Performance and Emission Analysis of Four-Stroke Diesel Engine Single Cylinder on Toroidal Piston Modification with B30 Fuel

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Abstract*— improvement of the performance of the diesel engine can be done by expanding the combustion chamber. One of the objectives of this research is to obtain optimal piston performance by modifying the piston crown to be 1mm deeper than the standard piston using B30 fuel. This research is also proof of previous research with a simulation that concluded that the performance of a diesel engine using a modified toroidal combustion chamber (TCC) +1mm piston has better performance than a standard piston. This research will analyze the comparison of the performance of a diesel engine using a standard piston and a modified piston on the diesel engine, using an experimental method with B30 biodiesel fuel with engine speed (RPM) variation of 1900 and 2100, also the dummy loads used are 1000, 2000, 3000, and 4000 Watts (W). From the results of the performance tests, it is concluded that the standard piston produces better performance than the modified piston with a very small difference in value in terms of torque, power, and SFOC. The level of NOx emissions produced by the standard RPM 1900 with 1000 W load is 1,483 g/KWh, at a load of 2000 W is 1,011 g/KWh, at a load of 3000 W is 1.375 g/KWh, at a load of 4000 W is 2,372 g/KWh, for standard piston RPM 2100 NOx emission levels produced at 1000 W load is 1,902 g/KWh, at 2000 W load is 1,450 g/KWh, at 3000 W load is 1.368 g/KWh, at 4000 W load is 1,066 g/KWh. The level of NOx emissions produced using a modified piston at 1900 RPM at 1000 W load is 1.865 g/KWh, at 2000 W load is 1.326 g/KWh, at 3000 W load is 1,250 g/KWh, at 4000 W load is 0.857 g/KWh, for RPM 2100 uses a modified piston at a 1000 W load is 1,970 g/KWh, at a 2000 W load is 1,583 g/KWh, at a 3000 W load is 1,465 g/KWh, at a 4000 W load is 1,226 g/KWh. NOx emission levels using standard pistons at RPM 1900 with B30 fuel tend to be smaller at low loads and larger at high loads compared to modified pistons, while NOx emission levels using standard pistons at RPM 2100 fueled by B30 are smaller than using a modified piston.

Keywords—diesel engine, emission, performance, piston, toroidal.

I. Introduction

With the development of diesel engine technology, in terms of increasing the potential for engine performance, the combustion engine must use fuel of good quality to maximize engine performance. The amount of power that can be removed from this heat energy depends on the size of the cylinder and combustion chamber. The power generated by the fuel will move the piston and the piston will drive all the mechanisms in the engine [1]. The piston is one of the components of a diesel engine that is used to compress the air in the combustion chamber, burn, and later will move all existing mechanisms. The piston consists of two parts, namely the piston head and connecting rod. The piston head consists of a piston crown, piston ring, and piston pin. One way to enlarge the combustion chamber is to reduce its thickness [2].

In Indonesia, there are regulations that regulate the use of diesel fuel. Referring to the Regulation of the Minister of Mineral Energy and Resources No. 12 Year 2015 that starting from 2020, Indonesia in certain fields has been required to use B30 biodiesel [3].

The piston consists of two major parts, namely the piston head and connecting rod. Based on the two research that has been carried out, it can be concluded that there is a way to increase the volume of the combustion chamber, namely by reducing the thickness of the piston crown [4]. Therefore, the author will experiment with the effect of modification of the piston surface on the performance of a diesel engine including torque, power, and specific fuel consumption on a four-stroke single-cylinder diesel engine.

Previous research entitled Analysis of the Effect of Modified Pistons on the Performance of a Simulation-Based Four-stroke Single Cylinder Diesel Engine Using B30 Fuel showed that a modified piston with a toroidal type with an added depth of 0.1 mm resulted in better performance compared to the piston. Standard [5].

A. *Diesel Engine*

Diesel engines are internal combustion engines that work processes differently from gasoline engines. The difference lies in the cycle process, where the fuel from the gasoline engine is ignited by a spark plug while the diesel engine fuel is ignited by compression [6].

The working principle of the diesel engine is that the air first enters the combustion chamber due to the intake

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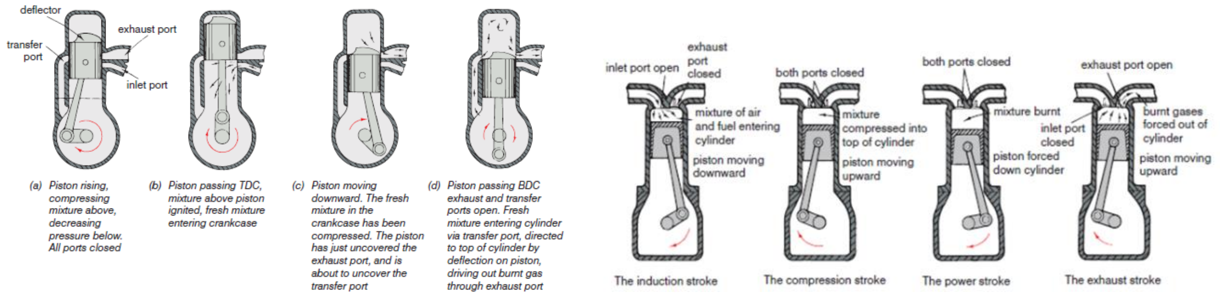
stroke and then is compressed during the compression stroke until it reaches a high temperature and pressure. When the piston is a few degrees before Top Dead Center (TDC) fuel is injected into the combustion chamber, because the compressed air already has a high temperature and pressure, the fuel will burn by itself. Therefore, diesel engines have a higher compression ratio than gasoline engines. The same thing with gasoline engines, and diesel engines there are two types, namely two-stroke and four-stroke diesel [2].

Diesel engines are also called compression ignition engines because the ignition process occurs due to the ignition process itself. Diesel engines are different from other piston fuel engines, for example, gasoline engines where the process of ignition occurs because of the jump of electric sparks from the spark plug. In a diesel engine during the intake stroke, only fresh air is sucked into the cylinder, then at the end of the compression stroke, the fuel is sprayed into the combustion chamber. Because the temperature in the combustion chamber has reached about 450-600 C where the temperature has exceeded the flash point of the fuel, the fuel that is sprayed will immediately burn by itself (combustion process), resulting in a business or work process. This will happen when a high compression ratio of 14-25 is used [7]. A low compression ratio is usually used in large diesel engines with low speeds. Meanwhile, a high compression ratio is widely used in small-sized diesel engines with a high speed of ± 4000 RPM [8]. Diesel engine working processes are shown in figure 1 and figure 2.



