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A Review on Effects of Water-Diesel Emulsions on the Performance and Emission Characteristics of Direct Injection Diesel Engine

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Abstract: Recently, the emphasis on fuel conservation and reduction of undesirable emissions has generated larger interest in utilizing water-in-oil emulsions in conventional liquid fuelled combustors. Emulsified Fuels are emulsions composed of water and a combustible fuel. In this work, the performance of an engine together with its effect on environment will be tested when engine powered by both pure diesel and emulsified fuel with various quantities of water content in the diesel fuel. The amount of water quantities added will be ranged between 5% and 30% by volume in a direct injection diesel engine. The physical properties of stable water-diesel emulsions such as density, viscosity and pour point will be observed. The aim of this work is to study the effect of water emulsified diesel on the performance characteristics (BTE, BSFC, BP and EGT), the emission characteristics (NO_2, PM, CO, CO_2, O_2, SO_2, and Smoke Density) and engine speed, torque, brake power output, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature for varying loads and speeds will be studied with required modifications in a CI engine to get the best results.

Keywords: Diesel engine, Engine performance, Emulsified fuel, Diesel fuel, Exhaust gas temperature, Engine emission.

I. INTRODUCTION

Recently, the emphasis on fuel conservation and reduction of undesirable emissions has generated larger interest in utilizing water-in-oil emulsions in conventional liquid fuelled combustors. Internal combustion engines generate undesirable emissions during the combustion process. The pollutants that are exhausted from the internal combustion engines affect the atmosphere and cause problems such as global warming, smog, acid rain, respiratory hazards etc. The major emissions include Nitrogen Oxides (NO_2), unburnt Hydrocarbons (HC), and oxides of Carbon, oxides of Sulphur and other carbon particles or soot. There are various ways to treat these pollutants. There are two major ways to treat the pollutants; one is to treat inside the combustion chamber whereas the other is to treat outside the combustion chamber. In this research work an emulsion acts as surfactant with the diesel fuel and correspondingly the emission and performance parameters are studied. Of all the methods proposed to introduce water into the combustion chamber, diesel oil emulsions appear to be the most appropriate because it requires no engine retrofitting. The water in the emulsion is suspended in the fuel by a surfactant, thus the water does not come into direct contact with engine surfaces. The emulsion fuel is defined as an emulsion of water in standard diesel fuel with specific additives, surfactants to stabilize the system. The environmental aspects are the main driving forces for the growing interest in the use of diesel emulsions and the literatures suggest that there may be a certain loss in engine performance due to the presence of water, but the subsequently diesel consumption is also reduced. Typical water content in the emulsion may vary from 10 to 20%. Considering the enormous volume of diesel fuel that is being consumed today, a replacement of just a fraction of regular diesel by water-in diesel emulsion would mean that a new and a very large application have been created. The stability requirements on such emulsions are obvious: they need to stay stable for a specific time and over a wide temperature range. The surfactants used, i.e., the emulsifiers, must burn readily without soot formation and should not contain Sulphur and Nitrogen. Thus, they should contain only carbon, hydrogen and oxygen and they preferably should not have aromatic rings in their structure. Non-ionic surfactants based on aliphatic hydrocarbon tails, such as alcohol ethoxylates, fatty acid ethoxylates and sugar esters of fatty acids are typical candidates.

II. EMULSIFIED FUELS IN DI DIESEL ENGINES – A REVIEWS

V. Murali, et al, carried out test on 6-cylinder diesel engine using a surfactant with HLB of 7 and found as percentage of water in emulsion increases, the SFC decreases. The reduction in SFC with water diesel emulsion may be attributed to formation of a finer spray due to rapid evaporation in the water, longer ignition delay results in more fuel burning in premixed combustion and suppression of thermal dissociation due to lower cylinder average temperature. The use of water diesel emulsion is found to increase the brake thermal efficiency. At the maximum power output of 63 KW, it is 32.05% with diesel and rises from 33.39% to 37.14%

with increase in percentage of water in emulsion. At maximum power output of 63 KW, the HC level with diesel is 74 ppm and it reduces to minimum of 55 ppm. CO also shows a similar behavior particularly at higher outputs. The reduction in the emission level is due to better combustion. The smoke density falls from 6.26 BSU to 5.84 BSU. At maximum output. The NO_2 decreases from 1389 ppm to 955 ppm at maximum output of 63 KW [1].

