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Research Note

# Effect of Biodiesel Blend on Exhaust Emission and Engine Performance of Diesel Dual Fuel Engine

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*A B S T R A C T*

In this study, four main types of fuel such as pure Diesel, Biodiesel, Diesel Dual Fuel (DDF), and Biodiesel with DDF were employed to obtain the comparison of the engine performance and emission parameter. The use of compressed natural gas (CNG) in diesel engines can be considered as one of the optimum alternative solution for reducing fuel consumption rate. CNG can partly replace diesel fuel in the combustion chamber, while the remaining diesel is used as a testing fuel. The biodiesel employed in this research was extracted from waste cooking oil which was provided by Forest Research Institute of Malaysia (FRIM). The results of the engine tests showed that an increase in biodiesel percentage in the testing fuel compound resulting in the reduction of the engine power. Biodiesel used with CNG (B20-DDF) showed a better result of engine torque compared to other types of fuel tested. It was recorded from this particular work research that, when the composition of the biodiesel in the fuel increased, the inherent biodiesel properties like NOx emissions seemed to decrease; however, unburnt hydrocarbon (HC) was found to increase due to incomplete combustion of biodiesel fuel compound.

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## INTRODUCTION

Nowadays, air pollution has become a thoroughly world's concern. The health of 1.6 billion people may be at risk from poor urban air quality, it becomes clear that the issue ranks alongside global problems as acid rain, stratospheric ozone depletion and even global warming [1]. Air pollution is a growing problem because of rising urban populations, unchecked urban and industrial expansion, as well as the phenomena surge in the number and use of motor vehicles [1].

There are three major sources of air pollution in Malaysia, which are mobile sources, stationary sources, and open burning sources. Over the past few years, air pollution has been caused by mobile sources, which produce about 70-75 % of the total air pollutions. About 20-25 % of the total air pollution is generated by emission from stationary sources, while 3-5 % is caused by open burning sources. The pattern of air pollution shows that emissions from mobile sources are the main problem regarding this environmental issue [2].

Emissions by diesel engines are a major source of air pollution, especially in developed countries and along urban traffic routes. The extreme durability of the diesel engine brings to long lasting up to 20-40 years [3]. This situation becomes worse when once they are introduced into an area; the diesel engines caused air pollution for decades. In addition, diesel engines produce particulate matter (PM) and hydrocarbon toxic air contaminants (TAC) which are hazardous to human health. Particulate emissions from Diesel engines are stringently regulated because of their harmful effects on health and the environment. $NO_x$ is also one of the substances emitted from diesel engines that are harmful to the environment.

There are also mechanisms that occur in a diesel engine that can lead to wear or compartments inside the engine. Some of the engine wear that occur are abrasion, adhesion, fatigue, corrosion and lubricant breakdown. Corrosion and lubricant breakdown involve a series of chemical reactions that lead to wear, while abrasion,

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fatigue, and adhesion cause mechanical damage of surfaces. For all the above five forms of wear, lubricant contamination is a predominant driver for wear [4].

Natural gas gives a positive impact for vehicles development and is an ideal fuel as alternative to gasoline widely used before. During combustions in engines, natural gas burns cleaner compared to gasoline, hence contributing less atmospheric ozone and carbon monoxide. In addition, natural gas is less expensive than gasoline and available in most developed countries especially in the US.

The main hydrocarbon emission of natural gas engine is methane, which is influenced by the high composition of methane in natural gas. In addition, nitrogen oxide ($NO_x$) emitted by natural gas engine is also lower because natural gas burns at a lower temperature than most liquid hydrocarbons [5]. Natural gas has the lowest carbon hydrogen ratio of all stable hydrocarbon fuels (twice as much hydrogen per carbon molecule), producing the lowest $CO_2$ emissions per unit energy released, with the extra energy coming from the combustion of hydrogen [6]. Since natural gas does not contain aromatic and polyaromatic compounds, as well as containing less dissolved sulfur compounds than petroleum fuels, hence particulate matter mass emissions are significantly reduced through the use of natural gas fuels [7].

