NOx Emission Reduction by Diesel Water Emulsion fuel- A Review

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ABSTRACT *Increased usage of diesel vehicles and equipment are big challenges in terms of pollution and depleting diesel fuel resources. Significant improvements in diesel emission levels have been achieved in the last 20 years. Development of diesel engine to meet new emission regulations and adopt renewable fuels is a challenging research objective. Oxides of nitrogen (NOx) are the main pollutant from diesel engines. Reduction of NOx is originated from the reduction of local high temperature due to vaporized water during combustion & the performance is improved due to micro explosion which leads secondary atomization of diesel fuel. In order to obtain the efficient energy development with less polluted environment with existing diesel engines, continuous efforts have gone into research and development of water-in-diesel (W/D) emulsion fuels, which have the potential to reduce nitric oxides (NOx) emission simultaneously with improved performance level. The current discussion addresses the principle of W/D emulsion fuel, the influence of micro-emulsion on the combustion and emission of water-in-diesel emulsion fuel.*

KEYWORDS: Diesel Engine, Emissions, Diesel Water Emulsion

1. INTRODUCTION

Diesel engines are widely used in engineering machinery, automobile, gen set and ships due to economy and part load efficiency. However, conventional CI engines produce high emissions of nitric oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), unburned hydrocarbon (HC), smoke and other harmful compounds. As Government is stricting emissions norms tightly, the emissions reduction is a major research objective. Emulsification is the best method to reduce CI engine emissions. Combustion of hydrocarbon witness the reaction of the hydrogen in the fuel and oxygen in the air to produces water in the form of steam. So the water mass produced during combustion can be greater than the mass of the fuel source. So emulsification of the fuel only changes the sequence in which the water is introduced into combustion and water is not introducing as a new compound.

2. FACTORS RESPONSIBLE FOR NOx FORMATION [07]

NOx formation mainly depends on the temperature of the burnt gas, the residencetime of the burnt gas a high temperature and the amount of excess oxygen and turbulence (Heywood, 1988). Residence time describes how long time the combustion gas is having the high temperature. Longer the duration of high temperature burnt gases, higher will be the NOx formation. Increased pressure due to continuing combustion causes the burnt gases to experience compression. The net result is the initial burnt gases spend a longer time under high pressure and temperature as compared with the burnt gas from the later stages of

combustion. This allows more time for NO to form. More the time for oxidation, more is the NOx produced. As the combustion process prolongs for a longer time period, there is more time available for NO to form in slow speed engines as compared to highspeed engines. A good degree of turbulence facilitates quick mixing of air with fuel and accelerates reaction rates.

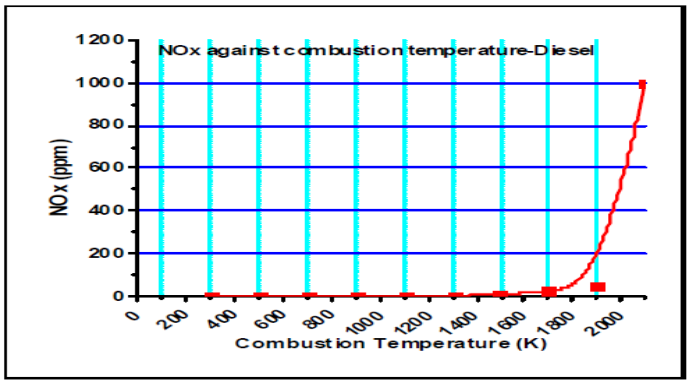

Fig1: Brake Power versus NOx

A plot of NO formation rate with temperature is shown in Fig 1. Other important factors apart from high temperature, in thermal NOx formation, are the residence time, amount of Longer the duration of high temperature burnt gases, higher will be the NOx formation. A good degree of turbulence facilitates quick mixing of air with fuel and accelerates reaction rates.

Thermodynamic reaction when hydrocarbons are completely burned in the presence of sufficient oxygen is [02]:

$C_nH_m + (n+m/4).O_2 \rightarrow nCO_2 + m/2 \cdot H_2O$

In the presence of water at a high temperature, the following steam reforming action and water gas reaction may proceed before the above reaction is initiated.

