# Stability Behavior of Water-in-Diesel Fuel Emulsion and Current Trends Engine Performance and Emission

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Abstract: Addition of water in the form of water emulsions in diesel (W/D) can reduce pollution levels and engine performance. W/D emulsion was carried out by mixing between water, pertaminadex, and surfactant (span 80 1.3% and tween 80 0.7%). In this study the parameters used were emulsion stabilization, fuel efficiency, neutralization of sprays, spray angles and trends using emulsions on engine performance and emissions. The process of mixing between water, pertaminadex, and surfactant with the composition of pertaminadex + 50% water + 2% Surfactant (span 80 + Tween 80), with stirring speed 1500 rpm for 30 minutes with stabilizer using a sonicator for 60 minutes and stabilized for 1 hour and 24 hours. The results of this study indicated that the emulsion of 50% W/D 1 hour emulsion stability 96% while 24 hours 92%, Density value 833 kg / m3, LHV value 36.922 kJ / kg, Flash Point 70°C, Spray Length 50 cm and spray angle 20°, and analyzed trends in the influence of emulsions on engine performance and emissions.

## 1 INTRODUCTION

Emulsion is a dispersion system, where one phase is dispersed in another phase in the presence of an emulsifying agent (Leal-Calderon et al., 2007) (Lin and Chen, 2006). Surfactants are widely used in various fields because surfactants have the ability to influence the surface properties of a material, including enhanced oil recovery (EOR) (Lin and Pan, 2000). The emulsion type also determines the size of the dispersed phase droplet (Nadeem et al., 2006). Droplets dispersed on multiple emulsions contain smaller sized droplets which are different in phase, thus the size of the double emulsion droplet will be larger than the simple emulsion (Aserin, 2008). To make a W/D emulsion, a lipophilic surfactant is needed to reduce the water-oil interface tension. Span 80 is able to stabilize the phase of water dispersed in the oil phase such as liquid paraffin.

The pollutants from combustion in the atmosphere will cause serious damage to the environment such as the greenhouse effect, acid rain, and destruction of the ozone layer. Some researchers have shown that the use of water in diesel fuel to produce emulsified diesel fuel can significantly reduce the levels of particle pollution and NOx (Muzio and Quartucy, 1997) (Hagos et al., 2011). According to Lin and Wang (2004), during the W/D emulsion combustion process, it is atomized into several liquid granules through the nozzle. Because the boiling point of water is lower than diesel, the layer that wraps the water will explode through the outer layer of oil. As a result of micro-explosion behavior, the emulsion granules which are atomized are then atomized into finer grains (Park et al., 2016).

At this stage the process of micro-explosion and pufing, micro-explosion droplets break into small grains quickly. While pufing increases granules in fogging. According to Morozumi and Saito (2010) micro-explosion is influenced by the volatility of the base fuel, type of emulsion and water content, an increase in the emulsifier content increases the temperature of micro-explosion. According to Fu et al. (2002) The mechanism of micro-explosion and dependence on various parameters will influence micro-explosion.

The research conducted by Abu-Zaid (2004) related to torque, power, brake specific fuel consumption and thermal efficiency, by varying the percentage of water volume from 0 to 20% in W/D at 5% intervals. Alahmer et al. (2010) examined the performance of the engine by varying the percentage of the volume of water from 0 to 30% water in diesel emulsion



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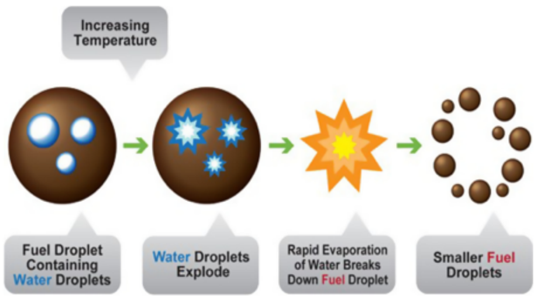


Figure 1: Mechanism of Micro-explosion Phenomenon.

(W/D) at 5% intervals.

