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# Experimental investigation on the use of water emulsified diesel in a single cylinder Compression Ignition engine

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**Abstract**. In this work, an experimental investigation has been carried on a single cylinder variable compression ratio CI engine to investigate its performance and emission characteristics using neat diesel and water emulsified diesel with 10% water content (WED10). The emulsion has been prepared in the laboratory using ultrasonic vibrator. The performance characteristics include brake thermal efficiency and BSFC, and the emission characteristics include $NO_x$ and HC emissions only. It is found that brake thermal efficiency undergoes no significant change for both the fuel variants and the BSFC is slightly reduced when only diesel is considered in the WED10. There is a considerable amount of reduction in $NO_x$ emission with the use of WED10. But HC emission increases with the use of WED10 due to decrease in combustion temperature and increase in ignition delay. Thus, WED10 may be considered as a viable alternate fuel having a greener emission and a comparable engine performance.

**Keywords:** Micro explosion, ignition delay, combustion efficiency, emulsion, emission.

## 1. Introduction

The emissions of green house gases into the atmosphere due to the combustion of fossil fuels resulted in melting of the glaciers, lowering of the snow covers, increase in sea level and also severe weather conditions such as drought, storm and floods. These emissions are largely contributed by the industrial and transport sectors [1]. Internal combustion engines are mostly used in the transport and agriculture sectors due to their simple and rigid structure and also high power to weight ratio. Diesel engines are mostly popularly used in marine and in-land transportation because of their high fuel economy [3]. But, diesel engines largely contribute to $NO_x$ and particulate matter (PM) emissions. Diesel engines also emit carbon monoxide (CO), carbon dioxide, black smoke, soot and hydrocarbons (HC) [1-4]. These emissions are found to be fatal not only for the ecosystem but also for the human beings as these are carcinogenic in nature and cause asthma, lungs disorder and many other diseases [1]. To mitigate the environmental issues due to these emissions, Kyoto protocol was established in 1997 [1, 2]. Several devices were invented to reduce $NO_x$ and PM emissions to combat the strict norms adopted in Kyoto protocol. Formation of $NO_x$ was reduced using devices such as $NO_x$ Absorber Catalyst (NAC) and Selective Catalyst Reduction (SCR). Similarly, PM emission was reduced using the devices like Diesel Oxidation Catalyst (DOCs) and Diesel Particulate Filters (DPFs). However, it was reported in the literature that $NO_x$ and PM could not be reduced simultaneously [1, 5]. The steady supply of fossil fuels is also questionable due to their limited storage under the earth surface. These problems have necessitated the search for alternate fuels to be used in diesel or compression ignition engines worldwide. Water emulsified diesel is found to be one of the most suitable alternate fuel which can be used in the exiting engines without any modification. Different approaches which tried to introduce water in the combustion zone are: (a) injecting water into the cylinder using a separate injector (b) intake air to engine mixed with fumigated water (c) mixing of water and fuel before injection (d) mixture of stabilized emulsions of fuel and water considered as a single fuel [3]. But the first three approaches need an extra retrofitting which increases the complexity of engine design and also cost. Hence, injecting water emulsified diesel may be considered as the most effective way as it requires no retrofitting to the engine and reduces emissions of $NO_x$ and PM simultaneously. [1, 2, 6]. The mixing process is found to be improved with the use of water emulsified diesel due to secondary atomization. The secondary atomization is mainly due to the volatility difference between the diesel and water, where water gets evaporated at 100ºC resulting in expansion and due to the exceeding of interfacial surface tension, the diesel droplets breaks into finer one. This phenomenon is known as micro-explosion [4, 6].

