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Evaluation of exhaust emission from emulsified fuels in diesel engine

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ABSTRACT

Fuel economy along with high thermal efficiency is the main incentive of diesel engine applications. However, pollutant gasses exhausted from diesel engines are considered as the important sources of air pollution. Emulsification the fuel by different percentage of water has been studied in this research and its effect on pollutant emissions has been investigated. Considerable reduction in NOX emission and less specific fuel consumption were observed when emulsified fuels were used. To determine the optimum water/diesel ratio, a factor (SEF) has been defined in this article which demonstrated that emulsified fuel 20% had the best performance comparing to 10%, 15% and neat diesel.

KEYWORDS

Emulsion;
Fuel;
Air pollution;
Diesel engine;
NOX emission.

INTRODUCTION

Diesel engines have been tremendously developed in last two decades which made them completely different from the last generation. Diesel engines have many preferences such as wide and various applications, along with high thermal efficiency, comparable durability, fuel economy, higher output torque and working in heavy duty conditions. On the other hand diesel engines are considered as one of the important sources of air pollution.

Among the main air pollutants, seven of them are more noticeable which are HC, CO, CO_2, NOX, Sox, PM and aldeids. These pollutants cause damage to the ozone layer, enhance green house effect and produce acid rain[1,2].

Nitrogen in the air is oxidized during the combustion in the engine and is converted to nitrogen oxides. In as much as all of these oxides have similar effects on air pollution, all of them are considered as NOX.

The most important effect of nitrogen oxides on air pollution is their contribution in constituting the smog[3].

Plenty of researches have been conducted to reduce the exhaust pollutants emitted from diesel or gas engines; the most remarkable ones are:[4]

- improving engine design, engine maintenance conditions, and fuel system
- Using catalyst converters
- Exhaust gas recirculation (EGR)
- Water injection into combustion chamber
- Using renewable energies

- Water-diesel emulsion

Water–diesel emulsion has been introduced as an effective method to improve the combustion[5].

Emulsion includes a non-homogeneous system comprising two insoluble liquids; one is in the shape of small drops usually less than 0.1 micron spread in the other liquid. Such system has low stability due to high surface tension inside each phase. Instability of emulsion can be eliminated using surface active agents so called surfactants or emulsifiers[6].

Fuel-water surfactants must be burnt without producing soot and their structure must be free of sulfur, nitrogen and aromatic chains. Therefore they must comprise of carbon, hydrogen and oxygen. To select an emulsifier and determine its activity HLB index is needed which shows the Hydrophile-Lipophile Balance of the aforementioned phases. However it must be noted that HLB of an emulsifier doesn't show its performance.

High temperature and pressure of combustion chamber in diesel engine is the main reason of emulsification of gasoil instead of gasoline to reduce the NOX.

Presence of water drops in the fuel has significant effects in reducing NOX and particulate matters[7-12]. Therefore considerable attention has been focused to use emulsified fuels to protect the environment especially for NOX and particulate matter that directed the engines to be approved adapted Euro4 and Euro5 standards.

In most of the researches 5-10% of water was used in emulsions[13]. However in some studies it has been mentioned that the best magnitude for reducing PM is 10-20% of water.

Intake of humid air to the engine in shape of aerosol and emulsion of water in diesel was performed by Schlit and Exner. Reduction in PM and Nox emissions was reported in both method comparing to neat diesel[14].

Lin and Chen used an ultrasonic method to prepare two phase and three phase emulsion. Result showed that there is not significant difference between w/o and o/w/o emulsions. Two phase emulsions appeared to have a lower fuel consumption, CO and black smoke opacity[15].

Samec *et* al. investigated the effect of 10 and 15% of water on NOX emission, HC, soot and specific fuel consumption (SFC). Considerable reduction in HC and soot was observed in emulsion with 10% of water. NOX reduction is mostly subjected to water extent and the maximum reduction was observed at highest percentage of water[16].

Nadeem *et* al. evaluated diesel engine performance and emission using emulsified fuels stabilized by two different kinds of surfactants. They used a four stroke, four cylinder engine (Ford XLD418) with a compression ratio 21.5 and maximum power of 60hp at 4800 rpm to investigate the emission of Co, Nox, and PM. The results showed that emulsions stabilized by Gemini surfactant had more identical distribution of water in diesel and were more stable which leads to better atomization of fuel[17].

