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Evaluation of Water-in-Diesel Emulsion Fuel in Compression Ignition Engines: Effects, Advantages, and Drawbacks

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Abstract

The reduction of pollutants released from diesel engines is one of the major challenges that scientists are trying to overcome. Some emission control techniques are developed for this purpose. The utilization of Water-in-Diesel Emulsion (WiDE) fuel is an efficient method for emission reduction with no need for any additional engine modification. Especially, simultaneous reduction effect on nitrogen oxides (NOx) and particulate matter (PM) emissions is the most remarkable side of WiDE. Another important phenomenon that emerged when WiDE combustion is micro-explosion which causes to improvement in combustion efficiency. In this study, diesel-water emulsion fuels, their effects on diesel engine performance and emissions, and advantages and disadvantages are reviewed and revealed.

Keywords: Diesel Engine, Emulsion Fuel, Water-in-Diesel.

1. Introduction

The diesel engine was invented and patented by German engineer Rudolf Diesel, at the end of the 1800s. These engines are also called as compression ignition engines referring to their working principle of them as combustion is initiated with an injection of fuel into compressed air. Compression ignition engines which have notable fame for being one of the most efficient ways of power generation have commonly been used in various areas such as transportation and power plants. It is not surprising that they are used so often since they have superior characteristics over spark ignition engines. Being thermally efficient since they allow engine operation with higher compression ratios, high torque levels, and power-to-weight ratios can be sequenced as several advantages of them.

Although petro-diesel has met the main energy requirement for goods carriage and the heavy vehicle sector, it exhibits poor environmental performance. Combusted diesel fuel emits high levels of carbon dioxide (CO_2), nitrogen oxides (NO_x), and particulate matter (PM) which creates health problems for living beings and environmental concerns [1]. If no precautions are taken, all these pollutants will seriously trigger depletion of the ozone layer, acid rains, greenhouse effect, and global warming and these all will result in catastrophic consequences [2]. Recently, strict emission regulations have forced engine manufacturers to produce engines with lower emission levels. Generally, engine modification, fuel modification, and treatment of exhaust gases are the major techniques for emission reduction [3]. Diesel engines release considerable amounts of NO_x and PM as combustion products. When the temperature inside the combustion chamber reaches values above 1600 °C, nitrogen starts to react with oxygen in the air, and NO_x emissions occur. It can be said that NO_x formation highly depends on temperature. On the other hand, the accumulation of partially burned fuel and oil is the main reason for the formation of PM [4]. Both two emissions have detrimental effects on human health and the environment. NO_x triggers acid rain and smog formation. Besides that, when someone is exposed to NO_x for a long period of time, respiratory and heart diseases may happen [5]. As NO_x, exposure to PM has also adverse effects on human health.

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Respiratory and heart problems may occur, especially the diameter of PM is less than 10 μm [6]. Therefore, there is a great effort to reduce NO_x and PM emissions in diesel engines in order to get rid of these harmful effects. Unfortunately, simultaneous reduction of these two emissions is very difficult. Conventional methods such as the utilization of biodiesel and fuel additives, catalytic converters, and exhaust gas recirculation systems generally don't allow a reduction in NO_x and PM together [7–9]. It is a well-known phenomenon from the obtained results of performed studies that the method which reduces the one increases the other one.

Fuel modification is one of the emission reduction techniques. Various additives, biofuels, and water can be evaluated as fuel modifiers [10]. Although the idea of water induction into the engine seems interesting, it is an efficient method to reduce emissions (NO_x and PM simultaneously) and it can commonly be achieved in three ways. These are fumigation through the intake manifold, direct water injection into the combustion chamber, and diesel-water emulsion fuel. Intake manifold fumigation and water injection into the combustion chamber require some engine modification to be used whereas no need to modify any engine design with diesel-water emulsion fuel [11,12]. It means that diesel-water emulsified fuels can directly be utilized in engines. On the other hand, water emulsification not only contributes to a reduction of released pollutants but also improves engine performance and thermal efficiency. Micro-explosion phenomenon which leads to further atomization of fuel in order to obtain more complete combustion in the cylinder is the major factor of performance enhancement [13,14].

