BACHELOR THESIS – ME141502

EXPERIMENT AND SIMULATION STUDY OF SINGLE CYLINDER DIESEL ENGINE PERFORMANCE, USING SOYBEAN OIL BIODIESEL

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DOUBLE DEGREE PROGRAM
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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APPROVAL FORM

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Bachelor Thesis

Submittedin order to comply one of the requirementsof Bachelor Engineering Degree
In
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Double Degree Marine Engineering Program
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Institut Teknologi Sepuluh Nopember

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ABSTRACT

The most common fuel uses in the world is made from fossil which is non-renewable energy source. There should be an alternative fuel to replace fossil fuel by using biodiesel and one of the stock comes from soybean . There should be a research conducted about engine performance by using the mixture of soybean oil biodiesel before using this biodiesel. The research can be conducted by experiment and simulation. This biodiesel properties are : Flash Point value is 182 ^{o} C , Pour Point value is -7 ^{o} C, Density at 15 ^{o} C is 890 Kg/m3, Kinematic Viscosity at 40 ^{o} C is 5.58 (cSt), and Lower Heating Value is 42.27686 MJ/kg.

The result from this research is the highest power from simulation is 9% higher than the experiment. The highest torque from the experiment is 37% lower than the simulation's torque. Lowest SFOC from experiment is 28% lower than the simulation's SFOC. Highest BMEP from simulation is 20% higher than the highest BMEP from experiment The highest thernal efficiency from experiment is 6% higher than the highest thermal efficiency from simulation. The engine performance result using soybean oil biodiesel is not better than the Pertamina Dex. For that reason, the use of this biodiesel is not suggested to substitute Pertamina Dex.

Keyword : Biodiesel, Power, Torque, SFOC, BMEP, Thermal Efficiency.

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STUDI EKSPERIMEN DAN SIMULASI PADA UJI PERFORMANSI MESIN DIESEL SATU SILINDER, MENGGUNAKAN BIODIESEL MINYAK KEDELAI

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ABSTRAK

Bahan bakar yang umum digunakan berasal dari fosil yang merupakan sumber energi tidak terbarukan sehingga perlu ditemukan bahan bakar dari energi terbarukan, salah satunya biodiesel kacang kedelai. Harus dilakukan sebuah uji performansi sebelum menggunakan bahan bakar ini baik secara eksperimen dan simulasi. *Properties* dari biodiesel minyak kedelai antara lain: nilai *Flash Point* 182 ^{o} C , nilai *Pour Point* -7 ^{o} C, nilai Densitas pada 15 ^{o} C adalah 890 Kg/m^{3}, Viskositas Kinematis pada 40 ^{o} C adalah 5.58 (cSt), dan nilai *Lower Heating Value* adalah 42.27686 MJ/kg.

Hasil dari penelitian ini menunjukkan daya simulasi 9% lebih besar dari daya eksperimen. Nilai torsi tertinggi dari eksperimen 37% lebih besar dari torsi tertinggi simulasi. SFOC paling rendah dari eksperimen lebih rendah 28% dari SFOC paling rendah simulasi. BMEP tertinggi dari simulasi lebih besar 20% dari BMEP tertinggi eksperimen. Efisiensi termis tertinggi dari eksperimen lebih besar 6% dari efisiensi termis teringgi simulasi. Hasil uji performansi menggunakan biodiesel minyak kedelai menunjukkan biodiesel ini tidak lebih bagus dari Pertamina Dex. sehingga penggunaan biodiesel minyak kedelai untuk mengganti Pertamina Dex tidak dianjurkan.

Kata Kunci : Biodiesel, Daya, Torsi, SFOC, BMEP, Efisiensi Termis.

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PREFACE

In the name of ALLAH SWT, author want to say thank you to ALLAH SWT because of His grace the author can finish this bachelor thesis. In this bachelor thesis, author discussed about the bachelor thesis process and result with the title **"Experiment And Simulation Study Of Single Cylinder Diesel Engine Performance, Using Soybean Oil Biodiesel"**.

Author hopes this bachelor thesis report will be useful for many people, especially people who study in the field of marine engineering, mechanical engineering, and renewable energy. Author expect good constructive criticism and constructive suggestion for the sake of this report. Author realized that author is only human which is far from perfect. Criticism and suggestion will be helpful for the better writing in the future. In this report, author want to say thank you to

1. Mother and Father that has been supporting me unconditionally so i can finish this bachelor thesis.
2. Ir. Aguk Zuhdi Muhammad Fathallah, M.Eng,Ph.D as first supervisor and Dr-Ing. Wolfgang Busse as second supervisor that guiding wholeheartedly and giving advice in completing this bachelor thesis.
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Author also thanks to all the people that help the process of finsihing this bachelor thesis which can't author call one by one.

Surabaya, Juli 2016

Muhammad Rizqi Ariefianto
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CHAPTER I
INTRODUCTION

1.1 Background

Fuel considered as the most essential item to provide the energy in this era. Nowadays, the most common fuel uses in the world is made from fossil. It is because fossil fuel has high contents of carbon which is needed for combustion process. Fossil fuel is categorized as a non-renewable energy source. It means that this energy source stock is limited and have finite amounts. This fossil took million years to transform to oil and it will be run out in the matter of time. In this time, the using of fossil fuels is become a discussion among the scientist, engineer and ordinary people. It is because the amounts of fossil fuels in the critical point that's why there are some increasing price of fuel oil in some areas. For that reason, there should be an innovation of new source of energy which is renewable and have infinite amounts. One of the alternative fuel comes from biodiesel.

Biodiesel is one of alternative energy which is renewable. It means biodiesel comes from the resources which is can be regenerated in a short of time. Biodiesel comes from many resources such as vegetable oil, animal oil, etc. Vegetable oil is an oil which is made from plants such as palm oil, soybean bean oil, rapeseed oil, etc. Biodiesel from vegetable oil is considered as eco friendly fuel. This biodiesels does not contain any of heavy metal contents such as sulphur, and it produce more harmless emmission.

Indonesia is a country with the high consumer of soybean bean. It is determined by Indonesia must imports the soybean bean from any other countries. Beside that, Indonesian farmers try to produce more soybean beans to fulfill the needs of soybean bean in Indonesia. In 2014, Indonesia was succeed to produce 954.000 tons of soybean bean. The growth rate of the soybean bean is 1,93 % per year which is make soybean bean as the crops product with the highest growth rate in Indonesia. Soybean bean is one of vegetable oil source which can be treated becoming biodiesel.

Before using the biodiesel made from soybean bean oil, there should be a research to find out the effect of biodiesel from soybean bean oil regarding the performance of the engine. This research shall be taken to determine the potency of soybean bean oil biodiesel for the future and is it be able to substitute the fossil fuel oil into this biodiesel in the future. Beside that, the research should be done very carefully for the precision result and for the continous research in the future. The research of engine performance analysis using soybean oil biodiesel can be done experimentally with the results of the data in the field and simulation by modeling experiments using the simulation in order to cut the experiment's cost.

1.2 Problem Statement

Substituting fossil fuels into biodiesel has already done since 1890's by the inventor of diesel engine, Rudolph Diesel and the government of French to power the diesel engine for agriculture in remote areas which is lack of fossil areas in that circumstances. In 1930s, a research in Belgium found the modern biodiesel fuel by converting vegetable oils into compounds called fatty acid methyl esters. Biodiesel industry started to be established in late 1980s. However, the most common fuels use in the world today is coming from fossil. To determine whether biodiesel fuels be able to substitute fossil fuels, there should be a study about the effect of using biodiesel fuels to the engine performance. This research might be done in two methods, experiment and simulation. To get the data from the field, the research can be done by conducting experiment. For some reason, experiment required much cost to be done. To cut the cost from experiment the research can be done using simulation. But the simulation need to be validated to the real engine performance. For that reason, there should be comparison between both methods.

Based on the description above, presented several problems, which are:

1. How to produce soybean oil biodiesel ?
2. What is the effect of soybean oil biodiesel to the engine performance’s result including Power, SFOC, Torque, BMEP, and Thermal Efficiency ?
3. How is the comparison of engine performance between experiment and simulation?

1.3 Scope of Problem

To answer all the question of the problem, there should be the scope of the problems. Scope of Problems are :

1. Production of biodiesel using transesterification method.
2. Not assesses the economic analysis.
3. The engine will be used is Yanmar TF 85 MH DI coupled to Dohai Generator.

1.4 Objective

1. To know the process of making biodiesel from soybean oil.
2. To know the effect of soybean oil biodiesel to the engine performance”s result.
3. To compare the performance of the diesel engine by experiment and simulation.

1.5 Benefit

1. As a research of alternative energy for the future.
2. The result of this study can be used as a reference for future research.

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CHAPTER II
LITERATURE STUDY

2.1 State of The Art

On of the studies in 2014 by Kumbar and Dange has explained that biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. This kind of fuel can be used as fuel in diesel engine. This fuel is considered as the future fuel. Biodiesel doesn't contain petroleum but biodiesel can be mixed to diesel fuel to biodiesel to make biodiesel mixture which is known as biofuel. The mixture blend of biodiesel usually called in different name such as B20 (20% biodiesel and 80% petroleum), B50 (50% biodiesel and 50% petroleum). For B100, only diesel engines that can use this kind of fuel. Biodiesel considered as biodegradable and non-toxic fuel so this kind of fuel is more harmless to the environment. (Kumbar, Dange.2014)

In 2014, Sampatrao and friends. Explained that biodiesel and diesel fuel has similar characteristics.There is no need modification to existing fuel storage, delivery and engine systems. Biodiesel is less flammable than petroleum diesel. This biodiesel also have some benefit for the use in the engine such as less particulate in Emissions, and increase lubricity so the engine life will be better. (Sampatrao and friends.2014)

Ethanol can be produced by soybeans. It is can be used to biodiesel production. Soybean hulls contain significant amount of carbohyd rate for ethanol production. Soybean hulls also contain high protein. (Mielenz etal.2009). In 2012, Kargbo explained that soybean biodiesel have separate processes in oil extraction and biodiesel conversion. The oil extraction can be done by using mechanical presses, solvent extraction, supercritical fluid extraction and microwave-and ultrasound-assisted solvent extractions. Transesterification method can be used to convert extracted oil to biodiesel. Transesterification is a chemical reaction process during which the oil is combined with alcohol, usually ethanol or methanol, in the presence of a catalyst to form fatty esters and glycerol. (Kargbo, 2010).

From all the explanation above, it provides the information that biodiesel has been the subject of research in last few years. Application of biodiesel to reduce the use of conventional fuel has been developed from year by year. The need of renewable energy fuel is one of the main reason why peopel need to start using biodiesel. The properties test of biodiesel and also the effect of biodiesel to the engine are being researched in last few decades. In indonesi itself, the government start applying 15% biodiesel as the mixture for solar. It is called biosolar. The national standard of biodiesel properties has been determined in Indonesia. This requirement standard is used to maintain the quality of biodiesel. The national standard of biodiesel can be seen in table below.

Table 2. 1 National Biodiesel Standard

No.	Parameter and Unit	Value Limit
1	Density at 15^o C, Kg/m3	850-890
2	Kynematic Viscosity at 40^{o}C , (cSt)	2,3-6,0
3	Cetane Number	Min. 51
4	Flash Point at 0^o	Min. 100
5	Cloud Point	Max. 18
6	Pour Point	Max. 18
7	Copper Strip Corrosion (3hours,500^o C)	Max. 3
8	Carbon Residue,%-weight	Max. 0,05
9	Water and Sediment,%-volume	Max. 0,05
10	Distillation Temperature 90%,0^o C	Max. 360
11	Sulfated Ash Content, %-weight	Max. 0,02
12	Sulphur, ppm-b (mg/kg)	Max. 100
13	Phospor,ppm-b (mg/kg)	Max. 10
14	Acid number, mg-KOH/gr	Max. 0,8
15	Free Glycerol, %-weight	Max. 0,02
16	Total Glycerol , %-weight	Max. 0,24
17	Ester Alkyl Content, %-weight	Min. 96,5

One of method to produce biodiesel is by using transesterification process. The transesterification process will be adopted for the preparation of ethyl ester or methyl ester of vegetable oil. In the preparation of ethyl ester (biodiesel), five distinct stages will be involved.

- Heating of oil.
- Preparation of metoxide mixture.
- Adding of metoxide to oil and stirring the mixture.
- Settling of separation of glycerol.
- Washing of methyl ester with water.

Transesterification of vegetable oil can be done by using ethanol or methanol. Transesterification reaction is a stage of converting oil or fat into methyl ester or ethyl esters of fatty acids which constitutes to biodiesel. Raja, Basavaraj, and Khanderao studies in 2014 explained that strong catalyst is required to complete the separation the vegetable oil into esters and glycerin. Usually the alkaline used potassium hydroxide (KOH) and sodium hydroxide (NaOH) that will be mixed with methanol (CH_3OH) to produce the mixture called metoxide. The metoxide will be used fot the biodiesel production. Vegetable oil and metoxide will bi mxed and heated to the boiling temperature of the alcohol (50^o C-60^o C) for 60 minutes. The mixture will be separated into two layers, upper layer of biodiesel (methyl ester).and lower layer of Glycerin .The fatty ester produced in the upper layer is neutralized and vacuum distilled for the removal of excess methanol. The methyl ester produced from the reaction is then washed with hot water andseparated out by centrifugation. (Raja, Basavaraj, and Khanderao.2014)

The four stroke cycle is so called because it takes four strokes of the piston to complete the processes needed to convert the energy in the fuel into work. Because the engine is reciprocating, this means that the piston must move up and down the cylinder twice, and therefore the crankshaft must revolve twice.

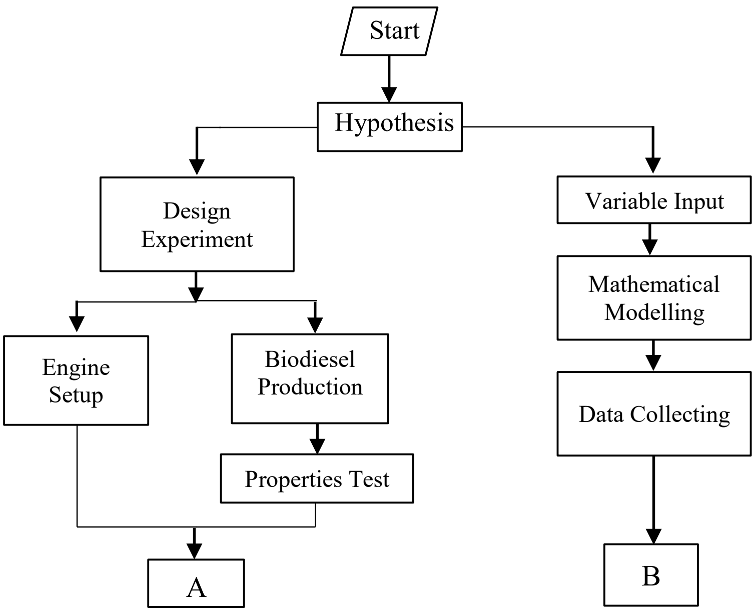
The four strokes of the piston are known as the induction stroke, the compression stroke, the power stroke, and the exhaust stroke.

Engine performance is defined as the maximum power or torque available at each speed within the useful engine operating range. The range of speed and power over which engine operation is satisfactory. The following performance definitions are commonly used Maximum rated power , normal rated power , and rated speed. (Heywood, 1988). In this research the parameter that will be measured are Brake Thermal Efficiency, Brake Spesific Fuel Consumption, and Brake Power.

In 2011, Richat and Desler studies explained that the use of one-dimensional computation fluid dynamic (1D CFD) engine simulation . The simulation allowed for characterizing engine operation without the need for high-end processing and time-intensive computations. The simulation method can reduce the time for engine design through experiment method. (Richtar , Desler.2011)

CHAPTER III
RESEARCH METHODOLOGY

This research conduct by doing the experiment and simulation. This experiment start from producing biodiesel from soybean oil using transesterification process and test the properties of soybean oil biodiesel. This experiment also conduct by doing engine performance test using the mixture of biodiesel and conventional fuel. The test will be using three variables which are rpm (five variables), fuel (three variables) and load (five variables) so the total of data collecting will be 75 points. This experiment will be conducted in Marine Power Plant Laboratory. For the simulation it starts by measure the engine components for variable input. It will shows the engine performance of the engine from variable input based on the engine components data. Explanation above will be shown in the diagram below.



