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ENGINE PERFORMANCE AND EXHAUST EMISSION OF DIESEL DUAL FUEL ENGINE FUELLED BY BIODIESEL, DIESEL AND NATURAL GAS

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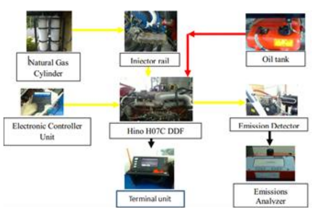
Graphical abstract



Abstract

The performance and exhaust emission of 6 cylinder four stroke direct injection diesel dual fuel (DDF) engine were investigated, the duel fuel used is corn oil methyl esters consist of 5%, 10%, 15% and 20% blends with diesel and compressed natural gas (CNG). Experiment was conducted at a fixed compression ratio of 17.5:1 with variance of engine speed 1400, 1800, 2400 and 2600 rpm. Combination of Biodiesel and CNG showed a better result on engine performance in terms of horse power and engine torque compared to other types of tested fuel. The substantial decrease of 25.6 % in exhaust emission flue was observed, giving lower value of UHC and nitrogen oxide (NO_x). However, when the fuel is blended with CNG, a poor performance on exhaust emission was recorded, which include carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (UHC) and nitrogen oxide (NO_x) due to presence of CNG in fuel.

Keywords: Biodiesel, diesel, natural gas, diesel dual fuel engine, engine performance, engine emission

Abstrak

Prestasi dan pelepasan ekzos 6-silinder empat suntikan terus diesel dua (DDF) lejang dikaji dengan penggunaan minyak jagung ester metil pada 5%, 10%, 15% dan 20% campuran dengan diesel, dan digabungkan dengan gas asli mampat (CNG). Eksperimen telah dijalankan pada nisbah mampatan 17.5:1 dan pada kelajuan enjin yang berbeza iaitu 1400 rpm, 1800 rpm, 2400 rpm dan 2600 rpm. Kesan enjin kepada prestasi enjin dan pelepasan ekzos telah dikaji dan dibentangkan. Gabungan Biodiesel dan CNG menunjukkan hasil prestasi enjin yang lebih baik dari segi kuasa enjin dan tork enjin jika dibandingkan dengan lain-lain jenis bahan api yang diuji. Penurunan sehingga 25.6 % bahan cemar diperolehi menunjukkan bahawa pelepasan pencemar seperti hidrokarbon tidak terbakar (UHC) dan oksida nitrogen (NO_x) pelepasan berkurangan disebabkan bersihnya pembakaran bahan bakar dalam enjin. Walau bagaimanapun, gabungan bahan api dan CNG menunjukkan hasil yang tidak memberangsangkan dari segi komposisi karbon dioksida (CO_2), karbon monoksida (CO), hidrokarbon tidak terbakar (UHC) dan nitrogen oksida (NO_x) kerana kehadiran CNG dalam bahan api.

Kata kunci: Biodiesel, diesel, gas asli, enjin diesel dwi-bahan api, pelepasan enjin, prestasi enjin

1.0 INTRODUCTION

Alternative fuels for Diesel engine have become more increasingly important due to increased environmental concerns, and several socioeconomic aspects [1-3]. One of the strategies to overcome this problem is by using alternative fuel as fossil fuel in transportation sector [2-5]. Alternative fuel automobile is defined as automobile that runs on fuel other than petrol or diesel fuel, and also refers to any technology of powering an engine that does not involve solely petroleum.

Many countries are using and considering the use of vegetable oil to reduce the dependence on fossil fuels for transportation purpose. Biodiesel is commonly recognized in the alternative fuel industry, derived from transesterification of vegetable oil or animal fat with alcohol in the presence of a catalyst to yield glycerin and methyl ester [1-8]. The main drawback of vegetable oil is their high viscosity and low volatility, which leads to poor combustion in diesel engine. The purpose of transesterification process is to lower the viscosity of the oil. This process reduces the viscosity to a value comparable to that of diesel and hence improves combustion [1].

Many studies have shown that the properties of biodiesel are very close to those of diesel fuel. Therefore, biodiesel can be used in Diesel engine with few or no modification. Biodiesel has a higher cetane number than diesel fuel, no aromatic and contains 10% to 11% oxygen by weight [7]. By using biodiesel blend as a fuel in engine system, it can decrease the emission of carbon monoxide (CO) [1-5, 8, 10], hydrocarbon (HC) [1-3], and nitrogen oxides (NO_x) [1-3, 8, 10].

