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Effect of Coconut Shell-Based Active Carbon Adsorbent on Motorcycle Exhaust Gas Emissions

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ABSTRACT

This study focused on the utilization of active carbon derived from coconut shells as an adsorbent to reduce exhaust gas emissions in motorcycles. The research aimed to compare the exhaust emissions before and after installing active carbon in the muffler and to analyze its effect on the levels of CO, HC, and CO_2 at different engine speeds. A laboratory experiment was conducted with varying masses of active carbon, and emission data were collected and analyzed using two-way ANOVA. The results demonstrated that with the use of 200 grams of active carbon, the CO emission decreased by 12.06%, HC by 16.96%, and CO_2 by 9.17%. These reductions are attributed to the strong adsorptive properties of active carbon, which facilitated the physical and chemical separation of harmful gases. The study concluded that active carbon significantly reduces exhaust emissions, providing a practical solution for improving air quality in motorcycles. The findings offer an effective method for emission control that could be applied under various operating conditions, making it suitable for widespread implementation in emission-reduction systems for small engines.

Keywords: Active carbon, exhaust gas emissions, coconut shell, emission reduction, motorcycle muffler, CO HC CO_2 emissions

1. INTRODUCTION

Currently, motorcycle exhaust emissions are a significant environmental issue, particularly in urban areas where motorcycles are a common mode of transportation, especially in developing countries. Motorcycles are a major contributor to air pollution, emitting harmful gases such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which negatively impact human health and the environment [1] Studies show that two-stroke motorcycle engines, in particular, produce high levels of HC due to incomplete combustion. In this context, finding effective and sustainable solutions to control motorcycle emissions is crucial.[2] One of the main challenges in controlling motorcycle emissions is the high levels of CO and HC, particularly under conditions of incomplete combustion. Carbon monoxide is produced when fuel is not fully burned, while HC emissions result from the breakdown of fuel into other hydrocarbon clusters that are not fully combusted [3] Previous research has indicated that controlling CO and HC emissions in motorcycles remains difficult because internal combustion engines often operate at low speeds, where the air-fuel mixture tends to be richer [4] To address exhaust emissions, adsorption technology using activated carbon presents a promising solution. Activated carbon, especially that derived from coconut shells, has excellent pore structure and high surface area, making it an ideal material for trapping pollutants like CO and HC [5]

Therefore, coconut shell-based activated carbon can serve as an effective adsorbent to reduce motorcycle exhaust emissions, while also offering an environmentally friendly solution by utilizing agricultural waste [6] [7] [8] The utilization of this agricultural waste not only helps address environmental issues related to exhaust emissions but also mitigates the impact of poorly managed agricultural waste.

