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Performance Characteristics of the Direct Injection Compression Ignition Engine Fuelled By Biodiesel

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Abstract

The purpose of this research is to prove the feasibility of palm-based biodiesel as an alternative fuel in diesel engine. The study was done as a response to the alarming level of the rise in cost of fossil fuel and the worrying level of nature resources till date. Thus, the primary objective of this research was to study the performance characteristics of the compression ignition engine fuel by using PETRONAS DYNAMIC DIESEL (Euro 2M), which is a B7 biodiesel blend and comparing these characteristics with pure diesel. The experiment was done on a four stroke four cylinder engine at wide open throttle load (100% throttle load) and idle throttle load (20% throttle load), lean mixture and various engine speeds. The results showed that Euro2M portrays a significant amount of improvement in performance characteristics at idle throttle load. It portrays an improvement of 25% in terms of highest Brake Torque (BT) achieved, 90% increment in Brake Specific fuel Consumption (BSFC) as engine speed increases from 3000 to 4000 rpm and 32% increment of highest Brake Thermal Efficiency (BTE) achieved. While for wide open throttle, Euro 2M experiences a slight 5% decrement but having an increment of highest BTE achieved. Thus, it can be concluded that palm oil-based biodiesel fuel is a viable alternative for diesel fuel as it produces better performance than conventional diesel fuel.

Keywords: Biodiesel, Brake Torque, Brake Specific fuel Consumption, Brake Thermal Efficiency, Euro 2M, Pure diesel, Idle Throttle, and Wide Open Throttle.

INTRODUCTION

The world is moving fast and carries along a very intense rate of industrialization with it. This fast moving current had transformed many sectors since the last century and resulted in rapid improvement of human civilization in various angles. It is not too much to say that the very soul of this phenomenon is the oil industry. The oil industry had changed greatly the human civilization towards better and laid a very solid foundation in the modern industrialization. One of the many sector that transformed greatly by the oil industry are transportation in general, and automotive in particular, with petroleum at its core of transformation. The invention of the internal combustion engine was the major influence in the rise in the importance of petroleum. However, petroleum is one of the fossil fuels, and therefore are subjected to depletion [1-5].

The depletion of the earth's finite reserves of oil has become an issue that needs major attention as it can proves to be a vital hazard for the progress of humanity on years to come. The use of fossil fuels, such as petroleum, has a negative impact on Earth's biosphere, damaging ecosystems through events such as oil spills and through indirect way, increasing cost. There are many alternatives that has been taken by various party in the world. These include looking for another alternative for fuel usage in vehicles [6-10].

The ever rising price of fossil fuel in general and diesel fuel in particular is also one of the reason contributing towards the cause. The increasing price affects the increase in many others daily consumer products and almost everyone is affected by it. The time could not be any more exact to find an alternative for fossil fuels. The longer we wait the more problem it could make for the mankind. Knowing the drawbacks and the hazard presented to the ecosystem by diesel fuel, an alternative should be searched. Biodiesel is a viable alternative as it is a fuel that produces less hazardous emission to the environment. Malaysia is blessed with palm oil production and it provides a large room for research and improvement of biodiesel. Palm oil based biodiesel is a very feasible alternative for diesel fuel in Malaysia as the resource is not a problem (Malaysia is one of the highest palm oil producer in the world) [11-18].

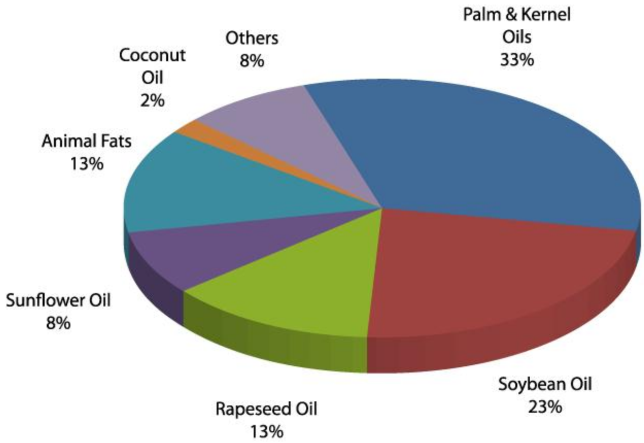


Figure 1 : Percentage contribution of different types of oil to Biodiesel [1]