Lin and Wang used four strokes, four cylinder diesel engine UMBDI to investigate the three phase o/w/o fuel emulsions. The engine had a compression ratio of 17 and maximum power of 88 hp at 2800 rpm. The results showed that three phase emulsions produce higher exhaust gas temperature compare to two phases w/o emulsions but lower CO and NOX emissions[18].

It can be inferred from the previous researches that pollutant emissions of emulsified fuels are different in some conditions such as engine power, rated rpm and output torque for heavy or light duty engines.

Thus the main objective of this study was to evaluate the emulsified fuels by different percentage of water on a light duty engine with maximum rpm of 1800.

It is also evident that in the previous researches, pure pollutant emission has been considered for introducing the optimum water/diesel ratio.

Therefore this study was performed to compare emissions of three different percentages of water /oil ratios 10%, 15% and 20% based on the proposed emission factor (e) which is introduced in this article. This factor makes it possible to compare emissions considering power and fuel consumption at the same time.

MATERIAL AND METHODS

A light duty diesel engine coupled to an electrical dynamometer was used to measure engine power and fuel consumption. Three different percentage of water in diesel was used to provide emulsified fuels 10%, 15% and 20%. Internal combustion engine in this study was a single cylinder, four stroke, water cooled with a brake horsepower of 9 hp at 1800 rpm. This maximum power can be reached at compression ratio of 18:1.

Displacement volume of the engine was 765 cc. The electrical dynamometer was used to exert variable loads on engine. There are 20 loading switch provided on dynamometer that each one exerts a torque equal to 2.7 N.M on engine.

Two kinds of surfactants were used to prepare two phase o/w emulsified fuels. The surfactants were a lipophilic agent "Span 80" and hydrophilic agent "Tween 80". Characteristics of these two surfactants are listed in TABLE 1.

TABLE 1 : Some physicochemical characteristics of surfactants used for emulsified fuels.

Surfactants	HLB	Specific gravity
Span 80 (sorbitan monooleate)	4.3	0.98
Tween 80 (polyoxyethylene sorbitan monooleate)	15	1.08

In as much as HLB is an important factor in emulsion stability, a mixture of Span 80 and Tween 80 was prepared to produce HLB=8 which has the most stability. The required amounts of these two surfactants were determined using equation 1:

$$\mathbf{HLB_{AB} = (H_A \times W_A)+(H_B \times W_B)} \quad (1)$$

W_A, W_B: weight of each surfactant A (Span 80), B (Tween 80), H_A, H_B: HLB value of the surfactants.

In TABLE 2, required amounts of these surfactants are shown to prepare emulsifier with HLB= 8 for 1 liter of fuel emulsion. 2%, 3% and 4% emulsifiers were respectively used for emulsions 10%, 15 % and 20% water in fuel.

TABLE 2 : Required amounts of surfactants used for preparing the emulsifier.

Surfactant	Emulsion 10%	Emulsion 15%	Emulsion 20%
Span 80	13.1	19.6	26.2
Tween 80	6.9	10.4	13.8

Preparing the fuel

To form an emulsion, energy is needed to spread the dispersed phase as small drops in the continuous phase. Mixing speed is one of the effective factors on stability of emulsion and diameter of the drops inside the continuous phase. So in this study a mixer with 300 rpm speed was used. In each test, four liters fuel prepared according to TABLE 3 following the stages below:

1- Mixing the gasoil and Span 80 by means of a mixer at 3000 rpm for 5 minutes.
2- Mixing Tween 80 and water at 3000 rpm for 5 minuets.
3- Mixing the part1 and 2 at the same speed for 5 minuets

TABLE 3 : Combination of the emulsified fuels

Emulsifier	Water (cc)	Gasoil	Mixture percentage
20	100	900	10%
30	150	850	15%
40	200	800	20%

Procedure of the tests

To ensure that engine is consuming the considered fuel, in each test, fuel system was completely vented and charged with the next fuel.

Tests were begun after warming up the engine to 80ºc, power measurements carried out using dynamometer by exerting variable loads. Tests were begun from the maximum revolution speed (at idling speed of 1800 rpm). At this speed, output torque and power were zero and gradually were increased by loading the engine.

