Analysis of The Injection Pressure Effect on Single Cylinder Diesel Engine Power with Diesel Fuel-Methanol Blend

Aguk Zuhdi M. Fathallah[2], Adhi Iswantoro[2], Semin[3], Beny Cahyono[4], I Made Ariana[5], Ananda Rizky Budi Pratama[6]

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Abstract— **the use of fossil diesel fuels still produces carbon dioxide emissions (CO_2), sulphur dioxide (SO_2), hydrocarbon emissions (HC), nitrogen oxide (NO_x), and high total particles and carbon monoxide (CO). Moreover, the need for transportation of motor vehicles will always increase every year. The emission of exhaust gases resulting from the combustion process can essentially be reduced by improving fuel quality, the homogeneity of the fuel mixture, and regulating proper combustion. There are several ways to reduce exhaust emissions from diesel engines by providing precise injection pressures. This is done to get the perfect combustion. In addition, improving fuel quality is a way to reduce emissions of exhaust gases. Another one is by adding methanol to the diesel. The addition of methanol can reduce the emission of exhaust gas produced. The process of mixing the solar and methanol takes the addition of surfactants to obtain good homogeneity. Testing was conducted using simulation software with engine modeling. The result can be seen in the reduction and the addition of standard pressure 200 bar, that the emulsion fuel in SFOC (specific fuel oil consumption) suffered a decrease and increased by 0.2% and 0.3% at pressure 160 bar and pressure 240 bar. The fuel solution on SFOC suffered a decrease and an increase of 0.3% and 0.25% was produced by pressure 160 bar and pressure 240 bar. The highest NO_x is produced by 240 bar injection pressures with Dexlite fuel while the lowest NO_x is produced by 160 bar injection pressure with emulsion fuel.**

Keywords— emission, homogeneity, injection, methanol, simulation, surfactants.

I. Introduction

Every year the need for transportation of motor vehicles will always increase. A widely used means of transportation are diesel motors and gasoline motors. The increasing number of motor vehicles makes the fuel need increase as well. Many countries including Indonesia are still dependent on fossil fuels, whereas the availability of fossil fuels in Indonesia is increasingly running low. The combustion produced by diesel or gasoline motors became one of the factors of global warming because of the increased air pollution resulting from the emissions generated by imperfect combustion.

For that, it is necessary to have innovations to create fuel that is low in emissions. Emissions from motor vehicles can essentially be solved by improving the combustion process. Some ways to solve that are by improving the quality of the fuel, the homogeneity of the fuel mixture, adding the injection pressure, and regulating the injection timing precisely [1]. In some of the ways already mentioned, adding injection pressure, and improving fuel quality can reduce the emissions of results from imperfect combustion. The addition of injection pressure makes the resulting fuel particles smaller and foggy. This facilitates the combustion process as it shortens the ignition delay process [2]. In the case of precise opening pressure, the result is optimal combustion in the cylinder of the motor. Perfect combustion will increase the performance of the engine and lower the exhaust emission levels in diesel motors.

Methanol is one of the fuels that can be renewed. The reason for using methanol is because it has laminar flame vines that are high enough that makes the combustion process finish faster. Solar mixing with methanol produces emissions reductions such as carbon dioxide, smoke concentrations, and NO_x and can optimize engine performance.

In this research, the method used to reduce emissions is to provide a variation of the injection pressure and the mixing of solar-methanol fuels. And will discuss the emission analysis and performance of the injection pressure variations using a diesel fuel-methanol mixture. This research will be conducted with a simulation method using software applications by looking at the emissions and performance of the injection pressure variations of 160 bar, 200 bar, and 240 bar. The analysis gained comparisons of the resulting emissions and the performance of the injection pressure variation.