Evaporation of water due to absorption of heat around it will reduce the temperature in the combustion chamber thereby reducing NOx (Maiboom and Tauzia, 2011). The addition of a small amount of water to NO and NOx emulation fuels increases, while for the addition of water content a lot of NO and NOx decreases. In the study of Ghojel and Honnery (2005), the reduction in HC emissions was 60-90% at W/D 13% by volume. Research conducted by Samec et al. (2000) decreased Hydrocarbon emissions by 52% and 33%, while for soot emission it was reduced by 68% and 75% compared to pure diesel fuel in the water in diesel content of 10% and 15% respectively.

## 2 MATERIALS AND METHODS

This research was conducted using experimental method. The mixer equipment used was magnetic stirrel, a stabilizer using a sonicator. The materials used were; PertaminaDex + 50% Water + 2% Surgaktan ( span 1.3%, tween 0.7%). The analysis was carried out starting from the mixer process, stabilization, stability emulsion, fuel properties test, neutralizing spray test and spray angle to the developer of emulsion fuel usage trends on engine performance and emissions.

The mixer process was carried out for 30 minutes of water and pertaminadex mixed first after several minutes of span and tween were added gradually, after the mixer process the fuel emulsion + water + surfactant was stabilized using a 60-minute sonicator and left for 1 hour and observed and measured changes in emulsion volume, after 24 hours observed and measured again the changes that occurred in the emulsion process, Testing the emulsion making process and properties test carried out in the Chemical Instrumental Laboratory of FIA ITS.

The fuel properties test was carried out only on Density, Viscosity, LHV, and Flash Point, after testing

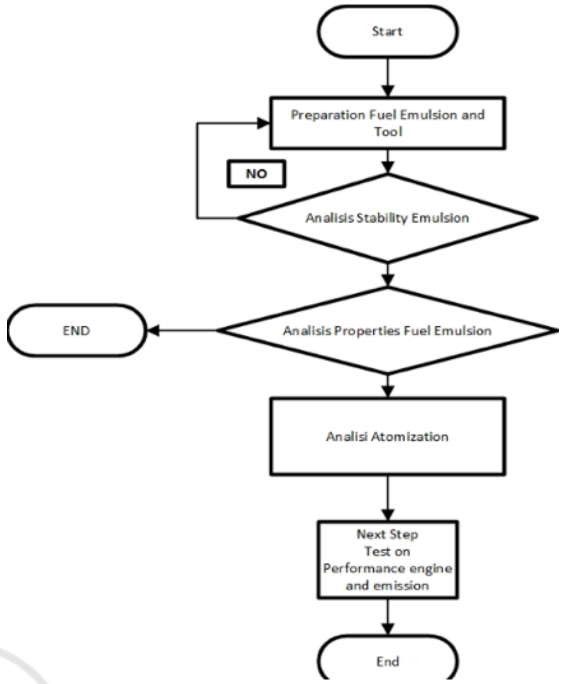


Figure 2: Schematic Diagram of The Emulsion Process.

properties and declared feasible to be used as fuel, a spray test was carried out at the Burning and Energy Laboratory of the ITS Mechanical Engineering Department

The spray test was carried out at a pressure of 200 bar comparing PertaminaDex and PertaminaDex + 50% water + Emulsion (Span 80 1,3 + Tween 80 0.7), from the results of the spray analysis then measured the length of the spray and the spray angle.

## 3 RESULTS AND DISCUSSIONS

In the process of making W/D emulsions it is generally a different liquid mixture, therefore it is necessary to know the dispersed duration phase which is spread evenly throughout the continuous phase. Emulsion formation criteria were carried out by two methods, namely Emulsion Stability (ES) and Emulsion Activity (EA) [11].

### 3.1 Emulsion Stability (ES)

ES shows the ability of the emulsion to stabilize the emulsifying layer after being stored immobile for a certain time. The ES value is determined by calculating the volume ratio of the emulsifying layer to the total volume of the emulsion. Experimental studies conducted by pertamina dex and water emulsion showed

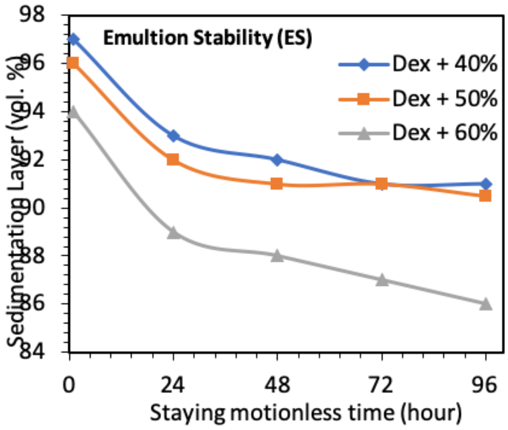


Figure 3: Result of Emulsion Volume.