The possible disadvantage of the natural gas as a fuel might come from the lower energy content from a similar volume to other fuels especially diesel. This could decrease the engine performance. In direct injection method, it can eliminate the loss in volumetric efficiency since natural gas is directly injected into the cylinder. However, natural gas engines may show a lower efficiency than diesel engines [5].

Biodiesel refers to the vegetable oil- or animal fat-based diesel fuels, consisting of long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is typically made by mixing chemically reacting lipids (e.g., vegetable oil, animal fat (tallow)) with an alcohol. Biodiesel is for use in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone, or blended with petro diesel. When biodiesel displaces petroleum based diesel, greenhouse gas emissions are significantly reduced. Sheehan et al.,[8] estimated that greenhouse gas emissions (including carbon dioxide, methane, and nitrogen oxide) are reduced by 41 % if biodiesel is produced from crops harvested from fields that are already in production.

Using biodiesel also can reduce emissions such as particulate matter, hydrocarbon (HC), and carbon monoxide (CO) from most four-strokes compression ignition or diesel engines. These are advantages biodiesel because biodiesel contains 11 wt% oxygen. Oxygen allows the fuel to burn completely, thus less unburned fuel emissions result. This same phenomenon reduces air toxics, which are associated with the unburned or partially burned HC and PM emissions. Tests have shown that PM, HC, and CO reductions vary depending on the biodiesel feedstock [8].

A Dual Fuel diesel engine (traditionally) is a diesel engine that has been fitted with additional devices, allowing it to utilize natural gas as a supplemental fuel. This engine type is a true diesel and requires some level of diesel for operation; for ignition of the gas fuel. The use of biodiesel as a pilot fuel in a DDF engine can decrease some of the pollutants but may also fail to achieve the desired requirement due to several aspects. Regarding this matter, previous study showed that the inherent biodiesel property CO and NOx emissions seemed to be reduced; however UHC was found to increase, due to incomplete combustion of B10 % fuel compound[9].

This paper presents the effect of biodiesel blends on engine performance and emissions of HINO H07C DDF engine. Biodiesel blends of B5, B10, B15 and B20 were used as testing fuels to partly replace common diesel, while CNG was used as a main fuel in the combustion chamber.

## MATERIALS AND METHODS

The engine was set for initial testing and compressed natural gas (CNG) mapping needed to be conducted prior to engine operation. This was to ensure the suitable amount of natural gas and combustion air to be delivered to the combustion chamber.

### Testing procedures

Firstly, the biodiesel blends were commenced as B5, B10, B15 and B20. After the blends were prepared, the fuel properties were analysed. Secondly, the engine was tuned to burn at optimum. The engine was then connected to the dynamometer and emission analyser.

Initial test run was performed on pure diesel and the engine performance (engine power, and engine torque) and emissions (NOx, and HC) results were recorded. After that, pure diesel and natural gas were used to fuel the engine. Similar results were recorded and the tests were repeated for five complete cycles and the average results were used in the analysis. The test engine was left idle to clear all remaining fuels before proceeding for the next tests using biodiesel blends of B5, followed by diesel and natural gas or DDF system Flushing process, repeated for each biodiesel blend of B10, B15 and B20. The engine performance and emission results were tested at the engine speed of 1000, 1500, 2000 and 2500 rpm.

## Experiment Setup

The equipment needed to be arranged in a suitable position prior to engine operation to ensure safe operation of the test. Major components such as DDF engine, dynamometer, and emission analyzer were securely connected to achieve accurate engine testing condition. Experimental setup of the testing rig is shown in Figure 1.

## Natural gas

To obtain the mixture and better combustion process, compress natural gas was used to gain better mixing and combustion inside the engine. The use of compressed natural gas was to ensure the gas in the vapour phase to suit the mixing process and easy to burn. Tables 1 and 2 respectively show the properties and composition of natural gas used in the experiment.

