Performance Evaluation of Different Octane Numbers on Toyota Yaris Through Dynamometer Test and Engine Simulation

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Abstract. On April 1st 2022, fuel prices in Indonesia including PT Pertamina's non-subsidized Pertamax RON 92 and Pertamax Turbo RON 98 fuels rose by up to 39% while the price of the subsidized Pertalite RON 90 fuel remained constant. The escalation of price differences appeared to sway the non-subsidized fuel consumer's preference to switch to the much cheaper subsidized fuel with lower Research Octane Number (RON), thus resulted in a market shift to the Pertalite RON 90 fuel, which fuel octane rating is lower than the requirement and recommendation from the car manufacturer, the government, and the fuel supplier. The purpose of the study is to compare, analyze and evaluate performance differences such as torque, power and specific fuel consumption when using different octane number of fuels including Pertalite, Pertamax and Pertamax Turbo on a 2015 Toyota Yaris with 1NZ-FE engine through dynamometer test and engine modeling simulation. The result from the dynamometer test revealed that using Pertalite RON 90 decreased the torque, power, and specific fuel consumption in average by 3.85%, 3.83% and 9.58% respectively, while using Pertamax Turbo RON 98 only increased the numbers by 2.3%, 2.31% and 13.43% respectively, both compared to when using Pertamax RON 92. The result from the engine modeling simulation also revealed similar trend, where using Pertalite RON 90 decreased the torque, power, and specific fuel consumption in average per cylinder by 1.22%, 1.21% and 1.22% respectively, while using Pertamax Turbo RON 98 only increased the numbers by 1.02%, 1.01% and 0.99% respectively, both also compared to when using Pertamax RON 92. The results illustrated the increase in performance when using higher RON, but the performance gain from Pertamax RON 92 to Pertamax Turbo RON 98 is smaller than the gain from Pertalite RON 90 to Pertamax RON 92.

Keywords: Engine Performance; Research Octane Number; Pertalite RON 90; Pertamax RON 92; Pertamax Turbo RON 98; Torque; Power; Specific Fuel Consumption

1. INTRODUCTION

Development in automotive industry is a phenomenon which occurs in the whole world including in Indonesia, which represented by the total amount of registered vehicles across Indonesia, counted at 156.08 million units as of July 1st 2023 (Korlantas, 2023) and the total amount of RON 90, RON 92 and RON 98 gasoline fuel sales nationwide, disclosed at 23.78 million kL across the calendar year of 2021 (Imron, et al., 2021). The Russia-Ukraine war which started in February 2022 has had its effects globally including the petroleum industry, resulted in worldwide crude oil supply crisis and fuel price inflation. The impact of fuel price inflation in Indonesia started on April 1st 2022, for example when the price of all non-subsidized gasoline fuels including PT Pertamina's Pertamax RON 92 and Pertamax Turbo RON 98 rose by 39% from Rp 9000/L to Rp 12500/L and 21% from Rp 12500/L to Rp 14500/L respectively, while the price of the subsidized Pertalite RON 90 fuel remained constant at Rp 7650/L. Since then, there were fluctuations in the fuel price but the price of Pertalite RON 90, Pertamax RON 92, and Pertamax Turbo RON 98 once peaked at Rp 10000/L, Rp 14500/L and Rp 17900/L respectively. The sudden steep price difference between the non-subsidized and subsidized fuel persuaded Pertamax consumers to buy the cheaper and lower quality Pertalite fuel with lower RON, which octane rating is lower than the requirement and recommendation from PT Toyota Astra Motor as the car manufacturer, Indonesia's Ministry of Industry as the government, and PT Pertamina as the fuel supplier, which led to excessive consumption of Pertalite RON 90 fuel due to the market shift of 25%. This market shift also generated by the owners of luxurious and passenger cars, whose conduct is against the recommendation regarding fuel requirement from the three credible sources mentioned above. PT Toyota Astra Motor stated on the car's owner manual book ranging from Toyota Agya, Toyota Yaris to Toyota Fortuner, the minimum gasoline fuel requirement is RON 91 to RON 92 fuel (Toyota, 2022). Indonesia's Ministry of Industry stated on its regulation that the gasoline fuel requirement of all passenger cars in Indonesia is RON 92 fuel (Perindustrian, 2013). PT Pertamina also stated on their website that all vehicles especially with engine compression ratio between 10:1 to 11:1 is required to use the RON 92 fuel (Retail, 2021).

