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Experimental Study of Performance and Emissions of a 4-Stroke Engine with a Capacity of 110cc

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Abstract
The research aims to identify the influence of variations in spark plugs, ignition coils, and the use of ferrite beads on the performance of a 4-stroke engine with a capacity of 110cc. The research employs various tools for data collection, including a dynamometer for assessing engine performance through torque and power metrics, a gas analyzer for evaluating emissions such as CO, CO_2, O_2, and HC, and a stopwatch and burette for measuring fuel consumption. Data collection involved configurations comprising three types of spark plugs, two ignition coils, and variations with and without ferrite beads. This process was repeated to attain optimal results, followed by data processing. The exhaust gas emissions results indicated that the configuration of coil A2, spark plug Y, and ferrite bead produced the lowest levels of HC and CO. In contrast, CO_2 emissions were the highest among the configurations, while O_2 levels demonstrated relatively favorable results. The fuel consumption measurement results were the lowest in comparison to other configurations. The research findings indicate that the power and torque parameters for engine performance are superior to those of other configurations, demonstrating a 3.33% increase in power and a 5.97% increase in torque. This configuration is recommended based on the research findings.

Keywords: spark plugs, ignition coil, ferrite bead, performa engine, emissions

1. Introduction

As automotive technology advances rapidly, ecological awareness in society is also on the rise. Implementing emission standards is an effective way to mitigate environmental impact [1][2]. Spark plugs are a key component of the ignition system in gasoline engines, affecting how much fuel is burned in the combustion cycle. It is one of the smallest and cheapest components of the internal combustion engine, yet it performs one of the most important tasks, which is to initiate fuel combustion inside the cylinder [3]. Using worn-out or damaged spark plugs that operate at high temperatures in the combustion chamber can lead to uneven engine performance, power loss, or increased fuel consumption [4][5]. Spark plugs play a crucial role in the ignition system by channeling electrical current into the combustion chamber and thereby igniting the compressed air-fuel mixture [6][7]. The primary function of spark plugs is to generate a spark within the combustion chamber that fulfills particular criteria, ensuring the engine operates reliably under low pressure and temperature conditions [8][9][10].

The discharge creates a spark between the center electrode, energized by high voltage and encased in a ceramic insulator, and the side electrode, which is grounded and fitted through the threaded plug body. The body is designed to secure the spark plug within the engine head socket while effectively dissipating heat from the electrode [11]. Spark plugs are capable of producing approximately a thousand sparks per minute within the combustion chamber, functioning under conditions of exceptionally high pressure and temperature [5]. Spark plugs must be properly selected for a specific engine. Its design, namely the shape of the combustion chamber, valve location, spark plug type, and operating parameters, affects the temperature reached inside the cylinder. In practice, many types of spark plug designs are used and adapted to the operating conditions in the combustion chamber of the chosen internal combustion engine: standard with one side electrode; special with multiple side electrodes; U-super with a groove in the side electrode; and experimental designs with a specially shaped insulator [12][13]. Spark plugs transfer ignition energy to the combustion chamber and generate a spark between the ground electrode and center electrode, thereby igniting the fuel-air mixture. Spark plugs operate under challenging conditions, with significant temperature fluctuations. The most important parameters that characterize a spark plug are its self-cleaning temperature and self-ignition temperature [14][15][16].

Motor operation involves a key component called the ignition coil [17]. The ignition coil provides the necessary electrical energy for the spark plug to create a spark within the combustion chamber, which facilitates the combustion process [18][19]. The ignition coil is a device that essentially acts as a step-up transformer to provide the proper spark. Ignition coils are exposed to harsh conditions and can fail due to unnecessary discharge. Insulating materials need to meet certain properties required for insulation. The insulating material must provide resistance to unnecessary discharge by having a higher breakdown voltage. Additionally, the insulating material must be able to transfer heat to the environment and protect the coil from dust particles, grease, and lubricating oil [17][20].