Loading the engine by means of electrical resistors in the dynamometer decreases the engine speed and makes the output torque to increase. Output torque can be measured by equation 2:

$$\mathbf{T = r.F} \quad (2)$$

Where T: output torque of the engine, F: reaction force of the engine measured at generator casing of the dynamometer, r: distance between scale and center of rotation of the generator.

Output power was then determined using equation 3:

$$\mathbf{P = 2\pi nT/60} \quad (3)$$

Where P: Output power in watt, N: Engine revolution speed (rpm)

Measuring specific fuel consumption (SFC)

Loading the engine increases fuel consumption. Fuel consumption was determined by measuring the time that engine consumed 15cc fuel. Specific fuel consumption was calculated using equation 4:

$$\mathbf{SFC = Q/P} \quad (4)$$

Where Q: fuel consumption (lit/hr)

Measuring pollutant emissions

Exhaust gases were measured using an exhaust gas analyzer EUROGAS model 8020. This instrument was able to measure gases Co, Co2 and O2 in percentage and gases No and HC in ppm.

In each stage exhaust gases were taken into analyzer and data were recorded after some seconds when measurements became stable.

RESULTS

All the tests were performed in three replications and data were recorded when two replications gave the same result.

Power test

Variations of the output power versus engine revolution speed were drawn in Figure 1 by measuring output torque and using equation 3.

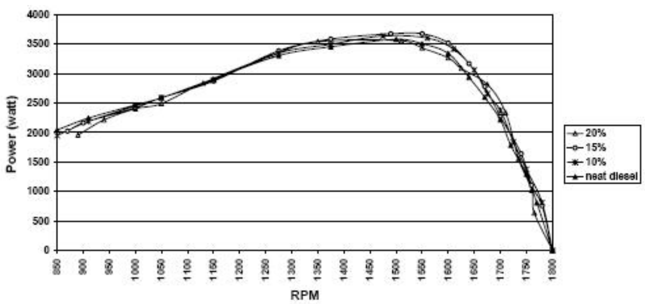

Figure 1 : Output power of neat diesel and emulsified fuels with 10%, 15% and 20% water content

As it can be seen, adding water to fuel in none of the aforementioned percentages decreased the output power. Although a small increase in power was observed at maximum power of emulsion 15% which was 2.6% respect to neat diesel.

Comparing different mixture percentage of water and diesel, it can be seen that output power with higher water content at high RPMs were higher than neat diesel but at low RPMs output power of emulsions were less than neat diesel. Two reasons can be mentioned for this case; Firstly, water has been converted to steam by absorbing the heat, and its expansion has raised the effective pressure on piston, but while using neat diesel, this high temperature gases exhausted ineffectual from the engine. Secondly, micro-explosions occur in emulsified fuels due to existence of water that makes the fuel to be atomized more effectively. This lowers ignition delay and raises the power at higher RPMs but this is not the case in lower RPMs because the flame has more time for expansion.

Specific fuel consumption (SFC)

Increasing water content in emulsified fuels has diminished the fuel consumption of the engines as it can be seen in Figure 2. Also it shows that the reduction in fuel consumption is proportional to water percentage of emulsified fuels.

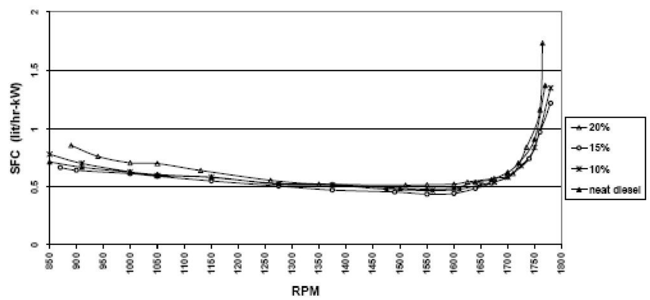

Figure 2 : Specific fuel consumption using emulsified fuels and neat diesel

It should be also noted that the pure gasoil consumption is lesser when the percentage of gasoil in mixture is considered. Figure 3 were drawn based on pure gasoil consumption for neat diesel and three emulsified fuels.

