

# Investigation of Diesel Engine with Water Emulsifier - A Review

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**Abstract** - There is a large use of C.I engine with many advantages, they produce large amount of pollutants. Diesel engines are known as one of the biggest contributors to environmental problems caused by exhaust emissions and they are the reasons for health hazardous as well. Nitrogen oxides (NO<sub>x</sub>) and particulate matters (PM) are the main pollutants from diesel engines. Researchers did many works on diesel engine to reduce emissions from exhaust of engine. W/D emulsion uses as alternative fuel and it decrease production of NO<sub>x</sub> and PM in CI engine. The W/D emulsion fuel contains water (range: 5-15%) and diesel fuel with proper surfactants, to make stable system. Due to vaporization of water there is reduction in combustion temperature so the production of NO<sub>x</sub> reduces. There is reduction in reaction rate. So it increase mixing time and so it has better time for proper mixing and it reduce production of NO<sub>x</sub>. Micro-explosion is known as second atomization which improves fuel combustion and reduces fuel consumption. By doing many experimental works we can optimize the water percentage and types of surfactants

**Key Words:** Diesel engine, Water-diesel emulsion, NO<sub>x</sub>, Span-tween, Micro-explosion, Emissions

## 1. INTRODUCTION

There are basically two types of Internal Combustion Engines (I.C Engine). One is Petrol engine (S.I Engine) and other is Diesel engine (C.I Engine). Diesel engine has a better efficiency, good durability, fuel economy, and power than the Petrol Engine. So Diesel engine mainly used in heavy duty applications. Diesel engine generally used in transporting, industrial, agricultural and power generating sector. Diesel engine has many advantages but it produce large amount of pollutants which is hazardous to the human health. [24] Diesel engine is a major source of black smoke, particulate matters (PM), sulphur oxide (SO<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), carbon-monoxide (CO) [1]. Combustion of fossils fuels is the biggest contributor to the climate change representing 57% of the total greenhouse gases [2]. Researchers have to do two main tasks in developing I.C Engines. One is improving the efficiency of diesel engines and other is to reduce the emissions from engine. [4] EGR reduces the NO<sub>x</sub> but it increases the soot (PM) formation. Another method is enriching oxygen, it reduces the level of soot (PM) formation but on other hand it increases the production of NO<sub>x</sub>. We cannot use these both methods in combination because of

high cost [8]. There are four methods of introducing water into combustion zone. 1. Circulating the water into engine intake air 2. Injecting water droplet directly into combustion zone with separate injectors. 3. Mix the water and air in line prior to the injection (unstable emulsion). 4. Mixture of water and diesel as stable emulsion as a single phase [4]. Water in Diesel emulsion (W/D emulsion) is one of the methods to reduce the emissions from engine exhaust and improve performance of engine. W/D emulsion uses as fuel in C.I engine without any change in engine. [3]. Water in W/D emulsion is generally used for clean combustion. Presence of water reduces nitrogen oxides (NO<sub>x</sub>) and soot (PM) formation. Actually the water in diesel reduces the flame temperature hence it reduces NO<sub>x</sub> production [25].

## 2. PRINCIPLE OF WATER -IN-DIESL EMULSION

When diesel and water mixed directly, diesel comes at top and water settles at bottom because diesel is lighter than the water [18]. Prof. B Hopkinson introduced the water in diesel emulsion in diesel engine for improvement of the thermal efficiency and minimizes the exhaust emissions of engines [24]. Emulsion fuel is mixture of two completely immiscible liquids which are not blend completely. In emulsion one substance is completely distributed throughout the other substance [1]. By using an appropriate surfactants (emulsifiers) we can bound these two together. Surfactant is the compound that lowers the tension between the two liquids which are immiscible. It bound them together to make a proper stable emulsion [18]. Surfactants are used to make kinetically stable W/D emulsion fuel. It depresses the tension between water and diesel molecules. Interface surface tension between two liquids, solids, and gases absorbed by the surfactants [23]. In water diesel emulsion, water mixes homogeneously with the diesel on volume basis. A surfactant is used to make stable emulsion. This W/D emulsion doesn't require any change in engine so it is very convenient fuel to use [24].

Emulsions are basically classified into two types. One is water in oil emulsion and other is oil in water emulsion (figure 1). Water in diesel emulsion comes under the water in oil emulsion type [19]. In Water in oil emulsion there is continues phase of oil and water is uniformly distributed. In oil in water emulsion there is continues phase of water and oil is uniformly distributed through it.

