SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Water-in-Biodiesel Emulsion with Hydroxy (HHO) Gas Fuel Enrichment for Single-Cylinder Diesel Engine Application

Wan Nur Izzati Wan Mahdi[1], Ahmad Muhsin Ithnin[1,*], Wira Jazair Yahya[1], Muhammad Izwan Wan Khairuzzaman[1], Muhammad Adib Abdul Rashid[1]

[1] Advanced Vehicle System (AVS), Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 19 November 2023
Received in revised form 17 March 2024
Accepted 25 March 2024
Available online 15 April 2024

Keywords:
High blending biodiesel; water-in-biodiesel emulsion; hydroxy (HHO); diesel engine

ABSTRACT

The rising issue of the depletion of fossil fuels opened a new pathway to seek alternative fuels to fulfil World Sustainable Development Goals (SDG). The application of high-blending biodiesel is possible however, it causes the diesel engine to perform poorly due to high viscosity, high fuel consumption, and increased NOx emission. To comply with the strict regulation, the idea of combining alternative fuels of high blending biodiesel, water-in-biodiesel emulsion, and hydrogen is seen as possible to solve the issue of each alternative fuel. Therefore, this study focused on the effect of high blending of biodiesel, water-in-biodiesel emulsion with hydroxy (HHO) enrichment in single-cylinder diesel engines on engine performance and exhaust emission. The fuel tested for this study are B10, B50, and an emulsion of B50 with the addition of HHO known as B50H and tested on engine speeds of 2400rpm under various loading conditions of 1kW, 2kW, 3kW, and 4kW. The result showed the B50H showed improvement in Fuel Consumption (FC) by 4%, 5% for Brake Thermal Efficiency (BTE), and reduced Nitrogen oxide (NOx) by 23% compared to B10 fuel. Thus, the combination of high blending of biodiesel, water-in-biodiesel emulsion, and HHO gas successfully improved diesel engine performance and reduced harmful exhaust emissions to promote clean and renewable energy, without depending on current diesel fuel.

1. Introduction

It's undeniable that the world still worries about global warming due to the greenhouse effect from carbon dioxide (CO_2) and the diminishing of natural resources from the increasing demand for fossil fuels [1-3]. The diesel engine is widely used in major industries like transportation, energy generation, and agriculture making this engine still preferable due to it provides more power and ruggedness, however, this engine also exhausted harmful emissions like particulate matter (PM) and Nitrogen Oxides (NOx) which still needs to be improved to reduce pollution in the world. The first sentence should start here [1].

* *Corresponding author.*
E-mail address: ahmadmuhsin@utm.my

https://doi.org/10.37934/arfmts.116.1.130138

Various efforts have been made to reduce the dependency on fossil fuels like petroleum and diesel fuel by shifting to alternative fuels. Various alternative fuels have been introduced in the diesel engine including methanol [4-6], butanol [7,8], dimethyl ether [9-11], nano additive [12-14], and biodiesel [15,16] have been thoroughly studied and used in diesel engines today.

Going higher biodiesel blend for diesel engine applications can be challenging due the several issues which are high kinetic viscosity and low energy content that can cause high fuel consumption and decrease power and torque. Furthermore, biodiesel also can cause increasing in NOx emissions during the combustion of biodiesel fuel [17].

The issue of biodiesel can be solved by introducing the water-in-biodiesel emulsion. The advantage of using a water-in-biodiesel emulsion (W/D emulsion) is the fuel can be used directly to the engine without any modification or retrofitting to the diesel engine itself and a potential strategy for reduced emission and increased engine performance [18]. The emulsion fuel is defined as the mixture of two or more immiscible liquids blended [19] with the addition of surfactant to keep the emulsion stable for certain periods and reduce the interfacial tension between two different immiscible liquids [20-23].

Many studies reported the combustion of W/D emulsion improved BTE and reduced NOx emissions due to the presence of water in the fuel and special occurrences known as micro-explosion phenomena. The water inside the fuel will reduce the peak temperature inside the combustion chamber to reduce the NOx formation [19,22,24]. The demonstration using water-in-diesel emulsion fuel showed that the smoke opacity was drastically reduced compared to diesel fuel use [22,25,26]. However, the problem with using the W/D emulsion is the stability issue which is the need for surfactant to keep the emulsion stabilized, reduced engine performance power, and increasing other pollutants such as CO and unburned hydrocarbon emissions.

