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Effects of Water-Diesel Emulsions on the Performance of Single Cylinder Direct Injection Diesel Engine - A Review

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Abstract—*Diesel engines are known for their simple mechanism, rigid structure, low breakdown rate and fuel economy and because of these features diesel engines are used as the major power source for both in-land and marine transportation. However pollutants emitted, mainly nitrogen oxides and particulate matters are serious problem with diesel engines. Water-Diesel emulsion is a new concept regarding fuel which can be used in place of diesel fuel for the purpose to get the reduction in emissions and improvement in the performance of diesel engines.*
The emulsified fuel contains water and diesel fuel with some suitable surfactants to stabilize the system. An important aspect pertaining to water-diesel emulsion as a fuel for diesel engines is that it can be used without any modification in the existing engine. This paper presents a review of recent progress in research of using water-diesel emulsion as a fuel for the purpose of improving engine performance of a single cylinder direct injection diesel engine in terms of engine torque, engine brake thermal efficiency, engine power, engine brake specific fuel consumption.

Keywords*: Diesel engine, Water-Diesel emulsion, engine torque, engine power, engine brake thermal efficiency, engine brake specific fuel consumption, micro-explosion;*

1. INTRODUCTION

Water-diesel emulsions are the fuel which can be used as an alternate fuel for diesel engine. Use of this alternate fuel gives an improvement in the performance and reduction of pollutants emitted from the engines simultaneously. Water-diesel emulsion is easily applicable alternative fuel and can be used in place of conventional diesel without any modification in the existing diesel engine. In this review paper the main focus is on water-diesel emulsion technique which has been proven that it is an effective and most universal method for reducing the emissions along-with improvement in the engine performance.

The water-diesel emulsions are found to be an appropriate method because this method does not require any modification in the existing engine [1]. It has also been concluded that water-diesel emulsion technique helps in occurring the micro-explosion and thus finally helps in improvement of atomisation and mixing process which results in improvement in combustion efficiency of diesel-engine [2].

The introduction of water with diesel has two contradicting effects [3]:

(1)The improvement of engine emissions because of occurrence of micro-explosion due to which the enhancement of fuel atomization occurs and thus leading to better fuel–air mixing.
(2)It decreases the engine efficiency because the energy needed for the evaporation of the water is higher (larger than 10 times as compare to energy needed for the evaporation of diesel fuel) and at the same time a reduction in calorific value also occurs.

2. WATER-DIESEL EMULSIONS

Water-diesel emulsion is an emulsion of water and standard diesel fuel with suitable surfactants to stabilise the emulsion for a specific duration of time so that emulsion can be used practically. Using water-diesel emulsions as a fuel in diesel engine have shown several interesting effects like reduction in NOx and PM emissions and at the same time improvement in the combustion efficiency.

Since diesel is a lighter liquid than water and because of this diesel comes at the top and water settles at the bottom of the container when they are to be mixed directly. The molecules of diesel and water can be bound together by using an appropriate surfactant. Stability of water-diesel emulsion for an appreciable period of time is one of the important factor without which emulsion cannot be used practically and it depends on the structure of the surfactant used in the emulsion.

3. SURFACTANTS

The emulsifying surfactant may be any surface-active substance which has ability to form a thin interfacial film between the two liquids and at the same time it must contain the ability to maintain the emulsion by minimizing the contact, coalescence and aggregation of the internal dispersed phase [4, 5]. The surfactants reduce the surface tension between oil and water and they may act as emulsifiers, detergents, wetting agents, foaming agents and dispersants. Table 1. shows the different types of emulsions and their respective HLB values. Choosing the right surfactant for the two liquids to be emulsified is one of the biggest challenges for emulsification process and this depends on the Hydrophilic Lipophilic Balance (HLB) value (which measures the degree of Hydrophilic or Lipophilic) of the surfactant. Table 2. shows some common surfactants and their respective HLB values.