A ferrite bead is a material shaped from ferrite or based on ferrite that is positioned inductively. A ferrite bead serves to attenuate noise and filter specific frequencies, thereby maintaining the integrity of the electrical current in the cable and preventing energy loss. Ferrite beads are employed in motorcycle installations on ignition coils to mitigate noise and interference in the electricity produced by the coil, thereby ensuring optimal electrical flow.

Tucki et al [3] examined the impact of spark plug electrode types on exhaust gas emissions, indicating that the results were reduced when employing iridium material. Research by Bas et al [11] identified variations in spark plug electrode gaps, indicating that iridium spark plugs enhance engine performance and fuel efficiency. Chen et al and Islam et al. assert that coil windings significantly influence the electrical input to the spark plug, thereby enhancing engine performance [17][19]. Muhammad et al. presented findings that demonstrate how differences in spark plugs and ignition coils affect engine performance [21]. A study will be conducted on the variation of spark plugs and ignition coils with and without ferrite beads, based on previous research.

2. Methods

The research for data collection was conducted at the MOSS workshop in Solo using a 4-stroke engine with a capacity of 110cc, where the engine specifications are displayed in Table 1. This research employs dyno test for measuring engine performance in terms of torque and power, a gas analyzer for assessing engine emissions including CO, CO_2, HC, and O_2, and a burette and stopwatch for calculating fuel consumption. The fuel utilized in this study is RON 92, with specifications detailed in Table 2. The research used different types of spark plugs, including Denso U22FS-U, NGK 14 mm, and Iridium IU27, as shown in Figure 1, and their details are listed in Table 3. Figure 2 shows the ignition coil, available in two variants: the PCX 150 brand and the COL 9001 brand. Table 4 presents the specifications, while Figure 3 shows the variations with and without ferrite beads. Table 5 presents the specifications. In this study, the ignition coils are designated as A1 for the PCX 150 brand and A2 for the COL 9001 brand. The spark plugs are classified as X for the Denso U22FS-U brand, Y for the NGK 14 mm brand, and Z for the iridium IU27 brand. This study presents the installation for testing as shown in Figure 4, followed by the subsequent steps of the testing process:

1) Tuning the motor on the dyno test with variations of spark plugs, ignition coils, and ferrite bead;
2) Turning on the fan for cooling;
3) Starting the motorcycle engine;
4) Turn on the gas analyzer and insert the sensor into the exhaust to measure gas emissions;
5) Turning the speed regulator on the motor to quickly increase the engine RPM, where dyno test measure the torque and power parameters;
6) The experiment was repeatedly conducted with variations that included type 3 spark plugs, two ignition coils, and conditions both with and without ferrite beads, ensuring that each variation of data collection was performed three times;
7) Data collection at 5500-8000 rpm;
8) Data processing.

Figure 1. 1) Denso U22FS-U, 2) NGK 14 mm, 3) Iridium IU27

Figure 2. 1) PCX 150 2) COL9001

Figure 3. Ferrite bead

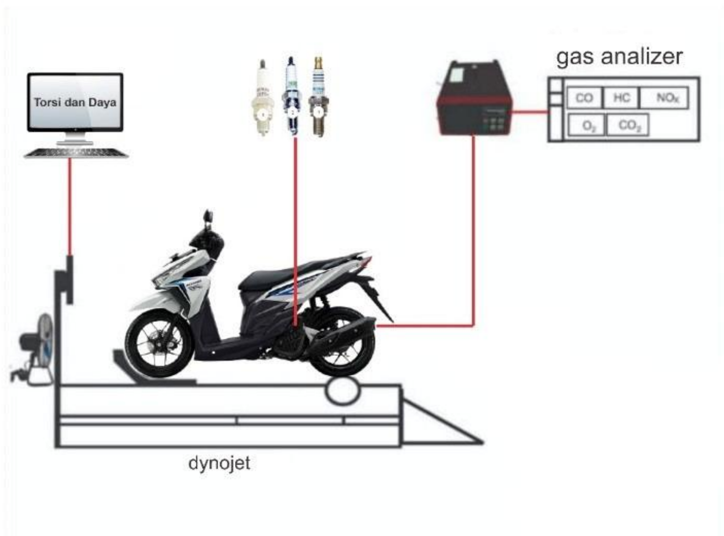


Figure 4. Research installation

Table 1. Engine specifications with a capacity of 110cc

Engine Category	4-stroke, SOHC liquid-cooled
Engine Size	110cc
Stroke x Diameter	55,1 mm x Ø 50 mm

