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EFFECT OF CYLINDER HEAD GASKET ADDITION AND VARYING OCTANE NUMBER GASOLINE TO INTERNAL COMBUSTION ENGINE PERFORMANCE

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ABSTRAK

Gasket kepala silinder memainkan peran penting dalam kinerja mesin secara keseluruhan. Ini memberikan segel antara blok mesin dan kepala silinder, mencegah kebocoran gas, cairan pendingin, atau oli. Setiap perubahan pada desain paking kepala silinder dapat mempengaruhi efisiensi dan kinerja mesin. Tujuan dari penelitian ini adalah untuk menyelidiki dampak tekanan kompresi yang berbeda terhadap keluaran daya dan torsi dengan menggunakan bensin RON 92, RON 95, dan RON 100. Penelitian ini melibatkan eksperimen menggunakan mesin sepeda motor satu silinder berkapasitas 125 cm^3. Pemilihan jenis mesin ini didasarkan pada popularitas kendaraan di Indonesia yang menggunakan mesin satu silinder dengan kapasitas 125 cm^3. Untuk memodifikasi tekanan kompresi, variasi dalam jumlah gasket diterapkan pada kepala silinder dengan jumlah 1 dan 3 gasket. Uji dinamometer dilakukan untuk mengukur perbedaan kinerja mesin. Selama pengujian, pengaturan untuk main jet, pilot jet, dan jumlah rotasi sekrup idle pada karburator tetap konstan.Temuan menunjukkan bahwa mesin dengan tekanan kompresi tertinggi 11,8 Kg/cm^2 yang menggunakan bensin RON 100 menghasilkan daya keluaran tertinggi sebesar 7,9 kW, dengan torsi tertinggi sebesar 10 Nm.

Kata kunci: gasket silinder, angka oktan, kompresi, performa.

ABSTRACT

The cylinder head gasket plays a crucial role in the overall engine performance. It provides a seal between the engine block and cylinder head, preventing leakage of gases, coolant, or oil. Any changes to the cylinder head gasket design can affect engine efficiency and performance. The aim of this research was to investigate the different impacts of compression pressure on power and torque outputs using gasoline RON 92, RON 95, and RON 100. The study involved experiments using a single-cylinder motorcycle engine with a capacity of 125 cm^3. The selection of this type of engine is based on the popularity of vehicles in Indonesia that use a single-cylinder engine with a capacity of 125 cm^3. To modify the compression pressure, variations in the number of gaskets were applied to the cylinder head, with quantities of 1 and 3 gaskets. Dynamometer tests were conducted to measure the engine's performance differences. Throughout the testing, the settings for the main jet, pilot jet, and the number of idle screw rotations on the carburetor remain constant. The findings indicate that the engine with the highest compression pressure of 11.8 Kg/cm^2, using RON 100 gasoline, produces the highest power output at 7.9 kW, with the highest torque at 10 Nm.

Keywords: *cylinder gasket, octane number, compression, performance.*

1. INTRODUCTION

The conversion of thermal energy into mechanical energy carried out by an internal combustion engine, where a series of devices convert heat energy into kinetic energy [1]. Several factors affected the performance of an internal combustion engine, including the quality of the fuel used and the compression pressure in the engine. Low-quality fuel in an engine with high compression would decrease engine performance and increase fuel consumption [2]. Internal combustion engines commonly used in motorcycles and cars have cylinder components with a piston that moves back and forth [3]. A four-stroke engine requires two revolutions of the crankshaft. In other words, each cylinder requires the piston to go through four strokes to complete one cycle within the cylinder [4].

The performance of an engine depends on the efficiency of fuel and air mixture combustion inside the cylinder. In engines with large compression and high-quality fuel, the result is the most efficient engine performance [5]. Information from the Indonesian Motorcycle Industry Association (AISI) data showed that domestic motorcycle sales increased in 2021, reaching 5,057,516 units sold, an increase of approximately 38.2% compared to the previous year. Motorized vehicles were the largest consumers of fuel in the transportation sector, especially those using gasoline [6]. Currently, there are several gasoline suppliers, both government and private companies, offering several fuel variants. Gasoline categories are grouped based on the Research Octane Number (RON). Some RON values found in gasoline in Indonesia include RON 90, RON 92, RON 95, RON 98 and even RON 100 [7].

