emitted CO almost zero but still increased with increasing engine speed and B20-DDF emitted higher CO compared to other fuels. Syazwan [16] found that CO emission was the lowest by fuel without CNG. Papagiannakis and Hountalas [18] tested four stroke engine fuelled with natural gas and diesel, and found that carbon monoxide concentration under dual fuel decreased with the increase of engine load, which was consequence of the improvement of gaseous fuel utilization.

1.2Carbon Dioxide (CO_2) Emission

Simon Damas [15] reported that B20-DDF emitted higher CO_2 at initial speed and when the speed was increased, DDF fuel emitted higher CO_2. Liaquat et al. [22] found that CO_2 emission for biodiesel blends increased compared to diesel fuel. Oxygen content in biodiesel was found reacting with unburned carbon atoms during the combustion and increased the formation of CO_2. More amount of CO_2 in exhaust emission indicates completeness of the combustion of fuel. Ramadhas et al. [23] compared the CO_2 emissions engine fuelled with methyl esters of rubber seed oil in the diesel engine, where they found CO_2 emission increased with increase in load. The amount of CO_2 emitted was very low in comparison with diesel when the percentage of biodiesel blend was lower. Syazwan [16] observed that there was increase in emission of CO_2 for all types of fuel, including diesel, diesel-CNG, B20 and

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B20-DDF. The presence of CNG in diesel cylinder produced the highest emission of CO_2 for diesel-DDF.

1.2Nitrogen Oxide (NO_x) Emission

Nurun Nabi et al. [4] observed that NO_x level was higher for biodiesel mixtures than conventional diesel fuel at the same engine torque. This might be contributed to the presence of extra oxygen in the molecules of biodiesel mixtures. Silva et al. [20] concluded that addition of higher sunflower methyl ester (SME) contents contributed to an increase of the NO_x concentration in the exhaust gas. Liaquat et al. [22] reported that NO_x emission for blends was found higher than diesel fuel. The formation of NO_x emission was found strongly dependent upon the equivalence ratio, oxygen concentration and burned gas temperature. Aizuddin [17] found that fuel which contained biodiesel emitted the lowest NO_x. Lower calorific value and longer ignition delay are responsible for lower emission of NO_x. Hakim [21] concluded that the concentration of NO_x released under normal diesel operation was much higher than the dual-fuel operation. Simon Damas found that B20 emitted the least NO_x compared to B20-DDF, DDF and diesel fuel. Syazwan [16] concluded that B20 emitted the lowest emission compared to other fuels, due to lower calorific value of biodiesel and longer time delay.

2.0 METHODOLOGY

2.1Experimental Facilities

In this study, the engine parameters for performance were measured using dynamometer for torque and BSFC. Meanwhile, the exhaust emission level for CO, CO_2, NO_x and HC was measured simultaneously using gas analyser. The specification of the engine is shown in Table 1.

Table 1: Engine specification

Model	Hino H07C 6-cylinder 6728 cc
Type	Water cooled, 4-cycle, direct fuel injection
No. of cylinder X Bore x Stroke	6 x 110 mm x 118 mm
Compression ratio	17.5: 1
Maximum Torque	657 N-m/1600 rpm
Rated output	132.7 kW

2.2Tested Fuel

Relevant properties of the test fuels used in this study are listed in Table 2. Before testing the CNG-diesel-biodiesel DDF system, test of diesel fuel was preceded to acquire the basic data of engine performance and exhaust gases fuelled with diesel only. All these parameters were recorded accordingly and the experiment was conducted for at least three times, where the averaged data were taken for further analysis.

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2.3Experimental Methods

During test for diesel fuel, the diesel engine was run for 20 to 30 minutes until reaching its steady state condition. The diesel engine was set to operate at speeds of 1400 rpm, 1800 rpm, 2200 rpm and 2600 rpm by controlling the gas throttle. Next, after all parameters had been tested and measured, the engine was switched off and it was left to cool to the ambient temperature. The entire steps were repeated again with dual fuel mode which utilized diesel and natural gas. After that, the test was continued with various types of palm oil which were B5, B10 and biodiesel blended with natural gas (B5-DDF and B10-DDF). This experiment was repeated for blended biodiesel and blended biodiesel-CNG for coconut oil. Figure 1 shows the entire step for the experiment.

2.4Engine Modification

Some modifications were made to the engine in order to reduce error during the experiment. Some of the modifications included installation of transparent fuel tubes, bubble remover system and fuel piping.To convert the engine fuel from diesel to biodiesel, transparent fuel tube was used to indicate if the diesel had been totally replaced by biodiesel when the colours of fuels in the inlet and returns tubes were the same. This modification was to ensure that the experiment could be conducted with low percentage error.The presence of air bubbles in diesel engine could harm the fuel pump. Therefore, fuel piping had been installed to separate diesel and biodiesel. The separation occurred when biodiesel valve could be shut-off during diesel testing and vice versa. As consequence of installation fuel piping, the fuel would not mix with each other, therefore could reduce the percentage of error [17].