Compression	9,5 : 1
Power	6,4 kW
Torque	9,1 Nm
Lubricant	Wet
Tooth Operation	Automatic
Combustion Work	Injection
Type of coupling	Automatic, Kering, Sentrifugal

Table 2 Specifications of RON 92

Properties	Method	Gasoline (RON 92)
Oxidation Stability (minutes)	ASTM D525	480
Octane Number	ASTM D 2699	92
Content Sulfur (%)	ASTM D 2622	0.05

Table 3. Specifications of Spark Plugs

Parameter	Spark Plugs		
	Denso U22FS -U	NGK 14 mm	Iridium IU27
Electrode Gap	0.9 mm	0.75	0.65
Electrode Diameter	2.5 mm	1 mm	0.6 mm
Electrode Material	Nickel	Platinum	Iridium

Table 4. Specifications of Ignition Coil

Parameter	Ignition Coil	
	PCX 150	COL 9001
Voltage	15.000 V	40.000 V
Primary Coil Resistance	1.5 Ω	1.3 Ω
Cable Diameter	6 mm	6 mm

Table 5. Specifications of Ferrite Bead

Parameter	Spesifikasi
Diameter Kabel	6 mm
Material	Plastic

3. Results and Discussion

We conducted the research and obtained engine performance data in the form of torque and power, along with exhaust emissions data. In this test, modifications were made to the spark plug with different center electrode shapes. Simultaneously, exhaust gases were also analyzed to assess the combustion effects. To simplify the graphs, the spark plugs and coils were given codes, with the Denso U22FS-U spark plug coded X, the NGK 14 mm spark plug coded Y, and the Iridium IU27 spark plug coded Z. The ignition coils were also coded, with the PCX 150 coil coded A1 and the COL9001 coil coded A2. The results will be shown below:

3.1. Power and Torque

The power test results presented in Figure 5 show an increase in power. Each modification indicates an improvement in the performance of spark plugs X, Y, and Z. The maximum power recorded during testing with coil A1 and spark plug X occurs at an engine speed of 7294.45 rpm, resulting in a power output of 5.69 kW. The investigation involving coil A1 and spark plug Y reveals that peak power is achieved at an engine speed of 7485.94 rpm, resulting in a power output of 5.53 kW. The maximum power recorded during testing with coil A1 and spark plug Z occurs at an engine speed of 7468.36 rpm, resulting in a power output of 5.59 kW. The peak power output for the experiment involving coil A2 and a ferrite bead included in spark plug X is 5.57 kW, attained at an engine speed of 7501.14 rpm. In the evaluation including coil A2 and the incorporation of a ferrite bead with spark plug Y, the peak power recorded is 5.73 kW, achieved at an engine speed of 7213.93 rpm. Data was collected for coil A2 with the incorporation of a ferrite bead and spark plug Z, yielding a maximum power output of 5.67 kW at an engine speed of 7470.00 rpm. The experiment with various spark plugs and two ignition coils demonstrated that coil A2, in conjunction with a ferrite bead and spark plug Y, yielded the highest power output. The study demonstrated that employing a spark plug with a center electrode diameter of 1 mm resulted in optimal fuel combustion in the combustion chamber, referred to as stoichiometric combustion. The incorporation of a ferrite bead mitigated excessive noise during the discharge of electricity from the ignition coil, facilitating a greater spark plug firing and enhancing compression.