(a) (b)

Figure. 1. (a) Four Stroke Combustion Cycle, (b) Two Stroke Combustion Cycle

B. Biodiesel

Biodiesel is a diesel engine fuel made from renewable materials or specifically a diesel engine fuel consisting of alkyl esters of fatty acids. Biodiesel can be made from vegetable oil, animal oil or from used or recycled cooking oil [9]. Biodiesel is a diesel engine fuel that is environmentally friendly and renewable. Biodiesel is composed of various kinds of fatty acid esters that can be produced from plant oils and animal fats. Plant oils that are often used include palm oil, coconut oil, jatropha oil, and kapok seed oil, while animal fats such as lard, chicken fat, beef fat, and also fat derived from fish [10].

C. Piston Crown

The piston crown is part of the piston located at the very top of the piston which functions to withstand pressure due to combustion in the combustion chamber [11]. This piston crown is designed with a strong material because the pressure that occurs in the combustion chamber is very large and the surface shape of the piston crown also varies, each with its own characteristics, the following types of surfaces of the piston crown:

1. Hemispherical Combustion Chamber (HCC)

This piston has a surface that gives a small squish (squish is the angle formed between the piston head and the fuel which aims to direct the combustion gases by pressing the parallel parts facing each other when the piston reaches TDC) which is obtained from several variations in the ratio of the depth to the surface diameter [11]. The HCC piston is shown in figure 2.

2. Toroidal Combustion Chamber (TCC)

These pistons provide relatively large compressed air. Due to the strong squish, the inlet requirement is relatively small and there is better oxygen utilization [11]. TCC piston is shown in figure 3.

3. Spherical Combustion Chamber (SCC)

This piston has a shallow surface depth so it is generally used in large engines at low speeds [11]. TCC piston is shown in figure 4.

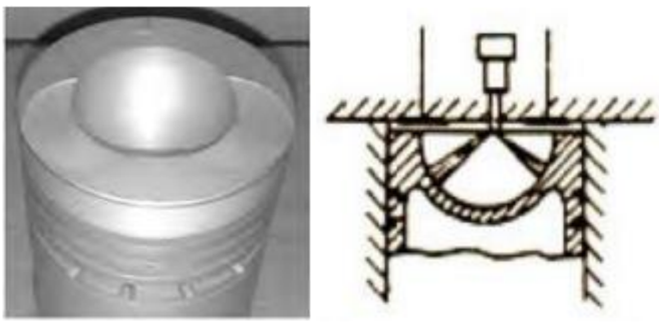


Figure. 2. Piston HCC

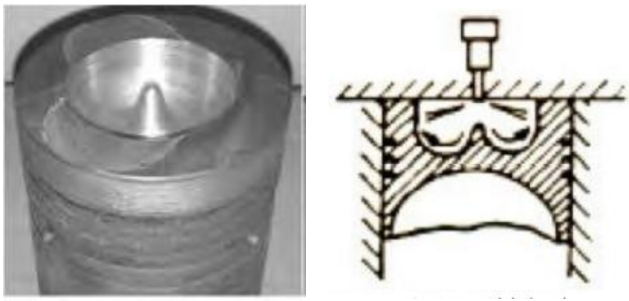


Figure. 3. TCC Piston

Figure. 4. TCC Piston

D. Engine Performance

Engine performance is the ability of a combustion engine to convert the input energy, namely fuel, to produce power. In a combustion engine, it is not possible to convert all fuel energy into power. From the experience, it can be seen that the useful power is only 25%, which means the engine is only able to produce 25% of the useful power that can be used as a drive from 100% of the fuel. The other energy is used to drive accessories or auxiliary equipment, friction losses, and some are wasted into the environment as flue gas heat and through cooling water. In the second law of thermodynamics, it is explained that "it is impossible to make an engine that converts all the incoming heat or energy into work" [12].

1. Torque

Torque is a measure of the engine's ability to do work, namely moving or moving a car or motorcycle from rest to running. For this reason, torque is related to acceleration and engine rotation [13].

$$T = \frac{P\ x\ 60000}{2\pi\ x\ RPM} \quad (1)$$

Where :
T = Torque of rotating object (Nm)
P = Engine Power (kW)
RPM = Revolution per Minute

2. Power

Power describes the amount of engine work output related to time, or the average work produced [13].

$$P = \frac{V\ x\ I\ x\ Cos\theta}{\mu\ Generator\ x\ \mu\ Slip} \quad (2)$$

Where :
P = Engine Power (kW)
V = Voltage (Volts)
I = Ampere (A)
$\cos\theta$ = 0.9
μ *Generator* = generator efficiency
μ slip = slip efficiency

3. SFOC

Specific Fuel Oil Consumption (SFOC) is the amount of fuel consumed by an engine that produces one horsepower for one hour. The greater the SFOC value, the more wasteful the use of fuel with the same power gain. On the other hand, the smaller the SFOC value, the more efficient the fuel consumption [14]. Specific Fuel Oil Consumption (SFOC) can be calculated by the following formula:

$$SFOC = \frac{V\ Fuel\ x\ \rho\ \text{Fuel}}{P\ x\ (\frac{t}{3600})} \quad (3)$$

Where :
SFOC = Specific Fuel Consumption (gr/kWh)
V Fuel = Fuel Volume (mL)
t = Fuel consumption time (s)
P = Engine Power (kW)

E. Emission

Emissions are residual combustion products from internal combustion engines that can pollute the environment. One of the biggest emitters is from transportation used by humans on road and at sea. Many kinds of exhaust gas emissions such as NOx, SOx, COx, and particulate matter.

F. Emission Regulation

MARPOL Annex VI regulation 13 discusses the regulation of NOx levels both released by the engine and as a result of fuel characteristics. In this regulation, several regulations regarding NOx levels are explained [15]:

1. Tier I
   The operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):
   a. 17.0 g/kWh when n is less than 130 rpm;
   b. $45 \cdot n(-0.2)$ g/kWh when n is 130 or more but less than 2,000 rpm;
   c. 9.8 g/kWh when n is 2,000 rpm or more.

2. Tier II
   The operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):
   a. 14.4 g/kWh when n is less than 130 rpm;
   b. $44 \cdot n(-0.23)$ g/kWh when n is 130 or more but less than 2,000 rpm;
   c. 7.7 g/kWh when n is 2,000 rpm or more.

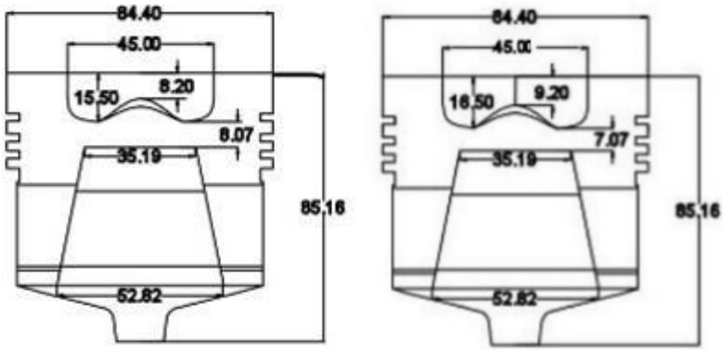
3. Tier III
   In an emission control area designated for Tier III NOX control under paragraph 6 of this regulation (NOX Tier III emission control area), the operation of a marine diesel engine that is installed on a ship is prohibited except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):
   a. 3.4 g/kWh when n is less than 130 rpm;
   b. $9 \cdot n(–0.2)$ g/kWh when n is 130 or more but less than 2,000 rpm;
   c. 2.0 g/kWh when n is 2,000 rpm or more;

II. METHOD

The research method used is experimental by modifying the piston crown using B30 fuel with variations in the load of 1000, 2000, 3000, and 4000 Watts using RPM 1900 and 2100.