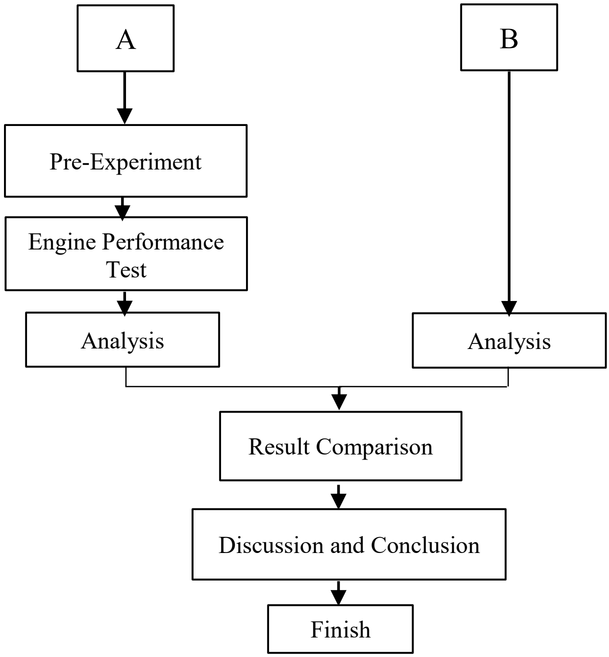


Figure 3. 1 Flowchart Of Research Methods

1. Hypothesis
   a. Biodiesl from soybean oil will fulfill the requirement of national biodiesel standard. Soybean oil biodiesel can be the fuel mixture for renewable energy in the future.
   b. Using the mixture of biodiesel from soybean oil will increase the engine performance. More content of soybean oil biodiesel in the fuel mixture will make the engine performance better.
   c. Result comparison between simulation and experiment will be precised. In the future, the experiment can be conducted by just using simulation. Because of this, the experiment cost will be cut.

2. Design Experiment

Design experiment is the planning, conducting, and analyzing of experiment. Design experiment will provide the best result of experiment. With good plan of the experiment will support to achieve the objective and the experiment will be well executed. This process also will provide good information to be analyzed .

3. Biodiesel Production

In this step biodiesel will be produced using kitchen equipment. Production of biodiesel using transesterification process based on the reference. In this process also conduct equipment and material preparation for producing biodiesel.

4. Biodiesel Properties Test

This test is conducted to know the succes level of the production process. This test also will show the information whether this type of biodiesel meet the requirement of national biodiesel standard or not. The biodiesel properties that will be tested are : viscosity, density, flash point, pour point, and lower heating value.

5. Engine Setup

Engine setup is a process of arranging the system configuration for the experiment. The engine setup will be shown in figure below.

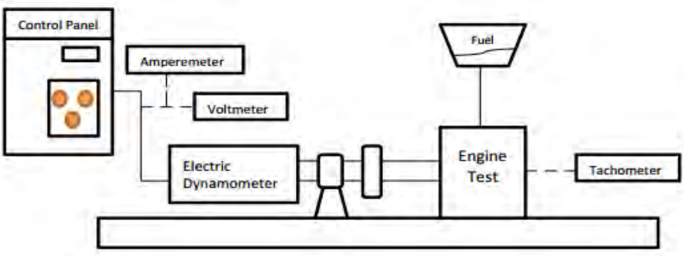


Figure 3. 2 Engine Setup

Equipment List :

- YANMAR TF 85 MH-di 493 cc. Four stroke, single cylinder.

Figure 3. 3 YANMAR TF 85 MH-di

- Electric Dynamometer

Figure 3. 4 Electric Dynamometer

- Control Panel

Figure 3. 5 Control Panel and Load

- Fuel
- Stopwatch

Figure 3. 6 Fuel and Stopwatch

- Tachometer

Figure 3. 7 Tachometer

- Amperemeter

Figure 3. 8 Clamp Meter

- Multimeter

Figure 3. 9 Multimeter

Experiment will be conducted using three variables . Three variables that will be used is load using electric dynamometer.

- RPM : 1800,1900,2000,2100,and 2200
- Fuel : Pertamina Dex, B10 (10% biodiesel and 90% Pertamina Dex), and B20 (20% biodiesel and 80% Pertamina Dex)
- Load (W) : 1000, 2000, 3000, 4000 and 5000.

From the explanation above there will be 75 times of data collecting.

6. Pre-Experiment.

Pre Experiment is a stage for preparing the data collecting for engine performance. The preparation for the engine are :

- Fuel
- Lubrication Oil
- Cooling Water
- Load
- Check Engine Installation and Engine Bed.
- If all the installation are installed correctly, start the engine for preheating.
- Watch measuring cylinder to observe the fuel consumption.
- Measure the Voltage and Current.

7. Engine Performance Test.

Engine Performance test will be conducted in the laboratory of Marine Power Plant using biodiesel engine. Experiments done by running to the engine and measure the parameters that have been determined. Data collection is done by measuring and record all parameters which have been determined in this research.

8. Analysis.

Analysis start by processing the data from engine performance test. The data will be processed and will be shown in trendline.

9. Variable Input.

Variable input is the procedure in this research is taken by opening the diesel engine and measure the components for the model.

10. Mathematical Modelling.

At this point the modelling will be designed. Variable input will be stored to simulate the model of the engine. The engine spesification is one of the requirement to input the variable. The engine spesification of YANMAR TF 85 MH-di are :

Table 3. 1 Engine Spesification

	TF 85 MH-di
Engine Type	4-stroke Diesel Engine
Bore	85 mm
Stroke	87 mm
Displacement,cc	493 cc
Compression Ratio	1: 18
No. Of Cylinder	1
Power	5.2 kW/2200 rpm

11. Analysis

    Analysis start by processing the data from Mathematical Modelling. The data will be processed and will be shown in trendline.

12. Result Comparison

    Analysis conducted on the data obtained from the results of experiments and simulations. The analysis will be used as the comparison charts that will be discussed in this study.

13. Discussion and Conclusion

    Make conclusions based on the results obtained and suggestions for further research development.

CHAPTER IV
RESULT AND DISCUSSION

4.1 Biodiesel Production

To answer the first problem in chapter 1, there should be an experiment for producing biodiesel. In this experiment, biodiesel is produced from soybean oil. The production of this biodiesel is using transesterification method using metoxide which ithe mixture is made by mixing the methanol and KOH. This process also conducted using kitchen tools. Soybean oil is one of commercial vegetable oil for kitchen purpose. There are several items that will be used for this production. The material that will be used in this process are :

- Soybean Oil
- Methanol
- KOH
- Aquades

Some equipments that will be used in this process are :

- Bottle
- Measuring cup
- Stove
- Blender
- Scale
- Thermometer

Before producing this biodiesel done, there are some following steps that need to be followed. The step for producing biodiesel are:

4.1.1 Mixing the Metoxide

Measure 200 ml of methanol and 5 gr of KOH. Pour methanol into glass bottle (don't use plastic bottle (PET) because this mixture can react to plastic). Put 5 gr of KOH inside the glass bottle within methanol inside the bottle. Close the cap of the bottle tightly. Methanol and KOH can absorb the water from the atmosphere. Make sure do this process fast and the cap already tighten.

Swirl round the bottle to mix this mixture. In this process will increase the temperature of this mixture so the mixture will get hot. Swirl it until all KOH content dissolve in methanol. This mixture is called metoxide. As the metoxide looks clear without any undissolved particles, this mixture can be used for the process.

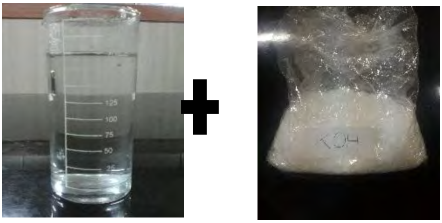


Figure 4. 1 Methanol and KOH

4.1.2 Pre Heating

Measure 1 litre of soybean oil and pour it into pan. Pre heat the soybean oil using the stove until it reach 55° C. Make sure the oil temperature below 60° C because this oil will be mixed with the metoxide and metoxide will evaporate if the temperature over 60° C.

Figure 4. 2 Measure 1 Litre of Soybean Oil

Figure 4. 3 Heat the Oil Until It Reach 55^o C

4.1.3 Biodiesel Processing

Using blender, pour the heated soybean oil and and metoxide inside the blender. Make sure the blender seals in good condition and the blender in dry and clear condition. Turn on the blender in low speed for 20-30 minutes.

Figure 4. 4 Mixing the Soybean Oil and Metoxide Using Blender

4.1.4 Settling

Pour the blended mixture into bottle and close the cap tightly. Allow this mixture to settle for minimum 12 hours. This mixture will be divided into two layers. Darker colour is called glycerine. Glycerine will collect in distinct layer at the bottom of the bottle. Clearer and yellow colour is called biodiesel. This biodiesel layer will stay above the glycerine.

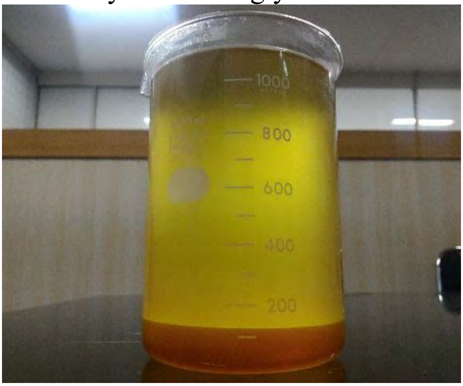


Figure 4. 5 Glycerine Layer and Biodiesel Layer

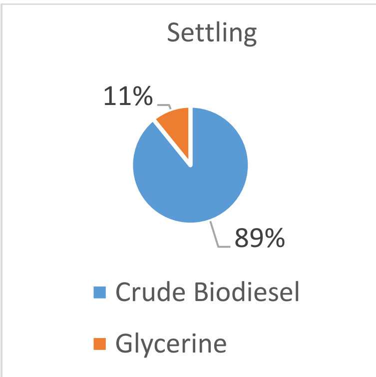


Figure 4. 6 Settling Losses Diagram

4.1.5 Washing

Add 500 ml of aquades into biodiesel bottle. Stir it slowly until the aquades will separate in the bottom of the bottle. Do this process for 2-3 times. On first wash, add 500 ml of aquades into biodiesel bottle. Stir it slowly until the aquades will separate in the bottom of the bottle. Do this process for 2-3 times. In this process the volume of biodiesel is 1070 ml and 500 ml of aquades. The result of this washing process is 800 ml of biodiesel.

Figure 4. 7 First Wash

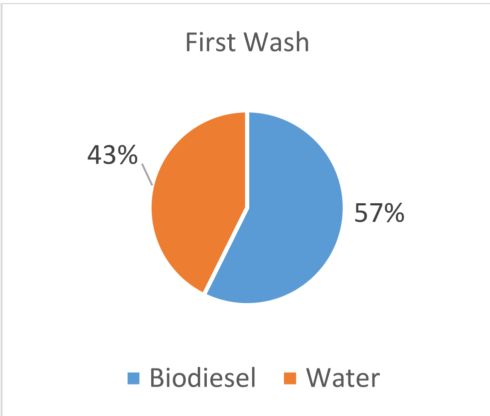


Figure 4. 8 First Wash Losses Diagram

For the second wash, add 500 ml of aquades into biodiesel bottle. Stir it slowly until the aquades will separate in the bottom of the bottle. Do this process for 2-3 times. In this process the volume of biodiesel is 800 ml and 500 ml of aquades. The result of this washing process is 700 ml of biodiesel.

Figure 4. 9 Second Wash

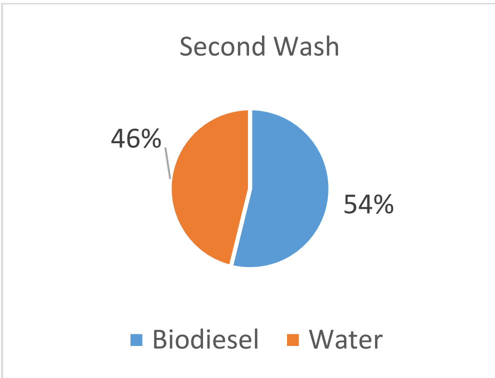


Figure 4. 10 Second Wash Losses Diagram

For third wash, add 500 ml of aquades into biodiesel bottle. Stir it slowly until the aquades will separate in the bottom of the bottle. Do this process for 2-3 times. In this process the volume of biodiesel is 700 ml and 500 ml of aquades. The result of this washing process is 500 ml of biodiesel.

Figure 4. 11 Third Wash

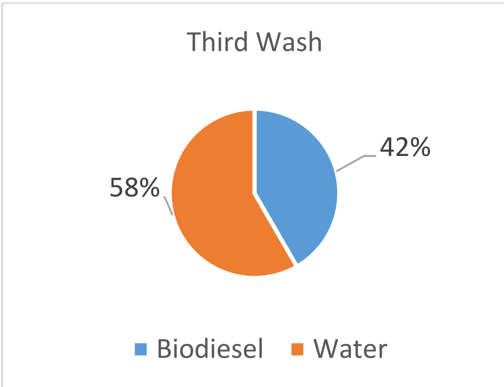


Figure 4. 12 Third Wash Losses Diagram

After the washing process has finished, separate the aquades from the biodiesel.

4.1.6 Drying

For drying the biodiesel, pour washed biodiesel into pan. Heat the biodiesel until 100° C. This process will evaporate the water content in biodiesel. After all the water content evaporate, the result is biodiesel within volume of 450 ml.

Figure 4. 13 Soybean Oil Biodiesel

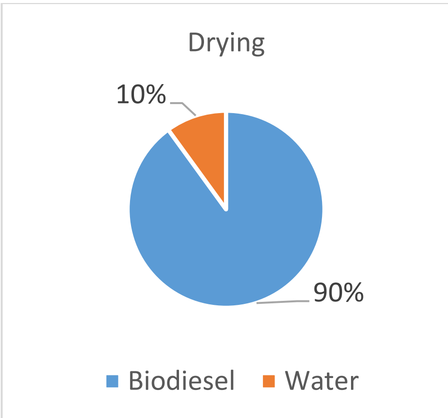


Figure 4. 14 Drying Losses Diagram

4.1.7 Properties Test

In this process the biodiesel properties will be tested. This test goal is to make sure this soybean oil biodiesel meet the requirement of National Biodiesel Standard. This test also conduct to check the quality of this biodiesel. If the biodiesel quality is poor and don't meet the requirement, this biodiesel can't be used as future fuel. The test is conducted in Energy Laboratory ITS and will test some parameter such as pour point, flash point, viscosity, density, and Lower Heating Value. The result of soybean oil biodiesel properties are :

Table 4. 1 Properties Of Soybean Oil Biodiesel

No.	Parameter and Unit	Value	Method
1.	Flash Point, ^{o} C	182	ASTM D-92-05
2.	Pour Point, ^{o} C	-7	ASTM D-92-02
3.	Density at 15^o C, Kg/m3	890	ASTM D-1480
4.	Kynematic Viscosity at 40^{o}C , (cSt)	5,58	ASTM D-445-97
5.	Lower Heating Value, MJ/kg	42,272686	-

From the table above, soybean oil biodiesel meet the requirement of SNI standard for biodiesel. The table show soybean oil biodiesel have 0% of error regarding all parameter that has been tested.