Most of the reviews on water-emulsified fuels have focused on the performance and emission responses of the engines. Although most of the studies express the reduction of NOx and PM emissions, there are inconsistent results on the other parameters. Therefore, this paper aimed to explain the different results obtained with their reasons for performance and emission parameters. Besides that, certain advantages, drawbacks, and limitations of the water emulsified fuels were also evaluated in order to guide the researchers who will intend to study water emulsified fuels.

2. Water Emulsified Fuel and Micro-Explosion Phenomenon

Emulsions are mixtures prepared by blending two or more liquids that do not naturally mix with each other in the presence of a chemical agent called surface-active agent (surfactant) material. The intent of surfactant utilization is to decrease interfacial tension between immiscible liquids and to obtain stable blended forms of emulsions [15]. In an emulsion, one of the liquids remains as dispersed droplets (dispersed phase) in the other liquid called as the continuous phase. Basically, emulsions are termed according to dispersed and continuous phases as oil-in-water (O/W) and water-in-oil (W/O). In O/W, the dispersed phase is oil and the continuous phase is water whereas phases vice versa in W/O [16]. Figure 1 schematically showed two emulsion types mentioned above. In diesel engine applications, the W/O type is preferred instead of O/W in order to eliminate direct contact of water with engine parts which can cause impairment in engine operation [16,17].

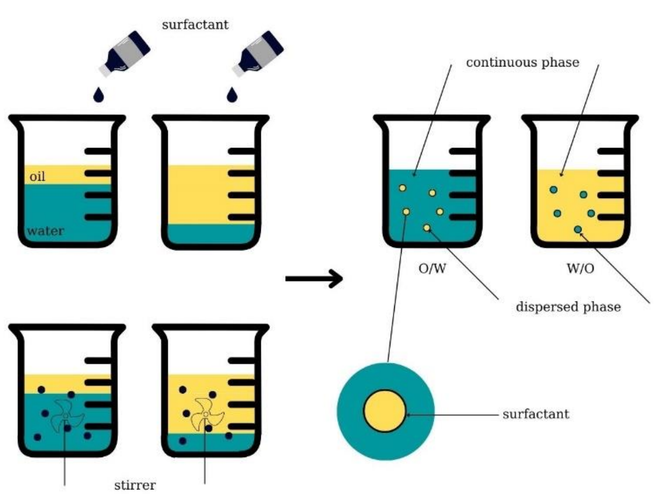

Figure 1. O/W and W/O emulsions

The difference between the boiling points of diesel fuel and water leads to the micro-explosion phenomenon. Water droplets suspended in diesel fuel pass from the liquid phase to the gas phase suddenly before diesel fuel since it has a lower boiling point when the temperature rises. This evaporation process occurs very fast as an explosion of water droplets that causes to split of diesel fuel droplets. Atomized fuel particles through injection are exposed to further disintegration called as secondary atomization. It is clear that there will be an improvement in combustion since the surface area/volume ratio of fuel is increased by micro-explosion [18,19]