Figure 6 shows an increase in torque, with each variant exhibiting elevated torque levels for spark plugs X, Y, and Z. Testing with coil A1 and spark plug X indicates that peak torque occurs at an engine speed of 6862.71 rpm, resulting in a torque value of 7.33 Nm. The assessment of coil A1 and spark plug Y indicates that peak torque occurs at an engine speed of 6656.46 rpm, resulting in a torque measurement of 7.28 Nm. The maximum torque for coil A1 and spark plug Z is achieved at an engine speed of 6484.74 rpm, yielding a torque value of 7.48 Nm. The experiment involving coil A2 and the incorporation of a ferrite bead with spark plug X yielded a maximum torque of 7.44 Nm at an engine speed of 6565.26 rpm. In the test with coil A2 and the ferrite bead with spark plug Y, the highest torque recorded is 7.67 Nm, reached at an engine speed of 6514.42 rpm. The evaluation, including coil A2 and the incorporation of a ferrite bead with spark plug Z, yields a peak torque of 7.59 Nm at an engine speed of 6569.77 rpm. The experiment's six variants revealed that the peak maximum torque of 7.67 Nm was attained with coil A2, the inclusion of a ferrite bead, and spark plug Y at an engine speed of 6514.42 rpm. Spark plug Y features a center electrode measuring 1 mm and employs coil A2, supplemented with a ferrite bead. The 1 mm center electrode dimension creates a greater spark jump, resulting in a stronger compression surge and higher torque. The dimensions of the central electrode facilitate a larger spark discharge, thereby allowing the spark plug to attain optimal combustion. Moreover, the incorporation of a ferrite bead on coil A2 mitigates noise in the ignition coil wire, facilitating an increased electrical flow to the spark plug, so producing a more substantial spark and enhanced compression.

Figure 7 shows the comparison results of all research configurations for power and torque parameters, indicating that the use of coil A2 + spark plug Y + ferrite beads results in better engine performance compared to other configurations. The percentage increase for torque and power is 3.33% and 5.97%, respectively, compared to other uses.