Table 1.1 : PT Pertamina's Recommended Fuel Based on Engine Compression Ratio

Petrol Fuel	Pertalite RON 90	Pertamax RON 92	Pertamax Turbo RON 98
Compression Ratio	9:1 to 10:1	10:1 to 11:1	Above 11:1

The objective of this study is to evaluate results data containing research questions such as torque, power and specific fuel consumption performance differences when using Pertalite RON 90, Pertamax RON 92 and Pertamax Turbo RON 98 through dynamometer test and engine modeling simulation, which main purpose will hopefully help bringing awareness and encouraging compliance to car owners about fuel RON requirement, reduce the excessive consumption of the subsidized fuel and re-balance the overall fuel consumption distribution between the subsidized and the non-subsidized fuel in Indonesia.

2. LITERATURE REVIEW

Gasoline or petrol is the required fuel for spark ignition (SI) engines, which is a type of ignition method where the ignition during combustion process is being generated by a spark plug. Research Octane Number (RON) in gasoline fuel is a type of octane rating which illustrates the fuel's capability to withstand high heat and pressure during combustion process to prevent an abnormal engine operating misbehavior called *knock* or *knocking*, or spontaneous auto-ignition, and the number displayed on the RON rating described the content percentage ratio of isooctane and the rest being the content percentage ratio of *n*-heptane (Heywood, 2018). The calorific value or heating value in gasoline fuel defines the fuel's capability to release high heat during combustion process, generally fuel with higher RON has higher calorific value. Regarding engine parameters, stroke is the maximum length or distance of movement of the piston inside the cylinder from bottom-dead-center (BDC) to top-dead-center (TDC) or vice versa, while bore diameter is the inner cylinder diameter. Displacement volume (V_d) is the volume displaced by the piston as it travels through one stroke between when the piston is at BDC defined as the total volume (V_t) and when the piston is at TDC defined as the clearance volume (V_c) in liter (Pulkrabek, 2004). The displacement volume formula is as follows:

$$V_d = V_t - V_c \quad (1)$$

Compression ratio (r_c) is the volume ratio of V_t to V_c, which formula is as follows:

$$r_c = \frac{Maximum\ Cylinder\ Volume}{Minimum\ Cylinder\ Volume} = \frac{V_t}{V_c} \quad (2)$$

Valve timing is the timing for the opening and closing of both the intake and exhaust valves (in degree). Engine torque is the rotational force transmitted through the crankshaft, which output known as brake torque can be measured generally in Newton meter using a dynamometer. The formula of torque is as follows:

$$T = F \cdot b \quad (3)$$

Engine power is the rate of applied torque over any period, which output can be calculated from the brake torque and engine speed from the dynamometer, generally in kilowatt. The formula of power is as follows:

$$P = 2 \cdot \pi \cdot N \cdot T \cdot 10^{-3} \quad (4)$$

Specific fuel consumption (sfc) is the fuel flow rate per unit power output in g/kWh. The formula of specific fuel consumption is as follows:

$$sfc = \frac{\dot{m}_f}{P}$$

(5)

