Impact of Emulsified Water/Diesel Mixture on Engine Performance and Environment

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Abstract *An experimental investigation was carried out to produce a stable diesel-water emulsion fuel to be used in a diesel engine under different operating conditions. The proper mixing technique and emulsifying agent were used to produce stable emulsions of 10% to 30 % water by volume in diesel. The stability of these emulsions ranges from one week up to 4 weeks. The physical properties of stable water-diesel emulsions such as density, viscosity and pour point were observed. The effect of water-diesel concentrations, on the performance of a single cylinder diesel engine in terms of engine speed, torque, brake power output, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature and emissions such as NOx and particulate matter (PM) were studied. The results showed that the water emulsification has a potential to improve the diesel engine performance and to reduce gas pollutants.*

Keywords:- *Diesel Engine, Water Diesel Emulsions, Physical Properties, Engine speed, Brake Power Output*

1. Introduction

Diesel engines exhausting gaseous emission and particulate matter have long been regarded as one of the major air pollution sources, particularly in metropolitan areas, and have been a source of serious public concern for a long time. The emulsification method is not only motivated by cost reduction but is also one of the potentially effective techniques to reduce exhaust emission from diesel engines. Water/diesel (W/D) emulsified formulations are reported to reduce the emissions of NOx, SOx, CO and particulate matter (PM) without compensating the engine's performance [1].

The Emulsified fuels have clear effect on combustion process. This is evident where the increase in water concentration in the emulsion produces a significant increase in the ignition delay. This is due to the heat absorption by water vaporization in the fuel jet [2-9]. In the emulsified Diesel fuel, the heat absorption by water vaporization causes a decrease of local adiabatic flame temperature and this reduces the chemical reaction in gas phase to produce thermal NO. Also, this helps to reduce soot, PM, CO and HC formation [3-5, 8, 10-12].

The increased viscosity of emulsified fuel tends to advance injection timing in some injection systems due to the modification of the dynamics of the command hydraulic system. This effect is mainly due to the flow variations through the control circuit [2, 4]. One of early reviews on advances in the combustion of water fuel emulsion which consists of base fuel and water doped with or without a trace content of surfactant was presented by [5]. They focused on the fundamental mechanism relevant to the micro-explosion phenomena leading to the secondary atomization which is not common to the combustion of pure fuel. They also described the kinetic and the probability models. Samec et al [2] conducted numerical and experimental studies on some of the chemical and physical properties of water/oil emulsified fuel (W/OEF) combustion characteristics. Their results of engine testing in a broad field of engine loads and speeds have shown a significant pollutant emission reduction with no worsening of specific fuel consumption. Lif and Holmberg [13] reviewed the influence of water on the emissions and on the combustion efficiency which is improved when water is emulsified with diesel. Also, they covered relationship of using different fuels, such as diesel-in-water emulsions, i.e., double emulsions, water-in-diesel micro emulsions, and water-in-vegetable oil emulsions, i.e., biodiesel emulsions.

Emulsions of diesel and water are often promoted as being able to overcome the difficulty of simultaneously reducing emissions of both oxidizes of nitrogen (NO_X) and particulate matter from diesel engines. Abu-Zaid [14] conducted an experimental study on water-in-Diesel emulsions to investigate the effect of water emulsification on a single cylinder Diesel engine performance and gases exhaust temperature. Emulsified Diesel fuels of 0, 5, 10, 15 and 20 water/Diesel ratios by volume were used in a Diesel engine, operating at 1200–3300 rpm. His results indicated that the addition of water in the form of emulsion improves combustion efficiency. The engine torque, power and brake thermal efficiency increase as the water percentage in the emulsion increases. The average increase in the brake thermal efficiency for 20% water emulsion is approximately 3.5% over the use of Diesel for the engine speed range studied. The proper brake specific fuel consumption and gases exhaust temperature decrease as the percentage of water in the emulsion increases.