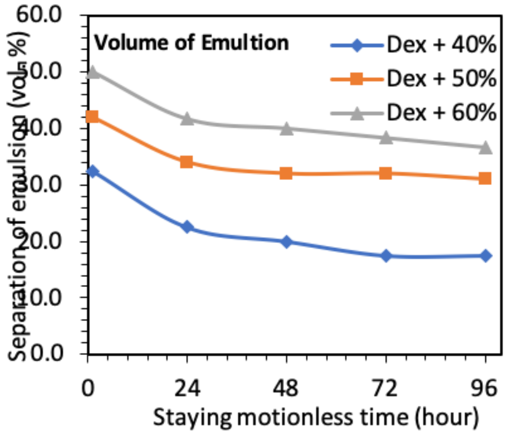


Figure 4: Result of Volume Emulsion.

that the emulsion layer remained stable at 1 hour up to 96 hours indicated by Dex + 50% emulsion. Percentage of sediment 1 hour 96%, 24 hours 92%, 48 hours 91%, 72 hours 91%, 96 hours 90.5% shown in (Figure 3). For emulsion volume in Dex emulsion observation + 40%, the most stable emulsion volume was observed at 72 hours 17.5% for Dex emulsion + 50% volume most stable at 48 hours 32% observation, while Dex + 60% for the most stable emulsion volume observed 48 hours 40% (Figure 4).

## 3.2 Emulsion Activity (EA)

Emulsion Activity is the ability of the emulsion to maintain the emulsifying layer under the centrifugal force, with the same amount of water and pertamina dex in W/D, when the centrifugal edge increases, the height of the sediment layer from W/D increases. This is because the specific gravity of the oil is lighter than the water and the emulsion is W/D.

## 3.3 Properties of Fuel

Specific Gravity to be able to calculate the mass of oil if the volume is known or to know whether there is contamination thus it can change the size of specific gravity. SG shows the weight per unit volume. Diesel specific gravity is measured using the ASTM D4052 or ASTM D1298 method.

Whereas Viscosity is the resistance held by the fluid if it is flowed in a capillary tube to the gravitational force, viscosity indicates the ease of whether liquid fuel is pumped and atomized. If the viscosity is higher, the resistance to flow is higher, this characteristic is very important because it affects the performance of the injector in the diesel engine. Viscosity is measured using the ASTM D445 or D1298 method. Fuel properties value as in Table 1.

Table 1: Properties of Pertamina Dex + 50% Water

| | |
|---|---|
| Density kg/m$^3$ | 833 |
| LHV, kJ/kg | 36,922 |
| Viskosity, cSt | 3.62 |
| Flash Pont, °C | 70 |

Flash point is the lowest temperature point where fuel can turn on spontaneously (Joshi and Pegg, 2007). This characteristic is determined by the ASTM D93 method. Heating Volue is measured using a tool called the bomb calorimeter.

## 3.4 Atomization of Pertamina dex fuel and W/D 50%

The atomization process is the process of converting liquid fuels injected by a machine injector into a sheet (thin sheet which later forms a ligament (bond) and breaks into a dropet with a certain pattern and direction. A more perfect atomization will produce better engine performance, this is because the injected fuel droplets are getting smoother as the fuel injection pressure increases which results in more perfect combustion in the combustion chamber (Watanabe et al., 2010). The parameters that can affect the atomization of fuel include Density, Viscosity, Flash Point, and Cetane numbers.

