EFFECTS OF ADDITIVE BLENDED EMULSIONS IN A DIESEL ENGINE – AN EXPERIMENTAL INVESTIGATION

Anfal Said Al Wahaibi* Amal Abdul Rahman Al Raisi* Muna Abdullah Al Shibli* Mazin Nasser Al Hamrashdi*
J. Sadhik Basha**

**UG Scholars, Department of Process Engineering, International Maritime College Oman (IMCO), Oman.*
*** Senior Faculty, Department of Process Engineering, International Maritime College Oman (IMCO), Oman.*

Abstract

Diesel engines play a vital role in all the major sectors like industrial, transport and power due to their transcendence in the fuel economy, and sturdiness. At the same time, diesel engines emit harmful pollutants such as NO_x (Nitrogen oxides), HC (Hydrocarbons), smoke, particulate matter and stinky odor, which degrade our ecological environment. Till date, numerous researchers have contributed their valiant efforts to reduce the emissions from diesel engines majorly by three ways: (i) Modifying the engine design (ii) Fuel modification/reformulation, and (iii) Exhaust gas treatment techniques. However, these techniques which are used to reduce NO_x, lead to increase in smoke and particulate matter and vice versa. To reduce the smoke and NO_x emissions simultaneously, water-diesel emulsification technique is widely adopted. In the present work, DEE (Di-Ethy Ether) blended water-diesel emulsion fuels are prepared to investigate the performance and emission characteristics of the diesel engine. The emulsion fuels are prepared by the emulsification method in the proportion of diesel, water, surfactants and DEE (by volume).

The whole experimentation is conducted in five phases. In the first phase, the performance (endurance) and emission characteristics of the diesel engine are carried out using neat diesel (for the reference reading). In the second phase, emulsions are prepared in the proportion of 88% Diesel, 10% water and 2% surfactants (Span 80 and Tween 80) with the aid of the mechanical stirrer. In the third phase, emulsions are subjected to the stability characteristic investigations. In the fourth phase, the prepared stable emulsion fuels were blended with 50, 100 and 150 ml of Di- Ethyl Ether by volume. In the fifth phase, the prepared emulsion fuels were subjected to the performance (in terms of endurance test) and emission characteristics of the diesel engine (in lower and higher acceleration modes).

The experimental outcome of this investigation reflected a drastic reduction in the harmful emissions (such as NO_x and smoke in particular) and a better performance (endurance) characteristics on compared to that of the neat diesel. Henceforth, it is observed that adding water and DEE will reduce the harmful emissions of the diesel engine without affecting its performance.

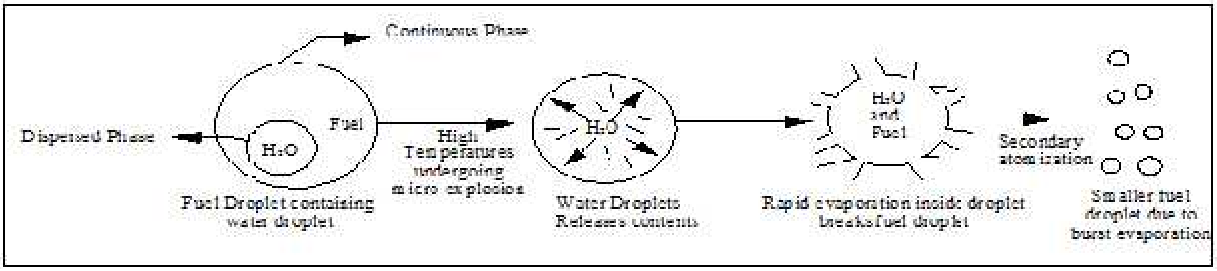
Keywords: Emulsions, Di-Ethyl-Ether, Emissions, Stability, Diesel Engine.