Coconut shell-based activated carbon is widely recognized for its ability to adsorb small molecules, including harmful gases like CO and HC, due to its microporous structure and large surface area [9] In this study, the variation in activated carbon mass used significantly influences the reduction of exhaust emissions, as demonstrated in previous studies [10] carbon monoxide [11] metal cadmium, copper, and lead [12] as well as hydrocarbons [13] The use of activated carbon as an adsorbent offers a cost-effective and sustainable alternative for controlling vehicle emissions.[14] and active sampling [15] Passive sampling takes a relatively long time (about one week) compared to active sampling, which only takes 25 minutes. Both passive and active sampling use activated carbon as an adsorbent. The NIOSH standard states that the mass of activated carbon from coconut shells used for sampling is 100 mg, and 50 mg are used in one sorbent tube [16] The mass of activated carbon is equivalent to 1.5 and 1 cm long in a sorbent tube with an inner diameter (ID) of 0.4 cm. However, studies on the effect of mass or thickness of activated carbon on the adsorption capacity of carbon pollutants in motor vehicle emissions (gas phase) have not been reported [1] This research is preliminary, and the first research related to motor vehicle emission adsorption using coconut shellbased activated carbon. Thus, research on the effectiveness of coconut shell-based activated carbon as an adsorbent for motorcycle exhaust emissions is highly relevant in the search for solutions to reduce the negative impacts of air pollution. In addition to contributing to emission reduction, this research also has the potential to enhance sustainability practices by utilizing renewable and abundant natural resources. Identifying the gaps in existing research is crucial for understanding how the current study advances knowledge in the field. In previous studies, the use of activated carbon for reducing exhaust emissions has been explored with various base materials, such as coal, wood, and other agricultural wastes [17]. However, research on the use of coconut shell-based activated carbon as an adsorbent specifically for motorcycle exhaust emissions remains limited. Most prior studies have focused on activated carbon's application in larger vehicles or stationary sources, neglecting the unique combustion characteristics of motorcycles, particularly under varying engine loads and speeds [18]. Additionally, while previous research has primarily concentrated on optimizing activation methods and enhancing adsorption properties of the carbon itself [19], limited work has been conducted to explore the direct correlation between the mass of activated carbon and its effect on different types of emissions (CO, HC, CO_2) in motorcycles under real-world conditions [20]. Another gap lies in the lack of a systematic comparison of the effectiveness of different carbon mass variations on emission reductions, which could offer valuable insights into the practical application of this technology [21]. Furthermore, prior research has not extensively addressed the sustainability benefits of using coconut shells, an abundant agricultural waste product, as a raw material for activated carbon production [22]. Given these gaps, the current study aims to investigate the effect of coconut shell-based activated carbon adsorbent on motorcycle exhaust emissions, focusing on CO, HC, and CO_2. The research seeks to determine the optimal mass of activated carbon that effectively reduces emissions and assess the environmental benefits of utilizing coconut shell waste as an alternative, sustainable adsorbent material. Ultimately, the goal of this research is to contribute to the development of an affordable and sustainable solution to reduce motorcycle exhaust emissions while enhancing the utilization of coconut shell waste.

2. RESEARCH SIGNIFICANCE

This research explores the potential of using coconut shell-based activated carbon as an adsorbent for reducing motorcycle exhaust emissions, particularly carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2), which contribute to air pollution. The study examines the production process of activated carbon, including dehydration, carbonization, and activation using sodium chloride (NaCl), highlighting its enhanced adsorption capacity through structural changes evidenced by SEM-EDX tests. Additionally, the research tests the effectiveness of this activated carbon in motorcycle exhaust systems by measuring emissions at various engine speeds and adsorbent mass variations. While the study demonstrates a reduction in harmful emissions, its broader significance in contributing to air pollution mitigation and the optimization of local resources for pollutant treatment remains unclear.

3. RESEARCH METHODS

3.1 Preparation of activated carbon (dehydration and carbonization)

The first process in the manufacture of activated carbon is the search for raw materials which is the tempurungkelap in the soybean plantation located in Malang Regency. The dehydration process of tempurungkelap is carried out by drying under the sun for 8 hours. The second process is the carbonization process, the carbonization process in this study is carried out by inserting the coconut shell that has been placed in a 50 ml porcelain crucible and then heated in a furnace with a temperature of 500 ° C for 60 minutes.

3.2 Preparation of activated carbon (activation)

The third process is Activation, in this research the activating solution used is Sodium Chloride (HCl). Before soaking with NaCl solution, the carbon powder produced from the carbonization process is crushed and then filtered with a sieve to obtain the same size carbon powder. The ratio of carbon powder to NaCl solution is 1:5 (1 gram carbon powder: 5 ml NaCl solution). Carbon powder that has passed the filter is then soaked with Hydrogen Chloride (NaCl) solution for 3 hours. After soaking the next stage carbon powder is filtered using filter paper and washed using distilled water until the wash water is clean and the pH is close to 7. Then the carbon powder which is still wet is dried in the sun for 1 day. After that, the carbon powder was put into a 50 ml porcelain crucible and oven at 108°C for 3 hours.

3.3 Exhaust gas emission data collection

Exhaust emissions data were collected using the Tecnotest MOD 488 tool. The adsorption media that has been made is installed on the exhaust. For measurements with the Tecnotest MOD 488 gas analyzer, the first tool must be used. calibrated first. The probe on the gas analyzer is inserted into the exhaust with the length of the probe entering ± 30 cm. Exhaust emission test data can be seen on the LCD of the Tecnotest MOD 488 measuring instrument. For Tecnotest MOD 488, if the data taken is sufficient, press hold on the measuring instrument and print to print the measurement results. Taking data on exhaust emissions without the addition of adsorbents, the test steps are the same as the addition of adsorbents.