Ghojel, et al [15] presented measurements of the performance and its effect on emissions (i.e NO_X and hydrocarbon emissions) of a diesel engine operating on a typical diesel oil emulsion and they examine through the use of heat release analysis the differences found during the combustion relative to standard diesel of the same engine. Also, Armas et al [16] illustrated the characterization of light duty Diesel engine pollutant emissions using water-emulsified fuel. While Conventional and Gemini surfactants were used in emulsified fuels by [1], they studied diesel engine performance and emission evaluation. Kannan and Udayakumar [17] Used commercial diesel fuel and diesel fuel with 10% and 20% water by volume. Their results showed that the water emulsification has a potential to improve brake thermal efficiency and brake specific fuel consumption. The NOx and hydrocarbon emissions were found to decrease with increase in water percentage in the emulsified diesel. 2009.The aim of the present study is to investigate the effect of Emulsion fuels with varying contents of water and diesel, which are prepared and stabilized, to test the diesel engine performance and exhaust emission.

2. Samples Preparation and Analysis

Diesel is the combustible material in emulsion that creates the energy, and has the heating value. Jordanian diesel fuel produced by JOPETROL was used in the present experimental work. Tape and demineralised water were added. The demineralised water gave better stability for the water-diesel emulsion than tape water which contains salts that has negative effect on the surfactant action. The surfactant is mainly used to stabilize water in diesel mixture, which can't be maintained by natural mixing of diesel with water, because of their different densities & forces of surface tension exist at the separation zone of the two substances, surfactant reduce surface tension forces to permit two different densities liquids to mix with stable chemical composition. The surfactant consists of two parts Hydrophilic and Hydrophobic, hydrophilic moiety has tendency to react with Water, on the other hand, hydrophobic moiety has tendency to react with oil.

Surfactants have many types, forms, and purposes. They are divided into two main classifications: organic and non-organic surfactants. An effective surfactant mixture was prepared from a polymeric non-ionic surfactant having hydrophilic and hydrophobic repeating units called Tween 80 (trademark) together with a fatty acid ester called Span 80 (trademark). An amount of 4 % by volume of surfactant mixture was added to the emulsified samples, Table 1. The main feature of the developed surfactant mixture is to use a minimum amount, to maximize stability time with acceptable cost. High speed mixer is used to carry out the mixing process to produce the required samples. The mixer can achieve a maximum of 2000 rpm. Mixing is applied after each addition for 15-20 minutes after the addition of all substances. The stability of emulsified samples is crucial matter, and the use of unstable emulsion is harmful to the engine due to the separated water which it is incombustible. Stability is affected by many factors, and depends strongly on preparing method and procedure, including: types of emulsifier being used and their percentages, mixing method and mixing time, type of water content, and quality of diesel.

Two 100 ml samples of emulsified fuel with 25% water content were prepared. Mixing process of 15 minutes was applied for both samples. The sample with demineralised water took more stability time of 12 days than tape water which gave only 10 days. It was noticed that as the percentage of water decreases in the samples the higher the stability time achieved.

HLB VALUE	TYPE OF EMULSION
< 10	Liquid soluble (water insoluble)
> 10	Water soluble
4 to 8	Antifoaming agent
7 to 11	Water in oil emulsifier
12 to 16	Oil in water emulsifier
11 to 14	Wetting agent
12 to 15	Detergents
16 to 20	Solubilise and hydrotrope

Table 1 HLB values of Different Emulsions

SURFACTANT	HLB VALUE
Sorbitan trioleate (Span 85)	1.8
Sorbitan monostearate, NF, (Span 60)	4.3
Sorbitan monooleate, NF, (Span 80)	4.7
Sorbitan monopalmitate, NF, (Span 40)	6.7
Sorbitan monolaurate, NF, (Span 20)	8.6
Polyoxyethylene sorbitan trioleate, (Tween 85)	11
Polysorbate 60, NF, (Tween 60)	14.9
Polysorbate 40, NF, (Tween 40)	15
Polysorbate 80, NF, (Tween 80)	15.6

Polysorbate 20, NF, (Tween 20)	16.7

Table 2 HLB values for some common surfactants

3. Diesel Engine Setup

A single cylinder, direct injection engine installed in the Mechanical Engineering Department Power Plant Laboratory at the Faculty of Engineering Technology/Al-Balqa Applied University was used for the experiments.