$C_nH_m + nH_2O \rightarrow n.CO + (m/2+n)\ H_2$

CO and H_2 may react with O_2 and

$CO + 1/2\ O_2 \leftrightarrow CO_2$

$H_2 + 1/2\ O_2 \leftrightarrow H_2O$

In the end equilibrium reaction is achieved. Due to the difference in boiling points, water expands or explodes first. Subsequently, the particles of oil are exploded and forced mixing with the air occur enabling complete combustion. So there is reduction of fuel consumption. Ordinarily, NOx is generated when the air is exposed to high temperatures. Water vapor suppressed the reactive region where the NOx is produced. The overall mass increases by adding water which has a higher density increases the momentum and improves the mixture with the air. Many researches focused in using water with fuel as an emulsified fuel.

3. EMULSIONS [08]

An emulsion can be defined as a mixture of two liquids in which one is present in droplets of macroscopic or ultramicroscopic size, distributed throughout the other. Emulsions are made from the constituents spontaneously or by a mechanical way. In spontaneous emulsions, the mixing is easy and spontaneous. But if they don't mix properly then a third chemical called a surfactant is used to bind the molecules of the constituent liquids. Then a

mechanical agitator is used to mix the liquids thoroughly. After mixing them for some time, emulsion is formed.

3.1 Types of emulsion: Depending upon the type of emulsification technique, the emulsions are classified into two types:

3.1.1 Two-Phase Emulsion: Two phase emulsion include one continuous and one dispersed phase liquid and sometime called primary emulsion. There are two basic form of two-phase emulsion as shown in figure 2.

3.1.1.1 Oil-in water emulsions (O/W): The emulsions where oil is the dispersed phase and water is present as the dispersion medium (continuous phase) is called oil in water emulsion.

3.1.1.2 Water – in- oil emulsions (W/O): The emulsion in which water forms the dispersed phase and the oil is present as a dispersing medium (continuous phase) is called water in oil emulsion

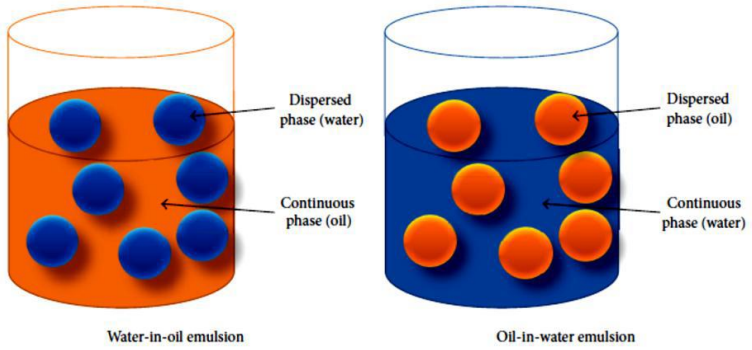

Fig 2: Concept of two-phase water-in-oil and oil-in-water emulsion

3.1.2 Three-Phase Emulsion: Three phase emulsion consist of one continuous phase and two or more dispersed liquid. These emulsions sometimes are called multiphase and secondary emulsion. On the basis of inner and outer phase as shown in figure 3 named as oil-in- water-in-oil and water-in-oil-water.

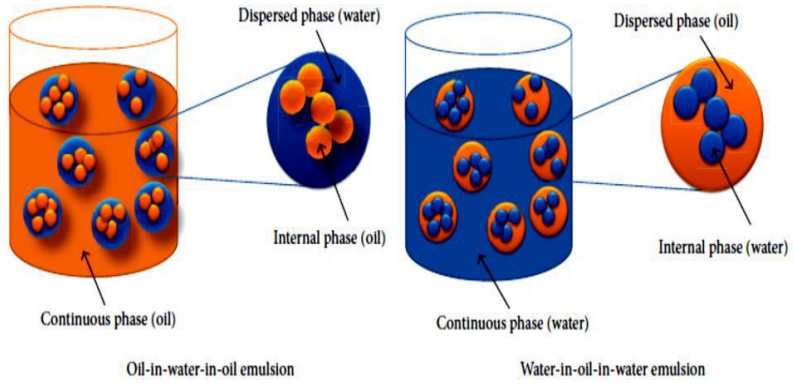

Fig 3: Concept of three-phase oil-in-water-in-oil and water-in-oil-in-water

3.2 Water diesel emulsion in diesel engine: Stringent emission norms and environmental concerns are prime mover for developing interest in water diesel emulsion. Induction of water has a convincing effect on various component of exhaust escaping to environment, such as nitrogen oxides (including NO and NO_2, which are collectively termed as NOx), particulate matter as well as soot formation. Water diesel emulsions are of more interest due to micro size dispersion of water molecule, which is desirable for better combustion of fuel. The various fuel additives are employed for emulsion fuels, including some light hydrocarbons and triglycerides. The main reason for increasing interest in water diesel emulsion as compared to gasoline is that the high combustion temperature and high pressure

that is present in the diesel engine is particularly appropriate for this concept. Use of diesel water emulsions have shown to give several interesting results:

- Reduction of nitrogen oxide NOx emissions, particulate contents and soot particles in the exhaust and
- Boost combustion efficiency of the engine.