Aguk Zuhdi M. Fathallah is with Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: fathalaz@its.ac.id

Adhi Iswantoro is with Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: adhi@ne.its.ac.id

Semin is with Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: semin@its.ac.id

Beny Cahyono is with Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: cak_beny@yahoo.com

I Made Ariana is with Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: ariana@its.ac.id

Ananda Rizky Budi Pratama, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: rizkybudipp@gmail.com

A. Injection Pressure

In the injection pressure setting, it impacts good or poor fuel economy. A good spray will facilitate the escort of the combustion process that occurs due to the combination of fuel with oxygen in the combustion chamber. How the injector work will be described below:

1) The first way of the injector is that the fuel will flow through the oil channel on the nozzle holder using the injection pump to the oil pool located on the nozzle body.
2) After that the injection occurs if there is a fuel pressure that makes the oil pool rise, to suppress the tip of the needle. When the resulting pressure exceeds the spring power, the needle nozzle will be pushed upward to the later rounded needle regardless of the body nozzle, this causes the nozzle to spray the fuel into the combustion chamber.
3) When the injection pump stops supplying the fuel, the spring pressure on the injector returns the needle nozzle position to its original position. When the needle is depressed, the body seat nozzle automatically closes the fuel line, and the process of initiators stops. The remaining fuel between the needle nozzle and the nozzle body will lubricate the components and return to the original state [3].

Nozzle Hole Injector has several types including single hole, multiple holes, throttle, and pintle type. These types of injection, holes have a different function when they allow in the combustion chamber. The type of multiple holes used for direct injection diesel engine is an injection that is directly sprayed into the combustion chamber, while the type of throttle and pintle is used for a type of indirect burning diesel engine (indirect injection) [4].

Good spray will facilitate the escort of combustion process that occurs due to the combination of fuel with oxygen in the combustion chamber. Fog of injection pressure affects the combustion process, fuel efficiency, and reduces fuel emissions. In a direct injection type, the diesel engine needs to be considered the nozzle hole size, spraying angle, and pressure valve. If the injection pressure condition increases, then the diameter of the fuel particles will shrink, the fuel shrinks then the resulting emissions are reduced. When the injection pressure is too high, it affects the ignition of the delay which becomes shorter. So the mixing between the fuel and oxygen is less homogeneous so the smoke visible in the engine exhaust [5].

B. Dexlite

Dexlite is a special fuel diesel engine launched by PT. Pertamina in the year 2016. With cetane number is better than the former solar with a minimum cetane number of 48. Dexlite properties can be seen in table 1.

C. Methanol

Alcohol with low viscosity properties makes it easier to soften and mix air in the combustion process. The addition of methanol to conventional diesel fuel is expected to reduce exhaust emissions and smoke concentrations produced by diesel engines [7]. As one of the promising alternative fuels, methanol has flammable properties and slight burning emissions. The methanol specification will be explained in table 2.

TABLE 1.
PROPERTIES OF DEXLITE [6]

Parameters	**Unit**	**Test Results**	**SNI limitations**	
			Min	**Max**
Cetane Number	-	56.7	48	-
Cetane Index	-	51.1	45	-
Specific gravity at 15° C	kg/m^3	845.7	815	670
Viscosity at 40° C	mm^2/s	2.92	2	4.5

TABLE 2.
PROPERTIES OF METHANOL [8]

Parameters	**Unit**	**Value**
Chemical formula	-	CH_3OH
Mole weight	gr/mol	32
Density	gr/cm^3	0.796
Lower heating value	MJ/kg	19.68
Heat of evaporation	kJ/kg	1110
Self-ignition temperature	C	470
Cetane number	-	5

A mismatch in the stability of solar-methanol blends is the main obstacle encountered in methanol utilization in the compression ignition engine. The results showed that the mixing of methanol with diesel resulted in good combustion, performance, and reduced emissions compared to diesel fuel. This is due to the characteristics of methanol which has a high oxygen content so that the combustion effectively generated can reduce smoke and emissions [9].

There are two ways to overcome the mismatch in the stability of the fuel mixture, namely the emulsion and solution. Emulsion means mixing particles of a liquid (dispersed phase) with other liquid substances (dispersing phase). The manufacture of emulsifying fuel, it requires less emulsifier or an appropriate surfactant. It affects the quality and stability of an emulsion. In the absence of surfactants, the emulsion results in a dispersed phase and the dispersing medium of a lightweight floating substance above the heavy. For the way solution is to mix fuel by heating the fuel up to 50°C, this is done so that the fuel mixture dissolved without any separations [10].