4.2 Effect Biodiesel In Engine Performance

To determine the potential of soybean oil biodiesel mixture, there should be a study on engine performance using soybean oil biodiesel mixture. Engine Performance can be conducted experiments and simulations. Experiment was done by using diesel engine in Marine Power Plant Laboratory while the simulation was done by modeling the engine that used for experiment. Several parameters were taken in the study include the Power, Torque, SFOC, BMEP, and Thermal Efficiency. Fuel used in this research are Pertamina Dex, B10 (10% biodiesel and 20 % Pertamina Dex), and B20 (20% biodiesel amd 80% Pertamina Dex)

4.2.1 Comparison Result Between SFOC and Power to RPM.

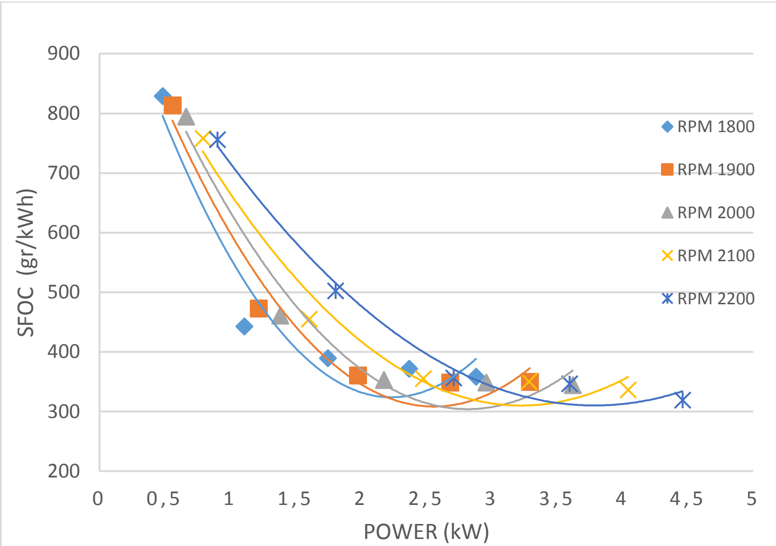


Figure 4. 15 Comparison Between Experiment's SFOC and Power to RPM Using Pertamina Dex.

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 2.878092 kW, at 1900 RPM is 3.28963 kW, at 2000 RPM is 3.618185 kW, at 2100 RPM is 4.041427 kW, at 2200 RPM is 4.458676 kW. Based on the graphic, it can be concluded that the power increasing about 10% to 24% in each RPM. In SFOC, the lowest consumption can be found at highest load in each RPM. At 1800 RPM the value SFOC shows 357.9558 gr/kWh, at 1900 RPM shows 349.3429 gr/kWh, at 2000 RPM shows 344.0952 gr/kWh, at 2100 RPM shows 336.0649 gr/kWh, and at 2200 RPM shows 319.121 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

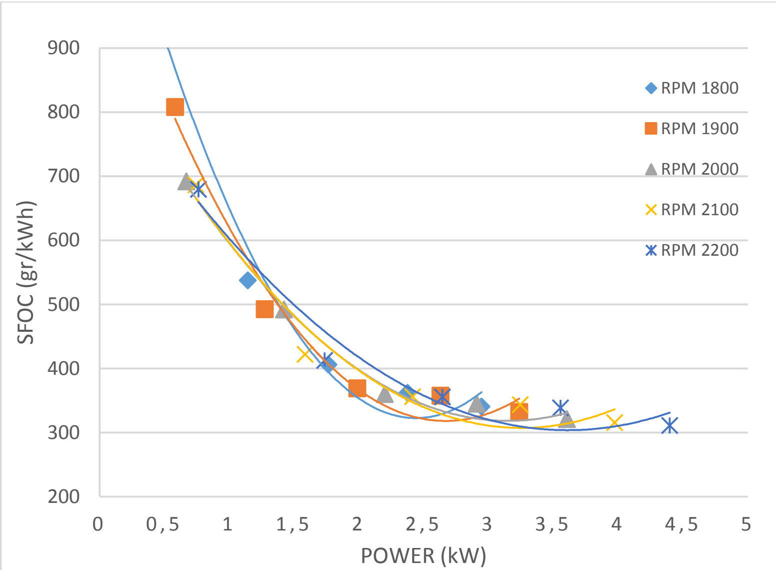


Figure 4. 16 Comparison Between Experiment's SFOC and Power to RPM Using B10.

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 2.944742 kW, at 1900 RPM is 3.236767 kW, at 2000 RPM is 3.603958 kW, at 2100 RPM is 3.973363 kW, at 2200 RPM is 4.396659 kW. Based on the graphic, it can be concluded that the power increasing about 5% to 19.5% in each RPM. In SFOC, the lowest consumption can be found at highest load in each RPM. At 1800 RPM the value of SFOC shows 340.675 gr/kWh, at 1900 RPM shows 332.0774 gr/kWh, at 2000 RPM shows 321.1853 gr/kWh, at 2100 RPM shows 315.6017 gr/kWh, and at 2200 RPM shows 311.1453 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

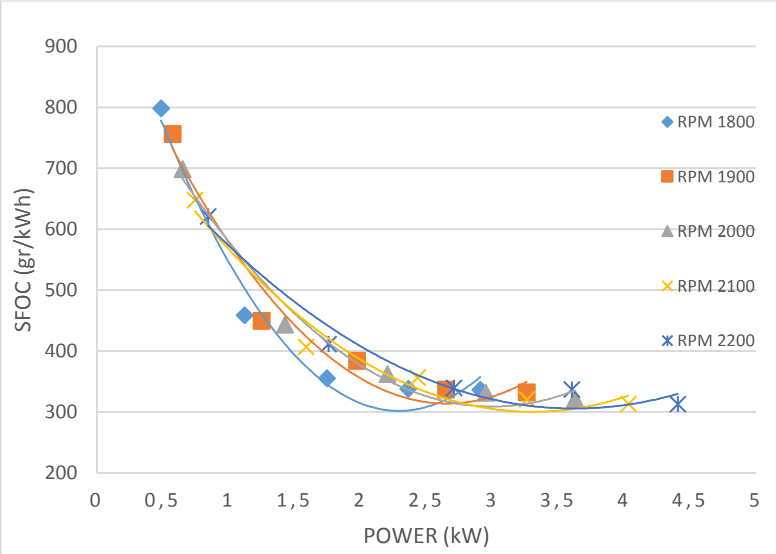


Figure 4. 17 Comparison Between Experiment's SFOC and Power to RPM Using B20.

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 2.906652 kW, at 1900 RPM is 3.258729 kW, at 2000 RPM is 3.626288 kW, at 2100 RPM is 4.032748 kW, at 2200 RPM is 4.406108 kW. Based on the graphic, it can be concluded that the power increasing about 9% to 15% in each RPM. In SFOC, the lowest consumption can be found at highest load in each RPM. At 1800 RPM the value of SFOC shows 336.403 gr/kWh, at 1900 RPM shows 332.2066 gr/kWh, at 2000 RPM shows 321.4985 gr/kWh, at 2100 RPM shows 313.1859 gr/kWh, and at 2200 RPM shows 312.7064 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

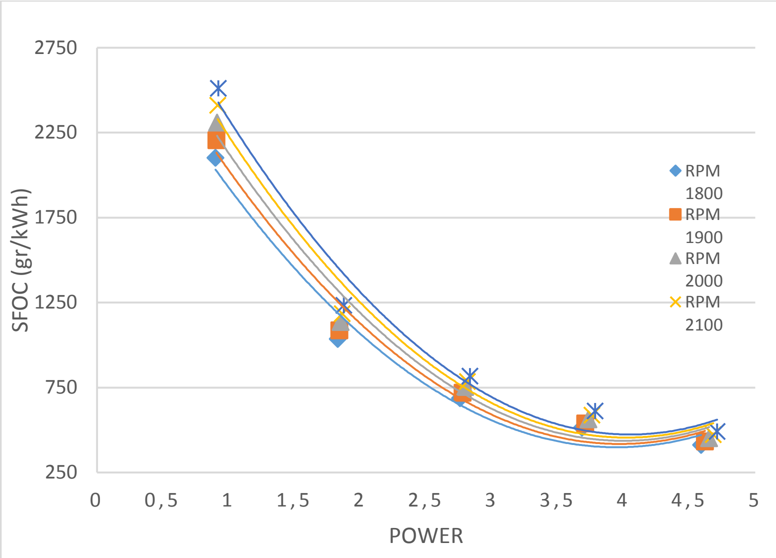


Figure 4. 18 Comparison Between Simulation's SFOC and Power to RPM Using Pertamina Dex

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 4.58887 kW, at 1900 RPM is 4.61803 kW, at 2000 RPM is 4.6505 kW, at 2100 RPM is 4.68022 kW, at 2200 RPM is 4.71144 kW. Based on the graphic, it can be concluded that the power increasing about 1% in as the RPM increase. In SFOC, the lowest consumption can be found at the highest load in each RPM. At 1800 RPM the value of SFOC shows 412.284 gr/kWh, at 1900 RPM shows 432.395 gr/kWh, at 2000 RPM shows 451.993 gr/kWh, at 2100 RPM shows 471.478 gr/kWh, and at 2200 RPM shows 490.619 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

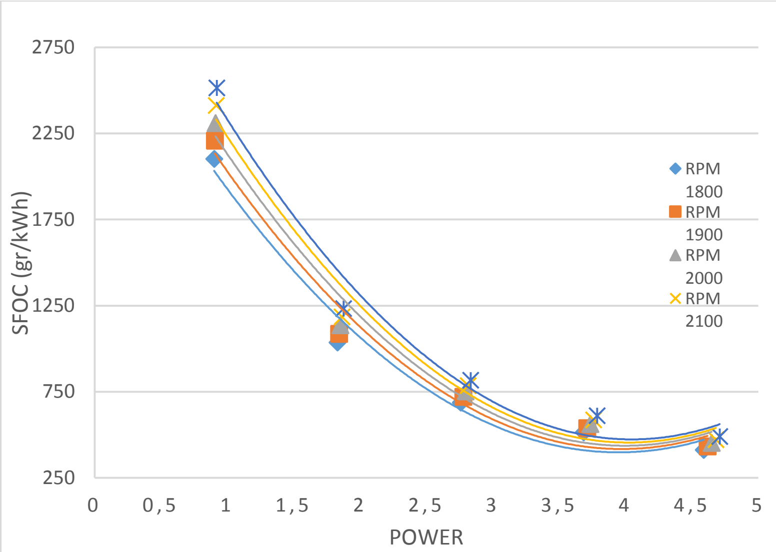


Figure 4. 19 Comparison Between Simulation's SFOC and Power to RPM Using B10.

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 4.58859 kW, at 1900 RPM is 4.61776 kW, at 2000 RPM is 4.64785 kW, at 2100 RPM is 4.68024 kW, at 2200 RPM is 4.7094 kW. Based on the graphic, it can be concluded that the power increasing about under 1% in as the RPM increase. In SFOC, the lowest consumption can be found at the highest load in each RPM. At 1800 RPM the value of SFOC shows 412.87 gr/kWh, at 1900 RPM shows 432.4 gr/kWh, at 2000 RPM shows 452.171 gr/kWh, at 2100 RPM shows 471.458 gr/kWh, and at 2200 RPM shows 490.815 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

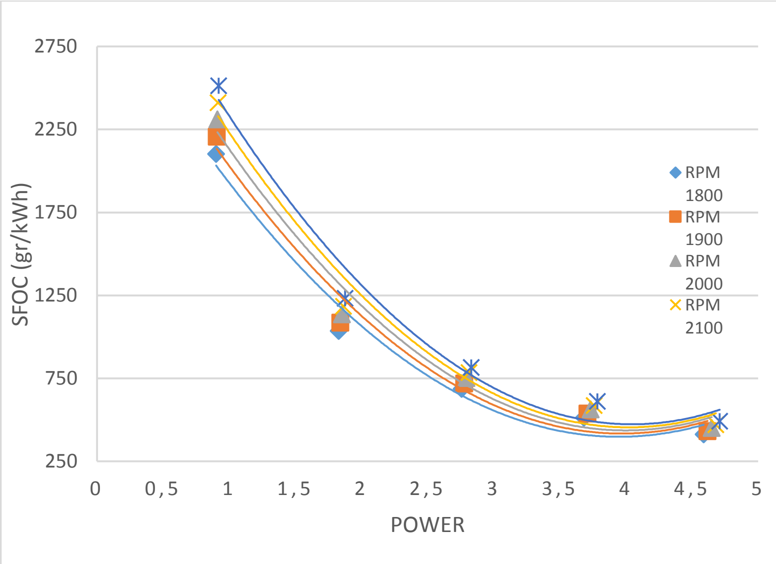


Figure 4. 20 Comparison Between Simulation's SFOC and Power to RPM Using B20.

From the graphic above, it is shown that the power's peak is in the highest load in each RPM. The highest rated power output in 1800 RPM is 4.58859 kW, at 1900 RPM is 4.61776 kW, at 2000 RPM is 4.64785 kW, at 2100 RPM is 4.68024 kW, at 2200 RPM is 4.7094 kW. Based on the graphic, it can be concluded that the power increasing about under 1% in as the RPM increase. In SFOC, the lowest consumption can be found at the highest load in each RPM. At 1800 RPM the value of SFOC shows 412.286 gr/kWh, at 1900 RPM shows 432.399 gr/kWh, at 2000 RPM shows 452.171 gr/kWh, at 2100 RPM shows 471.457 gr/kWh, and at 2200 RPM shows 490.815 gr/kWh. The trend shows that SFOC decreasing as the value of RPM increasing.

4.2.2 Comparison Between Maximum Power and RPM.

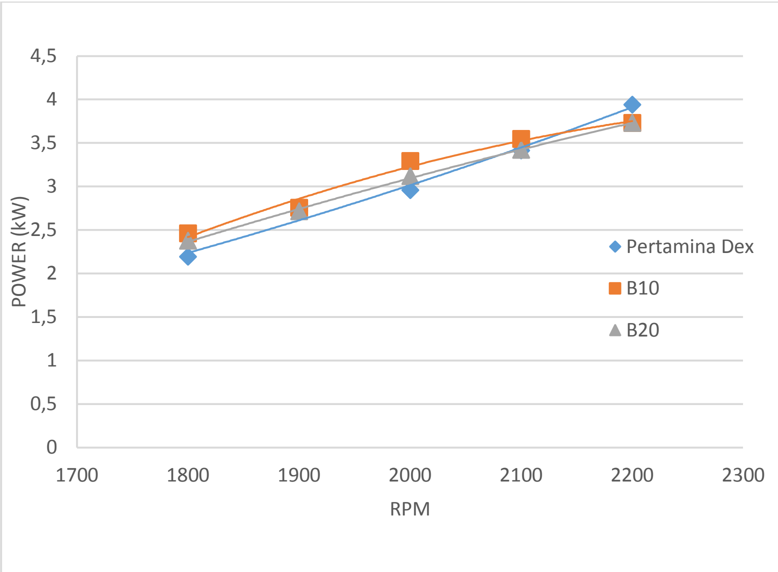


Figure 4. 21 Comparison Between Experiment's Maximum Power and RPM.

The graphic above is the experiment's comparison result between maximum power and rpm for each type of fuel. The highest power is produced in 2200 rpm for each fuel. Pertamina Dex produce the highest power of 3.93786 kW and follow by B10 that produce 3.73065 kW and the lowest power is produced by B20 with 3.7288 kW. The difference between the highest Power at 2200 rpm for each fuel is about 5%.

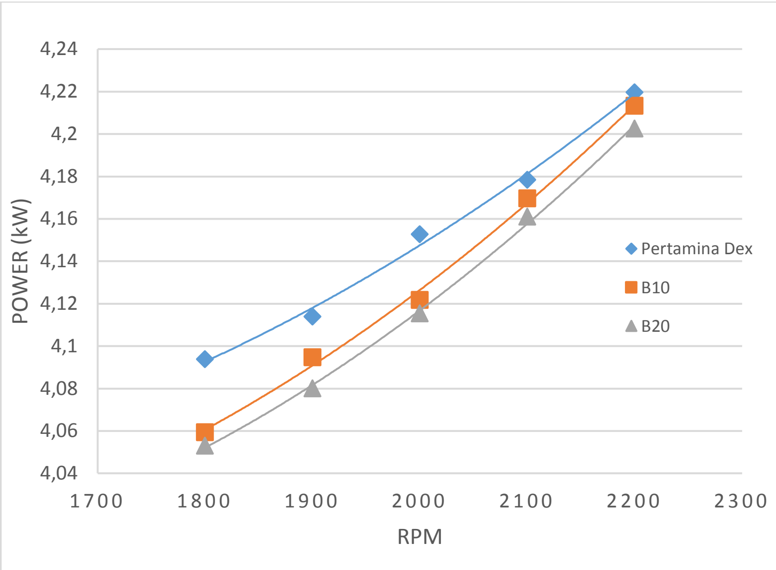


Figure 4. 22 Comparison Between Simulation's Maximum Power and RPM.