A. Piston Modification

This stage is about a modified piston based on a design that has been made with the TCC+1 type by turning the standard piston crown following the existing design [5]. The piston design can be seen in figure 5.



(a) (b)

Figure. 5. (a) Standard Piston Design, (b) Piston Design with TCC+1

B. Engine Set Up

Before testing the engine, the engine setup process is carried out first. Engine setup is the process of preparing test equipment that will be needed and calibration, such as the diesel engine with 8.5 horsepower (HP), electric dynamo, dummy load, fuel burette, emission gas analyzer, and tachometer to measure RPM.

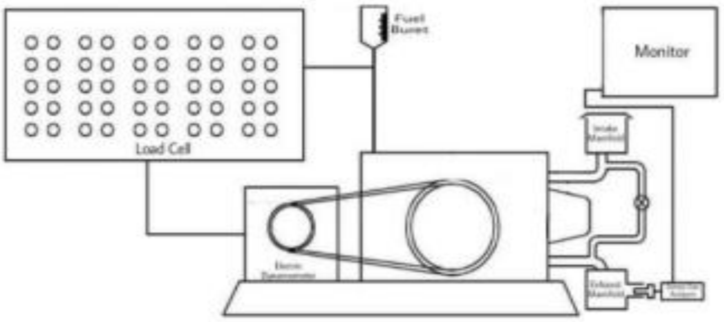


Figure. 6. Engine Setup

C. Engine Performance and Emission Test

Performance and emission of UHC and NOx testing were carried out on a diesel engine 8.5 HP. The data was taken in the form of engine speed, voltage, current, and time spent on fuel per 30 mL. The variables used during the performance test are as follows:

a. Fixed Variable :
- B30 as fuel
- Engine RPM: 1900 and 2100

b. Variable Change: Test load of 1000 Watt, 2000 Watt, 3000 Watt, and 4000 Watt.

D. Data Analysis

After getting the value of voltage, current, and time, then proceed with processing the torque, power, SFOC, NOx and UHC emission data. From the results of data collection, it is then converted into a graph and analyzed based on fluctuations in performance and emission that occur.

E. Conclusion

At this stage, conclusions and recommendations will be written based on the results obtained from the research that has been done. The conclusion here will explain the final results obtained from this research. It is expected that the conclusions will be able to answer the problem.

III. Results and Discussion

A. Results of Performance Based on Simulation

One of the things behind this research is to prove the simulation test which refers to the Final Project entitled "Analysis of the Effect of Modified Pistons on the Performance of a Single Cylinder Four-stroke Diesel Engine Based on Simulation Using B30 Fuel" [5]. The aspects of the research carried out in the simulation test are the power, torque, and SFOC of the standard piston, modified TCC -1 piston, and modified TCC +1 piston at RPM 1600, 1700, 1800, 1900, 2000, 2100, and 2200. For research, This analysis is the performance at RPM 1900 and 2100 using B30 fuel.

1. Performance Analysis between Torque and Power

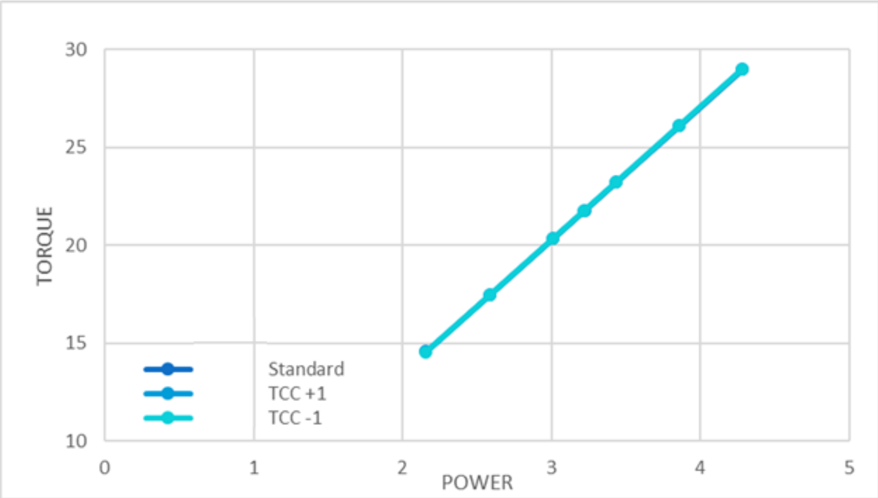


Figure. 7. Torque vs Power based on simulation at 1900 RPM

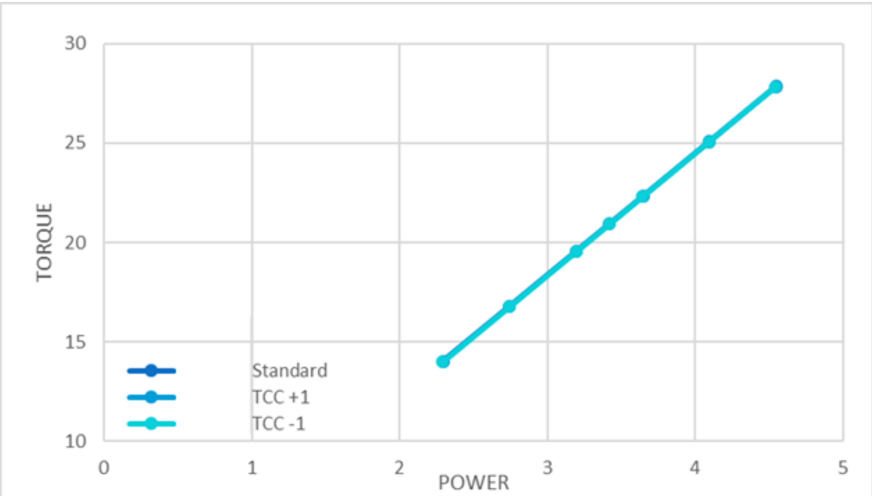


Figure. 8. Torque vs Power based on simulation at 2100 RPM

Figures 7 and 8 are graphs of comparison of torque performance against power on standard pistons, modified TCC +1 pistons, and modified TCC -1 pistons. From the graph, it can be concluded that the torque is directly proportional to the power produced by the diesel engine. From the three types of pistons tested at RPM 1900, the one with the highest torque was the modified TCC +1 piston of 28.989 Nm and the lowest torque was owned by the modified TCC -1 piston with a value of 14,552. At RPM 2100, it can also be concluded that the piston with the largest torque is the modified TCC +1 piston with a value of 27.852 Nm and the smallest torque is owned by the modified TCC -1 piston with a value of 14.021 Nm. From the graph, it can also be concluded that the torque tested in the simulation has a very slight difference in value at each point.