Based on the previous studies, Xue reported that with the use of vegetable oil ester as fuel in diesel engines, a diminution of harmful exhaust emissions, as well as equivalent engine performance with diesel fuel, were achieved [1-8]. They noticed that with increase of engine speed, biodiesel blends will decrease the engine torque [1-3, 6, 8-10] and increase the brake power [1-8]. Addition of biodiesel blends has effect on both torque and power towards engine speed. Torque is expected to be lower with the increase of biodiesel content due to lower caloric value of biodiesel compared with diesel fuel.[10] Biodiesel contains oxygen in its structure. When biodiesel is blended with diesel fuel, the oxygen content in the fuel blend is increased, thus less oxygen is needed for combustion. Oxygen content in fuel is the main reason for more complete combustion, hence carbon monoxide (CO) and hydrocarbon (HC) emission reduction [10].

Natural gas is one of the alternative fuels that contain mixture of gas species, which is methane, as a primary constituent. It can be categorized as clean combustion of alternative fuel. It is able to produce low polluted emission and exists in a huge quantity worldwide [13].

Researches have shown that higher percentage mass ratio of natural gas leads to the increase in the total brake specific fuel consumption (BSFC), torque and break power [10-13]. Application of dual-fuel engine system can satisfy performance characteristics within 5% variation, in contrast to diesel engine 12-13]. One of the reasons why this trend occurs is because the heating value of natural gas is higher compared to diesel fuel. This reveals a poor utilization of the gaseous fuel mainly due to the lower temperature inside the combustion chamber of the engine and the late start of ignition because of the higher ignition delay [13].

The engine operating with dual fuel mode, which operates by feeding natural gas to diesel fuel as its primary supply, is called diesel dual fuel (DDF). The DDF engine can achieve an attractive low polluting option for diesel engine by using natural gas and biodiesel instead of pure diesel from crude oils [12]. The DDF engine, powered by natural gas and biodiesel, has the advantage of not requiring heavy modification in engine system [10-13]. Biodiesel-diesel-natural gas blends in different ratio influence the engine performance and exhaust emission. In this study, corn oil (methyl esters of corn oil), blended with diesel, was chosen as a fuel for DDF engine. Various blends of corn oil, diesel, combination of diesel and CNG, and combination of biodiesel and CNG were prepared, and the following investigations were carried out.

- Engine performance in terms of engine torque and horse power
- Exhaust emission in terms of carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (UHC) and nitrogen oxide (NO_X).

2.0 EXPERIMENTAL

2.1 Type of Fuels

In this study, three types of fuel were used in the 6-cylinder HINO H07C, which were Compressed Natural Gas (CNG), Diesel and Biodiesel (B5, B10, B5 and B20). The biofuel, produced from corn oil, was used as biodiesel.

2.1.1 Natural Gas

Natural gas used in this study was supplied by Gas Malaysia Berhad. The natural gas was composed of 92.73 % of methane, 4.07 % of ethane and 3.20 % of other hydrocarbon. Table 1 shows the characteristic of the natural gas.

Table 1 Natural gas properties

Properties	Value
Compressibility	0.99
Vapour Density	0.747 kg/Sm³ @ 760 mmHg
Relative Density	0.61 @ 760 mm Hg
Molecular Weight	17.47
Gross Caloric Value	39.20 MJ/sm³
Boiling point	-162℃
Auto Ignition Temperature	537℃
Flammable Limit	UEL = 15.4% vol, LEL = 4.5% vol

2.1.2 Diesel and Biodiesel

The following (Table 2) are the properties of diesel fuel and corn oil biodiesel used in this study.

Table 2 Diesel and biodiesel properties

Properties	Diesel fuel	Corn oil biodiesel
Density @ 15°C (kg/m³)	829.11	956.50
Cetane number	50.60	55.40
Kinematic Viscosity @ 40°C (mm²/s)	4.48	5.43
Sulfur content (wt %)	0.0019	0.0003
Hydrogen content (wt %)	13.35	11.14
Carbon content (wt %)	86.10	76.31
Oxygen content (wt %)	-	10.96
Flash point (°C)	78	170
Caloric Value (MJ/kg)	45.85	39.87

2.2 Experimental Set-Up

Figure 1 shows the experimental set up. All the equipment involved in the experiment must be in the standard condition. The measuring equipment, for example, dynamometer and emissions analyzer, were calibrated deliberately. Major components such as DDF engine, dynamometer, and emission analyzer were also properly connected to ensure their operational reliability.

