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Performance and Emission Control of Using Steam Injection on Medium-Speed Marine Diesel Engine Running with Biodiesel Fuel

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ABSTRACT

Biodiesel fuel has been categorized as one of the promising renewable energy and at the same time can reduce our dependence on fossil fuels. Yet despite its many advantages, literature studies report that engines running with biodiesel fuel produce slightly less power and higher NOx gas emissions compared to standard diesel fuel. One of the possible ways to reduce NOx gas from marine engines running on biodiesel fuel is by injecting steam water into the air intake engine system. Therefore, this study attempts to investigate the effect of steam injection incorporated with biodiesel fuel on the performance and emissions of marine diesel engines. Experiments were conducted on medium-speed Cummins marine engines using biodiesel blends with concentrations of 10%, 20%, and 30%. Water steam has been injected into the air intake engine system. The results show that the use of steam does not have a significant effect on the torque and power of the marine engine. However, steam injection methods have successfully reduced the emissions of hazardous gases of nitrogen oxide and carbon monoxide by 37.2% and 66.7%, respectively. Furthermore, fuel consumption rate is also more economical as shown by the BSFC value decreasing up to 15.2%. Overall, the steam injection method can compensate for the lack of performance found in biodiesel fuel when used on marine diesel engines.

1. Introduction

Cumulative effects of exhaust emissions from the shipping activities are major contributors to air quality problems. Emissions from marine diesel engines are hazardous which contain nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxides (CO_2) and sulphur oxides (SOx) [1]. In fact, these gases are detrimental to the human health because several health issues may be triggered, such as lung cancer, cardiopulmonary death, bronchitis, and pneumonia. To address this issue, the Marine Pollution Act has limited the global sulphur level from the current 3.5 to 0.5%, effective on 1 January 2020 [2]. Meanwhile the NOx emissions levels were reduced from Tier I to Tier II and Tier III for global and North American Emission Control Area, respectively as shown in Figure 1.

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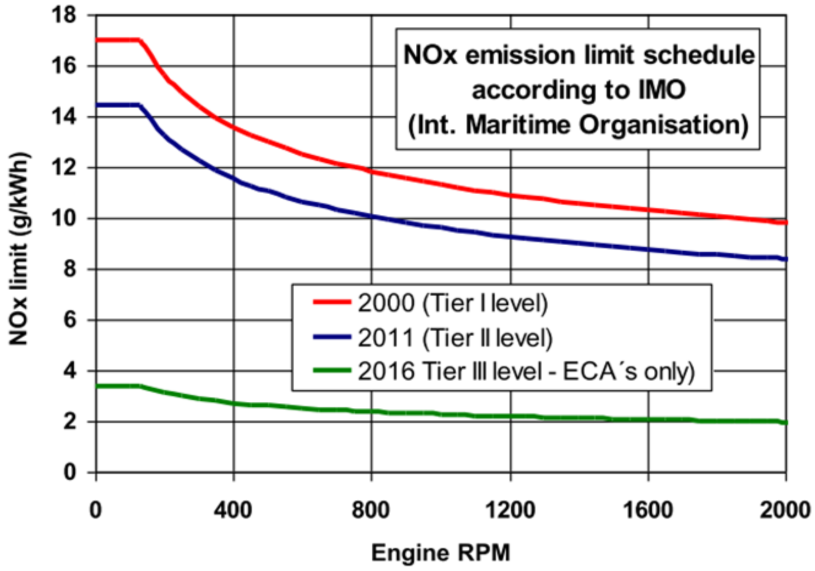

Fig. 1. The limits of NOx emission according to Marine Pollution Act

The increasing number of shipboard emissions and stringent regulations enforcement has encouraged the demands for more viable solutions. The usage of biodiesel fuel appears to be an effective measure in addressing the issue discussed. Biodiesel is a plant-based fuel, renewable, environmentally friendly, biodegradable, non-toxic, oxygenated and has similar properties to diesel fuel [3-6]. Biodiesel fuel is produced by mixing vegetable oil with methyl ester through the transesterification process [7-9]. Biodiesel also produces stable combustion in terms of cyclic variation compared to standard diesel fuel [10]. However, the use of biodiesel fuel contributes to slightly higher in NOx emission and lowers thermal efficiency due to the low energy of biodiesel content [11-14]. Several schemes have been proposed to reduce the discharge of hazardous gases from marine engines particularly NOx emissions, while using biodiesel fuel.

The discovery of post-treatment method such as the Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR) has successfully reduced the NOx emission efficiently, but the cost was very expensive to implement [1]. While the fuel-water emulsion and humid water motor methods are very complicated and adversely affect the condition of the engine cylinder [15]. Another way of reducing NOx emission in marine diesel engine is by humidifying the scavenge line where the warm water is injected and evaporated in the air intake. This technique able to reduced 40% of NOx emission but it requires a large amount of water [16].

One of cheapest and possible solution is by using steam injection. Parlak *et al.,* [17] developed a logical Fuzzy electronic system to control the entry of steam into a single cylinder engine. The steam produced is in superheated form which utilised heat source from the engine exhaust. The eexperiment results showed a decrease in NOx gas and specific fuel consumption by up to 33% and 5% respectively, while engine power increased by 3% [17]. Later, Gonca *et al.,* [18] also studied the effect of steam on a single cylinder diesel engine operating of Miller cycle with 5 and 10 crank angle degree in retard. The authors claim that NO and CO_2 gases have decreased by 48% and 2.2% respectively while emissions from HC and CO have increased by 46% and 34% respectively. Optimal conditions were achieved with 10 crank angle retarding and 30% of steam injection rate [18]. Another experimental research of using steam injection on a single cylinder engine reported that it saves fuel consumption by 6.1% and reduce NOx and CO_2 emissions by 22.4% and 4.3% respectively [19]. Steam injection on Kirloskar single cylinder engine running using soy biodiesel was performed by Manickam *et al.,* [20]. In this study, steam with a temperature of 110 °C and a pressure of 1.5 bar was passed through the engine manifold inlet. The results showed a significant decrease in NOx emission of 30%.