In the process of combustion in a diesel motor, there is a mixing between pure air and fuel. The air consists of fused gases, oxygen and nitrogen are the most content in the air. Nitrogen oxide gas (NO_x) is divided into two types namely nitrogen dioxide gas and nitrogen monoxide gas. Both gases have different properties but are very detrimental to health. Therefore, the magnitude of emissions depends on the opacity or the smoke thickness produced by the diesel engine. The formation of opacity is due to the sheer amount of fuel that is sprayed into the cylinder. When the fuel-burning process that occurs in the combustion chamber perfectly occurs will produce CO_2 (carbon dioxide), otherwise, if the element of oxygen is not enough then the combustion process becomes imperfect. Emissions are heavily influenced by the fuel and air mixtures that enter the fuel chamber, better known as the Air Fuel Ratio (AFR) [11]

D. NOx Emission

In the combustion process, the formation of NO_x depends on the temperature in the cylinder and oxygen concentration. The addition of methanol is expected to decrease the temperature in the cylinder because methanol has higher latent heat than diesel fuel. This is what makes the effect of the addition of methanol able to lower NO_x emission levels [12].

The increase in fuel consumption during the addition of methanol in fuel, but the emission of NO_x, thermal efficiency, and CO decreases if the addition of methanol to diesel fuel. The NO_x content will be high when the high temperature during the combustion process (combustion), as if the combustion process decreases in temperature, the NO_x produced is slightly lower. High NO_x emission rates indicate an increase in the heat release value. If the temperature in the combustion chamber does not decrease, then the resulting NO_x emissions are higher.

II. METHOD

The method used in this research is a simulation method using software applications. The methodology is described as follows

A. Problem identification and problem formulation

The search for a problem will be the background of this research. The problem raised in this research is the NO_x emissions of diesel motors that always increase annually due to increased transportation needs.

B. Literature

In this research, the fuel used is a mixture of diesel and methanol. The choice of diesel fuel in this research is dexlite. Below are the fuel and surfactant specifications to be mixed in an emulsion and solution. Table 3 are the specifications of the fuel and surfactants.

TABLE 3.
FUEL SPECIFICATION

Properties	Unit	Dexlite	Methanol	Oleic acid	Iso-butanol
Chemical formula	-	$C_{14}H_{28}$	CH_3OH	$C_{18}H_{34}O_2$	$C_4H_{10}O$
Density	kg/m^3	834.8	792	890.5	802
Viscosity at 40 C	mm^2/s	2.92	0.59	4.85	2
Heat of vaporization at 298 K	kJ/kg	270	1176.96	200	580
Low heating value	MJ/kg	42.74	21.11	38.65	33.4
Critical pressure	bar	24.6	79.5	13.32	45
Critical temperature	K	313.15	513	937.21	548

The engine used in the simulation method is the YANMAR TF 85MH engine, in below is the specification of the engine for simulations which is shown in table 4.

TABLE 4.
ENGINE SPECIFICATION

Engine Specification	
Stroke, cylinder, and injection system	4-stroke, 1-cylinder, direct injection
Bore x Stroke	85mm x 87mm
Injection timing	18^O before TDC
Cylinder volume	493 cc
Power	Cont. 7.5 hp/2200 rpm, Max. 8.5 hp/2200 rpm
Max. Torque	3.44 kg.m/1600 rpm
Compression ratio	18

Specific fuel oil consumption.	171 gr/hp-h
Injection pressure	200 kg/cm^2

C. Fuel Calculation of M15 (Emulsion and Solution)

There are two methods of mixing fuel used, namely by means of emulsions and solutions. Mixing is done in simulated software with the percentage needed in this research and the corresponding properties of each fuel. The emulsion is by mixing fuel with surfactants in order not to occur separations. The surfactants used are Oleic-Acid and Iso-Butanol. The composition of the emulsion's way is (83% dexlite, 15% methanol, 1% oleic-acid, and 1% ISO-butanol). For the way solution is mixing is done directly between dexlite and methanol and the composition of the way the solution is (85% dexlite and 15% methanol). the properties of emulsion and solution are shown in table 5.