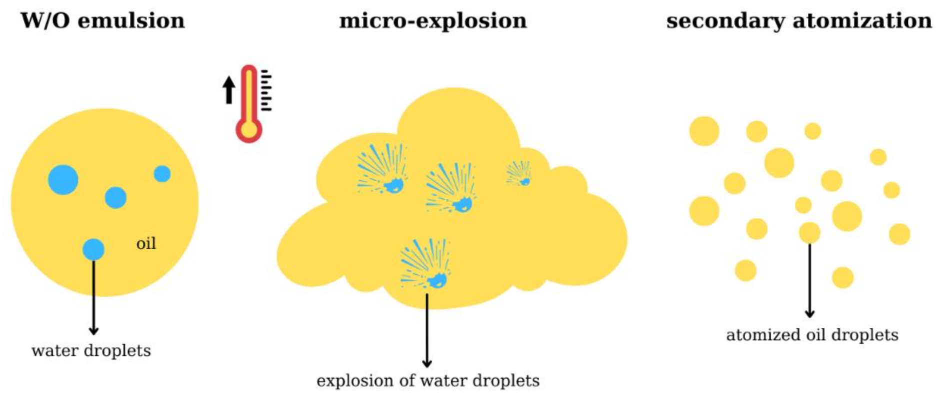

Figure 2. Micro-explosion phenomenon

3. Effects, Advantages, and Drawbacks of Water-in-Diesel Emulsion (WiDE) Fuel

Although the idea of water addition to diesel fuel appears a bit strange, it can provide notable improvements in performance and emission values, especially when applied with the right dosages and the right methods such as emulsification. In fact, the fundamental reason behind the utilization of WiDE is environmental concerns. It seriously contributes to reducing harmful exhaust emissions and this effect is very valuable for diesel engine studies.

The most important and featured term that researchers who worked WiDE for diesel engine applications is micro-explosion. They generally associate the consequences obtained from experimental engine works with this phenomenon. As shown in Figure 2, dispersed water droplets in diesel fuel realize local explosions first depending on the difference in boiling points of the liquids. The greatest effect created by micro explosions is to cause secondary atomization of fuel. Further atomization of fuel leads to obtaining a better distribution of fuel in the combustion chamber which means improved air-fuel mixing and more complete combustion [20]. Complete combustion due to micro-explosion can help to release less PM emission. On the other hand, NO_x emissions tend to fall down also. Since NO_x starts to appear at elevated temperatures in the cylinder (~ above 1600 ^oC) decreasing temperature is very crucial in order to slow down the NO_x formation. The high heat extraction capacity of water due to the higher latent heat of vaporization can decline NO_x by decreasing the temperature in the cylinder [21]. Most of the researchers emphasize that the simultaneous reduction of NO_x and PM with no engine modification requirement is the most notable advantage of WiDE utilization [22–25].

There is a strong consensus that emerged among researchers on NO_x and PM emission reduction with the use of WiDE. Unfortunately, it could not be achieved neither in other emissions nor in performance parameters.

Hasannuddin et al. (2016) and Kruczyński et al. (2018) stated that carbon monoxide (CO) was increased at low load conditions when the engine was operated with WiDE since water lead to reduce the combustion temperature and lessened time for oxygenation of CO, dependently. On the other hand, CO was improved since the temperature is high enough to oxidize CO molecules at higher load conditions [26,27]. According to Kumar et al. (2019) reduction or increasing levels of CO can be explained and evaluated by the combined effects of enhanced combustion by micro-explosion and combustion temperature reduction due to water. In their study, they lowered CO emission by use of WiDE and associated these outcomes with improved combustion due to micro-explosion occurred which resulted in better air-fuel mixing [28]. Bidita et al. (2014) also revealed CO improvement with WiDE utilization. The results of this study indicated that the combustion efficiency was increased with both micro-explosions which trigger better mixture formation and increased oxygen availability due to water. This fact caused to obtain lower CO levels [29].

There are also different results and discussions on the performance outcomes of diesel engines. Abu-Zaid (2004) obtained torque increment from the experimental studies when the engine was fueled with WiDE. He explained this torque increment with the additional force acting on the piston generated by water steam in the chamber [30]. Abdurahman et al., 2016 have obtained similar results for torque. When WiDE was fired in the combustion chamber, water changed phase suddenly from liquid to steam (micro-explosions) and combustion occurred more efficiently. Besides that, the lowered interfacial tension between fuel and water led to obtaining finer atomization during the injection. This caused to obtained improved combustion efficiency and torque increment also [31]. Contrary to these comments, Hoseini and Sobati (2021) obtained torque reduction with WiDE usage. They evaluated that the decrement in the calorific value of fuel with water addition was responsible for this reduction [32]. Seifi et al. (2016) related the torque reduction with increased percentages of water in emulsion with reaching higher pressure levels on the piston due to steam during the compression process [33].