Biodiesel also can be improved by blending with other natural gas such as hydrogen. Due to its high flame speed, high diffusivity, low heating value, low ignition energy, wide range of flammability, and short quenching distance, hydrogen is very promising. Additionally, hydrogen has a low heating value [27], which makes it a practical fuel source. Utilizing their carbonless atomic structure can also result in fewer carbon-based emissions [28,29]. Due to its high self-ignition temperature of 535 C, hydrogen cannot be used in a compression ignition engine without a spark plug or glow plug. Compression ignition engines cannot run solely on hydrogen. Hydrogen enrichment improves the combustion process and raises thermal efficiency. Additionally, pre-mixed fuel tends to rise during diffusivity with modest hydrogen enrichment [30,31].

The idea of introducing hydrogen with high-blending biodiesel B50 and water-in-biodiesel emulsion is very intriguing since this research has never been studied and done. Hydrogen gas can be produced through a concept of electrolysis of water and can be generated in real-time through a hydroxy (HHO) gas generator. The generation of hydrogen gas from a hydroxy (HHO) generator eliminates the hydrogen issue which needs a large tank to store the hydrogen gas and the high cost to modify the hydrogen gas to the vehicle needs some retrofitting to the engine itself. Therefore, the objective of this paper is to study the effect of a combination of hydroxy (HHO) gas with high blending biodiesel and water-in-biodiesel emulsion fuel toward engine performance and exhaust emissions compared to B10 and B50 of biodiesel fuel under various loading conditions of 1kW, 2kW, 3kW and 4kW of constant speed 2400rpm. This study also contributes to the body of knowledge in seeking alternative fuels that are sustainable, cleaner energy, and reduce the dependency on current conventional fossil fuels.

2. Methodology
2.1 Emulsion Fuel Preparation

There are three fuels used for this testing which are B10 fuel, B50, and emulsion fuel of B50H with additional HHO gas. The B50 fuel was selected to be tested as the main fuel with higher composition of biodiesel-diesel blending of 50:50, compared to B10 fuel, in which B10 fuel is commercial diesel fuel that can be found in local gas stations. The reason for using high blending biodiesel fuel of B50 was to study the performance of B50 fuel and the combination of B50 fuel with 5% water and HHO gas for engine performance and exhaust emission study. The emulsion fuel of B50H was made as shown in Table 1.

Table 1
Description of the fuel type used

Description	Label
B10 Biodiesel	B10
B50 biodiesel	B50
B50 biodiesel + water (5%) + Span 80 + HHO gas	B50H

For this experiment, B50 biodiesel made from palm oil will be the main fuel in this project. The emulsion fuel contained B50 biodiesel, span 80 (surfactant), and 5% of water, and the composition ratio used is 93% of B50 biodiesel + 2% of Span 80 + 5% of water and mixed by using an overhead stirrer with a speed of 5000rpm for 10 minutes. Meanwhile, for HHO production gas, an HHO generator was used to produce the hydroxy gas (HHO), and the newly made HHO gas was promptly supplied into the engine through the intake manifold. The HHO gas was produced through the concept of water electrolysis and the generator used is a dry type of generator. The electrolyte used for the electrolysis of water is 10% Sodium Hydroxide Solution (NaOH) and the production of HHO gas was set to the maximum current supply. Table 2 showed the specification of the HHO generator used for this testing.

Table 2
Specification of diesel engine

Parameter	Specifications
Model	Yanmar TF90M
Engine Type	4-Stroke, Single Cylinder
Rated Engine Speed (rpm)	2400
Continuous Rating Output (kW)	6.3 kW / 8.5 hp
Fuel Injection System	Direct Injection
Cooling System	Water-Cooled
Displacement, cc	0.493
Bore x Stroke, mm	85 x 87
Compression Ratio	18.0

2.2 Engine Testing

Figure 1 demonstrates the schematic diagram of the engine testing conducted while Table 2 shows the specification of the engine used for this testing. The engine was operated under the same speed of 2400rpm with various loading conditions which are 1kW, 2kW, 3kW, and 4kW. For loading conditions, the engine used was coupled with an eddy current dynamometer for load purposes. The eddy current used in the experiment is a 10kW KLAM RETARDER T10 dynamometer (dyno) which can sustain torque up to 25Nm at 3700rpm. The B10 and B50 were introduced to the engine through the fuel injector and the B50H fuel was introduced by using a fuel injector for emulsion and additional HHO gas through the intake manifold. The HHO gas was produced in real-time from the electrolysis of water using NaOH electrolyte with a concentration of 10% and the current supply for HHO gas was set to maximum. The HHO gas produced flowed into the flow meter and flame arrestor to prevent the backflow of gas. The data measured and collected from this testing were engine performance Brake Thermal Efficiency (BTE), Fuel Consumption (FC), and exhaust emissions of Nitrogen Oxides (NOx), and Carbon Monoxide (CO).