Increasing the fuel octane number shortens the combustion duration and reduces the likelihood of detonation. [8]. The research conducted by Rodríguez-Fernández and colleagues with the title "Enhancing fuel economy and vehicle performance through higher octane-rated gasoline" found that using higher octane number fuel significantly increases the power generated by the vehicle and shortens acceleration time. Additionally, using higher-octane fuel is also effective in reducing vehicle exhaust emissions due to reduced fuel consumption [9]. Bi and colleagues found that detonation (knocking) in engines reduces thermal efficiency and limits the improvement of gasoline engine performance. Detecting the characteristics of engine detonation, including mild detonation, were crucial for controlling engine detonation. The use of higher-octane fuel can reduce the effects of detonation and improve thermal efficiency in gasoline engines [10].

Knocking refers to the sound of waves associated with the spontaneous ignition of a portion of the air-fuel mixture before the flame from the spark plug ignition [11]. When detonation occurs, there are high-frequency pressure oscillations that could be observed [12]. Detonation has the potential to cause several forms of damage, including piston crown melting, piston ring sticking, and cylinder head gasket leaks [13]. The findings of the research conducted by Jiang and colleagues indicate that to achieve high power efficiency and reduce Nitrogen Oxide (NOx) emissions in internal combustion engines, adjustments to the Exhaust Gas

Recirculation (EGR) components are necessary, as well as selecting fuel with an appropriate octane number. The choice of fuel with the right octane number plays a crucial role in achieving optimal power output and maintaining low levels of exhaust emissions [14].

The study conducted by Zhang and colleagues reported that increasing the compression ratio in an engine can effectively reduce fuel consumption [15]. Increasing the compression ratio would also elevate the combustion temperature inside the cylinder, and the extent of the impact from different mechanisms varies with different compression ratios, resulting in a decrease in HC emissions when the compression ratio is increased [16]. Using fuel supplemented with methyl ester in high-compression engines would enhance performance and actively reduce emissions of Nitrogen Oxide (NOx) and Carbon Dioxide (CO_2) gases [17].

Today, automotive manufacturers have been producing high compression engines to enhance performance, both in motorcycles and cars. However, there is low consumer awareness about the need for high-octane fuel to achieve optimal performance in high compression engines. The consumption style can be seen in recent statistics released by the Directorate General of Oil and Gas, which showed that RON 90 gasoline continues to significantly outsell RON 92 and 95 gasoline. From this data, it can be concluded that many consumers still choose to use low-octane gasoline in their vehicles, even though these vehicles generally have large compression ratios [18]. Based on the explanation above, we will conduct a performance test on a single-cylinder engine with two different compression ratios: 11.8 Kg/cm2 and 10 Kg/cm2. This test will use three different types of fuel: RON 92, RON 95 and RON 100 gasoline, with the aim of observing the differences in power and torque output.

2. METHOD

This research involves experiments using a 125 cm^3 single-cylinder motorcycle engine. The selection of this type of engine is based on the popularity of vehicles in Indonesia that use single-cylinder engines with a 125 cm^3 capacity. To adjust the compression pressure in the engine, gaskets are used on the cylinder head in two different variations: one gasket and three gaskets. Adding gaskets to the cylinder head results in a change in the combustion chamber volume, which affects the compression pressure value. Throughout the testing, the settings for the main jet, pilot jet, and the number of idle screw rotations on the carburetor are kept constant. Test data results are then analyzed directly to draw conclusions. Additionally, the test data will be presented in the form of graphs and tables to facilitate the reader's understanding. It is clearly seen in Table 1.