The graphic above is the simulation's comparison result between maximum power and rpm for each type of fuel. The highest power is produced at 2200 rpm for each fuel. Pertamina Dex produce the highest power of 4.21968 kW and follow by B10 that produce 4.21332 kW and the lowest power is produced by B20 with 4.20257 kW. The difference between the highest Power at 2200 rpm for each fuel is about 5%.

4.2.3 Comparison Between Maximum Torque and RPM.

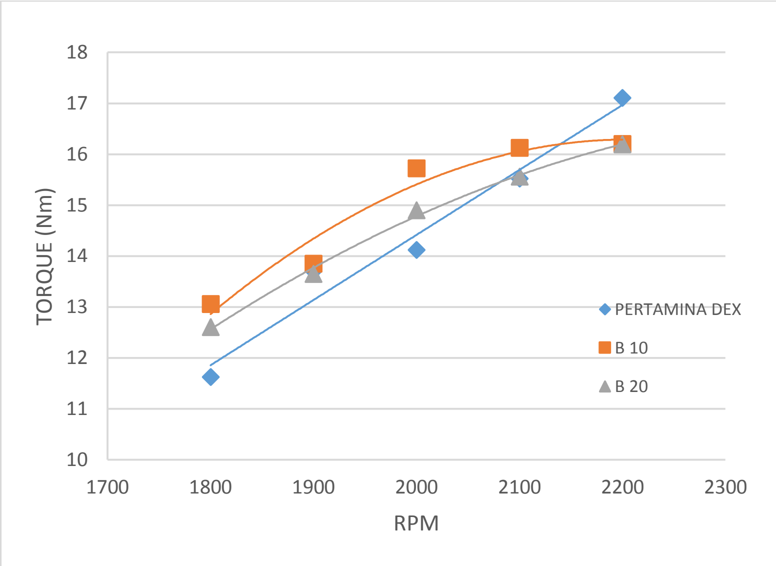


Figure 4. 23 Comparison Between Experiment's Maximum Torque and RPM.

The graphic above is the experiment's comparison result between maximum torque and rpm for each type of fuel. The highest torque is produced in 2200 rpm for each fuel. Pertamina Dex produce the highest torque of 17.1013 Nm and follow by B10 that produce 16.20143 Nm and the lowest torque is produced by B20 with 16.1934 Nm. The difference between the highest Torque at 2200 rpm for each fuel is about 5%.

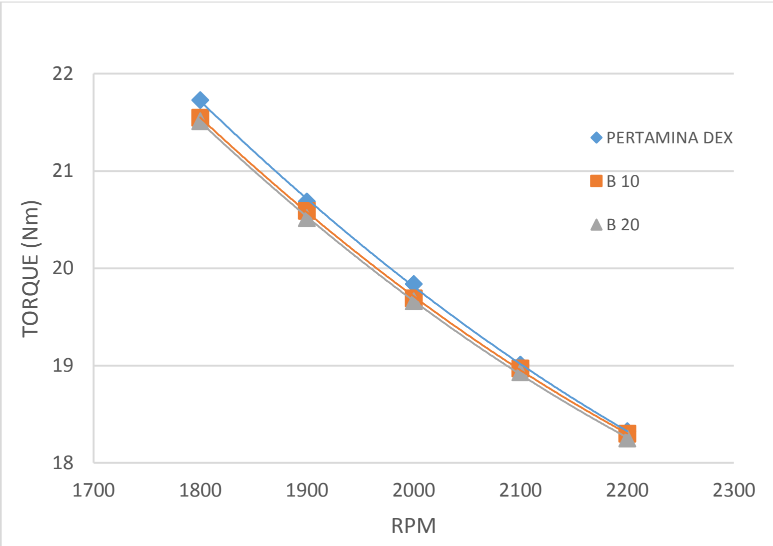


Figure 4. 24 Comparison Between Simulation's Maximum Torque and RPM.

The graphic above is the experiment's comparison result between maximum torque and rpm for each type of fuel. The highest torque is produced in 1800 rpm for each fuel. Pertamina Dex produce the highest torque of 21.72951 Nm and follow by B10 that produce 21.54671 Nm and the lowest torque is produced by B20 with 21.51332 Nm. The difference between the highest Torque at1800 rpm for each fuel is about 1%.

4.2.4 Comparison Between SFOC and RPM in Maximum Power.

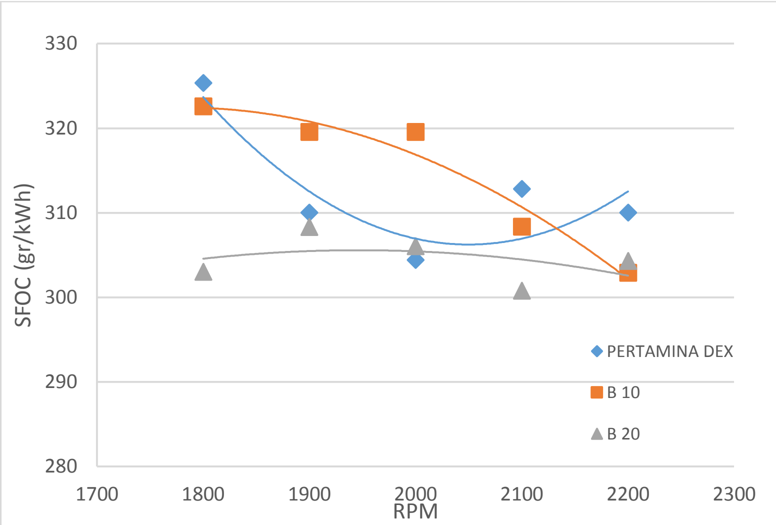


Figure 4. 25 Comparison Between Experiment's SFOC and RPM in Maximum Power.

The graphic above is the experiment's comparison result between SFOC and rpm in maximum power for each type of fuel. Each fuel shows the lowest value at 2200 rpm. The lowest value SFOC comes from B10 with the value of 302.918 gr/kWh and follows by B20 with the value 304.317 gr/kWh and the highest value of SFOC 309.02 gr/kWh. The difference between the lowest SFOC at 2200 rpm for each fuel is about is 2%.

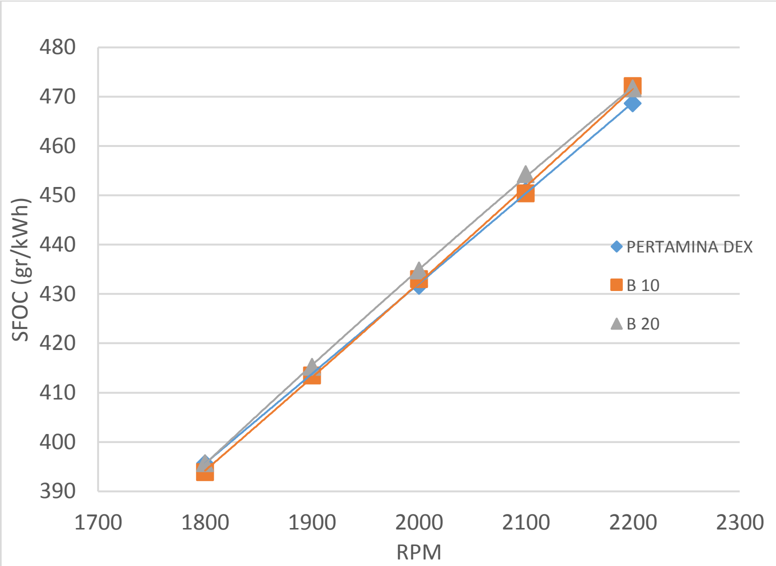


Figure 4. 26 Comparison Between Simulation's SFOC and RPM in Maximum Power.

The graphic above is the simulation's comparison result between SFOC and rpm in maximum power for each type of fuel. Each fuel shows the lowest value at 1800 rpm. The lowest value SFOC comes from B10 with the value of 393.876 gr/kWh and follows by B20 with the value 395.642 gr/kWh and Pertamina Dex with the highest value of SFOC 395.725 gr/kWh. The difference between the lowest value of SFOC at 1800 rpm is 4%.

4.2.5 Comparison Between Maximum BMEP and RPM.

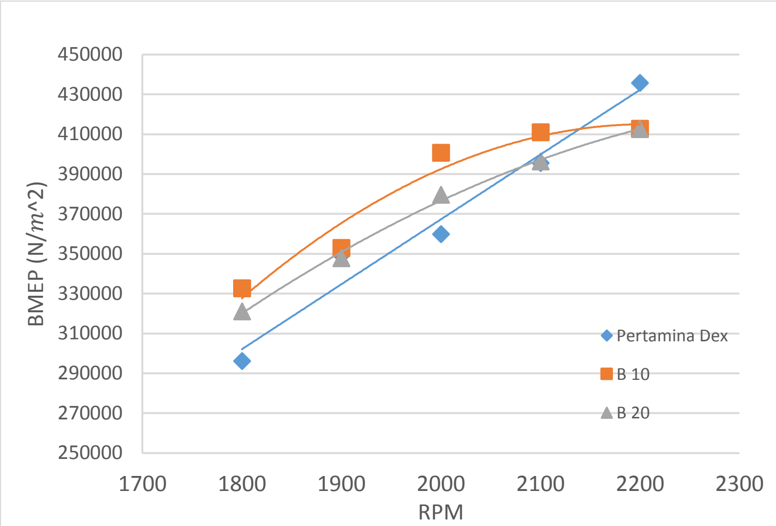


Figure 4. 27 Comparison Between Experiment's Maximum BMEP and RPM.

The graphic above is the experiment's comparison result between maximum BMEP and rpm for each type of fuel. The highest BMEP is produced in 2200 rpm for each fuel. Pertamina Dex produce the highest BMEP with the value of 435684.3 N/m^2 and follow by B10 that produce 412758.6 N/m^2 and the lowest BMEP that produced by B20 with 412553.9 N/m^2. The difference between the highest BMEP at 2200 rpm for each fuel is about 5%.

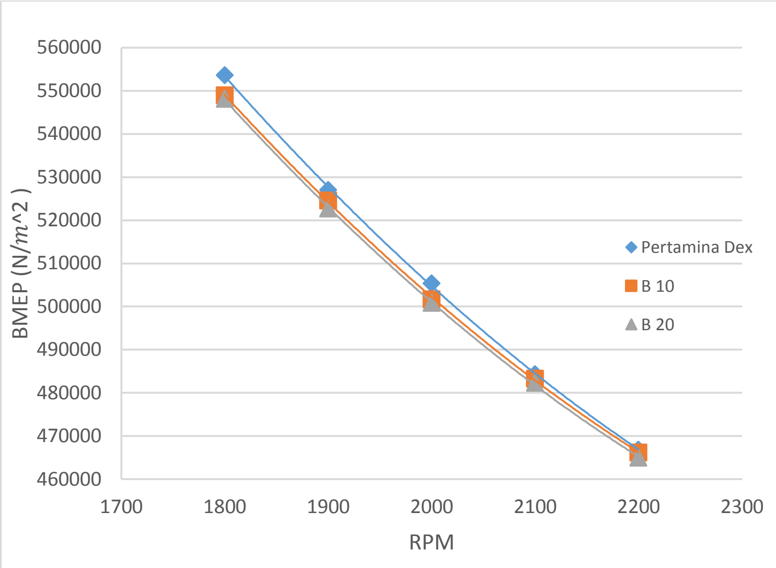


Figure 4. 28 Comparison Between Simulation's Maximum BMEP and RPM.

The graphic above is the simulation's comparison result between maximum BMEP and rpm for each type of fuel. The highest BMEP is produced at 1800 rpm for each fuel. Pertamina Dex produce the highest BMEP of 553595.7 N/m^2 and follow by B10 that produce 548938.5 N/m^2 and the lowest BMEP is produced by B20 with 548087.9 N/m^2. The difference between the highest value of BMEP at 1800 rpm is 1%.

4.2.6 Comparison Result Between Thermal Efficiency and Power to RPM.

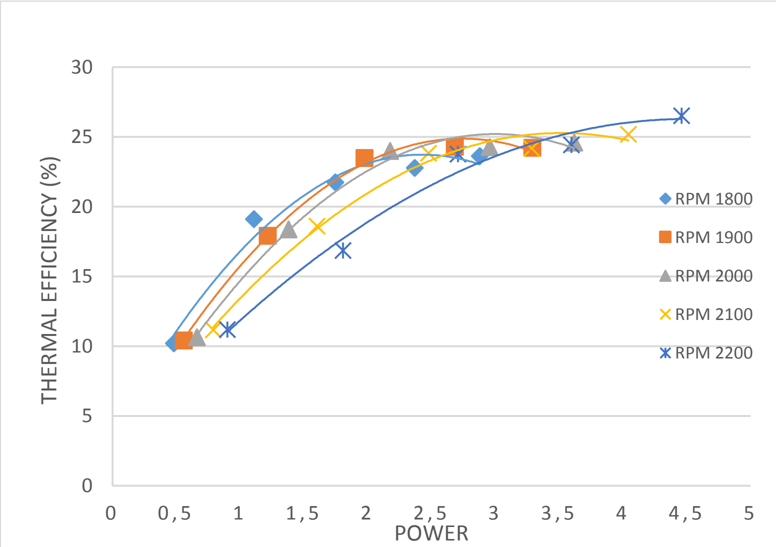


Figure 4. 29 Comparison of Experiment's Result Between Thermal Efficiency and Power to RPM Using Pertamina Dex

The graphic above show the comparison between thermal efficiency and Power. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 23.64006662 %, at 1900 RPM is 24.22560925 %, at 2000 RPM is 24.59506743 %, at 2100 RPM is 25.18276206%, at 2200 RPM is 26.51985574 %. The thermal efficiency is increasing with the value about 10 % from the lowest rpm to highest rpm. From this result, it can be concluded the thermal efficiency value is increasing when the rpm also increased.

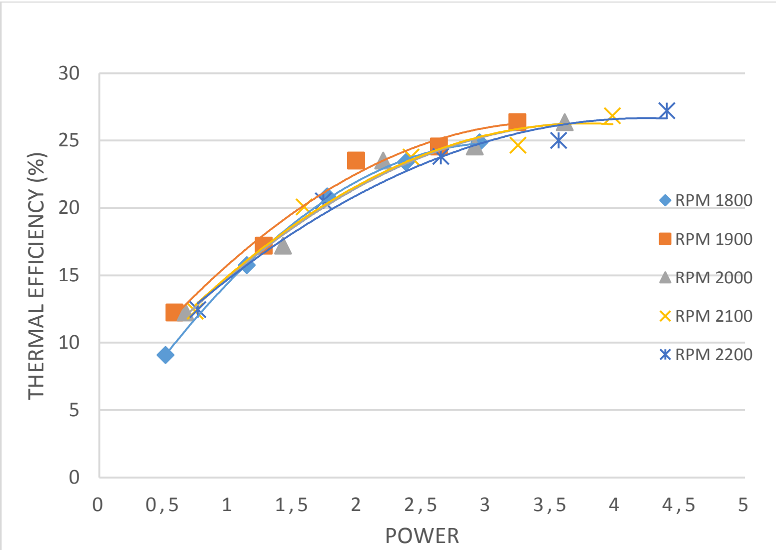


Figure 4. 30 Comparison of Experiment's Result Between Thermal Efficiency and Power to RPM Using B10.

The graphic above show the comparison between thermal efficiency and rpm. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 24.8574807 %, at 1900 RPM is 25.5010553 %, at 2000 RPM is 26.3658485 %, at 2100 RPM is 26.8323114 %, at 2200 RPM is 27.2166157 %. The thermal efficiency is increasing with the value about 10 % from the lowest rpm to highest rpm. From this result, it can be concluded the thermal efficiency value is increasing when the rpm also increased.

