Effect of Water in Fuel Emulsion on Performance and NOx of Diesel Engine

Beny Cahyono[1], Aguk Zuhdi M. Fathallah[2], Semin[3], Nauval Pahlevi[4]

Abstract**—** NOx one of the exhaust emissions is harmful to human health. Many methods can reduce NOx emissions, one of them is water in fuel emulsion. By using experiment, research has been conducted in surfactant selection. The results of experiment show 4 surfactant, which is best used to the diesel engine is tween 80 and span 80. This experiment needs some water contents variation emulsifier with 10%, 15%, and 20%. In this different variation of water is very influential on performance and NOx emissions. By using water fuel emulsion of 10% in SFOC has been increase 216,2 g/Kwh or 11.6% compared to Pertamina Dex of fuel. However, the water used in fuel emulsion of 15% and 20% in SFOC increased to compare 10% emulsion. The effect of water use in fuel emulsion has been reduce NOx emissions. Water in fuel emulsion has been decrease 50.5%. Generally, the emission level of a diesel engine that using water in fuel emulsion has been improved until entering on Tier 3 specification of IMO rules.

*Keywords***—**diesel engine, engine performance, fuel emulsion, NOx emissions, water emulsion.

I. Introduction

Emissions are a toxic gas that can endanger and threat human life on this earth. On the ship, the emissions are formed due to the combustion of fuel carried by diesel engines that occur in the combustion chamber. Diesel engine are the type of internal combustion engine which atomized fuel oil is sprayed into the cylinder and ignited by the heat generated by compression. In the Diesel engine are efficient, because it has a low level of carbon di-oxide, carbon monoxide and hydrocarbon emissions. However, the emissions are high in nitrous oxides. Marine engines use residual bunker fuels which contain sulphur, asphaltenes and ash. Due to these components in the fuel, the exhaust emissions contain oxides of sulphur and particular matter which are formed during the combustion process [1].

Fuel is injected at high pressure (through fuel injectors which atomize the fuel) into the combustion chamber towards the end of the compression stroke. The fuel ignites, thereby increasing the pressure in the combustion chamber and pushes the piston downward on the power stroke. When the fuel ignites the flame front travels rapidly into the combustion space and uses the compressed air to sustain the ignition. Temperatures at the envelope of the flame can exceed 1300 degrees C, although the mean bulk temperature in the combustion chamber is much lower. At these localized high temperatures molecular nitrogen in the combustion air is oxidized and Oxides of Nitrogen (NOx) are formed in the combustion chamber. Oxidation of molecular nitrogen in the combustion air comprises of about 90% of NOx, the other 10% is the result of oxidation of the organic nitrogen present in the residual fuel oil.

In recent years emissions of NOx, SOx and particulate matter from ships has increased. International shipping now contributes about 15% of the global NOx emissions and there is a substantial pressure to reduce NOx emissions from ships. Europe and USA has been established air quality standards with maximum levels of fine particles. These levels are exceeded in many coastal and harbor area. However it is not likely that particulate matter emissions from ships will be regulated, but it is still an important objective to minimize these emissions. NOx emissions from ships are regulated and the limits on NOx emission are getting stricter. The limitation on NOx emission means that different measures for NOx reduction will have to be used. These measures might have adverse effects upon the levels of other emissions like CO2, CO, unburned hydrocarbons and particulate matter. The magnitude of the effect upon CO2 is widely known; while the effects upon particulate matter are largely unknown [2-4].

The use of water in diesel engines has a number of possible benefits. It has been found that it has an influence on reducing the peak flame temperature and hence reducing the NOx emissions. The technique concerned with introducing water into engine combustion chamber was proposed by Prof. B. Hopkinson in 1913, to make better internal cooling of the gas engine and to increase the engine output. Furthermore, the technique was developed to improve the thermal efficiency and reduce exhaust emissions, or used as the safety fuel [5-15].

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Beny Cahyono of Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : benyjtsp98@gmail.com

Aguk Zuhdi Muhammad Fathallah of Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : fathalaz@its.ac.id

Semin of Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : semin@its.ac.id

Nauval Pahlevi of Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Campus ITS Sukolilo-Surabaya 60111, Indonesia, Email : nauvalpahlevi@gnail.com

the thermal efficiency and reduce exhaust emissions, or used as the safety fuel [1-5].

Water-in-oil emulsion is defined as a form of water in oil mixture that is not intermingled forced mixed stably or temporarily with the help of chemical surfactant (emulsifier) so that the water in the form of granules distributed in the oil phase. Emulsifier level is determined by the ability of surfactant, fluid viscosity, grain size, material composition and temperature of the mixture. In particular, the grain size smaller water desired to submicron size. Submicron grain size of water helps keep the liquid emulsion is stable in the long term. Water-in-oil emulsion is formed when the volume of water in amounts far less than the volume of oil that is mixed. Chemical surfactants (emulsifiers) is the key factor to get the oil in water emulsion to be stable for a long time. Water-in-oil emulsion can be used as a fuel where this emulsion can certainly burn. In an emulsion usually there are three main parts [2-22]

- Section dispersed consisting of grains which usually consists of fat.
- Media dispersant which is also known as the continuous phase, which usually consist of water.
- Emulsifiers which serves to keep the oil grains had remained suspended in the water.

