SIMULATION OF PERFORMANCE AND OPTIMIZATION FOR DIESEL ENGINE FUELED WITH HIGHER BIODIESEL BLEND

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ABSTRACT

With global energy demand that keeps on increasing by 1.2% every year, CO_2 was predicted to increase as well. A short-term solution to reduce CO_2 is to switch to carbon-neutral fuels and one of them is biodiesel. However, biodiesel's higher viscosity and lower calorific value compared to pure petroleum diesel lead to higher brake specific fuel consumption (BSFC) especially for higher biodiesel blend. Even though there are many ways to reduce the BSFC, to quantify how much these ways manage to reduce it requires experiments that are costly and time consuming. At the same time, a limited simulation model can be used as the alternative to the experiments. Therefore, the objective of this research is to develop a model based on the Yanmar L70N6 engine using GT-Suite simulation software, to predict engine performance, combustion, and emissions when using biodiesel. The engine model was then used to simulate a high biodiesel blend with a variation of injection timing (IT), injection pressure (IP), and preheat biodiesel fuel (PF). In this research, experimental work was conducted to obtain baseline data for validating the simulation study based on the manufacturer's default setting of IP (206 bar), IT (14 ºbTDC), and ambient temperature for fuel which is around 30°C. In the experiment, B10 and B30 were tested at four different speeds (1500, 2000, 2500, and 3000 rpm) with five different loads (3, 5, 7.5, 10, and 11.5 Nm) at each speed. Then, B30, B50, B70, and B100 were simulated with variations of IP (206, 220, 240, 260, 280, and 300 bars), IT (10, 12, 14, 16, 18, 20, 22, and 24 ºbTDC) and PF (30, 40, 50, 60, 70, 80, and 100°C). For model validation, the engine speed was simulated at 2000 rpm with five different loads and comparison between the simulation and the experimental results showed less than 10% differences in the BSFC of B10 (8.8%) and B30 (5.1%). The results showed that by increasing IP to 300 bar, retarding IT to 12ºbTDC, and PF to 100ºC, reduction of the BSFC was recorded from 2.1% to 5.4% meanwhile CO_2 emission reduction was recorded from 3.79% to 10.7% and by combining three optimized parameters, it helps reducing BSFC, and CO_2 for all blends. Among all biofuels, B100 has the lowest BSFC (8.8%) and CO_2 (22.3%) at 3000 rpm and 3 Nm load. In conclusion, the objective of the research, which is to develop a reliable simulation model and improve the performance of a high biodiesel blend, has been achieved successfully.