Different opinions have been reported on the effect of water on specific fuel consumption as a performance parameter. Alahmer (2013) observed an increment, especially at higher speeds, in brake-specific fuel consumption (BSFC). He supported this experimental result with a displacement of some diesel fuel with water in the emulsion which means that amount of diesel fuel per volume is lessened in the emulsion [34]. Dhahad et al. (2019) related BSFC increment compared to ultra-low sulfur diesel with a lower calorific value of water emulsion fuel [35]. According to the study by Vellaiyan and Amirthagadeswaran (2016) reduction in BSFC was observed due to better air-fuel mixing achieved by micro-explosion [36]. Ithnin et al., (2018) also observed a reduction of BSFC with emulsified fuel. They have attributed this situation to increased combustion efficiency due to the micro-explosion phenomenon [37].

One of the big challenges in front of WiDE utilization is the stability problem. The stability of an emulsion can be characterized by the elapsed time for the separation of two liquids. The change of emulsion stability highly affects the emulsion properties. Emulsification time and method, water amount, diesel fuel viscosity, surfactant dosage, emulsification temperature, and mixing speed affects the stability of WiDE crucially [38,39]. Researchers must determine the optimum values of the above parameters in order to keep emulsions stable for long times with no separation of water and fuel.

Other issues that may arise with the addition of water to the fuel are possible corrosion problems in the fuel supplying system and combustion problems which will cause a fault in engine operation and incomplete combustion. These adverse effects can be lessened by the use of W/O type instead of O/W type in order to avoid more direct water contact with engine parts [17,40].

Surfactant material which lowers the surface tension between two immiscible liquids to generate stable blends may also cause some problems. It should not have any effect on the burning characteristics of emulsions and should not create soot when burned. Chemically stable, with no reaction with other emulsion components, non-toxic and costly effective are the desired properties for surfactants. Less corrosion, anti-freezing, and better lubrication properties can be provided by using non-ionic surfactants [41,42].

4. Conclusions

In this study, the recent progress of water emulsified fuels, which is one of the emission reduction techniques in diesel engines, was evaluated by compiling the studies in the literature. The following conclusions have been drawn in light of the findings obtained regarding this method, which has become more important recently due to the fact that it does not require any engine modification.

- In all the studies examined, it was concluded that PM and NO_x decreased together and a consensus was reached on this issue. This improvement cannot be achieved with other emission control methods.
- When the studies are evaluated in terms of CO emission, torque, and BSFC performances, it is seen that different findings with positive or negative effects are obtained.
- The stability problem, which is expressed as the primary difficulty in the use of WiDE, can be minimized by determining the correct WiDE production methods and detailed analysis of the parameters in this process.
- Since water is a corrosive material, it can cause corrosion in the fuel lines and the engine, it would be appropriate to take preventive measures during production.

- Correct selection of the surfactant material that provides the formation of WiDE fuels and conducting innovative studies on it are among the topics recommended to be studied in the future. In this respect, it should be ensured that the surfactant does not create different harmful emissions in the fuel. In addition, the fuel cost of the material should not cause an increase in a way that will affect its use.
- Lots of the studies in the literature were performed experimentally. As a recommendation for future studies, numerical studies can be suggested. Once the experimental works are validated with numerical studies, costly and time-consuming laboratory works can easily be performed parametrically by computers and software.

References

[1] Bello, Y.H., Ookawara, S.A., Ahmed, M.A., El-Khouly, M.A., Elmehasseb, I.M., El-Shafai, N.M., et al., (2020). Investigating the engine performance, emissions and soot characteristics of CI engine fueled with diesel fuel loaded with graphene oxide-titanium dioxide nanocomposites. Fuel. 269(January): 117436. doi: 10.1016/j.fuel.2020.117436.