## Biodiesel

Biodiesel is noted for its similarity to petroleum-derived diesel fuel, while at the same time having negligible sulphur and ash content. Biodiesel has only about 70 % of the heating value of petroleum distillates such as gasoline, but its sulphur and ash contents are also very low. Both these liquid fuels have lower vapour pressure and flammability than their petroleum based competitors.

Biodiesel is a diesel replacement fuel for use in compressed ignition engines. It is manufactured from plant oils (soybean oil, cotton seed oil, canola oil), recycled cooking greases or oils (e.g: yellow grease), or animal fats (beef tallow, pork lard). These vegetable oils are renewable, since plants produce oils via photosynthetic process while carbon dioxide from air is continuously utilized. Animal fats are produced when the animal consumes plants or animals, and these are renewable as well. Used cooking oils are mostly plant based, but may also contain animal fats. Used cooking oils are both recyclable and renewable[10]. In this research, waste cooking oil (WCO) was chosen as our ignition source inside the engine, at the same time replace the use of diesel fuel. Tables 3 and 4 respectively show the comparison of diesel and WCO, as well as the percentage of biodiesel and diesel for each blend.

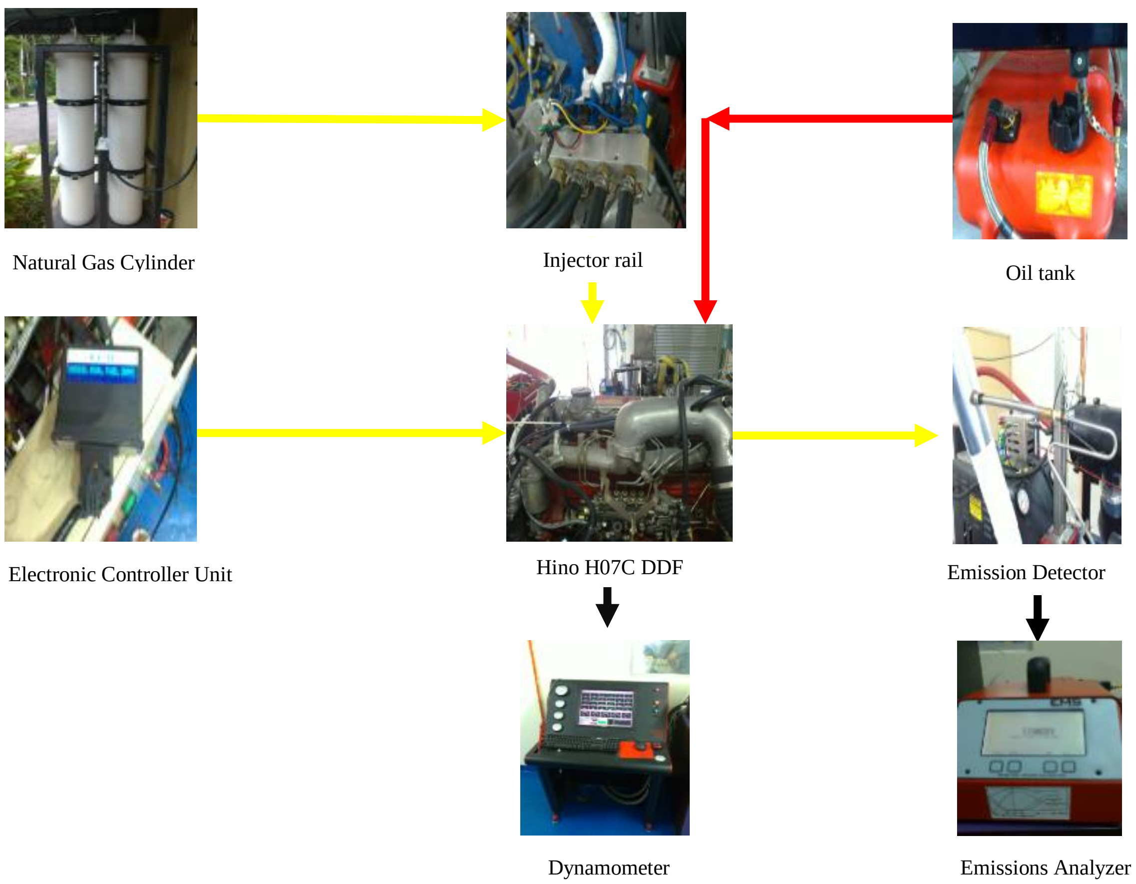


**Figure 1**. Experimental setup

**TABLE 1**. Properties of Natural Gas[11]

| Properties | |
|---|---|
| Compressibility | 0.9977 |
| Density | 0.7404 $kg/cm^3$ |
| Relative Density | 0.6042 |
| Molecular Weight | 17.4663 |
| Gross Calorific Value | 39.20 $MJ/cm^3$ |

**TABLE 2**. Compositions of Natural Gas[11]

| **Component** | **Mole%** |
|---|---|
| Methane | 93.07 |
| Ethane | 3.70 |
| Propane | 0.90 |
| i-Butane | 0.29 |
| n-Butane | 0.13 |
| i-Pentane | 0.07 |
| $C_{6+}$ | 0.07 |
| Nitrogen | 0.68 |
| Carbon Monoxide | 1.10 |