Data Processing

In this research, data processing will be carried out as follows:

1. Exhaust gas emission test data is entered into the data retrieval table.
2. After the data is complete, the data is processed using the Two Way Anova method.

3. To facilitate data analysis, the data is converted into a comparison graph.
4. After data processing and analysis is complete, conclusions are drawn and the effect of mass variation with variation in adsorbent surface area on exhaust can be known.

4. RESULTS AND DISCUSSION

4.1 Preparation of Activated Carbon

4.1.1 Dehydration and Carbonization Process

The first process in making activated carbon is the search for raw materials, namely coconut shell. Before the dehydration process, the coconut shell is cleaned and then formed into small pieces first. The coconut shell dehydration process is carried out by drying in the sun for 8 hours as shown in Figure 1.

Fig 1. Coconut Shell Dehydration Process

The second process is the carbonization process, the carbonization process in this study is carried out by inserting the coconut shell that has been formed into small pieces into a 50 ml porcelain crucible. The next step coconut shell that has been placed in a 50 ml porcelain crucible is then heated using a furnace with a temperature of 500ºC for 90 minutes. The results of carbonization can be seen in Figure 2.

Fig 2. Results of Coconut Shell Carbonization

4.1.2 Activation Process

The third process is activation, in this study the activating agent used is Sodium Chloride (NaCl). Before soaking in NaCl, the charcoal from the coconut shell was blended and filtered using a 60 mesh sieve. Carbon powder that has passed the filter is then soaked with 20% NaCl solution for 24 hours as shown in Figure 3 below.

Fig 3. Carbon Activation Process

After soaking, the next stage of carbon powder is filtered using filter paper and washed using distilled water until the filtrate water is neutral and then dried in a furnace at 105ºC for 3 hours.

4.2 SEM EDX Testing

Before and after activation of carbon powder, SEM EDX (Scanning Electronic Microscopy Energy Dispersive X-ray) test was conducted to determine the content and surface of coconut shell activated carbon. The results of the SEM EDX test for coconut shell activated carbon can be seen in Figure 4 and 5.