[2] Mohamed Y. E. Selim., Mamdouh T. Ghannam., Adel M. M. Hussein., (2015). Physical-Chemical Properties of Water-in-Diesel Fuel Emulsions. International Journal of Petroleum Technology. 2(2): 45–52. doi: 10.15377/2409-787x.2015.02.02.2.

[3] Basha, J.S., Anand, R.B., (2011). An experimental study in a CI engine using nanoadditive blended water-diesel emulsion fuel. International Journal of Green Energy. 8(3): 332–48. doi: 10.1080/15435075.2011.557844.

[4] Reşitoǧlu, I.A., Altinişik, K., Keskin, A., (2015). The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems. Clean Technologies and Environmental Policy. 17(1): 15–27. doi: 10.1007/s10098-014-0793-9.

[5] Ogunkunle, O., Ahmed, N.A., (2021). Overview of Biodiesel Combustion in Mitigating the Adverse Impacts of Engine Emissions on the Sustainable Human–Environment Scenario. Sustainability. 13(10): 5465. doi: 10.3390/su13105465.

[6] Kim, M.K., Park, D., Kim, M., Heo, J., Park, S., Chong, H., (2021). The characteristics and distribution of chemical components in particulate matter emissions from diesel locomotives. Atmosphere. 12(1): 1–17. doi: 10.3390/atmos12010070.

[7] Serrano, J., Jiménez-Espadafor, F.J., Lora, A., Modesto-López, L., Gañán-Calvo, A., López-Serrano, J., (2019). Experimental analysis of NOx reduction through water addition and comparison with exhaust gas recycling. Energy. 168(x): 737–52. doi: 10.1016/j.energy.2018.11.136.

[8] Chen, Z., Wang, L., Wang, X., Chen, H., Geng, L., Gao, N., (2022). Experimental study on the effect of water port injection on the combustion and emission characteristics of diesel/methane dual-fuel engines. Fuel. 312(December 2021): 122950. doi: 10.1016/j.fuel.2021.122950.

[9] Vellaiyan, S., Amirthagadeswaran, K.S., Vijayakumar, S., (2017). Combustion of stable water-in-diesel emulsion fuel and performance assessment. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. 39(5): 505–13. doi: 10.1080/15567036.2016.1233304.

[10] Sartomo, A., Santoso, B., Muraza, O., (2020). Recent progress on mixing technology for water-emulsion fuel: A review. Energy Conversion and Management. 213(February): 112817. doi: 10.1016/j.enconman.2020.112817.

[11] Kegl, B., Lesnik, L., (2019). Influence of Water/Diesel Emulsified Fuel on Diesel Engine Characteristics. Thermal Science. 23: 1745–55. doi: 10.2298/TSCI190222319K

[12] Rajammagari, H.V., Mohmad, M.W., (2020). The effect of mixed nanoadditive-blended diesel–water emulsion on the performance, combustion, and emission characteristics of a DI diesel engine. Heat Transfer. 49(6): 3531–48. doi: 10.1002/htj.21786.

[13] Hossain, A.K., Refahtalab, P., Omran, A., Smith, D.I., Davies, P.A., (2020). An experimental study on performance and emission characteristics of an IDI diesel engine operating with neat oil-diesel blend emulsion. Renewable Energy. 146: 1041–50. doi: 10.1016/j.renene.2019.06.162.

[14] Hoseini, S.S., Sobati, M.A., (2019). Performance and emission characteristics of a diesel engine operating on different water in diesel emulsion fuels: optimization using response surface methodology (RSM). Frontiers in Energy. 13(4): 636–57. doi: 10.1007/s11708-019-0646-7.

[15] Raheman, H., Kumari, S., (2014). Combustion characteristics and emissions of a compression ignition engine using emulsified jatropha biodiesel blend. Biosystems Engineering. 123(x): 29–39. doi: 10.1016/j.biosystemseng.2014.05.001.