ABSTRAK

Dengan permintaan tenaga global yang terus meningkat sebanyak 1.2% setiap tahun, CO_2 diramalkan akan meningkat juga. Untuk mengurangkan CO_2 dalam masa terdekat adalah dengan beralih kepada bahan api neutral karbon dan salah satunya ialah biodiesel. Kelikatan biodiesel yang lebih tinggi dan nilai kalori yang lebih rendah berbanding diesel petroleum membawa kepada penggunaan bahan api khusus brek (BSFC) yang lebih tinggi. Meskipun terdapat banyak cara untuk mengurangkan BSFC, tetapi ianya memerlukan pengujian yang mahal dan memakan masa. Sementara itu, model simulasi yang boleh digunakan sebagai alternatif kepada eksperimen juga adalah terhad. Oleh itu, objektif penyelidikan ini adalah untuk membangunkan model berasaskan enjin Yanmar L70N6 menggunakan perisian simulasi GT-Suite, untuk meramal prestasi enjin, pembakaran, dan pelepasan. Model tersebut kemudiannya digunakan untuk mensimulasikan biodiesel dengan variasi pemasaan suntikan (IT), tekanan suntikan (IP) dan bahan api biodiesel prapanas (PF). Dalam penyelidikan ini, kerja eksperimen dijalankan berdasarkan penetapan lalai pengeluar IP (206 bar), IT (14 ^{o}bTDC), dan suhu ambien untuk bahan api iaitu sekitar 30°C. Dalam eksperimen, B10 dan B30 diuji pada empat kelajuan berbeza (1500, 2000, 2500 dan 3000 rpm) dengan lima beban berbeza (3, 5, 7.5, 10, dan 11.5 Nm) pada setiap kelajuan. Kemudian, B30, B50, B70 dan B100 disimulasikan dengan variasi IP (206, 220, 240, 260, 280 dan 300 bar), IT (10, 12, 14, 16, 18, 20, 22 dan 24 ^{o}bTDC) dan PF (30, 40, 50, 60, 70, 80 dan 100°C). Untuk pengesahan model, kelajuan enjin disimulasikan pada 2000 rpm dengan lima beban berbeza dan perbandingan antara simulasi dan keputusan eksperimen menunjukkan perbezaan kurang daripada 10% dalam BSFC B10 (8.8%) dan B30 (5.1%). Dengan meningkatkan IP kepada 300 bar, melambatkan IT kepada 12^{o}bTDC, dan PF kepada 100^{o}C, pengurangan BSFC direkodkan daripada 2.1% kepada 5.4% dan pengurangan pelepasan CO_2 direkodkan daripada 3.79% kepada 10.7 % dan ianya juga membantu mengurangkan BSFC, dan CO_2 untuk semua bahan api. Di antara semua biofuel, B100 mempunyai BSFC (8.8%) dan CO_2 (22.3%) paling rendah pada 3000 rpm dan beban 3 Nm. Kesimpulannya, objektif penyelidikan, iaitu untuk membangunkan model simulasi yang boleh dipercayai dan meningkatkan prestasi biodiesel yang berbeza, telah dicapai dengan jayanya.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
B0	-	Biodiesel (0%)
B05	-	Biodiesel (5%)
B10	-	Biodiesel (10%)
B100	-	Biodiesel (100%)
B20	-	Biodiesel (20%)
B25	-	Biodiesel (25%)
B30	-	Biodiesel (30%)
B40	-	Biodiesel (40%)
B50	-	Biodiesel (50%)
B60	-	Biodiesel (60%)
B70	-	Biodiesel (70%)
BEV	-	Battery Electric Vehicle
BMEP	-	Brake Mean Effective Pressure
BP	-	Brake Power
BSFC	-	Brake Specific Fuel Consumption
BTE	-	Brake Thermal Efficiency
CA	-	Crank Angle
CI	-	Compression Ignition
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CRDI	-	Common Rail Direct Injection
DI	-	Direct Injection
ECU	-	Electronic Control Unit
EGR	-	Exhaust Gas Recirculator
EOI	-	End of Injection
EOS	-	Equation of State
EV	-	Electric Vehicle
FE	-	Finite Element
GHG	-	Green House Gases
H_2	-	Hydrogen
H_2O	-	Hydrogen Oxide
HC	-	Hydro Carbon
HP	-	Horse Power
ICE	-	Internal Combustion Engine
ISO	-	International Standard Operation
LCD	-	Liquid Crystal Display
MJ	-	Mega Joule
MPOB	-	Malaysia Palm Oil Board

MS	-	Malaysia Standard
N_2	-	Nitrogen
NO_X	-	Nitrogen Oxides
O_2	-	Oxygen
OH,	-	Hydroxide
POME	-	Palm Oil Methyl Ester
RPM	-	Revolution Per Minute
SI	-	Spark Ignition
SO	-	Sulphur Monoxide
SO_2	-	Sulphur Dioxide
SOC	-	Start of Combustion
SOI	-	Start of Injection
TDC	-	Top Dead Centre
ULSD	-	Ultra Low Sulphur Diesel

LIST OF SYMBOLS

N	-	Revolution per Minute
T	-	Temperature
C_p	-	Carbon Produced
C_r	-	Carbon Reduction
$\dot{m}_a$	-	Mass Air Rate
C_D	-	Coefficient of Drag
D_O	-	Diameter of Orifice
ρ_a	-	Air Density
Δp	-	Pressure differentiation
ρ_{man}	-	Density of Manometer
g	-	Gravity Acceleration
h	-	Height/Head
V_d	-	Displacement Volume
$\dot{m}_f$	-	Mass Fuel Rate
$\eta_{\boldsymbol{tb}}$	-	Thermal Efficiency
Q_{HV}	-	Heating Value

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Global energy demand keep on increasing by 1.2% every year (Lešnik et al., 2020). Increase on global energy demand, means that it might cause increment in greenhouses gases (GHG) too. Research conduct by Lešnik et al. (2020), shown that in European countries around 33% of all the energy demand were used for transportation sector, and around 81.7% of it were used for road transport sector.

Therefore, many governments around the world are pushing their road transport sector especially in private transportation (i.e. cars) to be electrified (Shammut et al., 2019). Electrification of cars doesn’t stop only in Hybrid or Plug-in Hybrid electric vehicle, but it will push to all electric vehicle, whether it will be battery electric vehicle (BEV) or hydrogen powered electric vehicle. For Example, Britain are planning to ban new car sales solely powered by Gasoline or Diesel in 2030 and Hybrid vehicle will be banned in 2038 onwards.

Study shown by Hu (2020) hydrogen might be another alternative than BEV, China already made plans for 2025 and 2030 for hydrogen fuel cell. The government of China sees hydrogen as future fuel. Even though hydrogen could be the future fuel, with the current price of manufacturing the fuel cell and hydrogen it self it can not compete with BEV. Hydrogen fuel cell needs to be cheaper and have a break through technologies to be able to compete against BEV and vehicle with internal combustion engine.