Steam injection also lowers the levels of other gases such as CO, CO_2 and HC as well as saves fuel consumption [20]. Based on the literature review, most of these findings have focused on small engines and there is no discussion on the influence of steam injection on marine engine applications so far. Therefore, this study aims to investigate the effect of steam injection running with biodiesel blends on marine diesel engine performance and emission. The tests have been subjected to various engine operating parameters in medium-speed four-stroke marine diesel engine.

2. Experimental Setup

The engine used for this experimental work was a low compression, medium-speed marine diesel engine; brand Cummins and having rated power of 201 kW. The engine was connected with a 250-kW eddy current dynamometer for measuring torque and load. The details of engine specifications and full engine setup are presented in Table 1 and Figure 2 respectively.

Table 1
Engine specification

Description	Specifications
Brand-Model	Cummins-NT855
Engine type	4 stroke, Inline 6-cylinder
Bore x stroke	139 mm x 152 mm
Displacement volume	14 liters
Compression ratio	14.5
Maximum torque	1068 N.m at 1400 rpm
Rated power	201 kW at 1800 rpm
Brake mean effective pressure	958 kpa
Air intake system	Single-stage turbocharger
Cooling system	Water cooled

Fig. 2. Full setup of marine diesel engine test-rig

The schematic prepared diagram for steam injection method is illustrates in Figure 3. The steam was produced by the steam generator with constant flowrate of 2 liter/hour. It has been channeled through a fine air filter to prevent water droplets before reaching the intake manifold. The air flow rate was measured using Veltron II flow transmitter as shown in Figure 4. A real time data acquisition was performed by interfacing the REO-DEC software from KLas Realtime Systems Ltd, UK with the relevant sensors. The dynamometer and engine demand could be remotely controlled by the REO-DEC systems as shown in Figure 5. The systems have high accuracy of ± 0.01% uncertainty. The engine throttle actuator was connected to the REO-DEC box to obtain the targeted engine speed and torque.

The experiments were run under steady-state conditions at varied engine speeds ranging from 800 to 1600 rpm. The test fuels used were B0, B10, B20 and B30 of palm biodiesel blends. Prior to the test, the engine was warmed up in an idle condition until the temperatures of the cooling water and lubrication oil attained stability. The cooling water was kept between 80–85 °C while the lubricating oil was between 90–100 °C. At each change of test fuel, the fuel lines were drained and the engine was allowed to run for a sufficient time in order to purge the remaining fuel from the previous test. The important engine operating engine parameters such as speed, torque, brake power, brake specific fuel consumption, exhaust temperature and exhaust emissions were measured and calculated accordingly.

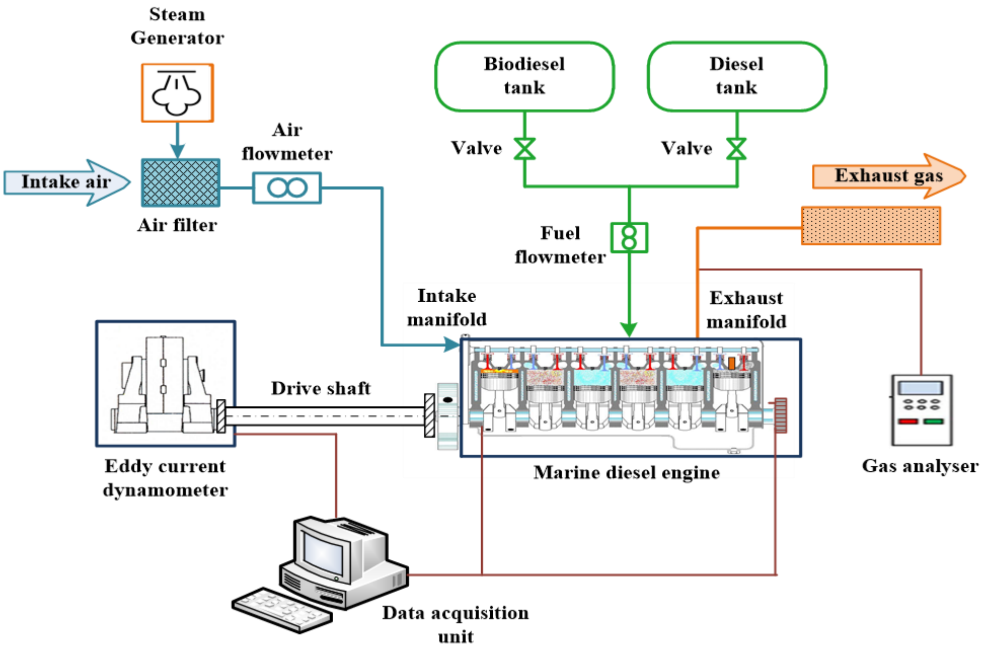

Fig. 3. The schematic diagram for steam injection method

Fig. 4. The Veltron II flow transmitter

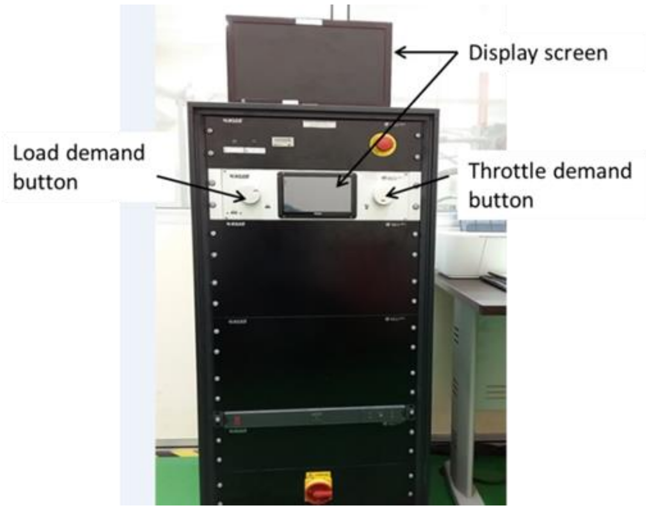

Fig. 5. REO-DCA Data acquisition unit

The test fuels used in this experiment were standard diesel (B0), B10, B20, and B30 biodiesel blend. The biodiesel blends were prepared by mixing the standard diesel with certified EN 14214 palm methyl ester biodiesels based on volumetric basis as listed in Table 2. Detailed specifications of diesel and biodiesel fuels used in this experiment are listed in Table 3.