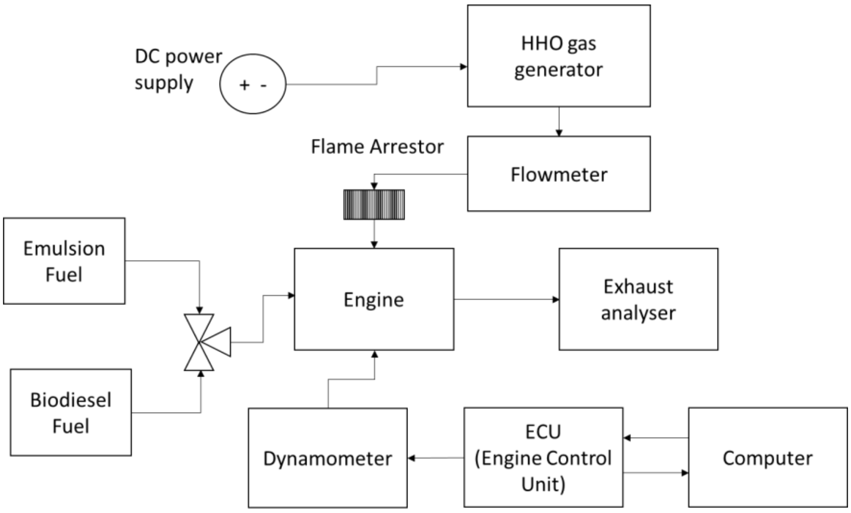

Fig. 1. The Schematic diagram of experimental testing

3. Results and Discussion

3.1 Combustion Performance

3.1.1 Brake thermal efficiency (BTE)

Figure 2 showed the BTE result by B10, B50, and B50H under a constant speed of 2400rpm with various loading conditions. As shown in Figure 2, as the load increases, the BTE for each tested fuel also increases. Notably, the B10, B50, and B50H fuel showed similar patterns for all loading conditions. The B50H has the highest overall efficiency of 23.3% compared to B10 fuel and B50 which is by 22.19% and 22.58% respectively. The emulsion fuel of B50H fuel improved in BTE compared throughout all load conditions due to micro-explosions phenomena [32]. the presence of water in the emulsion fuel puffing and explodes in small fine droplets which enhances more surface area during combustion. Thus, the combustion of fuel inside the combustion chamber becomes more uniform leading to higher BTE in B50H fuel compared to B10 and B50. Compared to both B50 and B50H, the BTE of B50H showed better results due to the addition of HHO gas. The HHO gas consists of hydrogen and oxygen gas. The hydrogen gas has high flammability and more energy content which accelerates to achieve the peak temperature during the combustion process. By promoting faster and more complete combustion, hydrogen contributes to maximizing energy release and utilization within the engine [33]. Thus, the HHO gas helps the B50H to enhance the overall efficiency and performance during the combustion process. The B50H improves BTE by 5.2% than B50 fuel by 1.7% compared to B10 fuel.