1. Introduction

Diesel engines are considered as prime movers in heavy-duty applications such as automobiles, marine and industrial sectors due to their superior thermal efficiency and fuel economy. In order to improve the performance and reduce the emissions from diesel engines, several techniques have been materialized. One of the possible attempts is the emulsification technique, which has the prolific potential to reduce the hazardous emissions from diesel engines. Further, to improve the quality of emulsion fuels some additives have been incorporated to attain better performance, emission and combustion characteristics of the diesel engine. The oil reserves in all over the world are obviously limited and are expected to be diminished for another few years. The enormous growth of world population, exorbitant industrialization and standard of living lifestyle has led to this elusive situation in the field of energy supply and demand. The prices of crude oil keep rising and wavering day by day owing to the aforementioned causes. The fossil fuel (particularly diesel) utilized by the diesel engine has played a very important role in all the major sectors (like transportation, power, industry, marine, agricultural, etc.) owing to their fuel economy, sturdiness, reliability and rigidity. But at the same time they emit hazardous emissions (such as NO_x, HC, PM and smoke) and thereby causing several global hazards such as acid rain, ozone depletion, greenhouse effect, climatic change, smog etc. It has been established that the use of water-diesel emulsion fuel in diesel engine produces significant effects in the reduction of NO_x, particulate and smoke emissions (Ahmad and Gollahali, 1994). Park *et al*. (2000) performed an experimental investigation in a rapid compression and expansion machine, to study the combustion characteristics of water-diesel emulsion fuel (20 and 40% of water content) by advancing the injection timing (10°, 15° and 20° bTDC). They observed that the 40 W/D emulsion fuel at 20° bTDC produced better fuel conversion efficiency among the other tested injection timings. In addition, they experienced a prolonged ignition delay for the both advanced injection timing and high W/D ratio operations. Armas *et al*. (2005) carried out experiments using the water-diesel emulsion fuel (10% of water content) in a Renault turbocharged car IDI diesel engine, and observed a slight improvement in the specific fuel consumption, and considerable reduction in the harmful pollutants such as NO_x, HC, soot and particulates. They also reported that there was a significant prolonged ignition delay due to the decrement in the cetane number (on the account of water addition) and early injection of the emulsified fuel in the combustion chamber compared to that of neat diesel operation. Kass *et al*. (2009) analyzed an experiment in a four cylinder Mercedes light duty diesel engine using soybean biodiesel emulsion fuel with EGR technique. They have observed a high premixed combustion resulting enhanced heat release rate (as a result of prolonged ignition delay) for the biodiesel emulsion fuels compared to that of neat biodiesel operation. In addition, they have also ascertained a reduction in the NO_x and PM emissions for the biodiesel emulsion fuel compared to that of neat biodiesel operation. However, they also ascertained a poor performance at low and part loads, and revealed that those effects can be improved on adding cetane improvers (such as Di-Ethyl-Ether).

To curtail the harmful emissions emitted from fossil fuels various techniques such as exhaust gas recirculation and engine design modifications have been adopted. But those techniques which are used to reduce NO_x will lead to increase in the smoke emissions, and vice versa. In order to reduce both NO_x and smoke emissions from the diesel engine, emulsification technique is widely adopted without affecting the performance characteristics. The water content in the emulsion fuel is suspended by a suitable surfactant and does not allow the water to direct contact with the engine surfaces. The other potential benefit associated with the water-diesel emulsion fuel is the combined effect of ‘micro-explosion’ and ‘secondary atomization’ phenomena, which break the large fuel droplets into smaller ones due to the volatility differences between the diesel and water. The micro-explosions in the water-diesel emulsion fuel are the result of instantaneous vaporization of water droplets present in the diesel fuel as depicted in the Figure 1.