Factors that affect the stability of the emulsion is the type of emulsifier, emulsifier concentration, droplet size, pH, viscosity, stabilizers, heating, cooling, freezing, or mixing

- Emulsions may occur permanently and temporarily.
- Permanent Emulsion is a material capable of forming membranes or films around the dispersed droplets thereby preventing the re-unification of these items. Such materials are known as emulsifier.
- The temporary emulsion occurs for example in a oil and water are shaken together, will form beads of fat and then form an emulsion.

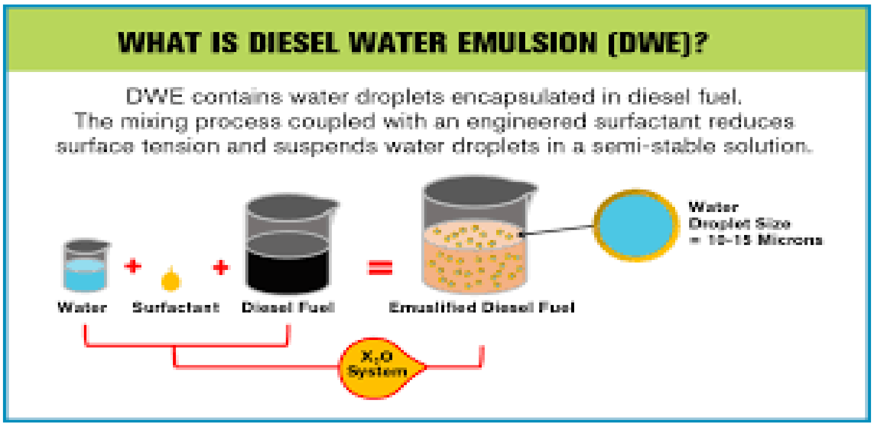

Figure. 1. Mixing Process

As show in figure 1 mixing process is the addition of additive materials into petroleum fraction in order to improve the quality of the product. To mixing wine oil with diesel oil. There are two ways in which to blending emulsion and solution technique. The emulsion is a mixture of particles of a liquid substance (the dispersed phase) with other liquids (dispersing phase). The emulsion is composed of three main components, namely: the dispersed phase, the phase of dispersant and emulsifier / emulsifier. In the manufacture of an emulsion, emulsifier selection is an important factor to be considered because of the quality and stability of an emulsion is heavily influenced by the emulsifier used. One surface active emulsifier or better known as surfactants [3].

Solution technique is done by heating the fuel mixture. Both fuels can be dissolved without separation when heated to a temperature of 50 ° C .

Water fuel emulsion system is based on mixing of water into the fuel with additive substances mixture. The emulsion is injected into the engine cylinder using the fuel injection system. Therefore additional injecting equipment is not needed. This is of course depends on the installed injection system and the desired effect. A system for WFE consists of different components. Foremost there is the water supply. This system needs to be able to feed water of a good enough quality with a high enough quantity. Water emulsified fuel is one of the promising emission reduction techniques with the potential to reduce NOX in diesel engines [4, 23-38].

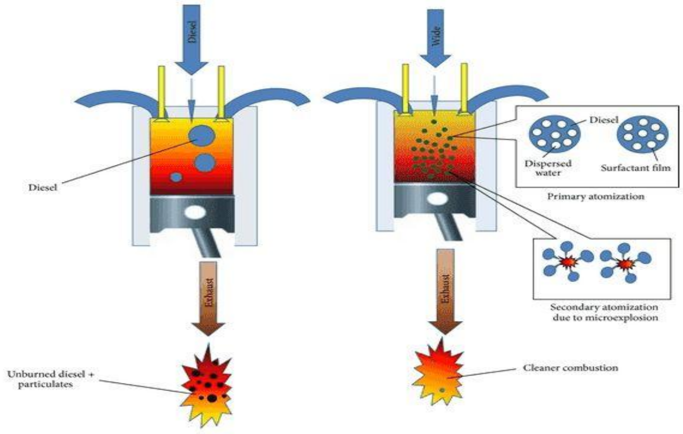

Figure. 2. Primary and secondary atomization in spray flame of emulsified

As show in figure 2 explain the comparation between the straight diesel combustion and a water-in-diesel emulsion The water-in-diesel fuel burns significantly cleaner. Emulsion is obtained by mechanical and ultrasound micronization process that results in micro-drops formed by the three basic elements of the product: water in the core, hydro fuel covering the water particles and finally the emulsifier between both previous elements with a membrane that also helps in binding them to other micro-drops. The nature of the new resulting fuel modifies the traditional combustion sequence. Engine injectors ignite the fuel by compressing hydro fuel in such a way that the explosion overheats the water particles trapped in the core of the micro-drops. This overheating results in water vapour that generates turbulence inside the engines combustion chamber. This vapour breaks up the hydrofuel molecules resulting in complete burning of the fuel that compensates the loss of energy due to the presence of the water particles added. The vapour also eliminates un-burnt residual particles and helps the cleaning of engine parts and exhaust system. [5, 30-38]

With more than 90% of global trade now carried by sea, the shipping industry has played a crucial role in shaping the integrated global economy. It is estimated that if the growth trend of the last 150 years continues, nearly 23 billion tons of cargo that will be transported by ship by 2060, compared to 8.5 billion tones in 2010. The environmental impact of shipping operations –whether at sea or in port– have been known for decades. But it is only in recent years that the damaging effects on human health and biodiversity have been demonstrated. This has led both international and regional organizations – most notably the International Maritime Organization (IMO) and the European Union (EU) – to regulate shipping emissions more stringently.