Table 2
Mixing percentage of the test fuels

Blend sample	Palm biodiesel (Volume %)	Diesel (Volume %)
B0	0	100
B10	10	90
B20	20	80
B30	30	70

The tests were carried out under steady-state condition at full engine loads and various engine speeds ranging from 800 to 1600 rpm. All tests were completed without any modifications on the test engine. Prior to the test, the engine was warmed up in an idle condition until the temperatures of the cooling water and lubrication oil attained stability. The cooling water was kept between 80–85 °C while the lubricating oil was between 90–100 °C.

Table 3
Basic properties of palm biodiesel and diesel fuel [21,22]

Fuel Properties	Unit	Palm biodiesel	Diesel
Density	kg/m^3 at 15 °C	875	825
Kinematic viscosity	mm^2/s at 40 °C	5.66	4.02
Heating value	MJ/kg	42.07	48.26
Flash point	°C	172	70
Pour point	°C	-	15 Max
Sulphated ash	% Mass	< 0.01	-
Total sulphur	mg/kg	1	500 Max
Carbon residue	% Mass	-	0.2 Max
Cetane number	-	62	49 Min
Oxidation stability	Hours at 110 °C	12.6	25 Min
Lubricity	micrometres	-	460 Max

The desired engine parameters such as speeds, brake power, torque, brake specific fuel consumption, exhaust temperature and exhaust gas emissions are measured and calculated accordingly. Exhaust emission parameters were measured by using the KANE AUTO 5-1 gas analyser. The accuracy, range and resolution of the measuring equipment are listed in Table 4. In order to ensure the measurement accuracy, the analyser was sent for calibration before it was used in the experiment. Carbon oxides concentrations were measured using Non-Dispersive Infrared detectors while oxygen and nitrogen oxides concentrations were measured using the principles of electro-chemical cells.

Table 4
Gas analyser measurement specifications

Exhaust gas	Range	Accuracy	Resolution	Method
Carbon monoxide	0–10%	± 0.06%	0.01%	Infrared
Carbon dioxide	0–16%	± 0.5%	0.1%	Infrared
Nitric oxide	0–5000 ppm	± 25 ppm	1 ppm	Fuel cell
Hydrocarbon	0–5000 ppm	± 12 ppm	1 ppm	Infrared

3. Results and Discussions
3.1 Torque

The torque value at difference engine speed with and without the steam injection for the B0, B10, B20 and B30 fuels at full load are shown in Figure 6. The graph trend for all fuels has shown that the torque value is directly proportional to the engine speed up to the optimum point at 1400 rpm and then decreases slightly. At constant load, an increase in engine speed after the optimum point will cause a reduction in the quantity of air intake as well as increase the value of frictional power. The graph appears that the torque performance for test fuels without steam injection is slightly better compared to fuels with the steam injection. However, the change is not significant and there is small percentage decreasing in average of 2.2% when steam injection was applied to the engine systems. The use of biodiesel blends B10, B20 and B30 also did not show significant different of torque value compare to B0 diesel which is between those values and B0.

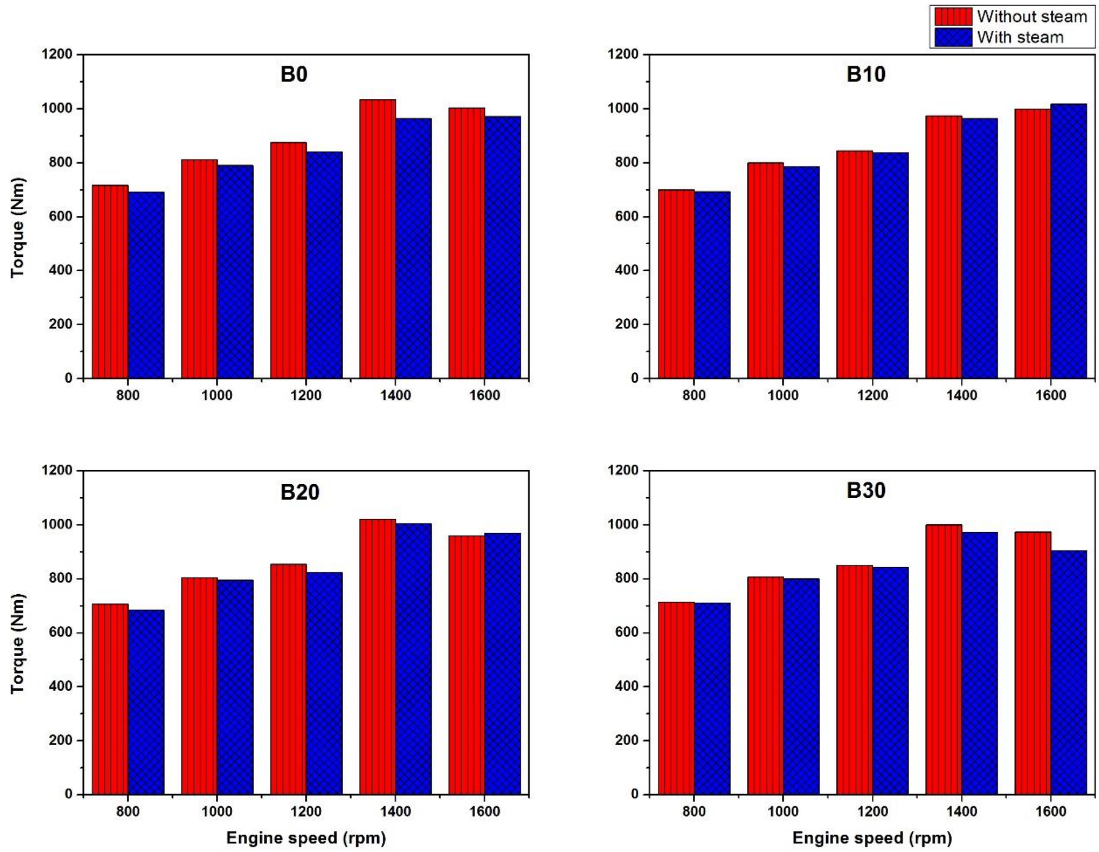

Fig. 6. Torque vs engine speed for B0, B10, B20 and B30 fuels

3.2 Brake Power

Brake power is the measurement of the horsepower of an engine before it loses power caused by the gearbox and other auxiliary components [23]. A device used to load and hold an engine at a desired engine speed also known as brakes dynamometer. Figure 7 illustrates the differences between standard diesel and three blends palm biodiesel in brake power at variable engine speeds with and without the steam injection. The trend of the graph for all fuel type indicates the increasing values of power when running without steam injection compare to steam injection at all speeds. It appears that the brake power performance for standard diesel produced the more power which is 167.2 kW maximum compared to other biodiesel fuel when running with and without steam injection. The output power difference of all the fuel type shows a small percentage decreasing when using steam injection which were between 2.5% to 6.8% (for B0), 0.9% to 1.8% (for B10), 0.9% to 3.7% (for B20) and 0.5% to 7.3% as for B30.