Table 2: Fuel properties

Properties	Diesel	NG	PALM OIL (B100)	COCONUT OIL (B100)
Density @ 15 °C (kg/m^3)	848.6	0.74	883.5	876.5
Cetane No.	50.6	130	46.8254	41.3379
Kinematic viscosity @ 40 °C (mm^2/s)	4.236	-	5.999	3.411
Pour point (°C)	-3	-	9	-3
Cloud point ((°C)	4	-	18	3

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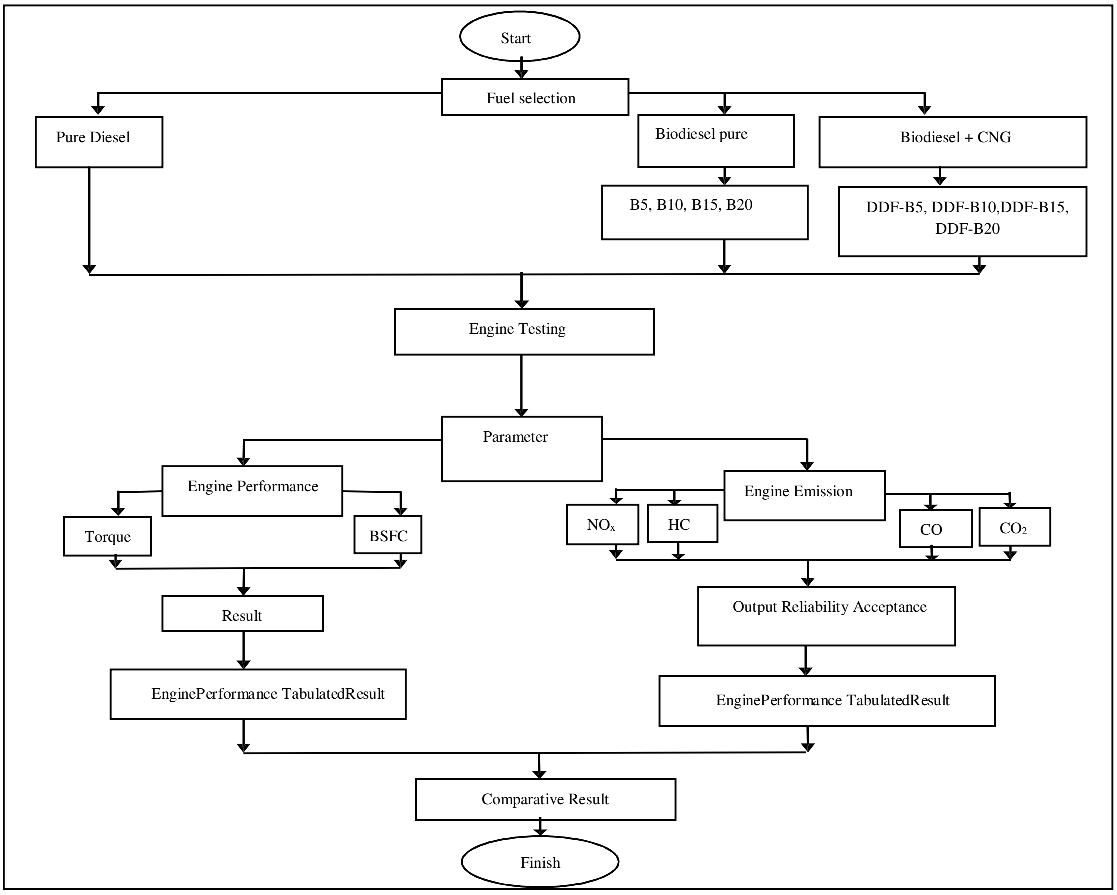

Figure 1: Flow chart of the entire step of experiment

3.0 RESULTS AND DISCUSSION

3.1Engine Torque

Figure 2 shows the variation of engine torque of different biodiesel. The engine torque was found increased with the increase of engine speed until it reached a maximum value and then decreased with further increase of engine speed for all types of biodiesel blends. This result is almost similar with the result reported by Semin et al. [24]. The increase of engine torque showed that more load could be supported and carried by the engine.B5-DDF coconut oil produced the highest torque compared to other fuels, due to lowest viscosity of the coconut oil. The lowest viscosity increased the combustion efficiency due to better fuel injection atomization. Buyukkaya [13] pointed out that, higher viscosity of biodiesel can affect the engine torque as it prevents sufficient breaking of the biodiesel during injection process. When the blend of biodiesel level increases, the viscosity of biodiesel also increases.