While pollutant emissions from land-based sources are gradually coming down, those from shipping show a continuous increase. Emissions from ships engaged in international trade in the seas surrounding Europe – the Baltic Sea, the North Sea, the north-eastern part of the Atlantic, the Mediterranean and the Black Sea – were estimated at 2.3 million tons of sulphur dioxide (SO2), 3.3 million tones of nitrogen oxides (NOx), and 250,000 tonnes of particulate matter (PM) a year in 2000.Under a business-as-usual scenario, it is expected that shipping emissions of SO2and NOx will increase by 40–50 per cent between the year 2000 and 2020. By 2020 the emissions from international shipping around Europe are expected to equal or even surpass the total from all land-based sources in the 27 EU member states combined.

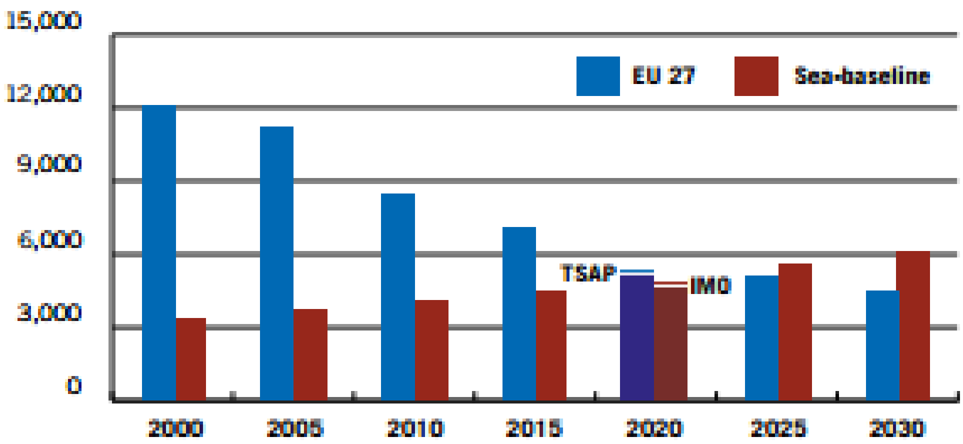

Figure. 3. Emissions of NOx

Figure 3 described the emissions calculation that carried out from a South American perspective for transporting 1000 tons of cargo between Manaus, Brazil and either Buenos Aires, Argentina or Santos, Brazil. For shipping this means that the international rules apply, that is, a maximum fuel sulphur content of 3.5% and, for ships constructed after 2000, tier 1 NOx levels [5]

II. METHOD

Before the experiment needs to prepare of fuel used for mixing with water. The type of fuel used is pertamina dex fuel (best level of diesel fuel). The materials and tools used in the experiment as follows:

- Aquades water
- Diesel oil
- Span 80
- Tween 80
- Aquades water
- Mixer
- bucket
- graduated cylinder
- Computer as data processing
- Diesel engine Shanhai MD180

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A. Fuel emulsion

At this step there is the process of making water in fuel emulsion to conduct fuel composition variation with water and the addition of emulsifier which serves to lower the surface tension (surface tension) of a medium and lower the interfacial tension (interfacial tension) between two different phases degree of polarity. In the process of mixing using a mixer.

B. Engine and its Specifications

In this step is before performing the test on a diesel engine, the first to be set-up diesel engine first by following existing procedures. Here are the detail specifications of the diesel engine is used and engine set-up for experiment.

- Engine Name : Shanhai
- Type : Horizontal, 4 stroke
- Model : R180
- Cooling System : Hopper
- Displacement : 402
- Stroke diameter : 80x80 mm
- Dimension : 658x341x463 mm
- Weight : 70 Kg
- Cylinder : 1 cylinder
- Combustion system : Indirect
- Max. Torque : 8 / 2600
- Continue Torque : 7 / 2200
- Compression Ratio : 21 : 1
- System Governor : Mechanic

Figure. 4. Shanhai Diesel Engine

Engine set-up for experiment:

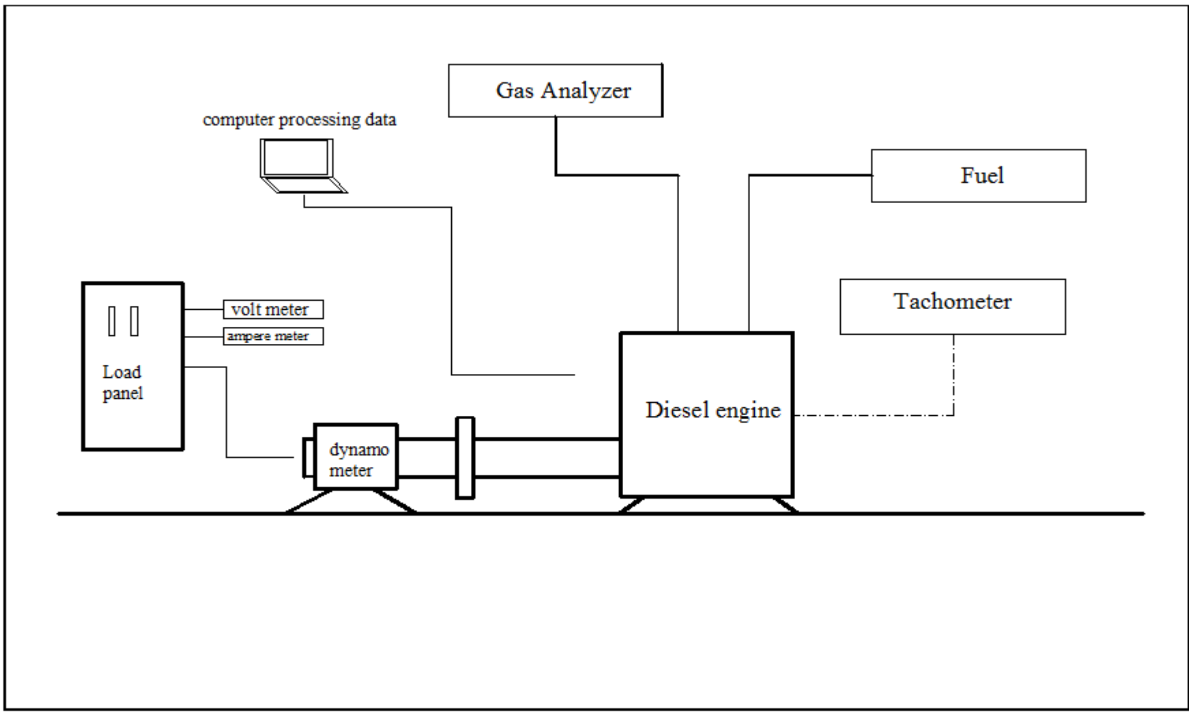

Figure. 5. Engine set-up

Equipment and tool used in experiment:

- Shanhai MD175A
- Electric dynamometer
- Control panel
- Fuel
- Amperemeter
- Voltmeter
- Tachometer

C. Engine Performance Test

- Fixed variable :
  - ✓ Engine used Water fuel emulsion
  - ✓ Engine speed (RPM)
- Variable result *:*
  - ✓ Power
  - ✓ Torsion
  - ✓ Load

D. NOx Emissions Test

- Fixed variable :
  - ✓ Engine used Water fuel emulsion
- Variable change :
  - ✓ Engine speed (RPM)
  - ✓ Load
- Variable result :
  - ✓ NOx,

For testing methods at emission test, RPM and load points follow the procedures on Marpol Annex VI IMO rules. Type of test selected is test cycle type E2, this type is chosen because the motor tested can function as the main driving force of the ship. The test method for type E2 is as shown in table 3.1 below:

TABLE 1.
MARPOL ANNEX VI, APPENDIX II TEST CYCLE

Test Cycle Type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weight Factor	0.2	0.5	0.15	0.15

*)where:

- ✓ For a constant speed diesel motor and used for prime mover or used as electric diesel using Test Cycle E2.
- ✓ For controllable-pitch propellers using Test Cycle E2.
- ✓ For auxiliary engines constant speed using Test Cycle D2

E. Data Analysis

In this section analyzes the data after the test diesel engine with performance parameters consisting of a diesel engine with a rotation comparison generator and additional burdens and knows the value of torque and SFOC.

F. Results and Conclusion

At this stage, namely the results of the data analysis by using fuel experiments to be compared with diesel fuel and determine efficient use of fuel and the results of exhaust emissions in diesel engines. After the conclusion and the underlying answer from this study answers.

III. RESULT AND DISCUSSION

A. Procedure Experiment

Based on the variables that hase been done, then the discussion of research results is divided into several points, namely:

- Preparation of water fuel in emulsion with variation of water content for emulsion fuel
- Preparation of surfactant solution with variations of surfactant type used.
- water fuel mixing during the process water emulsion.

B. Determining the composition of emulsifier

After determined the composition of diesel fuel with water to consider mixing with emulgator. Because we still do not know what is the approiate mix to able to mix between diesel fuel and water. That after we can do variations mix emulgator to water in fuel. The following variations are to be used:

- Solar 300 ml + water 10 % + 2% tween 80 + 2% span 80
- Solar 300 ml + water 15 % + 2% tween 80+ 2% span 80
- Solar 300 ml + water 20 % + 2% tween 80+ 2% span 80

C. Determination of surfactant

Water of fuel in emulsion stability depends on the type of emulsifier used because it will affect the permanent and non-permanent emulsion. The following is the type of emulsifier used in the experiments of fuel in water emulsion.