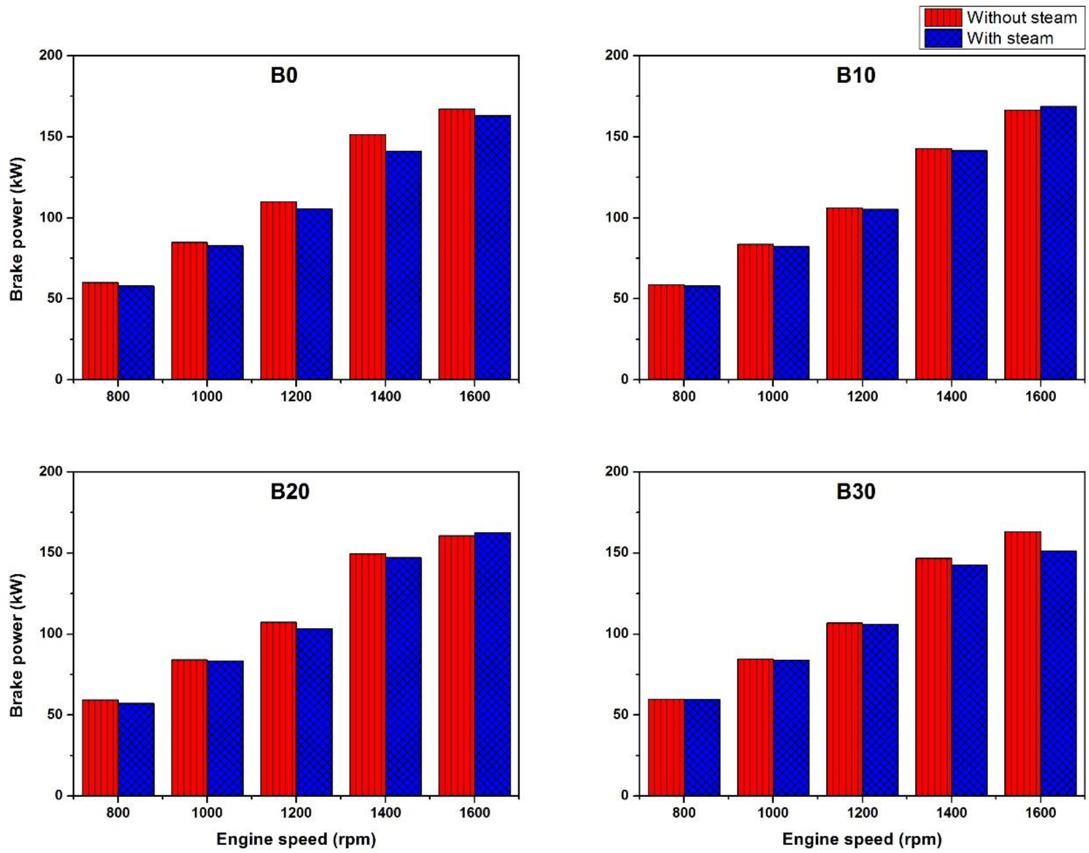

Fig. 7. Brake power vs engine speed for B0, B10, B20 and B30 fuels

3.3 Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is defined as the fuel consumption rate divided by its corresponding engine brake power output. Producing the same amount of work with less usage of fuel means BSFC is at lower rate. Figure 8 shows the BSFC differences between standard diesel fuel and three blends palm biodiesel at variable speeds with and without the steam injection. Generally, an increasing of engine speed reduces the BSFC value of the engine. It appears that the engine running with both standard diesel and palm biodiesel indicates the minimum values of BSFC at 1200 rpm. This is due to the engine ideal speed which means less of fuel will be used at the optimum speed of the engine. The trend of the BSFC graph for all fuels indicates the average decreasing rate of 4.3% when running with the steam injection compare to without steam injection. The BSFC reduction rate for B0 was between (0.3-15.2%), B10 (0.8-10.2%), B20 (0.2-8.5%) and B30 (0.69-7%). These findings agree with several previous results that reported a reduction in the value of BSFC of less than 10% [14,24]. The presence of water steam will lead to a finer atomization of fuel during injection, then enhance the fuel vaporization and mixing processes [19]. This indicates that the use of steam injection results in fuel savings in medium speed-marine diesel engines for all tested fuel.