The presence of water in diesel brings about an appreciable reduction in the quantity of NOx and particulate matters (PM) emissions. However it relates more to diesel fuels than any other fuels. For the fuels with high nitrogen content, such as some residual oils, the NOx in the exhaust comes mainly from oxidation of nitrogen.

4. Concept of micro explosion phenomena [09]:

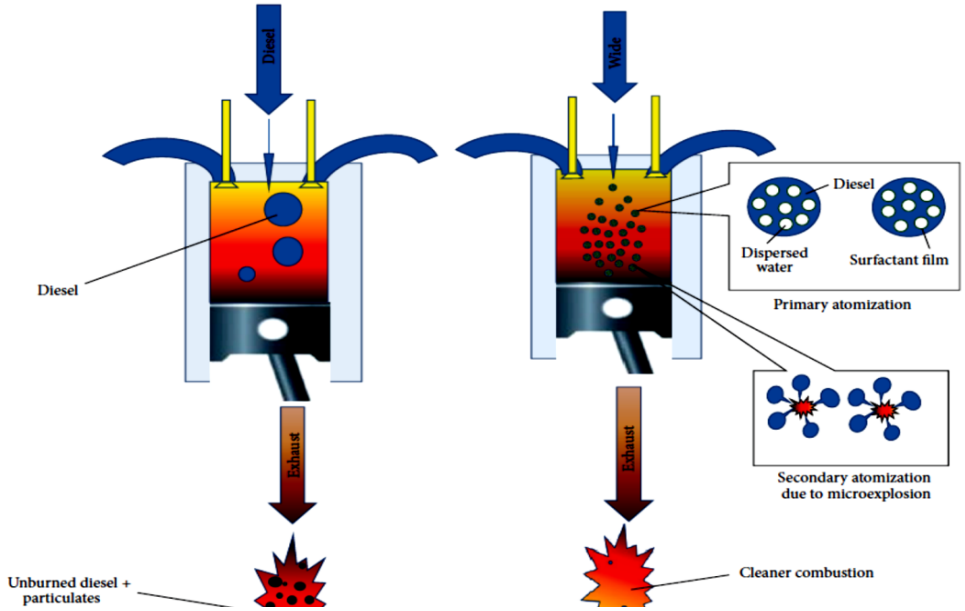

Fig 4:Concept of micro explosion phenomenon

The micro-explosion phenomena in W/D emulsion fuel were first reported by Ivanov and Nevedov. They reported thatthe suspended water particles in emulsion fuel reached their superheated stage faster than the diesel and created vapour expansion breakup (spontaneous explosion) during the combustion, forming very fine particles. More surface area of thefine particles with intake air leads to an improvement in the air and fuel mixing and increases the combustion efficiency.The secondary atomization of fuel droplet and enhanced air-fuel mixing is illustrated in Fig. 4. Sheng et al. also supported the micro-explosion behaviour of emulsion fuel by their observation in flame characteristics and flame angle study. Several studies have been carried out to research the micro explosion behavior of emulsion fuels. Mura et al. andTanaka et al. adopted a hot plate method to observe the occurrence of micro-explosion using a high-speed camera.Abu-Zaidused different hot plates (stainless steel and aluminium) to estimate the evaporation time of droplets. Watanabeet al. used the fine wire technique (ceramic fibre wire) to study the breakup characteristics of the secondary atomization. Mie scatter imaging system with high-speed camera was developed by Mizutani et al. to observe the microexplosionoccurrence in the spray flame. On the other hand, Fu et al. developed numerical models of micro-explosion andvalidated the data against the experimental values. (8)