Up until now, there has been numerous studies and research about biofuels. From its feasibility to its side effect, a wide area of biofuels had been covered by numerous institutions. This includes the variety of biofuel types from vegetables to animal fats. Narrowing the scope down, the study and research on biodiesel had also covers a wide area. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. Fig. 1 showed the percentage contribution of different types oil to Biodiesel. The process used to convert these oils to Biodiesel is called transesterification. The diesel can be used in existing compression-ignition engine without any modification.

Various researchers from all around the world have studied the implementation of biodiesel in compression-ignition engine. Xue, et al [12] showed that an increase in biodiesel fuel consumption was due to low heating value and high density and viscosity of biodiesel, but this trend will be weakened as the proportion of biodiesel reduces in the blend." In overall, they believe that especially for the blends with small portion of biodiesel, is technically viable as an alternative fuel in compression-ignition engines with little or no modifications to engine. They believe that their significant will grow over time, for economic and environmental reasons. There is another group of researchers that studied about the usage of biodiesel as an alternative fuel by using locally found resources. Özcanli, et al [13] revealed that biodiesel produced from castor oil methyl ester provided an increase on brake specific fuel consumption and a small decrease in brake power output. They found that power output of the engine with blends decreased by a maximum of 4.12% with B25 blend compared with convectional diesel fuel. They conclude that castor oil methyl ester diesel fuel blends can be used as alternative fuel in conventional diesel engines without any major modification. Another experimental investigation was conducted by Shirneshan,[14], also confirms the viability of biodiesel as an alternative fuel. He founds that the use of biodiesel resulted in brake power decreases up to 17% was found. Further results showed that the increase in engine load appeared to cause an increase in the brake power up to 69%. On the other hand by increasing engine speed of the engine, brake power increases continuously up to speed 1800 to 2000 rpm and after that decreases. His research was done on waste cooking oil. In addition, the brake torques was found to decreases slightly with the increasing amount of biodiesel in the fuel blend. The decrement is expected, as the heat content of the fuel blend decreases with the increasing amount of biodiesel when compared to diesel. High lubricity and the higher oxygen content of biodiesel might result in the reduced friction loss and thus improve the brake effective torque and compensates the loss of heating value of biodiesel. Most of the studies on the biodiesel were done on the part throttle load (50%) and slightly above, (75%). Many researches on this particular area had started from the concern of the depletion of petroleum-based fuel and in searching for a new alternative. According to Hassan and Kalam, [15] there are many prospective type of renewable energy such as wind, solar, tidal and fusion energy but for the sake of growing demand of transport fuel for millions of existing automobiles, an alternative that can easily adapt with the present supply and storing system is needed and biofuel seems the perfect choice. Research has shown that internal combustion engines designed for petroleum fuels usage is not suitable for long time operation on biofuel. Hence, a little modification can give a comprehensive solution in tailoring fuel properties for engine compatibility. On the contrary, to date, there is no modified vehicle patent that runs on biodiesel. Considering all the pros and cons and the fuel properties, this can be comprehended that multi-functional fuel additives may make biodiesels more engine compatible, but it will increases its price. So a mass production along with utilization needs a dedicated engine which could be done by modifying present day diesel engines on fuel supply system only. Friso, [16] compared between pure diesel and 100% biodiesel (B100) in two performance characteristics in an agricultural tractor; brake specific fuel consumption and brake thermal efficiency and found out that the brake thermal efficiency of the engine was unchanged, while the average brake specific fuel consumption was 19% higher with B100, consistent with the lower heating value of B100 (-17.2%). However, the power output of the engine with the B100 was not reduced by the same amount, but with an average value of 11%, as there was a partial recovery due to the slight increase in the fuel consumption rate. Same as the previous others found out that the use of biodiesel in a diesel engine causes an expectable decrease in the engine performance compared with the same system fuelled by diesel oil due to the differences in the molecular structure of these two fuels. Furthermore, the result equally showed that the engine fuelled with B100 had a brake thermal efficiency higher at low load and speed, but lower than that of B0 at high speed. This means that B100 burns better at reduced loads and speeds, while the combustion of B100 tends to worsen with the speed increase, due probably to reduced inclination to evaporate compared to diesel oil, which is critical when the speed increases and the time available for combustion is reduced. Even though, a lot of works has been done on the implementation of biodiesel fuel in compression ignition engine, however, comparative advantage of biodiesel fuel and convection diesel fuel in a direct injection compression ignition engine at wide open throttle (100%) and idle throttle (20%) load is relatively unclear. Thus, this research was conducted at wide open and idle throttle condition in the direct injection compression-ignition engine in order to examine its performance characteristics and clarify the engine performance under these operating conditions.