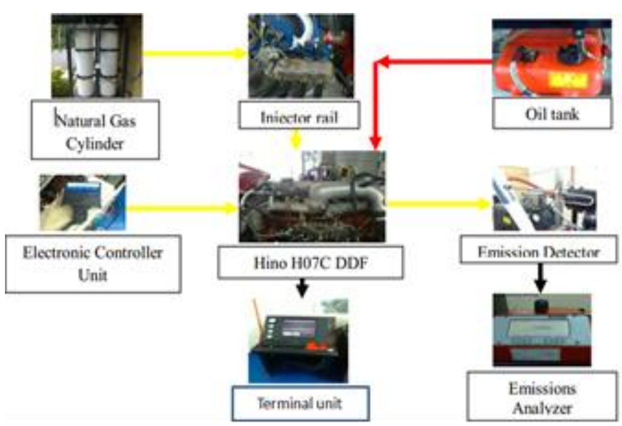


Figure 1 Schematic diagram for equipment setup

2.3 Experiment Procedure

The measurement was taken at four engine speeds which 1400, 1800, 2200 and 2600 rpm. As seen in Figure 2, for the first step, pure diesel fuel was used to determine the initial engine performance in terms of engine torque and brake power.

All these parameters were measured using dynamometer. Besides that, diesel fuel was also used to determine the exhaust emission composition consist of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO_x) and unburned hydrocarbon (UHC). The concentrations of CO, CO_2, UHC and NO_x in the exhaust emission were measured using the gas emission analyzer. All the parameters were recorded accordingly. The experiment was conducted for at least three times and the average of the data was calculated.

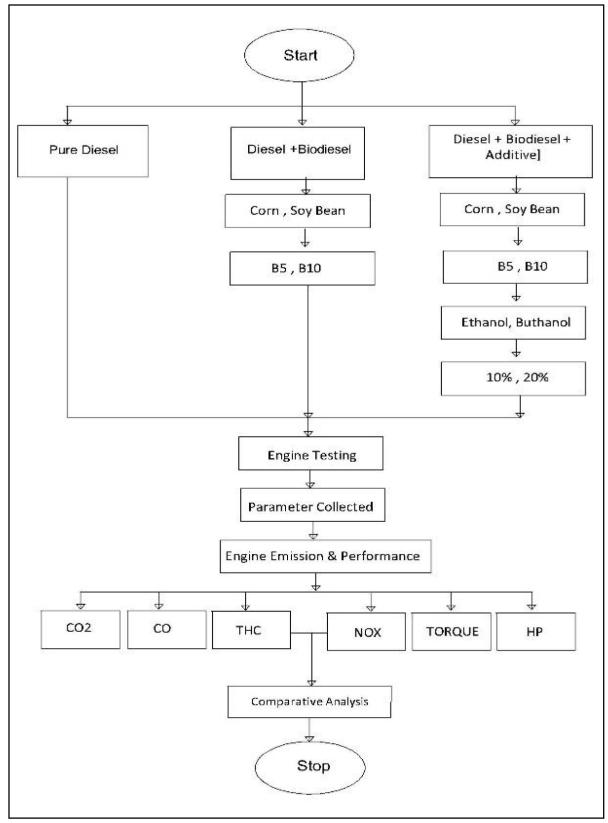


Figure 2 Overall methodology

The diesel engine was run until it reached the steady state condition within 20 to 30 minutes and the temperature inside the engine reached varied from 75°C to 80°C. The entire test was conducted at ambient temperature of approx. 23°C while the atmospheric condition is constant. The reading of engine performance and exhaust emission was recorded by controlling the gas throttle, where the engine speed was changed to 1800 rpm, 2200 rpm and 2600 rpm. After having tested the diesel fuel, the engine was left to cool to ambient temperature, and then the entire steps were repeated using dual-fuel (diesel and natural gas), followed by test on various percentage of biodiesel which were B5, B10, B15, B20 and biodiesel blended with natural gas (B5-DDF, B10-DDF, B15-DDF, B20-DDF).

The tests were conducted with three types of fuel which is diesel fuel, biodiesel blends which are B5, B10, B5 and B20. The tests were conducted by presence natural gas and without presence natural gas. Table 3 shows the test matrix adopted in this study.