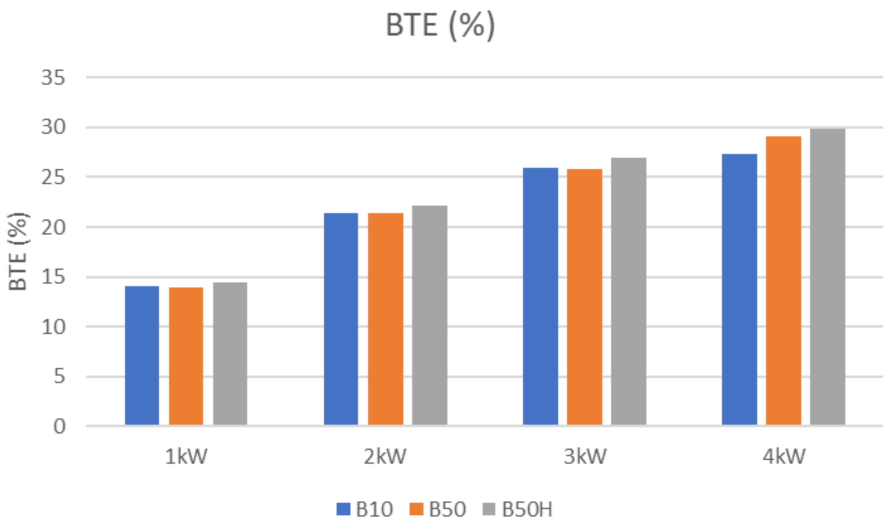

Fig. 2. Brake Thermal Efficiency (BTE)

3.1.2 Fuel consumption

Figure 3 demonstrates the fuel consumption (FC) of B10, B50, and B50H under loading conditions of 1kW, 2kW, 3kW, and 4kW with a constant speed of 2400rpm. As shown in the graph the B50 fuel has the highest fuel consumption at 1kW to 3kW however at 4kW the FC of B50 fuel is reduced compared to B10 fuel. Meanwhile, the B50H showed the lowest FC throughout all loading conditions. The reason for this occurrence was due to the enhancement of micro-explosion with the additional effect of HHO gas during the combustion of B50H fuel. The micro-explosion in the B50H fuel is stronger resulting larger surface area in fragmented small droplets size. More surface area of droplet fuel enhances the better-burning efficiency of B50H fuel during combustion, thus resulting in lower fuel consumption. The HHO enrichment in B50H exhibits better fuel efficiency compared to other fuels of B10 and B50. The HHO gas plays a significant role during the combustion process by rapidly igniting and reaching peak temperatures, providing complete combustion for fuel in the combustion chamber, and utilizing energy released in HHO gas. Thus, the HHO gas facilitates the combustion of B50H fuel to achieve low FC compared to B10 and B50 fuel. The overall FC for B50H is 16.58ml/min while B10 and B50 are 16.9 ml/min and 17.21 ml/min, respectively. The B50H showed better fuel saving by 4% than B50 fuel which increased the fuel consumption by 2% compared to B10 fuel.

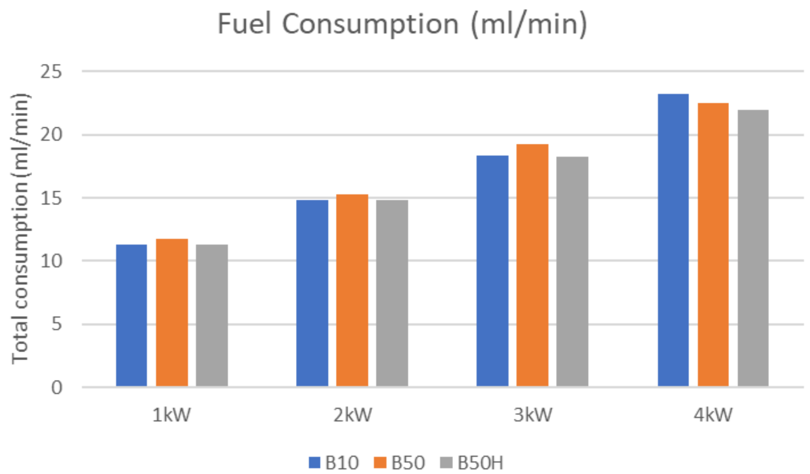

Fig. 3. Fuel Consumption (FC)

3.2 Exhaust Emission
3.2.1 Nitrogen oxide (NOx)

Figure 4 showed the Nitrogen Oxides (NOx) for all tested fuels under constant speed and loading of 0kW to 4kW. The result showed that the B50H fuel has the lowest NOx emissions compared to other fuels with an overall NOx reduction of 254.81ppm compared to B50 and B10 which are 408.55ppm and 395.96ppm respectively. The B50 increased the NOx emission for all loading conditions due to the properties of biodiesel which increased the NOx emission. However, the B50H showed the lowest NOx emission compared to other tested fuels for all loading conditions. This observation was due to the impact of the presence of water in the emulsion fuel of B50H and HHO enrichment. Water alters combustion characteristics, leading to more controlled and efficient combustion and lower NOx emissions. Additionally, the surfactant in the fuel mixture aids in emulsion formation and stability, contributing to NOx reduction. It promotes a homogeneous fuel-air mixture, enhancing combustion and minimizing nitrogen oxide formation. Overall, the B50H showed a NOx reduction of 23.4% than the B50 fuel of 4.5% increments compared to the B10 fuel.