[16] Ithnin, A.M., Noge, H., Kadir, H.A., Jazair, W., (2014). An overview of utilizing water-in-diesel emulsion fuel in diesel engine and its potential research study. Journal of the Energy Institute. 87(4): 273–88. doi: 10.1016/j.joei.2014.04.002.

[17] Vellaiyan, S., Amirthagadeswaran, K.S., (2016). The role of water-in-diesel emulsion and its additives on diesel engine performance and emission levels: A retrospective review. Alexandria Engineering Journal. 55(3): 2463–72. doi: 10.1016/j.aej.2016.07.021.

[18] Attar, A., Waghmare, J., Mane, S., (2022). Water in diesel emulsion fuel: production, properties, performance, and exhaust emission analysis. International Journal of Energy and Environmental Engineering. 13(2): 729–38. doi: 10.1007/s40095-021-00459-0.

[19] Woo, S., Kim, W., Lee, J., Lee, K., (2021). Fuel properties of water emulsion fuel prepared using porous membrane method for low pollutant engine at various temperatures. Energy Reports. 7: 6638–50. doi: 10.1016/j.egyr.2021.09.082.

[20] Syed Masharuddin, S.M., Abdul Karim, Z.A., Meor Said, M.A., Amran, N.H., Ismael, M.A., (2022). The evolution of a single droplet water-in-palm oil derived biodiesel emulsion leading to micro-explosion. Alexandria Engineering Journal. 61(1): 541–7. doi: 10.1016/j.aej.2021.06.043.

[21] Park, S., Woo, S., Kim, H., Lee, K., (2016). Effect of Diesel-Water Emulsified Fuel on the NOx and PM Emissions of a Diesel Engine. Energy and Fuels. 30(7): 6070–9. doi: 10.1021/acs.energyfuels.6b00089.

[22] Lif, A., Holmberg, K., (2006). Water-in-diesel emulsions and related systems. Advances in Colloid and Interface Science. 123–126(SPEC. ISS.): 231–9. doi: 10.1016/j.cis.2006.05.004.

[23] Maiboom, A., Tauzia, X., (2011). NOx and PM emissions reduction on an automotive HSDI Diesel engine with water-in-diesel emulsion and EGR: An experimental study. Fuel. 90(11): 3179–92. doi: 10.1016/j.fuel.2011.06.014.

[24] Jhalani, A., Sharma, D., Soni, S.L., Sharma, P.K., (2019). Effects of process parameters on performance and emissions of a water-emulsified diesel-fueled compression ignition engine. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. 00(00): 1–13. doi: 10.1080/15567036.2019.1669739.

[25] Yahaya Khan, M., Abdul Karim, Z.A., Hagos, F.Y., Aziz, A.R.A., Tan, I.M., (2014). Current trends in water-in-diesel emulsion as a fuel. The Scientific World Journal. 2014. doi: 10.1155/2014/527472.

[26] Hasannuddin, A.K., Wira, J.Y., Sarah, S., Ahmad, M.I., Aizam, S.A., Aiman, M.A.B., et al., (2016). Durability studies of single cylinder diesel engine running on emulsion fuel. Energy. 94(x): 557–68. doi: 10.1016/j.energy.2015.10.144.

[27] Kruczyński, P., Orliński, P., Kamela, W., Ślęzak, M., (2018). Analysis of selected toxic components in the exhaust gases of a CI engine supplied with water-fuel emulsion. Polish Journal of Environmental Studies. 27(1): 129–36. doi: 10.15244/pjoes/74689.

[28] Kumar, N., Raheman, H., Machavaram, R., (2019). Performance of a diesel engine with water emulsified diesel prepared with optimized process parameters. International Journal of Green Energy. 16(9): 687–701. doi: 10.1080/15435075.2019.1618309.

[29] Bidita, B.S., Aien, N., Suraya, A.R., Mohd Salleh, M.A., Idris, A., (2014). Effect of Experimental Variables on the Combustion Characteristics of Water-in-Diesel Emulsion Fuels. Journal of Dispersion Science and Technology. 35(2): 185–92. doi: 10.1080/01932691.2013.780241.