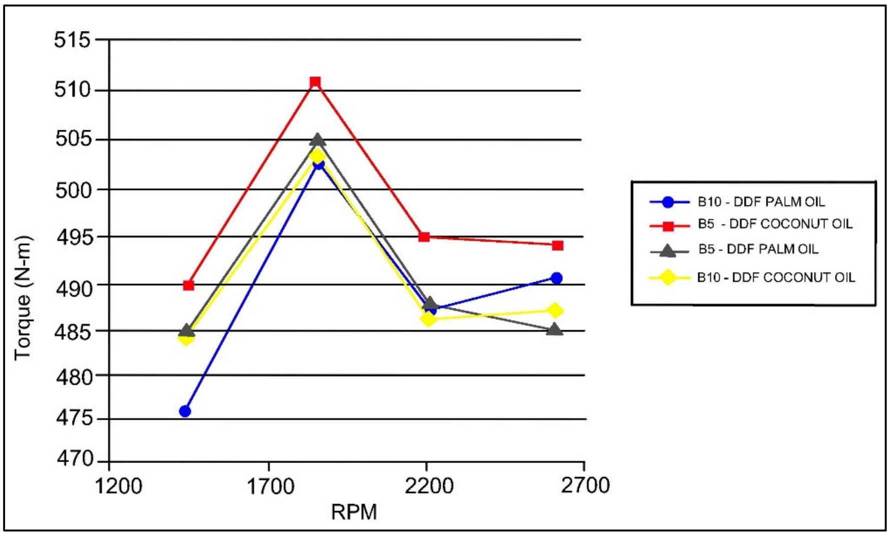

Figure 2: Torque against engine speed (RPM) for various blends of biodiesel-natural gas

Figure 3 shows the effects of the three fuels on the engine torque. The measurement showed that the addition of CNG into biodiesel had a positive effects on the torque. The presence of CNG in the engine allowed engine compression ratio to increase. As the compression ratio increased, it would partially increase ideal efficiency and torque [24]. The reduction of engine torque at high speed indicated that less force was needed to push the engine speed piston at high speed. This was due to reduced load at higher speed.The average torque over the engine speed ranged from 497.3167, 450.0083 and 433.4833 N-m by B5-DDF coconut oil, B5 coconut oil and diesel, respectively. The B5-DDF coconut oil produced higher engine torque (by 36%) than B5 coconut diesel and diesel. This result is similar with findings by Lim et al. [25] regarding engine optimization and emission characteristic fuelled with natural gas and diesel.

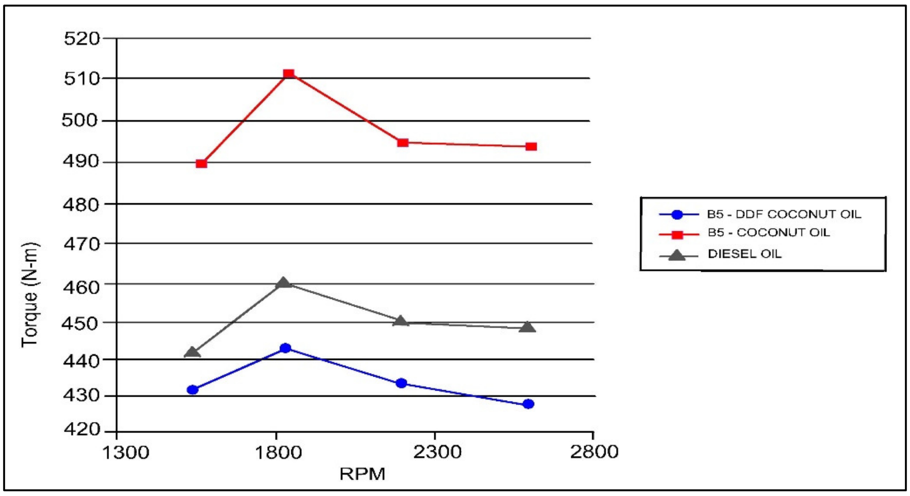

Figure 3: Torque against Engine Speed (RPM) for various fuels

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3.2 Brake Specific Fuel Consumption (BSFC)

Figure 4 shows the variation of brake specific fuel consumption (BSFC) versus engine speed for all the test engines from 1400 rpm to 2600 rpm. It was seen that BSFC increased initially at 1400 rpm for all fuels due to an increase in magnitude of friction, which was decrease of fuel conversion efficiency, as stated by Kalam and Masjuki [26]. The average BSFC over the test cycle for B10-DDF palm oil, B5-DDF coconut oil, B5-DDF palm oil and B10-DDF coconut oil were 0.4154 kg/kWh, 0.3461 kg/kWh, 0.4363 kg/kWh and 0.4404 kg/kWh, respectively.B5-DDF coconut oil produced the lowest BSFC compared to other fuels, as shown in Figure 4. The lower BSFC for B5-DDF coconut oil compared to other fuels was contributed by the higher heating value of biodiesel, and thus less biodiesel blend was required in order to maintain constant power output [4]. In addition, the higher oxygen content resulted in lower heating value. Therefore, the same energy output from the engine required larger mass fuel flow, thus increasing BSFC to compensate the reduced chemical energy in the fuel.