Table 3 Test matrix

Case no.	Primary fuel	Secondary fuel
I.	Diesel	-
II.	Diesel	Natural Gas
III.	Biodiesel (B5)	-
IV.	Biodiesel (B5)	Natural Gas
V.	Biodiesel (B10)	-
VI.	Biodiesel (B10)	Natural Gas
VII.	Biodiesel (B15)	-
VIII.	Biodiesel (B15)	Natural Gas
IX.	Biodiesel (B20)	-
X.	Biodiesel (B20)	Natural Gas

3.0 RESULTS AND DISCUSSION

3.1 Engine Performance

3.1.1 Engine Power

Figure 3 shows that the horse power increased with increasing engine speed. As shown in Figure 3, compared to B10 fuel oil, B5 oil recorded a high amount of horse power at the range 1500 and 2500 rpm speed due to higher viscosity and lower heating value of corn oil methyl ester.

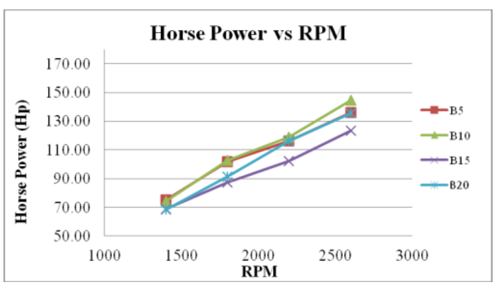


Figure 3 Horse Power against engine speed (RPM)

This result is in a good agreement with the result obtained by Xue *et al.* [3] in their study. Different value of viscosity and heating value will affect the horse power of an engine. It may see that for the use of natural gas give the higher output torque. This may be postulated to be due to the lower heating value for methane in natural gas mixture compare to the normal diesel fuel. Besides that, higher viscosity will enhance fuel spray penetration, and thus improve air-fuel mixing.

Figure 4 shows that the increment of horse power for each type of biodiesel blends with CNG. In this research, B5-DDF showed the highest amount of horse power. All types of biodiesel blends with CNG had similar horse power at the lowest speed, but after the engine speed reached at 2600 rpm, the value of horse power changed. It was observed that the horse power reduced with the increase of content of biodiesel blends with CNG.

Figure 5 shows the horse power comparison between four different types of fuels, which are pure diesel, biodiesel blend (B5), combination of diesel and CNG (Diesel-CNG) and biodiesel blend with (B5-DDF). It shows that the horse power increased with the increase of engine speed. The value of horse power increased when using CNG as the main fuel in the engine cylinder. At initial engine speed (1400 RPM), the difference of horse power value between fuel without CNG, (B5 and diesel) and fuel with CNG, (B5-DDF and DDF) was almost 20 %. This proves that, the horse power of the engine increased significantly with the presence of CNG as the main fuel.

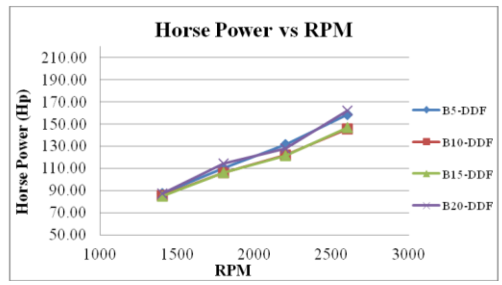


Figure 4 Horse power against engine speed (RPM)

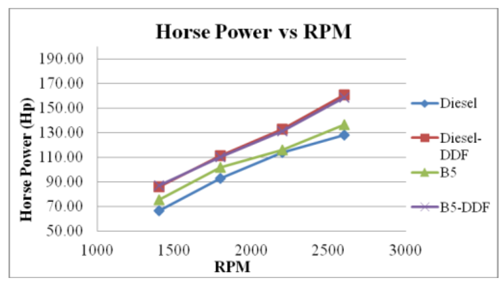


Figure 5 Horse power against engine speed (RPM)

3.1.2 Engine Torque

As shown in Figure 6, the engine torque initially increased with the increase of engine speed until it reached a maximum value, and then decreased with further increase of engine speed for biodiesel blends with the diesel (B5, B10 and B20). This trend very much agreed with the result obtained by Ghobadian *et al.* [5] that investigated the engine performance and exhaust emission by using biodiesel in diesel engine.

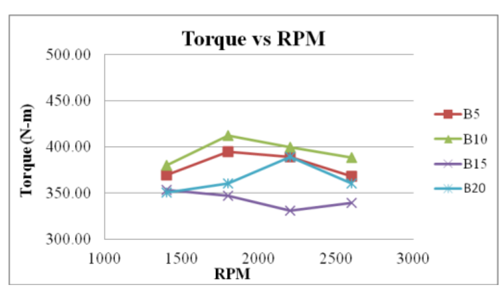


Figure 6 Torque against engine speed (RPM)

As seen in Figure 6, the engine test results using B10 showed that the maximum torque was 412.27 Nm, at 1800 rpm, but decreased to 5.8% at highest engine speed (2600 RPM). As a result, less force was needed to push the engine piston at higher speed. At high speed, smaller amount of fuel was injected into the cylinder, hence slowing the combustion rate.