2. Performance Analysis between SFOC and Power

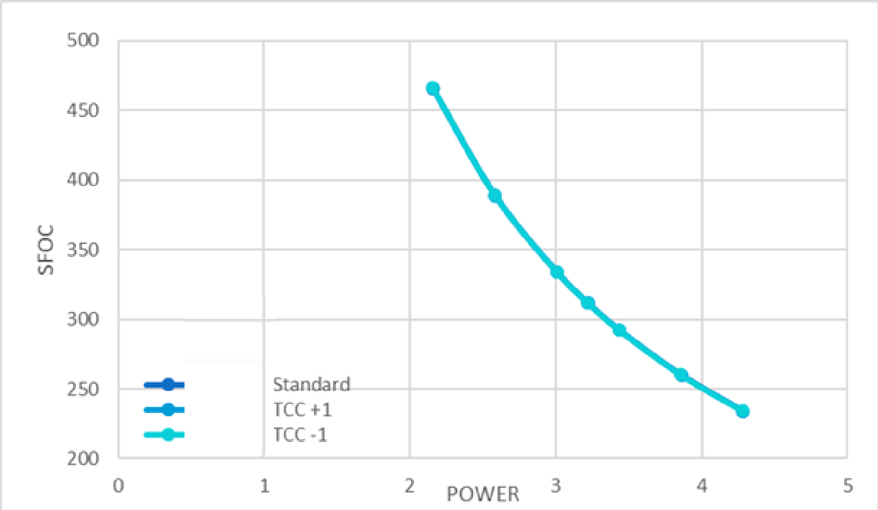


Figure. 9. SFOC vs Power based on Simulation at 1900 RPM

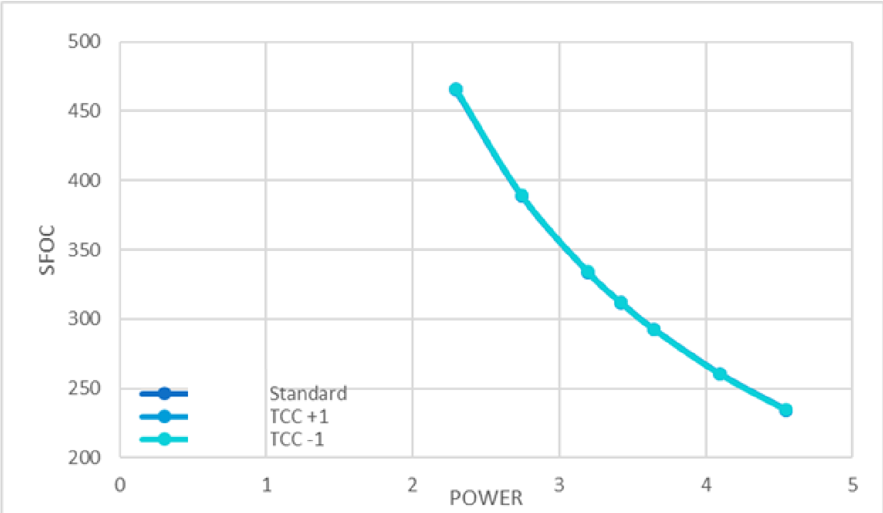


Figure. 10. SFOC vs Power based on Simulation at 2100 RPM

Figures 9 and 10 are graphs of the performance comparison of SFOC to power on standard pistons, modified TCC +1 pistons, and modified TCC -1 pistons. From the graph, it can be concluded that SFOC is inversely proportional to the power generated by the engine. The greater the power produced by the engine, the smaller the SFOC produced by the engine. At RPM 1900 the highest SFOC value is owned by the modified TCC -1 piston with a value of 466,283 g/kWh and the lowest value is owned by the modified TCC +1 piston with a value of 233.978 g/kWh. At 2100 RPM the highest SFOC value is owned by the modified TCC -1 piston with a value of 466,040 g/kWh and the lowest value is owned by the modified TCC +1 piston with a value of 234.383 g/kWh.

3. Performance Analysis between Power and RPM

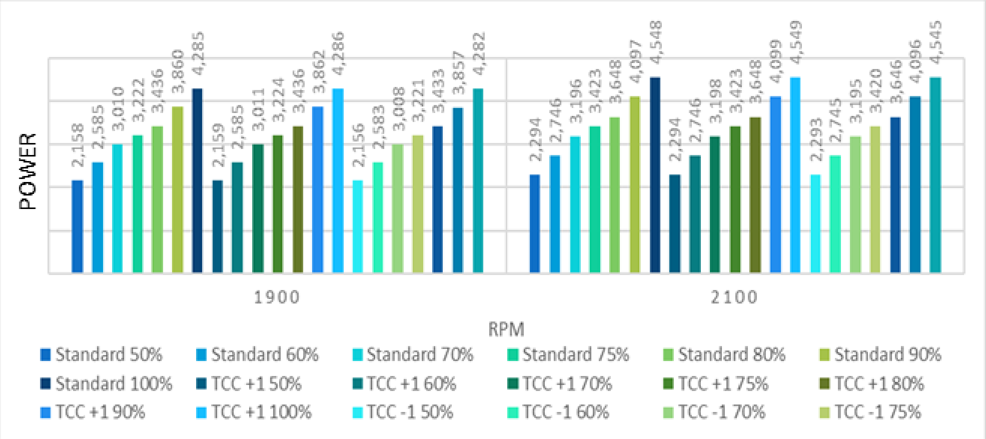


Figure. 11. Power vs RPM based on Simulation at 1900 and 2100 RPM

Figure 11 is a graph of the performance comparison of power to RPM on standard pistons, modified TCC+1 pistons, and modified TCC -1 pistons. Based on the graph, the largest power is owned by the modified TCC +1 piston with 2100 RPM and a 100% load of 4,549 kW, and the lowest power is owned by the modified TCC -1 piston with a 50% load of 2,156 kW.