TABLE 5.
SPECIFICATION OF EMULSION AND SOLUTION FUEL

Properties	**Unit**	**M15 (emulsion)**	**M15 (solution)**
Chemical formula	-	$C_{12}H_{16.5}O_{0.18}$	$C_{12}H_{15.93}O_{0.15}$
Density	kg/m^3	823.60	828.38
Viscosity at 40 C	mm^2/s	2.58	2.57
Heat of vaporation at 298 K	kJ/kg	408.44	406.04
Low heating value	MJ/kg	39.35	39.5
Critical pressure	bar	25.42	25
Critical temperature	K	352	343

D. Engine Modeling

Modeling is made as well as possible using software simulations according to the basic specifications of the YANMAR TF85 MH diesel engine. In its modeling, there are stages that must be performed resulting in valid and analyzed data. Modeling stages include design measurements, manufacturing system & models, defining objects, and object framing. Figure 1 is a schematic of diesel engine modeling in the simulation software.

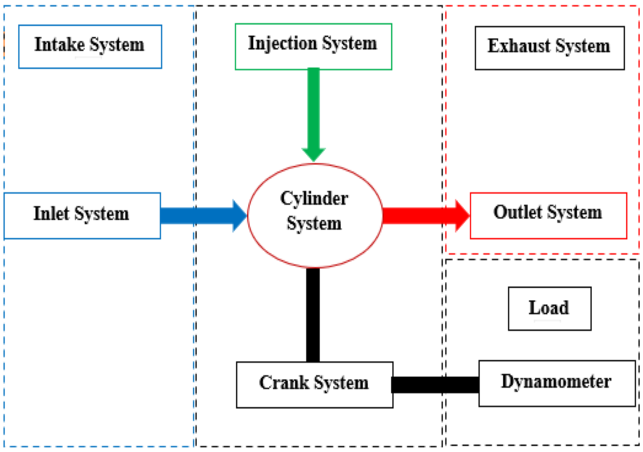

Figure. 1. Schematic of Diesel Engine

1) Intake System

In the intake system, there are several components that must be defined, including:

a. Inlet Environment: The initial stage of the intake system is to make it more difficult to condition the environment, by determining the value of pressure, temperature, and air composition.
b. Piping System: In modeling, this system serves to drain the air and fuel into the cylinder system.
c. Intake Runner: This system is included in the piping system that serves to connect the inlet environment with the intake port.
d. Intake Port: Next make an intake port, which is also included in the piping system, and serves to connect the intake runner with the intake valve.
e. Intake Valve: Intake valve In its modeling is made by entering the value of valve diameter, cam timing angle, valve lash, and elevator arrays.

2) Injection systems, cylinder systems, and Cranktrain systems

In this system, there are several components that must be defined, including:

a. Injector: Nozzle injector used for an engine with direct injection type, the attributes that exist in this component, among others, fuel time injected, injection timing, fuel used, and nozzle specifications consisting of the number of holes and nozzle diameter.

b. Cylinder: This section is part of the cylinder and piston model. To make such models required data such as cylinder temperature, heat transfer, and combustion model.
c. Engine Cranktrain: In this section describes the type of engine used (2-stroke or 4-stroke), to make the engine cranktrain needed data including, rotation of the motor, friction value, value of inertia, and the specifications of the piston (bore, stroke, and compression ratio).
d. Dynamometer (Load): The dynamometer is used to regulate the loading on the engine on the condition of having to be coupled in advance with cranktrain engine and then change the speed to load on the Cranktrain engine part setting.

3) Exhaust System

In this system, there are several components that must be defined, including:

a. Exhaust Valve : In this section is the same as the intake valve in making the data needed valve diameter, cam timing angle, valve lash.
b. Exhaust Port : Next the exhaust port has the function as a connector for the exhaust valve with the exhaust runner. For the required data of diameter, pipe length, type of material used, and temperature.
c. Exhaust Runner: The last part in the piping system before removing the combustion results through the outlet environment. The Data needed include the diameter, length, and material used
d. Outlet Environment: The last part of the simulation modeling, in this section, is to set the boundaries of the exhaust gas environment by regulating the value of pressure, temperature, and air composition.

E. Data Validation

At this stage is the tuning part of the simulation model to get an external result that fits the manual of the Engine book YANMAR TF 85MH or better known by calibration. The intended reference Parameter is the maximum torque at 1600 RPM, the maximum power at 2200 RPM, and the fuel consumption (SFOC) at RPM 2200. And the calibration result shown in table 6.