In Figure 5, the spray results for pertamina dex fuel injection pressure by Diamond Di 800 engine injector at injection pressure of 200 kg/cm$^2$, it is shown that the atomization results obtained spray length ($L$) with a length of 50 cm and spray angle ($\phi$) of 19°, While in Figure 6 the results of the spray / droplet are shown for fuel injection pressure Pertamina dex Emulsion + 50% water by the Diamond engine injector Di 800 at an injection pressure of 200 kg/cm$^2$, it is shown that the spray ($L$) is 50 cm long and spray angle ($\phi$) of 20°. From the results of the two atomiza-

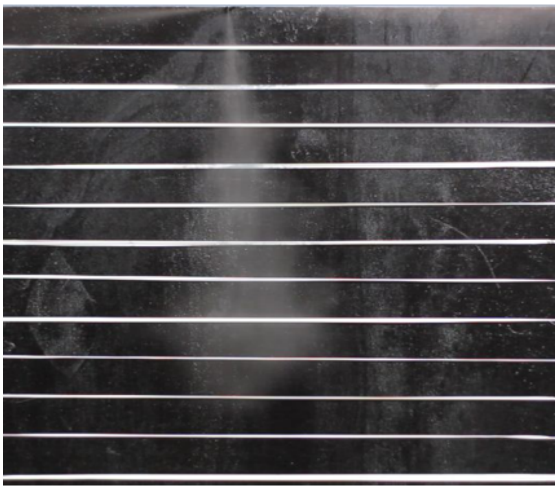

Figure 5: The Result of Pertamina Dex Atomization.

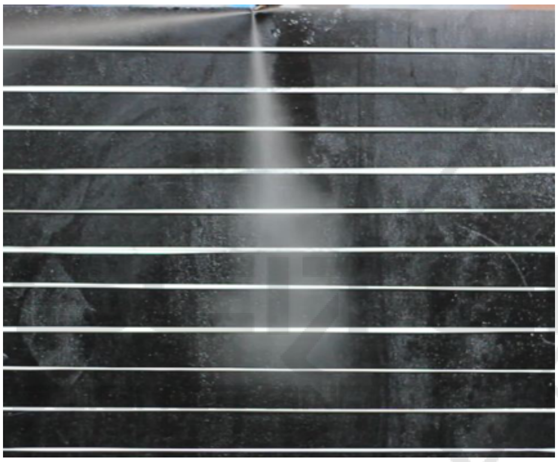

Figure 6: The Result of Pertamina Dex Atomization + 50% Water.

tion above it is stated that the 50% W/D emulsion can be used as a substitute fuel for pertamina dex, because the atomization value is almost the same.

## 3.5 Trends of using Emulsion Fuels on Diesel Engines

### 3.5.1 Effects of Water Emulsion in Diesel (W/D) on the Process of Combustion

Emulsion fuel when sprayed into the combustion chamber, heat will be transferred to the surface of the emulsion granules through the process of conversion and radiation, because diesel fuel and water have different temperatures, the evaporation rate will also be different. As a result the water molecules will reach the super-heat stage faster than diesel fuel and there will be a breakdown of the steam expansion (Elazzazy et al., 2015). At this stage the process of micro-explosion and pufing, micro-explosion droplets break into small grains quickly. While pufing increases granules in fogging. According to Morozumi and Saito (2010), micro-explosion is influenced by the volatility of the base fuel, type of emulsion and water content, an increase in the emulsifier content increases the temperature of micro-explosion. According to Fu et al. (2002) the mechanism of micro-explosion and dependence on various parameters will affect micro-explosion .

Ochoterena et al. (2010) in their study that the W/D spray characteristics, micro water emulsion in diesel at conventional diesel at high pressure and constant volume at high temperatures, observed neutralization and measurement of the cone angle of atomization, neutralization of longer droplets and wider crank angle with emulsion fuel compared to pure diesel fuel. The ignition delay is a little long. The longer duration of combustion occurred in emulsion fuels, an effect of lower flame temperatures, ignition delays up to 29%. According to Subramanian (2011),in his research, the ignition delay is much higher W/D than water injection into the manifold during the suction step.