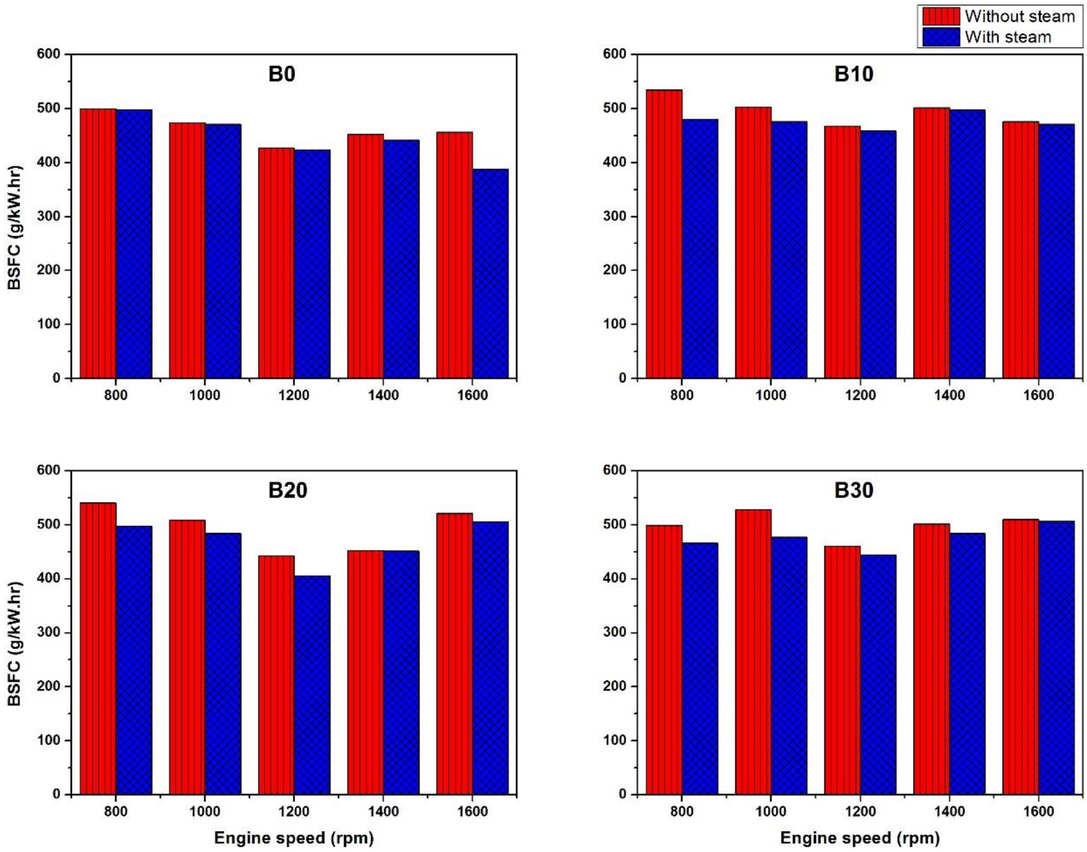

Fig. 8. BSFC vs engine speed for B0, B10, B20 and B30 fuels

3.4 Exhaust Gas Temperature

Engine exhaust gas temperature (EGT) is an important indicator of the cylinder combustion temperature which reflects combustion efficiency and engine exhaust emissions. The variations of EGT of marine diesel engine, when operated with B0, B10, B20 and B30 at full engine loads with and without steam injection are shown in Figure 9. EGT was found to be decreased when steam injection was applied to the fuel. The EGT's percentage difference for all the fuel is reducing which were between 7.3% to 18.1% (for B0), 1.6% to 16.0% (for B10), 2.5% to 16.5% (for B20) and 0.4% to 20.0% as for B30. This indicates that the use of steam injection can lower the combustion temperature of the engine without significantly affecting the output power of the medium speed-marine diesel engine. It also inhibited the decreasing of EGT in average of 11.6% with the application of biodiesel blends compare to standard diesel. This could be high values of biodiesel cetane number minimize the combustion premixing phase in the engine compression stroke.

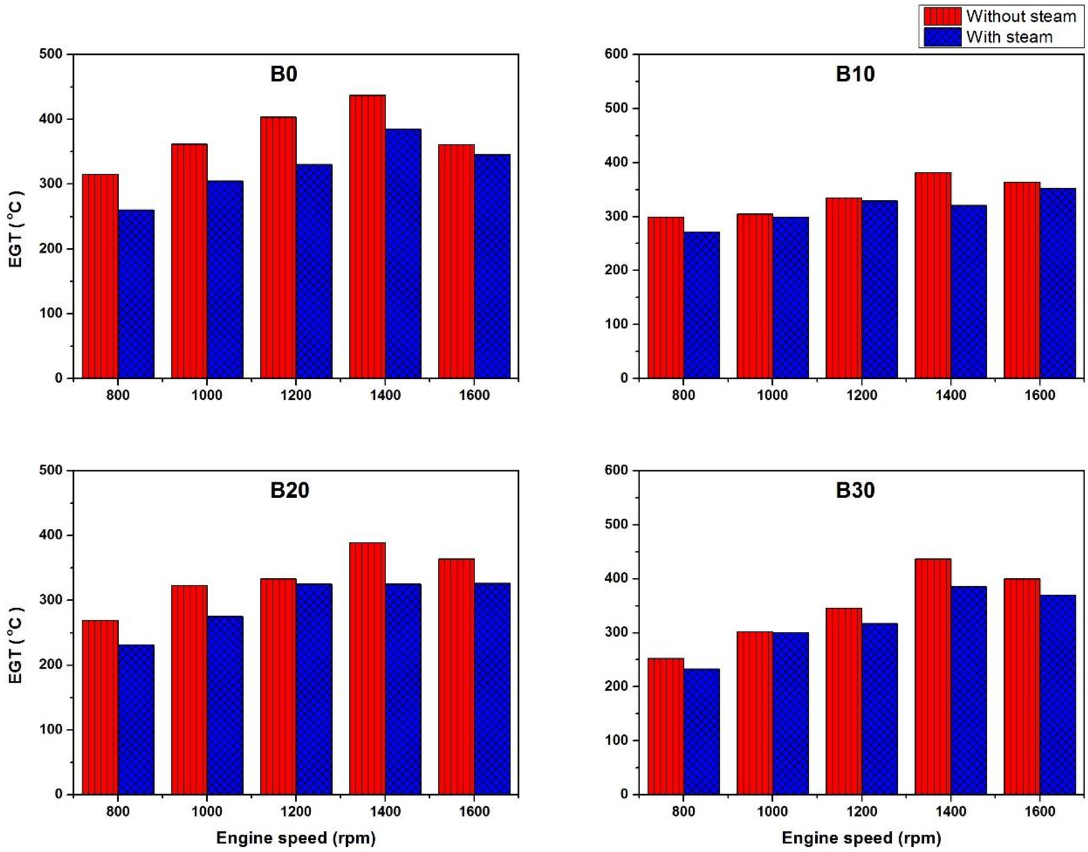

Fig. 9. EGT vs engine speed for B0, B10, B20 and B30 fuels

3.5 Nitrogen Oxide Emissions

Emissions of thermal nitrogen oxides (NOx) are formed as a result of fuel combustion at high temperature in the engine cylinder. NOx engine emissions consist of the elements nitrogen monoxide (NO), nitrogen dioxide (NO_2) and nitrogen oxide (N_2O) [25]. The NOx gas is released by the reaction of nitrogen bound with oxygen during the fuel combustion process. The kinetics of NOx formation involving the reaction of nitrogen and oxygen is described by the Zeldovich theory mechanism as shown in Eq. (1) to Eq. (3). The effects of steam injection on the NOx emissions at full load and different engine speed are shown in Figure 10. In overall, the NOx pattern is seen to increase with the increase of engine speed, where the maximum amount of NOx was 1388.1 ppm at 1600 rpm engine speed. This phenomenon occurs due to more fuel burned at high speeds which are directly proportional to the combustion temperature and NOx emission released. The use of the water element can reduce NOx emissions due to its effect in reducing the adiabatic flame temperature of fuel combustion [27].