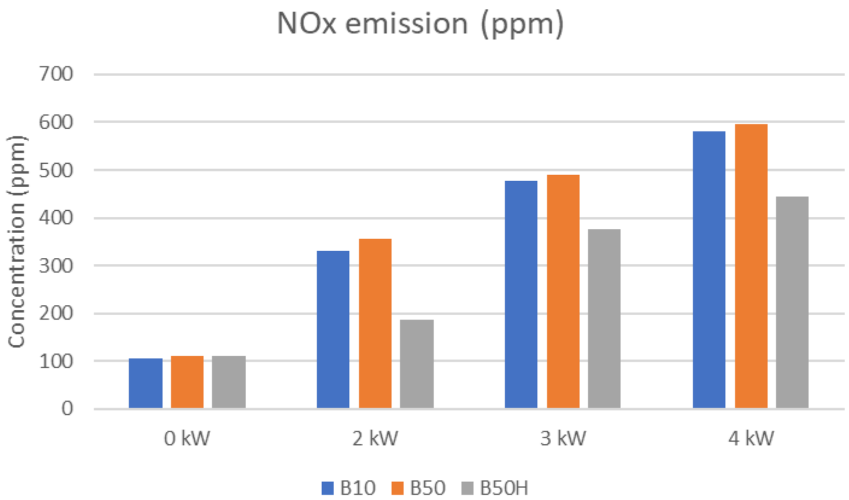

Fig. 4. Nitrogen Oxide (NOx) concentration (ppm)

3.2.2 Carbon monoxide (CO)

Figure 5 showed the Carbon Monoxide (CO) emission for B10, B50, and B50H with a constant speed of 2400rpm under increasing load conditions of 1kW to 4kW. The B50 showed the lowest CO emissions compared to B10 and B50H fuel across all loading conditions. The B50 reduced CO emission compared to other fuels with a concentration of 392.01 ppm from the B10 fuel and B50H fuel. However, the B50H showed the highest CO emission with an overall concentration of 562.86ppm than B10 fuel of 477.27ppm. The increase in CO emission in B50H fuel was due to the presence of water in emulsion fuel. The water embedded inside the emulsion fuel could freeze the temperature inside the combustion chamber which limits the conversion process of CO to be converted to CO_2. Thus the complete combustion was limited to insufficient temperature [34]. As a result, more CO emission formation was recorded for B50H fuel. The B50 improved CO emission by 18% while the B50H increased CO emission by 17% compared to B10 fuel.

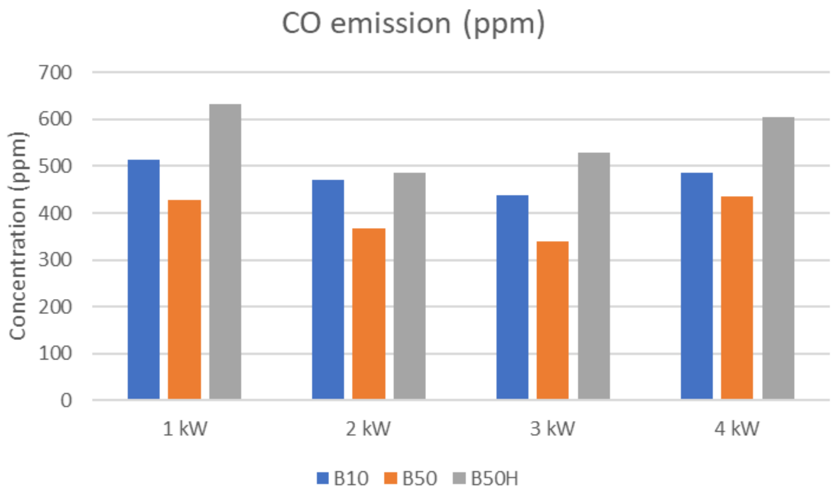

Fig. 5. Carbon Monoxide (CO) concentration (ppm)

4. Conclusions

In conclusion, the combination of sustainable sources like water and HHO in biodiesel emulsion fuel of B50 brings a new finding and benefit as the main source of energy that is very green, greener, and environmentally friendly. The performance and exhaust emission shown by B50H under various loading conditions from 1kW to 4kW are as the following

i. The B50H showed the highest BTE by 23.3% with water and HHO compared to B10 and B50
ii. The FC of B50H recorded the lowest fuel consumption at 16.58ml/min compared to B50 and B10 by 16.9ml/min and 17.21ml/min respectively.
iii. The B50H has an overall reduction of NOx emission by 23.4%, while B50 increased NOx emission by 4.5% compared to B10 fuel.
iv. The CO emission for B50H increased by 17% while B50 improved CO emission by 18% compared to B10 fuel.