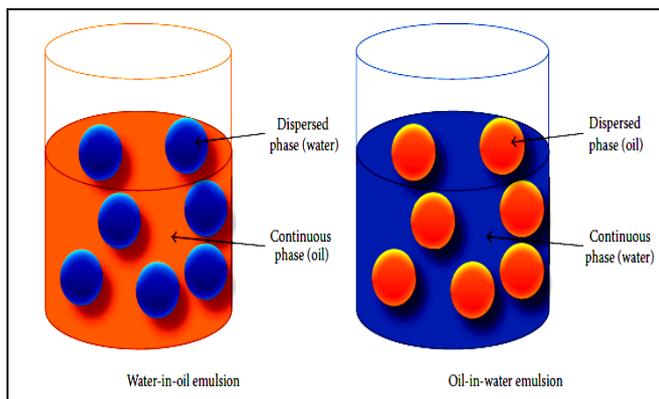


Fig -1: Two phase water in oil and oil in water emulsion [16]

In Water in oil emulsion there is continuous phase of oil and water is uniformly distributed. In oil in water emulsion there is continuous phase of water and oil is uniformly distributed through it. There are two types of three-phase emulsions can be resulted from the three-phase emulsification technique depending on the inner and outer phases (Figure 2), namely, oil-in-water-in-oil and water-in-oil-in-water emulsions. Oil-in-water-in-oil emulsions use as fuel in the I.C engine while water-in-oil-in-water emulsion use in cosmetics, food, or pharmaceutical manufacturing [16].

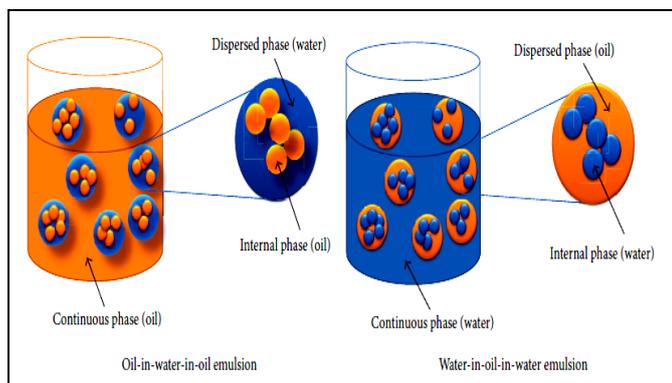


Fig -2: Three phase water in oil and oil in water emulsion [16]

Three-phase oil in water in oil emulsion uses two stage emulsification processes and it requires two types of surfactants. Mainly the cost of process for three phase emulsion is greater than the two phase emulsion. To produce proper emulsion first take all the components (diesel, water and surfactants) in the vessel and mix them properly so that there is proper shear built up and we get the droplets of desired size [22]. The emulsion fuel is generated by high energy technique in the presence of surfactants. These high energy emulsification techniques include agitation, homogenizer with high pressure, ultrasonic and supersonic vibrations. [24]

### 3. SURFACTANTS

Surfactant (emulsifier) is a compound which reduces the tension between the diesel and water and bound them together to make stable emulsion. For stable emulsion we have to choose proper surfactants [18]. The selection of surfactant depends on the value of HLB. HLB means Hydrophile Liphophile Balance [19]. HLB value is the measure of degree of lipophilic or hydrophilic.

Table -1: HLB for different type of emulsions [18]

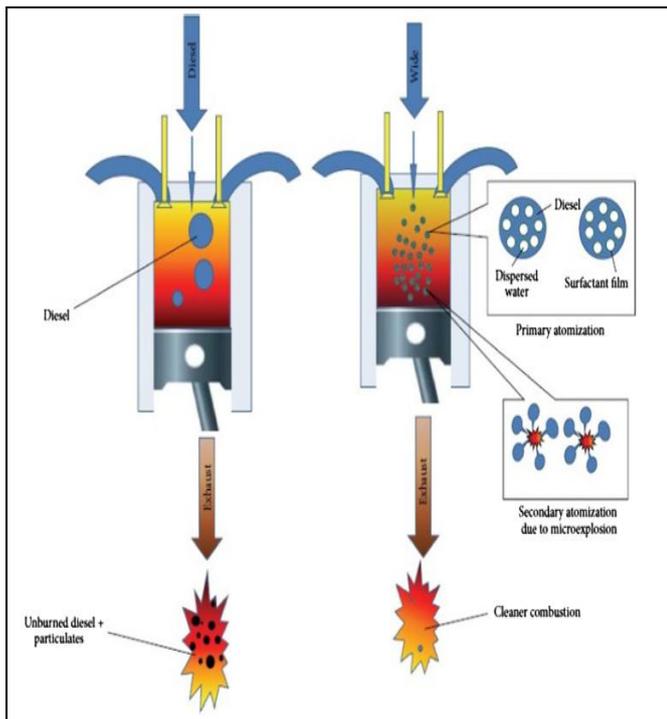
HLB value	Type of Emulsion
<10	Lipid-soluble (water-insoluble)
>10	Water-soluble (lipid-insoluble)
4 - 8	Antifoaming agents
7 - 11	Water in oil emulsifier
12 - 16	Oil in water emulsifier
11 - 14	Wetting agents
12 - 15	Detergents
16 - 20	Solubilize and hydro trope