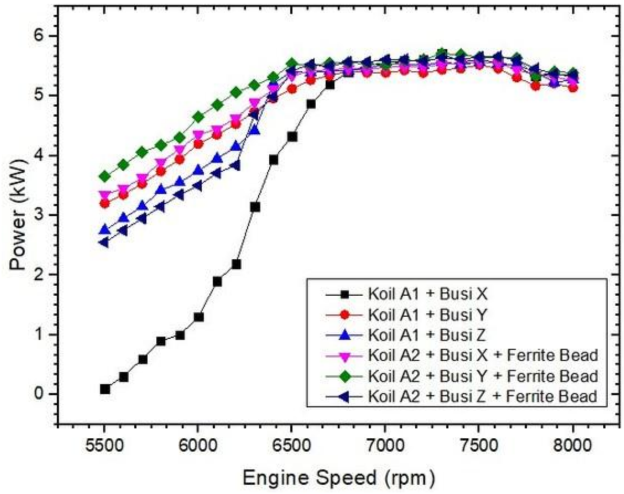


Figure 5. Engine Break Power

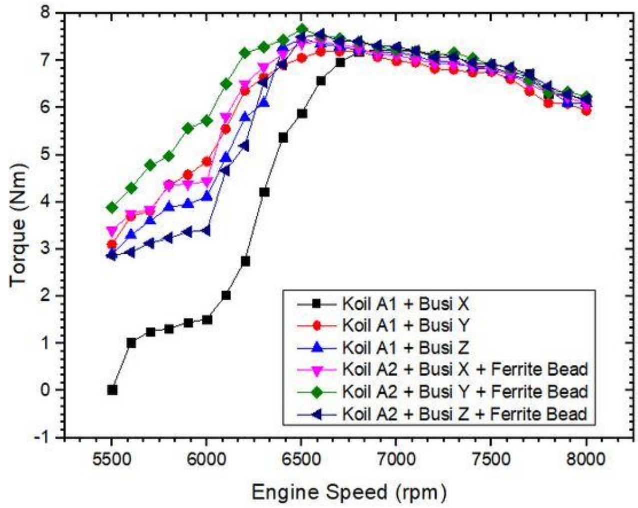


Figure 6. Engine Break Torque

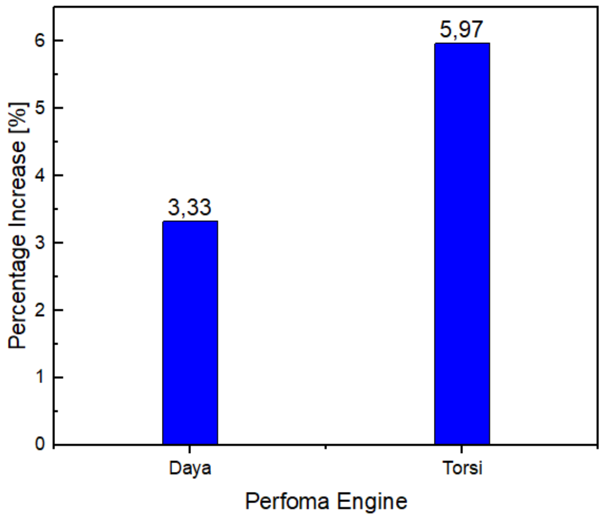


Figure 7. Percentage Increase Daya and Torsi

3.2. Fuel Consumption

The engine performance data for fuel consumption shown in Figure 8 reveals that all configurations demonstrate a decrease in fuel consumption at 5500-6500 rpm, followed by an increase at 7000-8000 rpm. At 8000 rpm, the fuel consumption rates for Coil A1 with Spark Plug X, Spark Plug Y, and Spark Plug Z are 0.161 kg/h.hp, 0.173 kg/h.hp, and 0.141 kg/h.hp, respectively. The addition of a ferrite bead to Coil A2+Spark Plug X, Coil A2+Spark Plug Y, and Coil A2+Spark Plug Z yields fuel consumption rates of 0.135 kg/h.hp, 0.125 kg/h.hp, and 0.139 kg/h.hp, respectively. The examination of the fuel consumption curve reveals that the combination of Coil A2, Spark Plug Y, and Ferrite Bead demonstrates the lowest fuel consumption compared to alternative configurations. The integration of a ferrite bead enhances the electrical supply for optimal ignition, resulting in improved fuel efficiency.

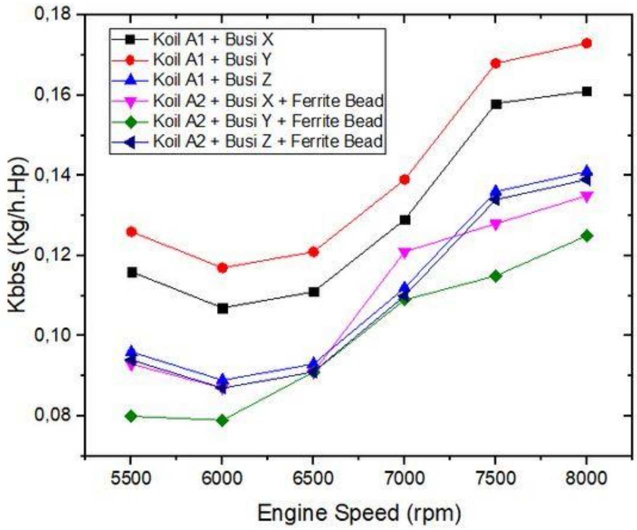
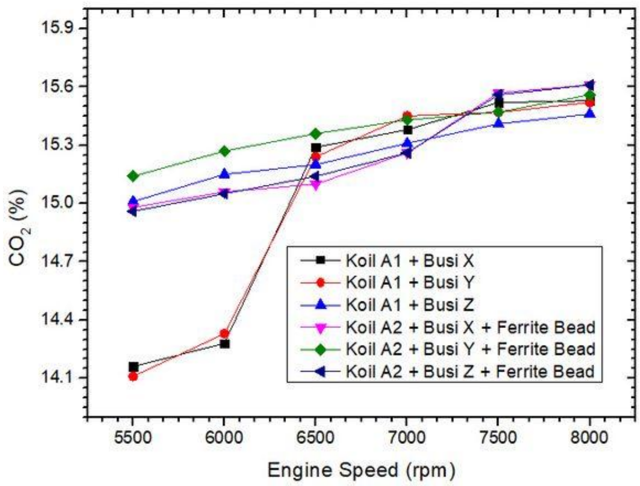