Overall, the combination of water with high blending biodiesel of 50% and HHO gas has immense potential to be explored as sustainable and renewable energy in diesel engine applications. Thus, more research works need to be studied for this potential fuel to utilize its full performance.

Acknowledgement
The authors would like to express their gratitude to the Advanced Vehicle System (AVS), Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM) for their support on equipment and financial. The highest appreciation goes to Universiti Teknologi Malaysia for the financial support through a research grant (Q.K130000.3843.22H38).

References
[1] Rehan, Rashid, and Moncef Nehdi. "Carbon dioxide emissions and climate change: policy implications for the cement industry." *Environmental Science & Policy* 8, no. 2 (2005): 105-114. https://doi.org/10.1016/j.envsci.2004.12.006
[2] Oreskes, Naomi. *The scientific consensus on climate change: How do we know we're not wrong?*. Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-65058-6_2
[3] Battin, Tom J., Sebastiaan Luyssaert, Louis A. Kaplan, Anthony K. Aufdenkampe, Andreas Richter, and Lars J. Tranvik. "The boundless carbon cycle." *Nature Geoscience* 2, no. 9 (2009): 598-600. https://doi.org/10.1038/ngeo618

[4] Li, Zhiyong, Yang Wang, Zibin Yin, Zhanbin Gao, Yongjian Wang, and Xudong Zhen. "Parametric study of a single-channel diesel/methanol dual-fuel injector on a diesel engine fueled with directly injected methanol and pilot diesel." *Fuel* 302 (2021): 121156. https://doi.org/10.1016/j.fuel.2021.121156
[5] Wang, Yang, Ge Xiao, Bo Li, Hua Tian, Xianyin Leng, Dongsheng Dong, and Wuqiang Long. "Study on the performance of diesel-methanol diffusion combustion with dual-direct injection system on a high-speed light-duty engine." *Fuel* 317 (2022): 123414. https://doi.org/10.1016/j.fuel.2022.123414
[6] Ahmad, Zeeshan, Ossi Kaario, Cheng Qiang, and Martti Larmi. "Effect of negative valve overlap in a heavy-duty methanol-diesel dual-fuel engine: A pathway to improve efficiency." *Fuel* 317 (2022): 123522. https://doi.org/10.1016/j.fuel.2022.123522
[7] Ma, Qixin, Quanchang Zhang, Zheng Chen, and Jichao Liang. "The energy analysis and performance of heavy-duty diesel engine with n-butanol addition and different coolant temperature." *Fuel* 316 (2022): 123323. https://doi.org/10.1016/j.fuel.2022.123323
[8] Devarajan, Yuvarajan, Dinesh Babu Munuswamy, Bhanu Teja Nalla, Gautam Choubey, Ruby Mishra, and Suresh Vellaiyan. "Experimental analysis of Sterculia foetida biodiesel and butanol blends as a renewable and eco-friendly fuel." *Industrial Crops and Products* 178 (2022): 114612. https://doi.org/10.1016/j.indcrop.2022.114612
[9] Zhu, Qiren, Yichen Zong, Wenbin Yu, Wenming Yang, and Markus Kraft. "Understanding the blending effect of polyoxymethylene dimethyl ethers as additive in a common-rail diesel engine." *Applied Energy* 300 (2021): 117380. https://doi.org/10.1016/j.apenergy.2021.117380
[10] Liu, Junheng, Lejian Wang, Pan Wang, Ping Sun, Haifeng Liu, Zhongwei Meng, Lidong Zhang, and Hongjie Ma. "An overview of polyoxymethylene dimethyl ethers as alternative fuel for compression ignition engines." *Fuel* 318 (2022): 123582. https://doi.org/10.1016/j.fuel.2022.123582
[11] Agarwal, Avinash Kumar, Hardikk Valera, and Nirendra Nath Mustafi. "Di-ethyl ether-diesel blends fuelled off-road tractor engine: Part-II: Unregulated and particulate emission characteristics." *Fuel* 308 (2022): 121973. https://doi.org/10.1016/j.fuel.2021.121973