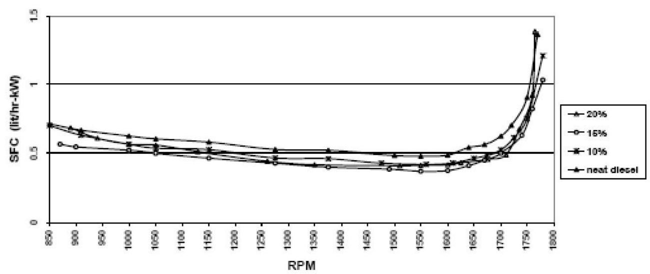

Figure 3 : Pure specific fuel consumption using emulsified fuels and neat diesel

CO emission

Carbon monoxide is one of the most important toxic and pollutant gases produced from incomplete combustion in engine. Figure 4 shows the effect of adding water to gasoil on CO emission at different revolution speed.

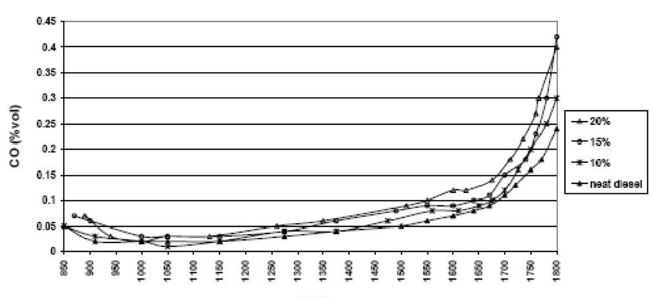

Figure 4 : CO emission of neat diesel and emulsified fuels with 10, 15 and 20% water content.

It can be seen that CO emission have been increased when water content of the emulsified fuel were increased. Also this increase in CO emission was proportional to the water extent added. This is due to the fact that water causes the combustion temperature to drop which in turn causes the incomplete combustion. Also existence of water in combustion chamber decreases the contact of oxygen and fuel molecules that also causes incomplete combustion.

CO_2 emission

CO_2 is a desirable product of complete combustion. Higher CO_2 emission is a result of better performance of the engine. In fact CO_2 and water vapor are two main gases make the pressure on piston and produce mechanical energy in engine. Figure 6 shows that loading the engine from the idle speed causes CO_2 emission in engine to increase. But this increase drops with loading the engine after reaching a relative maximum.

Also it is seen that adding water didn't have the significant difference on CO_2 emission.

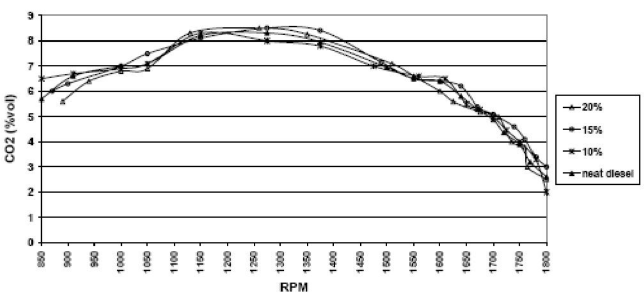

Figure 5 : CO_2 emission of neat diesel and emulsified fuels

HC emission

Unburned Hydrocarbons has been increased by adding water percentage in emulsion (Figure 6). It means that existence of water in fuel causes misfire of some extents of fuel.

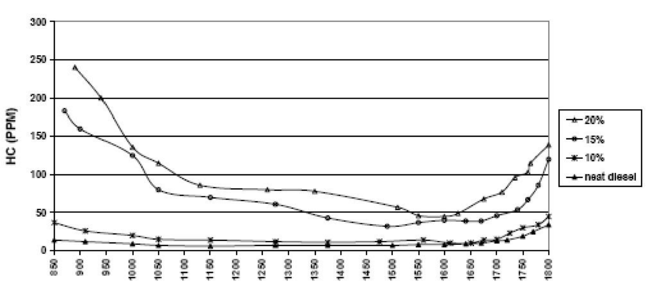

Figure 6 : HC emission of neat diesel and emulsions

There is not a significant difference between the increase in HC emission for emulsions with 15%, 20% of water comparing to neat diesel and emulsion 10%.