3. METHODOLOGY

The dynamometer testing method used in this study is the hub-chassis dynamometer, and the engine modeling simulation program used in this research is the Lotus Engine Simulation (LES). Both the hub-chassis dynamometer and engine modeling simulation are already widely-known and advanced methods used in global automotive industries to collect and improve car performance. The performance output parameters to be compared, analyzed, and evaluated are brake torque, brake power, and brake specific fuel consumption (BSFC). Hub-chassis dynamometer is a type of dynamometer device to measure the torque output of a vehicle through its wheel axle. The type of dynamometer device used in this experiment is a hydraulic dynamometer, where it uses fluid as the braking force to absorb and hold the force at the wheel hub. The hub chassis dynamometer experiment took place in Jakarta in a car tuning workshop facility called REV Engineering who provides services regarding engine and electronic control unit (ECU) tuning and upgrade, and provides roller- and hub-chassis dynamometer facilities to measure the car's performance output. The hub-chassis dynamometer devices in REV Engineering are supplied by Dynapack USA. The Lotus Engine Simulation program is a licensed program from Lotus Engineering which can model and simulate various types of internal combustion engines (ICEs).

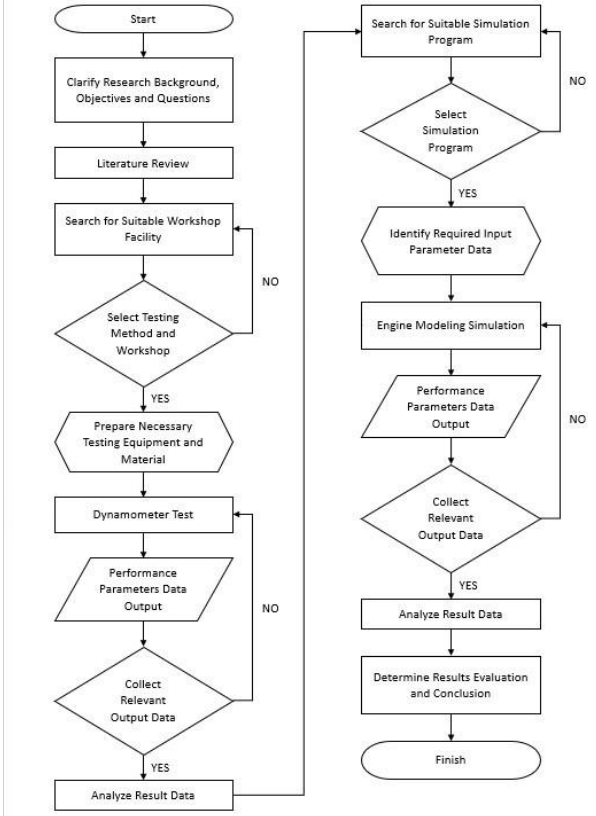

Figure 3.1 : Flowchart of Research Study

3.1 Testing Vehicle and Fuel Specifications

The vehicle used in this experiment was a Toyota Yaris 2015 S TRD Sportivo with automatic transmission and 1.5 L 1NZ-FE SI engine, and the gasoline fuels used were PT Pertamina's Pertalite RON 90, Pertamax RON 92, and Pertamax Turbo RON 98. Below is the technical specification of the tested vehicle engine and fuels in this experiment.

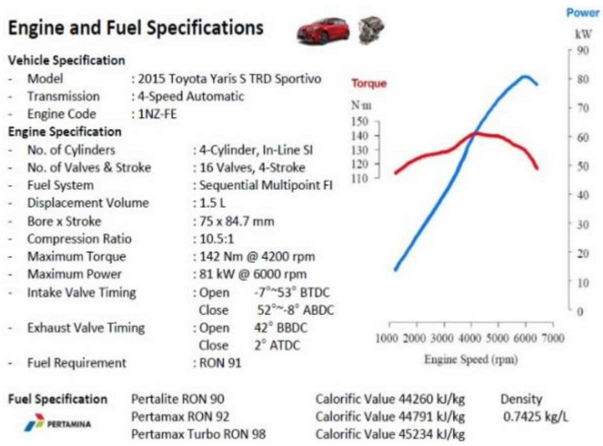

Figure 3.2 : Technical Specifications of Toyota 1NZ-FE Engine and PT Pertamina Pertalite RON 90, Pertamax RON 92, and Pertamax Turbo RON98
Source: Hussain (2015), Kinam (2021), Dharmanasa, Danial, & Ivanto (2021), Supply & Distribution Management (2020)