F. Data Retrieval

Performed data retrieval after running simulation. The results of simulated experiments obtained external performance such as power, torque, fuel consumption, and emissions produced in the form of NO_x.

TABLE 6.
COMPARISON MANUAL BOOK AND SIMULATION

Parameter	Manual Book	Simulation	Margin
Maximum Torque	3.44 kg.m/1600 RPM	3.13 kg.m/1600 RPM	9.012%
Maximum Power	6.33 kW/2200 RPM	6.32 kW/2200 RPM	0.44%
SFOC	171 gr/HP-h	173.70 gr/HP-h	1.58%

G. Injection Setting

After the data retrieval, the next step is to adjust the injection pressure in the software simulation according to the required variables, namely 160 bar, 200 bar, and 240 bar.

H. Analysis and Discussion

After obtaining the performance and NO_x emissions data from each injection pressure variable, analysis and discussion can be done. Analysis of the data carried out is a performance analysis and NO_x emissions of each injection pressure variable.

I. Conclusion and Suggestion

After all the stages are done, then the next step is to draw conclusions from data analysis and simulations. It is hoped that it can answer the problems that are the purpose of this research. And it takes suggestions based on the research results for improvement and also to develop further research.

III. RESULT AND DISCUSSION

Data retrieval is carried out with injection pressure variables 160, 200, and 240 bar. For the rounds used in this experiment were 1000 RPM up to 2200 RPM, with 10%, 25%, 50%, 75% and 100% load variations.

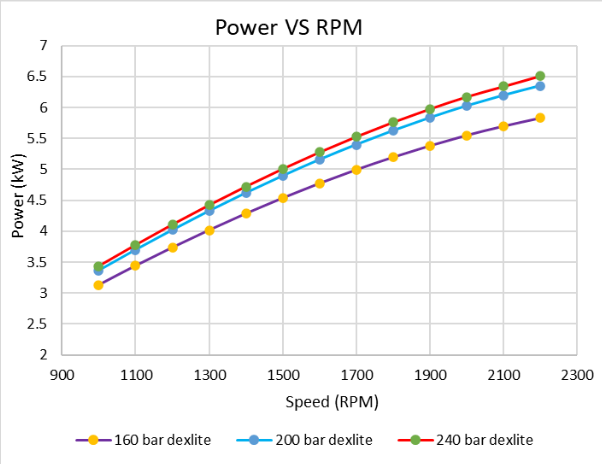

Figure. 2. Graphic Power Vs RPM at Dexlite Full Load Condition

Figure 2 shows that the comparison of power values are generated when at pressure 160, 200, 240 bar using dexlite fuel on a full load condition. The obvious addition of injection pressure gives the effect of higher generated power. When compared to the power generated by each injection in the 1000 RPM engine rounds obtained successive power values of 3.12 kW, 3.36, and 3.43 kW. In round 1100 RPM produced consecutive power values of 3.43 kW, 3.69 kW, and 3.77 kW. In a round of the 1200 RPM engine resulted in a consecutive power value of 3.73 kW, 4.01 kW, and 4.10 kW. And it continues to increase at 1300 RPM engine rounds and produces consecutive power values of 4.01 kW, 4.32 kW, and 4.42 kW. The next round of the 1400 RPM engine results in a consecutive power value of 4.28 kW, 4.61 kW, and 4.72 kW. In the round 1500 RPM produced consecutive power values of 4.53 kW, 4.89 kW, and 5 kW. At 1600 RPM resulted in the value of the consecutive power of 4.77 kW, 5.15 kW, and 5.27 kW. In the engine rotation 1700 RPM produces consecutive power values of 4.99 kW, 5.39 kW, and 5.52 kW. In a round of the 1800 RPM engine resulted in a consecutive power value of 5.19 kW, 5.62 kW, and 5.76 kW. In the 1900 RPM engine round produced consecutive power values of 5.37 kW, 5.83 kW, and 5.97 kW. Then in the 2000 RPM engine round resulted in the value of the consecutive power 5.54 kW, 6.02 kW, and 6.17 kW. Continuously inflated engine rounds result in greater power. At 2100 RPM engine rounds produce consecutive power values of 5.69 kW, 6.19 kW, and 6.33 kW. The maximum round occurs in the 2200 RPM engine round which results in the maximum possible power value of 5.82 kW, 6.35 kW, and 6.50 kW.