Table 1: HLB values for different types of emulsions [6, 7].

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	Solubilize and hydro trope

Table 2: HLB values for some common surfactants [6, 7].

Surfactant	HLB Value
Sorbitan trioleate (Span 85)	1.8
Sorbitan monooleate, NF, (Span 80)	4.3
Sorbitan monostearate, NF,(Span 60)	4.7
Sorbitan monopalmitate, NF,(Span 40)	6.7
Sorbitan monolaurate, NF, (Span 20)	8.6
Polyoxyethylene trioleate(Tween 85)	11
Polysorbate 60, NF, (Tween 60)	14.9
Polysorbate 80, NF, (Tween 80)	15
Polysorbate 40, NF, (Tween 40)	15.6
Polysorbate 20, NF, (Tween 20)	16.7

4. CHALLENGES AND LIMITATIONS WITH EMULSION

When a trial is made for high reduction in the emission of NOx from a diesel engine using water-diesel emulsion as a fuel in practice then at that time fuel pump capacity and the fuel nozzle sizes are the main limitations. When high water content is used in the emulsion of water-diesel as a fuel for diesel engine a limiting factor of pump capacity comes into the picture at high load because the energy needed for the evaporation of the water is higher as compare to diesel. Therefore more energy is required to drive the pump which will increase the fuel consumption and price. If a standard fuel nozzle is to be used in the system and if the system is in operating condition for a longer period of time, the fuel consumption will increase to inject the larger mass (at high load). On the other hand if a fuel nozzle with increasing size is used, it will increase the emissions in diesel engine at low load condition when the system is switched off [8]. As the fuel injection starts (water-diesel emulsion is used as a fuel) in diesel engine, the water comes with the diesel but when combustion starts the water tends to evaporate faster than that of diesel with a higher heat release and thus it may cause a undesirable temperature decrease and cause an ignition delay. To compensate the ignition delay, the injection timing has to be adjusted. Table 3. shows Preparing conditions and stability period of water-diesel emulsion for different water concentration.

Table 3: Preparing conditions and stability period of water-diesel emulsion for different water concentration [2].

Water-diesel Ratio	Mixing speed (rpm)	Mixing time (min)	Surfactant (percentage)	Period of stability	Sautor mean droplet diameter (Micro-meter)
10/90	15,000	2	0.2	4 weeks	4.24
20/80	15,000	10	0.2	10 days	3.71
20/80	15,000	10	1.0	4 weeks	3.71
30/70	20,000	30	1.7	1 week	1.70
40/60	20,000	30	2.0	4 hours	2.25
50/50	20,000	30	2.0	1 hour	2.62

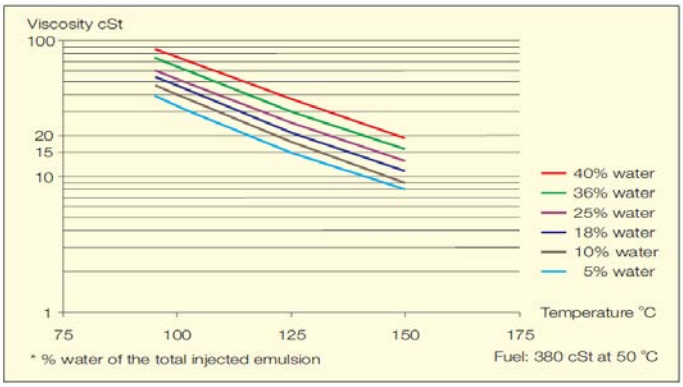

Fig. 1: Water-in-fuel emulsion viscosity versus temperature [9].