$$N_2 + O \leftrightarrow NO + N \tag{1}$$

$$N + O_2 \leftrightarrow NO + O \tag{2}$$

$$N + OH \leftrightarrow NO + H \tag{3}$$

On the other hand, the used of steam injection has reduced the NOx emission rate for all fuels as indicates by 2.7% to 36.9% for B0, 3.6% to 6.9% for B10, 5.7% to 37.2% for B20 and 0.6% to 12.8% as for B30. Lower combustion temperature when operated with steam injection is the main factor of NOx reduction in this study. Steam particles would absorb some heat during the fuel combustion process in turn lowers the combustion temperature.

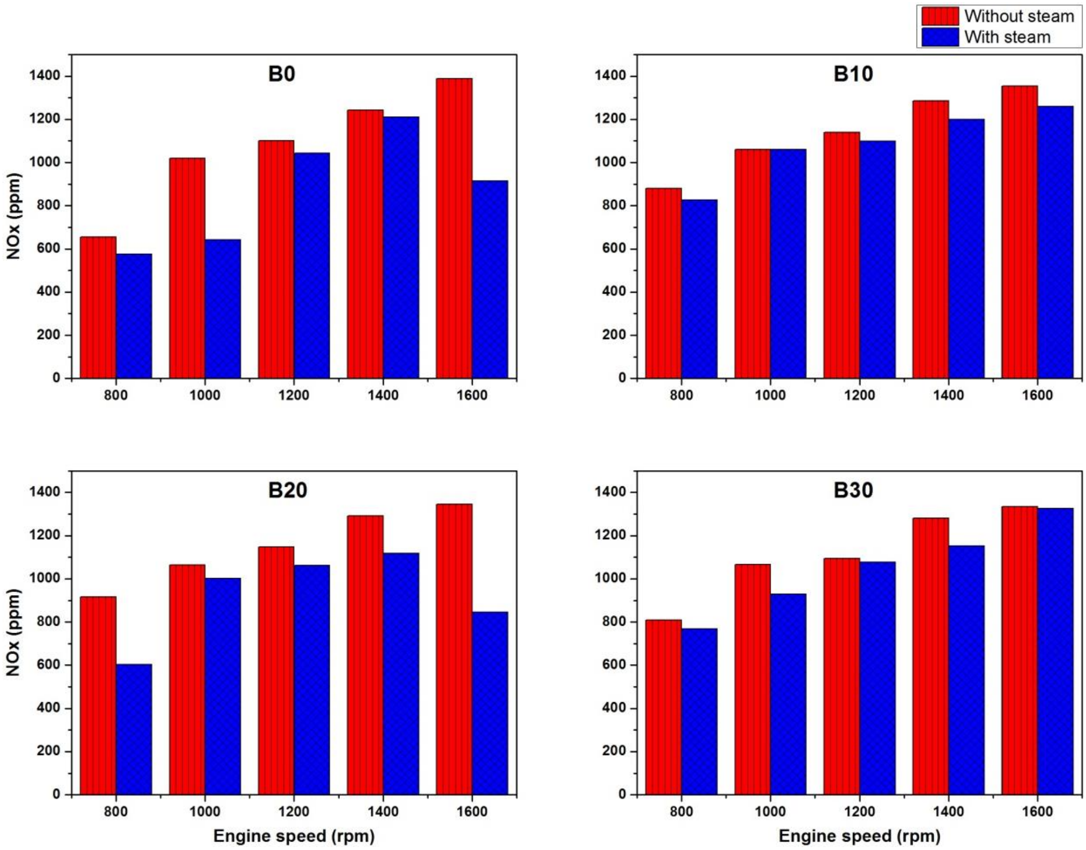

Fig. 10. NOx vs engine speed for B0, B10, B20 and B30 fuels

3.6 Carbon Monoxide

Carbon monoxide (CO) emissions are intermediate combustion products resulting from incomplete combustions of engine fuel. CO emissions are hazardous and detrimental to the human health such as vomiting, nausea, unconscious and death. The effect of steam injection on CO emissions with respect to the engine speeds can be observed from Figure 11. The CO emissions are at lower range for all test fuels. On overall, the presence of steam in the fuel has significantly reduced the emission of CO gases between 20.0-66.7% for all tested fuels. The main reason for this trend is the additional oxygen molecules in steam particles and biodiesel that promotes complete combustion of fuel and therefore reduces the CO emissions. Additionally, a decrease of 20.3% average was also noticed when using biodiesel blend of B0, B10, B20 and B30 compare to standard diesel. Previous findings state that the oxygen element in biodiesel is capable of completing the combustion process in diesel engines [28].