Figure 8. Fuel Consumption

3.3. *Emissions*

Figure 8 shows how the exhaust gas emissions consist of HC, CO_2, CO, and O_2. At increased engine speeds, all exhaust gas emissions decrease, except for CO_2. Figure 8 (1) shows carbon monoxide (CO_2) emissions from the exhaust rise when the motorcycle is started at high engine speeds, especially at 8000 rpm. The experiment conducted in coil A1 utilizing spark plug X resulted in a CO_2 concentration of 15.53%. The assessment of coil A1 in conjunction with spark plug Y yielded a CO_2 concentration of 15.52%. The experiment using coil A1 and spark plug Z produced a CO_2 concentration of 15.46%. Testing with coil A2, a ferrite bead, and spark plug X yielded a CO_2 level of 15.61%. Testing of coil A2 with a ferrite bead and spark plug Y yielded a CO_2 measurement of 15.56%, whereas testing with spark plug Z resulted in a CO_2 measurement of 15.61%. A high carbon dioxide concentration is essential for an optimal combustion process, as increased carbon dioxide levels during engine combustion enhance efficiency. The test results indicate elevated carbon dioxide (CO_2) levels correlated with high engine rpm. Figure 8 (2) shows the results of carbon monoxide (CO) emissions. For the experiment with coil A1 using spark plug X, CO emissions were obtained at 1.08%. During testing with coil A1 using spark plug Y, CO emissions were obtained at 1.06%. For testing with coil A1 using spark plug Z, CO emissions were obtained at 1.03%. During testing with coil A2 with the addition of a ferrite bead using spark plug X, CO emissions were obtained at 1.09%. During testing with coil A2 with the addition of a ferrite bead using spark plug Y, CO emissions were obtained at 1.06%, and for testing with coil A2 with the addition of a ferrite bead using spark plug Z, CO emissions were obtained at 1.07%. The level of carbon monoxide (CO) emissions in motorcycles is controlled by the air-fuel ratio. When a motorcycle runs at a high air-fuel ratio, carbon monoxide (CO) is produced. There is not enough oxygen to convert all the carbon into carbon dioxide (CO_2), so some fuel cannot be burned, and some carbon ends up as CO. Figure 8 (3) shows the results of hydrocarbon emissions. For the experiment with coil A1 using spark plug X, HC emissions were obtained at 62.67 ppm. During testing with coil A1 using spark plug Y, HC emissions were obtained at 57.67 ppm. For testing with coil A1 using spark plug Z, HC emissions were obtained at 51.00 ppm. During testing with coil A2 with the addition of a ferrite bead using spark plug X, HC emissions were obtained at 53.33 ppm. During testing with coil A2 with the addition of a ferrite bead using spark plug Y, HC emissions were obtained at 51.67 ppm, and for testing with coil A2 with the addition of a ferrite bead using spark plug Z, HC emissions were obtained at 53.33 ppm. Hydrocarbon emissions are the result of incomplete combustion in the combustion chamber. Some studies also suggest that non-stoichiometric air-fuel ratios can lead to incomplete combustion. An increase in hydrocarbon emissions indicates that engine power continues to decrease and fuel consumption continues to increase. Figure 8 (4) shows the results of oxygen (O_2) emissions testing. For the experiment with coil A1 using spark plug X, O_2 emissions were obtained at 1.82%. During testing with coil A1 using spark plug Y, O_2 emissions were obtained at 1.65%. For testing with coil A1 using spark plug Z, O_2 emissions were obtained at 1.72%. During testing with coil A2 with the addition of a ferrite bead using spark plug X, O_2 emissions were obtained at 1.65%. During testing with coil A2 with the addition of a ferrite bead using spark plug Y, O2 emissions were obtained at 1.71%, and for testing with coil A2 with the addition of a ferrite bead using spark plug Z, O2 emissions were obtained at 1.64%. Oxygen content in the combustion process must be balanced for stoichiometric or perfect combustion to occur. If oxygen remains in the combustion chamber, perfect combustion will not occur. The addition of a ferrite bead also affects this.