Figure 7 presents the comparison between different types of biodiesel blends with CNG, which are B5-DDF, B10-DDF, B15-DDF and B20-DDF. As shown in Figure 7, the engine torque initially decreased with the increase of engine speed until it reached a minimum value, and then increased with further increase of engine speed for biodiesel blends with CNG (B10-DDF, B15-DDF and B20-DDF). This type of value trend of torque for high speed is considered normal for all types of engine. The efficiency the engine to produce higher torque at high speed will decrease as increasing the speed of the engine.

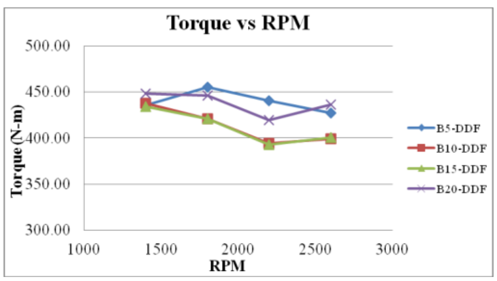


Figure 7 Torque against engine speed (RPM)

Figure 8 shows the comparison between four different types of fuels which are pure diesel, biodiesel blend (B5), diesel dual fuel with CNG (DDF) and biodiesel blend with CNG (B5-DDF). It shows that the engine torque initially increased with the increase of engine speed until it reached a maximum value, and then decreased with further increase of engine speed for all different types of fuels. This trend is in agreement with the observation made by Lin *et al.* [10] in their study.

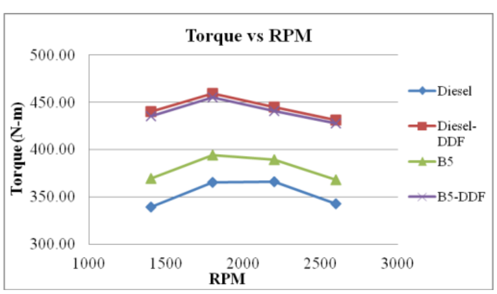


Figure 8 Torque against engine speed (RPM)

It worth nothing that better combustion was achieved at the presence of CNG in the engine cylinder, better combustion was achieved. This leads to high engine speed yet; it would cause low engine torque. Combination of Diesel and CNG could lower down the torque value to 6.03% at the highest engine speed. This was important to ensure that there would be no extra force inside the cylinder that might burst the engine at highest speed.

3.2 Exhaust Emission

3.2.1 Carbon Dioxide (CO_2)

Figure 9 shows the total CO_2 result obtained from the biodiesel blends (B5, B10, B15, and B20) at highest engine speed. The result demonstrated that CO_2 increased when the engine speed increased. This pattern is strongly agreed by Gumus and Kasifoglu [9] in their investigation on performance and emission of a compression ignition engine using biodiesel blends as a fuel.

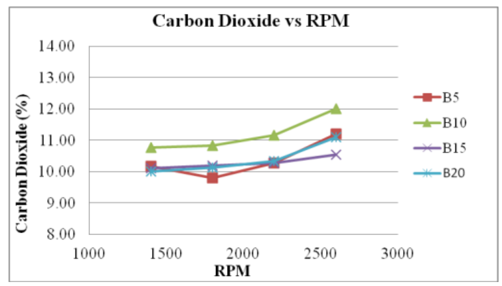


Figure 9 Carbon dioxide against engine speed (RPM)

It can be seen that B10 had highest amount of emission at maximum engine speed. More amount of CO_2 in exhaust emission is an indication of complete combustion of fuel. Higher CO_2 emission from B10 indicated effective combustion. Higher percentage of biodiesel blends would emit low amount of CO_2 emission as a consequence of higher viscosity of biodiesel.

Figure 10 presents the comparison between different types of biodiesel blends with CNG for B5-DDF, B10-DDF, B15-DDF and B20-DDF. According to Figure 10, B5-DDF gave the highest amount of CO_2, starting from 1400 RPM. It can be seen that the plot of B10-DDF, B15-DDF and B20-DDF have similar value at the minimum until maximum engine speed. The figure shows that using B5-DDF as a fuel gave better performance of the engine, closer to complete combustion compared to other fuels.