**TABLE 3**. Comparison of diesel and waste cooking biodiesel properties [8]

| **Property** | **Unit** | **ASTM method** | **Diesel** | **ASTM D-6751** | **MS 123:2005** | | **Biodiesel B100** | **FRIM test results** |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Min.** | **Max.** | | |
| Higher calorific value | kJ/kg | D-4809 | 42,232 | | | | | |
| Density | $kg/m^3$ | D-4052 | 0.831 | | 0.810 | 0.870 | 0.8815 | 0.8845 (@ 15) |
| Kinematic viscosity @ 40ºC | $mm^2/s$ | D-445 | 3.21 | 1.9 - 6.0 | 1.5 | 5.8 | 5.628 | 7.759 (@ 28) |
| Acid.no | mg. KOH/gm | D-664 | 0.2 | ≤ 0.8 | - | 0.25 | | 0.80 |
| Cloud point | ºC | D-2500 | -12 | - | - | - | 9 | 8 |
| Pour point | ºC | D-97 | -17 | - | - | 15 | 9 | |
| Flash point | ºC | D-93 | 76 | 130 | 60 | - | 182 | 184 (COC) |
| Cetane number | - | - | | ≥ 47 | 49 | - | | 70 |
| FFA content | % | - | | | | | | 0.20 |
| Ash (Sulfated) | wt% | - | | | | | | 0.012 |
| Carbon residue | wt% | - | | ≤ 0.05 | | | | 0.025 |
| Water content (by distillation) | Vol % | - | | ≤ 0.05 | | | | 0.0 |

**TABLE 4.** Percentage of biodiesel and diesel for each blend

| Biodiesel blend | Percentage of Biodiesel (%) | Percentage of Diesel (%) |
|---|---|---|
| B5 | 5 | 95 |
| B10 | 10 | 90 |
| B15 | 15 | 85 |

### Specification of Hino H07C engine

In this study, HINO H07C DDF Engine was employed to conduct the experiment. The specification of the engine is shown in Table 5.

**TABLE 5**. HINO H07C specifications (national trucks spares, 2012) [12]

| | |
|---|---|
| Type | Water cooled, 4-cycle, Overhead valve, in-line 6-cylinder, direct fuel injection |
| No. of cylinder x bore x stroke | 6 x 110mm x 118mm |
| Total displacement | 6728 cc |
| Compression ratio | 17.5 : 1 |
| Rated output | 180PS/2100 rpm (132.7 kW/2100 rpm) |
| Maximum torque | 67kgf-m/1600 rpm) (657N-m/1600 rpm) |

## RESULT AND DISCUSSION

### Exhaust Emission

### Nitrogen oxide

Figure 2 shows the decreasing pattern of NOx in the fuel mixtures containing biodiesel. This was due to lower combustion temperature as a result of lower biodiesel calorific value and the longer ignition delay.