Table 1. Engine Specification for Testing

Engine type	4-*stroke*, SOHC
Cylinder volume (cc)	124.8
Bore x Stroke (mm x mm)	52.4 x 57.9
Compression ratio	9.0 : 1
Fuel supply system	Carburettor
Ignition system	Capacitor Discharge Ignition (CDI)

The basic principle of a dynamometer is to measure the power, torque, or force generated by an engine or vehicle by measuring the forces generated by the engine or vehicle. The operation of a dynamometer involves applying a resistance load to the engine or vehicle being tested, and then measuring the reaction or force generated by the engine or vehicle in response to this load. In the context of engine performance testing, the dynamometer will record data on the torque produced by the engine at several engine speeds, and based on this data, it is processed to calculate the power generated by the engine at specific RPMs. This basic principle allows us to gain a more accurate understanding of the engine's characteristics. Engine performance can be measured using Equation (1), where (T) represents torque, (F) is the force applied to the rotor, and (r) is the distance used as a multiplication factor.

$$T = \int r \cdot F \, \delta r \quad (1)$$

The power generated can be calculated using Equation (2), with N as the Crankshaft's rotational speed (Rpm).

$$P = \frac{2 \pi N T}{60 \times 1000} \quad (2)$$

The performance test of the single-cylinder engine was conducted using a dynamometer and additional equipment such as a toolset, measuring burette, and stopwatch. The fuel specifications used in this test are indicated in Table 2.

Table 2. Fuel Specification for Testing

Unit	RON 92	RON 95	RON 100
RON (Research octane number)	92	95	100
Caloric value (kJ/kg)	43848	43920	47336
Distillation			
10% evaporation volume (°C)	70	68	62
50% evaporation volume (°C)	110	103	105
90% evaporation volume (°C)	180	165	151
Final boiling point (°C)	215	205	203
Density (Kg/m^3)	770	760	721

Before undergoing testing using the dynamometer, it is necessary to position the motorcycle precisely so that the rear wheel is directly over the dynamometer's roller. Next, it is important to connect the tachometer cable to the high-tension cable at the spark plug and disconnect the hose connected to the carburetor. Then, the hose from the measuring burette will replace the one leading to the carburetor. The measuring burette will then be filled alternately with RON 92, RON 95, and RON 100 fuel. The testing scheme with the dynamometer can be found in Figure 1. Once all preparations are completed, the performance test can be conducted by two Persons. One person will operate the dynamometer testing software, while the other person is responsible for operating the engine.

Figure 1. Dynamometer Test Scheme: (a) Monitor, (b) Dynamometer Roller, (c) GPU (graphic processing unit), (d) High-Tension Cable, (e) Measuring Burette.

3. RESULTS AND DISCUSSION

3.1. *Torque output comparison*

Torque testing has been conducted at different levels of compression pressure using RON 92, RON 95, and RON 100 gasoline. Table 3 displays the torque testing results for the engine using RON 92 fuel. Each torque value is obtained through three repeated tests, and the numbers listed in Table 3 represent the average values. In general, the engine exhibiting a compression pressure of 11.8 Kg/cm^2 demonstrated higher torque [19]. Specifically, when operating at a compression pressure of 11.8 Kg/cm^2, the engine produced a peak torque of 9.31 Nm within the engine speed range of 5000 RPM. In summary, the engine featuring a compression pressure of 11.8 Kg/cm^2 is capable of achieving a 7.3% increase in torque output compared to the engine with a compression pressure of 10 Kg/cm^2. The torque output comparison across several compression pressure variations using RON 92 gasoline is visually represented in Figure 2.

Table 3. Torque Output Using RON 92 fuel

	Torque output at several compression	
Rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	9.26	9.31
5500	8.85	8.98
6000	8.25	8.52
6500	7.32	7.85
7000	6.05	6.86
7500	5.27	6.04
8000	3.75	4.78

The outcomes of the engine torque tests utilizing RON 95 gasoline are outlined in Table 4. The highest recorded torque, reaching 9.61 Nm, was achieved when the engine operated at a compression pressure of 11.8 Kg/cm^2 within the engine speed range of 5000 RPM. In contrast, the engine featuring a compression pressure of 10 Kg/cm^2 yielded a lower torque output of 9.26 Nm during the same conditions.