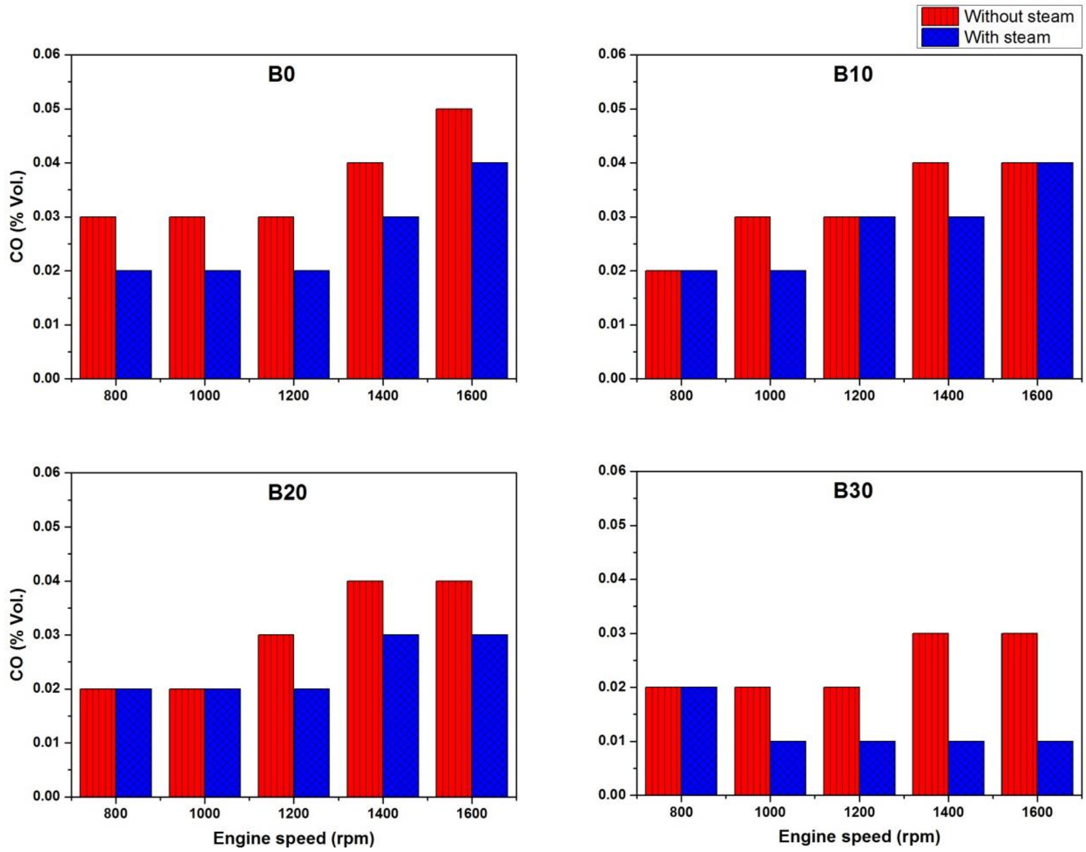

Fig. 11. CO vs engine speed for B0, B10, B20 and B30 fuels

4. Conclusions

The effects of steam injection on the medium-speed marine diesel engine running with biodiesel fuel were investigated in this study. The palm biodiesel blend B10, B20 and B30 were used in the engine testing and the results are compared with the standard diesel (B0) in terms of their performance and emission characteristics. The engine laboratory test was conducted at full load and various engine speeds ranging from 800–1600 rpm. Some conclusions can be drawn from this study as follows

i. The use of steam injection does not give a significant change in torque and power on the marine diesel
ii. The BSFC value was found to be reduced up to 15.2% with the injection of steam into the engine. This can compensate the increase in fuel consumption with the use of biodiesel without neglecting the output power.
iii. The use of steam injection methods contributes to the reduction of nitrogen oxide emissions by a maximum of 37.2%.
iv. This is also in line with the decrease in exhaust engine temperature by 20% with the use of steam injection method.
v. The hazardous emissions of carbon dioxide were reduced significantly 66.7% due additional effects of oxygen molecules in steam particles and biodiesel that promotes complete combustion.

References

[1] Wang, Huaiyu, Huibing Gan, Guanjie Wang, and Guoqiang Zhong. "Emission and performance optimization of marine four-stroke dual-fuel engine based on response surface methodology." *Mathematical Problems in Engineering* 2020 (2020). https://doi.org/10.1155/2020/5268314

[2] Ni, Peiyong, Xiangli Wang, and Hu Li. "A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines." *Fuel* 279 (2020): 118477. https://doi.org/10.1016/j.fuel.2020.118477

[3] Dharma, S. M. H. H., H. H. Masjuki, Hwai Chyuan Ong, A. H. Sebayang, A. S. Silitonga, F. Kusumo, and T. M. I. Mahlia. "Optimization of biodiesel production process for mixed Jatropha curcas-Ceiba pentandra biodiesel using response surface methodology." *Energy Conversion and Management* 115 (2016): 178-190. https://doi.org/10.1016/j.enconman.2016.02.034

[4] Erdiwansyah, Mahidin, Ahmad Fitri Yusop, Muhammad Zaki, Rizalman Mamat, Muhibbuddin, Ratna Eko Sardjono, Nor Azwadi Che Sidik, and Husni Husin. "Investigation of The Effect Biodiesel-Butanol-Water Fuel Blend Pressure on A Single-Cylinder Diesel Engine." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 79, no. 2 (2021): 39-47. https://doi.org/10.37934/arfmts.79.2.3947

[5] Sreenath, Jishnu, and Anand Pai. "Biodiesel: a review on next generation fuels." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 43, no. 1 (2018): 58-66.

[6] Zulkurnai, Fatin Farhanah, Wan Mohd Faizal Wan Mahmood, Norhidayah Mat Taib, and Mohd Radzi Abu Mansor. "Simulation of Combustion Process of Diesel and Ethanol Fuel in Reactivity Controlled Compression Ignition Engine." *CFD Letters* 13, no. 2 (2021): 1-11. https://doi.org/10.37934/cfdl.13.2.111

[7] Maksom, Mohammad Syahadan, Nurul Fitriah Nasir, Norzelawati Asmuin, Muhammad Faqhrurrazi Abd Rahman, and Riyadhthusollehan Khairulfuaad. "Biodiesel Composition Effects on Density and Viscosity of Diesel-Biodiesel Blend: A CFD Study." *CFD Letters* 12, no. 4 (2020): 100-109. https://doi.org/10.37934/cfdl.12.4.100109

[8] Hayder, G., and P. Puniyarasen. "Identification and evaluation of wastes from biodiesel production process." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 3, no. 1 (2016): 21-29.

[9] Putradamazman, Shahrul Azmir Osman, Mas Fawzi, and Siti Hajar Saimi. "A Review of Comparative Characteristic Study on Effect of Biodiesel B20 on Compression Ignition (CI) Engine Performances and Exhaust Emissions." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 62, no. 2 (2019): 221-235.