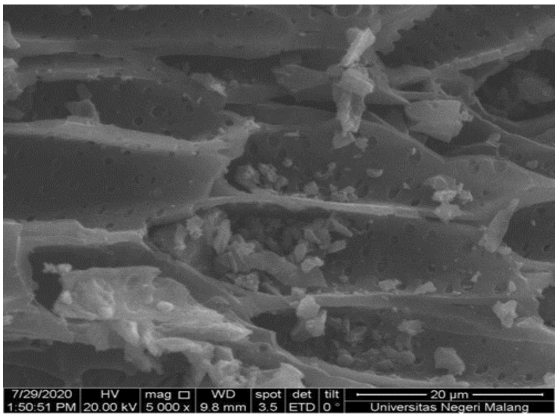

Fig 4. Carbon Surface Before Activation

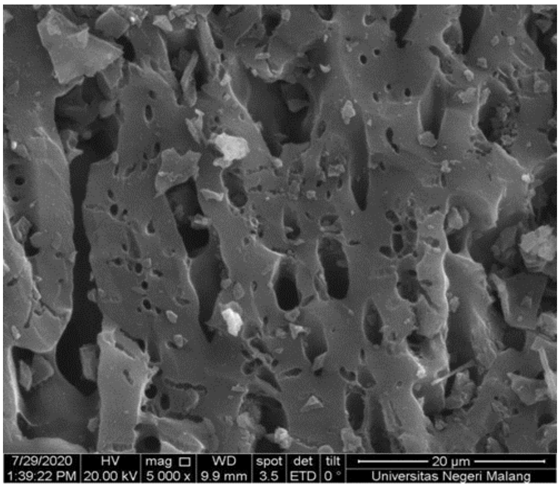

Fig 5. Carbon Surface After Activation

Figure 4 and 5 shows the surface of the carbon. From the picture above, we can see the difference in the surface of the carbon before activation and after activation. The surface of activated carbon after activation using NaCl experienced the formation of a new surface that is more regular and looks clean. Figures 4 and 5 illustrate the morphological changes in the surface of carbon before and after the activation process using NaCl. From these images, it is evident that the activation process led to the formation of a new, more regular surface structure. This surface appears smoother and cleaner compared to the untreated carbon. These changes suggest that the activation process plays a significant role in improving the physical properties of the carbon, making it more effective for adsorption applications, particularly in filtering CO gas emissions from exhaust gases. The surface structure of carbon before activation typically exhibits an irregular, rough texture. This is due to the presence of natural impurities and the non-uniform structure of raw coconut shell carbon. Activation with NaCl induces several changes in the carbon's surface morphology, primarily by removing volatile organic components and other impurities during the carbonization and chemical activation processes. This results in a cleaner, more porous surface, which is a critical factor in enhancing the adsorptive capacity of activated carbon. Several studies have shown that chemical activation with salts such as NaCl can significantly increase the porosity and surface area of carbon, which directly influences its adsorption performance [23] The variation in activated carbon mass plays a crucial role in the efficiency of CO gas adsorption. A higher mass of activated carbon increases the available surface area for gas interaction, which in turn enhances the adsorption capacity. The graph comparing CO emissions with different masses of activated carbon reveals that as the mass of the adsorbent increases, the concentration of CO gas in the exhaust decreases. This inverse relationship can be attributed to the greater number of active sites available for gas adsorption, resulting from the increased mass of activated carbon. Other researchers have explored the relationship between adsorbent mass and pollutant adsorption, with findings indicating that an increase in the adsorbent mass typically leads to a higher removal efficiency for gases like CO, provided that the system does not reach saturation [24]. However, it is important to note that the efficiency of CO adsorption is not solely dependent on the mass of activated carbon. The surface area, pore structure, and the nature of chemical activation also play a vital role in determining the adsorption capacity. While increasing the mass of activated carbon improves adsorption efficiency, there is an optimal range beyond which the benefits plateau due to mass transfer limitations. Simply increasing the mass without optimizing pore structure or activation techniques may result in diminishing returns [25]. Activated carbon adsorbs gases through physical and chemical interactions between the gas molecules and the carbon surface. The adsorption capacity of activated carbon depends on the Van der Waals forces and the surface characteristics, including the presence of functional groups introduced during the activation process. In this study, activation with NaCl enhances the surface properties, which increases the carbon's affinity for CO molecules. The enhanced surface area, combined with the presence of more functional groups, allows for more effective adsorption of CO gas molecules, leading to lower exhaust emissions. This mechanism is supported by findings that chemical activation improves the pore structure and introduces functional groups that increase the adsorptive interaction between the carbon surface and gas molecules [26]. The activation of carbon using NaCl significantly alters the surface morphology of the material, resulting in a more regular and clean surface with enhanced adsorption properties. The increase in adsorbent mass improves the CO adsorption efficiency, as reflected in the reduction of CO emissions in the exhaust tests. These findings are consistent with previous literature, which emphasizes the importance of surface area, pore structure, and activation methods in optimizing carbon's adsorption performance. However, the relationship between mass and adsorption efficiency follows a trend that may reach saturation, suggesting that further optimization in activation processes may yield better results without solely relying on increasing the mass. To see the effect of activated carbon mass variation on CO gas emissions more clearly can be seen in the Fig 6.

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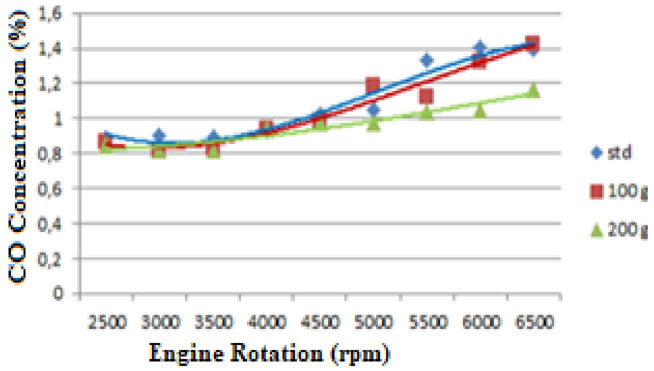