Several number of studies were conducted with the water emulsified diesel as fuel to observe the influence on the emission and the performance characteristics of the diesel engine. Ithnin *et al*. [2] observed a reduction in specific fuel consumption when only diesel portion of WED was considered. They also noted reductions in $NO_x$ and PM emissions with WED and the maximum reduction was observed with WED having 20% water. Alahmer [3] reported that BSFC using WED increased at higher speeds but had no significant change was noted at lower speeds. He also reported that at lower water content $NO_x$ emission increased but decreased with increase in water content in the emulsified fuel. Attia and Kulchitskiy [6] reported that with smaller droplet size of water particles the brake mechanical efficiency increased upto 20% and emissions of HC reduced even more than 35%. The emulsion with larger droplet size resulted in greater reduction of $NO_x$ (upto 28%). Ghojel and Honnery [7] reported that the specific fuel consumption increased upto 26% with the use of WED with 13% water content, but $NO_x$ emission reduced greatly due to the quenching effect of water in the WED. No significant change in the brake thermal efficiency was observed using normal diesel and water emulsified diesel. Lin and Chen [4] experimented with neat diesel, two-phase WED (W/O) and three-phase WED (O/W/O) which were prepared using ultrasonic vibrator. The BFSC values were found to be maximum with O/W/O emulsion and least with neat diesel. But W/O emulsion had the largest brake thermal efficiency as compared to the other tested fuels. $NO_x$ was found to be reduced when emulsified fuels were used in the diesel engine. Ithnin *et al*. [1] reviewed the status of using WED and concluded that thermal efficiency was increased and BSFC was reduced when only diesel fraction of the emulsion was considered as fuel mass. They noted from the existing literature that the emission of unburnt hydrocarbon was inconsistent. However, many papers depicted that there was a reduction in its emission which was attributed to micro-explosion leading to improved combustion. Armas *et al*. [8] reported that there was a better air-fuel mixing due to micro-explosion which resulted in the reduction of hydrocarbon emission.

The review of literature on the use of WED as CI engine fuel reveals that it needs further investigation before adopting as a potential fuel. Keeping this in mind the authors have studied experimentally the effect of 10% water addition to diesel in emulsified mode on brake thermal efficiency, brake specific fuel consumption and emissions of $NO_x$ and hydrocarbons.

## 2. Water emulsified diesel

Emulsion is the blending of two immiscible liquids where one is in the dispersed phase and the other phase is the continuous phase [1]. Emulsions are of two types, two-phase and three-phase. Two phase emulsion i.e. water in oil (W/O) or oil in water (O/W) consists of a dispersed phase and a continuous phase. Three phase emulsion i.e. water in oil in water (W/O/W) or oil in water in oil (O/W/O) consists of an inner phase and an outer phase (continuous phase) and dispersed phase [3, 4, 9]. The structure of two-phase and three phase emulsion are shown in figure 1.The emulsion is generally prepared using mechanical homogenizer and ultrasonic vibrator. The mechanical homogenizer uses a mechanical stirrer which rotates at a certain rpm to make the desired emulsion. And the ultrasonic vibrator uses a horn which produces sonic waves whose pressure is greater than that of the surrounding liquid resulting in the liquid particles to get twisted and hollowed out to form cavities. This produces a strong mechanical stirring effect. Ultrasonic vibrator produces a much more homogenized emulsion than mechanical homogenizer, but it is limited to two-phase emulsions only [4]. The two immiscible liquids have the tendency to gradually separate out in the emulsion due to the difference in their surface tension. To overcome this problem, surfactants are added to the emulsion which stabilizes the emulsion by reducing the interfacial surface tension [1-4]. Surfactant consists of a hydrophilic group and a lipophilic group. The most commonly used surfactants are Tween 80 and Span 80. Span 80 which is also called sorbitan mono-oleate is a lipophilic surfactant having HLB (hydrophilic lipophilic balance) value of 4.3. Tween 80 which is also called polyoxyethelenesorbitan mono-oleate is a hydrophilic surfactant having HLB value of 15. It is preferred to have a lower HLB value of a surfactant for the preparation of W/O emulsion and vice versa [1, 2, 9]. The stability of the emulsion prepared by ultrasonic vibrator depends on the HLB value of the surfactant, position of horn tip in the mixture, sonic time and the size of the dispersed phase [1, 4, 6, 9]. The preparation of emulsion using ultrasonic vibrator is shown in figure 2.