When the water-in-fuel emulsion is used, the viscosity increases with the water amount at a given temperature as shown in Fig. 1. The temperature of the emulsion must be increased to avoid the too high viscosity. But question is how much temperature of the emulsion must increase to avoid the too high viscosity and solution of this problem is as it depends on what heavy fuel oil is to be used for the emulsion and what is its viscosity at the beginning. The viscosities of most of the heavy fuel oil used today are of 180 or 380 cSt (at 50 °C) and the share of heavy fuel oil with viscosity 500 cSt is increasing [8]. Apart from this it has also been concluded that the

relationship of viscosity-temperature depends on the quality of crude oil and fuel refining process. A thumb rule that the fuel temperature must be increased by 0.5 - 1 °C for each percentage of added water in order to keep the injection viscosity of heavy fuel oil at the same level as in normal operation (20 cSt) [8].

O-rings of the fuel injection pumps start to suffer at a higher temperature and because of this problem it is desired that heavy fuel injection temperature should not exceed 140 °C [8]. On the other hand there are more expensive sealing materials available and if 140 °C temperature is not maintained then it could be an alternative. So for compromising between these two problems the pressure must be increased to avoid evaporation and boiling of the emulsion system. The mixing of water and fuel is an another challenge, they must mixed together properly and at the same time emulsion is required to be a stable for a certain period of time when emulsion is being used practically. Generally there are three types of instability in emulsions are found [6].

(a)**Flocculation:** is the process in which the dispersed phase of the emulsion comes out of suspension in the form of flakes. (b)**Coalescence**: when very small droplets bump into each other and combine to form progressively larger droplets then this type of instability is known as coalescence. (c) **Creaming**: Emulsions can also undergo creaming, under the influence of buoyancy the migration of one of the substances to the top or the bottom of the emulsion. Another issue is the quality of water used for the emulsion because it affects the emulsion itself and causes corrosion problem in the cylinder of the engine and thus finally results wear of the engine parts. So to overcome this problem high quality water is required for the emulsion of water-diesel. According to MAN [10] distilled water is needed for good durability but according to Wartsila [8] tap water is good enough for preparing emulsion of water-diesel.

Some disadvantages of using water-diesel emulsion technology on the performance of diesel engine: (a) since as the amount of water in the water-diesel increases the viscosity and density of emulsion fuel also increases and thus it affects the performance of fuel injection system significantly [11]. (b) This technology is inherently unstable and tends to phase separation problem which may damage the various parts of the engine. Presence of water in the emulsion may cause the corrosion in the surface of various parts of the engine [12]. (c) Due to presence of water in the emulsion, a temperature fall in the in the combustion chamber occurs which may cause an increase in the engine noise [13].

5. ENGINE PERFORMANCE

Engine Torque

To know the effect of using water-diesel emulsions on the gas temperature and performance of single cylinder diesel engine many experimental investigations were carried out. The water content used for experimental work was in the rations (water/diesel) of 0, 5, 10, 15 and 20 by volume. The result showed that the addition of water with diesel fuel improves the engine torque and it increases as the percentage of water content by volume in the emulsion increases. Experiments revealed that an increase in the content of water in the water-diesel emulsions by volume results an increment in the engine torque [14, 15].

On the other hand after conducting an experimental work a reduction in the engine torque had been reported with water-diesel emulsion as a fuel instead of pure diesel [16]. A relatively comparative torque was observed with 5% water content by volume in the emulsion of water-diesel. Gemini surfactant as an emulsifier for the emulsion of water-diesel was used. Results revealed that reduction in heating value with an addition of water is the cause for the reduction of engine torque. A maximum engine torque at a water content of 5% by volume in the emulsion had been reported when the experimental work with water content ranged between 5% and 30% was conducted [17]. Fig. 2. shows the variation of engine torque as the water content increases in water-diesel emulsion fuel at different engine speed. Experimental investigations were carried out to compare the performance and emission characteristics of emulsions. The produced engine torque was maximum at 5% water content in water-diesel emulsion because increase in the water content beyond 5% will lower the calorific value of the fuel. Also this maximum torque was observed at 2000 rpm engine speed beyond which it starts decrease due to friction losses (negative torque) and at high speed engine will not be able to get full charge of air [22].