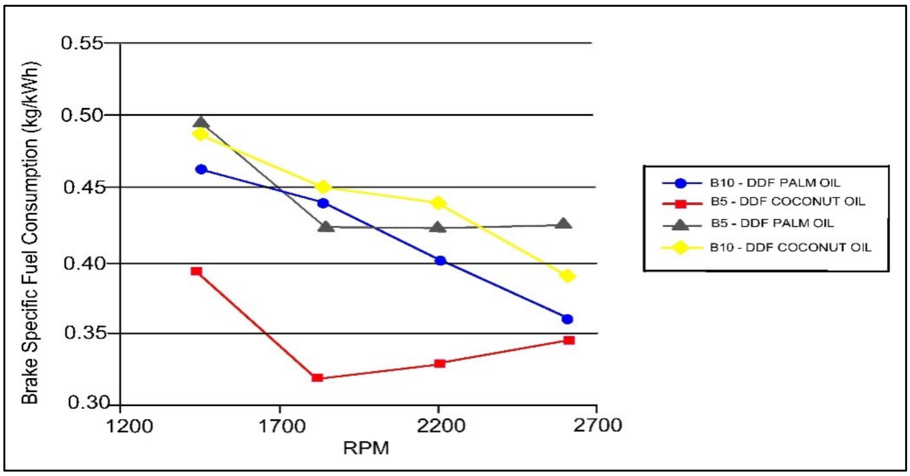

Figure 4: Brake specific fuel consumption against engine speed (RPM) for various blend biodiesel-natural gas

Figure 5 shows the variation of brake specific fuel consumption at 1400 rpm and 2600 rpm engine speed under diesel, blend of biodiesel-DDF and blend of biodiesel respectively. As shown, at low and higher speed, B5-DDF coconut oil had considerably lower BSFC compared to B5 Coconut oil and diesel. The reasons for lower brake specific fuel consumption for blend of biodiesel-DDF might be due to the higher heating value of natural gas than diesel. Higher heating value could improve the utilization of the gaseous fuel due to higher temperature inside the combustion chamber of the engine and shortest start of ignition [27]. The combination of biodiesel and CNG as a fuel produced the lowest BSFC compared to other fuels.Over the entire speed range, the average of BSFC was found to be 0.3461 kg/kWh for B5-DDF Coconut oil, 0.4390 kg/kWh for B5-Coconut oil and 0.4499 kg/kWh for diesel. The lower value of BSFC indicated that the engine consumed less fuel. The B5-DDF Coconut oil produced lower BSFC by 28.02% than B5 Coconut oil and pure diesel.

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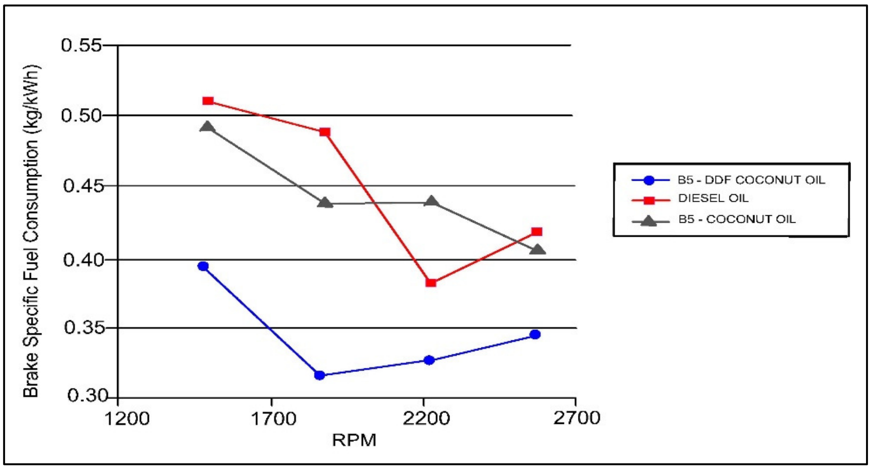

Figure 5: Brake specific fuel consumption against engine speed (RPM) for various fuels

3.3 Carbon Dioxide (CO_2)

The emission level of carbon dioxide (CO_2) emission for the blend of biodiesel-DDF at 1400 RPM until 2600 RPM is shown in Figure 6. It can be seen that CO_2 emission was very high at higher engine speed. Liaquat et al. [22] concluded that, the high emission of carbon dioxide is attributed to the presence of oxygen content in the biodiesel which reacts with unburned carbon atoms during the combustion and increases the formation of CO_2. The higher amount of CO_2 thus signified a complete combustion of fuel. On average for all the engine speed range, the CO_2 levels were at 11.1583%, 10.9%, 10.925% and 11.042% by B10-DDF palm oil, B5-DDF coconut oil, B5-DDF palm oil and B10-DDF coconut oil, respectively. B5-DDF coconut oil fuel produced the lowest CO_2 emission compared to other fuels.