Figure. 6. Result of mixture water fuel in emulsion with additive tween 80 and span 80

This is the result of a mixing process of emulsified fuel with varying water content. The material used in the manufacture of solar-water emulsions is pertamina dex pertamina which has a cetane number of 53 with sulfur content below 300 ppm. This cetane number indicates the quality of fuel for diesel engine. This figure affects the combustion process that occurs in diesel engine. The higher the value, the easier the combustion process will reduce the load of the engine and the diesel will be smoother. This material is chosen because it has a cetane number that is high and good for diesel engine. The emulsion made in this research is a water-in-oil emulsion emulsion known as water fuel in emulsion. This emulsion is carried out by addition of moisture content in diesel by emulsification process using surfactant. In this type of emulsion, water (water) is the dispersed phase (inside) while diesel (oil) is the dispersant phase (outside).

D. The process mixing diesel fuel with water

First prepare the water, fuel and additive materials. then steps both fuel blend with a mixer while slowly pouring the emulsifying additive until well blended. Let stand for 1 hours, until the diesel regain its color and transparency. after that the next steps are mixing the first mixture (diesel-additive) while adding water very slowly until the mixture gets an intense and homogeneous white. Then continue mixing for a few minutes (in case of larger amounts of make mix to at least three complete cycles of The total volume of emulsion). As whiter is the emulsion, as better stability.

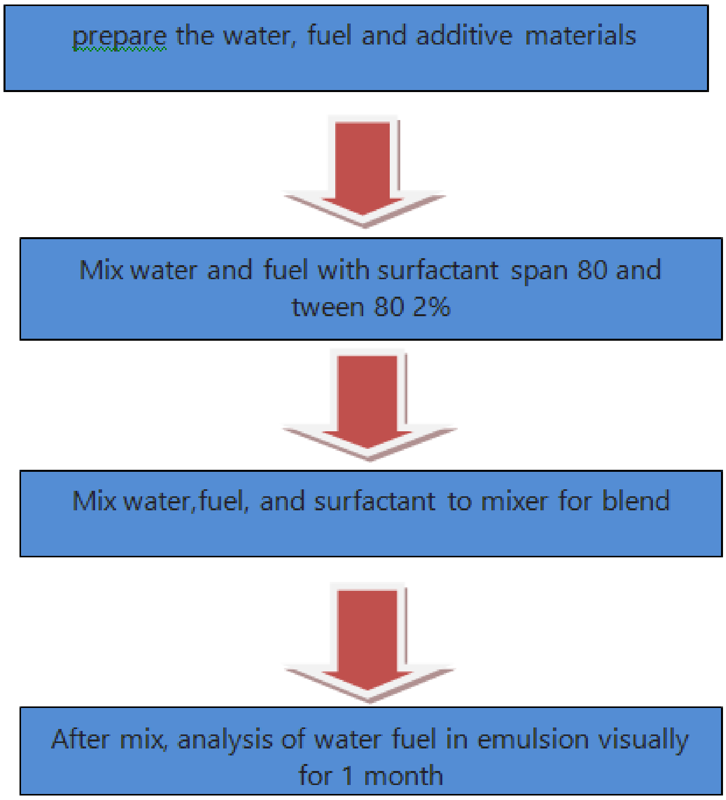

Figure. 7. Chart the process of making water fuel in emulsion

As show in figure 4.3, the result experiment mixture of fuel with 10% water and 4% additive, figure b the mixture of fuel with 15% water and 6% additive, and figure c fuel mixture of 20% water with 8% additive and to settlink for 5 days. as an figure 3.3, the result experiment mixture of fuel with water added additive span 80, ABS, and CMC less than perfect. The types of additive will affect permanent and non permanent emulsion of water in fuel. Additive ABS and CMC is types additive for water with fuel is unstable additive mixing.

E. Comparasion between power with SFOC against fuel emulsion and pertamina dex at 2200 RPM

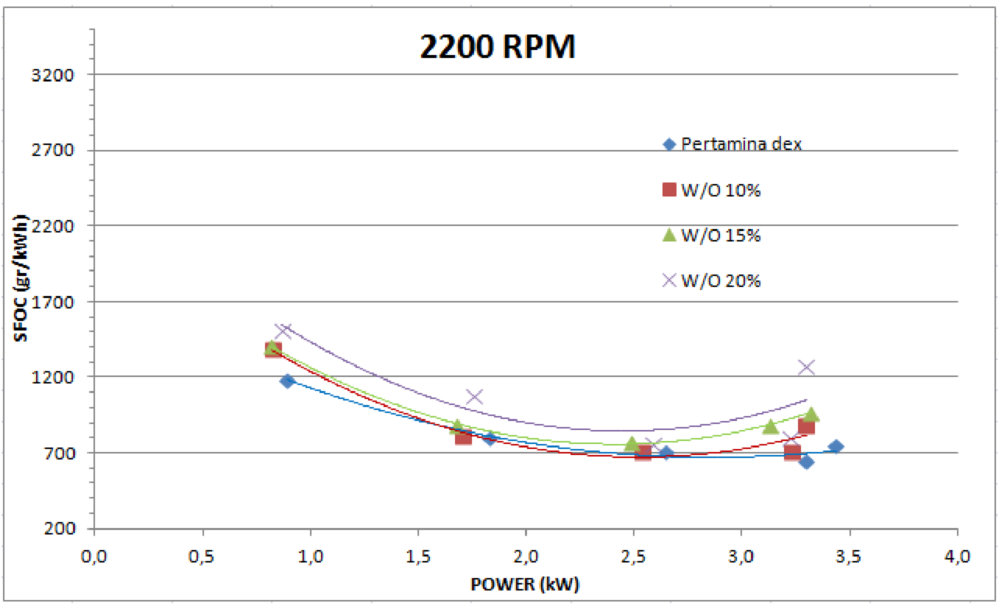

Figure. 8. Comparasion of power with SFOC of diffrent fuel compotition at 2200 RPM