1.1.1 Challenge to Reduce Green House Gas

To achieve greenhouse gases reduction in developing or under developing countries, the ICE automobiles manufacturer needs to do something to reduce the greenhouse gases. There are two ways to reduce it, the first one is to improve the combustion efficiency and the second one is switching to carbon neutral fuel. Recent study shown by Ayompe et al. (2021) and Wahyono Y (2020) for countries like Indonesia and Malaysia, it will be easier to switch to carbon neutral fuel such as biodiesel. Both countries are the major palm oil production in the world (Ayompe et al., 2021). Study shown by Khalid et al. (2017) using palm oil as biodiesel feedstock, considered as one of the best biodiesel feed stock. Palm oil derivatives also considered as one of the best biodiesel feed stock, one of them is waste cooking oil (Priyadarshi & Paul, 2018). Based on the fact mentioned above, it is easier for both countries to switch to biodiesel. As shown on Figure 1.1, using biodiesel will reduce greenhouse gases.

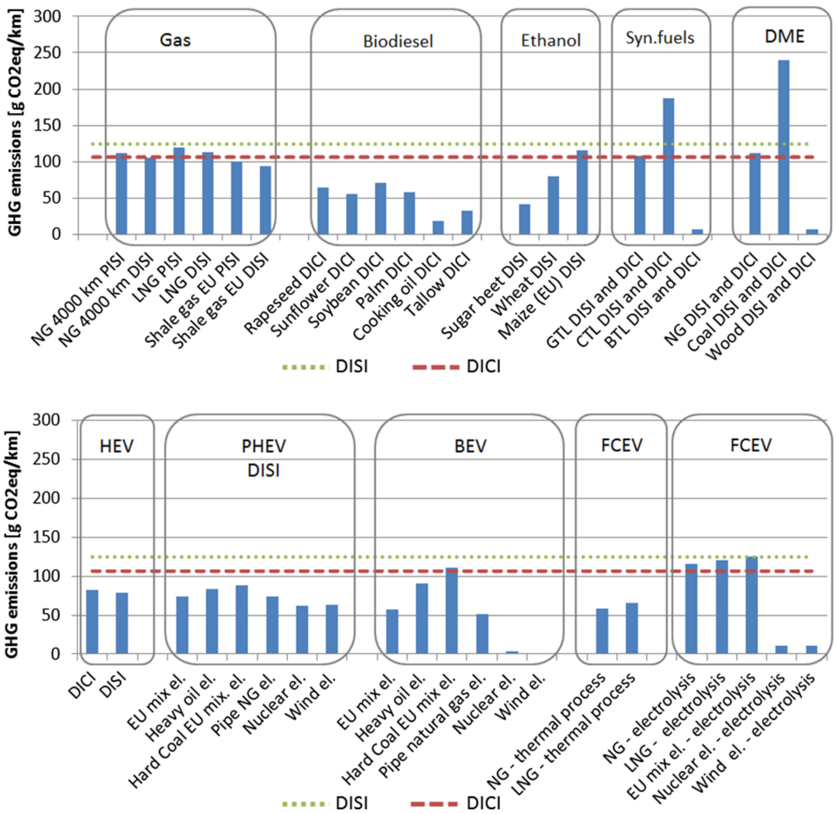

Figure 1.1. GHG emissions comparison (Lešnik et al., 2020).

1.1.2 Biodiesel Challenges

Using biodiesel to reduce greenhouse gases will be beneficial, because diesel engine is widely use in transportation sectors (Fridstrøm & Østli, 2021). Truck, bus and marine vehicle use diesel engine as their main propulsion. Therefore, usage of biodiesel as fuel will reduce greenhouse gases in transportation sector. Studies shown by C H et al. (2020), Abed et al. (2018) and Tziourtzioumis and Stamatelos (2017) shown clear benefits of using lower biodiesel blend as diesel engine fuel. There are clearly some reductions on greenhouse gases but, it might lead to reduce engine power output and tend to increase NO_x emission. Power decrease mainly caused by lower calorific value compared to petroleum diesel. To maximize greenhouse gas reduction in diesel engine, there are several things to do such as using high biodiesel blend fuel and optimized the overall engine performance to reduce power gap between petroleum diesel fuel and biodiesel fuel but still maintain reduction of overall emission.

Study shown by (Setiawan, 2019), using Mitsubishi 4D56 common-rail and biodiesel fuel between B0 to B50 using 100% load. It is clearly seen that higher biodiesel blend, tend to reduce power and torque output, especially on B50. Overall, B50 has the biggest power and torque reduction. B50 has 12.48% power reduction and 9.74% torque reduction.