Figure 1: Schematic sketch of micro-explosion phenomenon of water-diesel emulsion fuel [Sadhik and Anand, 2011a]



Once the water droplets encapsulated in the diesel fuel are exposed to high pressure and high temperature environment in the engine cylinder, the water present in the diesel fuel absorbs heat quickly and explodes through the surrounding oil layers as an effect of micro-explosion (Sadhik and Anand, 2011a, 2011b, 2011c). Subsequently, the secondary atomization phenomenon follows immediately and provides a number of secondary fuel droplets, and in turn enhances the combustion efficiency and reduction in the harmful pollutants. On the contrary, there is a problem of prolong ignition delay associated with the water-diesel emulsion fuels leading to high premixed combustion rate and high peak pressure causing rough engine operation. To overcome those problems associated with the water-diesel emulsion fuels, some potential additives have been adopted to eradicate the aforementioned problems. Recently, oxygenated additives are considered as a propitious blending medium to improve the fuel properties, owing to their better thermal properties and higher oxygen content. Due to those characteristics of oxygenated additives, the degree of mixing are enhanced during the combustion, leading to better performance and emission attributes of the diesel engine. Information indicates that addition of oxygenated additives (such as Di-Ethyl Ether, Diglyme etc.) to any fuel enhances the brake thermal efficiency, ignition and favors better combustion characteristics. Very few works have been reported on incorporating the oxygenated additives with the emulsion fuels to improve the performance, and to reduce the harmful emissions from the diesel engine. The important motivation of this study is to investigate the utilization of oxygenated additive (Di-Ethyl-Ether) with the water-in-diesel emulsion fuel in a direct injection diesel engine. The prominent motivations of the present investigations are enumerated as follows:

- To produce the water-diesel emulsion and to improve their fuel quality on adding potential oxygenated additives.
- To study the stability characteristics of water-diesel emulsion fuel.
- To study the performance (endurance) and emission characteristics of water-diesel emulsions in a direct injection diesel engine.

2. Experimental Methodology

The following section describes the experimental methodology adopted to study the performance (endurance) and emission characteristics of a diesel engine using neat diesel, water-in-diesel emulsion fuel and DEE blended water-in-diesel emulsion fuels. Water-in-Diesel fuels were prepared by mixing the two immiscible fluids (say diesel and water) in the presence of surfactants. Surfactants were added to the water-diesel mixture, to reduce the interfacial surface tension, and to maximize their superficial contact areas to make stable emulsions (Chiaramonti *et al*. 2003). A mixture of two non-ionic surfactants, Span80 (hydrophobic), Tween80 (hydrophilic) and DEE were used to produce the water-in-diesel emulsion fuel and DEE blended water-in-diesel emulsion fuels (Refer the Fig. 2).

Figure 2: Photographs of Span80, Tween80 and Di Ethyl Ether

The water-in-diesel emulsion fuels were prepared by the water percentage (10% by volume) with the diesel fuel in the presence of surfactants. A mixture of two surfactants namely, Span80 (Sorbitane monooleate) and Tween80 (Polyxyethylene sorbitane monooleate) were used, as it provided better emulsification results (Sadhik and Anand, 2012). The value of hydrophilic-lipophilic balance (HLB) indicates the relative strength of the hydrophilic and lipophilic characteristics of the molecules in the surfactant. The combined HLB values of the two surfactants were estimated (Sadhik and Anand, 2011b) by:

$$HLB_{AB} = [(H_A * W_A) + (H_B * W_B)] / (W_A + W_B) \quad (2.1)$$

where, H_A, H_B, W_A and W_B denote the HLB values and weights of the two surfactants, Span80 and Tween80 respectively. In the first step, the surfactant mixture was prepared by mixing the two surfactants with 2% by volume with an HLB value of 8, to provide a stable water-in-diesel emulsion fuel (Sadhik and Anand, 2010a, 2010b, 2010c). In the second step, the neat diesel (88% by volume) was mixed with the surfactant mixture by means of a mechanical stirrer at the agitation speed of 2000 rpm and simultaneously, water (10% by volume) was added by means of injection nozzle for 30 minutes at a room temperature of 25 °C in a container.Thus, the water-in-diesel emulsion fuel (D88W10S2) was prepared. The prepared water-in-diesel emulsion fuels (D88W10S2) had a creamy white color, and kept in the transparent graduated glass test tubes under static conditions for stability investigations (Refer the Fig. 3).