3.2 Experiment Equipment Setup

Below are the equipemt for the hub-chassis dynamometer test:

a. Dynamometer Dynapack DAQ Plus 33.
b. Air blower; to cool the engine during runs.
c. Hub adaptor; to connect wheel hub to dynopod.
d. Fuel container; as car's fuel tank replacement.
e. Fuel hose; to channel fuel to fuel injectors.
f. Measuring cup; to measure fuel volume.
g. Stopwatch; to time dyno runs.
h. Table sheet; to write down fuel rate results.

Below is the equipment for the engine modeling simulation test:

i. Computer with installed LES program.

3.3 Hub-Chassis Dynamometer Test Procedures

a. Gear Ratio Calibration

Before running the dynamometer test program, it is necessary to carry out the gear ratio calibration procedure to match the rpm readings on both the computer monitor and the car's tachometer. Below are the procedures of the gear ratio calibration:

1. Set control speed and gear position on the monitor.
2. Apply light throttle until engine speed on the tachometer matches the set control speed on the monitor.
3. Adjust gear ratio value on the monitor until the speed on the monitor and tachometer matches steadily.
4. Confirm gear ratio result on the monitor.

In this case of experiment, the set control speed was 3000 rpm in D-3 gear and the confirmed gear ratio result was 4.487:1.

b. Dynamometer Test Procedures

Before the procedures of the hub-chassis dynamometer test, the planned dyno run program for this experiment involved the run condition of full-load steady-state 10-second run and the 10 sets rpm of 2500, 3000, 3500, 4000, 4200, 4500, 5000, 5500, 5750 and 6000. Below are the procedures of the hub-chassis dynamometer test for each rpm set and each fuel RON:

1. Pour the testing fuel into the fuel container and open the fuel pressure valve.
2. Turn on the engine and apply full throttle until set RPM is reached and stable.
3. Shut off the fuel valve and pour the testing fuel into the fuel container until full (measured at 700 ml).
4. Open the fuel valve, start recording data for ten seconds.
5. Stop recording the data, shut off the fuel valve, let go of the throttle and turn off the engine.
6. Pour the remaining fuel in the fuel container into the measuring cup.
7. Write down the remaining fuel volume and calculate the deficit from the initial full 700 ml.

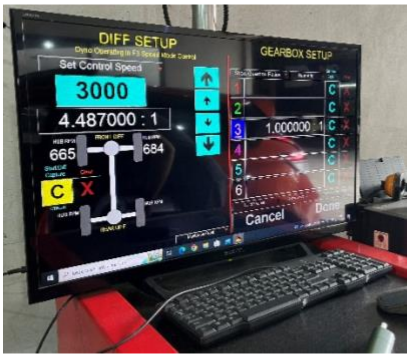

Figure 3.3 : Gear Ratio Calibration Result

Figure 3.4 : Hub-Chassis Dynamometer Test Setup

3.4 Engine Modeling Simulation Procedures

Below are the procedures of the engine modeling simulation for each fuel RON with a single-cylinder naturally aspirated spark ignition engine model:

1. Add Cylinder Element; On the cylinder data tab, change the bore diameter to 75 mm, the stroke length to 84.7 mm, the connecting rod length to 140.8 mm and the compression ratio to 10.5.
2. Add Intake Valve Element; On the valve data tab, change the intake valve open timing to 23° BTDC and the intake valve close timing to 22° ABDC.
3. Add Exhaust Valve Element; On the valve data tab, change the exhaust valve open timing to 42° BBDC and the exhaust valve close timing to 2° ATDC.
4. Add Intake Port Element; On the port data tab, change the intake port diameter to 30.5 mm.
5. Add Exhaust Port Element; On the port data tab, change the exhaust port diameter to 25.5 mm.
6. Add Inlet and Exit Boundary Elements.
7. Add Fuel Element; On the fuel properties data tab, change the fuel system to Port Injection, the fuel type to User Defined, and the user fuel type to Gasoline. Change the calorific value depending on the tested fuel RON (44260 kJ/kg for Pertalite RON 90, 44791 kJ/kg for Pertamax RON 92 and 45234 kJ/kg for Pertamax Turbo RON 98). Change the fuel density to 0.7425 kg/L.
8. Define Steady State Test Condition; Select By Speed Increment option, change the minimum speed to 1500 rpm, maximum speed of 6500 rpm and the speed increment to 500 rpm.
9. Save the model and run the model simulation.
10. Load the text and graphic simulation data results.

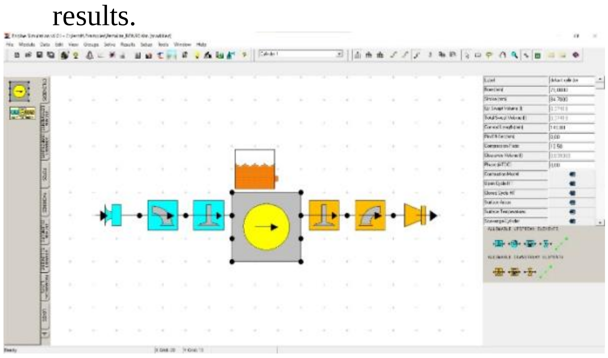

Figure 3.5 : Builder Window with Engine Elements

4. RESULT

4.1 Hub-Chassis Dynamometer Test Results

a. Brake Torque

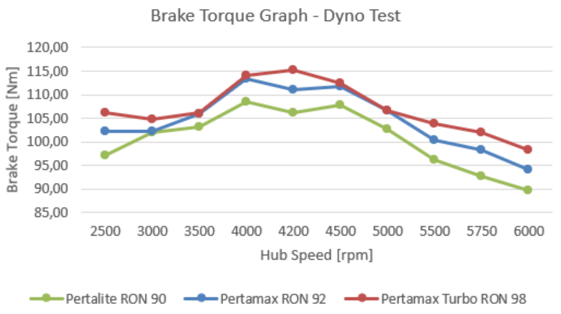

Figure 4.1 : Brake Torque Result Graph from Dynamometer Test

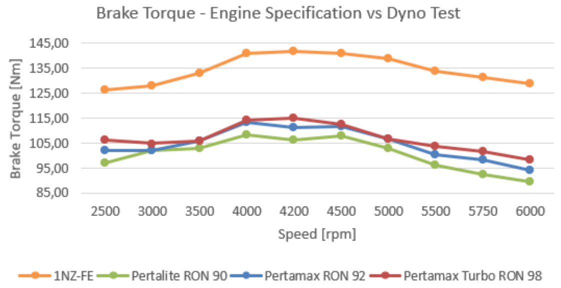

Figure 4.2 : Brake Torque Result Graph from Dynamometer Test Compared to Official Manufacturer Engine Specification

From the graph of brake torque result from the dynamometer test on Figure 4.1, all three graphs show the same curve trend of a downward curve where the torque increases from the lowest rpm until the peak torque point at 4000 to 4200 rpm before it starts decreasing until the highest rpm. In average, using Pertalite RON 90 fuel decreases the torque performance by 3.85%, and using Pertamax Turbo RON 98 fuel increases the torque performance by 2.3%, both compared to the Pertamax RON 92 fuel. From the graph of brake torque result from the dynamometer test compared to the manufacturer engine specification on Figure 4.2, the graph from the official manufacturer engine specification shows the same curve with all three graphs from the dynamometer test result, only apart from the drop in torque performance by 20.49%-25.23% in average.