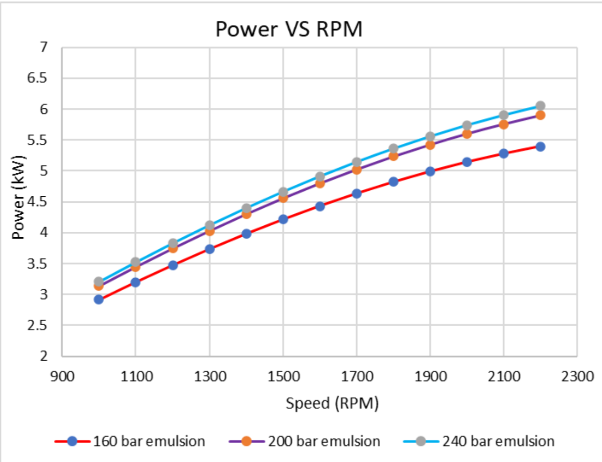

Figure. 3. Graphic Power Vs RPM at Emulsion Full load Condition

Figure 3 shows that comparison of the resulting power value when at pressures 160, 200, 240 bar using emulsion fuel on a full load condition. When compared to the power generated from each of the lowest power injections occurring by the 1000 RPM engine round obtained a consecutive power value of 2.91 kW, 3.13, and 3.20 kW. In round 1100 RPM produced consecutive power values of 3.20 kW, 3.44 kW, dan 3.52 kW. In a round of the 1200 RPM engine resulted in a consecutive power value of 3.47 kW, 3.74 kW, and 3.82 kW. And it continues to increase at 1300 RPM engine rounds and produces consecutive power values of 3.73 kW, 4.03 kW, dan 4.12 kW. The next round of the 1400 RPM engine results in a consecutive power value of 3.98 kW, 4.30 kW, and 4.40 kW. In the round 1500 RPM produced consecutive power values of 4.21 kW, 4.55 kW, dan 4.66 kW. At 1600 RPM resulted in the value of the consecutive power of 4.43 kW, 4.80 kW, and 4.91 kW. In the engine rotation 1700 RPM produces consecutive power values of 4.63 kW, 5.02 kW, dan 5.14

kW. In a round of the 1800 RPM engine resulted in a consecutive power value of 4.81 kW, 5.23 kW, and 5.36 kW. In the 1900 RPM engine round produced consecutive power values of 4.98 kW, 5.42 kW, dan 5.56 kW. Then in the 2000 RPM engine round resulted in the value of the consecutive power 5.14 kW, 5.60 kW, and 5.74 kW. At 2100 RPM engine rounds produce consecutive power values of 5.27 kW, 5.75 kW, and 5.90 kW. Up to 2200 RPM engine rounds resulted in maximum power values of up to 5.39 kW, 5.89 kW, and 6.05 kW.