When this result is combined to results of power performance of the engine (Figure 1) it is seen that in spite of incomplete combustion, output power of the engine has not decreased. It means that the amount of power increment due to vapor expansions and micro-explosions has been higher than deficiency in power due to misfires.

O_2 emission

Existence of O_2 in exhaust in contrast to CO is an indication of a lean air/fuel mixture. High amount of O_2 is a symptom of incomplete combustion and misfire that normally is together with increasing unburned hydrocarbons or CO.

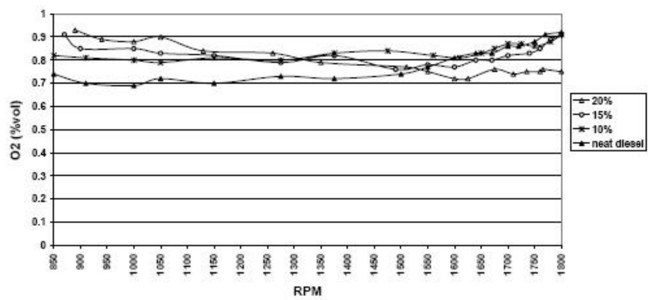

Figure 7 : O_2 emission for neat diesel and three kinds of emulsions

Figure 7 represents that adding water to gasoil had increased O_2 existence in exhaust which means that adding the water prevented complete fuel consumption. This is in accordance with the results of CO emissions previously discussed.

NOX emission

As it can be seen in Figure 8 adding water to diesel has been caused reduction in NOX emission. It is due to the fact that the high temperature in combustion chamber which is necessary for NOX formation drops due

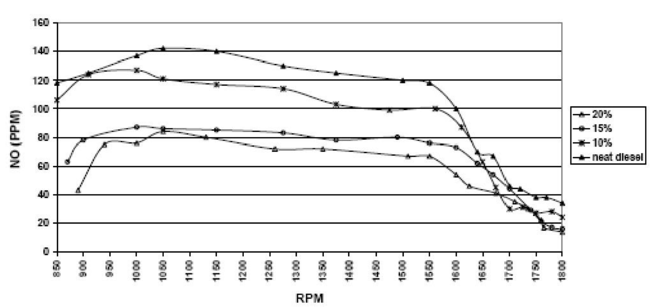

Figure 8 : NOX emission of neat diesel and emulsions

to existence of water in emulsified fuel. It is also evident that NOX emission has been reduced when the percentage of water in emulsions have been increased however there is not a significant difference between emulsion 15% and 20%.

Comparing the result of NOX emission to other exhaust pollutant, it is inferred that the most noticeable effect of adding water to diesel is NOX reduction.

Reduction in NOX emission was specifically observed at lower engine speeds because loading the engine increased the temperature of combustion chamber and water could diminish the temperature more effectively.

It is interesting that reduction in engine temperature did not cause the power of the engine to drop. The reason is that the produced heat of combustion has been absorbed by water and converted to steam which raised the pressure on the piston and power. It means that however the combustion temperature has been fallen but the overall energy content of the combustion has not decreased and the effect of high temperature of combustion has been changed to expansion of water steam.

To select the best emulsion composition, a comparison between these fuels was achieved. At first sight, emulsion 20 with less emission seems to be a good selection. It is obvious that more water percentage will produce less emission. However the output power will also diminish. Therefore, a ratio of emission to power must be considered for comparison between the fuels.

On the other hand it is possible that the high power produced is a result of more fuel consumed. Thus a ratio of power to fuel consumption must also be considered.

Accordingly it is more rational that emission to be considered respect to power produced and fuel consumed. Therefore in this study "specific emission factor" (SEF) was defined to be used as a criterion for this selection.

$$\mathbf{SEF} = \frac{\mathbf{Emission} \times \mathbf{Fuel Consumption}}{\mathbf{Output Power}} \quad (5)$$

or

$$\mathbf{SEF} = \mathbf{Emission} \times \mathbf{SFC} \quad (6)$$

Figure 9 represents the mean SEF values for emulsified fuels and neat diesel. It shows that SEF value for emulsion 20% was less than the other fuels. Thus it can be said that emulsion 20% has been emitted less NOX corresponding to power produced and fuel consumed.