Biplab K. Debnath, et al, reviewed that the increase in speed of revolution of mechanical homogenizing machine and increase in duration of ultrasonic agitation have found to reduce the droplet size of the dispersed phase. However, the later on produces lower droplet diameter and reduces the rate of water separation. The emulsion stability of three phase water oil emulsion is found to be better than two phase one. The micro emulsion of water diesel emulsion consumes time and has found to increase the ID. Further evaporation of water and consequently localized cooling of charge may be held responsible for higher ID. The emulsion prepared by using ultrasonic emulsification is found to generate lower CO than mechanical homogenizer. HC emission from engine depends on the mixing of air and fuel. Micro explosion of emulsified fuel improves fuel air mixing and hence is expected to reduce HC. Further the water emulsification in droplet combustion reduces the burning rate constant results in the prolonged ignition delay and suppresses the formation of soot [2].

Ahmed MuhsinIthnin et al, found that improvement of the combustion efficiency is due to the increase of ignition delay and micro explosion phenomenon. The reduction in NO_2 is due to lower peak temperature of flame during combustion. PM is reduced due the effect of micro explosion process which leads an increase in combustion efficiency. UHC and CO exhaust emission is found to be increased by using the water diesel emulsion. Durability testing of using water diesel emulsion fuel is potential research study that seldom people explored. Friction analysis on the piston rings and engine block, carbon deposit on fuel injector, metal debris and water content on lubricating oil and corrosion analysis are the potential research areas that can be investigated after running the engine using water diesel emulsion fuel for long period of time [3].

B. Sachuthananthanand K. Jeyachandranconcluded that the brake thermal efficiency at full load increases from 28.3% to 29% diethyl ether addition. HC and CO levels drop from 75 ppm to 40 ppm at full load. There is significant reduction in smoke level. It is 4.2 BSU for diesel, 4.5 for BSU for biodiesel and 2.5 BSU for 30% water biodiesel emulsion. With the addition of 15% diethyl ether it was further reduced to 1.6 BSU. The NO_2 level for diethyl ether addition is lower than that of water biodiesel emulsion and neat diesel modes of operation. At full load it was only 568 ppm for 10% diethyl ether addition as compared to 651 ppm with 30% water biodiesel emulsion [4].

MohammedYahayaKhan, et al, found that the effect of water content on the simultaneous reduction of both NOx and PM. The inconsistency was on the percentage amount reduction compared to pure diesel. Up to 37% reduction NO_2 and 90% reduction in PM were reported by different researchers [5].

Peramanan A, Saravanakumar, et al, taken trial on diesel engine and found that the specific fuel consumption was observed to decrease with increase in the percentages of water in diesel. However, the fuel consumption is higher for higher loads for emulsion than diesel. The NO_2 emission is bought down by 20%-40% by the use of diesel water emulsion. This trend goes on increase with the increase in the amount of water in the emulsion.at lower loads the hydrocarbon emissions are lesser for the emulsion than diesel however when the load increases HC emissions are higher for the emissions. CO and CO_2 emissions increase with increase in water percentage in the fuel [6].

A. N. Dibofori-Orji found that the successful combustion of fuels emulsified with water can only be achieved if the emulsion is of water in oil type. The limit on the percentage water content of an emulsion for effective and controllable combustion depends on the chemical nature of the emulsifying agent and the mixing device employed. Over the range of emulsions burnt during the experiments, the emulsified fuels exhibited characteristic higher combustion efficiency than neat diesel fuel under same conditions. The maximum efficiency in each case was obtained with emulsions containing 5% water [7].

Pradeep S. Kumar, et al, studied a water diesel emulsion and carried a test on single cylinder diesel engine and found out that the use of emulsified fuel improves engine efficiency in certain operating modes. They suggested that the water emulsification has a potential to slightly improve the emulsions of diesel and water are often promoted as being able to reducing emissions of both NO_2 and HC in a diesel engine further experimental work for both optimizing the emulsions formulation in terms of water content and internal structure is recommended [8].