Several samples of emulsified Diesel-Water fuel were prepared to be compared with pure Diesel and Diesel with surfactant only, to study the impact of emulsified fuel on engine performance. The engine specifications are listed in Table 3

Make of engine	*Kirloskar , TV1*
General Details	*Four stroke, compression ignition, constant speed, vertical, water cooled, computerized diesel engine*
No. of cylinder	*One*
Bore	*87.5 mm*
Stroke	*110 mm*
Swept Volume	*661 cc*
Compression Ratio	*17.5:1*
Rated Output	*5.2 kw at 1500 rpm*
Injection Nozzle	*3 hole*
Fuel Injection Pressure	*205 bar*
Dynamometer	*Eddy current , water cooled, with loading unit*
Propeller Shaft	*With universal joints*
Air box	*MS fabricated with orifice meter and U tube manometer*
Fuel Tank	*Capacity 15 lit with glass fuel metering column*
Calorimeter	*Type pipe in pipe out*
Piezo sensor	*Range 5000 PSI, with low noise cable*
Crank angle sensor	*Resolution 1 Deg , Speed 5500 rpm with TDC pulse*

Table 3 Engine Specification

The engine Performance analysis has included the following features: torque, brake horsepower, brake specific fuel consumption, and brake thermal efficiency and finally the temperature of the outlet exhaust gas.

Seven blends were prepared to test the engine performance, and NOx emission. These blends were: pure diesel, diesel with surfactant only, diesel with surfactant and 10%, 15%, 20%, 25%, and 30% water added by volume. Three samples were tested for each blend to validate the results.

The experimental error was recorded to be in the range of ± 8 %. All tests are carried out at constant and variable engine speed starting from 1000 rpm up to 1500 rpm for the performance evaluation.

4. Results and Discussion

Different operational conditions were studied. And the characteristic behaviour of the engine performance under various emulsions were recorded and analysed. The torque with a function of engine speed is plotted in Fig.1. From Fig.1 it can be seen that at low revolution per minute (rpm), torque increases as engine speed increase until it reaches a maximum value around 1400 rpm. Afterwards, as engine speed increases above 1400 rpm, the torque starts to decrease. This is due to engine being unable to ingest a full charge of air at high speeds.

Also Fig. 1 illustrates that as the percentage of water increases in the emulsion sample, the torque produced increases. This may be attributed to the additional force on top of the piston provided by the pressure exerted by the vapour from the emulsified liquid. When the charge is fired in the cylinder, the water would turn to high pressure vapour. In addition, due to the higher viscosity of the emulsified fuel than that of the base fuel (pure diesel), and the presence of water promote a finer cloud which promotes atomization of the emulsified mixture during injection.

This improves engine efficiency significantly. The effect of the emulsion on the engine power is shown in Fig.2, the power increases as the engine speed increases and reaches highest power at speed of 1500 rpm at present test.

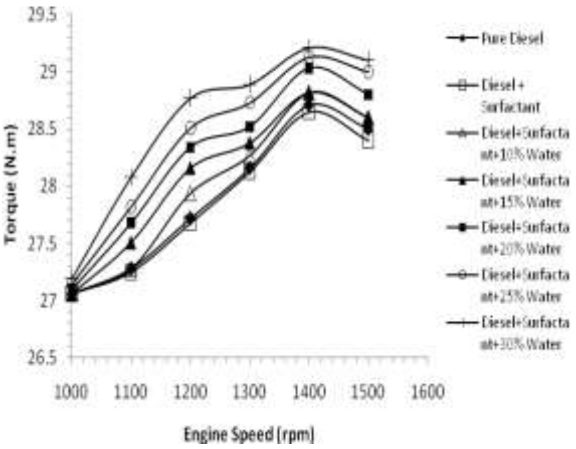

Fig.1. Engine torque versus engine speed using water diesel emulsion.