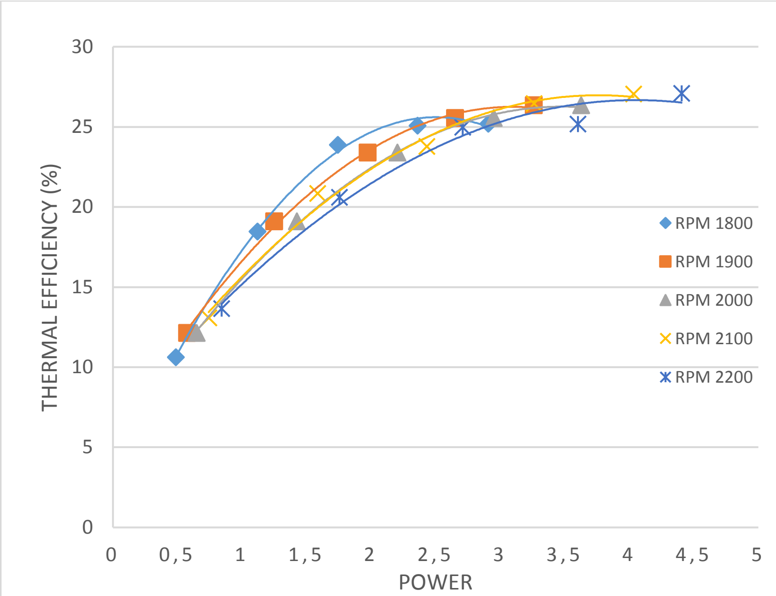


Figure 4. 31 Comparison of Experiment's Result Between Thermal Efficiency and Power to RPM Using B20.

The graphic above show the comparison between thermal efficiency and rpm. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 25.1888609 %, at 1900 RPM is 25.5070447 %, at 2000 RPM is 26.3566045 %, at 2100 RPM is 27.0561634 %, at 2200 RPM is 27.0976492 %. The thermal efficiency is increasing with the value about 10 % from the lowest rpm to highest rpm. From this result, it can be concluded the thermal efficiency value is increasing when the rpm also increased.

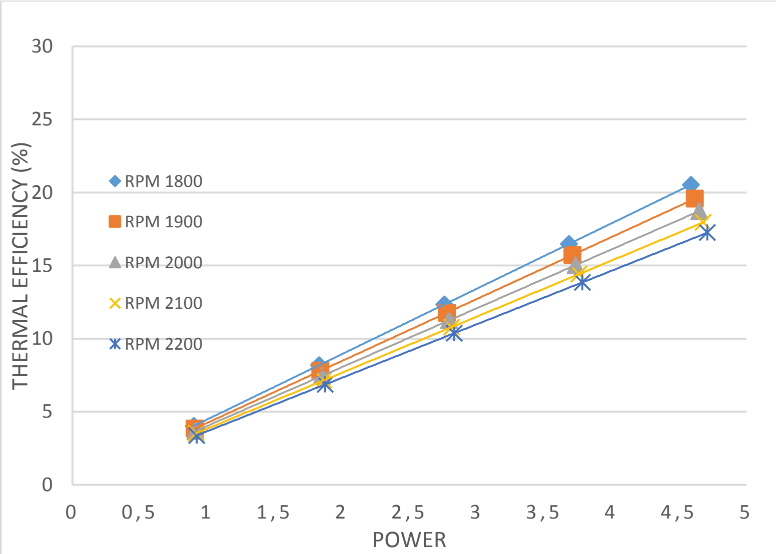


Figure 4. 32 Comparison of Simulation's Result Between Thermal Efficiency and Power to RPM Using Pertamina Dex.

The graphic above show the comparison between thermal efficiency and Power. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 20.52721809 %, at 1900 RPM is 19.57248252 %, at 2000 RPM is 18.72632355%, at 2100 RPM is 17.95002859 %, at 2200 RPM is 17.24972653 %. The thermal efficiency is decreasing with the value about 10 % from the highest rpm to the lowest rpm. From this result, it can be concluded the thermal efficiency value decrease as the rpm increase.

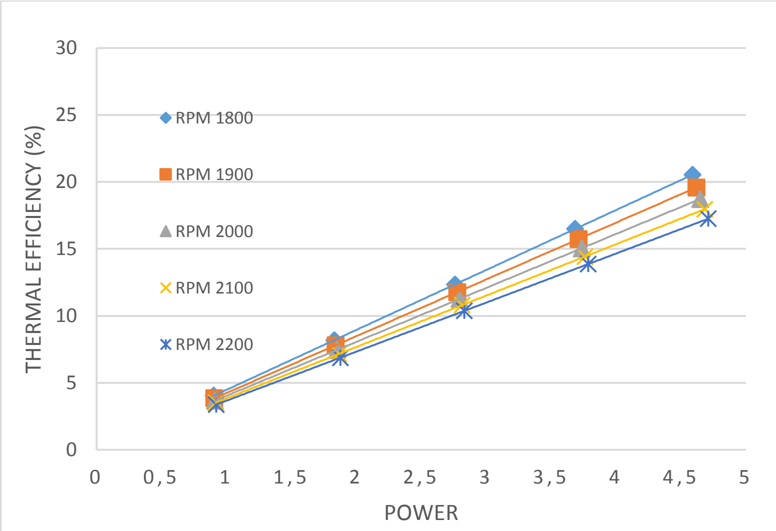


Figure 4. 33 Comparison of Simulation's Result Between Thermal Efficiency and Power to RPM Using B10.

The graphic above show the comparison between thermal efficiency and Power. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 20.53987 %, at 1900 RPM is 19.58447 %, at 2000 RPM is 18.72814 %, at 2100 RPM is 17.96199 %, at 2200 RPM is 17.25359 %. The thermal efficiency is decreasing with the value about 10 % from the highest rpm to the lowest rpm. From this result, it can be concluded the thermal efficiency value decrease as the rpm increase.

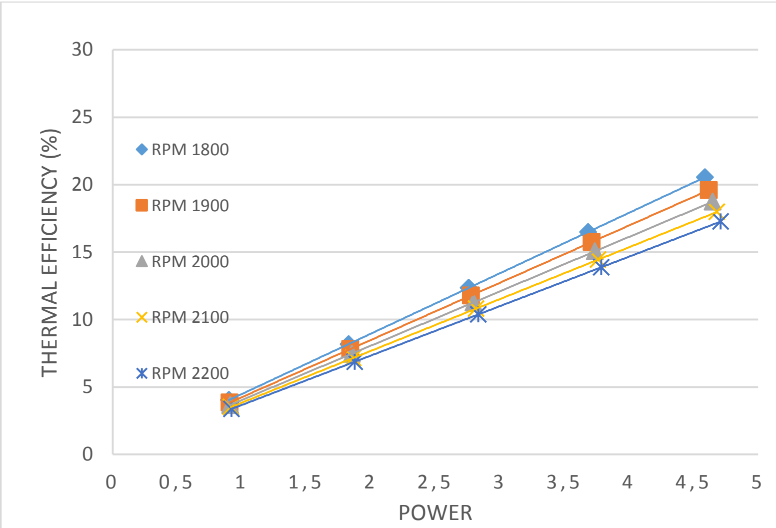


Figure 4. 34 Comparison of Simulation's Result Between Thermal Efficiency and Power to RPM Using B20.

The graphic above show the comparison between thermal efficiency and Power. Each rpm produce the highest thermal efficiency in its maximum load. The highest thermal efficiency in 1800 RPM is 20.55275 %, at 1900 RPM is 19.59674 %, at 2000 RPM is 18.73983 %, at 2100 RPM is 17.97324 %, at 2200 RPM is 17.26436 %. The thermal efficiency is decreasing with the value about 10 % from the highest rpm to the lowest rpm. From this result, it can be concluded the thermal efficiency value decrease as the rpm increase.

4.2.7 Comparison Between Thermal Efficiency and RPM in Maximum Power.

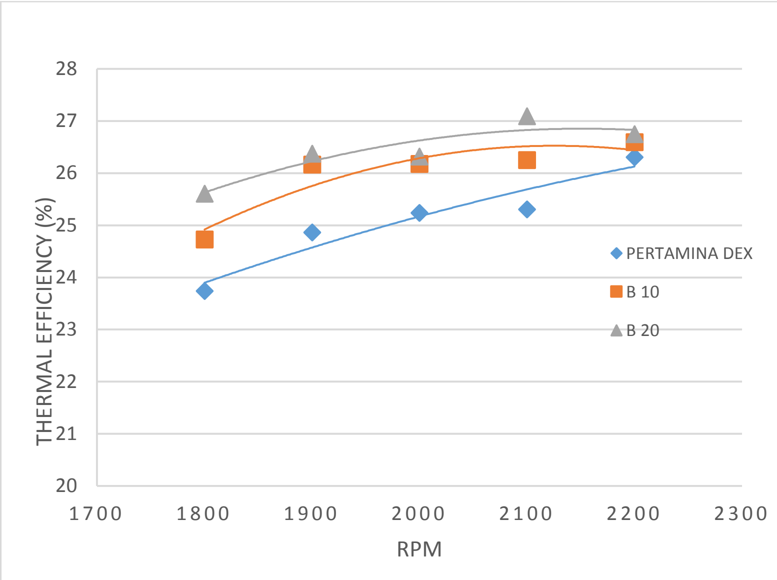


Figure 4. 35 Comparison Between Experiment's Thermal Efficiency and RPM in Maximum Power.

The graphic above is the experiment's comparison result between Thermal Efficiency and rpm in maximum power for each type of fuel. As the thermal efficiency value increase as the rpm increase except for B20 fuel. B20 has the highest Thermal Efficiency value with 27.0918% at 2100 rpm and decrease at 2200 rpm to 26.7448 % but still have the highest thermal efficiency among the other fuel. The second highest thermal efficiency comes from B10 with 26.5896 % at 2200 rpm and the lowest is Pertamina Dex with 26.3044% at 2200 rpm. The difference between the highest thermal efficiency and the lowest thermal efficiency is 3%.

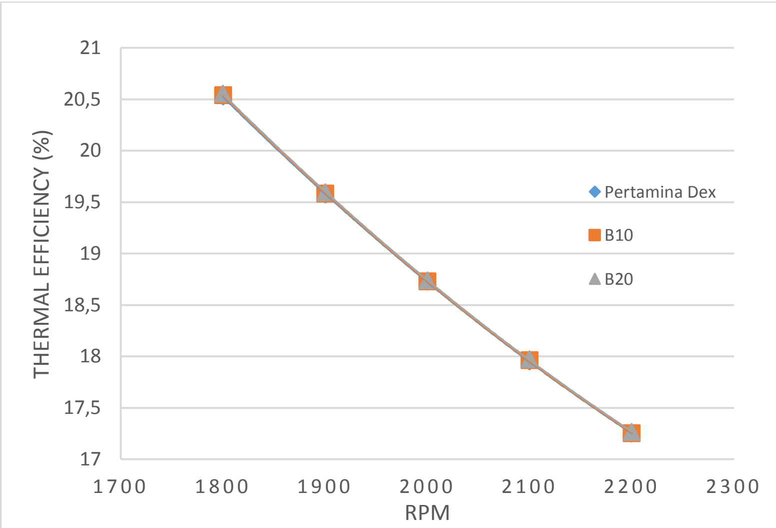


Figure 4. 36 Comparison Between Simulation's Thermal Efficiency and RPM in Maximum Power.

The graphic above is the experiment's comparison result between Thermal Efficiency and rpm in maximum power for each type of fuel. Thermal efficiency value decrease as the rpm increase. The graphic shows the highest thermal efficiency at 1800 rpm. B20 havethe highest thermal effciency value among others. B 20 thermal efficiency value is 20.55276 % at 1800 rpm, the second highest is B10 with 20.53987 % at 1800 rpm and the lowest is Pertamina Dex with 20.52721809 % at 1800 rpm. The difference between the highest Thermal Efficiency at 1800 rpm is below 1%.

4.3 Comparison Result Of Engine Performance Between The Experiment And Simulation.

There are several methods to conduct this engine performance research. The methods are experiment and simulation. Experiment was done by using diesel engine in Marine Power Plant Laboratory. Simulation was done by modeling the engine that used for experiment. The simualtion can reduce the research's cost that is done by experiment.

4.3.1 Comparison Between Maximum Power and RPM.

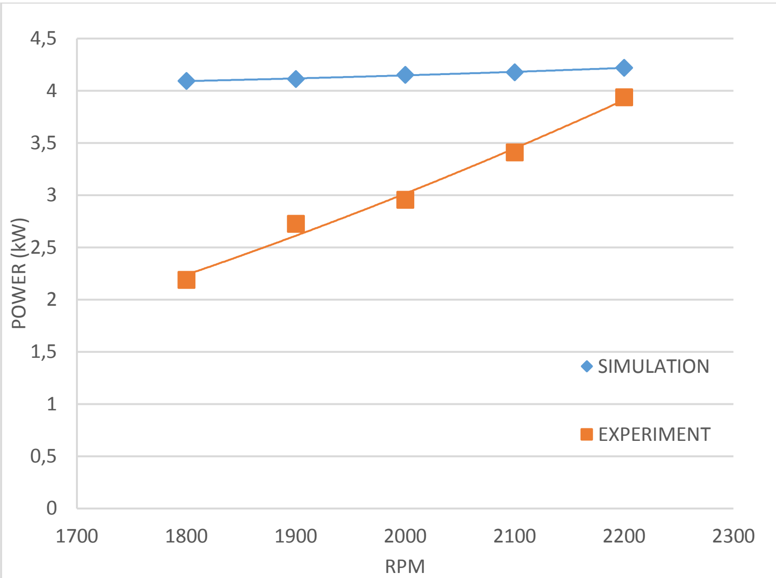


Figure 4. 37 Comparison Between Experiment and Simulation Maximum Power and RPM Using Pertamina Dex.

The graphic above is the comparison result between maximum power and rpm for Pertamina Dex. The highest power is produced at 2200 rpm for each method. Pertamina Dex Simulation produce the higher power of 4.21968 kW than Pertamina Dex

Experiment's power that produce value of 3.93786 kW . The difference value of Power between these two methods ia about 9%.

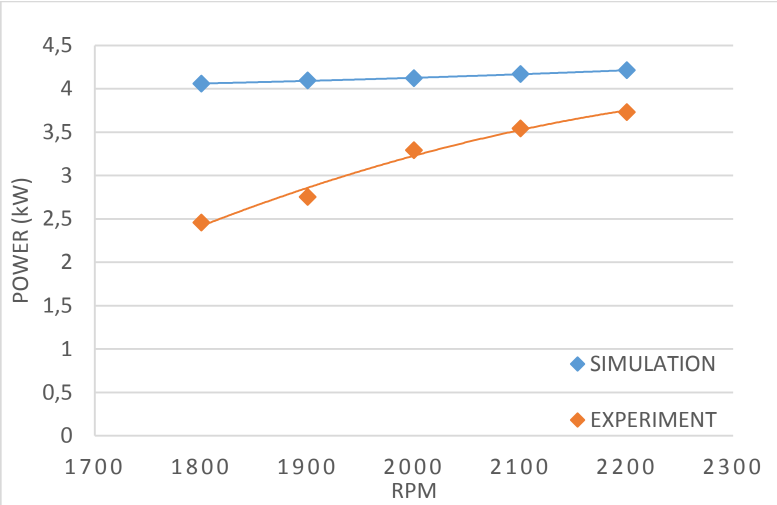


Figure 4. 38 Comparison Between Experiment and Simulation Maximum Power and RPM Using B10.

The graphic above is the comparison result between maximum power and rpm for B10. The highest power is produced at 2200 rpm for each method. B10 Simulation produce the higher power of 4.21332 kW than B10 Experiment's power that produce value of 3.73065 kW . The difference value of Power between these two methods ia about 13%.