Fig 6. The Activated Carbon Mass Variation Against CO Emissions

Figure 6 show that CO emissions are high because the engine rotation is at low rpm, so it requires more fuel mixture so that the engine is easy to start the mixture becomes rich. The rich mixture causes the fuel to not burn completely, resulting in high CO emissions. But when the engine rotation is at 3000 to 3500 rpm CO emissions tend to decrease, this is due to the increasingly ideal fuel and air mixture and the achievement of engine working temperature. After engine speed is above 4000 rpm, CO emissions increase because at this rpm a rich fuel mixture is required. So that the CO gas emissions that come out increase as well. The richer the mixture of fuel and air, the more CO levels in the resulting emissions. Meanwhile, if the air used in the fuel mixture is more, the CO levels produced will be less. In the combustion process, oxygen is needed to break down the CO that is burned. The analysis of the graph in Figure 6 reveals important insights into the behavior of CO emissions at different engine speeds, primarily related to the fuel-air mixture and combustion efficiency. CO emissions are higher at lower engine rotations per minute (rpm), specifically when the engine is idling or operating at low speeds. This can be attributed to the rich fuel mixture required during initial ignition, where the engine needs more fuel to compensate for insufficient airflow, ensuring smooth operation. However, a rich fuel mixture means that not all of the fuel combusts completely, resulting in higher CO emissions. This finding is consistent with existing literature that states CO levels rise when excess fuel remains unburned due to inadequate oxygen during the combustion process [27] As the engine rotation increases to around 3000 to 3500 rpm, the fuel and air mixture becomes more balanced, allowing for more complete combustion. This results in lower CO emissions, as the engine reaches its ideal operating temperature and efficiency. This is a typical behavior observed in combustion engines, where optimal engine speeds facilitate better fuel-air mixing, leading to reduced incomplete combustion and lower CO output [28]. However, at engine speeds above 4000 rpm, the CO emissions rise again. This is due to the need for a richer fuel mixture at higher engine speeds to maintain performance, leading to incomplete combustion of the fuel. At this stage, the richer mixture provides more fuel than the oxygen available for combustion, causing an increase in CO emissions. The relationship between engine speed and CO emissions aligns with studies that show how variations in fuel-air ratios at different engine loads and speeds impact the production of CO, with richer mixtures always leading to higher CO levels [29] The use of adsorbents, as indicated by the graph in Figure 6, demonstrates a positive impact on reducing CO emissions. The addition of activated carbon adsorbents significantly lowers the emission levels compared to the scenario without adsorbents. Activated carbon works by adsorbing pollutants like CO from the exhaust gases, reducing their concentration in the emissions. Among the tested variations, the use of 200 grams of activated carbon yields the most effective results, achieving a 12.06% reduction in CO emission levels. This suggests that an optimal mass of activated carbon provides sufficient surface area and adsorption sites to capture CO molecules efficiently. The results highlight the critical role of activated carbon's adsorptive properties in emission control. Several studies have reported the effectiveness of activated carbon in reducing CO, NOx, and other harmful gases from exhaust systems. The porous structure of activated carbon, combined with its large surface area, enhances the adsorption of gas molecules, thereby decreasing the emission levels of pollutants like CO [30] Moreover, the efficiency of adsorption depends on the surface characteristics of the activated carbon, which are improved through processes like chemical activation, as employed in this study. Higher masses of adsorbents, as seen in the 200-gram variation, provide more adsorption capacity, leading to better performance in reducing CO emissions [31]. In conclusion, the addition of activated carbon adsorbents significantly improves the reduction of CO emissions, with the 200-gram mass showing the best results in this study. These findings align with existing research on the effectiveness of activated carbon in filtering exhaust emissions, particularly in conditions where fuel-rich mixtures increase the production of CO. The observed decrease in CO emissions at mid-range engine speeds also reflects the improved combustion efficiency when the fuel-air mixture reaches an optimal ratio. However, higher engine speeds that require richer fuel mixtures still present challenges in reducing CO emissions, underscoring the need for further optimization of adsorbent properties and mass for better emission control. From the graph in Figure 6 above, it can be seen that the addition of adsorbents affects the exhaust emissions produced. With the addition of adsorbents, the exhaust emissions produced are lower than without the addition of adsorbents. Based on the graph in Figure 4.8, it can be seen that the best reduction in exhaust emissions is in the 200 gram activated carbon mass variation with a percentage reduction in CO emission levels of 12.06%.