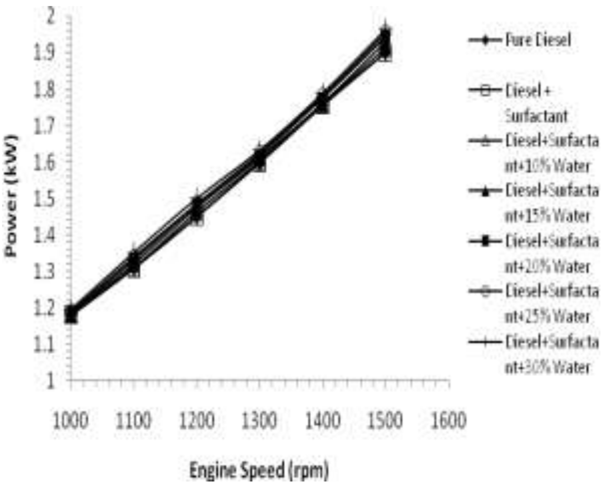

Fig. 2. Engine power output versus engine speed using water diesel emulsion.

Also, Fig. 2 shows that there is a slight increase in the engine power with increase of the water content in the emulsified samples. It was found that the introduction of water in diesel prolongs the ignition delay. The ignition delay period is when the fuel that has been injected into the cylinder is undergoing chemical and physical preparation for combustion.

Thus, the emulsion fuel requires less compression (negative) work than the diesel due to the longer ignition delay during the compression stroke. This helps to reach a higher peak pressure after top dead centre (TDC) to produce more power output during the expansion stroke.

In addition, when the ignition delay increases, more diesel would be physically prepared (evaporation, mixing) for chemical reaction, which increases the amount of diesel burned and the rate of heat release in the premixed burning. This results in enhancement of combustion and improvement of combustion efficiency. Also the use of the emulsion is also shown to result in a retarded fuel injection, but smaller ignition delay for the same engine timing.

As a result of these changes, cylinder pressures and temperatures are lower. Fig. 3 shows the variation of brake specific fuel consumption (BSFC) with engine speed considering the emulsion (diesel -water) as total fuel.

It shows that BSFC decreases as engine speed increases (at low speed), and then it would reach a minimum and then increases at higher speeds. It is that as the water percentage in the emulsion increases, the BSFC increases, this is because as the percentage of water in the emulsion increases, a larger amount of diesel is displaced by an equal amount of water. This means that less diesel fuel is actually contained within each volume of the emulsion.

As the percentage of water in the emulsion increases, BSFC of diesel decreases (i.e. diesel calorific value decrease). The minimum value occurs at a water percentage 30% by volume. The reduction in BSFC with water emulsified diesel 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 evaporation and additional mass of water cause the cylinder average temperature to become lower as the water amount was increased.

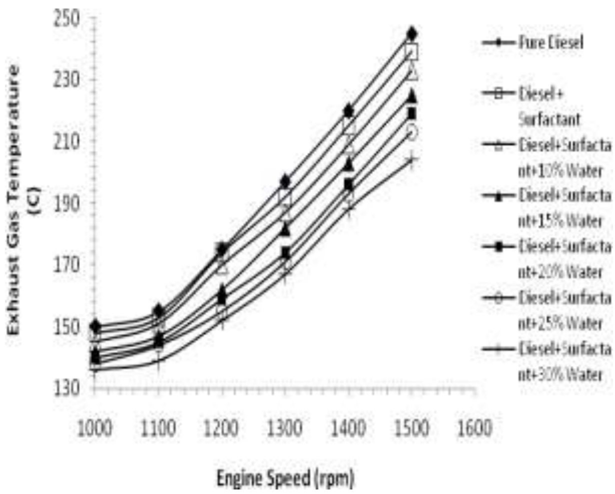

Fig.3. Exhaust gas temperatures versus engine speed using water diesel emulsion.

The variation of exhaust gas temperature with engine speed using emulsion is shown in figure 3. It is clear that as the percentage of water in emulsion increases, the exhaust temperature decreases.