The researchers [14, 15] reported an improvement in the engine torque as the water content by volume in the emulsion increases but [16, 17, 22] reported a negative effect on the engine torque when emulsion of water-diesel as a fuel is used as compare to pure diesel.

Engine brake Power

An experimental investigation was performed and conclusions were made on the basis of results found. The addition of water with diesel fuel improves the engine power and it increases as the percentage of water content by volume in the emulsion increases. An increase in the engine power with increase in water content by volume in the emulsion was observed [14, 15]. Maximum engine power was reported at a water content of 5% by volume in the emulsion when experimental work was performed with water content ranged between 5% and 30% [17, 22] whereas better power output had been reported with pure diesel as compared to all the sample of emulsion of water-diesel at 4000 rpm. Fig. 3. shows the variation of engine brake power as the water content increases in water-diesel emulsion fuel at different engine speed.

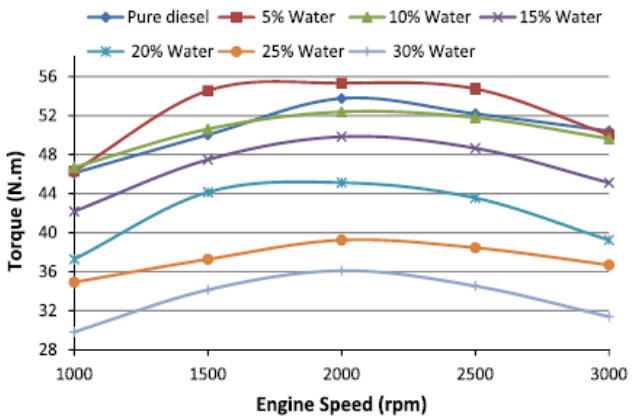

Fig. 2: Variation of engine torque with pure diesel and different water content in water-diesel emulsion at different engine speed [22].

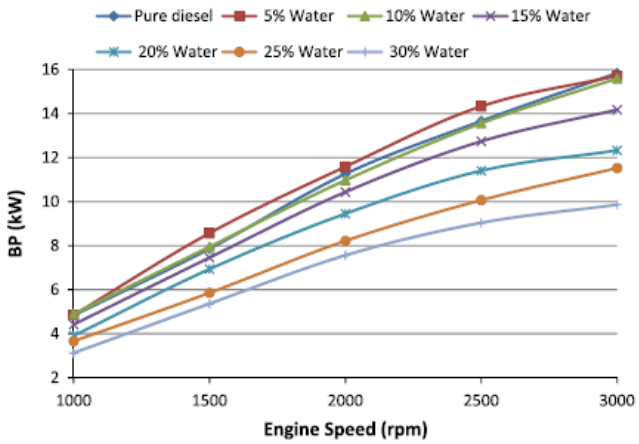

Fig. 3: Variation of engine brake power with pure diesel and different water content in water-diesel emulsion at different engine speed [22].

Engine Brake Thermal Efficiency

An increase in brake thermal efficiency was reported with increase in water content in water-diesel emulsion [14, 18]. Maximum brake thermal efficiency had been reported at water content of 5% by volume in the emulsion [17, 15, 22] when experimental work was performed with water content ranged between 5% and 30%. Similarly an increase in the brake thermal efficiency is 4.59% for a water content of 8% and 2.48% for a water content of 5% by volume in the water-diesel emulsion [19]. Fig. 4. shows the variation of engine thermal efficiency as the water content increases in water-diesel emulsion fuel at different engine speed.

Table 4. shows the variation of engine brake thermal efficiency as compare to pure diesel fuel with different water content in water-diesel emulsion [22].

Table 4: The variation of engine brake thermal efficiency as compare to pure diesel fuel with different water content in water-diesel emulsion [22].