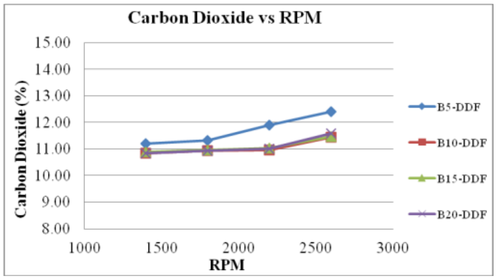


Figure 10 Carbon dioxide against engine speed (RPM)

The graph of CO_2 emissions as presented in Figure 11 shows that the emission of CO_2 increased for all types of fuel; diesel, diesel with CNG (Diesel-DDF), biodiesel blends (B5), and biodiesel with CNG (B5-DDF). With the presence of CNG in the engine cylinder, Diesel-DDF and B5-DDF produced the highest amount of CO_2. Both fuels produced similar result at the initial and final speed except for 2400 rpm. Diesel-DDF had a lower amount of CO_2 compared to B5-DDF

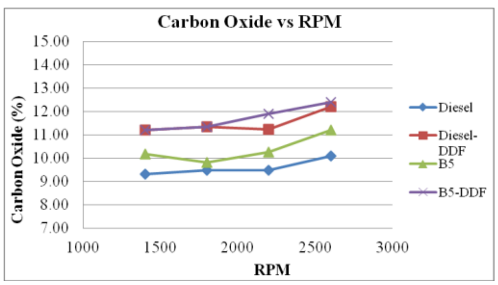


Figure 11 Carbon dioxide against engine speed (RPM)

3.2.2 Carbon Monoxide (CO)

Figure 12 presents a plot of amount of CO which shows that the amount of CO decreased with the increase of engine speed. Arslan [15] also found that the CO amount of biodiesel blends decreased with the increase of engine speed. The test result showed that B10 and B15 produced the highest amount of CO at maximum engine speed. The CO emissions of B10 and B15 decreased by an average of 15.15% and 10%, respectively.

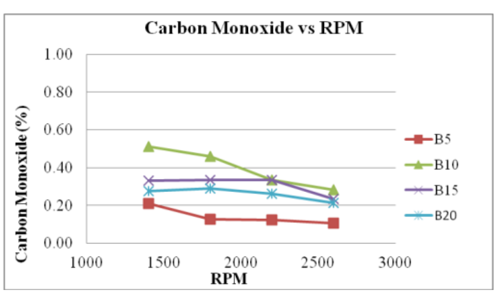


Figure 12 Carbon monoxide against engine speed (RPM)

The CO emissions for biodiesel blends with CNG at different engine speeds are given in Figure 13. As shown in this figure, the CO emission increased with the increase of engine speed for all types of fuel. The plot shows that the amounts of CO for all fuels at maximum speed did not have much difference. Additional biodiesel percentage would cause reduction in CO emission.

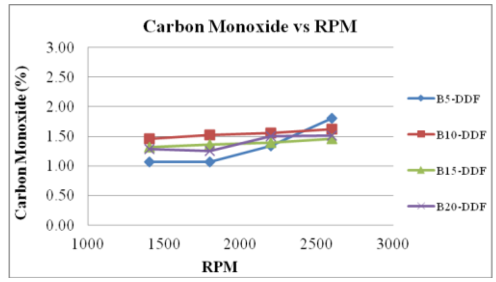


Figure 13 Carbon monoxide against engine speed (RPM)

The variation of CO emission with engine speed for different type of fuels, which are Diesel, Diesel-DDF, B5 and B5-DDF, can be seen in Figure 14. As shown in this figure, CO emissions were reduced when the no blending on fuels. Pure Diesel and B5 tested in this experiment produced almost zero emission of CO but still increased with the decrease of engine speeds. The result has similarity with the result obtained by Arslan [15] who investigated the emission characteristic of a diesel engine by using biodiesel as a fuel. The recorded data proved that the CO emitted from the engine became higher in the presence of CNG in the fuel. The test result showed that Diesel-DDF produced higher amount of CO than B5-DDF.

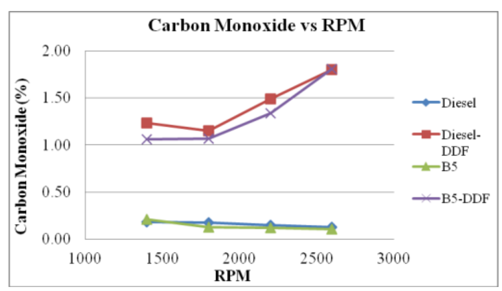


Figure 14 Carbon monoxide against engine speed (RPM)

3.2.3 Unburned Hydrocarbon (UHC)

Figure 15 shows the plot UHC emission of the biodiesel blends at different engine speed. The UHC emission was found to decrease with the increase of engine speed for B5 and B10. However, for B15 and B20, the UHC emission was fluctuated and the test result showed that the amount of UHC was similar at every engine speed.