According to the results obtained, at 1000 rpm, a similar pattern of decreasing in $NO_x$ emission was obtained from all types of biodiesel blends used, which were B5, B10, B15, and B20. As the rpm increased up to 2500 rpm, the amount of $NO_x$ emitted also increased due to additional combustion occurred inside the engine cylinder. However, there was no significant decrease due to only 5% of the biodiesel compositions increase in each of biodiesel blends tested.

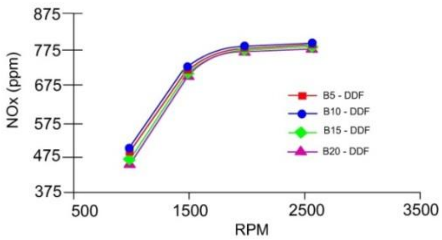


**Figure 2**. $NO_x$ against engine speed

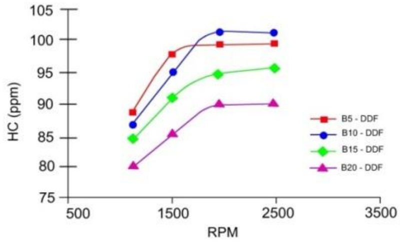


**Figure 3**. HC against engine speed

### Unburned hydrocarbon

Figure 3 shows that the amount of unburned hydrocarbon decreased with the increasing amount of biodiesel compositions in the biodiesel blends. It is inexplicable why there was an increment of UHC amount when B10 was used at an initial speed (1000 rpm) of the engine.

This phenomenon has shown that most of the hydrocarbons in this combustion chamber came from the pure diesel used, since the amount of gas injected was constant for each type of fuel tested. It was proven by the results obtained from the B20-DDF which had the lowest amount of hydrocarbon due to the lowest amount of pure diesel in the B20-DDF blends. The decreasing pattern of the hydrocarbon emitted was followed by B15-DDF, B10-DDF and B5-DDF.

The amount of hydrocarbon emitted increased with the increment of the engine speed which was set to 1500, 2000 and 2500 rpm. However, the amount of hydrocarbon released was still lower for the larger blends compared to smaller blends.

### Engine performance

### Engine torque

As shown in Figure 4, the torque decreased for each type of biodiesel blends used in this research. The value of torque decreased as the engine speed increased, as a result of less force needed to push the engine piston at high speed. At high speed, smaller amount of fuel was injected into the cylinder hence slowing down the combustion rate.

The decreasing value of torque for high speed was considered normal for every type of engine. The difference was to determine how low or high the torque value could be achieved by using different types of fuel. Based on Figure 4, B5-DDF gave better results as it could achieve the highest value of torque and decreased to 16 % at highest engine speed (2500 rpm).

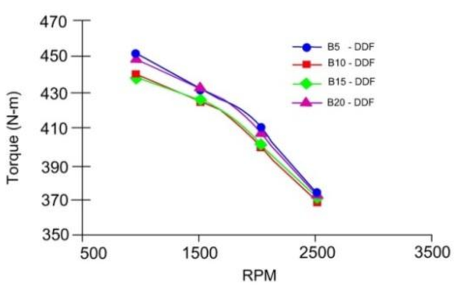


**Figure 4**. Torque against engine speed

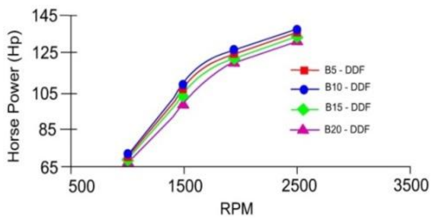


**Figure 5**. Horse power against speed

### Horse power (HP)

Figure 5 shows the graph of horse power against speed. The horse power (HP) increased for all types of fuels tested, which were B5-DDF, B10-DDF, B15-DDF and B20-DDF. The values of HP obtained were similar for all types of blends. HP increased with the increase of engine speed. Due to the lower calorific value and energy content of biodiesel, the loss in engine power was predictable as this also happened for natural gas fuelled engine. However, since the difference in percentage of biodiesel in each fuel blend was only 5 %, similar results were obtained, as shown in Figure 5.