Significance Statement

This study discovers the implementation of biodiesel (B7) otherwise known as EURO 2M in direct injection compression ignition engine at wide open and idle throttle conditions that is very beneficial as a suitable fuel replacement for convectional diesel fuel in a direct injection compression ignition engine. This study will help the engine researchers to understand the comparative advantage of implementing biodiesel (B7) as a fuel over convectional diesel fuel in a direct injection compression ignition engine at wide open and idle throttled conditions respectively which until now difficult to understand. Thus, new findings on the comparative advantage of these two fuels in a direct injection compression ignition engine may be realized.

EXPERIMENTAL SET UP AND PROCEDURE

The specifications of the test engine are listed in Table 1. A four-stroke four cylinder compression engine was used to investigate the performance characteristics of direct injection compression ignition engine fuelled by biodiesel. Figure 2 below shows the experimental set up. The experiment was done in the "Centre for Automotive Research, University of Kuala Lumpur (UniKL)" on the 15th June, 2017.

Table 1: Engine specifications

Engine Properties	
Displacement volume	3200 dm^3
No and Arrangement of Cylinders	4 in Line
Compression Ratio	17
Combustion Chamber	Direct Injection
No of Intake / Exhaust Valve per Cylinder	2
Valve Mechanism	Double Overhead Camshaft, 4-valve
Cylinder bore and Stroke (mm)	98.5 x 105
Dynamometer	Eddy Current with maximum reading of 50Nm
ECU	Orbital Inc

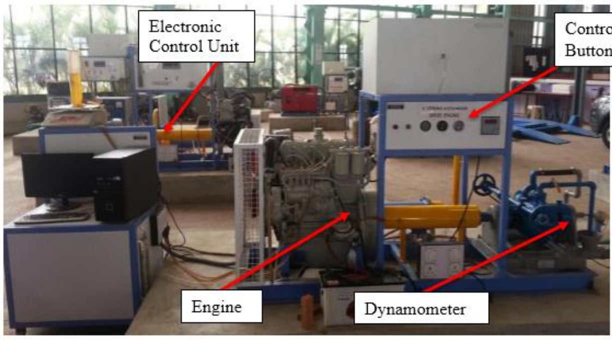


Figure 2: Experimental set up.

In the experiment set-up, the supply system consists of biodiesel fuel line, pressure gauge and flow meters. The experiment begins after the engine had been let running for a period of time to let the oil and coolant temperature become stable. Biodiesel fuel was injected into the engine cylinder. An Electronic Control Unit (ECU) was used to control all the engine operating parameters such as throttle position, stoichiometric air-fuel ratio, engine speed and various others. A dynamometer was used to collect the performance characteristics data. The research was carried out at wide open and idle throttled respectively, late injection timing and various engine speed of 1000, 2000, 3000 and 4000 r/mins, were being utilized.