The heat absorbed by the additional water can explain the decrease in the exhaust temperature. The latent heat of water will cool the charge due to the evaporation of water, and the cylinder average temperature following injection and before ignition becomes lower as the water percentage increases [14]. Figure 4 shows the effect of emulsified fuel on the brake thermal efficiency.

The maximum increase in the brake thermal efficiency occurs when 30% water in the emulsion is used, and this is due to the fact that the BSFC was at its minimum value, average increase in brake thermal efficiency for 30% water emulsion is approximately 5% over the use of diesel for the engine speed range studied.

Figs 4 and 5 represent the environmental assessment on the impact of using emulsified fuel on a KIA bus model which uses a four cylinders diesel engine. It is clear that at an optimum run speed between 1400 to 1500 rpm and using 30% water gave minimum particulate matter and NOx emissions.

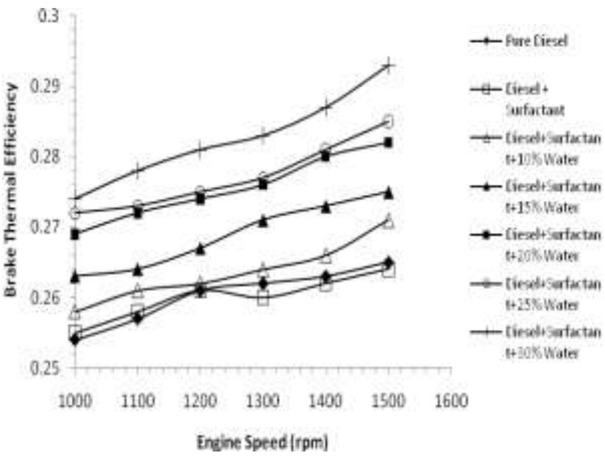

Fig. 4. Brake thermal efficiency versus engine speed using water diesel emulsion.

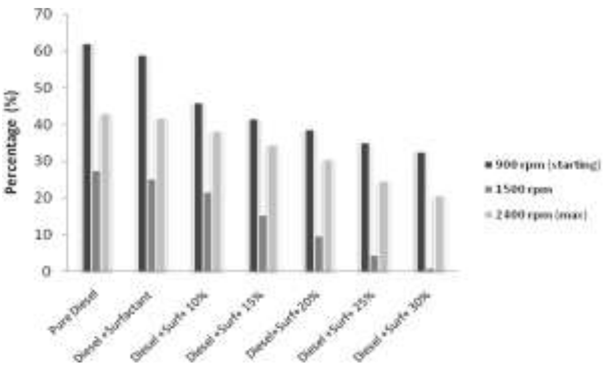

Fig.5. Particular matters Reduction effect analysis

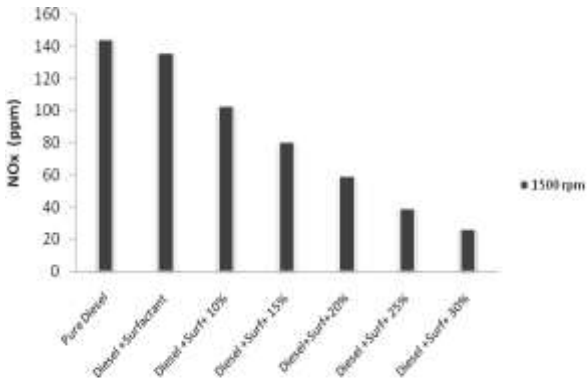

Fig. 6. NO_X Reduction effect analysis

5. Conclusions

This present study of water in diesel emulsions investigated the effect of water emulsification on diesel engine performance and exhaust gases emissions. Emulsified diesel fuels of 0, 10, 15, 20, 25 and 30 water/Diesel ratios by volume, were used in a single cylinder, direct injection Diesel engine, operating between 1000-1600 rpm. The results indicated 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 ranges studied. The particulate matter and NOx 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 nitrogen oxides and particulates.