5. Primary and secondary atomization in spray flame of emulsified fuel [09]

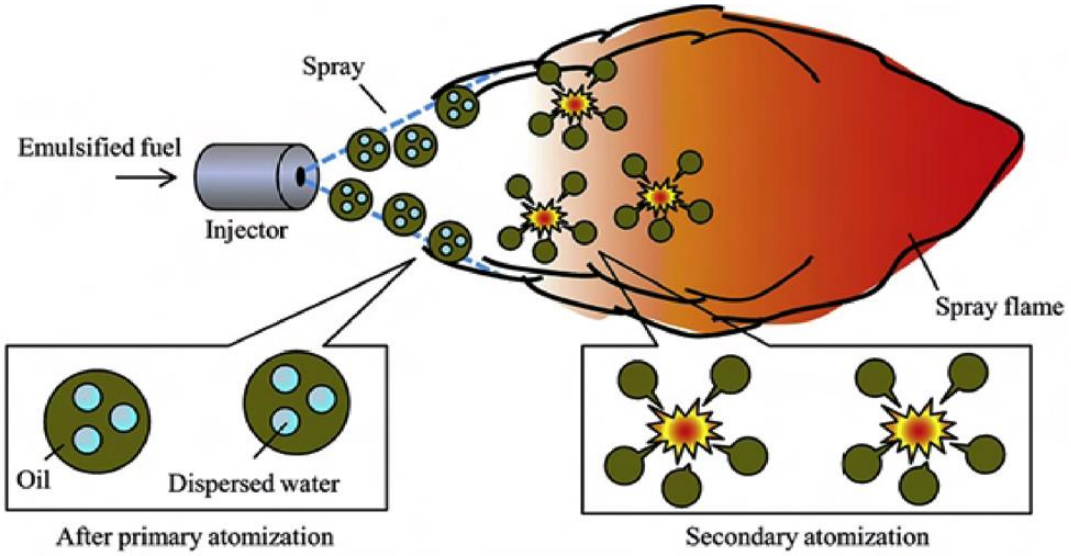

Fig 5:Primary and secondary atomization in spray flame of emulsifiedfuel

The advantages of micro-explosion in the performanceand emission of water-in-diesel fuel, and factors affectingmicro-explosion have been extensively researched by manyresearches, however, Weibiao and co-authors havechallenged its occurrence inside diesel engine combustionchamber. Based on their conclusion, the droplet diameter ofan emulsion in the combustion chamber is in the range of 20-30 μm and micro-explosion phenomenon wouldn't occurwith this range of droplet sizes. Though this report isagreeable with most of the reports that state the effect ofmean water particle size diameter on the intensity of microexplosion, it contradicts with most of the literature onthe occurrence of micro-explosion in diesel enginecombustion chamber.

6. EMULSION CHARACTERISTICS [01]

6.1 Stability:

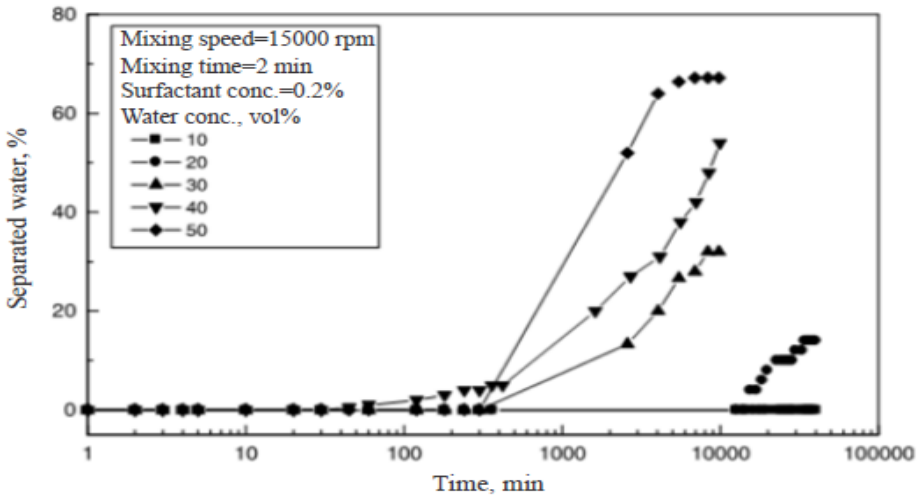

Fig 6: Stability profile of a water-in-diesel emulsion for different water content.

In the stability of water-in-diesel emulsion versus water concentration, surfactant concentration, mixing speed and time was investigated. For a given surfactant concentration and mixing speed and time, the percentage of separated water gradually increased with the water concentration (fig6).