b. Brake Power

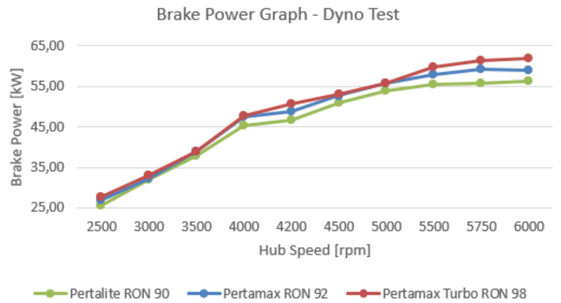

Figure 4.3 : Brake Power Result Graph from Dynamometer Test

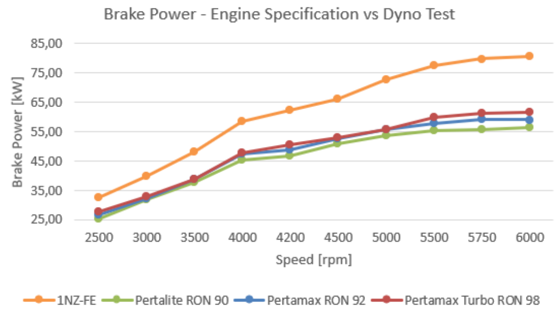

Figure 4.4 : Brake Power Result Graph from Dynamometer Test Compared to Official Manufacturer Engine Specification

From the graph of brake power result from the dynamometer test on Figure 4.3, all three graphs show the same curve trend where the power increases from the lowest rpm until the peak power point at highest rpm from 5750 to 6000 rpm. In average, using Pertalite RON 90 fuel decreases the power performance by 3.83%, and using Pertamax Turbo RON 98 fuel increases the power performance by 2.31%, both compared to the Pertamax RON 92 fuel. From the graph of brake power result from the dynamometer test compared to the manufacturer engine specification on Figure 4.4, the graph from the official manufacturer engine specification shows the same curve with all three graphs from the dynamometer test result, only apart from the drop in power performance by 20.05%-24.82% in average.

c. Brake Specific Fuel Consumption (BSFC)

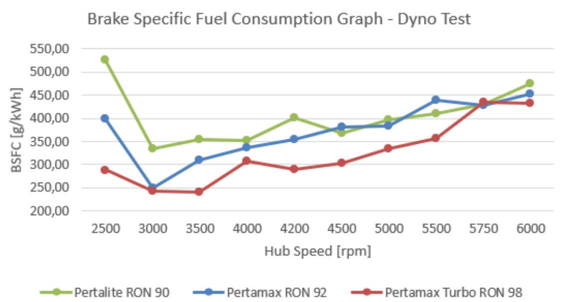

Figure 4.5 : Brake Specific Fuel Consumption Result Graph from Dynamometer Test

From the graph of brake specific fuel consumption (BSFC) result from the dynamometer test on Figure 4.5, all three graphs show the same trend of an upward curve where the BSFC decreases from the lowest rpm until the lowest point still at low rpm from 3000 to 3500 rpm, before it starts increasing until peak at high rpm from 5750 to 6000 rpm. In average, using Pertalite RON 90 fuel decreases the BSFC performance by 9.58%, and using Pertamax Turbo RON 98 fuel increases the BSFC performance by 13.43%, both compared to the Pertamax RON 92 fuel.

4.2 Engine Modeling Simulation Results

a. Brake Torque

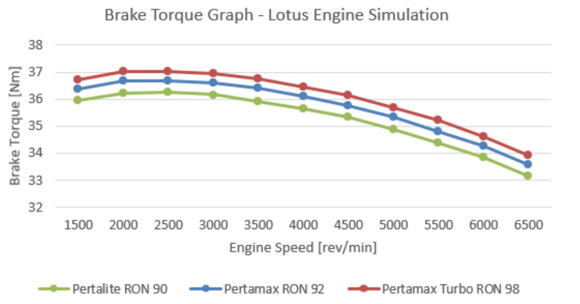

Figure 4.6 : Brake Torque Result Graph from Lotus Engine Simulation

From the graph of brake torque result from the Lotus Engine Simulation on Figure 4.6, all three graphs show the same curve trend of a downward curve where the torque increases from the lowest rpm until the peak torque point at 2500 rpm before it starts decreasing until the highest rpm. As a reminder that this experiment is a simulation on a single-cylinder engine model, so the figures represented the value in one cylinder. In average, using Pertalite RON 90 fuel decreases the torque performance by 3.85% per cylinder, and using Pertamax Turbo RON 98 fuel increases the torque performance by 2.3% per cylinder, both compared to the Pertamax RON 92 fuel.