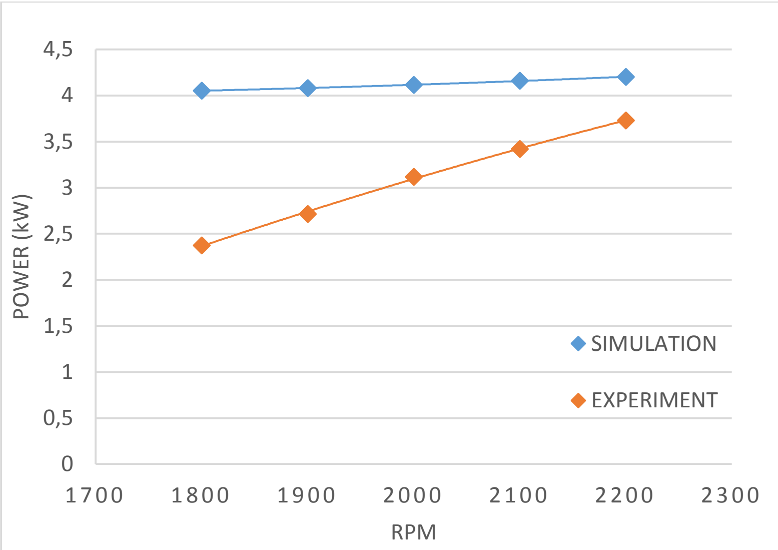


Figure 4. 39 Comparison Between Experiment and Simulation Maximum Power and RPM Using B20.

The graphic above is the comparison result between maximum power and rpm for B20. The highest power is produced at 2200 rpm for each method. B20 Simulation produce higher power of 4.20257 kW than B20 Experiment's power that produce value of 3.7288 kW . The difference value of Power between these two methods ia about 11%.

4.3.2 Comparison Between Maximum Power and Torque Using Pertamina Dex.

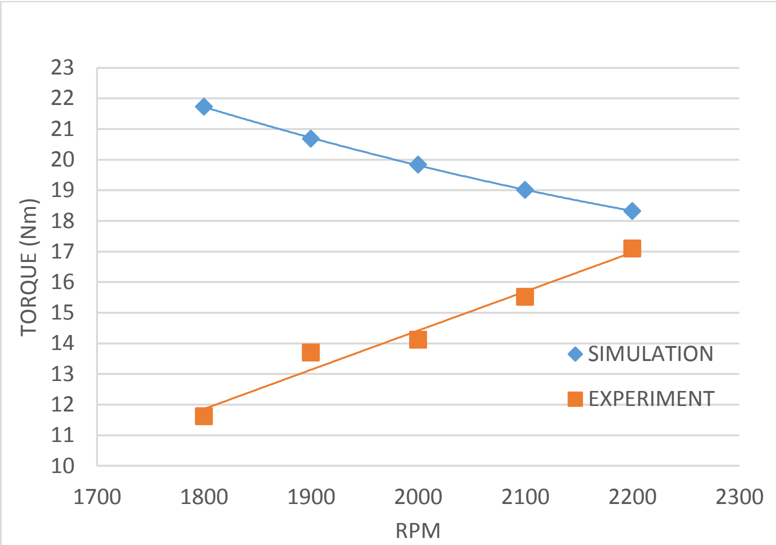


Figure 4. 40 Comparison Between Experiment and Simulation Maximum Torque and RPM Using Pertamina Dex.

The graphic above is the comparison result between maximum torque and rpm for pertamina dex using experiment and simulation method. The highest torque is produced in 1800 rpm for simulation and at 2200 rpm for the experiment. Pertamina Dex simulation produce the highest torque of 21.72951 Nm and Pertamina Dex experiment's Produce 17.1013 Nm for the highest torque. The difference between the highest value of Torque for each fuel is about 37%.

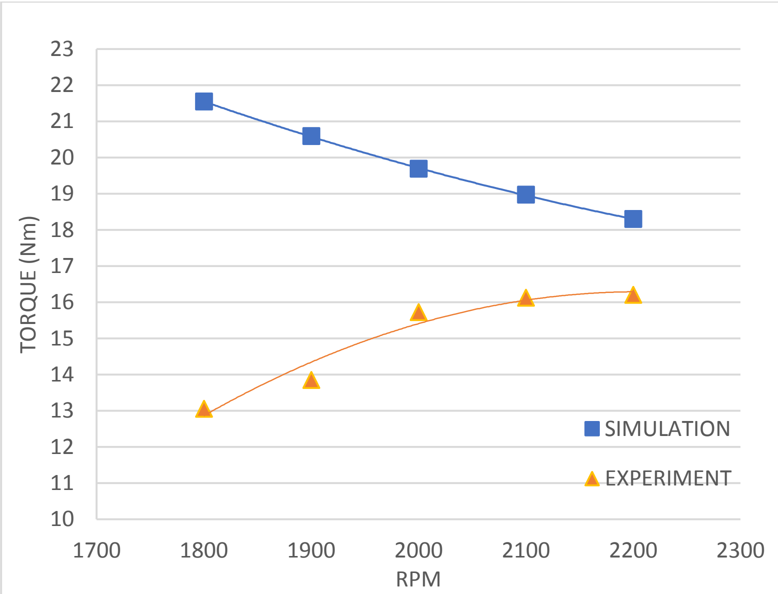


Figure 4. 41 Comparison Between Experiment and Simulation Maximum Torque and RPM Using B10.

The graphic above is the experiment's comparison result between maximum torque and rpm for B10 using experiment and simulation method. The highest torque is produced at 1800 rpm for simulation and at 2200 rpm for the experiment. B10 simulation produce the highest torque of 21.54671 Nm and B10 Experiment Produce 16.20143Nm for the highest torque. The difference between the highest value of Torque for each fuel is about 37%.

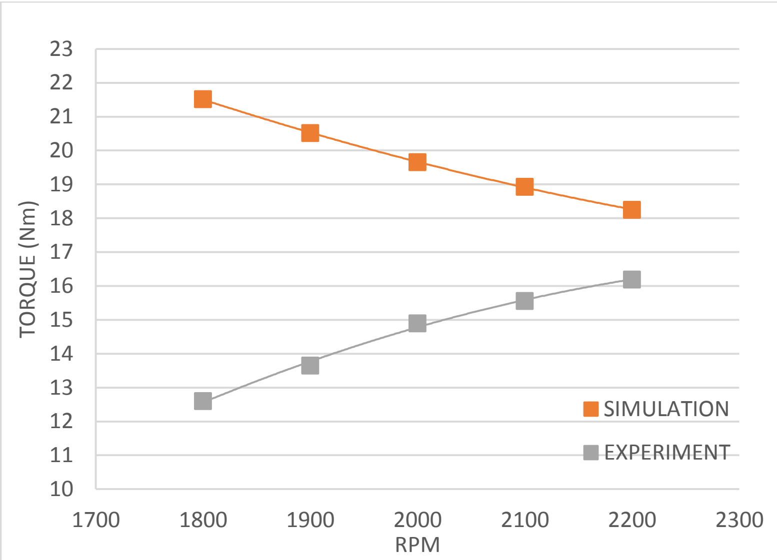


Figure 4. 42 Comparison Between Experiment and Simulation Maximum Torque and RPM Using B20.

The graphic above is the comparison result between maximum torque and rpm for B20 using experiment and simulation method. The highest torque is produced at 1800 rpm for simulation and at 2200 rpm for the experiment. B20 simulation produce the highest torque of 21.51332 Nm and B20 Experiment Produce 16.1934 for the highest torque. The difference between the highest value of Torque for each fuel is about 37%.

4.3.3 Comparison Between SFOC and RPM at Maximum Power Using Pertamina Dex.

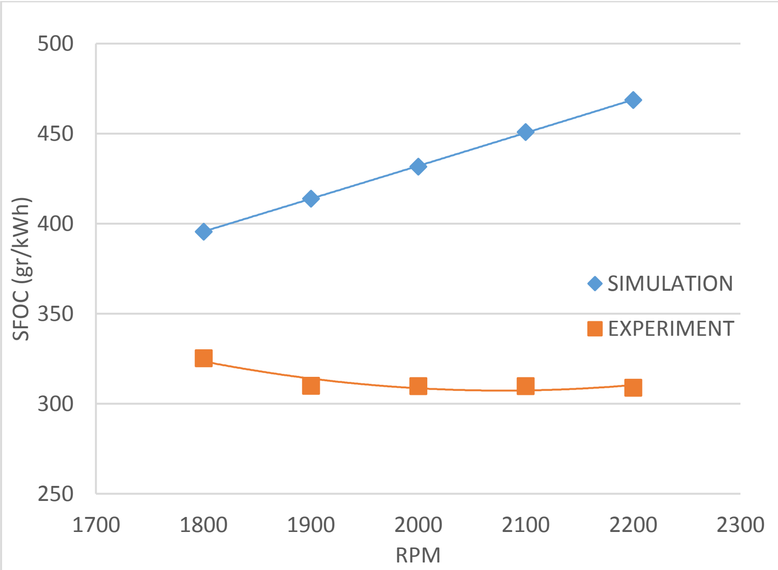


Figure 4. 43 Comparison Between Experiment and Simulation's SFOC and RPM in Maximum Power Using Pertamina Dex.

The graphic above is the experiment and simulation comparison result between SFOC and rpm in maximum power for each type of fuel. At the 1800 rpm for Pertamina Dex simulation show the lowest value of SFOC but Pertamina Dex experiment's show the lowest value at 2200 rpm. Pertamina Dex simulation SFOC value at 1800 rpm is 395.642 gr/ kWh and Pertamina Dex simulation SFOC value at 2200 rpm is 468.664 gr/kWh. For Pertamina Dex experiment, SFOC value at 1800 rpm is 325.362 gr/kWh and at 2200 rpm is 309.02 gr/kWh. The difference between the lowest value of SFOC for each fuel is about 28%.

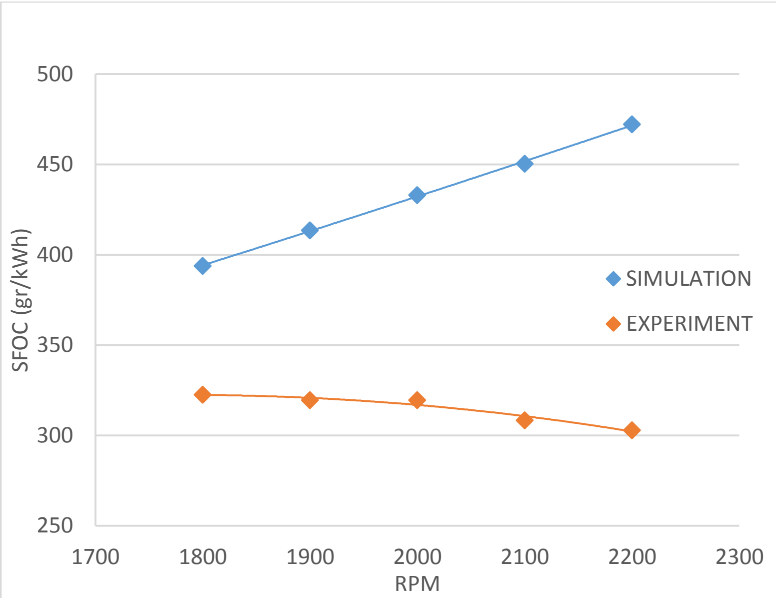


Figure 4. 44 Comparison Between Experiment and Simulation's SFOC and RPM in Maximum Power Using B10.

The graphic above is the experiment and simulation comparison result between SFOC and rpm in maximum power for B10 fuel. At the 1800 rpm for B10 simulation show the lowest value of SFOC but B10 experiment's show the lowest value at 2200 rpm. B10 simulation SFOC value at 1800 rpm is 393.876 gr/kWh and B10 simulation SFOC value at 2200 rpm is 472.164 gr/kWh. For B10 experiment, SFOC value at 1800 rpm is 322.578 gr/kWh and at 2200 rpm is 302.918 gr/kWh. The difference between the lowest value of SFOC for each fuel is about 29%.

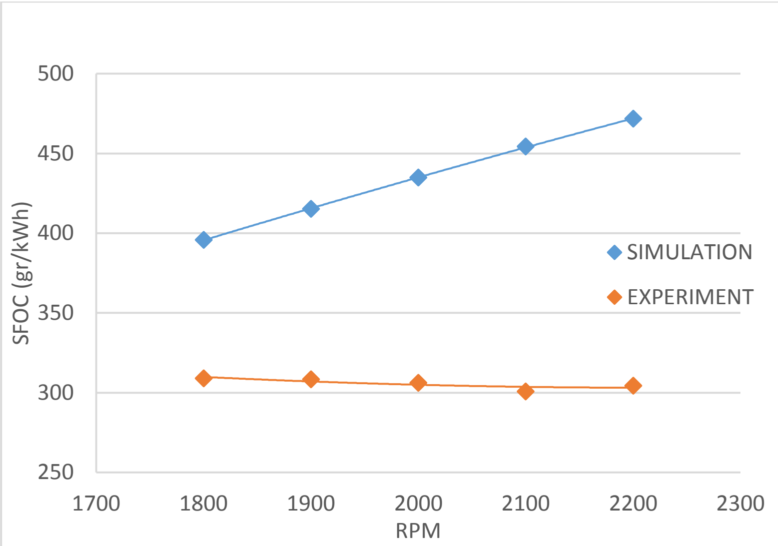


Figure 4. 45 Comparison Between Experiment and Simulation's SFOC and RPM in Maximum Power Using B20.

The graphic above is the experiment and simulation comparison result between SFOC and rpm in maximum power for B20 fuel. At the 1800 rpm for B10 simulation show the lowest value of SFOC but B20 experiment's show the lowest value at 2200 rpm. B20 simulation SFOC value at 1800 rpm is 393.876 gr/kWh and B20 simulation SFOC value at 2200 rpm is 472.164 gr/kWh. For B20 experiment, SFOC value at 1800 rpm is 309 gr/kWh and at 2200 rpm is 304.317 gr/kWh. The difference between the lowest value of SFOC for each fuel is about 29%.

4.3.4 Comparison Between BMEP and RPM at Maximum Power Using Pertamina Dex.

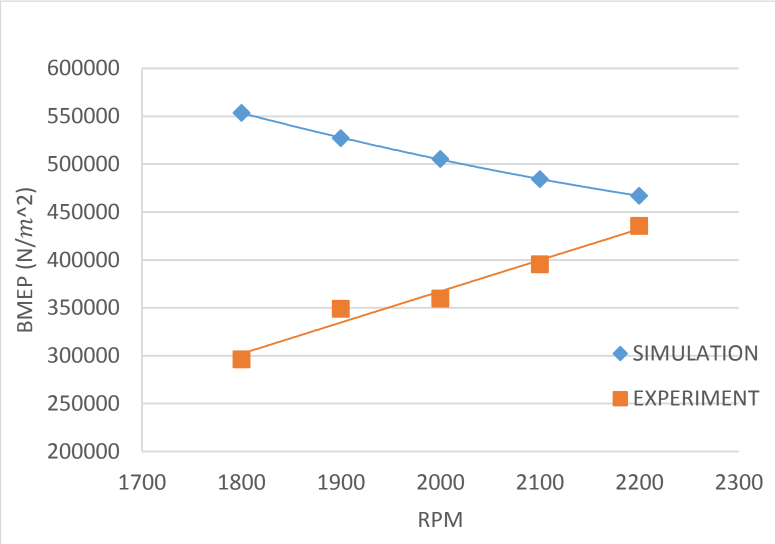


Figure 4. 46 Comparison Between Experiment and Simulation Maximum BMEP and RPM Using Pertamina Dex.

The graphic above is the experiment and simulation comparison result between BMEP and rpm in maximum power for Pertamina Dex fuel. At the 1800 rpm for Pertamina Dex simulation show the highest value of BMEP but Pertamina Dex experiment's show the lowest value at 2200 rpm. Pertamina Dex simulation BMEP value at 1800 rpm is 553595.7 N/m^2 and Pertamina Dex simulation BMEP value at 2200 rpm is 466864.8 N/m^2. For Pertamina Dex experiment, BMEP value at 1800 rpm is 296136.6 N/$m^2$and at 2200 rpm is 435684.3 N/m^2. The difference between the highest value of BMEP for each fuel is about 20%.