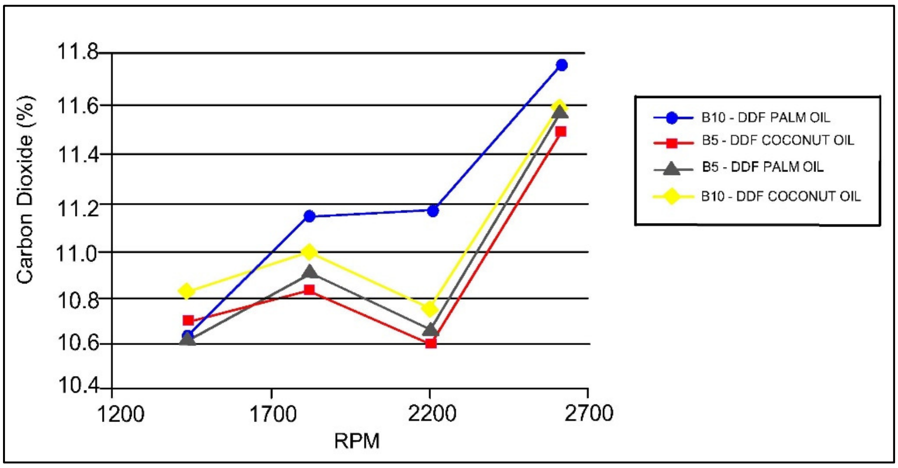

Figure 6: Carbon dioxide against engine speed (RPM) for various blend biodiesel-natural gas.

The effects of diesel, B5-DDF Coconut oil and B5-Coconut oil on emission of carbon dioxide are shown in Figure 7. It was found that the lowest CO_2 was produced by 10.9% B5-DDF Coconut oil, followed by 11% from the diesel and 11.30833% from B5 Coconut oil. Lim et al. [3] also found that in case of diesel fuel, CO_2 emission is higher than dual-fuel mode. The

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low carbon content of CNG is responsible for lower carbon dioxide emission, as CNG is mainly made up of methane (CH_4).

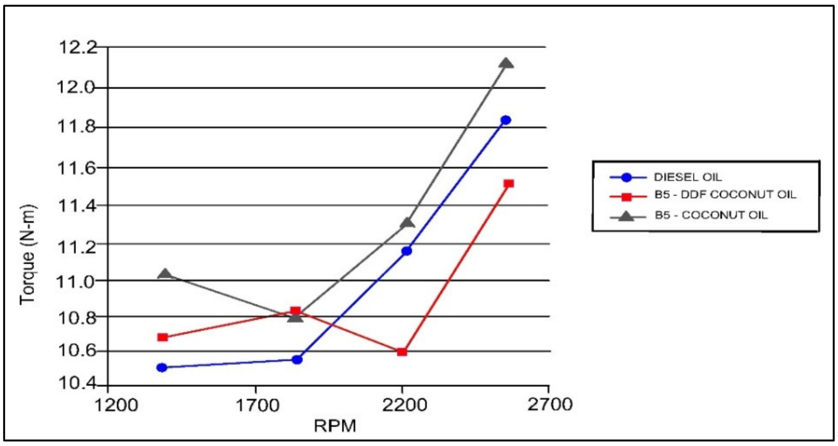

Figure 7: Carbon dioxide against engine speed (RPM) for various fuels

3.4 Carbon Monoxide (CO) Emission

The variation of carbon monoxide (CO) as a function of engine speed (RPM), from 1400 to 2600 rpm, is given in Figure 8. CO is an intermediated combustion product and was formed mainly due to incomplete combustion of fuel. CO was produce due to shortage of combustion air. On average over the engine speed range, it is found that the CO produced was 2.3525%, 2.2625%, 1.9942%, and 2.4617% by B5-DDF palm oil, B10-DDF coconut oil, B10-DDF palm oil, B5-DDF coconut oil respectively.Based on the average, B10-DDF palm oil emitted the lowest CO compared to other fuels. The higher oxygen in the molecule resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO into CO_2 [4]. By increasing the blend of biodiesel, the oxygen level also increased. Besides, at higher engine speed, the emission of CO increased, which might also decrease air fuel ratio, thus reducing the oxygen content.

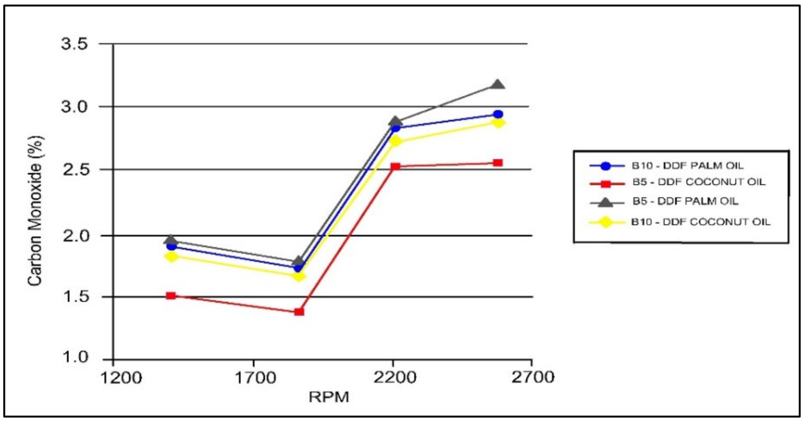

Figure 8: Carbon monoxide against engine speed (RPM) for various blends of biodiesel-natural gas