6.2 Viscosity:

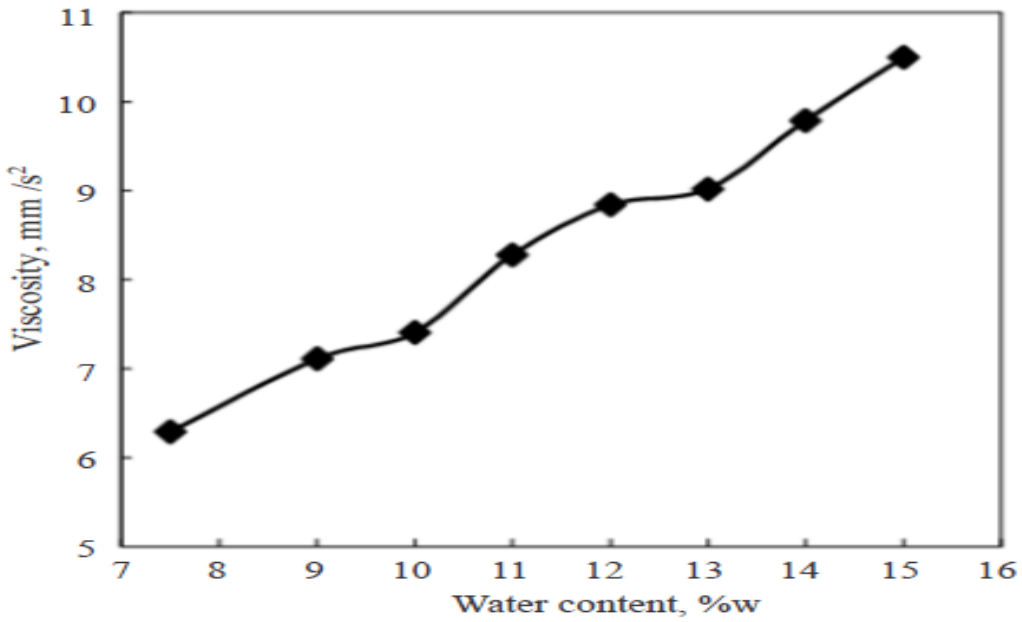

Fig7: Brake Power versus NOx

Viscosity is an important property of diesel fuel, which effects fuel combustion performance. The less the fuel viscosity, the better the fuel fluidity, which improves fuel atomized property so as to decrease fuel consumption and pollutant emission. In general, water-fuel emulsions exhibit greater viscosity than pure liquid fuels, and both water content and size of the droplets dispersed in the emulsion significantly influence its viscosity (fig. 7)

6.3 Heating value:

In general, torque and power produced by emulsified fuels are lower as compared to the neat diesel fuel due to the lower heating values for emulsified fuels. The effect of water content in diesel-water emulsion on the low heating value of the emulsion is presented in fig 8.

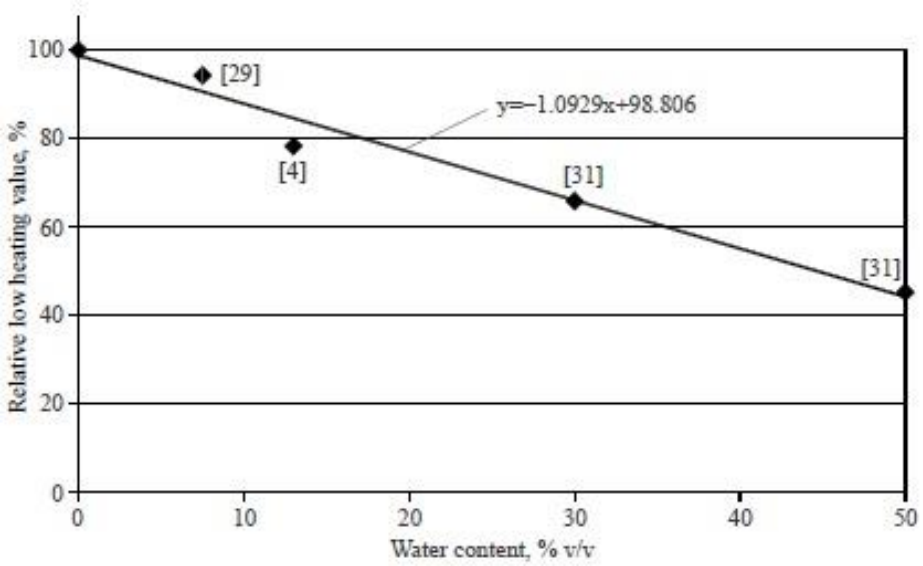

Fig8: Reduction of relative low heating value versus water content in emulsion.