Combustion Equation for Biodiesel

The combustion equation representing biodiesel utilized for this research is [21]:

$$C_{19}H_{36} + a\,(O_2 + 3.76N_2) \leftrightarrow x\,CO_2 + y\,H_2O + z\,3.76N_2 \qquad (1)$$

Thus, the balanced equation is;

$$C_{19}H_{36}O_2 + 27(O_2+3.76N_2) \rightarrow 19CO_2 + 18H_2O + 101.52N_2 \qquad (2)$$

Where:

a, x, y and z are constants determine by applying the principle of conservation of mass.

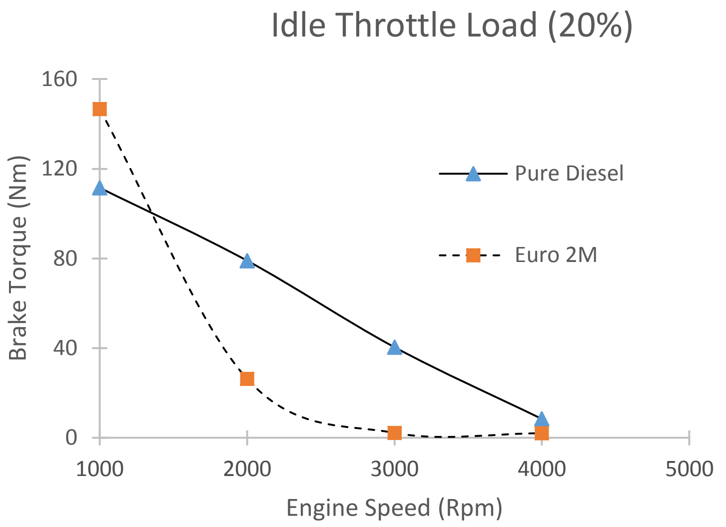
RESULTS AND DISCUSSION

The results on performance characteristic from the experiments performed on the four cylinder four stroke compressed-ignition engine for two different type of diesel on two different throttle loads were presented. The different throttle loads used in this experiment were 20% (idle throttle), and 100% (wide open), while the engine speeds utilized were 1000, 2000, 3000 and 4000 rpm. The two diesel type used are PETRONAS DYNAMIC DIESEL (Euro 2M), which are B7 biodiesel blend and pure diesel (100% diesel). The two types of diesel were analyzed for its performance characteristics such as **Brake torque**, **Brake specific fuel consumption (BSFC)**, and **Brake thermal efficiency.**