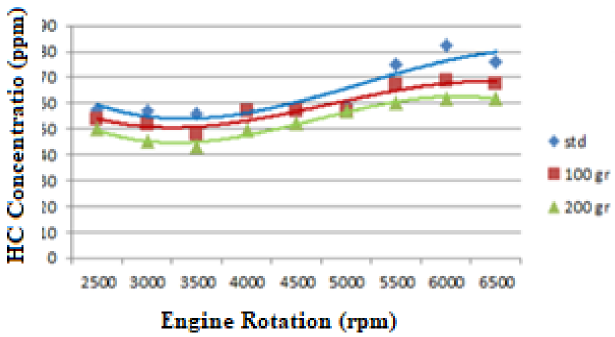

Fig 7. The Mass Variation of Activated Carbon against HC Emissions.

Figure 7 show that at low revolutions, the engine working temperature has not been reached, therefore the fuel mixture tends to be rich so that in the combustion process the fuel does not burn completely or is split due to heat reactions and forms other HC clusters that come out with the exhaust gas. This causes HC emissions to be high. When the engine speed increases to 3500 rpm, the fuel and air mixture is close to ideal so that HC emissions decrease. When the engine speed is above 3500 rpm, more fuel supply is needed so that the incomplete combustion process occurs again, resulting in high HC emissions again. The graph in Figure 7 illustrates the relationship between engine speed and hydrocarbon (HC) emissions, which are influenced by the fuel-air mixture and combustion efficiency. At low engine revolutions per minute (rpm), the engine has not yet reached its optimal operating temperature, leading to a rich fuel mixture. This excess fuel does not fully combust due to the incomplete heat reaction, resulting in unburned hydrocarbon clusters escaping with the exhaust gases. As a result, HC emissions are high at these low rpm levels. This behavior is consistent with combustion engine theory, which states that at lower temperatures, the fuel does not ignite efficiently, leading to higher emissions of unburned hydrocarbons [32]. As engine speed increases to 3500 rpm, the fuel and air mixture approaches the ideal stoichiometric ratio, enabling more complete combustion. This results in a significant reduction in HC emissions. At this mid-range rpm, the engine operates more efficiently, burning most of the fuel, which reduces the number of unburned hydrocarbons exiting the exhaust system. Several studies have confirmed that optimal engine performance occurs at these moderate speeds, where the balance between fuel and air supports more efficient combustion, lowering emissions [33]. However, as engine speed exceeds 3500 rpm, HC emissions rise again. This is due to the increased demand for fuel at higher engine speeds, requiring a richer mixture. The excess fuel leads to incomplete combustion, with some fuel not fully burning before it exits the combustion chamber, increasing HC emissions. This phenomenon is well-documented in research that explains how high engine loads and rich fuel mixtures at higher speeds lead to more unburned fuel being released as HC emissions [34]. The graph also highlights the effectiveness of activated carbon in reducing HC emissions. The addition of activated carbon adsorbents significantly lowers the HC emission levels across the engine speed range, as shown in Figure 7. Activated carbon's porous structure and large surface area allow it to adsorb unburned hydrocarbons from the exhaust gases, reducing the overall emission levels. Among the tested mass variations of activated carbon, the 200-gram sample shows the most substantial reduction in HC emissions, achieving a 16.96% decrease. This reduction can be attributed to the enhanced adsorption capacity provided by the increased mass of activated carbon. The larger amount of activated carbon offers more surface area and adsorption sites, allowing it to capture more hydrocarbon molecules from the exhaust stream. Activated carbon's efficiency in adsorbing volatile organic compounds (VOCs) and other pollutants like HC has been supported by numerous studies. These studies emphasize how activated carbon's high porosity and adsorption capabilities can effectively mitigate emissions, particularly in automotive applications [35]. In conclusion, the findings from Figure 7 indicate that engine speed plays a crucial role in determining HC emissions, with lower and higher rpm levels producing higher emissions due to inefficient combustion. The addition of activated carbon adsorbents, particularly in the 200-gram variation, effectively reduces these emissions, demonstrating the potential for activated carbon to play a significant role in controlling exhaust emissions in internal combustion engines. These results are in line with previous research highlighting the benefits of adsorbent materials in reducing VOCs and hydrocarbons from combustion systems, and they suggest that further optimization of adsorbent mass could lead to even greater reductions in harmful emissions. The rise and fall of HC levels produced is caused by the amount of fuel supply mixed with clean air. A poor mixture also results in greater levels of HC produced due to the slow combustion process that occurs so that the fuel will come out before the fuel burns completely. The effect of activated carbon mass variation on HC emissions can be seen more clearly in the graph in Figure 7 above. Based on the graph in Figure 6 it can be seen that the best reduction in exhaust emissions is in the 200 gram activated carbon mass variation with a percentage reduction in HC emission levels of 16.96%.