Based on the graph above we can see the value of water content in the emulsion fuel affecting the SFOC value. The greater the value of the fuel content of the emulsion, the smaller the SFOC value. At low load, 10% emulsion fuel produces the low SFOC value. However, at 20% water fuel in emulsion when large load produces the highest SFOC values. On the Pertamina Dex fuel of 2100 rpm produce low SFOC value. The value of SFOC at water fuel in emulsion 10% at low load 1464.3 g/Kwh, Water fuel in emulsion on content 15% produce SFOC value of 1498.2 g/ Kwh, Water fuel in emulsion content 20% produce SFOC value of 1628.2 g/Kwh, and Pertamina Dex Of fuel produce SFOC value of 1185.5 g /KWh. Then on the graph above can be concluded that the greater value the smaller the SFOC value at 2200 round emulsion fuel. It can be concluded that on Pertamina Dex fuel is more efficient SFOC value than water in fuel emulsion for at low load and at 2200 rpm.

F. Comparasion between RPM with Maksimum power against fuel emulsion and pertamina dex

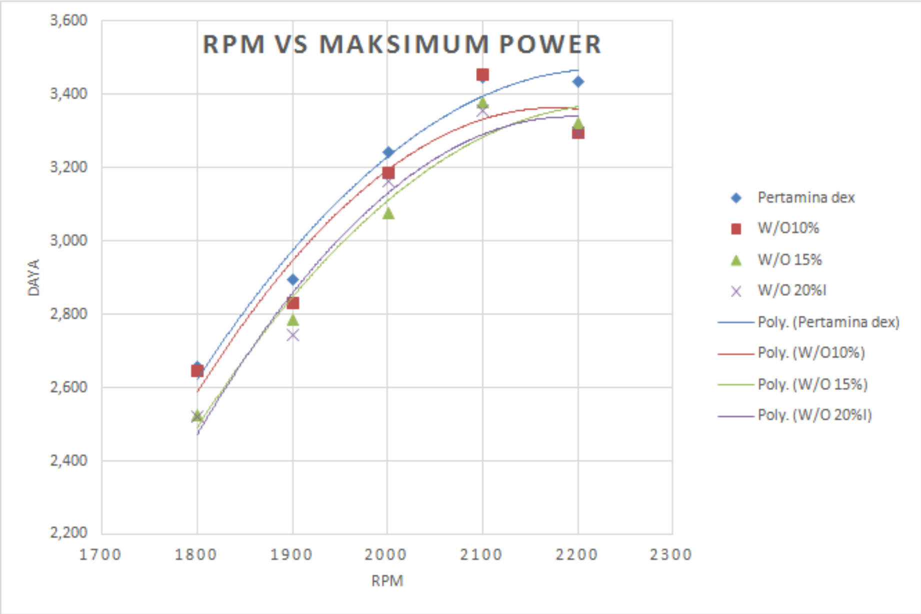

Figure. 9. Comparasion of power with RPM of different fuel compotition

As show in figure 9 is a graph of power performance comparison to RPM on water fuel in emulsion content of 10%, 15%, 20% and pertamina dex of fuel. The above graph is the value of 100% power. This value is derived from the lowest SFOC point described in the previous graphs. In the power chart above, seen in the initial RPM when using water fuel in emulsion 15% power increased about 2.93% compared to water fuel in emulsion 10% and 20%. At 1800 RPM on water fuel in emulsion 10% maximum power is at 2.646 kW, water fuel in emulsion 15% of 2.526 kW, and water fuel in emulsion 20% power value is at 2.52 kW. However, in the final RPM, the power value in water fuel in emulsion 10%, 15%, and 20% are at different points. From this graph can be analyzed that at the beginning of RPM should use water fuel in emulsion 10%.