Figure 3: Stability Investigations of the prepared water-in-diesel emulsion fuels

The percentage of separated water layer (by volume) with respect to the elapsed time was measured for each sample. The percentage of separated water layer was calculated by:

$$\text{Separated water layer (\%)} = [(H_2O)_{initial} - (H_2O)_{final}] * 100 / (H_2O)_{initial} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..... (2.2)$$

where, $(H_2O)_{initial}$ denotes the initial water content, and $(H_2O)_{final}$ denotes the final water content. It was noted that the prepared emulsion fuels were stable for more than seven days. Further the prepared stable emulsion fuels were subjected for the performance and emission characteristics of the diesel engine. The DEE blended water-in-diesel emulsion fuels were prepared as follows. The DEE (50ml) is mixed along with the diesel (88% by volume) and Span 80 (100ml) at an agitation speed of 2000 rpm in a container. Simultaneously, water (10% by volume) mixed with Tween 80 (100ml) is injected in the container for 30 minutes at a room temperature of 25 °C. This process is carried out for about 30 minutes. The resulting solution from the container is the DEE blended water-in-diesel emulsion fuel (D88W10S2DEE50). The same procedure was carried out (for the other dosage of 100 and 150 ml) to prepare D88W10S2DEE100 and D88W10S2DEE150 fuels. The details of prepared emulsion fuels are shown in the Table 1.

Table 1: Details of water-in-diesel emulsion fuels

S. No	Emulsion Fuel	Diesel (%) by vol.	Water (%) by vol.	DEE (ml)	Surfactants	
					Span 80 (%) by vol.	Tween 80 (%) by vol.
1	D88W10S2	88	10	--	1	1
2	D88W10S2DEE50	88	10	50	1	1
3	D88W10S2DEE100	88	10	100	1	1
4	D88W10S2DEE150	88	10	150	1	1

The prepared samples of DEE blended water-in-diesel emulsion fuels had a creamy white color, and kept in the graduated glass test tubes for the stability investigations. The percentage of separated water layer (by volume) with respect to the elapsed time was measured for each sample. The percentage of separated water layer was calculated from the equation 3.4. It was observed that the DEE were completely dispersed in the distilled water during the agitation and this leads to possible encapsulation of DEE within the water droplet present in the continuous diesel layer (Sadhik and Anand, 2011c). The properties of the diesel, Di Ethyl Ether and DEE blended water-in-diesel emulsion fuels are presented in the Table 2 and Table 3.

Table 2: Details of Di-Ethyl-Ether (Subramanian and Ramesh, 2002)

Item	Specification
Manufacturer	Alfa Aesar, USA
Formula	C_2H_5-O-C_2H_5
CAS No.	60-29-7
Molecular weight	74.12
Appearance	Colorless liquid
Density	0.7134 g/cm^3
Boiling point	34.6°C
Viscosity	0.224 cP @ 25°C
Flash point	−45 °C
Autoignition temperature	160 °C
Cetane Number	125

Table 3: Fuel properties (Subramanian and Ramesh, 2002)

Properties	Diesel	D88W10S2	DEE
Density @15°C, kg/m^3	830	855.5	713
Kinematic viscosity @ 40°C ($\times 10^{-6}$ m^2/s)	2.1	4.60	0.223
Flash point, °C	50	60	- 45
Net calorific value, MJ/kg	42.3	39.9	33.9
Cetane No.	46	43	125

The experiments were conducted in a diesel car engine. One of the method for testing the diesel engine is the endurance characteristics. The most important parameters for determining engine endurance are abnormal noise, abnormal vibration, continuity of operation, engine operating temperature and lubrication oil (IS:10000 - Part 8). In the current work, the endurance characteristics of the diesel engine is focused on three important parameters such as abnormal noise, abnormal vibration and continuity of operation for the prepared emulsion fuels. First of all, the diesel engine was started and further accelerated on using the emulsion fuels at static conditions and the operating characteristics such as abnormal noise, abnormal vibration and continuity of operation was observed. A gas analyzer was used for measuring the NO, CO, HC, and smoke in the exhaust gas. The emission testing of the diesel engine is carried out in two modes.