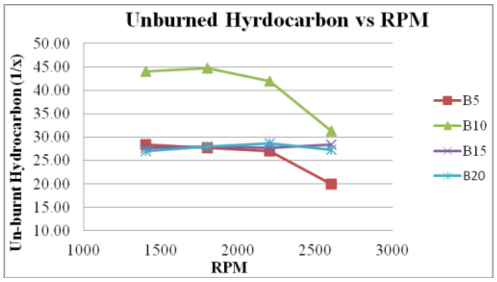


Figure 15 Unburned hydrocarbon against engine speed (RPM)

The variation of UHC emission with different engine speed for different biodiesel blends with CNG is presented in Figure 16. The figure shows that the emissions of UHC decreased with increase of engine speed. This trend is in agreement with the observation made by Arslan [15]. B10-DDF had higher amount of UHC and B5-DDF showed the lowest amount of UHC at highest engine speed. Both fuels had reduction of UHC emission by an average of 25.6% and 3.7%, respectively. At maximum engine speed of 2200 rpm to 2400 rpm, the UHC emission was totally diminished. This was due to high cetane number on biodiesel, giving sufficient ignition performance and shorter ignition delay period, which led to the reduction of UHC emission due to less local extinction.

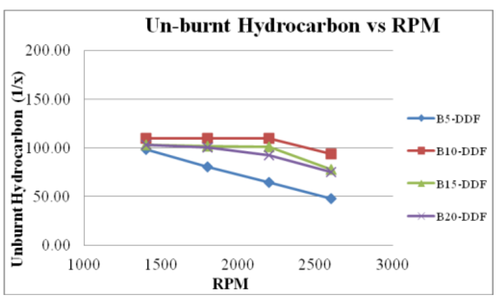


Figure 16 Unburned hydrocarbon against engine speed (RPM)

Figure 17 shows the comparison between four different types of fuels which are pure diesel, biodiesel blend (B20), diesel dual fuel with CNG (DDF) and biodiesel blend with CNG (B20-DDF). It shows that the amount of UHC decreased with the increase engine speed. This very much agrees with the result obtained by Nwafor [13]. Figure 17 indicates that the value of UHC increased when using CNG as the main fuel in the engine cylinder. At initial engine speed (1400 RPM), the different UHC value between fuel without CNG, (B20 and diesel) and fuel with CNG, (B20-DDF and DDF) was almost 54%. It was proven that, the amount of UHC of the engine increased significantly with the presence of CNG as the main fuel. A combination between diesel and CNG (Diesel-DDF) showed a very poor result, which emitted up to 106 ppm UHC at lowest engine speed.

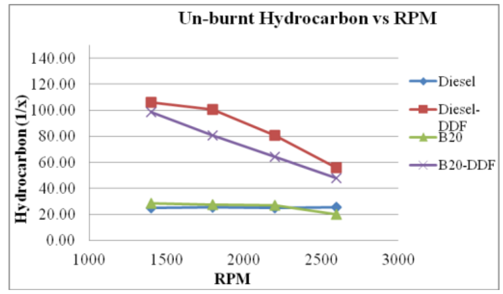


Figure 17 Unburned hydrocarbon against engine speed (RPM)

3.2.4 Nitrogen Oxide (NOx)

Figure 18 shows the variation of NOx emission with engine speed for different fuels. As shown in the figure, it was clear that the NO_x emission varied considerably according to the test fuels at all engine speeds. Among the tested fuels, B5 produced the highest amount of NO_x at initial speed (2400 rpm) and B5 produced the highest NO_x at final speed (2600 rpm). This was due to the lower combustion temperature as a result of lower biodiesel calorific value and longer ignition delay. It was also observed that the NOx emission for B5 and B5-DDF decreased about an average of 8.33% and 3.25%, respectively. Increasing NO_x emission is an indication of higher heat release, and it can be explained by the decrease of the cetane number with the addition of the oxygenates.