G. Comparasion between RPM with Torque against fuel emulsion and pertamina dex

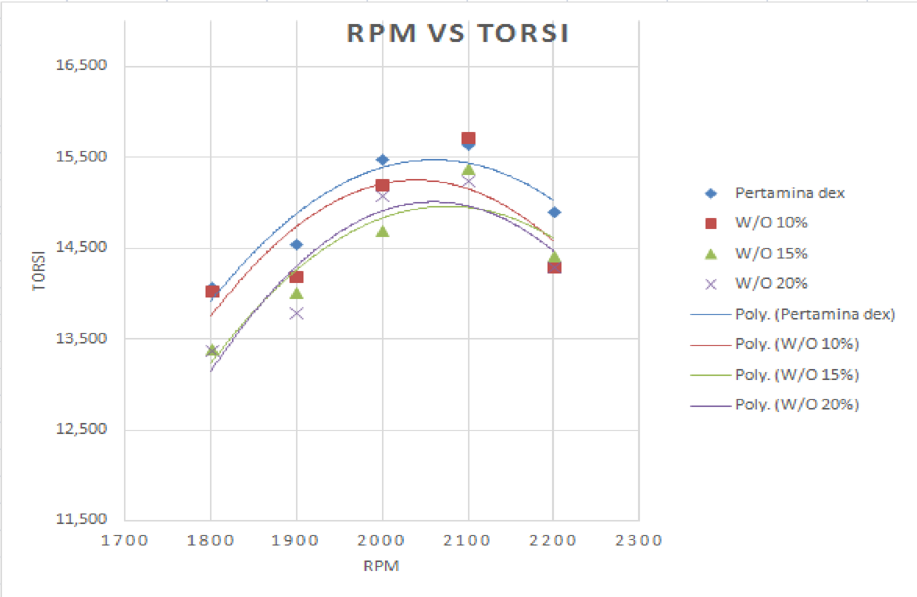

Figure. 10. Comparasion of RPM with Torque of different fuel compotition

Show in figure 10 above is a comparison graph between torque and engine speed at maximum power. Pertamina dex fuel produces torque of 14,90 Nm, water in fuel emulsion content 10% produces 14,027 Nm of torque, water in fuel emulsion content 15% produces 13,384 Nm of torque, and water in fuel emulsion content 20% produces 13,37 Nm of torque. From the graph above can be seen that the larger the water content of fuel then the resulting torque can be greater, But the influence of the water content of fuel on the engine power is not too significant because the difference from the torque on water in fuel emulsion 10%,15% and 20% only 0.5 Nm.

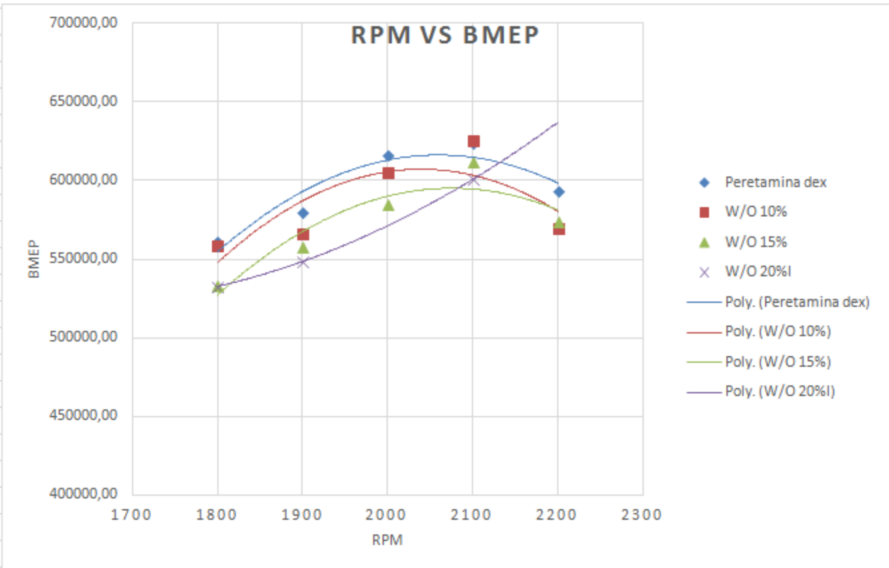

Figure. 11. Comparasion of RPM with BMEP of different fuel compotition

Show in figure 11 above is a comparison graph between BMEP and engine speed at maximum power. Pertamina dex of fuel produces BMEP of 593120 N/m2, water in fuel emulsion content 10% produces BMEP 569506 N/m2, water in fuel emulsion content 15% produces BMEP 591356 N/m2, and water in fuel emulsion content 20% produces BMEP 569506 N/m2. BMEP produced pertamina dex of fuel is the largest, while water in fuel emulsion contents 10%,15% and 20% produce a smaller BMEP, from the graph above can be seen the greater water content of fuel the BMEP value generated can be greater. But the effect of water content of fuel on engine power is not too significant.