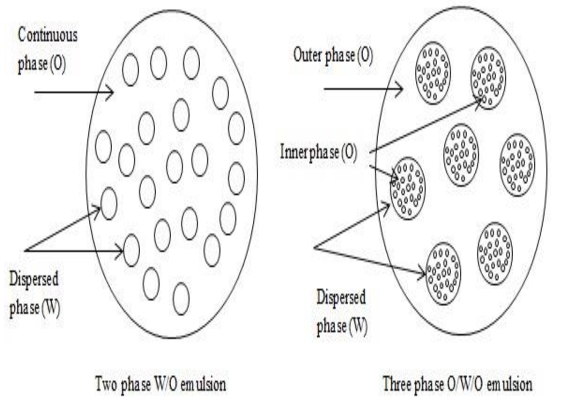


**Figure 1.** Structure of two phase and three phase emulsion [3]

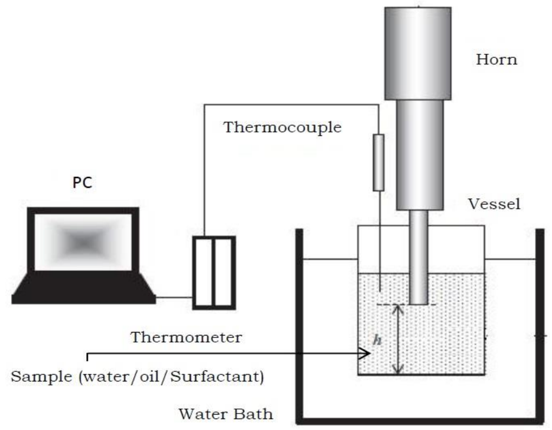


**Figure 2.** Schematic diagram for preparation of emulsified fuel using Ultrasonic vibrator

The surfactant used for the preparation of emulsion is the mixture of Tween 80 and Span 80 having an effective HLB value of 8. The HLB value of the surfactant mixture is calculated following Saravanan *et al*. [9] as:

$$HLB_{surfactant} = \frac{(HLB_{span80} \times W_s) + (HLB_{tween80} \times W_t)}{W_s + W_t} \quad (1)$$

where $W_s$ = amount of Span 80 used in percentage of total surfactant volume and
$W_t$ = amount of Tween 80 used in percentage of total surfactant volume = 100-$W_s$,

## 3. Experimental set-up

Experimental investigation has been carried out with neat diesel and water emulsified diesel containing 10% water (WED10) and 2% surfactant. The performance test is carried out on a single cylinder variable compression ratio CI engine. Experiments have been conducted at a rated speed of 1500 RPM and compression ratio of 16.0. The load on the engine has been gradually varied up to a maximum value of 11 kg. Figure 3 shows a schematic diagram of the test engine setup and the detailed specifications of the test engine are provided in table 1.

The engine is directly coupled to an eddy current dynamometer using flexible coupling and a stub shaft assembly. The output of the eddy current dynamometer is fed to a strain gauge load cell of electronic data acquisition system for measuring load applied to the engine. An auto exhaust multi gas analyzer (Model NPM-MGA-1) fitted at the exhaust is used for the measurement of nitric oxide ($NO_x$) and unburned hydrocarbon emissions. A glass burette is provided at the fuel tank assembly for diesel and water emulsified diesel fuel measurement separately. The performance parameters are directly obtained from a lab view based software, ENGINE-SOFT, installed in a laptop, which is directly connected to the electronic data acquisition system of the engine set up. No adjustment is made at the fuel injection timing and 23° BTDC is used for both diesel and water emulsified diesel.