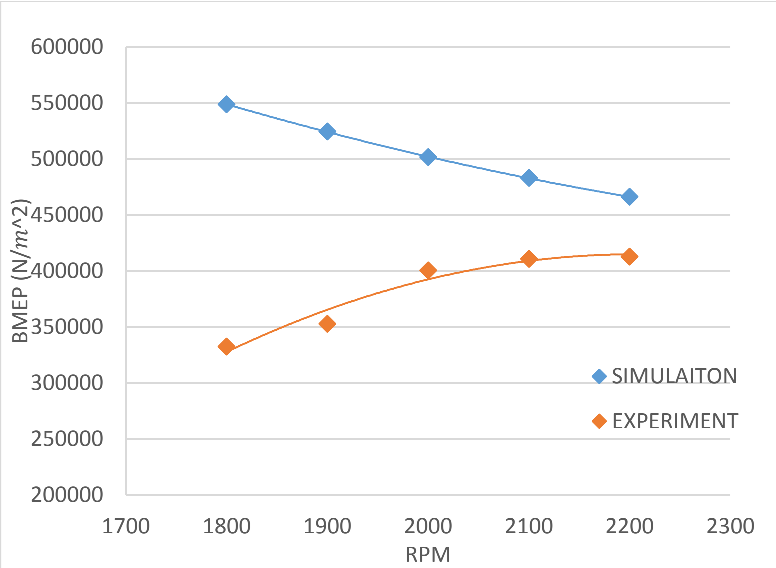


Figure 4. 47 Comparison Between Experiment and Simulation Maximum Power and RPM Using B10.

The graphic above is the experiment and simulation comparison result between BMEP and rpm in maximum power for B10 fuel. At the 1800 rpm for B10 simulation show the highest value of BMEP but B10 experiment's show the lowest value at 2200 rpm. B10 simulation BMEP value at 1800 rpm is 5489385.5 N/m^2 and B10 simulation BMEP value at 2200 rpm is 466161.2 N/m^2. For B10 experiment, BMEP value at 1800 rpm is 332599.1 N/$m^2$and at 2200 rpm is 412758.6 N/m^2. The difference between the highest value of BMEP for each fuel is about 33%.

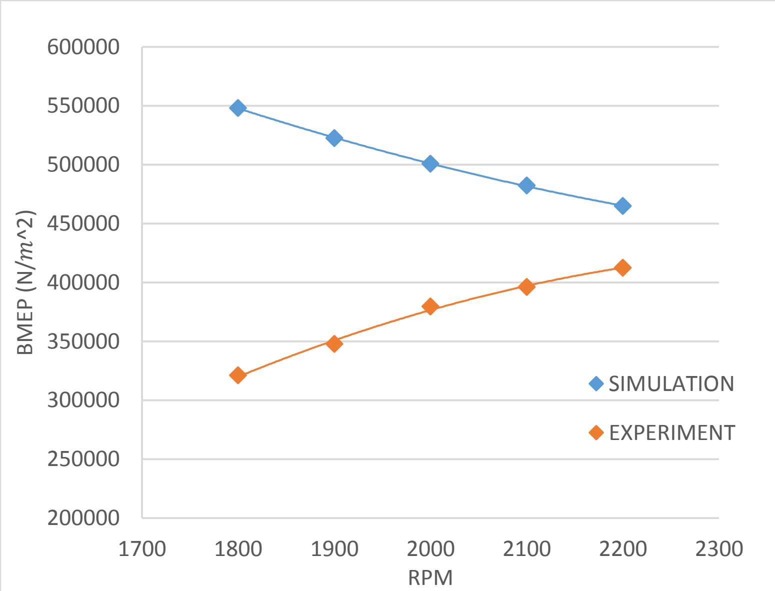


Figure 4. 48 Comparison Between Experiment and Simulation Maximum Power and RPM Using B20.

The graphic above is the experiment and simulation comparison result between BMEP and rpm in maximum power for B20 fuel. At the 1800 rpm for B20 simulation show the highest value of BMEP but B20 experiment's show the lowest value at 2200 rpm. B20 simulation BMEP value at 1800 rpm is 548087.9 N/m^2 and B20 simulation BMEP value at 2200 rpm is 464971.8 N/m^2. For B20 experiment, BMEP value at 1800 rpm is 321068.3 N/$m^2$and at 2200 rpm is 412553.9 N/m^2. The difference between the highest value of BMEP for each fuel is about 33%.

4.3.5 Comparison Between Experiment's Thermal Efficiency and RPM in Maximum Power Using Pertamina Dex.

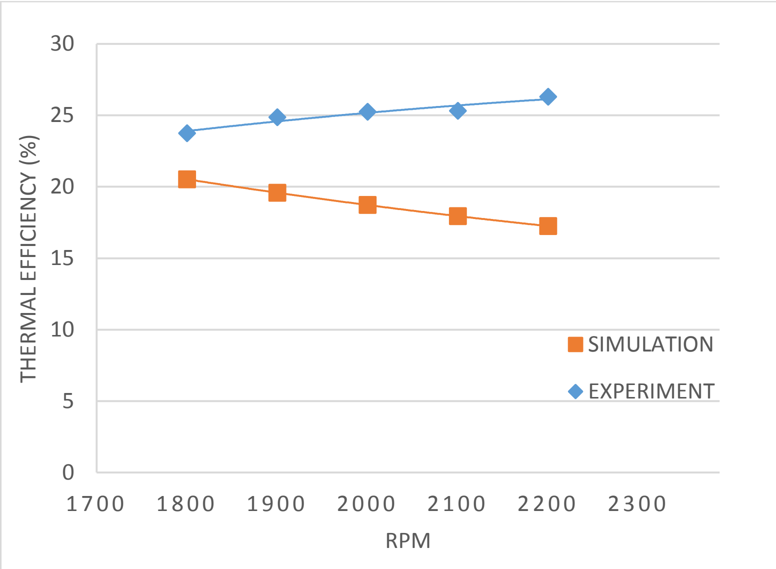


Figure 4. 49 Comparison Between Experiment and Simulation's Thermal Efficiency and RPM in Maximum Power Using Pertamina Dex.

The graphic above is the experiment and simulation comparison resut of thermal efficiency vs rpm in maximum power by using Pertamina Dex. At the 1800 rpm for Pertamina Dex simulation show the highest value of Thermal Efficiency but Pertamina Dex experiment's show the lowest value at 2200 rpm. Pertamina Dex simulation Thermal Efficiency value at 1800 rpm is 20.52721809 % and Pertamina Dex Thermal Efficiency value at 2200 rpm is 17.24972653 %. Pertamina Dex experiment Thermal Efficiency value at 1800 rpm is 23.7397 % and Pertamina Dex Thermal Efficiency value at 2200 rpm is 26.304 %.

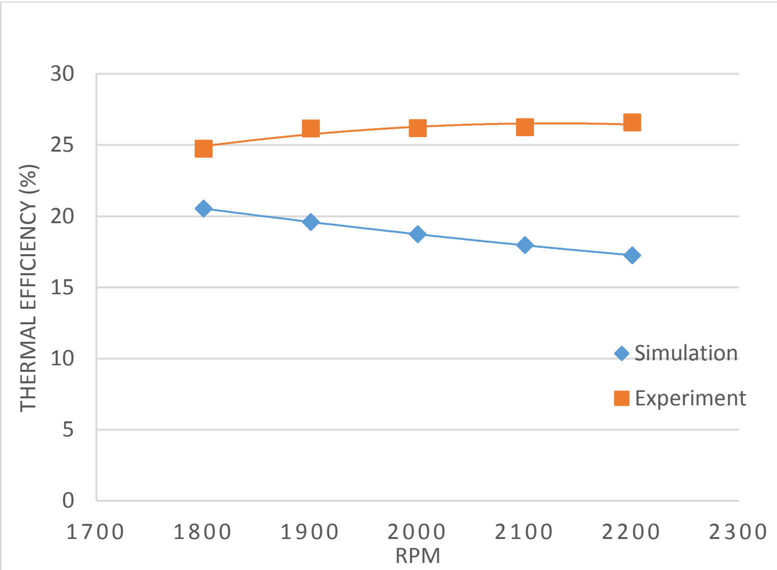


Figure 4. 50 Comparison Between Experiment and Simulation's Thermal Efficiency and RPM in Maximum Power Using B10..

The graphic above is the experiment and simulation comparison resut of thermal efficiency vs rpm in maximum power by using B10. At the 1800 rpm for B10 simulation show the highest value of Thermal Efficiency but B10 experiment's show the lowest value at 2200 rpm. B10 simulation Thermal Efficiency value at 1800 rpm is 20.53987 % and B10 Thermal Efficiency value at 2200 rpm is 17.25359 %. B10 experiment Thermal Efficiency value at 1800 rpm is 24.7294 % and Pertamina B10 Efficiency value at 2200 rpm is 26.5896 %.

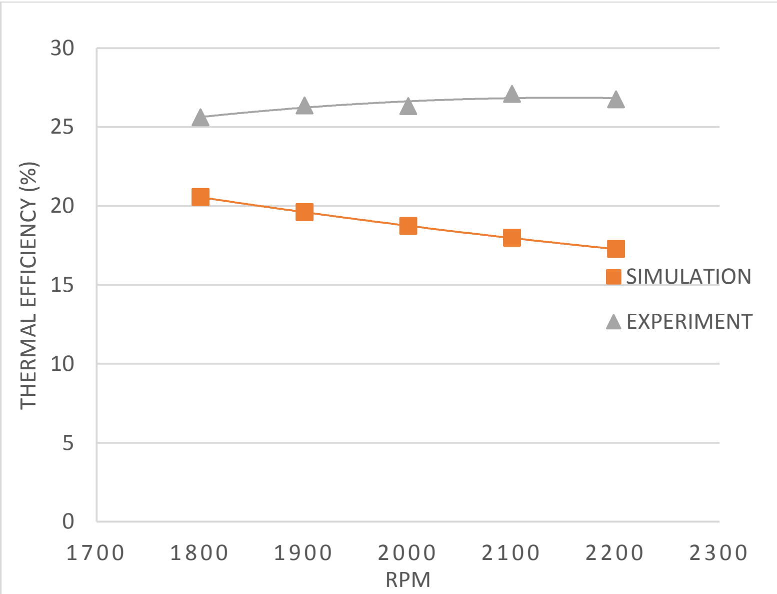


Figure 4. 51 Comparison Between Experiment and Simulation's Thermal Efficiency and RPM in Maximum Power Using B20.

The graphic above is the experiment and simulation comparison resut of thermal efficiency vs rpm in maximum power by using B20. At the 1800 rpm for B20 simulation show the highest value of Thermal Efficiency but B20 experiment's show the lowest value at 2200 rpm. B20 simulation Thermal Efficiency value at 1800 rpm is 20.55275 % and B20 Thermal Efficiency value at 2200 rpm is 17.26436 %. B20 experiment Thermal Efficiency value at 1800 rpm is 25.6065 % and B20 Thermal Efficiency value at 2200 rpm is 26.7448 %.

4.4 Discussion

Pertamina Dex is a fuel that made from fossil without any mixture of Biodiesel. B10 and B20 are fuels that has been mixed between soybean oil biodiesel and Pertamina Dex. B 10 contain (10% of Soybean Oil Biodiesel and 90 %). Engine Performance test that has been done in two ways which experiment and simulation. The result shows engine Pertamina Dex is better than biodiesel. For the engine performance result, simulation method produce more power compare to the experiment.

For the result, simulation method produce more power compare to the experiment. The difference vaue of the power possibly occured because experiment have mechanical loss and volumetric efficiency losses. The losses might be occured inside the cylinder (friction losses between piston and cylinder liner), bearing, gears, and valve. It is better to check all the engine components to check the realibility of the component and replace the component with the new component to reduce the losses in the engine.

4.4.1 Biodiesel Properties

Pertamina Dex have higher Lower Heating Value compare to two others fuel. B10 and B20 have the value of LHV below Pertamina Dex. Lower Heating Value influence the Fuel to produce power. That's why Pertamina Dex produce better engine performance's result compare to two others fuel. Lower Heating Value is the value of of heat release by burning some quantity of fuel when there is water vapor in the combustion gas.

4.4.2 Engine Performance

Engine performance result shows simulation method produce more power compare to the experiment. The difference vaue of the power possibly occured because experiment have mechanical loss and volumetric efficiency losses. The losses might be occured inside the cylinder (friction losses between piston and cylinder liner), bearing, gears, and valve. It is better to check all the engine components to check the realibility of the component and replace the component with the new component to reduce the losses in the engine.

APPENDIX

CALCULATION FORMULA :

- **Power**

$$P = \frac{V \times I \times \cos\varphi}{\eta_G \times \eta_B}$$

Where :

P	= Power (W)
V	= Voltage (V)
I	= Current (I)
$\cos\varphi$	= 0.9
η_G	= Generator efficiency
η_B	= Belt Efficiency

- **Torque**

$$\mathcal{T} = \frac{P}{2\pi \times rps}$$

Where :

$\mathcal{T}$	= Torque (Nm)
P	= Power (W)

- **SFOC**

$$SFOC = \frac{FCR}{P}$$

Where :

SFOC	= gr/kWh
FCR	= mass flow rate (gr/hr)
P	= Power (kW)

$$FCR = \frac{\rho \times \nu}{t}$$

Where :
FCR = mass flow rate (gr/hr)
ρ = density of fuel (gr/m^3)
ν = volume of fuel (m^3)

- **BMEP**

$$BMEP = \frac{2\pi \times \mathcal{T} \times n_c}{V_d}$$

Where :
BMEP = Brake Mean Effective Pressure (N/m^2)
$\mathcal{T}$ = Torque
n_c = Number of revolution per cycle (2 for 4 stroke engine)
V_d = Volume Displacement (m^3)

- **Thermal Efficiency**

$$\eta_{th} = \frac{P}{LHV \times FCR} \times 100\%$$

Where :
η_{th} = Thermal Efficiency (%)
LHV = Lower Heating Value (J/kg)
FCR = mass flow rate (kg/s)

Experiment Table Pertamina Dex

LOAD	RPM	RPM	V	I	Volume	Time	Volume	Time	Density	LHV	P	FCR	SFOC	Torque	BMEP	Eff Thermal
Watt	Engine	Generator	Volt	Ampere	ml	second	m3	hour	gr/m3	J/kg	Kw	gr/h	gr/kwh	Nm	N/m2	%
1000	1800	1155	150	3	10	75	0.00001	0.020833333	830000	42537888	0.480596	398.4	828.9709	2.550934	64989.3	10.209096
2000	1800	1155	157	6.6	10	61	0.00001	0.016944444	830000	42537888	1.106652	489.8361	442.6288	5.87395	149649	19.119958
3000	1800	1154	160	10.2	10	44	0.00001	0.012222222	830000	42537888	1.744471	679.0909	389.2818	9.259402	235899	21.740149
4000	1800	1151	160	13.8	10	34	0.00001	0.009444444	830000	42537888	2.366319	878.8235	371.3885	12.56008	319989	22.787577
5000	1800	1150	156	17.2	10	29	0.00001	0.008055556	830000	42537888	2.878092	1030.345	357.9958	15.2765	389194	23.640067
1000	1900	1219	163	3.2	10	66	0.00001	0.018333333	830000	42537888	0.556813	452.7273	813.0688	2.799931	71332.9	10.408766
2000	1900	1219	170	6.7	10	52	0.00001	0.014444444	830000	42537888	1.215893	574.6154	472.587	6.114113	155767	17.907906
3000	1900	1213	172	10.7	10	42	0.00001	0.011666667	830000	42537888	1.974362	711.4286	360.3333	9.928071	252934	23.486709
4000	1900	1211	172	14.5	10	31	0.00001	0.008611111	830000	42537888	2.679957	963.871	359.6592	13.47615	343327	23.530733
5000	1900	1210	169	18.1	10	26	0.00001	0.007222222	830000	42537888	3.289693	1149.231	349.3429	16.5422	421440	24.225609
1000	2000	1285	182	3.4	10	57	0.00001	0.015833333	830000	42537888	0.659789	524.2105	794.5124	3.151858	80298.9	10.65187
2000	2000	1279	184	7	10	47	0.00001	0.013055556	830000	42537888	1.379759	635.7447	460.7651	6.591205	167922	18.367372
3000	2000	1278	186	10.9	10	39	0.00001	0.010833333	830000	42537888	2.173534	766.1538	352.4922	10.38312	264527	24.009164
4000	2000	1276	186	14.8	10	29	0.00001	0.008055556	830000	42537888	2.955846	1030.345	348.5786	14.12028	359738	24.278722
5000	2000	1275	182	18.5	10	24	0.00001	0.006666667	830000	42537888	3.618185	1245	344.0952	17.28432	440347	24.595067
1000	2100	1349	200	3.7	10	50	0.00001	0.013888889	830000	42537888	0.788757	597.6	757.648	3.588521	91423.6	11.170153
2000	2100	1346	200	7.5	10	41	0.00001	0.011388889	830000	42537888	1.602395	728.7805	454.807	7.290241	185731	18.607987
3000	2100	1343	201	11.5	10	34	0.00001	0.009444444	830000	42537888	2.474806	878.8235	355.108	11.25936	286851	23.83231
4000	2100	1342	199	15.4	10	26	0.00001	0.007222222	830000	42537888	3.283558	1149.231	349.9956	14.93884	380592	24.180427
5000	2100	1339	195	19.3	10	22	0.00001	0.006111111	830000	42537888	4.041427	1358.182	336.0649	18.38684	468435	25.182762
1000	2200	1413	216	3.9	10	44	0.00001	0.012222222	830000	42537888	0.898897	679.0909	755.4716	3.90372	99453.8	11.202332
2000	2200	1408	216	7.8	10	33	0.00001	0.009166667	830000	42537888	1.804178	905.4545	501.8655	7.835166	199614	16.863169
3000	2200	1408	216	11.7	10	31	0.00001	0.008611111	830000	42537888	2.706266	963.871	356.1626	11.75275	299421	23.761738
4000	2200	1403	209	16	10	24	0.00001	0.006666667	830000	42537888	3.593703	1245	346.4393	15.6067	397607	24.428646
5000	2200	1400	207	20	10	21	0.00001	0.005833333	830000	42537888	4.458676	1422.857	319.121	19.3631	493307	26.519856