### 3.5.2 Effect of Water Emulsion in Diesel (W/D) on the Performance Engine

The research conducted by Abu-Zaid (2004) related to torque, power, brake specific fuel consumption and thermal efficiency, by varying the percentage of water volume from 0 to 20% in W/D at 5% intervals. Alahmer et al. (2010) examined the performance of the engine by varying the percentage of the volume of water from 0 to 30% water in a diesel emulsion (W/D) at 5% intervals. Park et al. (2004) analyzed the effect of the percentage of water volume in diesel emulsion (W/D) 0, 16.67%, 28.6% about combustion characteristics with emulsion fuel. In other study of Park et al. (2000), he analyzed the combustion characteristics with pure diesel and W/D variations of 13%, 15%, 17% based on the volume of water in the emulsion.

In the study of Abu-Zaid (2004), torque increases with increasing percentage of water in the emulsion. According to research conducted by Alahmer et al. (2010), maximum torque was obtained at 5% moisture content based on emulsion volume. A decrease in torque occurs in emulsion fuel because the calorific value is reduced in the emulsion fuel system.

The research conducted by Abu-Zaid (2004) about the effect of water content in the emulsion system affected the power produced, the higher the percentage of water content in the emulsion, the higher the power. Alahmer et al. (2010) explained that the maximum engine power is achieved by adding 5% water to the emulsion based on volume. However, in Barnes et al. (2000)'s study on the use of water-in-diesel emulsion fuel (W/D) it decreased or lost power by 7-8% at diesel W/D with a moisture content of 10% based on volume.

The research conducted by Abu-Zaid (2004) by increasing the percentage of water in the emulsion had an effect on the decrease in BSFC, the greatest decrease occurred in the use of a percentage of 20% water in emulsion, this was due to secondary atomization due to micro-explosion. In the study conducted by Kaliaperumal and Udayakumar (2009) the percentage effect on emulsion, a decrease in BSFC along with an increase in the percentage of water volume in the emulsion, the minimum BSFC value occurred at a percentage of 20% W/D. Whereas the research conducted by Ghojel et al. (2006) experienced a 22-26% increase in BSFC with 13% emulsion fuel water in volume based emulsions compared to diesel fuel.

#### 3.5.3 Effect of Water Emulsion in Diesel (W/D) on Emissions

Evaporation of water due to absorption of heat around it will reduce the temperature in the combustion chamber thereby reducing NOx. The addition of a small amount of water to NO and NOx emulation fuels increases, while for the addition of water content a lot of NO and NOx decreases. The decrease in NO at W/D variations of 10% and 20% were 18% and 21.5%, while NOx decreased were 10% and 25% respectively. In the study of Ghojel et al. (2006) the decrease in NOx was 29-37% at W/D 13% by volume. The research conducted by Samec et al. (2002) decreased NOx emissions by 20% and 18% compared to pure diesel fuel in the water in diesel content of 10% and 15% respectively. Barnes et al. (2000) in their study of the effect of 10% of water based on the volume mixed with diesel fuel in emulsions reduced NOx emissions by 9%.

In the study of Ghojel et al. (2006), the reduction in HC emissions was 60-90% at W/D 13% by volume. Research conducted by Samec et al. (2002) decreased Hydrocarbon emissions by 52% and 33%, while those for soot emission were reduced by 68% and 75% compared to pure diesel fuel at 10% and 15% respectively in water in diesel. Barnes et al. (2000) in their research PM emissions decreased 20% at 10% W/D based on volume.

## 4 CONCLUSION

This research conclude that addition of water in the form of water emulsions in diesel (W/D) can reduce pollution levels and engine performance. W/D emulsion was carried out by mixing between water, pertaminadex, and surfactant (span 80 1.3% and tween 80 0.7%) where the parameters used were emulsion stabilization, fuel efficiency, neutralization of sprays, spray angles and trends using emulsions on engine performance and emissions. The water was mixed with pertaminadex and surfactant with the composition of pertaminadex + 50% water + 2% Surfactant (span 80 + Tween 80), under stirring speed 1500 rpm for 30 minutes with stabilizer using a sonicator for 60 minutes and stabilized for 1 hour and 24 hours. The results of this study indicated that the emulsion of 50% W/D 1 hour emulsion stability 96% while 24 hours 92%, Density value 833 kg/m$^3$, LHV value 36.922 kJ / kg, Flash Point 70°C, Spray Length 50 cm and spray angle 20°. Trends in the influence of emulsions on engine performance and emissions were also analyzed.

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