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Experimental study of the influence of displacement volume on fuel consumption of a four-stroke single cylinder engine

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ABSTRACT: *As the number of vehicles increases, so does the fuel consumption. With the decreasing stock of fuel oil, humans need to try to save fuel with new alternative ways that do not reduce vehicle performance. One of the solutions is by making energy-efficient vehicles with better fuel efficiency as done by the Mandalika Desantara Team in making ICE prototype vehicles in the Shell Eco Marathon Asia Pacific and Middle Eats competition. Modifications made to the vehicle engine are the reduction of engine displacement by reducing the displacement volume and increasing the compression ratio. The purpose of this study is to determine the effect of displacement volume variations (59.13 cc, 85.88 cc and 97.19 cc) and engine speed on fuel consumption and specific fuel consumption effective. Engine performance testing using a rope brake dynamometer tool using pertalite fuel which has an octane value of 90. The results of this study indicate that the 59.13 cc cylinder volume produces more efficient fuel consumption compared to the other displacement volume variations (85.88 cc and 97.19 cc). The lowest fuel consumption was achieved at a cylinder volume of 59.13 cc (0.670 kg/h), and the highest fuel consumption was achieved at a displacement volume of 97.19 cc (1.169 kg/h) at 7,000 rpm. While the best SFCe is at a displacement volume of 59.13 cc of 0.129 kg / h.PS at 6000 rpm engine speed.*

Keywords: *Piston diameter, displacement volume, fuel consumption, compression ratio*

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I. INTRODUCTION

As the number of vehicles continues to rise, fuel consumption increases accordingly—placing greater strain on the dwindling reserves of fuel oil. To address this challenge, it is essential to explore alternative strategies that conserve fuel without compromising vehicle performance. One promising solution is the development of energy-efficient vehicles with enhanced fuel economy. This approach has been exemplified by the Mandalika Desantara Team, who engineered an internal combustion engine (ICE) prototype vehicle to compete in the Shell Eco Marathon Asia Pacific and the Middle Eats competition. This increased demand leads to a depletion of fuel stocks, emphasizing the need for innovative solutions to conserve energy without compromising vehicle performance. In response, the automotive industry is shifting its focus towards enhancing energy efficiency. The primary goal is to reduce energy consumption while simultaneously improving vehicle performance and sustainability. One significant solution is the development of energy-efficient vehicles, which are designed to optimize fuel usage and be environmentally friendly [1, 2, 4]. These advancements go beyond merely transitioning from fossil fuels to alternative energy sources. They also focus on utilizing fuel more efficiently, aligning with efforts to tackle environmental challenges and the energy crisis [3, 6]. A notable initiative addressing this issue is the Shell Eco-marathon competition. This global event encourages teams to design, build, and test ultra-energy-efficient vehicles, showcasing innovative approaches to minimizing energy usage [5, 7]. Such initiatives inspire technological breakthroughs, paving the way for a future of sustainable mobility in the automotive sector.

In a modern era that increasingly emphasizes sustainability and emission reduction, attention to the environmental impact of motor vehicles has become crucial. One of the main factors influencing pollution levels is engine displacement, or displacement volume. While larger engines offer high performance and powerful acceleration [13, 14, 15], they have significant environmental consequences due to higher fuel consumption and higher exhaust emissions. Larger engines burn a larger volume of air and fuel in each combustion cycle. As a result, the amount of carbon dioxide (CO_2) produced increases proportionally [8, 11, 17]. CO_2 is a major greenhouse gas contributing to global warming. Furthermore, incomplete combustion in large engines, especially when used in heavy traffic or at low speeds, can produce harmful emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x). These gases contribute to local air pollution and can cause health problems such as respiratory illnesses and eye irritation [8, 9].

In terms of energy efficiency, large displacement volume engines often do not operate at their optimal thermal efficiency during everyday use. When used for short trips or city traffic condition, these engines tend to be more wasteful and produce more pollutants than smaller engines designed for efficiency [10, 12]. Furthermore, vehicles with large engines typically have a higher weight, which increases the engine's workload and worsens fuel consumption and emissions.