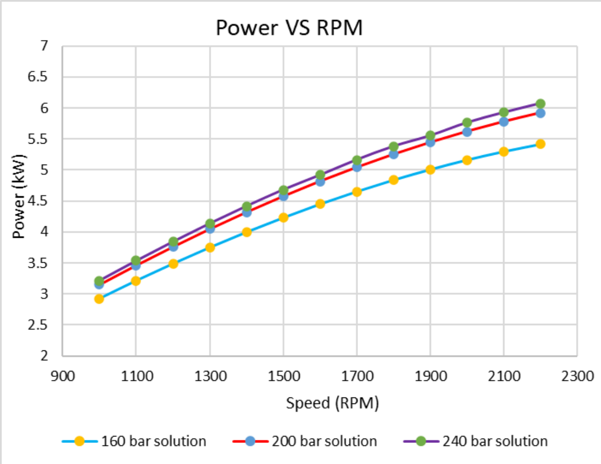

Figure. 4. Graphic Power Vs RPM at Solution Full Load Condition

Figure 4 shows the power value generated when at the pressure 160, 200, 240 bar use the fuel solution on a full load condition. When compared to the power generated by each injection in the 1000 RPM engine round obtained a consecutive power value of 2.92 kW, 3.14, and 3.21 kW. In round 1100 RPM produced consecutive power values of 3.21 kW, 3.46 kW, dan 3.53 kW. In a round of the 1200 RPM engine resulted in a consecutive power value of 3.48 kW, 3.75 kW, and 3.84 kW. And it continues to increase at 1300 RPM engine rounds and produce consecutive power values of 3.74 kW, 4.04 kW, dan 4.13 kW. The next round of the 1400 RPM engine results in a consecutive power value of 3.99 kW, 4.31 kW, and 4.41 kW. In the round 1500 RPM produced consecutive power values of 4.22 kW, 4.57 kW, dan 4.68 kW. At 1600 RPM resulted in the value of the consecutive power of 4.44 kW, 4.81 kW, and 4,916 kW. In the engine rotation 1700 RPM produces consecutive power values of 4.64 kW, 5.04 kW, dan 5.16 kW. In a round of the 1800 RPM engine resulted in a consecutive power value of 4.83 kW, 5.25 kW, and 5.37 kW. In the 1900 RPM engine round produced consecutive power values of 5 kW, 5.44 kW, and 5.55 kW. Then in the 2000 RPM engine round resulted in the value of the consecutive power 5.16 kW, 5.61 kW, and 5.76 kW. At 2100 RPM engine rounds produce consecutive power values of 5.29 kW, 5.77 kW, dan 5.92 kW. At 2200 RPM, the maximum power of 5.41 kW, 5.91 kW, and 6.07 kW. It was concluded that the largest power was produced by injection pressure 240 bar because the particle diameter of the resulting allow was smaller so that spraying the fuel evaporated faster, the effect of power produced higher.

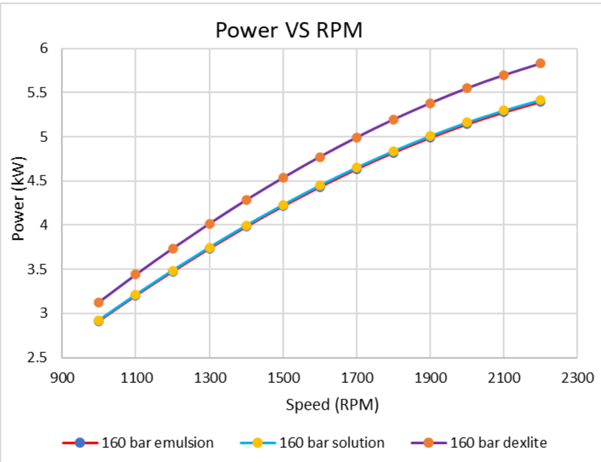

Figure. 5. Graphic Power Vs RPM at 160 Bar Full Load Condition

Further comparison of power to variable speed with 160 bar on dexlite fuel, emulsion, and solution. Figure 5 shows that the comparison of power values is generated when the pressure of 160 bar uses dexlite fuel, emulsion, and solution. The difference in the fuel used provides different power effects. The power generated from each fuel at 1000 RPM gained a consecutive power value of 3.12 kW, 2.91 kW, and 2.92 kW. Dexlite fuels will always excel in terms of the power generated when compared to emulsion fuels and solutions. When compared to the maximum power generated in the 2200 RPM engine round with successive power values of 5.82 kW, 5.39 kW, and 4.41 kW. Then it can be concluded that dexlite fuel is better in generating power because it has a higher caloric value.