[30] Abu-Zaid, M., (2004). Performance of single cylinder, direct injection Diesel engine using water fuel emulsions. Energy Conversion and Management. 45(5): 697–705. doi: 10.1016/S0196-8904(03)00179-1.

[31] Abdurahman, N.H., Rosli, Y.M., Azhari, N.H., Abdul Adam, A., (2016). The Potential of a Water-in-Diesel Emulsion for Increased Engine Performance and as an Environmentally Friendly Fuel. MATEC Web of Conferences. 70(x). doi: 10.1051/matecconf/20167001003.

[32] Hoseini, S.S., Sobati, M.A., (2021). Assessment of the performance and exhaust emission of a diesel engine using Water Emulsion Fuel (WEF) in different engine speed and load conditions. Journal of Renewable Energy and Environment. 18(1): 58–68. doi: 10.30501/JREE.2020.233709.1115.

[33] Seifi, M.R., Hassan-Beygi, S.R., Ghobadian, B., Desideri, U., Antonelli, M., (2016). Experimental investigation of a diesel engine power, torque and noise emission using water-diesel emulsions. Fuel. 166: 392–9. doi: 10.1016/j.fuel.2015.10.122.

[34] Alahmer, A., (2013). Influence of using emulsified diesel fuel on the performance and pollutants emitted from diesel engine. Energy Conversion and Management. 73(x): 361–9. doi: 10.1016/j.enconman.2013.05.012.

[35] Dhahad, H.A., Chaichan, M.T., Megaritis, T., (2019). Performance, regulated and unregulated exhaust emission of a stationary compression ignition engine fueled by water-ULSD emulsion. Energy. 181: 1036–50. doi: 10.1016/j.energy.2019.05.200.

[36] Vellaiyan, S., Amirthagadeswaran, K.S., (2016). Influence of Water-in-Diesel Emulsion Fuel and Compression Ratio on Combustion, Performance and Emission Characteristics of Diesel Engine. Journal of Sustainable Energy Engineering. 3(3): 238–53. doi: 10.7569/jsee.2015.629515.

[37] Ithnin, A.M., Yahya, W.J., Ahmad, M.A., Ramlan, N.A., Abdul Kadir, H., Sidik, N.A.C., et al., (2018). Emulsifier-free Water-in-Diesel emulsion fuel: Its stability behaviour, engine performance and exhaust emission. Fuel. 215(May 2017): 454–62. doi: 10.1016/j.fuel.2017.11.061.

[38] Wahhab, H.A.A., Mashkour, M.A., Madodi, S.A., (2020). Investigation of water-diesel emulsion characteristics using optical technique. Journal of Applied Fluid Mechanics. 13(1): 349–55. doi: 10.29252/jafm.13.01.30133.

[39] Attia, A.M.A., Kulchitskiy, A.R., (2014). Influence of the structure of water-in-fuel emulsion on diesel engine performance. Fuel. 116: 703–8. doi: 10.1016/j.fuel.2013.08.057.

[40] Nazha, M.A.A., Rajakaruna, H., Wagstaff, S.A., (2001). The use of emulsion, water induction and EGR for controlling diesel engine emissions. SAE Technical Papers. (724). doi: 10.4271/2001-01-1941.

[41] Mondal, P.K., Mandal, B.K., (2019). A comprehensive review on the feasibility of using water emulsified diesel as a CI engine fuel. Fuel. 237(October 2018): 937–60. doi: 10.1016/j.fuel.2018.10.076.

[42] Hassan, Z.U., Usman, M., Asim, M., Kazim, A.H., Farooq, M., Umair, M., et al., (2021). Use of diesel and emulsified diesel in CI engine: A comparative analysis of engine characteristics. Science Progress. 104(2): 1–19. doi: 10.1177/00368504211020930.