7. Brake Power Vs NOx

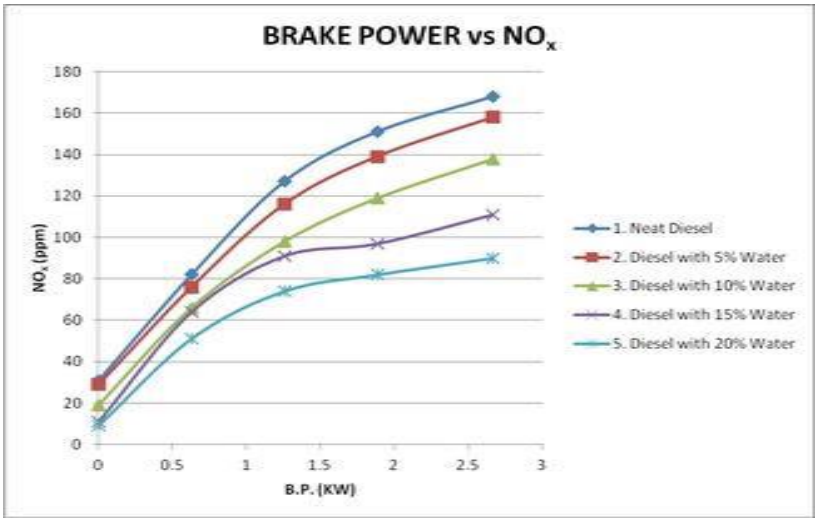

Fig 9: Brake Power versus NOx [03]

The experimental result (fig 9) reveals that 20% water-in-diesel reduces around 45% of NOx emission.

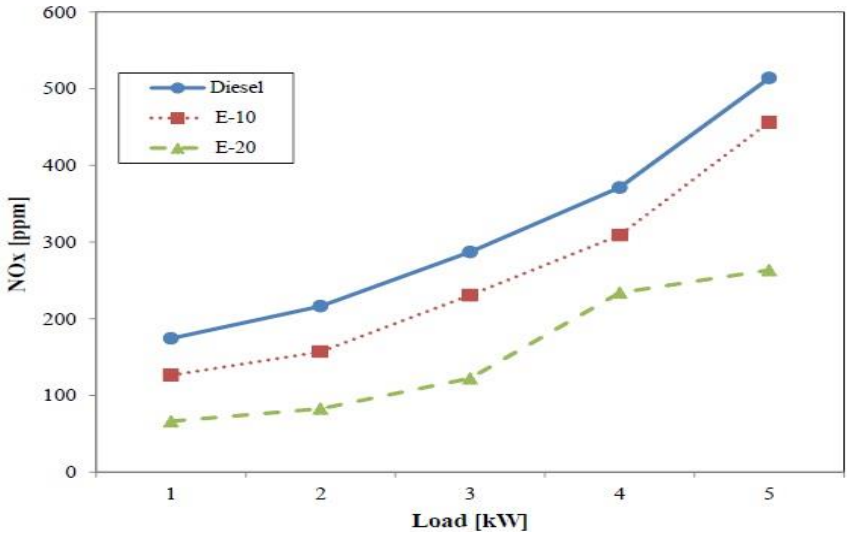

Fig 10: Brake Power versus NOx [05]

Fig10 shows the amount of emitted NOx using different fuel. From the graph, the NOx for emulsion fuels are reduced from 10% up to 51% in comparison with conventional diesel fuel. NOx using E-20 (diesel with 20% water) shows more reduction than E-10 (diesel with 10% water) at all load conditions.

8. Conclusion

1. Water-in-oil emulsion is best suited type of fuel for diesel engines rather than oil-in-water type due to the micro-explosion phenomenon of droplet of water, which causes a large fragmentation of the oil and less change inviscosity with water content.
2. In general, engine power decreases with water content, due to lower heating value of emulsion compared to pure diesel fuel.

3. NOx emission tend to decrease as the emulsion ratio increases due to the lower peak temperature in cylinder due to the water content in emulsion fuel and enhanced mixing with air by micro-explosions.
4. Higher water content up to 20 volume % in W/D emulsion give greater reduction of NOx

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