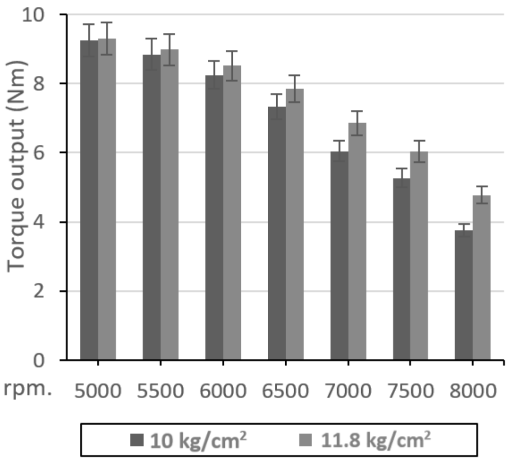

Figure 2. Engine Torque Output at Several Compression Pressure Using RON 92 Fuel

Overall, when fueled with RON 95, the engine operating at a compression pressure of 11.8 Kg/cm^2 exhibited higher torque compared to the engine with a compression pressure of 10 Kg/cm^2. The lowest recorded torque output, at 4.07 Nm, was observed in the engine with a compression pressure of 10 Kg/cm^2 within the engine speed range of 8000 RPM. Meanwhile, within the identical engine speed range, the engine operating at a compression pressure of 11.8 Kg/cm^2 generated an additional 1.09 Nm of torque. This represents a 7.3% increase in torque output, with the engine at 11.8 Kg/cm^2 producing 8.16 Nm compared to the engine with a compression pressure of 10 Kg/cm^2 within the engine speed range of 6500 RPM.

Table 4. Torque Output Using RON 95 Fuel

Torque output at several compression		
Rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	9.26	9.61
5500	8.81	9.31
6000	8.12	8.78
6500	7.60	8.16
7000	7.46	7.23
7500	5.79	6.33
8000	4.07	5.16

The engine with a compression of 11.8 Kg/cm2 demonstrated a higher torque output of 0.5 Nm at an engine speed of 5500 RPM and 0.66 Nm at 6000 RPM, respectively, in comparison to the engine with a compression pressure of 10 Kg/cm^2 [20]. This trend indicates that the torque output increases with higher engine compression pressure. The torque variations among different compression pressures are visually depicted in Figure 3.

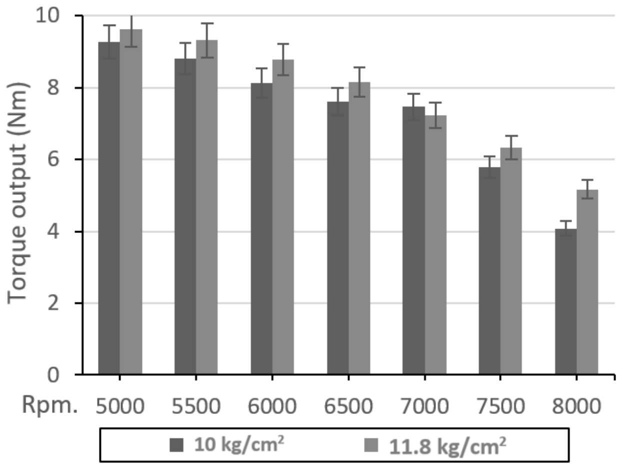

Figure 3. Engine Torque Output at Several Compression Pressure Using RON 95 Fuel

Torque testing has been conducted on the engine with several compression pressure variations using RON 100 gasoline, and the results have been compiled in Table 5. Each torque value recorded in Table 5 represents the average result of three experiments. In general, the engine with the highest compression pressure, which is 11.8 Kg/cm^2, tends to produce higher torque output at all engine speed [21].

Table 5. Torque Output Using RON 100 Fuel

Torque output at several compression		
Rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	8.97	9.93
5500	8.57	9.78
6000	8.05	9.25
6500	7.44	8.57
7000	6.47	7.60
7500	5.50	6.64
8000	4.18	5.79

The engine operating at a compression pressure of 11.8 Kg/cm^2 attained its peak torque output of 9.93 Nm within the engine speed range of 5000 RPM. Within the identical engine speed range, the engine featuring a compression pressure of 10 Kg/cm^2 generated a lower torque, exhibiting a difference of approximately 0.96 Nm compared to the engine at 11.8 Kg/cm^2. The torque comparison results for the engine with various compression pressure settings using RON 100 fuel are visually represented in Figure 4. The engine, running at a compression pressure of 10 Kg/cm^2, recorded the lowest torque output at 4.18 Nm, specifically at an engine speed of 8000 RPM. Within the identical engine speed range of 8000 RPM, the engine operating at a compression pressure of 11.8 Kg/cm^2 exhibited a higher torque output, reaching 5.79 Nm.