Cherng-Yuan Lin and Kuo-Hua Wang concluded that compered to diesel fuel the emulsions had lower exhaust gas temperature, greater CO_2 and CO emissions, and smallerO_2, NO_2 emissions and smoke opacity. The HLB values in the 6-8 range influenced the BSFC slightly for two phase W/O and three phase O/W/O emulsions with 10% water content [9].

Ajay Kumar and Manish Kumar studied and overviewed of the recent investigations in emulsion technique must be adapted for diesel and usage in compression ignition engine to have a comparable fossil diesel performance and to realize the dream of usage biodiesel to extend the fossil fuel availability. Hence it is concluded that there is a benefit in emulsion technique biodiesel in terms of better brake thermal efficiency, BSFC and emission performance.During the combustion process at very high temperature and pressure nitrogen reacts with oxygen toform oxides and other gases. There are a number of possible reactions that form NO_2. Some reactions that occur inside the CI engine are:

$$O + N_2 \rightarrow N + N,$$
$$N + O_2 \rightarrow NO + O,$$
$$N + OH \rightarrow NO + H,$$
$$NO + H_2O \rightarrow NO_2 + H_2,$$
$$NO + O_2 \rightarrow NO_2 + O$$ [10].

Omar Barran, et al. studied the water emulsified diesel and find out the results that indicates that the addition of water to diesel in the form of emulsion improves combustion efficiency. The engine torque, power and brake thermal efficiency increase as the water percentage by volume in the emulsion increases. The average increase in the brake thermal efficiency for 30% water emulsion is approximately 5% over the use of diesel for the engine speed range studied. The PM and NO_2 emissions decrease as the percentage of water in the emulsion increased to 30%. So that the benefits of adding water to diesel fuel results in substantial reductions in NO_2 and PM [11].

AgungSudrajad, et al. did experimental study of single cylinder diesel emulsions by using W/O emulsion fuel has been examined. Emissions of NO_2 and SO_2 concentration by emulsion fuel are lower than base diesel oil. Effect of adding water in the oil give results on high oxygen content in the fuel, hence larger amount of fuel can burn in a given lower fuel consumption. Moreover, reduce of sulfur content in the fuel caused by adding water give results in decreasing of SO_2. The results from the experiments prove that W/O emulsions fuel potentially good alternative fuels for diesel engine in the near future because of give a benefit on the fuel oil consumption and reduction of the pollutants [12].

Narindersingh and R. S. Bharjmade the experiments on the diesel engine with water diesel emulsion and concluded that rate of pressure rise in the cylinder for 15% water diesel emulsion is high compared to pure diesel it is also observed that net heat release rate for the 5%, 10%, 15% and 20% water diesel emulsion Is high compared to pure diesel. It is due to enhance premixed combustion resulted by longer ignition. The brake specific fuel consumption was observed to decrease with water diesel emulsion. Results showed that the lowest specific fuel consumption at full load is 0.30 kg/kw-hr for 20% water diesel emulsion. The highest brake thermal efficiency was observed for 15% water diesel emulsion is 28.6. NO_2 emissions was found 390 ppm for 20% water diesel emulsion as compared to 428 ppm for pure diesel. Lowest HC produced by pure diesel is 11 ppm however it is highest of 19 ppm when using 20% water diesel emulsion. When load increases HC emissions are higher for water diesel emulsion [13].

R. Vigneswaran, et al. found out NO_2 for the emulsified fuel could be reduced from minimum of 10% to a maximum 17%. CO emission could be reduced up to 50% under part load condition. HC emissions could be reduced up to 67% for the emulsified fuel [14].

Nitesh Kumar Singh have reported that the Fuel emulsions results into higher BSFC; Addition of water in the form of emulsion improves combustion efficiency in diesel engine. 20% water content has higher BSFC and Exhaust gas temperature decreases with increase in water percentage in emulsion. The exhaust gas temperature decreases with the increase of water percentage in the emulsion. Emulsion with 20% water content has lowest exhaust gases temperature [15].