Slow Speed Mode 1
In this type of operation, the engine is started without any acceleration. During this operation, the gas analyzer is kept near to the smoke pipe and the magnitude of emissions is noted for all the tested fuels.

Accelerated Speed Mode 2
In this type of operation, the engine is started with any acceleration on pressing the accelerator of the diesel engine. During this operation, the gas analyzer is kept near to the smoke pipe and the magnitude of emissions is noted for all the tested fuels.

3. Results and Discussion

The following sections describe the results obtained from the experiments on the performance (endurance) and emission characteristics of a four stroke direct injection diesel engine using neat diesel, water-diesel emulsion fuels and DEE blended water-diesel emulsion fuels. The neat diesel and the prepared emulsion fuels were subjected for the performance (endurance) characteristics of the diesel car engine as explained in the section 3.5. The endurance test was carried out for all the emulsion fuels and there was no observance of any abnormal noise, abnormal vibration, continuity of operation or difficulty in starting of the engine. Henceforth, the emulsion fuels can be subjected for the diesel engine without incorporating any major modification.

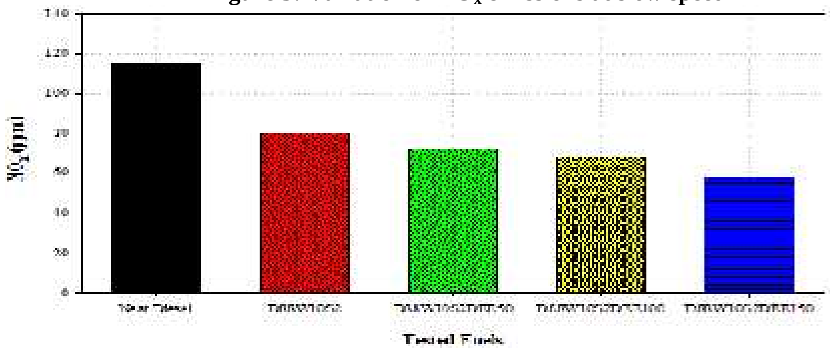
3.1 Emission Characteristics of Diesel Engine at Slow Speed

The neat diesel and the prepared emulsion fuels were subjected for the emission characteristics of the direct injection diesel engine at slow speed as explained in the section 3.6.

3.1.1 Variation of NO_x Emissions

The variation of NO_x emissions with respect to the tested fuels is depicted in the Figure 8. It is observed from the figure that the emulsion fuels produced lesser NO_x emissions compared to that of neat diesel. This is due to the heat sink effect caused by the fine dispersed water droplets in the emulsion (Sadhik and Basha, 2011c). On the other hand, in the case of DEE blended water-in-diesel emulsion fuels, the magnitude of NO_x emission is further reduced than that of water-diesel emulsion fuel due to shorten ignition delay, lower combustion pressure and less fuel accumulation in the engine cylinder during combustion in the engine cylinder (Subramanian and Ramesh, 2002).

Figure 5: Variation of NO_x emissions at slow speed



4. Conclusions

The performance (endurance) and emission characteristics of a direct injection diesel engine using neat diesel, water-diesel emulsion fuel and DEE blended water-in-diesel emulsion fuels were investigated. In addition, the stability characteristics of the tested fuels were also studied. Based on the experimental investigations, the following conclusions are drawn.:

- The incorporation of the Di-Ethyl-Ether with the water-diesel emulsion fuels have significantly improved the performance and emission characteristics of the diesel engine.
- There was no observance of any abnormal noise or starting difficulty during the entire experimentation using the DEE blended water-diesel emulsion fuels.
- The stability of the water-in-diesel emulsion fuel and DEE blended water-in-diesel emulsion fuels were more than seven days under static conditions.
- At the both higher and lower speeds, the level of harmful pollutants in the exhaust gases (such as NO_x and smoke) of the emulsion fuels were drastically reduced when compared to that of neat diesel.
- There was also a marginal reduction in the HC and CO emissions for the DEE blended water-in-diesel emulsion fuels when compared to that of neat diesel.