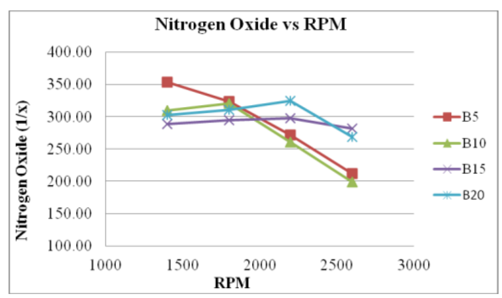


Figure 18 Nitrogen oxide against engine speed (RPM)

Figure 19 shows the comparison between different types of biodiesel blends with the CNG for B5-DDF, B10-DDF, B15-DDF and B20-DDF. As shown in Figure 19, the amount of NO_x for B5-DDF decreased with the increase of engine speed. Besides that, NOx emission initially increased with the increase of engine speed until it reached a maximum value, and then decreased with further increasing engine speed for biodiesel combined with CNG (B10-DDF, B15-DDF, and B20-DDF). It was also observed that the NOx emissions for B5-DDF had the lowest amount of NO_x at the highest engine speed (2600 rpm).

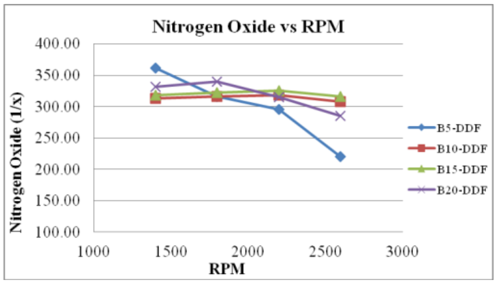


Figure 19 Nitrogen oxide against engine speed (RPM)

Figure 20 presents the comparison between different types of fuel which are Diesel, Diesel-DDF, B5 and B5-DDF. According to Figure 20, the amount of NOx initially 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 fuel (Diesel, Diesel-DDF, B5, and B5-DDF). This trend is in agreement with the investigation made by Ocktaeck *et al.* [16] in their research of Engine Optimization and Emission Characteristic of Dual Fuel Engine Fueled with Natural Gas and Diesel.

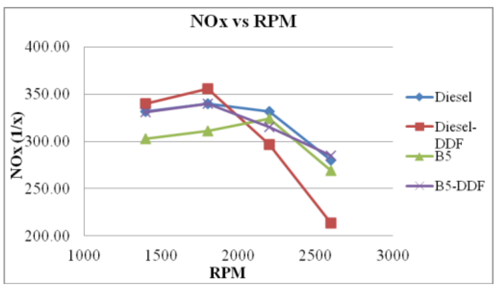


Figure 20 Nitrogen oxide against engine speed (RPM)

In all fuel blends combinations, the amount of NOx for B5 was lower than the pure diesel and combination of fuels with CNG. This was due to the occurrence of NOx emission at high temperature combustion. Lower NOx in the fuel mixtures containing biodiesel indicated lower combustion temperature due to lower biodiesel calorific value and longer ignition delay.

4.0 CONCLUSION

The performance and exhaust emission of a DDF engine fueled with Diesel, Biodiesel, combination of Diesel with CNG, and combination of Biodiesel with CNG, had been investigated. Experiment was conducted with a fixed compression ratio of 17.5:1 and at different engine speed which were 1400 rpm, 1800 rpm, 2400 rpm and 2600 rpm. The following conclusions are drawn from this investigation:

- Blended fuel either diesel and CNG (Diesel-DDF) or biodiesel and CNG (Bio-DDF) showed an increase in the value of horse power with the increase of engine speed. Diesel-DDF and Bio-DDF gave the highest engine power due to presence of CNG and combustion came closer to completion due to higher calorific value of pure diesel compared to biodiesel.
- Engine torque recorded in this research showed that all types of biodiesel blend and CNG gave similar result, which decreased with the increase of engine speed. In comparison between various types of fuels, Diesel-DDF and B5-DDF achieved the highest performance 12% since they gave the highest torque at initial speed (1400 RPM). Besides, B5 gave higher engine torque than Diesel due to the 10% content of oxygen in biodiesel that could be used in combustion. Thus, more complete combustion could happen, thereby increasing the engine power of biodiesel fuel.
- Results obtained indicated that pollutant emissions such as unburned hydrocarbon (UHC) and nitrogen oxide (NO_x) emissions decreased due to clean combustion of the engine. However, the data for carbon dioxide (CO_2) and carbon monoxide (CO) failed to gain lower emissions. Biodiesel showed the lowest CO emission compared to other types of fuel, especially diesel. Moreover, the results obtained for CO_2 indicated that Bio-DDF fueling could increase in CO_2 emissions. However, the value of the CO_2 for biodiesel was still lower compared to DDF fueling.

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