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Figure 9 shows the comparison of the CO emission of various fuels used in the diesel engines. The CO emission decreased with increasing engine speed for diesel and B10 palm oil, but it was vice versa for B10-DDF palm oil, which emitted more CO compared to other fuels. Since natural gas is in gaseous state, it will reduce the volumetric efficiency or in other words, it will displace 8 to 10% of oxygen available for combustion process [24]. Hence, this will reduce the total excess air ratio. Shah et al. [28] also found that CO emission under dual fuel operation is significantly higher than under normal diesel operation.It is interesting to note that, the engine emitted more CO using diesel as compared to biodiesel blend fuel. The higher oxygen content in B10 Palm oil compared to diesel helped the mixture to completely burn, thus reducing the amount of CO. This result is similar with the findings made by Ramadhas et al. [23].

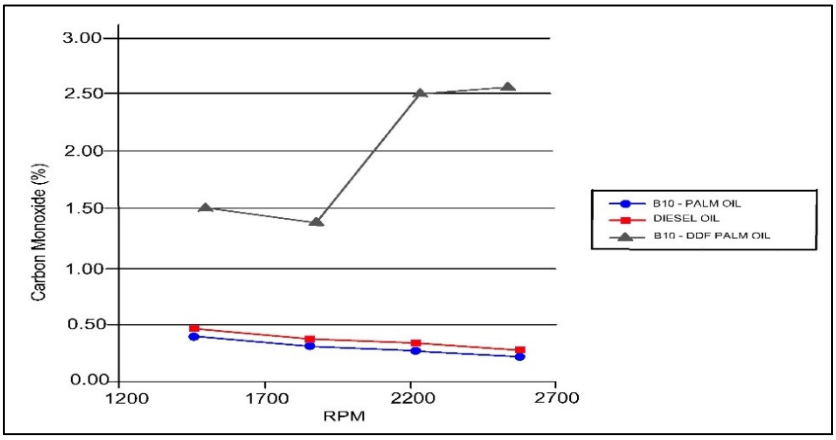

Figure 9: Carbon monoxide against engine speed (RPM) for various fuels

3.5 Nitrogen Oxide (NOX) emission

The result of NO_x emission from 1400 to 2600 rpm engine speed is shown in Figure 10. The NO_x emission for all four type of fuel were found decreasing as the engine speed increased. NO_x level was higher due to lower cetane index. High cetane index caused significant reduction in the NO_x emission due to shorter ignition delay times and resulted in lower average combustion temperature.Figure 10 also indicates that the lowest NO_x was produced by B5-DDF palm oil (average 253.4167) followed by B5-DDF coconut oil (average 253.5833), B10-DDF coconut oil (average 258.08) and B10-DDF palm oil (average 268.9167).

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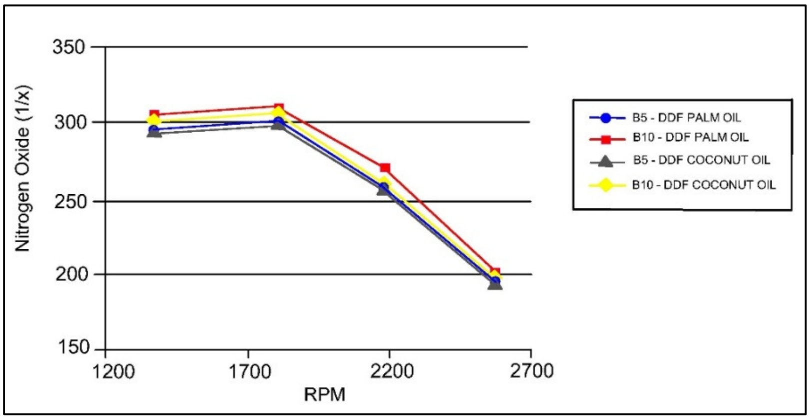

Figure 10: Nitrogen oxide against engine speed (RPM) for various blends of biodiesel-natural gas

Figure 11 shows the comparison of the CO_2 emission of various fuels used in the diesel engine. The emission was found decreasing with increase in engine speed. The B5-DDF palm oil and B5 palm oil emitted low amount of NO_x in comparison with diesel. This was probably due to cool gas CNG entering the engine cylinder and thus overall combustion was completed at low temperature [26]. Knothe et al. [29] concluded that with increasing cetane index causes significant reduction in the NO_x emission due to shorter ignition delay times and result in lower average combustion temperature.The average NO_x emission over the engine speed range were 253.4167, 256.5833and 259.8333 by B5-DDF Palm oil, B5 palm oil and diesel, respectively. Maxey and Kalaskar [30] reported in their study, NO_x emission decreases when using natural gas substitution.