[10] Noor, Che Wan Mohd, Rizalman Mamat, Obed Ali, Gholamhassan Najafi, and Wan Nur Diyana Mansor. "Cyclic Variation Analysis of Palm Biodiesel Fuel in Low Compression Marine Diesel Engine." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 75, no. 2 (2020): 43-58. https://doi.org/10.37934/arfmts.75.2.4358

[11] Sun, Chunhua, Yu Liu, Xinqi Qiao, Dehao Ju, Qing Tang, Xiaoyuan Fang, and Feng Zhou. "Experimental study of effects of exhaust gas recirculation on combustion, performance, and emissions of DME-biodiesel fueled engine." *Energy* 197 (2020): 117233. https://doi.org/10.1016/j.energy.2020.117233

[12] Puškár, Michal, Melichar Kopas, Dušan Puškár, Ján Lumnitzer, and Eva Faltinová. "Method for reduction of the NOX emissions in marine auxiliary diesel engine using the fuel mixtures containing biodiesel using HCCI combustion." *Marine Pollution Bulletin* 127 (2018): 752-760. https://doi.org/10.1016/j.marpolbul.2017.08.031

[13] How, Heoy Geok, Haji Hassan Masjuki, M. A. Kalam, Yew Heng Teoh, and Hun Guan Chuah. "Effect of Calophyllum Inophyllum biodiesel-diesel blends on combustion, performance, exhaust particulate matter and gaseous emissions in a multi-cylinder diesel engine." *Fuel* 227 (2018): 154-164. https://doi.org/10.1016/j.fuel.2018.04.075

[14] Cesur, Idris. "Investigation of the effects of steam injection on the emissions and performance of a diesel engine using waste chicken oil methyl ester." *Journal of Mechanical Science and Technology* 30, no. 10 (2016): 4773-4779. https://doi.org/10.1007/s12206-016-0949-0

[15] Woodyard, Doug. *Pounder's marine diesel engines and gas turbines*. Butterworth-Heinemann, 2009. https://doi.org/10.1016/B978-0-7506-8984-7.00031-X

[16] Zhu, Sipeng, Bo Hu, Sam Akehurst, Colin Copeland, Andrew Lewis, Hao Yuan, Ian Kennedy, Johan Bernards, and Ciaran Branney. "A review of water injection applied on the internal combustion engine." *Energy Conversion and Management* 184 (2019): 139-158. https://doi.org/10.1016/j.enconman.2019.01.042

[17] Parlak, Adnan, V. Ayhan, Yasin Üst, Bahri Şahin, I. Cesur, B. Boru, and Görkem Kökkülünk. "New method to reduce NOx emissions of diesel engines: electronically controlled steam injection system." *Journal of the Energy Institute* 85, no. 3 (2012): 135-139. https://doi.org/10.1179/1743967112Z.00000000024

[18] Gonca, Guven, Bahri Sahin, Adnan Parlak, Yasin Ust, Vezir Ayhan, İdris Cesur, and Barış Boru. "The effects of steam injection on the performance and emission parameters of a Miller cycle diesel engine." *Energy* 78 (2014): 266-275. https://doi.org/10.1016/j.energy.2014.10.002

[19] Kökkülünk, Görkem, Güven Gonca, Vezir Ayhan, Idris Cesur, and Adnan Parlak. "Theoretical and experimental investigation of diesel engine with steam injection system on performance and emission parameters." *Applied Thermal Engineering* 54, no. 1 (2013): 161-170. https://doi.org/10.1016/j.applthermaleng.2013.01.034

[20] Manickam, Madhavan V., Senthilkumar Duraisamy, Mahalingam Selvaraj, and Piramanandhan Marimuthu. "Effect of steam injection on nox emissions and performance of a single cylinder diesel engine fuelled with soy methyl ester." *Thermal Science* 21, no. 2 (2017): 473-479. https://doi.org/10.2298/TSCI17S2473M
[21] Choke, T. Chung. "Certificate of quality EV Fuel." *ExcelVite Sdn. Bhd*., Perak, Malaysia, 2016.
[22] Petronas Dagangan. "Diesel Euro 2 Specification." *Sabenajadi Sdn. Bhd*. Accessed November 11, 2020. http://www.sabenajadi.com/downloads/DYNAMIC%20DIESEL%20(Euro%202M).pdf.
[23] Noor, Che Wan Mohd, Rizalman Mamat, Wan Mohd Norsani, and Muhamad Mat Noor. "An investigation of using palm biodiesel blend on the performance of a stationary marine diesel engine." *Science & Technology Research Institute For Defence* 9, no. 2 (2016): 86-97.
[24] Teodosio, Luigi, Vincenzo De Bellis, and Fabio Bozza. "Combined effects of valve strategies, compression ratio, water injection, and cooled EGR on the fuel consumption of a small turbocharged VVA spark-ignition engine." *SAE International Journal of Engines* 11, no. 6 (2018): 643-656. https://doi.org/10.4271/2018-01-0854
[25] Wei, Lijiang, Rupeng Cheng, Hongjun Mao, Peng Geng, Yanjie Zhang, and Kun You. "Combustion process and NOx emissions of a marine auxiliary diesel engine fuelled with waste cooking oil biodiesel blends." *Energy* 144 (2018): 73-80. https://doi.org/10.1016/j.energy.2017.12.012
[26] Akude, Yash, Trupti Chavan, Priyanka Temgire, and Aniket More. "Biodiesel as Alternative Fuel for Diesel Engine." *International Journal of Current Engineering and Technology* 6 (2016): 212-214.
[27] Kotob, Mostafa Raafat, Tianfeng Lu, and Seddik S. Wahid. "Experimental Study of Direct Water Injection Effect on NOx Reduction from The Gas Fuel." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 76, no. 3 (2020): 92-108. https://doi.org/10.37934/arfmts.76.3.92108
[28] Hariharan, N., V. Senthil, S. V. Karthic, and M. Krishnamoorthi. "Influence of hydrogen enrichment on the combustion, efficiency and emissions of dual fuel engine." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* (2019): 1-18. https://doi.org/10.1080/15567036.2019.1675816