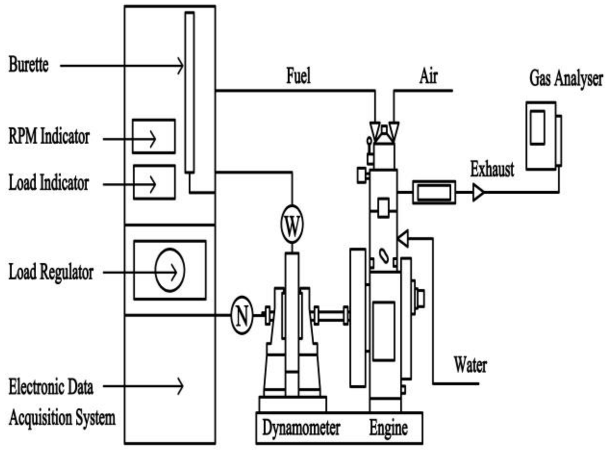


**Figure 3.** Schematic Diagram of Experimental setup

**Table 1:** Specification of Engine

| | |
|---|---|
| Manufacturer | Kirloskar Oil Engines Ltd. |
| Product | Computerized variable compression ignition engine, Code: 234 |
| Type | Single cylinder, DI, diesel |
| Rated Power | 5.2 kW @ 1500 RPM |
| Compression Ratio | 11:1 to 18:1 |
| Bore | 87.5 mm |
| Stroke | 110 mm |
| Injection Timing | 23° before TDC |
| Method of Loading | Eddy Current Dynamometer |
| Swept volume | 661 cc |

## 4. Results and Discussion

The viability of using any alternate fuel depends on its performance as well emission characteristics. The most important performance parameters investigated in this work are brake thermal efficiency and brake specific fuel consumption. On the other hand, the emissions of $NO_x$ and HC have been studied considering their greater environmental impact

### *4.1. Brake thermal efficiency*

Brake thermal efficiency of the engine powered by emulsified fuel with 10% water and neat diesel at constant speed and for variable loads has been presented in figure 4. From the figure it is clear that that there is no significant change in brake thermal efficiency. Although the calorific value of WED10 is less than that of neat diesel, still have similar efficiencies. This may be due to the fact that air fuel mixing is improved due the phenomenon of micro-explosion in case WED. Similar results were also reported by Ghojel and Honnery [7] and Saravanan *et al*. [9] using water emulsified diesel having 13% (WED13) and 15% (WED15) water in the respectively. Vellaiyan *et al.* [10] reported that brake thermal efficiency improved by 12% with 10% water (WED10).

### *4.2. Brake specific fuel consumption*

The variations of brake specific fuel consumption (BSFC) of the engine with load using neat diesel and WED10 have been shown in figure 5. A minute look into the figure reveals that BSFC reduces marginally with WED10 as compared to that with normal diesel. It may be noted that only the mass of diesel has been considered as fuel mass in case of WED10 for calculating BSFC. The same trend was also observed in the experimental investigation by Vellaiyan *et al.* [10].Several factors may be responsible for this. Firstly, the formation of finer droplets due to micro-explosion improves the atomization and hence the combustion. Secondly, premixed combustion to diffusion combustion ratio of fuel burnt is more due to longer ignition delay. The presence of water in the fuel increases local excess air. Also, more air goes into the spray due to increased momentum and penetrating force. Cooling loss is reduced due to the lowering of flame temperature in the vicinity of water present in the fuel [1-3].