Water content in %	5	10	15	20	25	30
Variation in %	8.31	6.58	3.74	-3.96	-0.88	-6.26

Engine Brake Specific Fuel Consumption (BSFC)

Experimental studies had been done to know the effect of water percentage on BSFC. They reported the decrement in BSFC of diesel engine. The results showed that as the volume percentage of water content in the water-diesel emulsion increases, BSFC decreases. The reason behind the decrement in the BSFC is replacement of diesel by water in same amount and thus less amount of diesel contained in the emulsion [1, 14, 18, 20]. On the other hand an increase in the BSFC as compared to pure diesel had been reported with a water content of 10% by volume [21]. Minimum BSFC had been reported at 5% water content in water-diesel emulsion and at an engine speed of 2000 rpm [22].

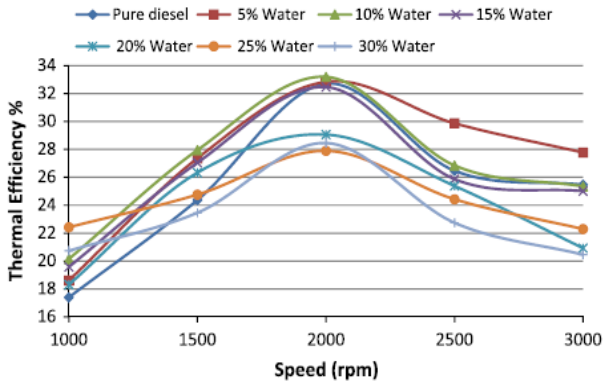

Fig. 4: Variation of engine thermal efficiency with pure diesel and different water content in water-diesel emulsion at different engine speed [22].

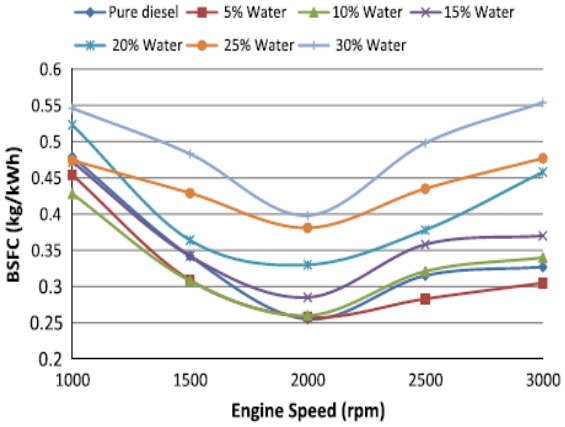

Fig. 5: Variation of engine BSFC with pure diesel and different water content in water-diesel emulsion at different engine speed [22].

Most of the researchers [1, 14, 18, 20.] reported an improvement in the BSFC as the water content by volume in the emulsion increases whereas Armas et al. [21] reported a negative effect on the BSFC as the water content by volume in the emulsion increases.

6. CONCLUSION

The technique of using water-Diesel emulsion in place of conventional diesel in diesel engines has been shown to be an effective method which has a great contribution in the improvement of engine performance in terms of engine torque, engine power, engine brake thermal efficiency, engine brake specific fuel consumption. Most of the researchers reported an improvement in the engine torque, engine power, engine brake thermal efficiency, engine brake specific fuel consumption with an increase in the amount of water percentage in the water-diesel emulsion but on the other hand some researchers also reported a negative effect of water-diesel emulsion in engine torque, engine power, engine brake specific fuel consumption with an emulsion of water-diesel as compared to pure diesel. This kind of inconsistency in the obtained results is because of use of different engine setups, variation in the percentage of water and surfactants used in the emulsions.

This review paper provides some useful information about the different types of surfactant and emulsion along-with their HLB values and effect of water-diesel emulsion on the performance of diesel engines. Experimental investigation about the effect of various surfactants in the water-diesel emulsion and finally on engine performance and emission characteristics is not known and thus requires more investigation.

7. ACKNOWLEDGMENT

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