B. Results of Performance Testing Based on Experiment

1. Performance Analysis between Torque and Power

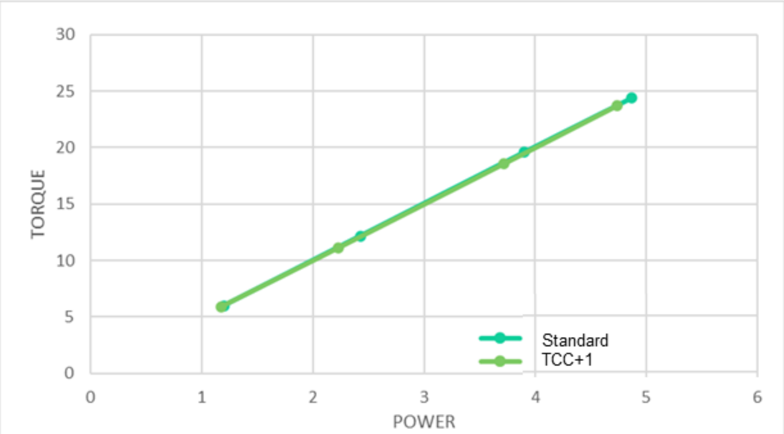


Figure 12. Torque vs Power based on Experiment at 1900 RPM

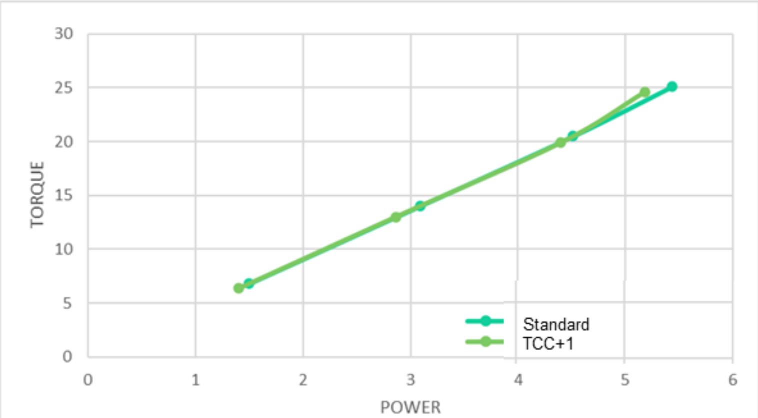


Figure 13. Torque vs Power based on Experiment at 2100 RPM

In testing the performance of a diesel engine, the RPM value at each additional load needs to be measured first with the RPM value taken close to the RPM control value, namely at 1900 and 2100 RPM by using a load variation on the generator of 1000, 2000, 3000, and 4000 Watts on each RPM. After that, the aspects taken are the actual RPM data I and II on the Engine and Generator, voltage, current, time, and fuel volume.

Figures 12 and 13 are graphs of the ratio of torque to power generated by the engine. From the graph, it can be concluded that the engine torque is directly proportional to the power produced by the diesel engine. The torque value using a standard piston is better than using a modified piston. At 1900 RPM the highest torque value is owned by the standard piston with a value of 24.380 Nm and the lowest torque is owned by the modified piston with a torque value of 5.917 Nm. While at 2100 RPM the highest torque value is owned by the standard piston with a value of 25.097 Nm and the lowest torque is owned by the modified piston with a torque value of 6.353 Nm.

2. Performance Analysis between SFOC and Power

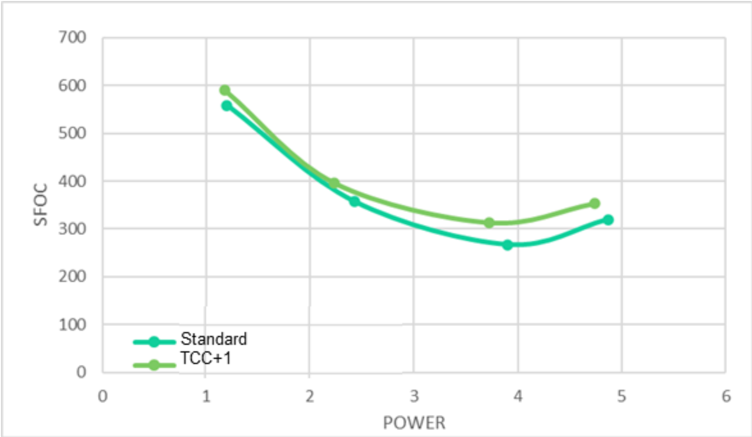


Figure. 14. SFOC vs Power based on Experiment at 1900 RPM

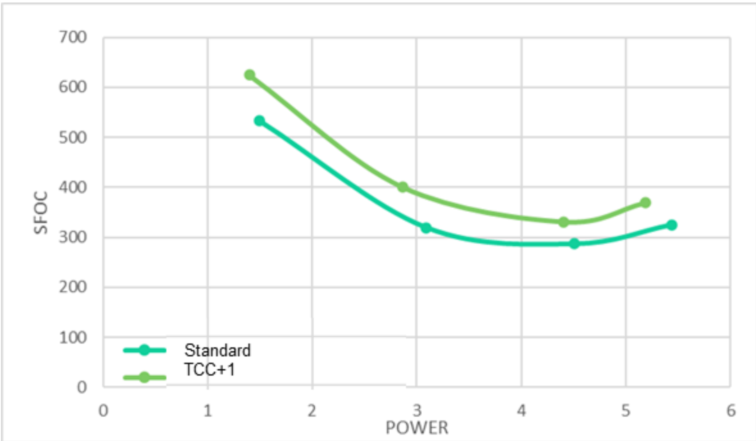


Figure. 15. SFOC vs Power based on Experiment at 2100 RPM

Figures 14 and 15 are graphs of the comparison of SFOC to the power generated by the engine. From the graph, it can be concluded that the greater the power, the lower the SFOC, but after meeting the optimal point of the engine, the SFOC will increase again as the engine power increases. The SFOC value using standard pistons is better than using modified pistons. At 1900 RPM the lowest SFOC value is owned by a standard piston with a value of 267.185 g/kWh and the highest SFOC is owned by a modified piston with an SFOC value of 590.218 g/kWh. While at RPM 2100 the lowest SFOC value is owned by the standard piston with a value of 286.743 g/kWh and the highest SFOC is owned by the modified piston with an SFOC value of 624,959 g/kWh.

3. Performance Analysis between Power and RPM

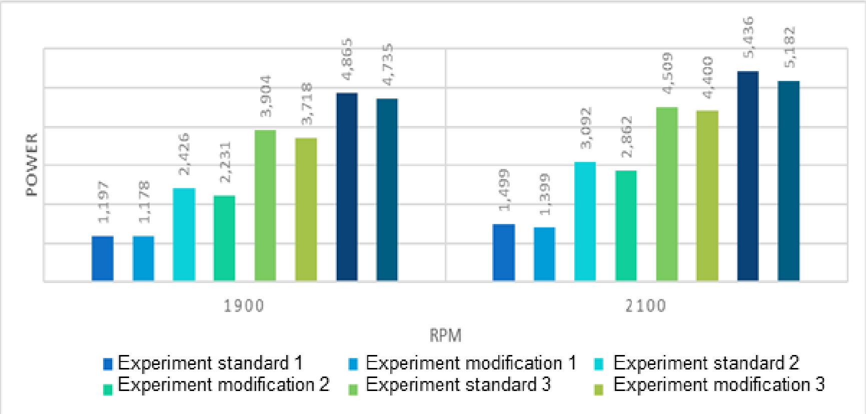


Figure. 16. Power vs RPM between the standard piston and modified piston at each experiment

Figure 16 is a graph of the comparison of power to engine RPM. Based on the graph, it can be concluded that the RPM is directly proportional to the power generated by the engine. The greater the RPM on the engine, the greater the power generated by the engine. The highest power value is found in the standard piston with RPM 2100 with a value of 5,436 kW and the lowest power is found in the modified TCC -1 piston with RPM 1900 with a value of 1,178 kW.