The Shell Eco-marathon is an event to develop innovative mobility solutions by designing, building, testing, and driving future vehicles that meet safety requirements and can cover the longest distances using minimal energy sources. The Shell Eco-marathon is open to all university students. This event challenges young people around the world to work together in teams and explore transportation solutions and energy challenges today and for the future. The vehicle categories competed are prototypes and urban concepts [20, 21].

One modification made to a vehicle engine is reducing the vehicle's cc to save fuel consumption. The solution used to reduce the vehicle's displacement volume is by reducing the cylinder volume by reducing the piston diameter from 50 mm to 39 mm and increasing the engine's compression ratio to reduce fuel consumption. Many methods are used to save vehicle fuel, one of which is by changing the cylinder volume and increasing the compression ratio in the vehicle engine. Where the cylinder volume is affected by the piston diameter and piston stroke, the piston is a crucial part of the main engine in compression which produces the pressure that causes the motor to work. When the piston moves from TDC to BDC, the intake valve opens, and air enters the cylinder. Then, when the piston moves from BDC to TDC, the intake and exhaust valves close, and the air in the cylinder is utilized, increasing air pressure and temperature [19].

A larger displacement volume allows more air and fuel to enter the combustion chamber during each cycle. This means more fuel is required to support the combustion process [16, 18]. Because the cylinder volume is larger, each combustion cycle requires more fuel to maintain the optimal stoichiometric ratio [22, 23]. A larger displacement provides advantages in terms of increased power and torque, but at the cost of higher fuel consumption, especially if not utilized to its full capacity. Therefore, stroke volume selection must be tailored to operational requirements and desired energy efficiency.

The displacement volume is the volume of the cylinder when the piston is at top dead center (TDC) until the piston is at bottom dead center (BDC). The size of this cylinder volume will affect the amount of power produced by the engine. The larger the cylinder volume, the more fuel and air mixture can be sucked into the cylinder, which will affect the vehicle's engine performance [25, 26]. Where the cylinder volume also affects the compression ratio. The compression ratio is a value indicated by the comparison between the engine cylinder volume and the combustion chamber volume. The compression ratio is the result of dividing the total volume by the remaining volume of the combustion chamber (clearance volume). Based on research by Mara, et al., (2018) [16], regarding the analysis of exhaust emissions and motorcycle power at a reduced cylinder volume, it was found that reducing the piston diameter can reduce: fuel consumption, engine power, and exhaust emissions produced by the vehicle engine.

Based on the description above, in this study the author is interested in knowing how the variation of cylinder volume affects the engine performance of the Mandalika Desantara team's energy-efficient vehicle in the prototype internal combustion engine (ICE) category, especially on fuel consumption by varying the cylinder volume with the cylinder volume (97.19 cc, 85.88 cc and 59.13 cc) and determining the compression ratio.

II. EXPERIMENTAL SETUP

This study uses an experimental quantitative method, using two research variables, namely dependent variables and independent variables. The dependent variables in this study are engine performance parameters (torque, effective power, fuel consumption, and specific fuel consumption effective) while the independent variables consist of variations in cylinder volume (59.13 cc, 85.88 cc, and 97.19 cc) and engine speed (4000 rpm, 5000 rpm, 6000 rpm, and 7000 rpm). The apparatus scheme is as shown in Figure 1. The stages carried out in this research are the process of changing the cylinder block, the process of installing the piston, installing the cylinder block, the process of installing the cylinder head, assembling the rope brake dynamometer test equipment [24], burette and stopwatch and calibrating the measuring instrument.