In summary, the torque output recorded in the engine with a compression pressure of 11.8 Kg/cm^2 is 17% higher compared to the torque output in the engine with a compression pressure of 10 Kg/cm^2. The test results reiterate the importance of using fuel with a higher-octane number in engines with elevated compression pressure to attain optimal torque output [22]. The data in Figure 5 showed a comparison of torque output generated by an engine operating at a compression pressure of 11.8 Kg/cm^2 and using three types of fuel, namely, RON 92, RON 95, and RON 100. From the engine speed range of 5000 RPM to 8000 RPM, it is evident that the engine using RON 100 gasoline produced higher torque output than the engine using RON 92 or RON 95 gasoline. Overall, the engine using RON 100 gasoline is capable of producing 5.3% more torque output compared to the engine using RON 95 gasoline [23].

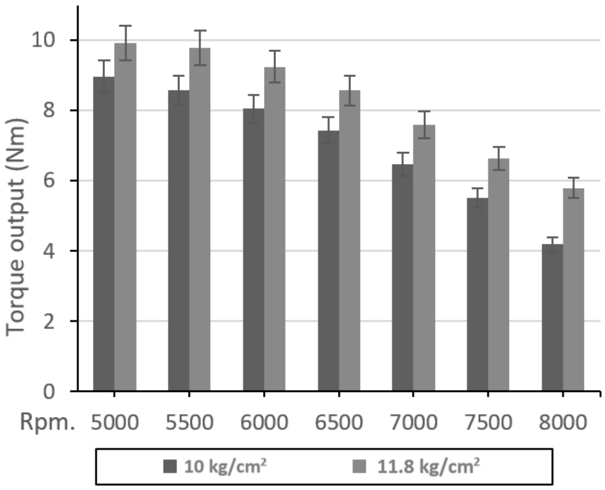

Figure 4. Engine Torque Output at Several Compression Pressure Using RON 100 Fuel

Utilizing on the data in Figure 5, engine torque output with compression pressure of 11.8 Kg/cm^2 using RON 95 and RON 100 gasoline is clearly depicted. For instance, in the engine speed range of 6000 RPM, the engine using RON 95 achieves a torque output of approximately 8.78 Nm, while the engine using RON 100 gasoline can produce 5.3% more torque, which is 9.25 Nm. Another example in the engine speed range of 8000 RPM, the engine using RON 95 only generates a torque result of 5.16 Nm, meanwhile the engine using RON 100 gasoline can achieve a 12% larger torque output, which is 5.79 Nm.

The engine using RON 100 gasoline is capable of producing more significant torque, with a variance of approximately 9.8%, when compared to the engine using RON 92 gasoline. Data from Figure 5 indicates that in the engine speed range of 5500 RPM, the engine using RON 92 gasoline only generates a torque result of 8.98 Nm, while the engine using RON 100 gasoline can generate higher torque, approximately 8.9% more, which is 9.78 Nm. This further underscores that employing large octane fuel in an engine with elevated compression pressure leads to optimal torque output [24].

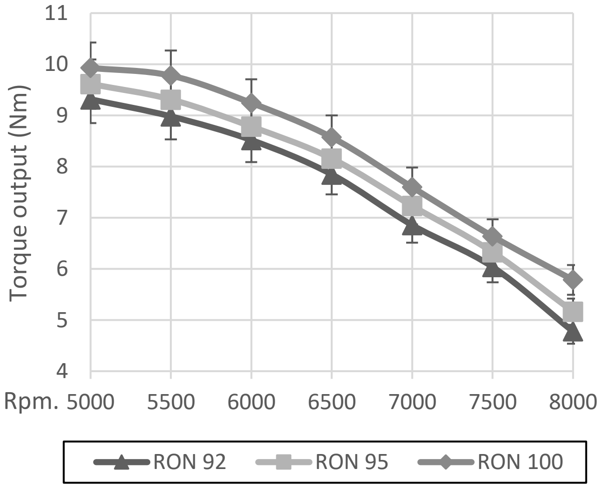

Figure 5. Torque Output at 11.8 kg/cm^2 Compression Pressure Using RON 92, 95 & 100 Fuel

3.2. *Power output comparison*

Based on the data in Table 6, we can observe the comparison of power output from several compression pressures of engines fueled with RON 92 during the testing. Each power output value was obtained through a three-times test, and the values listed in Table 6 are their averages. Generally, an engine with higher compression pressure, 11.8 Kg/cm^2, generates greater power output across all engine speeds [25]. Table 6 records the generated power in Kilowatts (kW) for several compression pressure variations.