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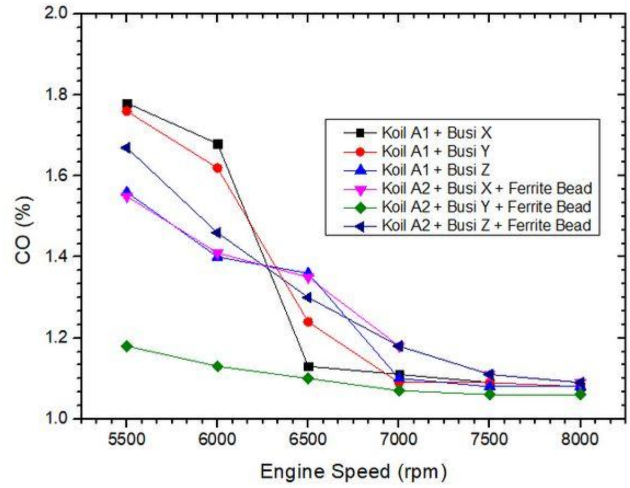

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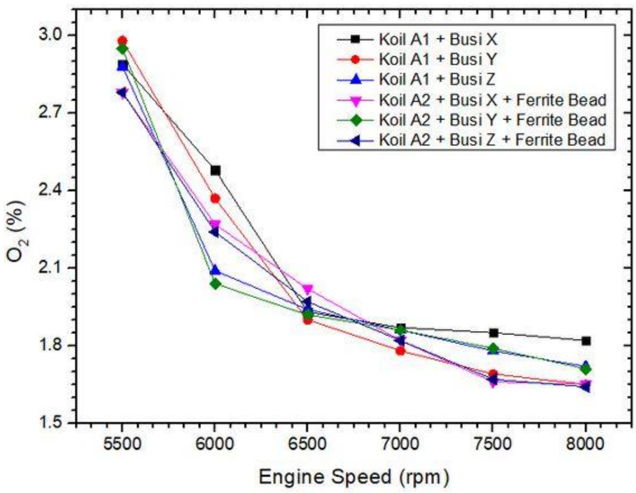

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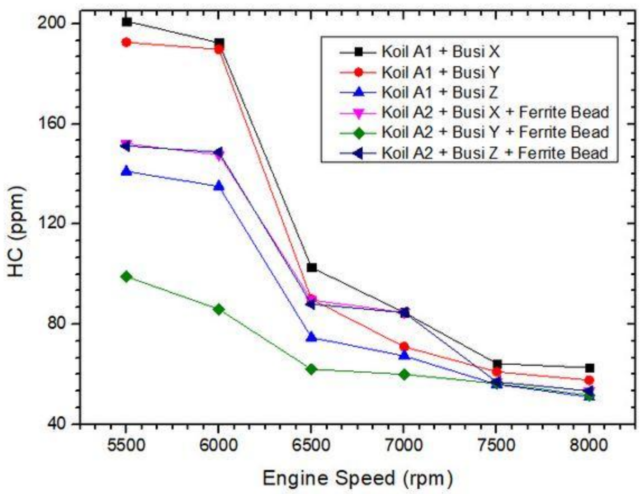

(4)

Figure 8. 1) CO_2, 2) CO, 3) O_2, 4) HC

4. Conclusion

Engine performance and exhaust pollutants were meticulously examined for various spark plugs paired with different ignition coils. The evaluation was performed utilizing three spark plugs: Denso U22FS-U, NGK 14 mm, and Iridium IU27, alongside two distinct ignition coil types, including the COL9001 coil augmented with a ferrite bead. The findings indicated that the NGK 14 mm spark plug, in conjunction with the COL9001 ignition coil and the inclusion of a ferrite bead, yielded the most torque and power, achieving a torque of 7.67 Nm at 6514.42 rpm and a power output of 5.73 kW at 7213.93 rpm. The optimal results for exhaust emissions were achieved using the NGK 14 mm spark plug in conjunction with the COL9001 ignition coil and the addition of a ferrite bead for CO, CO2, HC, and O2 emissions.

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