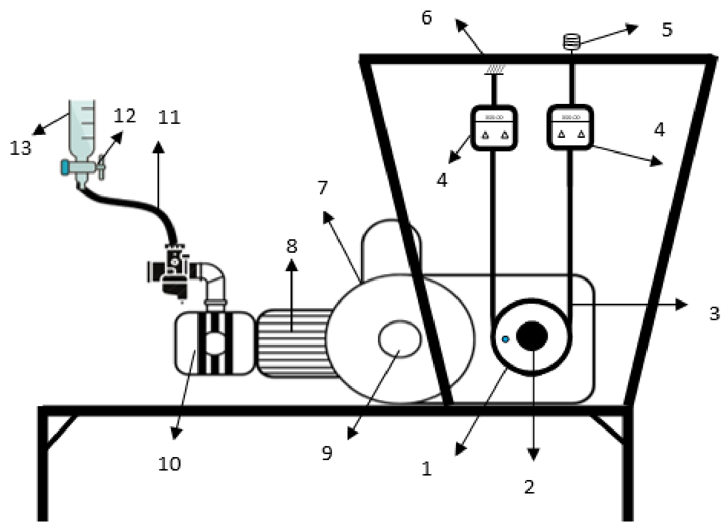

Figure 1. Layout of experimental test equipment (1) pulley, (2) Output shaft, (3) Rope, (4) Digital balance, (5) Load adjusting bolt, (6) Lock, (7) Engine Prototype, (8) Cylinder block, (9) Magnet sump, (10) Cylinder head, (11) Carburetor hose, (12) Fuel tank valve, (13) Burette.

III. RESULTS AND DISCUSSION

3.1 Displacement Volume and Compression Ratio Calculation

Table 1. Results of compression ratio comparison calculations

Piston diameter (mm)	Displacement volume (cc)	Clerance volume (cc)	Compression ratio
39	59,13	7,5	8.88:1
47	85,88	11,0	8.81:1
50	97,19	12,5	8.78:1

From table 1, the combustion chamber volume of each cylinder volume variation is different, this is due to the adjustment of the liner diameter which is reduced and adjusted to the size of the piston diameter used. So that the smaller the piston diameter, the volume displacement (Vd), combustion chamber volume (Vc), combustion chamber pressure and the resulting compression ratio will decrease. Therefore, researchers attempted to determine the compression ratio by cutting the cylinder head in the volume clearance section to adjust the combustion chamber volume to the displacement volume.

3.2 *Fuel Consumption* (FC)

Figure 2 shows the effect of engine speed on fuel consumption, where the higher the engine speed, the more fuel is needed. This is because increasing engine speed reduces the time required for one combustion cycle. Therefore, at high speeds, there will be more combustion cycles per unit time compared to low speeds, so the fuel supply entering the combustion chamber also increases. The increasing engine speed and decreasing cylinder volume from 97.19 cc to 59.13 cc will significantly affect fuel consumption. This is because the smaller the cylinder volume, the less fuel mixture is sucked together with air into the cylinder chamber. This is in accordance with research [16].