Table 6. Power Output Using RON 92 Fuel

	Power output at several compression	
rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	6.5	6.6
5500	6.9	7.0
6000	7.0	7.2

Table 6. Power Output Using RON 92 Fuel, continued

Power output at several compression		
rpm	10 Kg/cm^2	11.8 Kg/cm^2
6500	6.8	7.2
7000	6.0	6.8
7500	5.6	6.4
8000	4.2	5.4

The 10 Kg/cm^2 compression engine yielded lower power output compared to the 11.8 Kg/cm^2 compression engine. At a compression pressure of 10 Kg/cm^2, the peak power output only reaches 7.0 kW when the engine runs at 6000 rpm. On the other hand, the 11.8 Kg/cm^2 compression engine can achieve the same power outcome at lower engine speeds. This is because higher compression pressure results in better power output [26]. Also from Table 6 provided a clear depiction of the power output patterns in engines with compression pressure variations fueled with RON 92 gasoline. In the 8000 rpm engine speed range, the engine at 11.8 Kg/cm^2 compression pressure produced 5.4 kW of power, whereas the engine at 10 Kg/cm^2 compression pressure yielded a power output that is roughly 28% less, amounting to about 4.2 kW at the identical engine speed. Besides the octane number of the fuel, compression pressure is also a factor that influences the value of power output [27].

Table 7. Power Output Using RON 95 Fuel

Power output at several compression		
rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	6.6	6.8
5500	6.9	7.2
6000	6.9	7.5
6500	7.0	7.5
7000	6.4	7.2
7500	6.0	6.7
8000	4.6	5.8

Based on the data in Table 7, the variations in power output among engines with different compression settings while using RON 95 fuel can be observed. Overall, the 10 Kg/cm^2 compression engine also produced lower power output compared to the 11.8 Kg/cm^2 compression engine. At a compression pressure of 10 Kg/cm^2, the highest power output is only 7.0 kW at 6500 rpm. Overall, the power output generated by an engine using RON 95 gasoline inlined with an 11.8 Kg/cm^2 compression engine is higher than that of a 10 Kg/cm^2 compression engine. Table 7 shows the peak power output, 7.5 kW, recorded in the 11.8 Kg/cm^2 compression engine when running at 6000 to 6500 rpm. On the other hand, at the same engine speed range, the 10 Kg/cm^2 compression engine only produced a power output of about 6.9 kW. This finding further reinforces the concept that engines with larger compression require higher-octane rating gasoline for optimal power output [28].

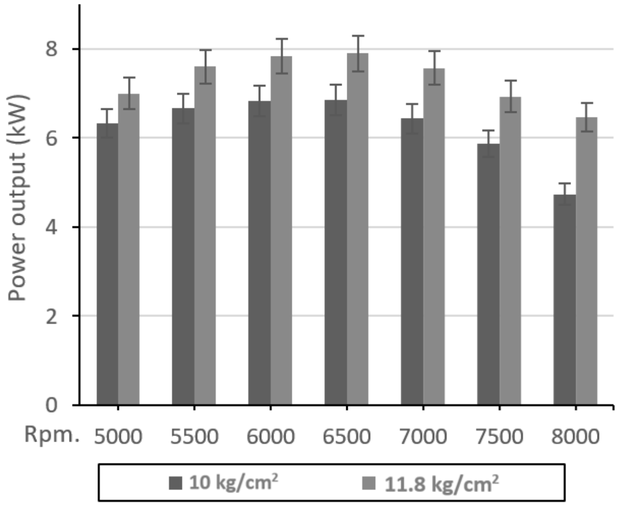

Figure 6. Engine Power Output at Several Compression Pressure Using RON 100 Fuel

The results of the power tests for several compression pressure variations when using RON 100 gasoline are recorded in Table 8. Overall, engines with high compression pressure, 11.8 Kg/cm^2, also yielded considerable power at all engine speeds. Conversely, engines with low compression pressure, specifically 10 Kg/cm^2, tend to generate lower power across all engine speed ranges. The engine's maximum power output with a 10 kg/cm^2 compression pressure is only 7.0 kW.