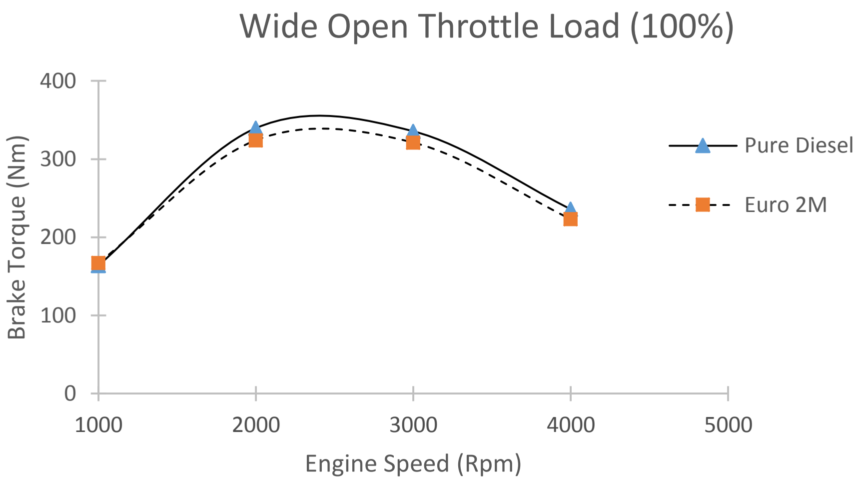
Brake Torque

Figure 3 displays the relationship between brake torque and various engine speeds for wide open throttle and idle throttle. It is obvious from the graph, the difference of the curve between two throttle loads on two different types of fuels. A decrement can be observed from start to end for 20% throttle load and is largely be due to the reduction in burning velocity and combustion maximum temperature occurring at that operating condition while steady increment followed by decrement can be observed for 100% throttle load. The highest brake torque recorded for 20% throttle load is at 146.6 Nm at 1000rpm (Euro 2M) while for 100% throttle load is 339.5 Nm at 2000rpm (Pure Diesel). It is apparent that 20% throttle load has lower maximum brake torque achieved. This might be so because of cycle by cycle combustion variation. Consequently, the brake torque decreases. For 100% throttle load, the decreasing trend of the graph can be explained by, and relating to the previous 20% throttle load that the brake torque increases with increasing throttle load and this is due to the increase in combustion temperature and burning velocity that leads to more complete combustion during the higher load.

Comparing the brake torque between pure diesel and Euro 2M for both throttle positions under considerations. The results revealed that higher brake torque occurs at pure diesel for both throttle positions. This might be so, because of the higher energy content possessed by the diesel fuel (Higher heating value) as compared to the biodiesel fuel (Euro 2M). Exception to this observation occurs at idle throttle (20 % throttle position) and at engine speed of 1000-1500 rpm where biodiesel [Euro 2M] fuel has higher brake torque as compared to the pure diesel fuel. This could be due to deterioration in combustion quality occasioned by variation in mixture composition at that operating condition of the engine. Good agreement was achieved between these experimental results and Jinlin Xueab et al [12], Ozcanli M., et al [13], Ozcanli M., et al [19], Alireza Shirneshan [20], Heywood J. B [21].



(a)



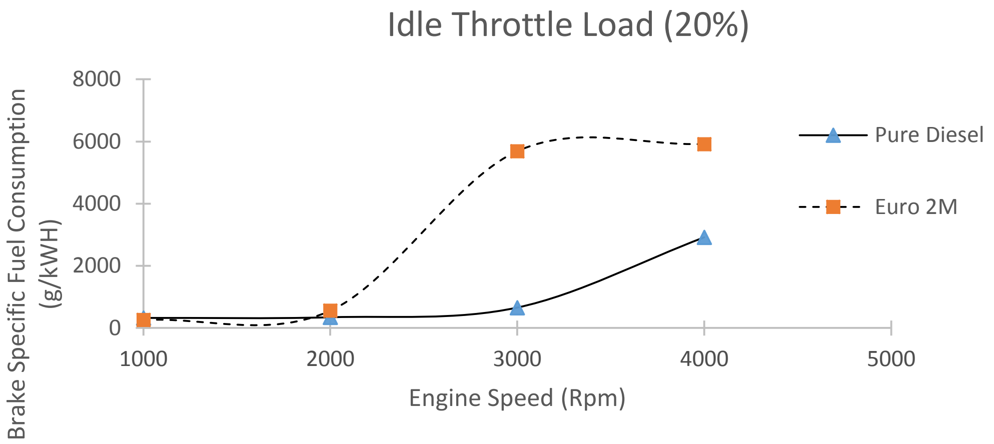
(b)

Figure 3: Graph of Brake Torque vs Engine Speed at (a) idle throttle (20%) load and (b) wide open throttle (100%).

Brake Specific fuel Consumption (BSFC)

Figure 4 shows the relationship between Brake Specific Fuel Consumption and engine speed at wide open throttle and idle throttle load. It can be observed from the following graphs that increase in engine speed from 1000 to 2000 rpm shows a constant trend line for Euro 2M at idle throttle before it start to increase when the engine speed increases from 2000 to 3000 rpm. The increase in the brake specific fuel consumption might be due to the increase in relative importance of friction and importance of heat transfer within the engine cylinder. While for pure diesel at idle throttle load, the brake specific fuel consumption shows approximately constant trend line. Increase from 3000 to 4000 rpm shows that the brake specific fuel consumption has an increasing trend. The increasing trend might be due to the increased magnitude of friction (due to the increase in pumping work). For wide open throttle load, the brake specific fuel consumption shows approximately increasing trend line. This might be due to the deterioration in combustion quality caused by cycle by cycle combustion variation. In addition, comparing the brake specific fuel consumption of the two fuels at idle throttle load. The lower brake specific fuel consumption occurs at pure diesel while the higher brake specific fuel consumption occurs at Euro2M. For wide open throttle, there are no clear distinctions between the two fuels under consideration as the curves are approximately the same in trend line shape. Consider brake specific fuel consumption at idle throttle for the two fuels under consideration. For Euro2M at engine speed of 2000 to 3000 rpm, the brake specific fuel consumption respectively are 562.32- g/kWH and 5686.01 g/kWH. This shows an approximately **90% increment** in fuel consumption at that operating condition. This might be due to increase in pump work occasional by increase in friction. While for pure diesel and at engine speed of 3000 to 4000 rpm, the brake specific consumption respectively are 655.2 g/kWH and 2915.97