Table -2: HLB for various surfactants [18]

Surfactant	HLB value
Sorbitan trioleate (span 85)	1.8
Sorbitan monooleate (span 80)	4.3
Sorbitan monostearate (span 60)	4.7
Sorbitan monopalmitate (span 40)	6.7
Sorbitan monolaurate (span 20)	8.6
Polyoxyethylene sorbitan trioleate (tween 85)	11
Polysorbate 60 (tween 60)	14.9
Polysorbate 80 (tween 80)	15
Polysorbate 40 (tween 40)	15.6
Polysorbate 20 (tween 20)	16.7

#### 4. EFFECT OF WATER - DIESEL (W/D) EMULSION ON COMBUSTION

Micro-explosion phenomenon affects the C.I engine combustion process. Water-diesel emulsion fuel when inserted through a nozzle, it atomize into fine droplets. Water has boiling point below diesel so it absorbs heat and reaches its boiling point first and vaporizes. Fuel atom also atomize into very fine particles. This process is called microexplosion (secondary atomization) phenomenon (Figure 3) [8].



**Fig -3:** Diagram of microexplosion (secondary atomization) [21]

Strength of Micro-explosion (secondary atomization) affected by the content of water in the emulsion fuel, size of dispersed water atom, droplet size, surrounding temperature and pressure. As the water concentration increases strength of secondary atomization increase but after some level of water percentage there is a failure of injection system. So we have to optimize the water concentration level. As ambient temperature increase the strength of micro-explosion decrease. As the size of droplet is small, the strength of micro-explosion is low [21]. Secondary atomization or micro explosion reduces the particulate matter formation and improve the combustion efficiency [10]. Micro explosion promote the oxidation of hydro carbons so it reduces the production of soot formation. Micro explosion also affect the mixing of air and fuel. It improves the mixing of air and fuel. Overall micro explosion improve the burning efficiency and reduce the fuel consumption. The strength of micro explosion is determined by the thickness of the oil membrane. The occurrence of micro explosion process doesn't depend on choice of surfactants [6].

#### 5. EFFECT OF WATER - DIESEL (W/D) EMULSION ON ENGINE PERFORMANCE

When we replace existing diesel fuel by any emulsion fuel or biodiesel we have to check the performance and combustion characteristics of engine. Performance characteristics include the measurement of brake power (B.P), BSFC, torque, and thermal efficiency under various conditions.

##### 5.1 Brake power (B.P)

A Alahmer in their research state that the maximum power produce by engine when we have water diesel emulsion with 5% water at normal engine speed. It also states that as water percentage increases the power produce by engine decreases [1]. But other research shows that there was slight drop in value of engine power at all engine speed with emulsified fuel comparatively pure diesel. This situation comes due to low calorific value of W/D emulsified fuel because of water content [26, 21]. As load increased on engine the power produced by engine for both pure diesel and emulsified fuel increase. But as previous research shows that the power obtained by the emulsified fuel was low because of its low heating value than the pure diesel fuel [05].

##### 5.2 Torque

At low water content torque produce by the engine was more than the diesel, but as water content increase in emulsified fuel the torque produce by engine decrease. It also state that as speed increase the torque decrease [15]. As the torque produce by the engine is high the temperature of exhaust becomes high. But when we use emulsified fuel with 20% water content the temperature of exhaust decrease compare to pure diesel fuel [09, 21]. We have to optimize the water content in emulsified fuel to achieve higher torque.

##### 5.3 Brake specific fuel consumption (BSFC)

A Alahmer et al. in study found that there is decrease in BSFC as speed of engine increase until it attains a minimum value, then after BSFC increases. At low speed there is more heat loss into combustion chamber wall so poor combustion efficiency. At high speed there is more friction loss [01]. There are two opposite effect of W/D emulsified fuel. One is micro-explosion and other is heat loss to combustion wall. So value of BSFC depends on the running condition. At minimum load (10% loads) diesel has low BSFC value and at high load (30% load) W/D emulsified fuel has low BSFC [20]. So by optimizing the water percentage in water diesel emulsive fuel we get low BSFC.