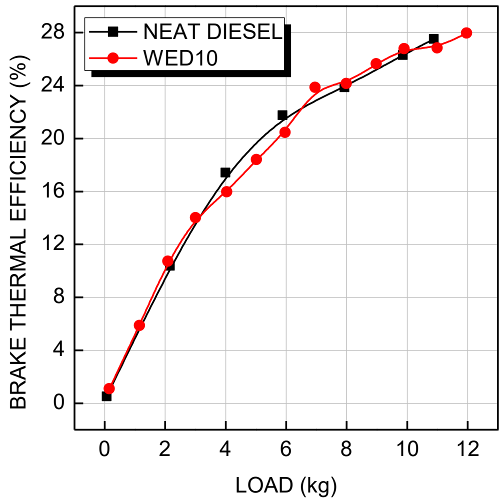


**Figure 4.** Brake thermal efficiency of the engine using neat diesel and WED10

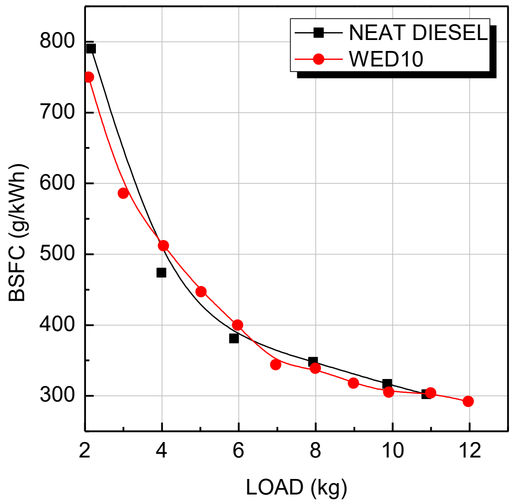


**Figure 5.** BSFC for neat diesel and diesel only in WED10

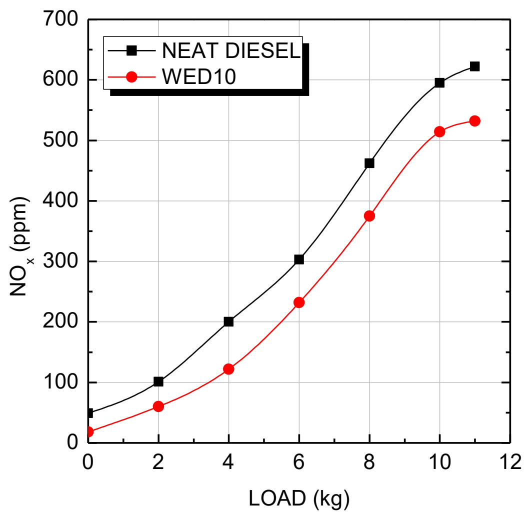


**Figure 6.**NO$_x$ emission from neat diesel and WED10

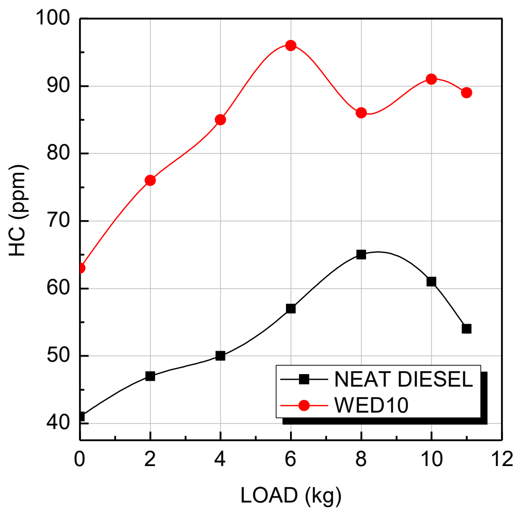


**Figure 7.** HC emission from neat diesel and WED10

*4.3. Nitrogen oxides emissions*

The variations of NO$_x$ emission with loads using neat diesel and WED10 has been presented in figure 6. It is clearly seen that there is a significant reduction in NO$_x$ emission using WED10 instead of neat diesel. The maximum reduction in the NO$_x$ emission is observed to be 14.46% compared to that with neat diesel. This is due to the water present in dispersed phase in the water diesel emulsion which reduces the adiabatic flame temperature. This phenomenon is referred in the literature as heat sink effect. Alahmer [3], Ithnin *et al.* [2], Nadeem *et al.* [5] and Lin [4] also reported reductions in NO$_x$ emission with WED, but the actual amount of reductions were different in many cases even with same amount of water in the emulsion.

### *4.4. Hydrocarbon emissions*

The variation of HC emission with varying loads using neat diesel and WED10 is shown in figure 7. It is observed from the figure that the HC emission increases with the use of WED10 as fuel instead of normal diesel. This increase in HC emission is due to decrease in combustion temperature and increase in ignition delay [1]. However, Saravanan *et al.* [9] and Armas [8] reported the reduction of that HC emission with the use of WED due to micro explosion phenomenon. It is clear that final HC emission depends on the relative impact of combustion temperature, ignition delay and micro-explosion. However, the variation in the HC emission is inconsistent as reported by many researchers and the reason for its inconsistency is not completely revealed.

## 5. Conclusion

Based on this experimental investigation, the following conclusions on the use of water emulsified diesel as CI engine fuel can be drawn:

- Brake thermal efficiencies with normal diesel and water emulsified diesel having 10% water are comparable.
- When only diesel fraction of WED is taken as fuel mass, BSFC is noted to be marginally lower with WED than that using normal diesel.
- $NO_x$ emission reduces significantly with the use of WED and the maximum reduction is found to be around 14.46%.
- HC emission increases when WED is used instead of normal diesel in CI engine. Opposite trend is also observed by some researchers.
- WED10 may be considered as a promising alternative fuel in Diesel engine.

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