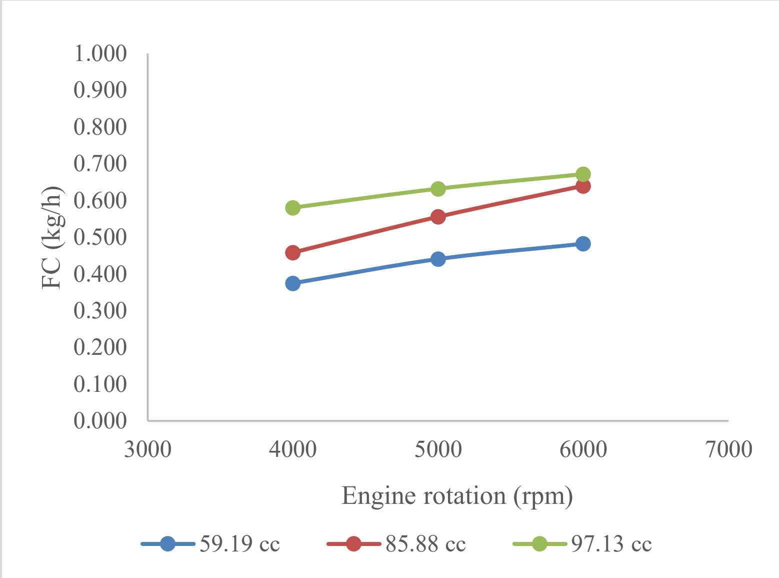

Figure 2 Relationship between fuel consumption and engine speed

At 4000 rpm engine speed the average value of fuel consumption at a cylinder volume of 97.19 cc with a compression ratio of 8.77: 1 consumes 0.671 kg / hour of fuel, at a cylinder volume of 85.88 cc with a compression ratio of 8.81: 1 consumes 0.529 kg / hour of fuel and for a cylinder volume of 59.13 cc using a compression ratio of 8.89: 1 consumes 0.433 kg / hour of fuel. Of the three variations of cylinder volume at 4000 rpm engine speed there is a decrease of 35.47% from the cylinder volume of 97.19 cc to 59.13 cc, this is due to the reduction in the piston diameter from Ø 50 mm to Ø 39 mm so that the gas entering the combustion chamber will decrease along with the reduction in the piston diameter. At 5000 rpm engine speed there is an increase in the cylinder volume of 97.19 cc by 8.08% from 4000 rpm engine speed to 5000 rpm engine speed, at 85.88 cc cylinder volume increases by 17.60% and for 59.13 cc cylinder volume there is also an increase of 14.93%. For 6000 rpm engine speed it still increases from the three variations of cylinder volume, where at 97.19 cc cylinder volume increases by 21.59% from 5000 rpm engine speed to 6000 rpm, at 85.88 cc cylinder volume increases by 13.12% and 59.13 cc cylinder volume increases by 8.62%. And at 7000 rpm engine speed, the fuel consumption value continues to increase along with increasing engine speed, where 7000 rpm engine speed at a cylinder volume of 97.19 cc consumes 1,169 ml of fuel, at a cylinder volume of 85.88 cc it consumes 0.887 ml of fuel with the same engine speed and at a cylinder volume of 59.13 cc it consumes 0.670 ml of fuel

The engine works by burning a mixture of air and fuel to produce power. Engines with a larger displacement volume burn more fuel and air mixture in one cycle compared to engines with a smaller displacement volume [19]. While engines with a larger displacement volume produce more power and also consume more fuel, because more volume of fuel and air mixture enters the cylinder.

3.3 S*pecific fuel consumption effective* (SFCe)

From Figure 3, it can be seen that the higher the engine speed, the lower the SFCe value produced. This is because the higher the engine speed, the higher the fuel consumption and effective power of the engine, resulting in low SFCe. The lower the SFCe value produced, the better the level of fuel efficiency in terms of the effective power produced (Irawan & Adityo, 2016). However, the SFCe at 7000 rpm engine speed increased due to the increase in the high fuel consumption value, but the effective power value produced experienced a not very significant increase. This is what causes the SFCe value at 7000 rpm engine speed to increase. Therefore, the size of the SFCe obtained is influenced by fuel consumption and effective power.