### Comparison between different types of fuel

### Nitrogen Oxide

In all fuel combinations, the amount of $NO_x$ was lower than the neat petro- diesel. This was due to the occurrence of $NO_x$ emission at high temperature combustion. Therefore, lower $NO_x$ in the fuel mixtures containing biodiesel was an indication of lower combustion temperature due to lower biodiesel calorific value and the longer ignition delay. Figure 6 indicates the influence of biodiesel on reduction of $NO_x$ emission. The graph also indicates that, the amount of $NO_x$ in the fuel was raised in the present of CNG. As it can be observed, B20-DDF and DDF fuels gave higher amount of $NO_x$ compared to both B20 and pure diesel tested.

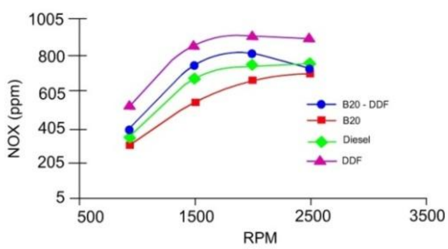


**Figure 6**. $NO_x$ against engine speed

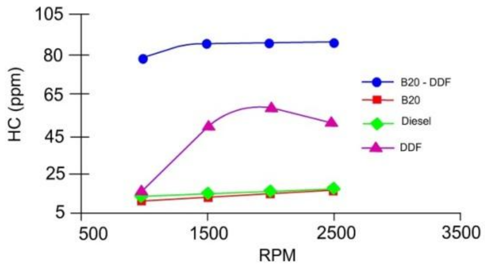


**Figure 7**. HC against engine speed

## Hydrocarbon

CNG was the main source of the unburnt hydrocarbons emitted from the engine combustion chamber. It can be considered that the gas injected into the cylinder was not completely consumed in the combustion chamber. The main component of CNG, which is methane, was among the unburnt hydrocarbons emitted.

As shown in Figure 7, pure diesel and B20 produced small amount of HC as there was no CNG in the fuels. Unfortunately, there was a significant increase in the amount of HC when CNG was injected into the cylinder. Combinations between biodiesel and CNG (B20-DDF) showed very poor results, which released up to 90 ppm HC at increasing engine speed. The main factor was because biodiesel failed to burn the gaseous injected due to the low calorific value of the biodiesel.

## Horse power (HP)

Figure 8 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). This figure shows that the HP increased with the increasing engine speed. It was considered normal since at high speed, the combustion inside the cylinder was close to completions which gave increasing horsepower.

Figure 8 also indicates that the value of HP increased through the use of CNG as the main fuel in the engine. At initial engine speed (1000 rpm), the HP showed slight difference for the fuel without CNG, (B20 and diesel) and fuel with CNG, (B20-DDF and DDF) was about 35%. Clearly, the HP of the engine increased significantly with the presence of CNG as a main fuel. Diesel with CNG (DDF) fuel gave the highest HP at higher engine speed. The presence of CNG as a main component and diesel as an ignition source caused significant increase of HP. The high calorific value of pure diesel indirectly caused complete combustion of natural gas in the engine cylinder.

## Engine torque

As a result of better combustion due to the presence of natural gas, high HP was gained, thus producing high engine torque for the fuels containing CNG (B20-DDF and DDF). The combination of B20 blends and CNG (B20-DDF) gave the best torque as it produced 20 % lower torque value at the highest engine speed. This was important to ensure that there would be no extra force produced inside the cylinder that could cause the engine to burst at high engine speed. Diesel fuel also gave the lower torque value at high speed which had a 24 % difference between 1000 rpm and 2500 rpm. However, using diesel without CNG, lower torque value was obtained at the initial engine speed. Figure 9 shows the engine torque against engine speed.