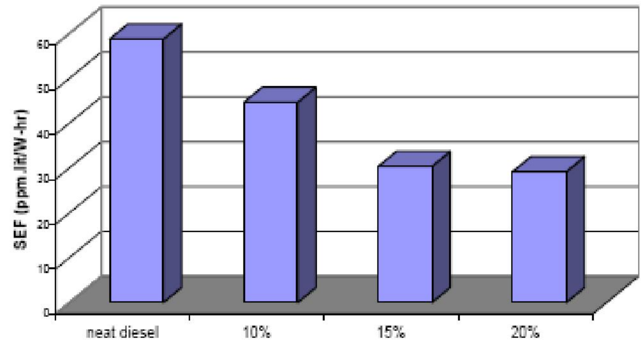

Figure 9 : SEF value for diesel and emulsions

CONCLUSION

Different emulsified fuels have been provided in this study by adding three different percentage of water to diesel. These fuels have been compared to neat diesel for their performance and exhaust emissions. Following conclusions were deduced from the results:

- Adding water to diesel not only causes the power not to diminish but also a little increase in power may be observed.
- Specific fuel consumption of emulsified fuels was less than that of neat diesel; reminding that reduction of SFC means reduction in overall air pollution
- Adding water to diesel as emulsion specifically reduces NOX emission which is more considerable at higher engine loadings.
- In as much as combustion temperature and pressure in diesel engines are higher than that of gas engines, using emulsified fuels can diminish a large portion of overall NOX pollution in the air.
- Specific emission ratio (SEF) was defined to compare different fuels based on emission, considering fuel consumed and power produced. Emulsification the fuel with 20% water which has less SEF is recommended to limit air pollution.

In brief, preferences of adding water to gasoil in the shape of emulsified fuels can be mentioned respectively based on their importance as:

- reduction in NOX emission
- relative increasing power
- reduction in fuel consumption

REFERENCES

[1] C.Y.Lin; Ocean Engineering., **46**, 589 **(2000)**.

[2] C.Y.Lin, J.Y.Pan; Corros Prev Control., **47**, 83 **(2001)**.

[3] C.Y.Lin, K.H.Wang; Fuel., **83**, 507 **(2004)**.

[4] R.J.Crookes, F.Kiannejad, M.A.A.Nazha; Energy Conservation and Management., **38**, 1785 **(1997)**.

[5] M.Abu-Zaid; Energy Conversion and Management., **45**, 697 **(2004)**.

[6] C.Gonglun, T.Daniel; Fuel Process Technol., **86**, 499 **(2005)**.

[7] J.M.Ballester, N.Fueyo, C.Dopazo; Fuel., **75**, 695 **(1996)**.

[8] R.W.Gunnerman, R.L.Russel; SAE Tech Pap., 972099 **(1997)**.

[9] G.E.Andrews, S.W.Bartle, S.W.Pang, A.M.Nurein, P.T.Williams; 'Proceedings of the International Centre for Heat and Mass Transfer', Hemisphere Publ Corp; New York, **(1989)**.

[10] W.Bernhardt, K.Weidmann; Erdol Kohle Erdgas Petrochem., **40**, 86 **(1987)**.

[11] D.Hall, C.Thorne, S.Goodier; SAE Tech Pap., 2003-01-3168, 153 **(2003)**.

[12] M.Tsukahara, Y.Yoshimoto; International Congress and Exposition, Detroit, USA, 24–28 Feb. **(1992)**.

[13] A.Lif, K.Holmberg; Advances in Colloid and Interface Science., **123–126**, 231 **(2006)**.

[14] H.G.Schlitt, P.Exner; Glueckauf-Forschungsh., **52**, 278 **(1991)**.

[15] C.Y.Lin, L.W.Chen; Fuel Processing Technology., **87**, 309 **(2006)**.

[16] N.Samec, B.Kegl, R.W.Dibble; Fuel., **81**, 2035 **(2002)**.

[17] M.Nadeem, C.Rangkuti, K.Anuar, M.R.U.Haq, I.B.Tan, S.S.Shah; Fuel., **85**, 2111 **(2006)**.

[18] C.Y.Lin, K.H.Wang; Fuel., **83**, 537 **(2004)**.