References

1. Afify, H.M., N.S. Korah and D.W. Dicky (1987) The effect of air charge temperature on performance, ignition delay and exhaust emissions of diesel engines using W/O emulsions as fuel. SAE Paper No. 870555.
2. Ahmad, I. and S.R. Gollahali (1994) Combustion of micro-emulsion sprays. Journal of Propulsion and Power, 10, 744-745.
3. Armas, O., Ballesteros, R., Martos, F.J. and Agudelo, J.R. (2005) Characterization of light duty Diesel engine pollutant emissions using water-emulsified fuel. Fuel, 84,1011–1018.
4. Chiaramonti, D., M. Bonini, E. Fratini, G. Tondi, K. Gartner, A.V. Bridgwater, H.P. Grimm, I. Soldaini, A. Webster and P. Baglioni (2003), Development of emulsions from biomass pyrolysis liquid and diesel and their use in engines - Part 1: emulsion production. Biomass Bioenergy, 25, 85-99.
5. Kass, M.D., S.A. Lewis, M.M. Swartz, S.P. Huff, D.W. Lee, R.M. Wagner and J.M.E. Storey (2009) Utilizing water emulsification to reduce NO_x and particulate emissions associated with biodiesel. Transactions of the ASABE, 52, 5-13.
6. Park, J.W., Kang Y. Huh and J. H. Lee (2001) Reduction of NO_x, smoke and brake specific fuel consumption with optimal injection timing and emulsion ratio of water-emulsified diesel. Proc.of Institution of Mech.Engrs, Part D: Journal of Automobile Engineering, 215, 83-93.
7. Sadhik Basha. J and R.B. Anand (2010a) Effects of Nanoparticle Blended Water-Biodiesel Emulsion Fuel on Working Characteristics of a Diesel Engine", Int. Journal of Global Warming, 2, 330-346.
8. Sadhik Basha. J and R.B. Anand (2010b) Applications of Nanoparticles/ Nanofluid in Compression Ignition Engines – A Case Study", Int. Journal of Applied Engg & Res., 4, 697-708.
9. Sadhik Basha. J and R.B. Anand (2010c) Performance and Emission Characteristics of a DI Compression Ignition Engine using Carbon Nanotubes Blended Diesel", Int. Journal of Advances in Thermal Science & Engg., 1, 67-76.
10. Sadhik Basha. J and R.B. Anand (2011a) An Experimental Investigation in a Diesel Engine using CNT Blended Water-Diesel Emulsion Fuel, Proc. of IMechE, Part A: Journal of Power and Energy, 225, 279-288.
11. Sadhik Basha. J and R.B. Anand (2011b) Role of Nano-Additive Blended Biodiesel Emulsion Fuel on the Working Characteristics of a Diesel Engine, Journal of Renewable and Sustainable Energy, 3, 1-17.
12. Sadhik Basha. J and R.B. Anand (2011c) An Experimental Study in a CI Engine using Nano-Additive Blended Water-Diesel Emulsion Fuel. Int. Journal of Green Energy, 8, 332-348.
13. Sadhik Basha. J and R.B. Anand (2012) Effects of Nanoparticle Additive in the Water-Diesel Emulsion Fuel on the Performance, Emission and Combustion Characteristics of a Diesel Engine, Int. Journal of Vehicle Design, 59, 164-181
14. Subramanian, K.A. and A. Ramesh (2002) Use of diethyl ether along with water-diesel emulsion in a DI diesel engine. SAE Technical Paper No. 2002-01-2720.