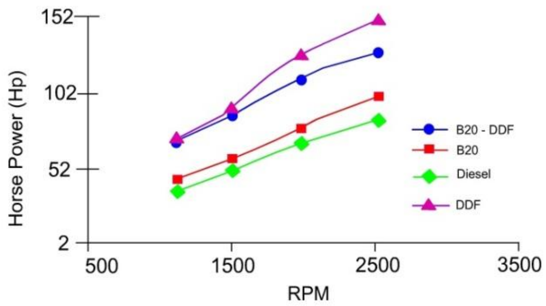


**Figure 8**. Horse power against engine speed

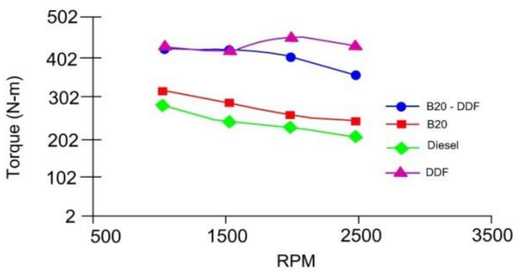


**Figure 9**. Torque against engine speed

## CONCLUSION

According to the results obtained, it can be concluded that for the exhaust emissions, $NO_x$ decreased due to clean combustion of the engine. As more biodiesel was being consumed, smaller amount of $NO_x$ was emitted. In contrast, as CNG was injected into the engine, more $NO_x$ was produced. However, the amount of $NO_x$ emitted was still lower when using biodiesel as an ignition source, compared to using pure diesel for similar purpose in DDF engine system. In contrast, HC emission was higher from biodiesel fuelled engine compared to neat petrol diesel fuel. Although the data showed a decrease in HC emission with the increasing percentage of biodiesel in the fuel blends (B20-DDF), it was still not satisfactory to reach the desired level because it was above the HC level emitted by neat petro diesel (DDF) system.

Meanwhile, for the engine performance, it was observed that the combinations of biodiesel and CNG increased the engine power with the increase of engine speed. In comparison to pure diesel, B20, DDF and DDF with biodiesel, DDF gave the highest engine power due to the presence of CNG as the combustion system, which was close to completion due to higher calorific value of pure diesel, compared to using biodiesel.

Furthermore, the engine torque decreased for all types of biodiesel blended with CNG. The engine torque decreased with the increase of engine power. In comparison, the combination of B20 and CNG (B20-DDF) had the greatest performance since it gave the highest torque at an initial engine speed (1000 rpm) and had a slightly reduction of total torque by 20% at maximum speed (2500 rpm).

## ACKNOWLEDGEMENT

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**Persian Abstract**

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**چکیده**

در این مطالعه، چهار نوع اصلی از انواع سوخت ها شامل گازوییل خالص، بیودیزل، سوخت دیزل دوگانه و ترکیب بیودیزل و سوخت دیزل دوگانه به منظور مقایسه بازدهی و آلایندگی مورد بررسی قرار گرفت. استفاده از گاز طبیعی فشرده (CNG) در موتورهای دیزل به عنوان یکی از راه حل های بهینه به منظور کاهش مصرف سوخت در نظر گرفته شود. CNG میتواند به صورت جزیی در محفظه احتراق جایگزین گازوییل شود، در حالی که گازوییل باقی مانده به عنوان سوخت آزمایشی مورد استفاده قرار می گیرد. بیودیزل مورد استفاده از روغن سوخته پخت و پز استخراج شده و از انستیتو مطالعات جنگل های مالزی تهیه شده است. نتایج حاصل از آزمایش بر روی موتور نشان می دهد که افزایش درصد بیودیزل در موتور مورد آزمایش باعث کاهش قدرت موتور می شود. بیودیزل ترکیبی با CNG نتایج بهتری را در میزان گشتاور در مقایسه با سایر سوخت های مورد بررسی نشان داد. نتایج بدست آمده در این مطالعه نشان می دهد که زمانی که ترکیب درصد بیودیزل در سوخت افزایش می یابد، خواص ذاتی بیودیزل از جمله آزاد شدن $NO_x$ در زمان احتراق کاهش می یابد. با این حال در خروجی به دلیل سوختن ناقص بیودیزل هیدروکربن نسوخته مشاهده شد.