M. Abu-Zaid concluded that the addition of water in the form of emulsion improves the combustion efficiency and performances in a Diesel engine. As the water percentage in the emulsion increases up to 20% by volume, the engine torque, power and brake thermal efficiency increase. The average increase in the brake thermal efficiency for 20% water emulsion is approximately 3.5% over the use of diesel. The BSFC calculated

by considering the total fuel as strictly the amount of diesel fuel that is burned and the gases exhaust temperature decrease as the percentage of water increases. Also, it was found that the addition of 2% surfactant to the emulsions seems to have almost negligible effects on the engine performance parameters measured [16].

A.K. Hasannuddin, et al. concluded that the emulsion fuel helps to reduce the level of both NO_2 and PM simultaneously. About 20-90% reduction in NOx and 16-60% reduction in PM can be achieved by emulsifying 20-40% W/O. there is only a limited amount of information about durability studies of the diesel engine using emulsion fuel. The concern regarding of introduction of water in the combustion chamber in the long term operation is that it may reduce engine life especially the service time for the engine itself [17].

A.M.Al-sabagh, et al. concluded that the stability of the studied emulsions increases with increasing the total emulsifier concentration at low water content. Regarding the emission characteristics, it was found that a lower concentration of NO_2 was emitted, when emulsions were used as an engine fuel. Also, the concentration of the CO_2 emission is higher in emission fuel when compared to pure diesel fuel. The emulsions had lower exhaust gas temperatures and lower calorific values as expected [18].

M. Saravanan, et al. conducted an experimental work and concluded that the water blend diesel offers better emission characteristics and require no engine modifications when the concentration of water in the fuel is up to a certain value. The test results from the engine fueled with water blend diesel showed reduction in emissions as compared to that of engine fueled with conventional diesel. The better emissions in the CI engine using water blend diesel is due to the incorporation of the water which reduces NO_2 emissions by lowering the peak combustion temperature. Water blend fuel enhances fuel atomization by micro explosion. The addition of water to diesel fuel lowers PM emissions by serving as diluents to the key combustion intermediates that lead to particulate formation. It is further justified that water's availability is abundant in nature, thus, it will not lead to any increasing cost and there's no further for any extra machinery for the blending of water with diesel [19].

R. Vigneswaran, et al. done experiment on diesel engine with water diesel emulsion fuel and concluded that the emulsion will meet to a certain extent the shortage of availability of diesel. Also water is easily available source on the earth surface. It will be economical. BP and IP follows the same trend for 23º bdc when compared to normal diesel. CO has been reduced by 12% to 20%. HC also reduced by 25% to 50%. NO_2 as reduced by 36% because of water suppress the temperature. BTE and ITE are also follow the same trend as diesel. To conclude injection timing 23º bdc with emulsion fuel gives same performance when compared with diesel. Also diesel has been saved when water was replaced with diesel fuel by 10% [20].

III. CONCLUSION

1. Addition of water to diesel fuel has great influence on reducing heat flux, metal temperature and thermal loading of combustion chamber components [1].
2. NOx emission decreases due to reduction in gas temperature and increase in OH radical concentration. PM decreases due to micro-explosion (secondary atomization) phenomenon of water [1].
3. When the water diesel emulsion is injected into the cylinder, fine water droplets burst spontaneously and form high pressure steam. This acts as an additional pressure force on the piston top that improves torque of the engine [2].
4. As the water quantity increases in emulsion, a higher amount of diesel is replaced by equal amount of water. As a result, a lower quantity of diesel is actually remains in emulsion. [2].
5. Improvement in combustion efficiency is due to increase of ignition delay which results in more fuel burning in premixed combustion and micro explosion phenomenon [3].
6. Reduction in temperature suppresses the dissociation reaction [3].
7. Increase in excess of air ratio due to presence of water in the fuel [3].
8. Effect of adding water in the oil give results on high oxygen contain in the fuel hence larger amount of fuel can burn in a given lower fuel consumption [12].
9. Rate of pressure rise and net heat release rate are higher for water diesel emulsion as compared to pure diesel. [13].
10. Water blend diesel fuel offers fuel lubricity [19].

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