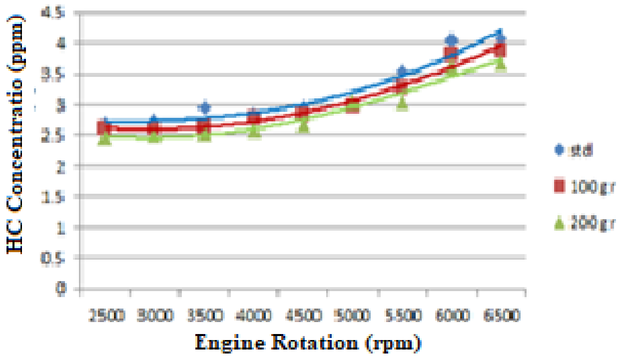

Fig 8. The Mass Variation of Activated Carbon Against CO_2 Emissions

In the graph in Figure 8, it can be seen that at low revolutions CO_2 gas emissions are also low, this is because the mixture of air and fuel is rich so that exhaust emissions come out in the form of high CO and HC, while CO_2 is low. As engine speed increases, the fuel mixture becomes more ideal so that CO_2 emissions also increase. The graph in Figure 8 provides insights into the behavior of carbon dioxide (CO_2) emissions at varying engine speeds and the influence of activated carbon adsorbents on reducing those emissions. At low revolutions per minute (rpm), CO_2 emissions are relatively low due to the rich fuel mixture, which results in incomplete combustion. In this scenario, exhaust gases primarily consist of unburned hydrocarbons (HC) and carbon monoxide (CO), while CO_2 levels are lower. This is because CO_2, a product of complete combustion, requires a more ideal air-to-fuel ratio to form in higher concentrations. The findings align with combustion principles that show a direct relationship between efficient fuel combustion and higher CO_2 emissions, as CO_2 is the primary indicator of combustion efficiency [36] As engine speed increases, the fuel mixture becomes more balanced, nearing the stoichiometric ratio. In this range, combustion becomes more complete, resulting in an increase in CO_2 emissions. This is a well-established trend in automotive emission studies, where more ideal combustion conditions—such as those at mid-range engine speeds—lead to more CO_2 being formed as fuel is burned more thoroughly [37]. At higher rpm, the engine reaches an optimal working temperature and fuel-air ratio, improving the combustion process. CO_2 emissions rise correspondingly, signaling that the engine is operating at a higher efficiency and that more of the fuel is being fully combusted into CO_2 rather than CO or HC. However, while higher CO_2 levels are generally indicative of more complete combustion, the goal of reducing overall emissions—especially greenhouse gases like CO_2—remains critical. This is where the addition of activated carbon adsorbents becomes significant. Activated carbon is known for its high surface area and adsorption capacity, particularly for trapping volatile organic compounds (VOCs) and other pollutants. The graph in Figure 8 demonstrates that the incorporation of activated carbon into the exhaust system helps reduce CO_2 emissions, with the 200-gram mass variation proving to be the most effective. This variation results in a 9.17% reduction in CO_2 emissions. The reduction in CO_2 emissions with activated carbon can be attributed to its adsorption efficiency and catalytic properties. Activated carbon adsorbs unburned hydrocarbons and other volatile compounds, potentially decreasing the formation of CO_2 in the combustion process. Research has indicated that activated carbon can also promote the breakdown of intermediate carbon-containing species before they fully oxidize to CO2, thereby limiting the amount of CO_2 released into the atmosphere [38]. This ability to adsorb and chemically interact with pollutants suggests that activated carbon is not only a physical filter but also influences the chemical reactions occurring in the exhaust gases, leading to a more environmentally friendly exhaust profile. The 200-gram activated carbon mass variation likely provides the optimal balance between adsorption capacity and practical application. As the mass of activated carbon increases, so does the available surface area for adsorption, enhancing its effectiveness in trapping pollutants. However, larger quantities of activated carbon may also create flow resistance, which could counteract its benefits by reducing engine efficiency or increasing back pressure. Therefore, the 200-gram mass variation represents the best compromise for reducing CO_2 emissions without negatively impacting engine performance or exhaust flow. In conclusion, the graph in Figure 8 illustrates that while CO_2 emissions naturally increase with engine speed due to more complete combustion, the use of activated carbon adsorbents—especially in the 200-gram variation—effectively reduces these emissions. This finding supports the role of activated carbon as a valuable tool in emission control strategies, offering a balance between reducing harmful pollutants like CO and HC, while also mitigating CO_2 emissions. The results are consistent with previous studies that emphasize the multifaceted role of activated carbon in both adsorbing pollutants and influencing combustion chemistry to reduce overall emissions [39]. The results shown in the graph in Figure 8 are the best reduction in exhaust emissions found in the 200 gram activated carbon mass variation with a percentage reduction in CO_2 emission levels of 9.17%.