[12] Oni, Babalola Aisosa, Samuel Eshorame Sanni, David Oyinkepreye Orodu, and Temitope Fred Ogunkunle. "Comparing the effects of Juliflora biodiesel doped with nano-additives on the performance of a compression ignition (CI) engine: Part A." *Energy* 244 (2022): 122635. https://doi.org/10.1016/j.energy.2021.122635
[13] Ge, Shengbo, Kathirvel Brindhadevi, Changlei Xia, Amany Salah Khalifa, Ashraf Elfasakhany, Yuwalee Unpaprom, and Kanda Whangchai. "Performance, combustion and emission characteristics of the CI engine fueled with Botryococcus braunii microalgae with addition of TiO2 nanoparticle." *Fuel* 317 (2022): 121898. https://doi.org/10.1016/j.fuel.2021.121898
[14] Karishma, Shaik Mullan, Upendra Rajak, B. Kiran Naik, Abhishek Dasore, and Ramakrishna Konijeti. "Performance and emission characteristics assessment of compression ignition engine fuelled with the blends of novel antioxidant catechol-daok biodiesel." *Energy* 245 (2022): 123304. https://doi.org/10.1016/j.energy.2022.123304
[15] Ashfaque, Amir, SCV Ramana Murty Naidu, Manoj Kumar, Raj Kumar Yadav, Jasmeet Kaur Sohal, Sheik Hidayatulla Shariff, Anil Singh Yadav, and Abhishek Sharma. "Impact of biodiesel on engine performance and emission." *Materials Today: Proceedings* (2023). https://doi.org/10.1016/j.matpr.2023.07.275
[16] Ramadhas, A. S., S. Jayaraj, and C. J. R. E. Muraleedharan. "Use of vegetable oils as IC engine fuels—a review." *Renewable energy* 29, no. 5 (2004): 727-742. https://doi.org/10.1016/j.renene.2003.09.008
[17] Atabani, Abdelaziz E., Arridina S. Silitonga, Irfan Anjum Badruddin, T. M. I. Mahlia, HHm Masjuki, and Saad Mekhilef. "A comprehensive review on biodiesel as an alternative energy resource and its characteristics." *Renewable and sustainable energy reviews* 16, no. 4 (2012): 2070-2093. https://doi.org/10.1016/j.rser.2012.01.003
[18] Vellaiyan, Suresh. "Recent advancements in water emulsion fuel to explore efficient and cleaner production from various biodiesels: A retrospective review." *Renewable and Sustainable Energy Reviews* 187 (2023): 113704. https://doi.org/10.1016/j.rser.2023.113704
[19] Ithnin, Ahmad Muhsin, Hirofumi Noge, Hasannuddin Abdul Kadir, and Wira Jazair. "An overview of utilizing water-in-diesel emulsion fuel in diesel engine and its potential research study." *Journal of the Energy Institute* 87, no. 4 (2014): 273-288. https://doi.org/10.1016/j.joei.2014.04.002
[20] Li, De-gang, Huang Zhen, Lǔ Xingcai, Zhang Wu-gao, and Yang Jian-Guang. "Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines." *Renewable energy* 30, no. 6 (2005): 967-976. https://doi.org/10.1016/j.renene.2004.07.010
[21] Abu-Qudais, M., O. Haddad, and M. Qudaisat. "The effect of alcohol fumigation on diesel engine performance and emissions." *Energy conversion and management* 41, no. 4 (2000): 389-399. https://doi.org/10.1016/S0196-8904(99)00099-0
[22] Swamy, L. Ranganatha, N. R. Banapurmath, P. A. Harari, T. K. Chandrashekar, B. L. Keerthi, C. Hemanth, S. S. Naveen, Bhaskar B. Katti, and Pratap S. Kulkarni. "Diesel engine performance fuelled with manifold injection of ethanol and

water-in-diesel emulsion blends." *Materials Today: Proceedings* 66 (2022): 1914-1919. https://doi.org/10.1016/j.matpr.2022.05.419

[23] Bharathiraja, M., R. Venkatachalam, A. Murugesan, and N. Tiruvenkadam. "Experimental investigation of a novel alcohol fumigation in a single-cylinder constant speed diesel engine." *International Journal of Ambient Energy* 38, no. 8 (2017): 794-802. https://doi.org/10.1080/01430750.2016.1222950