Experiment Table B10

LOAD	RPM	RPM	V	I	Volume	Time	Volume	Time	Density	LHV	P	FCR	SFOC	Torque	BMEP	Eff Thermal
Watt	Engine	Generator	Volt	Ampere	ml	second	m3	hour	gr/m3	J/kg	Kw	gr/h	gr/kwh	Nm	N/m2	%
1000	1800	1155	150	3.2	10	63	0.00001	0.0175	836000	42511368	0.512636	477.7143	931.8789	2.720996	69321.92	9.0873647
2000	1800	1152	157	6.8	10	49	0.00001	0.013611	836000	42511368	1.143156	614.2041	537.288	6.067708	154585	15.761238
3000	1800	1152	160	10.3	10	42	0.00001	0.011667	836000	42511368	1.764632	716.5714	406.0741	9.366414	238625.1	20.854135
4000	1800	1147	160	13.8	10	35	0.00001	0.009722	836000	42511368	2.374571	859.8857	362.1226	12.60388	321104.9	23.385241
5000	1800	1145	158	17.3	10	30	0.00001	0.008333	836000	42511368	2.944742	1003.2	340.675	15.63026	398207.1	24.857481
1000	1900	1217	165	3.3	10	64	0.00001	0.017778	836000	42511368	0.582214	470.25	807.6925	2.927661	74587.06	10.484589
2000	1900	1216	170	7	10	48	0.00001	0.013333	836000	42511368	1.27347	627	492.3554	6.403639	163143.4	17.199615
3000	1900	1212	173	10.7	10	41	0.00001	0.011389	836000	42511368	1.98748	734.0488	369.3365	9.994032	254614.7	22.928478
4000	1900	1210	171	14.3	10	32	0.00001	0.008889	836000	42511368	2.629797	940.5	357.6322	13.22392	336901.5	23.678864
5000	1900	1209	168	17.9	10	28	0.00001	0.007778	836000	42511368	3.236767	1074.857	332.0774	16.27607	414660.1	25.501055
1000	2000	1283	179	3.5	10	65	0.00001	0.018056	836000	42511368	0.66904	463.0154	692.059	3.196052	81424.78	12.236417
2000	2000	1280	182	7.3	10	43	0.00001	0.011944	836000	42511368	1.422139	699.907	492.1508	6.793659	173079.8	17.206765
3000	2000	1279	185	11.1	10	38	0.00001	0.010556	836000	42511368	2.199794	792	360.0337	10.50857	267723.4	23.520918
4000	2000	1276	183	14.8	10	30	0.00001	0.008333	836000	42511368	2.908171	1003.2	344.959	13.89254	353935.7	24.548779
5000	2000	1273	181	18.5	10	26	0.00001	0.007222	836000	42511368	3.603958	1157.538	321.1853	17.21636	438615.6	26.365848
1000	2100	1344	193	3.6	10	59	0.00001	0.016389	836000	42511368	0.743334	510.1017	686.235	3.381865	86158.66	12.340267
2000	2100	1344	195	7.6	10	45	0.00001	0.0125	836000	42511368	1.585522	668.8	421.8169	7.213476	183775.4	20.075827
3000	2100	1342	196	11.5	10	35	0.00001	0.009722	836000	42511368	2.415042	859.8857	356.0541	10.98745	279923.8	23.783811
4000	2100	1338	196	15.4	10	27	0.00001	0.0075	836000	42511368	3.243725	1114.667	343.6378	14.75762	375975.1	24.643162
5000	2100	1334	193	19.1	10	24	0.00001	0.006667	836000	42511368	3.973363	1254	315.6017	18.07717	460546.2	26.832311
1000	2200	1410	193	3.7	10	58	0.00001	0.016111	836000	42511368	0.763613	518.8966	679.5279	3.316213	84486.08	12.462068
2000	2200	1409	208	7.8	10	42	0.00001	0.011667	836000	42511368	1.736123	716.5714	412.7423	7.53962	192084.4	20.517217
3000	2200	1406	209	11.8	10	32	0.00001	0.008889	836000	42511368	2.644701	940.5	355.6168	11.48538	292609.3	23.813058
4000	2200	1402	208	15.9	10	25	0.00001	0.006944	836000	42511368	3.55669	1203.84	338.472	15.44596	393511.7	25.019272
5000	2200	1399	205	19.9	10	22	0.00001	0.006111	836000	42511368	4.396659	1368	311.1453	19.09377	486445.8	27.216616

Experiment Table B20

LOAD	RPM	RPM	V	I	Volume	Time	Volume	Time	Density	LHV	P	FCR	SFOC	Torque	BMEP	Eff Thermal
Watt	Engine	Generator	Volt	Ampere	ml	second	m3	hour	gr/m3	J/kg	Kw	gr/h	gr/kwh	Nm	N/m2	%
1000	1800	1155	147	3.1	10	78	0.00001	0.021667	842000	42484848	0.486683	388.6154	798.4973	2.583245	65812.5	10.6119452
2000	1800	1151	156	6.7	10	59	0.00001	0.016389	842000	42484848	1.120143	513.7627	458.658	5.945559	151473.1	18.4747871
3000	1800	1148	159	10.2	10	49	0.00001	0.013611	842000	42484848	1.742629	618.6122	354.9879	9.249623	235649.6	23.8701331
4000	1800	1147	159	13.8	10	38	0.00001	0.010556	842000	42484848	2.35973	797.6842	338.0405	12.52511	319098	25.0668489
5000	1800	1146	157	17.2	10	31	0.00001	0.008611	842000	42484848	2.906652	977.8065	336.403	15.42809	393056.3	25.1888609
1000	1900	1215	162	3.3	10	70	0.00001	0.019444	842000	42484848	0.572569	433.0286	756.2901	2.879162	73351.48	11.2041787
2000	1900	1215	169	6.9	10	54	0.00001	0.015	842000	42484848	1.248921	561.3333	449.4546	6.280193	159998.4	18.853092
3000	1900	1214	172	10.7	10	40	0.00001	0.011111	842000	42484848	1.972736	757.8	384.1365	9.919894	252725.9	22.0588486
4000	1900	1210	171	14.4	10	34	0.00001	0.009444	842000	42484848	2.648187	891.5294	336.6565	13.3164	339257.5	25.1698982
5000	1900	1208	169	17.9	10	28	0.00001	0.007778	842000	42484848	3.258729	1082.571	332.2066	16.3865	417473.6	25.5070447
1000	2000	1280	178	3.4	10	67	0.00001	0.018611	842000	42484848	0.647809	452.4179	698.3819	3.094628	78840.82	12.1332028
2000	2000	1278	182	7.3	10	48	0.00001	0.013333	842000	42484848	1.424365	631.5	443.3555	6.804291	173350.7	19.1124488
3000	2000	1277	185	11.1	10	38	0.00001	0.010556	842000	42484848	2.203239	797.6842	362.0506	10.52503	268142.7	23.4044861
4000	2000	1274	184	14.9	10	31	0.00001	0.008611	842000	42484848	2.948442	977.8065	331.635	14.08491	358836.7	25.5510094
5000	2000	1272	181	18.6	10	26	0.00001	0.007222	842000	42484848	3.626288	1165.846	321.4985	17.32303	441333.2	26.3566045
1000	2100	1345	193	3.6	10	63	0.00001	0.0175	842000	42484848	0.742781	481.1429	647.7586	3.37935	86094.6	13.0814315
2000	2100	1343	195	7.6	10	47	0.00001	0.013056	842000	42484848	1.586703	644.9362	406.4632	7.218847	183912.2	20.8471766
3000	2100	1340	197	11.5	10	35	0.00001	0.009722	842000	42484848	2.430987	866.0571	356.2574	11.06	281771.9	23.7850742
4000	2100	1339	196	15.5	10	29	0.00001	0.008056	842000	42484848	3.26235	1045.241	320.3952	14.84236	378133.9	26.4473637
5000	2100	1335	193	19.4	10	24	0.00001	0.006667	842000	42484848	4.032748	1263	313.1859	18.34735	467429.5	27.0561634
1000	2200	1409	207	3.8	10	58	0.00001	0.016111	842000	42484848	0.841737	522.6207	620.8834	3.655489	93129.69	13.6476652
2000	2200	1405	207	7.9	10	42	0.00001	0.011667	842000	42484848	1.754909	721.7143	411.2545	7.621204	194162.9	20.6042979
3000	2200	1403	210	12	10	33	0.00001	0.009167	842000	42484848	2.708173	918.5455	339.1753	11.76103	299631.9	24.9829792
4000	2200	1402	208	16.1	10	25	0.00001	0.006944	842000	42484848	3.601428	1212.48	336.6664	15.64025	398461.5	25.1691543
5000	2200	1396	205	19.9	10	22	0.00001	0.006111	842000	42484848	4.406108	1377.818	312.7064	19.1348	487491.2	27.0976492

Experiment Table Normal Continous Rating

	RPM	LHV	P	FCR	SFOC	Torque	BMEP	Eff Thermal
FUEL	Engine	J/kg	Kw	gr/h	gr/kwh	Nm	N/m2	%
DEX	1800	42537888	2.18993	712.52	325.362	11.62383	296136.5788	23.7397
DEX	1900	42537888	2.72513	844.8448	310.02	13.7033	349114.5511	24.863
DEX	2000	42537888	2.95559	915.7896	309.85	14.11906	359706.6937	25.236
DEX	2100	42537888	3.41204	1057.101	309.815	15.52338	395484.2075	25.3055
DEX	2200	42537888	3.93786	1216.877	309.02	17.1013	435684.3076	26.3044
B10	1800	42511367.8	2.45957	793.4032	322.578	13.05504	332599.0534	24.7294
B10	1900	42511367.8	2.75409	880.0777	319.553	13.84893	352824.597	26.1631
B10	2000	42511367.8	3.29146	1051.796	319.553	15.72354	400583.3671	26.173
B10	2100	42511367.8	3.54464	1093.032	308.362	16.12666	410853.6656	26.251
B10	2200	42511367.8	3.73065	1130.081	302.918	16.20143	412758.6207	26.5896
B20	1800	42484847.6	2.3743	733.6587	309	12.60244	321068.2894	25.6065
B20	1900	42484847.6	2.71459	837.0085	308.337	13.6503	347764.2789	26.3693
B20	2000	42484847.6	3.11837	954.4395	306.07	14.89667	379517.6471	26.3167
B20	2100	42484847.6	3.41951	1028.554	300.79	15.55737	396350.0435	27.0918
B20	2200	42484847.6	3.7288	1134.737	304.317	16.1934	412553.9369	26.7448

Simulation Table Normal Continous Rating

	RPM	LHV	P	FCR	SFOC	Torque	BMEP	Eff Thermal
FUEL	Engine	J/kg	Kw	gr/h	gr/kwh	Nm	N/m2	%
DEX	1800	42537888	4.09384	1619.695	395.642	21.729512	553595.7	20.5272181
DEX	1900	42537888	4.11395	1703.035	413.966	20.686976	527035.3	19.5724825
DEX	2000	42537888	4.15267	1792.571	431.667	19.837596	505395.9	18.7263236
DEX	2100	42537888	4.17849	1883.843	450.843	19.010419	484322.2	17.9500286
DEX	2200	42537888	4.21968	1977.612	468.664	18.325188	466864.8	17.2497265
B10	1800	42511368	4.0594	1598.9	393.876	21.546709	548938.5	20.53987
B10	1900	42511368	4.09476	1692.97	413.448	20.590479	524576.9	19.58447
B10	2000	42511368	4.1218	1784.822	433.02	19.690127	501638.9	18.72814
B10	2100	42511368	4.16964	1878.077	450.417	18.970155	483296.4	17.96199
B10	2200	42511368	4.21332	1989.378	472.164	18.297568	466161.2	17.25359
B20	1800	42484848	4.05311	1603.917	395.725	21.513323	548087.9	20.55275
B20	1900	42484848	4.0801	1694.282	415.255	20.516762	522698.8	19.59674
B20	2000	42484848	4.11539	1789.31	434.785	19.659506	500858.8	18.73983
B20	2100	42484848	4.16106	1890.428	454.314	18.931119	482301.9	17.97324
B20	2200	42484848	4.20257	1982.243	471.674	18.250883	464971.8	17.26436

CHAPTER V
CONCLUSION AND SUGGESTION

5.1 Conclusion

1. Soybean Oil have the potential to be used as biodiesel. In the process of making this biodiesel using transesterification method, the soybean oil can be converted into soybean oil biodiesel. From the properties test result, it can be concluded that soybean oil biodiesel meet the requirement of national biodiesel standard. Soybean Oil Biodiesel properties are : Flash Point value is 182 ^{o} C , Pour Point value is -7 ^{o} C, Density at 15 ^{o} C is 890 Kg/m3, Kinematic Viscosity at 40 ^{o} C is 5.58 (cSt), and Lower Heating Value is 42.27686 MJ/kg.

2. From the engine performance test , it can be concluded that soybean oil biodiesel mixture of B10 and B20 have lower performance than Pertamina Dex. The highest power, highest torque, and highest BMEP was produced by Pertamina Dex. For the SFOC, B10 have lower value than B20 and the highest value produced by Pertamina Dex. For thermal Efficiency, B20 produced the highest value among B10 and Pertamina Dex. It means soybean oil biodiesel . This result shows that the use of soybean oil biodiesel as the mixture or substitute for Pertamina Dex is better not be done. This is because the result shows the engine performance using B10 and B20 didn’t have better result compare to the engine performance using Pertamina Dex.

3. From the engine performance comparison result between experiment and simulation method, it can be concluded that simulation produce higher value in Power, Torque, SFOC, and BMEP than the Experiment.For thermal effciency, Experiment shows higher value than the simulation. For the highest Power that was produced at 2200 rpm for both method. In

Experiment, the torque, SFOC, BMEP , and thermal efficiency goes higher as the rpm goes higher. In Simulation, the torque, SFOC, BMEP , and thermal efficiency goes lower as the rpm goes higher.

5.2 Suggestion

1. There might be a research conducted focus on configuring the simulation by overhauling the engine and break down all the component to make the drawing of the engine and to make the simulation's result more valid.
2. If there is any follow up experiment for engine performance using load from electric dynamometer, it is advisable to make varable control for rpm generator.

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