C. Performance Analysis between Simulation and Experiment

After performing a performance test based on simulations and experiments, the analysis of the two test results was then carried out. The analysis carried out is torque, SFOC, and power with engine power at RPM 1900 and 2100. However, power comparisons were carried out at the highest load from simulation and experiment due to differences in the type of load used. The simulation uses a real load from the engine while the experiment uses a generator load.

1. Performance Analysis between Torque and Power

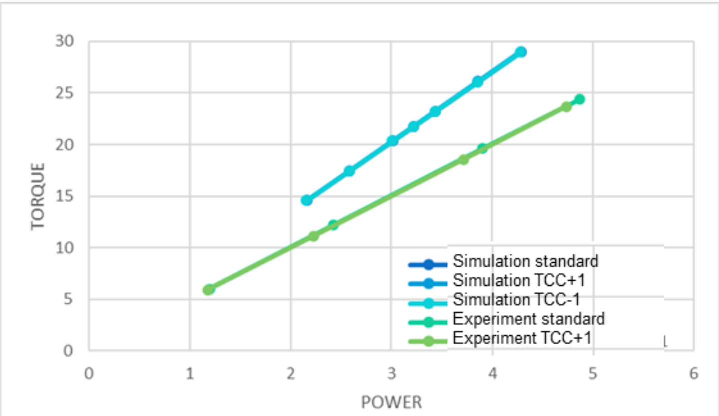


Figure. 17. Torque vs Power based on Simulation and Experiment at 1900 RPM

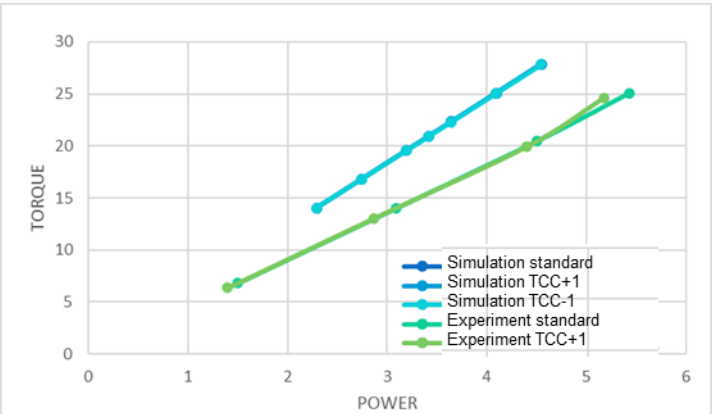


Figure. 18. Torque vs Power based on Simulation and Experiment at 2100 RPM

Figures 17 and 18 are graphs of the ratio of torque to power generated by the engine. In comparison between the simulation and experiment, it was found that both have the same fluctuation trend. At 1900 RPM the highest torque is owned by the TCC +1 piston simulation with a value of 28.989 Nm and the lowest torque value is owned by the TCC +1 modified piston experiment with a value of 5.917 Nm. While at 2100 RPM the highest torque is owned by the modified TCC +1 piston simulation with a value of 27.852 Nm and the lowest torque value is owned by the TCC +1 modified piston experiment with a value of 6.353 Nm.

2. Performance Analysis between SFOC and Power

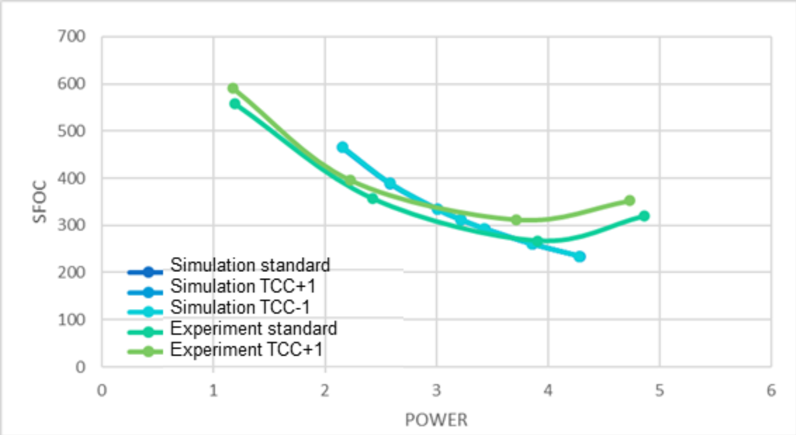


Figure. 19. SFOC vs Power based on Simulation and Experiment at 1900 RPM

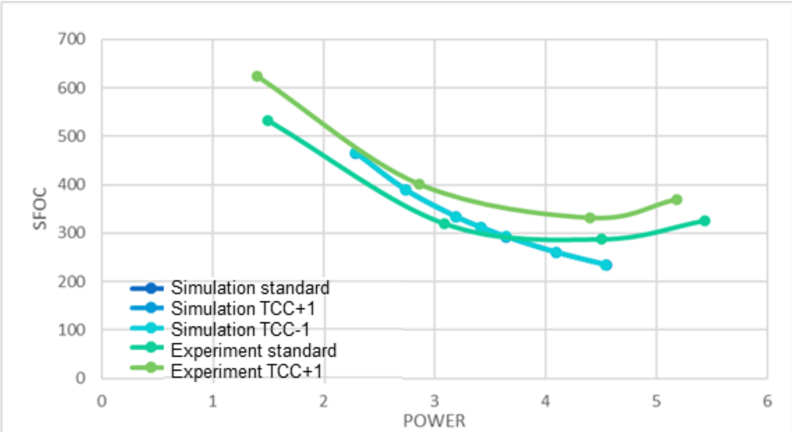


Figure. 20. SFOC vs Power based on Simulation and Experiment at 2100 RPM

Figures 19 and 20 are a comparison of the SFOC to the power generated by the engine. In comparison between the simulation and experiment, it was found that both have the same fluctuation trend. At 1900 RPM, the highest SFOC value is owned by the TCC +1 modified piston experiment with a value of 590.218 g/kWh, and the lowest SFOC value is owned by the TCC +1 modified piston simulation with a value of 233.978 g/kWh. While at RPM 2100 the lowest SFOC value is owned by the modified TCC +1 piston simulation with a value of 234.383 and the highest SFOC value is owned by the TCC +1 modified piston experiment with a value of 624,959 g/kWh.