g/kWH and this shows an approximately **77% increment** in fuel consumption at that operating condition. The same previous explanation can be used to describe the reason for the increment. The result showed here is coherent with Ozcanli M., et al [13], Heywood, J [21].



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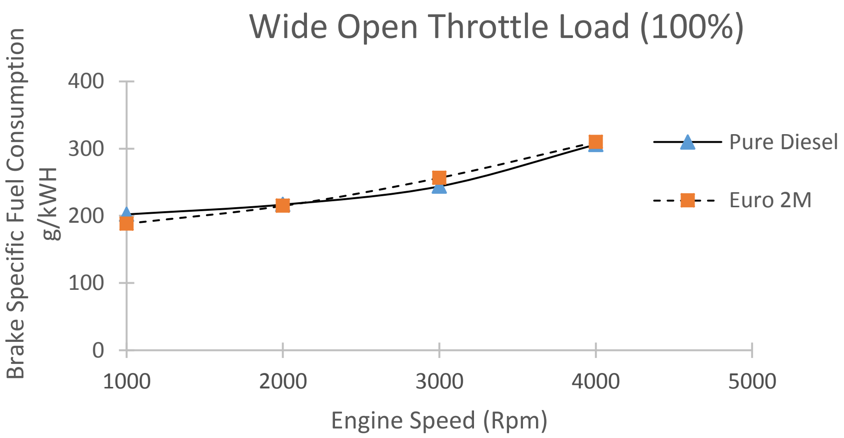
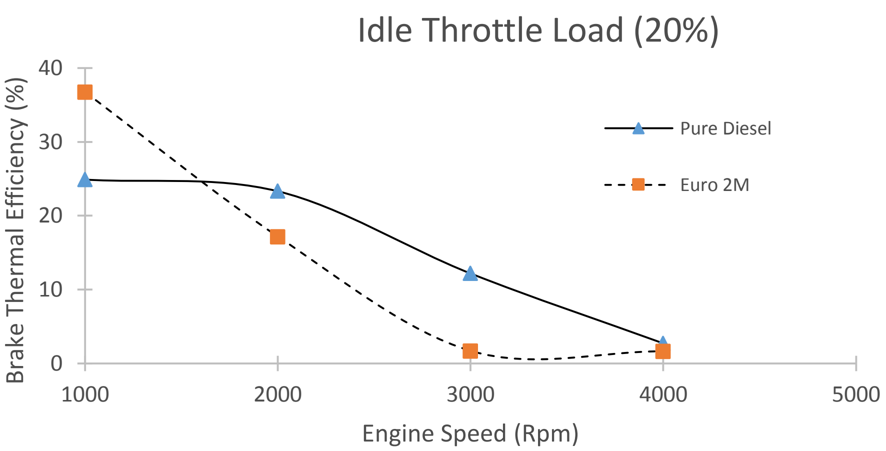


(b)

Figure 4: Graph of Brake Specific Fuel Consumption vs Engine Speed at (a) idle throttle (20%) load and (b) wide open throttle (100%).