b. Brake Power

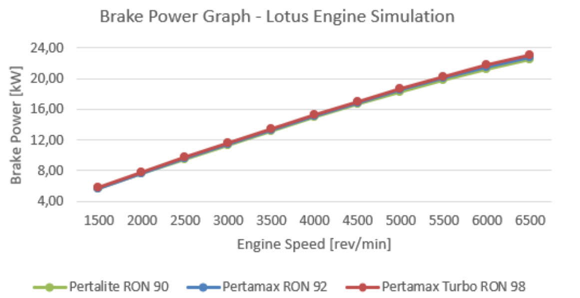

Figure 4.7 : Brake Power Result Graph from Lotus Engine Simulation

From the graph of brake power result from the Lotus Engine Simulation on Figure 4.7, all three graphs show the same curve trend of an ascending trajectory where the power constantly increases from the lowest rpm until the highest rpm. In average, using Pertalite RON 90 fuel decreases the power performance by 1.21% per cylinder, and using Pertamax Turbo RON 98 fuel increases the torque performance by 1.01% per cylinder, both compared to the Pertamax RON 92 fuel.

c. Brake Specific Fuel Consumption (BSFC)

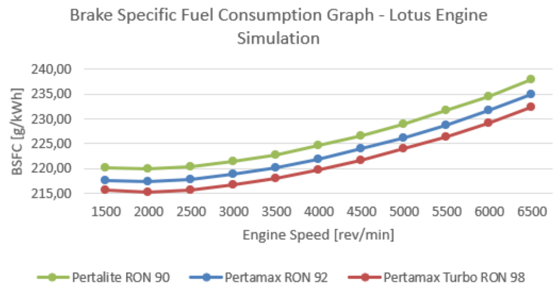

Figure 4.8 : Brake Specific Fuel Consumption (BSFC) Result Graph from Lotus Engine Simulation

From the graph of brake specific fuel consumption (BSFC) result from the Lotus Engine Simulation on Figure 4.8, all three graphs show the same trend of an upward curve where the BSFC decreases from the lowest rpm until the lowest point still at low rpm at 2000 rpm, before it starts increasing until peak at highest 6000 rpm. In average, using Pertalite RON 90 fuel decreases the BSFC performance by 1.22% per cylinder, and using Pertamax Turbo RON 98 fuel increases the BSFC performance by 0.99% per cylinder, both compared to the Pertamax RON 92 fuel.

5. CONCLUSION

Below are the conclusions from the experiment results:

a. Using gasoline fuel with higher RON increases all torque, power, and specific fuel consumption performances.

b. The performance gain from Pertalite RON 90 fuel to Pertamax RON 92 fuel is bigger than the performance gain from Pertamax RON 92 to Pertamax Turbo RON 98, even though the RON difference between Pertamax and Pertamax Turbo is three times the RON difference between Pertalite and Pertamax. The only exception is the result of fuel consumption rate and brake specific fuel consumption (BSFC) from the dynamometer test, which was the only experiment that was done manually.

c. The drop in torque and power performances when comparing the results from hub-chassis dynamometer test and the official manufacturer engine specification illustrated the mechanical loss between the crankshaft and the wheel hubs, for example through the vehicle transmission and chassis.

d. Considering the gap in RON difference and fuel price, using the required Pertamax RON 92 is the most recommended rather than using the fuel with highest RON available.

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