However, there is an anomaly in the simulation in the previous research due to the graph trend that continues to decrease until the engine load reaches 100%. It is said to be an anomaly because normally in the Project Guide each diesel engine has fuel consumption at X% load and it shows that there are optimal points for these fluctuations. Meanwhile, the simulation test results do not show an optimal point due to the downward trend of the graph.

3. Performance Analysis between Power towards RPM

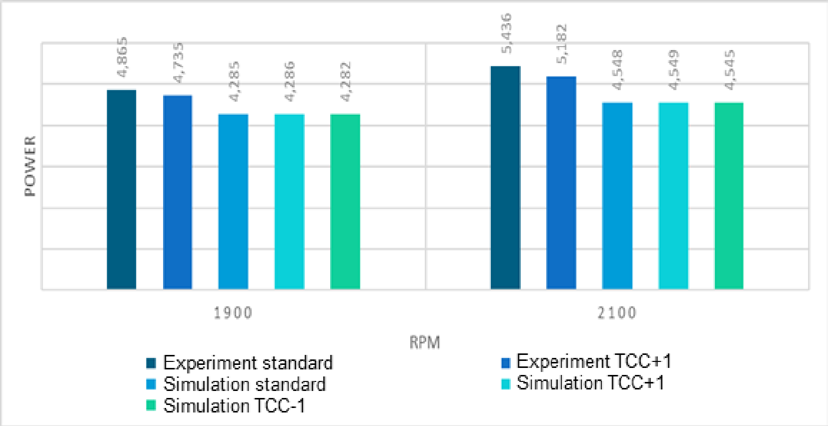


Figure. 21. Power vs RPM based on simulations and experiments at the highest load

Figure 21 is a comparison of power to engine RPM. In the comparison between the simulation and experiment, it is concluded that both have the same fluctuation trend. Based on the graph, it can be concluded that the highest power is found in the standard piston experiment with a value of 5,436 kW, and the lowest power is found in the modified piston experiment with a value of 4,735 kW.

D. NOx Emission Analysis

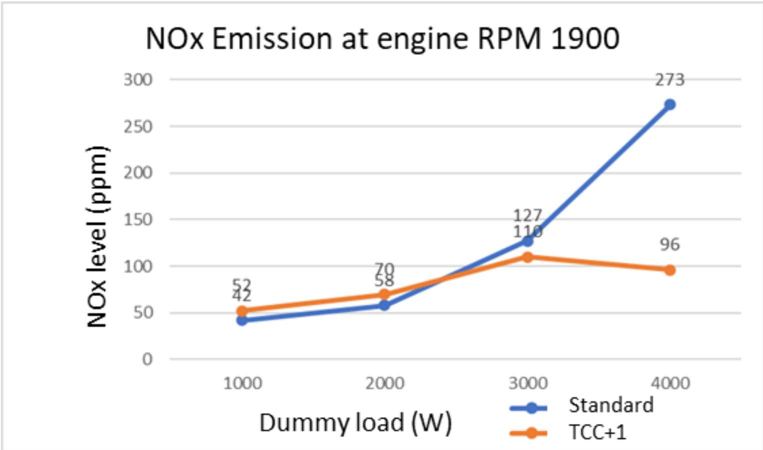


Figure. 22. Graphic of NOx Emission Level (ppm) at 1900 RPM vs engine load

Based on figure 22, at 1900 RPM the standard piston has a tendency for higher NOx emission levels at an increase in load carried out from 1000 to 4000 Watts and the standard piston produces the highest emission of 273 ppm at 4000-Watt load and produces the lowest emission of 42 ppm. at 1000-Watt load, while on the modified piston the emission levels have a fluctuating tendency, namely at 1000 load it produces 52 ppm emission levels and at 2000-Watt load produces 70 ppm emission levels. These results show higher emission levels compared to emission levels produced by standard pistons. at the load of 1000 and 2000 Watt which is worth 42 and 58 ppm, but at load of 3000 and 4000 Watt the modified piston produces lower emission levels than the standard piston which is valued at 110 and 96 ppm.

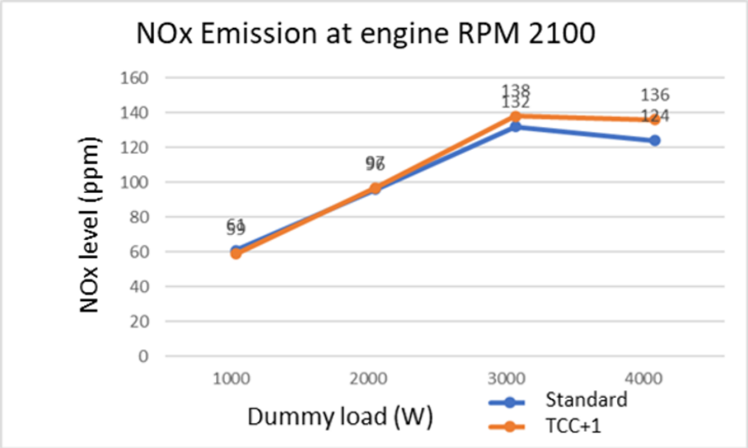


Figure. 23. Graphic of NOx Emission Level (ppm) at 2100 RPM vs engine load

Based on figure 23, at RPM 2100 standard pistons and modified pistons have a tendency for higher emission levels to increase at load from 1000 to 3000 Watts but experience a decrease at 4000 Watt load. The standard piston produces higher emissions at 1000-Watt load, which is 61 ppm compared to the emission produced by the modified piston, while for 2000 to 4000 Watt load the standard piston produces lower emissions than the standard piston. In the test conditions of 2100 RPM, the highest emission level is located on the modified piston with a 4000-Watt load, which is 136 ppm, while for 1000 Watt load the modified piston has lower emissions than the standard piston, which is 59 ppm