[24] Selim, Mohamed YE, and Mamdouh T. Ghannam. *Performance and engine roughness of a diesel engine running on stabilized water diesel emulsion*. No. 2007-24-0132. SAE Technical Paper, 2007. https://doi.org/10.4271/2007-24-0132

[25] Park, Jinkyu, and Jungmo Oh. "Study on the characteristics of performance, combustion, and emissions for a diesel water emulsion fuel on a combustion visualization engine and a commercial diesel engine." *Fuel* 311 (2022): 122520. https://doi.org/10.1016/j.fuel.2021.122520

[26] Gopidesi, Radha Krishna, and S. R. Premkartikkumar. "Evaluating the hythane/water diesel emulsion dual fuel diesel engine characteristics at various pilot diesel injection timings." *Materials Today: Proceedings* 80 (2023): 3033-3037. https://doi.org/10.1016/j.matpr.2021.07.127

[27] Uludamar, Erinç, Erdi Tosun, Gökhan Tüccar, Şafak Yıldızhan, Ahmet Çalık, Sefa Yıldırım, Hasan Serin, and Mustafa Özcanlı. "Evaluation of vibration characteristics of a hydroxyl (HHO) gas generator installed diesel engine fuelled with different diesel–biodiesel blends." *International Journal of Hydrogen Energy* 42, no. 36 (2017): 23352-23360. https://doi.org/10.1016/j.ijhydene.2017.01.192

[28] Kopp, Martin, David Coleman, Christoph Stiller, Klaus Scheffer, Jonas Aichinger, and Birgit Scheppat. "Energiepark Mainz: Technical and economic analysis of the worldwide largest Power-to-Gas plant with PEM electrolysis." *International Journal of Hydrogen Energy* 42, no. 19 (2017): 13311-13320. https://doi.org/10.1016/j.ijhydene.2016.12.145

[29] Yao, Mingfa, Hu Wang, Zunqing Zheng, and Yan Yue. "Experimental study of n-butanol additive and multi-injection on HD diesel engine performance and emissions." *Fuel* 89, no. 9 (2010): 2191-2201. https://doi.org/10.1016/j.fuel.2010.04.008

[30] An, H., W. M. Yang, A. Maghbouli, J. Li, S. K. Chou, K. J. Chua, J. X. Wang, and L. Li. "Numerical investigation on the combustion and emission characteristics of a hydrogen assisted biodiesel combustion in a diesel engine." *Fuel* 120 (2014): 186-194. https://doi.org/10.1016/j.fuel.2013.12.021

[31] Ozcanli, Mustafa, Mustafa Atakan Akar, Ahmet Calik, and Hasan Serin. "Using HHO (Hydroxy) and hydrogen enriched castor oil biodiesel in compression ignition engine." *International Journal of Hydrogen Energy* 42, no. 36 (2017): 23366-23372. https://doi.org/10.1016/j.ijhydene.2017.01.091

[32] Mondal, Pijush Kanti, and Bijan Kumar Mandal. "Optimization of water-emulsified diesel preparation and comparison of mechanical homogenization and ultrasonic dispersion methods to study CI engine performances." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45, no. 3 (2023): 6566-6595. https://doi.org/10.1080/15567036.2019.1675811

[33] Baltacioglu, Mustafa Kaan, Hüseyin Turan Arat, Mustafa Özcanli, and Kadir Aydin. "Experimental comparison of pure hydrogen and HHO (hydroxy) enriched biodiesel (B10) fuel in a commercial diesel engine." *International Journal of Hydrogen Energy* 41, no. 19 (2016): 8347-8353. https://doi.org/10.1016/j.ijhydene.2015.11.185

[34] Mazlan, Nurul Aiyshah, Wira Jazair Yahya, Ahmad Muhsin Ithnin, A. K. Hasannuddin, Nur Atiqah Ramlan, Dhani Avianto Sugeng, AR Muhammad Adib, Tsuyoshi Koga, Rizalman Mamat, and Nor Azwadi Che Sidik. "Effects of different water percentages in non-surfactant emulsion fuel on performance and exhaust emissions of a light-duty truck." *Journal of cleaner production* 179 (2018): 559-566. https://doi.org/10.1016/j.jclepro.2018.01.143