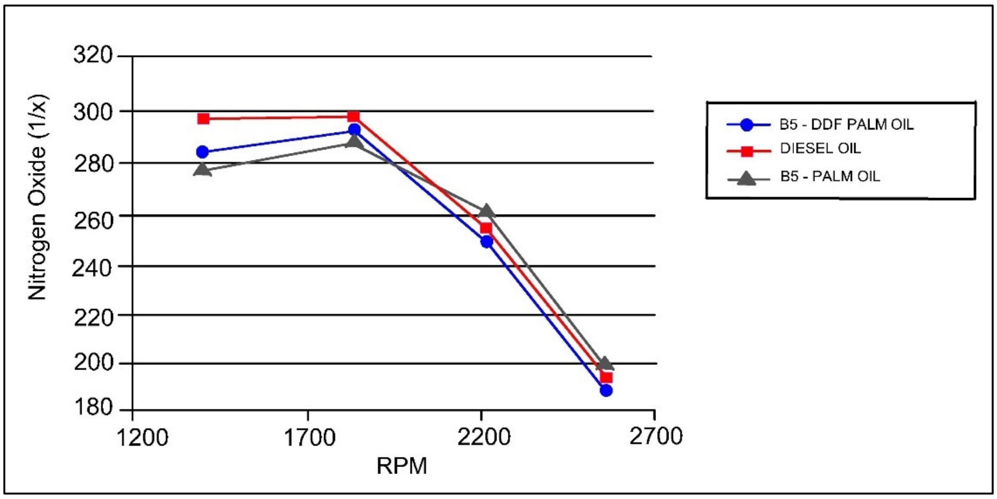

Figure 11: Nitrogen oxide against engine speed (RPM) for various fuels

3.6 Unburned Hydrocarbon (HC) Emission

The variation of unburned hydrocarbon concentration is given in Figure 12, set at 1400 rpm to 2600 rpm engine speed for various blends of biodiesel DDF system. As observed, all the emission of unburned hydrocarbon decreased as engine speed increased. Higher unburned hydrocarbon emission at initial speed might be due to lower charge temperature and air fuel ratio which caused slower combustion and small quantities of fuel to escape during combustion process [18]. The average HC emission over the engine speed range were 87.67,

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99.58, 80.92 and 83.42 by B5-DDF palm oil, B5-DDF coconut oil, B10-DDF coconut oil and B10-DDF palm oil, respectively. Based on Figure 12, B10-DDF coconut oil emitted low unburned hydrocarbon compared to biodiesels. This was due to higher oxygen content in the biodiesel. When complete combustion occurred, more hydrocarbons in fuel were burned and thus reduced the emission of unburned hydrocarbon.

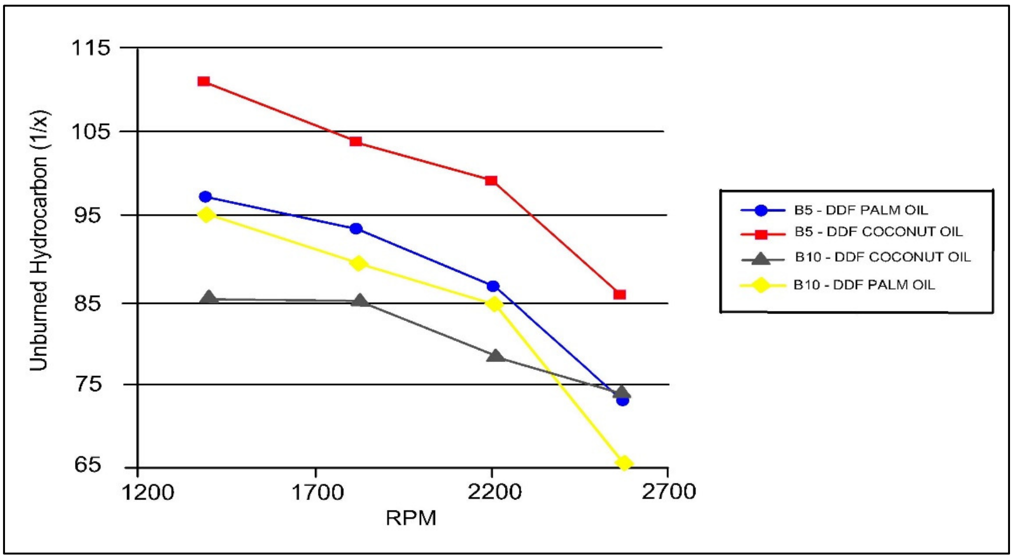

Figure 12: Unburned hydrocarbon emission against engine speed (RPM) for various blends of biodiesel-natural gas