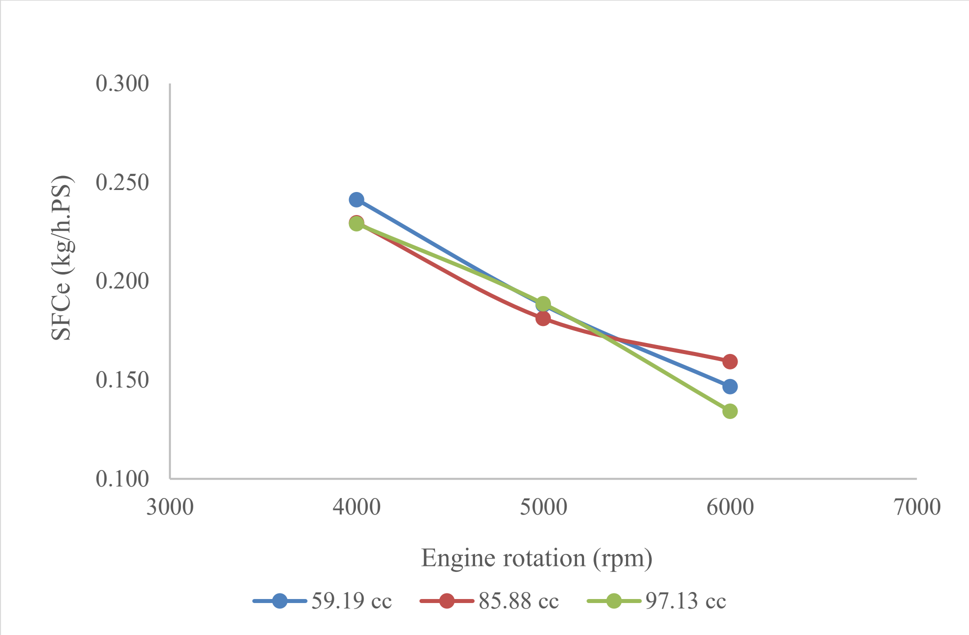

Figure 3 Relationship between SFCe and engine speed

At 4000 rpm engine speed the lowest average SFCe value is produced by a cylinder volume of 59.13 cc of 0.192 kg/hour.PS while for the highest SFCe is at a cylinder volume of 97.19 cc of 0.211 kg/hour.PS and at a cylinder volume of 85.88 cc of 0.198 kg/hour.PS at the same engine speed. At 5000 rpm engine speed there is a decrease in the SFCe value for each variation of the cylinder volume from 4000 rpm to 5000 rpm engine speed with a percentage of 18.48% at a cylinder volume of 97.19 cc, for a cylinder volume of 85.88 cc there is a decrease of 15.66% and at a cylinder volume of 59.13 cc there is a decrease of 15.62%. The decrease in the SFCe value occurred again at engine speeds of 5000 rpm to 6000 rpm for each variation of cylinder volume used, where at a cylinder volume of 97.19 cc there was a decrease of 15.11%, a cylinder volume of 85.88 cc there was a decrease of 13.17% and a cylinder volume of 59.13 cc there was a decrease of 20.37%. At engine speeds of 7000 rpm there was an increase in the SFCe value for each variation of cylinder volume used, at a cylinder volume of 97.19 cc there was an increase in SFCe of 20.22%, a cylinder volume of 85.88 cc there was an increase of 16.67% and a cylinder volume of 14.57%. Of the three variations of cylinder volume, the lowest Specific Fuel Consumption effective (SFCe) is produced by a cylinder volume of 59.13 cc at an engine speed of 6000 rpm of 0.129 kg/hour.PS and for the highest SFCe value is produced by a cylinder volume of 97.19 cc of 0.146 kg/hour.PS at the same engine speed. With a decrease in cylinder volume from a cylinder volume of 97.19 cc to a cylinder volume of 59.13 cc, with a difference of 39.16%. So there is a decrease in power of 30.41% and a decrease in fuel consumption of 42.60%. The decrease in fuel consumption that occurs is greater than the decrease in effective power, so that a more effective fuel savings are obtained. This is similar to the test of Mujaddi et al., (2016) [15].

IV. CONCLUSION

Based on the analysis and discussion of research on the effect of cylinder volume variations on engine performance of energy-efficient vehicles from the Mandalika Desantara team in the internal combustion engine (ICE) prototype category, the engine performance parameters analyzed fuel consumption and specific fuel consumption. The lowest fuel consumption was achieved at a cylinder volume of 59.13 cc (0.670 kg/h), and the highest fuel consumption was achieved at a cylinder volume of 97.19 cc (1.169 kg/h) at 7,000 rpm. The lowest specific fuel consumption was achieved at a cylinder volume of 59.13 cc (0.129 kg/h), and the highest specific fuel consumption was achieved at a cylinder volume of 97.19 cc (0.146 kg/h), at 6,000 rpm. The lower the SFCe value, the better the fuel efficiency in terms of effective power.

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