Table 8. Power Output Using RON 100 Fuel

Power output at several compression		
rpm	10 Kg/cm^2	11.8 Kg/cm^2
5000	6.3	7.0
5500	6.7	7.6
6000	6.8	7.8
6500	6.9	7.9
7000	6.4	7.6
7500	5.9	6.9
8000	4.7	6.5

For instance, at 6500 rpm, the 10 Kg/cm2 compression engine produced power that is 8.6% lower than the 11.8 Kg/cm^2 compression engine. In the engine speed range of 7500 rpm, a power of 6.9 kW generated by the 11.8 Kg/cm^2 compression engine, which is 1.0 kW higher than the 10 Kg/cm^2 compression engine. More detailed data on engine power tests fueled with RON 100 gasoline can be observed in Figure 6. Comparison of power outcome evident across all engine speed. Using RON 100 gasoline with the 11.8 Kg/cm^2 compression engine also produced higher power output than the 10 Kg/cm^2 compression engine. This result confirmed that an engine with higher compression requires a higher octane rating of gasoline to achieve optimal power output [29].

Based on data in Figure 7 clearly showed the power output comparison between the use of three types of fuel, namely RON 92, RON 95, and RON 100, in the 11.8 Kg/cm^2 compression engine in the engine speed range of 5000 rpm to 8000 rpm. It can be observed that the engine using RON 100 fuel produced higher power output than the engine using RON 95 or RON 92 gasoline [19].

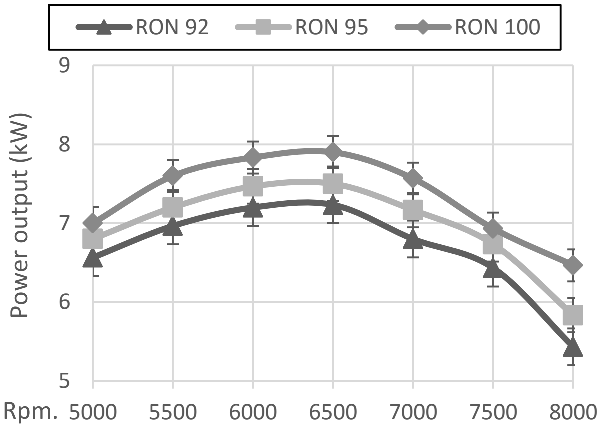

Figure 7. Power Output at 11.8 kg/cm² Compression Pressure Using RON 92, 95 & 100 Fuel

Overall, the engine fueled with RON 100 gasoline can produce power output that is 5.3% higher than the engine using RON 95 and 10% higher than the engine using RON 92 fuel. For instance, at 8000 rpm, the engine using RON 100 gasoline generates a power output of 6.46 kW, while the engine given RON 92 and RON 95 gasoline yielded lower power output with a difference of approximately 0.66 KW and 0.37 kW, respectively. The 11.8 Kg/cm^2 compression engine and using RON 100 gasoline achieved a peak power output of 7.9 kW when running at 6500 rpm. This test result reaffirmed that selecting the appropriate octane rating fuel for high compression engines will yield effective power output [28].

4. CONCLUSION

Internal combustion engine performance is notably affected by both the compression pressure and the octane number of the fuel utilized. The test results indicate that when the 11.8 Kg/cm^2 compression engine uses RON 100 gasoline, it generates the highest torque and power output.

Therefore, selecting fuel with the right octane rating for the engine's compression pressure is crucial to achieving optimal power and torque output. While this testing provides insights into the relationship between compression pressure and fuel octane rating on engine performance, further research is needed to evaluate the impact of octane rating on carbon emissions produced by the engine.

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