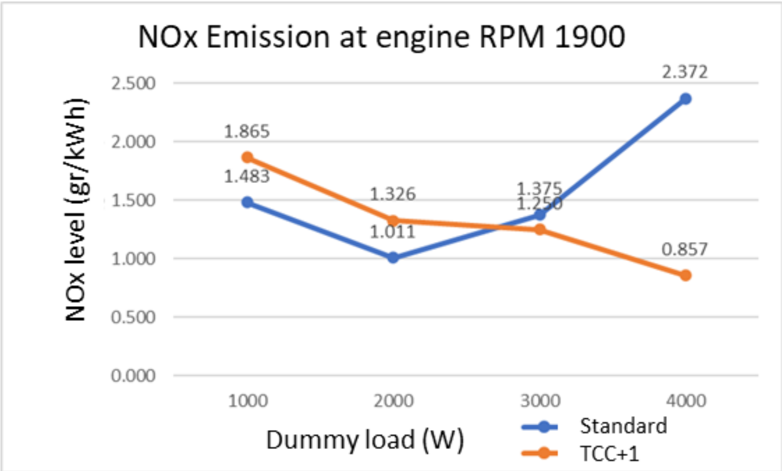


Figure. 24. Graphic of NOx Emission Level (g/kWh) at 1900 RPM vs engine load

Based on figure 24, at 1900 RPM the modified piston and the standard piston produce NOx emission levels which tend to fluctuate. The modified piston produces a higher emission level than the standard piston at a certain point, which is 1,865 g/kWh at 1000 Watt load and 1,326 g/kWh at 2000 Watt load, while at 3000 and 4000 Watt loads the modified piston produces lower emissions than the standard piston that is 1,250 g/kWh for 3000 Watt load and 0.857 g/kWh for 4000 Watt load. In the 1900 RPM test conditions, the largest emission was produced by a standard piston with a 4000 Watt load with an emission value of 2,372 g/kWh, and the lowest emission was produced by a modified piston with 4000 Watt load, 0.857 g/kWh.

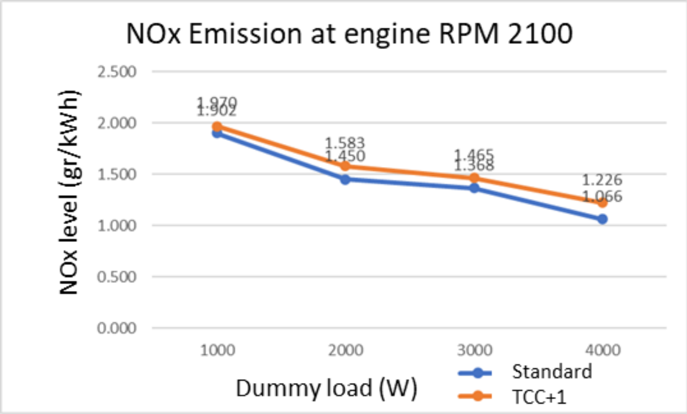


Figure. 25. Graphic of NOx Emission Level (g/kWh) at 2100 RPM vs engine load

Based on figure 25, at RPM 2100 the standard piston and the modified piston have emission values that tend to decrease at each load from 1000 to 4000 Watt. In the 2100 RPM test conditions the modified piston has a higher emission value than the standard piston at each load, at 1000 Watt load produces 1,970 g/kWh emissions, at 2000 Watt load produces 1,583 g/kWh emissions, at 3000 Watt load produces 1,465 g/kWh, at 4000 Watt load it produces 1,226 g/kWh. The standard piston produces 1,902 g/kWh emission at 1000 Watt load, at the 2000 Watt load produces 1,450 g/kWh. emission, at 3000 Watt load produces 1,368 g/kWh emission, at 4000 Watt load produces 1,226 g/kWh. Standard piston conditions with 4000 Watt load produce the lowest emission for the 2100 RPM test.

E. Unburned hydrocarbon (UHC) emission analysis

Based on the data from table 1, table 2, table 3, and table 4 of unburned hydrocarbon (UHC) emission test results, the results for standard and modified pistons are 0 ppm. This is caused by the limitations of the emission test equipment used to measure UHC emission levels belonging to a third-party Surabaya K3 Laboratory. The emission test equipment used can only read emission levels of at least 1 ppm so if the emission test results obtained are 0 ppm, it can be assumed that the emission levels of Unburned Hydrocarbon are below 1 ppm. As a result, UHC emission values cannot be graphed, so it is not possible to analyze the UHC emissions produced using standard pistons and modified piston

TABLE 1.
RESULT UHC TEST AT 1900 RPM WITH STANDARD PISTON

Engine rotation		Load (Watt)	Alternator		Watt	UHC (ppm)
RPM Control	RPM Actual		Voltage (Volt)	Current (A)		
1900	1907	1000	218	4.48	1.197	0
1900	1902	2000	217	9.09	2.426	0
1900	1901	3000	227	14.12	3.904	0
1900	1905	4000	218	18.40	4.865	0

TABLE 2.
RESULT UHC TEST AT 1900 RPM WITH MODIFICATION PISTON TCC+1

Engine rotation		Load (Watt)	Alternator		Watt	UHC (ppm)
RPM Control	RPM Actual		Voltage (Volt)	Current (A)		
1900	1901	1000	217	4.44	1.178	0
1900	1916	2000	220	9.12	2.231	0
1900	1914	3000	219	13.84	3.718	0
1900	1909	4000	212	18.22	4.735	0

TABLE 3.
RESULT UHC TEST AT 2100 RPM WITH STANDARD PISTON

Engine rotation		Load (Watt)	Alternator		Watt	UHC (ppm)
RPM Control	RPM Actual		Voltage (Volt)	Current (A)		
2100	2158	1000	253	4.87	1.499	0
2100	2170	2000	255	10	3.092	0
2100	2137	3000	249	14.94	4.509	0
2100	2070	4000	231	19.14	5.436	0

TABLE 4.
RESULT UHC TEST AT 2100 RPM WITH MODIFICATION PISTON TCC+1

Engine rotation		Load (Watt)	Alternator		Watt	UHC (ppm)
RPM Control	RPM Actual		Voltage (Volt)	Current (A)		
2100	2103	1000	243	4.77	1.399	0
2100	2103	2000	244	9.17	2.862	0
2100	2110	3000	244	14.78	4.400	0
2100	2012	4000	221	18.74	5.182	0

IV. Conclusion

Based on the standard piston performance test and the modified piston for the diesel engine 8.5 HP using B30 fuel, the following conclusions can be taken based on experimental, it can be concluded that the best torque is found in the standard piston at 2100 RPM with a torque of 25.097 Nm. While the lowest torque is owned by a standard piston at 1900 RPM with a torque of 5,917 Nm. The torque generated using the standard piston has better results than the modified piston at both RPM but with an insignificant difference in value. It can be concluded that the lowest SFOC is found in the standard piston at 1900 RPM with an SFOC of 267,185 g/kWh. While the highest SFOC is owned by a modified piston at 2100 RPM with an SFOC of 624,959 g/kWh. The SFOC produced using the standard piston has better results than the modified piston at both RPM. It can be concluded that the highest power is found in the standard piston 4 at 1900 RPM with a power of 5,436 kW. While the lowest power is owned by the standard 1 piston at 2100 RPM with a power of 1,178 kW. The power generated using the standard piston has better results than the modified piston at both RPM but with an insignificant difference in value. NOx emission levels using standard pistons at RPM 1900 with B30 fuel have a tendency to be smaller at low loads and larger at high loads compared to modified pistons, while NOx emission levels using standard pistons at RPM 2100 fueled by B30 are smaller than using modified pistons on each load. UHC emission levels cannot be compared because emission levels using standard and modified pistons at RPM 1900 and RPM 2100 are 0.

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