This study has several limitations that should be addressed. First, the research is limited to motorcycle engines, which restricts the applicability of its findings to other types of vehicles, such as cars or larger engines. The effectiveness of the coconut shell-based activated carbon on other engine sizes or fuel types remains unexplored. Additionally, the experiments were conducted in a controlled laboratory environment, which may not fully represent real-world conditions where factors like weather, traffic patterns, and engine maintenance could influence the adsorbent's performance. Furthermore, the study only tested the effect of different masses of active carbon, with a maximum of 200 grams, without exploring other variables such as particle size or structural modifications that might further enhance the adsorbent's efficiency. Another limitation is the short-term focus of the research, which does not account for the long-term performance or degradation of the activated carbon over time. Lastly, the study only measured CO, HC, and CO_2 emissions, leaving out other harmful pollutants like nitrogen oxides (NOx) and particulate matter (PM), which are significant contributors to air pollution. Despite these limitations, the study aims to evaluate the effectiveness of coconut shell-based activated carbon in reducing specific motorcycle exhaust emissions under controlled experimental conditions and limited operational scenarios.

5. CONCLUSIONS

This research investigates the impact of using activated carbon derived from coconut shells on motorcycle exhaust gas emissions. The production of activated carbon involves dehydration, carbonization, and activation using sodium chloride (NaCl) solution. SEM EDX analysis results demonstrate changes in the carbon surface after activation. The research findings show that the use of activated carbon reduces CO, HC, and CO_2 emissions. The most significant reduction occurred with a 200-gram mass variation of activated carbon, resulting in a 12.06% decrease in CO, a 16.96% decrease in HC, and a 9.17% decrease in CO_2 emissions. Throughout the testing sequence, the use of activated carbon positively influenced exhaust emissions, particularly at specific engine RPM levels.

6. ACKNOWLEDGEMENTS

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7. AUTHOR CONTRIBUTIONS

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Writing publication: Najmul Hidayat, Dwi Pebrianti
Approval of final publication: Nahindi Putra Gitama,
Resources, technical and material supports: Dwi Pebrianti
Supervision: Nahindi Putra Gitama,

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