Figure 13 shows that the quantity of unburned hydrocarbon decreased as engine speed increased. This result is almost similar with the result reported by Papagiannakis, and Hountalas [18]. As seen in Figure 13, it is obvious that HC emission under B10-DDF coconut oil was significantly higher than diesel and B10 coconut oil. This was the consequence of the presence of methane in natural gas that slowed down the reaction with other hydrocarbon in very lean mixtures. The flame was also lowered, which might have been too low for combustion to take place [10]. Kalam and Masjuki [26] stated that the quantity of unburned hydrocarbon emission can be increased if a) the injection occurs too early, which causes increase of delay time and thus more fuel goes to contact at cool cylinder wall, or b) injection is too late due to insufficient time for complete combustion. The above statement may be the reasons for highest emission of unburned hydrocarbon by B10-DDF coconut oil, when the cool CNG entered the engine cylinder and thus increased the emission of unburned hydrocarbon.

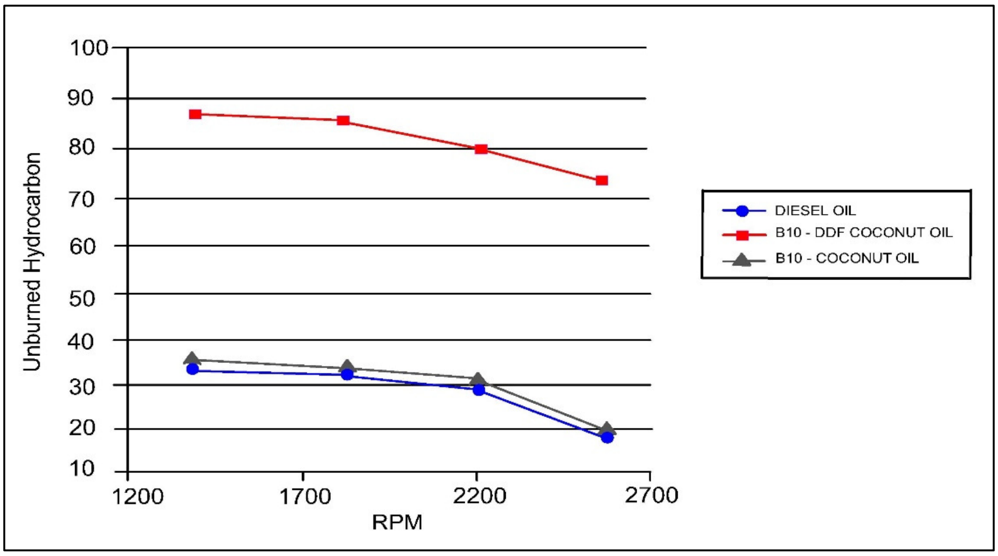

Figure 13: Unburned hydrocarbon emission against engine speed (RPM) for various fuels

4.0 CONCLUSSION

This paper has presented an investigation on the performance and emission of DDF diesel engine fuelled by multi-variant biofuel by using DDF engine system. The experiment study has been performed and the following results are summarized as follows:

1. B5 coconut oil produces the highest torque compared to other fuel. This is due to lowest viscosity of coconut oil that eases the flow of the fuel through the injector and contributes to better fuel injection atomization and thus increases combustion efficiency. Besides, the presence of CNG in the engine produces better fuel mixing thus increases the combustion efficiency. The B5-DDF Coconut oil produces higher engine torque (by 10.8%) than B5-coconut oil and diesel.

2. B5-DDF coconut oil requires less amount of fuel blend, proven when the BSFC produced is the lowest compared to other fuels. This is due higher heating value of coconut oil. As a result, for the same energy output from the engine, it requires smaller mass fuel flow, thus decreases the BSFC to compensate the reduced chemical energy of the fuel. The analysis shows that B5-DDF coconut oil produces lower BSFC by 28.02% than B5 Coconut oil and pure diesel.

3. The B5-DDF coconut oil emits the lowest CO_2 as compared to other fuels. This may be attributed to lower oxygen content of biodiesel and low carbon content of CNG.

4. B10-DDF palm oil emits the lowest CO as compared to coconut oil. The extra oxygen in the molecule results in complete combustion of the fuel and supplies the necessary oxygen to convert CO to CO_2, in contrary with B10 palm oil and diesel. Since natural gas is in gaseous state, it will reduce volumetric efficiency and thus reduce the oxygen available for combustion.

5. Over the entire range of speed, B5-DDF palm oil emits lower NO_x compared to other fuels. The higher cetane index causes significant reduction in the NO_x emission due to shorter ignition delay times and results in lower average combustion temperature.

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6. Among four types of different blend of biodiesel-CNG, B10-DDF coconut oil emits the lowest unburned hydrocarbon compared to other fuels. This is due to higher oxygen content in B10-DDF coconut oil. The higher emission of unburned hydrocarbon signifies the result of incomplete combustion. However, B10-DDF coconut oil emits the highest HC as compared with B10 coconut oil and diesel. This is due to higher methane content in natural gas that slows down the combustion; in addition, the flame speed may have been too low, which prolongs the total combustion duration.

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