##### 5.4 Engine brake thermal efficiency

The thermal efficiency of engine increase with increase in engine speed until it reaches its maximum value and after that the value of thermal efficiency decreases [01]. As one research shows that the thermal efficiency is higher at mid and high speed because of micro-explosion phenomenon [26]. All emulsified fuel ratio gave the higher thermal efficiency than the pure diesel [13].

### 5.5 Brake mean effective pressure (BMEP) and Indicated mean effective pressure (IMEP)

Similar to B.P the values of both BMEP and IMEP at all speed would be low because of emulsified fuel has low heating value than pure diesel [26]. As the water level increase in emulsified fuel the mean effective pressure decrease and attain minimum value at 30% water content [20].

## 6. EFFECT OF WATER - DIESEL (W/D) EMULSION ON EXHAUST EMISSIONS

When we introduce water in diesel emulsified fuel as replacement fuel for diesel engine then we have to check its effect on exhaust emissions of engine and compare it with the emissions from pure diesel engine.

### 6.1 Nitrogen oxide (NO<sub>x</sub>) emissions

Alain Mainboom et al. in their research study the combine effect of WDE and EGR effect to reduce the emission level from engine exhaust. They found that at same EGR rate there is decrease in NO<sub>x</sub> with WDE (water diesel emulsion). It is possible to achieve very low value of NO<sub>x</sub> using EGR and WDE at low load condition [03]. At low level of water content production of NO<sub>x</sub> is more compare to high content of water in emulsified fuel [01]. Formation of NO<sub>x</sub> is due to the high temperature of combustion. Water content in emulsified fuel mainly affects the peak temperature of combustion and it reduces it. So the production of NO<sub>x</sub> emission decreases [06, 28].

### 6.2 Particulate matters (PM) emissions

Alain Mainboom et al. in their experiment state that the level of PM increases as load increase. When they use WDE with high EGR rate there is large reduction in production of PM emissions [03]. It state that due to the volatility differences between water and diesel fuel there is micro-explosion occurs. Due to this micro-explosion phenomenon there is better mixing of air and diesel and proper atomization of diesel. So it reduces the PM and soot [17].

### 6.3 Hydro carbon (HC) emissions

Arun kumar et al. in their research shows that there is enough oxygen available for fuel to burn completely due to water content available in emulsified fuel. So there is reduction in value of HC and CO emission compared to neat diesel fuel [07].

### 6.4 Carbon dioxide (CO<sub>2</sub>) emissions

Research states that there is increase in emission of CO<sub>2</sub> compared to pure diesel because of large amount of oxygen available in emulsified fuel at higher content of water [01]. As engine speed increase the level of production of CO<sub>2</sub> increase and as content of water in emulsified fuel increase the production of CO<sub>2</sub> decrease because of micro-explosion [04].

### 6.5 Oxygen (O<sub>2</sub>) emissions

As the percentage of water in emulsified fuel increase there is increase in O<sub>2</sub> emissions. There is large amount of O<sub>2</sub> atoms available when the percentage of water in emulsified fuel increases [04].

### 6.6 Smoke emissions

In emulsified fuel due to micro-explosion there is better mixing of water and diesel fuel so it reduces smoke level.

## 7. CONCLUDING REMARKS

Overall, it is observed from the research that the formation of W/D from low grade diesel is a promising alternative fuel that can be used for greener exhaust emissions and it reduce diesel fuel usage without deteriorating its performance. Water diesel emulsified fuel can be used without any engine modification so it is good replacement for diesel. However, in order to have its ideal effect on the engine, the optimum W/D characteristics, such as water content, should be varied when it is utilized in different engine conditions.

We also conclude from our research that there is a decrease in emissions of nitrogen oxides and particulate matters, there is an increase in the emissions of hydrocarbons and carbon monoxide with increasing water content of the emulsion. The combustion efficiency is improved when water is emulsified with diesel. This is a consequence of the microexplosions, which facilitate atomization of the fuel.

For making stable emulsion we have to choose proper surfactant or mixture of surfactants.

## 8. SCOPE OF WORK

There is a chance of corrosion due to water in diesel emulsion fuel. So some surfactants may be used to make proper emulsion which reduces the corrosion probability by not preventing direct contact of water with combustion chamber wall.

By using an appropriate surfactant the molecules of water and diesel can be bound together. The stability of the emulsion made is very important, because if it's not stable for an appreciable period of time it won't be practically useful.

Various types of surfactants will be used like Span 20, Span 80, Tween 20, Tween 80 etc. And result will be compared. We will also use mixture of these surfactants and compare performance and emission result.

We have to use various level of water content in emulsified fuel and compare its result like 5% water, 10% water in water diesel emulsified fuel.

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