References

[1] Nadeem M., C. Rangkuti, K. Anuar, M. Haq, I. B.Tan and S. Shah, Diesel engine performance and emission evaluation using emulsified fuels stabilized by conventional and gemini surfactants, *Fuel,* Volume 85, Issues 14-15, October 2006, Pages 2111-2119.

[2] Samec, N., B. Kegl, and R.W. Dibble, Numerical and experimental study of water/oil emulsified fuel combustion in a diesel engine, *Fuel*, Volume 81, Issue 16, 2002, Pages 2035-2044

[3] Park JW, KY. Huh, JH. Lee, Reduction of NOx, smoke and brake specific fuel consumption with optimal injection timing and emulsion ratio of water-emulsified Diesel. *Proc Inst Mech Eng* 2001; 215:83–93. http.dx.doi.org/10.1243/0954407011525476

[4] Andrews GE, Bartle KD, Pang SW, Nurein AM and Williams PT, 1988, the reduction in Diesel particulate emissions using emulsified fuels. *SAE paper*. 880348.

[5] Park JW, Huh KY and Park KH., 2000, Experimental study on the combustion characteristics of emulsified Diesel in a rapid compression and expansion machine. *Proc Inst Mech Eng* ;214(Part D):579–86.

[6] Ocampo-Barrera R, R. Villasenior, A. Diego-Marıan, An experimental study of the water content on combustion of heavy fuel oil/water emulsion droplets. *Combustion & Flame*;126:1845–55,.2001. http.dx.doi.org/10.1016/S0010-2180(01)00295-4

[7] Harbach JA and V. Agosta, Effects of emulsified fuel on combustion in a four-stroke Diesel engine. *J Ship Res*.;35(4), 1991, pp: 356–63.

[8] Tsukahara M, Yoshimoto Y., 1992, Reduction of NOx, smoke, BSFC, and maximum combustion pressure by low compression ratios in a Diesel engine fuelled by emulsified fuel. *SAE paper* 920464; 1992.

[9] Selim, MYE, and SMS. Elfeky, Effects of Diesel/water emulsion on heat flow and thermal loading in a pre combustion chamber Diesel engine. *Appl Thermal Eng*; 21, 2001, 1565–82. http.dx.doi.org/10.1016/S1359-4311(01)00019-9

[10] Desantes JM, J. Arre`gle, S. Ruiz, A. Delage, P.Schmelezle, O.Esmilaire, Characterisation of the injection-combustion process in a common rail D.I. Diesel engine running with fuel–water emulsion. *Proceedings of EAEC Congress*, Barcelona 1999 pp. 59–68.

[11] Kadota T and H. Yamasaki, Recent advances in the combustion of water fuel emulsion, *Progress in Energy and Combustion Science*, Volume 28, Issue 5, 2002, Pages 385-404.
http.dx.doi.org/10.1016/S0360-1285(02)00005-9

[12] Odaka M, N. Koike, Y. Tsukamoto, Reduction effect of emulsified fuel on NOx and smoke emissions from direct injection Diesel engines. 9303537. *JSAE Rev* 1993;14(2).

[13] Lif A. and K. Holmberg, Water-in-diesel emulsions and related systems, *Advances in Colloid and Interface Science*, Volumes 123-126, 16 November 2006, Pages231-239. http.dx.doi.org/10.1016/j.cis.2006.05.004

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

[15] Ghojel J.,D.Honnery., K. Al-Khaleefi, Performance, emissions and heat release characteristics of direct injection diesel engine operating on diesel oil emulsion, *Applied Thermal Engineering*, Volume 26, Issues 17-18,m2006, Pages 2132-2141

[16] Armas O., R. Ballesteros., FJ. Martos., and J. R. Agudelo, Characterization of light duty Diesel engine pollutant emissions using water-emulsified fuel, *Fuel*, Volume 84, Issues 7-8, 2005, Pages 1011-1018.

[17] Kannan, K., M. Udayakumar, NOx and HC emission control using water emulsified diesel in single cylinder diesel engine. *ARPN Journal of Engineering and Applied Sciences.* Vol.4, No. 8, 2009.