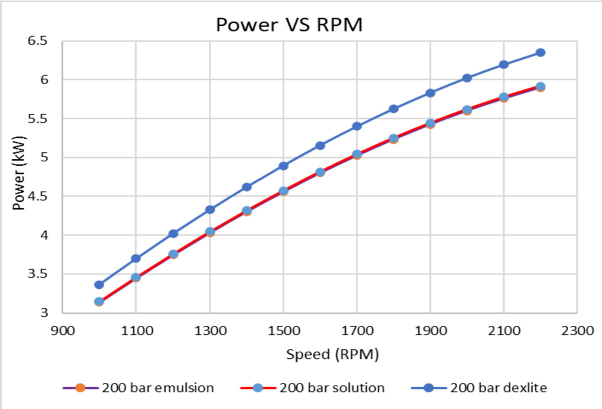

Figure. 6. Graphic Power Vs RPM at 200 Bar Full Load Condition

Figure 6 shows obtained power value generated when at pressure 200 bar using dexlite fuel, emulsion, and solution. The difference in fuel used provides different power effects. The power generated from each fuel at 1000 RPM gained a consecutive power value of 3.36 kW, 3.13 kW, and 3.14 kW. Dexlite fuels will always excel in terms of the power generated when compared to emulsion fuels and solutions. If compared to the maximum power generated at 2200 RPM with successive power values of 6.35 kW, 5.89 kW, and 5.91 kW.

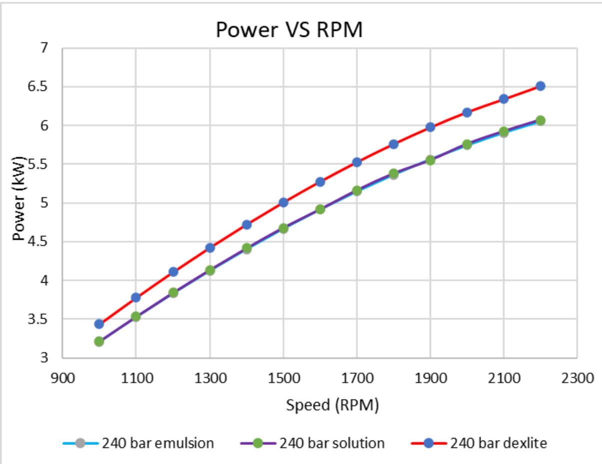

Figure. 7. Graphic Power Vs RPM at 240 Bar Full Load Condition

Figure 7 shows the comparison of power values is generated when at pressure 240 bar using dexlite fuel, emulsion, and solution. The difference in fuel used provides different power effects. The power generated from each fuel at 1000 RPM gained a consecutive power value of 3.43 kW, 3.2 kW, and 3.21 kW. Dexlite fuels will always excel in terms of the power generated when compared to emulsion fuels and solutions. If compared to the maximum power generated at 2200 RPM with successive power values of 6.50 kW, 6.05 kW, and 6.07 kW. Then it can be deduced dexlite fuel is better in generating power because it has a higher caloric value. There is no significant difference between emulsion fuels and solutions due to the sheer heat value.

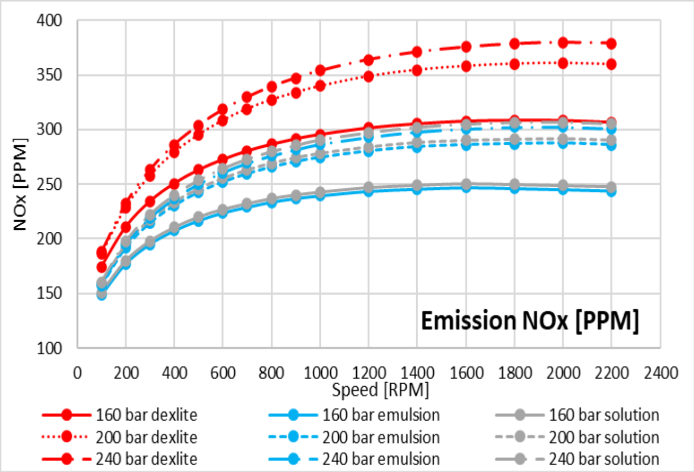

Figure. 8. Graphic NOx (PPM) Vs RPM

Figure 8 shows the comparison of NO_x emissions generated at various pressure using dexlite fuel, emulsion, and solution. With changes in engine speed at various pressure variations and fuel variations. The result is that the greater the speed, the greater the emissions produced. Dexlite gives the greatest emission compared to emulsion and solution.

IV. CONCLUSION

Based on the simulation results of this research regarding the effect of variations in injection pressure using diesel-methanol mixed fuel, the conclusions can be drawn are maximum power is generated by an injection pressure of 240 bar on dexlite fuel. The maximum power generated is 6.5 kW and decreases power when methanol is added to dexlite by 6.05 kW on emulsion fuel and 6.07 kW on solution fuel.

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