1.2 Problem Statement

Diesel engine widely use in buses and trucks, recent study already shown several benefits of using biodiesel as diesel engine fuel, there are still some drawbacks of using biodiesel. In example, the power and torque from the engine might decrease as biodiesel blend get higher due to lower calorific value and even though biodiesel reduce CO, HC and CO_2, but NO_x emissions tend to be higher than petroleum diesel when it could be compared. In terms of heat release rate and ignition delay, biodiesel tend to have later ignition delay and lower heat release rate as shown by Azad et al. (2019). From brief literature review, some of the method of preheat fuel, variation of injection timing and injection pressure still use lower biodiesel blend in example they usually use between B20 and B50. Even though it is known that higher biodiesel blend decreasing engine performance, certain country for example Indonesia are pushing to increase biodiesel percentage to B100. Therefore, it is necessary to develop this research with higher biodiesel blend and optimize the performance, combustion and emissions of each biodiesel blend using variation of injection timing, injection pressure and preheat biodiesel fuel using GT-Suite software.

1.3 Purpose Statement

The purpose of this study is to determine the effect of using high biodiesel blend on diesel engines and optimize it with variation of injection timing, injection pressure and preheat biodiesel fuel and perform 1-D modelling simulation with GT-Suite. Optimization is done to get the optimum power and torque but can reduce NO_x emissions as well.

1.4 Research Question

1. How to simulate single cylinder diesel engine performance, combustion and emissions using high biodiesel blend from Palm Oil Methyl Ester?
2. How to improve engine performance, combustion and emissions using high biodiesel blend from Palm Oil Methyl Ester?

1.5 Objectives

OBJ1. To develop a validated single cylinder diesel engine model for the prediction of engine performance, combustion, and emissions.

OBJ2. To improve engine performance, combustion and emissions of high biodiesel blend on diesel engine with variation of injection timing, injection pressure, preheat biodiesel fuel.

1.6 Scope

This research was conducted in a single cylinder diesel engine with B10 and B30 as baseline data. Then a model of a single cylinder diesel engine was developed in 1-D simulation software. The simulation was carried out in GT-Suite, GT-Suite was chosen because it has met international standards.

Simulation was conducted in GT-Suite using B10 and B30 as baseline data and validation for the model. Biodiesel that was used is B50, B70, and B100. These biodiesel blends were chosen because the blend will soon be used in Indonesia. Currently Indonesia is using B30 as the diesel fuel and Indonesian government are ready to implement B40 by 2023. It is also known that Indonesian government are pushing to use B100 in the next 5 years. Palm Oil Methyl Ester (POME) will be used in this research because palm oil is the main biodiesel feedstock in Malaysia and were provided by Malaysia Palm Oil Board. Biodiesel from MPOB has already met the MS 2008: 2008. In the future, palm oil might be substitute with waste cooking oil or other waste oil to avoid food fuel competition.

Performance parameters were brake thermal efficiency, brake specific fuel consumption, brake mean effective pressure, brake power, and brake torque. The combustion parameter was heat rate release. Meanwhile, emissions parameters were CO_2 and NOx. To improve the engine performance, variation of injection timing, injection pressure, preheat biodiesel fuel were used to explore the engine potential. To validate the result of simulation, validation was done by reviewing other papers and journals.

1.7 Expected Project Outcome

This research is expected to overcome several issues of using higher biodiesel blend, especially for blend more than B50. Based on study by Churkunti et al. (2016), Said et al. (2018), Kaya and Kökkülünk (2020), and Lewiski et al. (2017) usage of high biodiesel blend in diesel engines leads to decrease power and torque output, but on the other sides CO_2, HC, and CO is decreasing. Therefore, it is needed to do optimization of diesel engines to have optimum power and torque output while still reducing the overall emissions. Result of this project could bring some idea on developing next generation of diesel engines and might reduce the cost of conducting engine research by doing simulation works.

1.8 Significant of Study

After this research was completed, it was expected to help eliminate diesel engine vehicle users who feel the vehicle is underpowered due to the higher biodiesel blend used for their vehicle so that the implementation of biodiesel can be applied more broadly.

This research does not require or require minimal changes to the components on the engine therefore, it could be easily implemented into the automotive industry. This study will not require any changes toward engine geometrical. One of the reasons is, generally, modern diesel vehicles already use ECUs in managing fuel injection to the combustion chamber. So, there is no need to modify engine components, by merely remapping the ECU it might increase the overall performance and emissions of the vehicle.

With the end of this research, it is also hoped that the use of biofuels as a renewable energy, specifically in Malaysia and Indonesia can be further developed, especially in land transportation and in maritime which use diesel engine.

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