(a)

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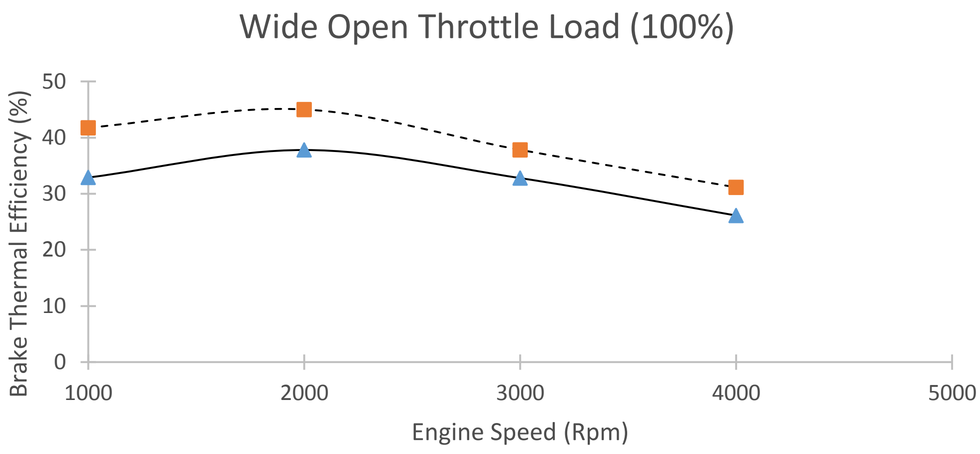

(b)

Figure 5: Graph of Brake Thermal Efficiency vs Engine Speed at (a) idle throttle (20%) load and (b) wide open throttle (100%).

Brake Thermal Efficiency (BTE)

Figure 5 illustrates the relationship of brake thermal efficiency against engine speed at wide open throttle and idle throttle load. Both wide open and idle throttle load shows a decreasing trend line as oppose to brake specific fuel consumption's graph. In addition, the difference in trend line for both graphs can be clearly seen. For idle throttle load, pure diesel experiences a slight decrease at 2000 rpm, and then decreases in a much higher slope as it reaches 4000rpm. Euro 2M decreases in a constant trend until 3000rpm and then stays constant until 4000rpm. The decreasing trend for both type of fuels can be explained by the cycle-by-cycle combustion variation occasional by the variation in mixture compositions. For wide open throttle load, a slight increment followed by steady decrement as the engine speed increases can be seen. Both pure diesel and Euro2M shows a similar curve trend, only difference is Euro2M records a higher value of data. The decrement in brake thermal efficiency can be explained by the reduction in combustion quality as the engine speed increases. Comparing the brake thermal efficiency between pure diesel and Euro2M for idle throttle respectively. The highest attainable brake thermal efficiency for both fuels under consideration respectively are 24.91% and 36.72%. This shows that higher brake thermal efficiency occurs at Euro 2M. It display an approximately **32% increment** of brake thermal efficiency at that operating condition. While for wide open throttle, the highest attainable brake thermal efficiency recorded respectively are 37.8% and 45%. This reveals that the higher brake thermal efficiency occurs at pure diesel. It produces an **increment of 18%** in brake thermal efficiency at that operating condition. Thus, it is clear that idle throttle load shows a higher percentage of increment of brake thermal efficiency compared to wide open throttle load. The result obtained here is coherent with Frisco D [16].

CONCLUSION

The experimental study has been conducted to investigate the comparative advantage of performance characteristics of the direct injection compression ignition engine fuelled by biodiesel (Euro 2M) and convectional diesel fuel at idle (20%) and wide open (100%) throttle positions respectively. The main findings are summarized below:

- Euro 2M showed 25% increment in maximum brake torque when compare with convectional diesel fuel at idle throttle just as 5% decrement in maximum brake torque was observed for Euro 2M when compare with convectional diesel fuel at WOT. Euro 2M shows approximately 13% increment in maximum BSFC when compare with convectional diesel fuel at idle throttle while there is no significant increment for the two fuels under consideration at WOT, just as nearly 32% and 18% increment in maximum brake thermal efficiency (BTE) occurred at Euro 2M when compare to convectional diesel fuel at idle throttle and WOT respectively.

ACKNOWLEDGEMENT

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