H. Comparasion between RPM with Torque against fuel emulsion and pertamina dex

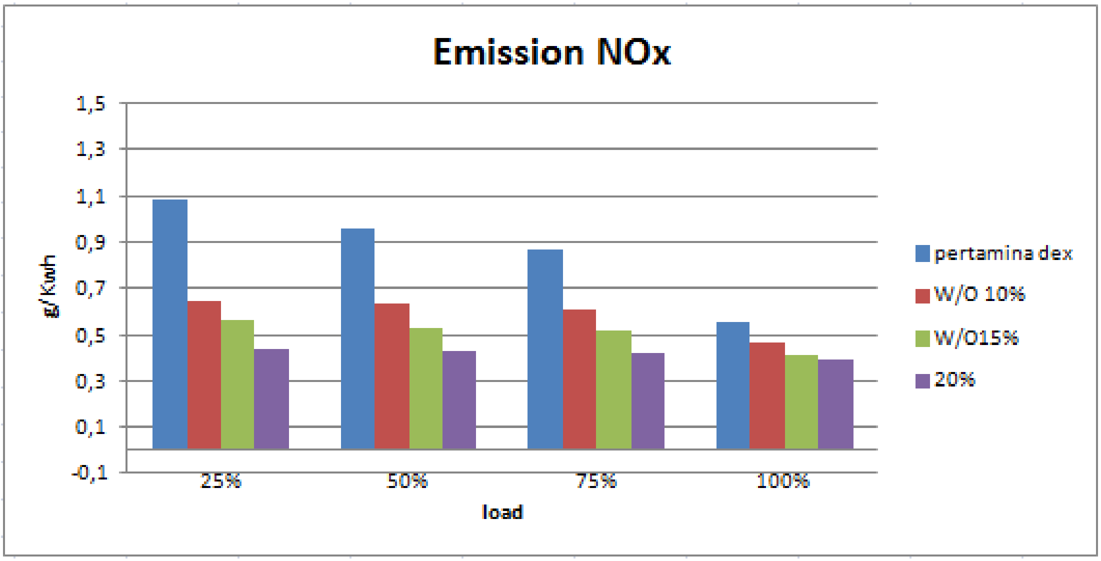

Figure. 12. NOx content at 100% RPM and load conditions various

Levels of NOx emissions generated in water fuel in emulsion 10% standard diesel motor conditions ranging from 25% -100% load are 0,642 g / kWh, 0.639 g / kWh, 608 g / kWh and 0.467 g / kWh, respectively. At load conditions 25% - 100% of TIER 3 qualified NOx emissions, making it safe for the environment. As explained in Chapter II earlier that TIER 1 qualification is NOx 7.7 - 9.8 g / kWh emission at a turn of more than 2000 RPM. The qualification of TIER 2 is the emission of NOx diesel engine between 1.96 to 7.7 g / kWh at 2000 RPM. The TIER 3 qualification is an NOx emission of a diesel motor that is less than 1.96 g / kWh in turn over 2000 RPM.

Levels of NOx emissions generated in water fuel in emulsion 15% ranging from 25% -100% load are 0.566 g / kWh, 0.530 g / kWh, 0,515 g / kWh and 0.414 / kWh, respectively. When load conditions 25% - 100% of NOx emissions are included in TIER 3 qualification.

Levels of NOx emissions generated in water fuel in emulsion 20% ranging from 25% -100% load are 0.434 g / kWh, 0.427 g / kWh, 0.423 g / kWh and 0.392 g / kWh, respectively. When load conditions 25% - 100% of NOx emissions are included in TIER 3 qualification.

Levels of NOx emissions produced in Pertamina Dex of fuel ranging from 25% -100% load are 1082 g / kWh, 961 g / kWh, 868 g / kWh and 555 g / kWh, respectively. When the load condition is 25%, - 100% of NOx emissions are included in the TIER 3 qualification.

I. Discussion

This chapter is a general discussion of the results of making water fuel in emulsion, performance results, and NOx as described in sub chapters 4.1 until 4.13. The discussion is the process of making water fuel in emulsion by determining the type of surfactant and analysis of the graph obtained during experiment step on diesel motor using water fuel in emulsion with a variation of percentage of water content 10%, 15, and 20%. The analysis based on the experimental results can be compared with the basic theories and the results that already existed in the previous research reference.

The experimental results of water fuel in emulsion using a surfactant as an additive are tween 80 and span 80 with 10%, 15%, and 20% water content composition and 2% surfactant mixture. The use of water in emulsified fuel is to determine the performance and emission of NOx on a diesel engine.

The experimental results have been obtained SFOC graphics as shown in Figures 4.6 to 4.13. On the graph shows that the use of water fuel in emulsion 15% can improve the value of SFOC on diesel motor performance. In the use of water fuel in emulsion 10%, the SFOC value is reduced by about 10%. However, on the water fuel in emulsion chart, 20% of SFOC values are increasing. Several previous studies have suggested that the addition of water fuel emulsion on the diesel engine can lead to increased SFOC values. When associated with experimental results in this study, there are limits to the addition of water content that can lead to increased SFOC values.

Reduced performance is an indication that the use of water in fuel emulsion is less efficient. However, functionally, water in fuel emulsion is an NOx to reduced technology. NOx emission results in this experiment are shown in Figure 4.14. On the graph it is seen significantly that the use of water in fuel emulsion can reduce NOX levels up to 50.5%. This is in line with the basic theory and reference of previous researchers who explained that the use of water in fuel emulsion able to reduce levels of NOx

IV. CONCLUSION

In the process of producing water fuel in emulsion, the determination of surfactant type greatly influences the emulsion stability. In this case it can be seen that comparison of surfactant tween 80, 80 span with 80, ABS span in the range of 7 days looks different. In the use of ABS surfactant type and span 80 is not homogeneous. In this case the type of surfactant used is not good in the process of producing water fuel in emulsion.

The use of water fuel in emulsion 10% resulted in SFOC increased 323.8 g/kWh or fuel consumption improvident 16.5% compared to diesel engine using Pertamina Dex. However, the use of water fuel in emulsion 15% and 20% resulted in SFOC increase compared to water fuel in emulsion 10%. In comparison power, torque, and BMEP on water fuel in emulsion decreased compared to Pertamina Dex of fuel at conditions 1800-2000 RPM.

By using water in fuel emulsion with a variation of water content 10%, 15%, and 20% NOx emission level produced can decrease to 0.216 g / kWh or reduced by 50.5%. Generally, the emission level of a diesel engine that has been using water fuel in the emulsion can be improved until entering on TIER 3 specification.

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