An Improvement of Catalytic Converter Activity Using Copper Coated Activated Carbon Derived from Banana Peel

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**Abstract.** The emission of nitrogen oxide (NO\textsubscript{x}), nitrogen monoxide (NO) and carbon monoxide (CO) from vehicle exhaust gas generates an adverse effect to the environment as well as the human health. Therefore, the need to reduce such emission is urgent. The decrease of the emission can be achieved through the use of catalytic converter. This study explains the application of catalytic converter prepared from activated carbon to enhance the activity through its adsorption ability. The activated carbon was derived from banana peels after heating them up at 400 °C for 1.5 hours and achieved through the use of catalytic converter. This study explains the application of catalytic converter prepared from activated carbon to enhance

**Keywords:** Catalytic converter, emission, copper, activated carbon, banana peel

1. **Introduction**

Exhaust gas from vehicles contribute the highest pollution to the air, and threaten the atmosphere, environment, and human health. One of the main sources of pollution that produces toxic gases is diesel-engined vehicles. Diesel engine exhaust gases were found to contain many toxic air contaminants (Sugavaneswaran et al., 2019). These pollutants contain numerous hazardous gases such as CO, NO\textsubscript{x} and hydrocarbons (S. Dey & Chandra Dhal, 2020). Diesel fuel combustion specifically produces CO, NO\textsubscript{x}, SO\textsubscript{2}, and particulate matter (Nofendi, 2019). Unfortunately, an incomplete combustion generates a high number of such gases. Such a situation resulted in air pollution and decreased air quality to the point where it could create inconvenience and health problems (Manojkumar et al., 2021; Naveen Kumar et al., 2020). The higher pollutant in the air leads to the more serious issues like greenhouse effect, acidic rain and climate change. Subsequently, there is an immense urge to resolve this challenge.

Many studies have been conducted to control the amount of NO\textsubscript{x} and CO emission (Ghofur et al., 2018; Rajakrishnamoorthy et al., 2020). Catalytic converter was considered as the promising solution owing to its capability to transform CO and hydrocarbon into less hazardous CO\textsubscript{2} through redox reaction (Sugavaneswaran et al., 2019). A catalytic converter was commonly prepared from platinum (Kora et al., 2019), palladium (Abdi et al., 2020), zinc (Udhayakumar et al., 2021), aluminum (Fedotov et al., 2017) and copper (Manojkumar et al., 2021). Among those metal, copper was preferable based upon the high corrosive resistance and economic point of view.

Irawan et al. (Bagus Irawan et al., 2015) investigated the manganese-coated copper for a catalytic converter of diesel engine. The catalytic converter showed a high performance with 76% reduction of CO emission at 3000 rpm. On the other hand, the uncoated copper was reported to decrease 13% CO and 19% hydrocarbon emission (Manojkumar et al., 2021). Hence, modification of the catalytic converter using copper as catalyst was inevitably required. This is inline with the several studies that mentioned coating with high porosity and thermal stability material like activated carbon is an ideal option (Fuentes-Cano et al., 2013; Klinghoffer et al., 2012).

Activated carbon is carbon that has been activated chemically, physically, or both (Dada et al., 2022; Pullas Navarrete & de la Torre, 2022; Tono An et al., 2022). This activation process produces a carbon structure with open pores (Chowdhury et al., 2012), a larger carbon surface area and a...
higher adsorption capacity (Black et al., 2016; Sethia & Sayari, 2016). Activated carbon is widely used in various fields of water treatment (Oyim et al., 2022; Soliman et al., 2022), catalysts (Méndez et al., 2022a), gas storage (Ramesh et al., 2021), as well as the cosmetic and pharmaceutical industries (Hamamni et al., 2019). In addition, activated carbon is usually also used for air filtration and treatment of exhaust gases or emissions (Bader et al., 2019; Rodríguez-Sánchez et al., 2022). Activated carbon is also a porous material that can be produced from agricultural and food waste (Daouda et al., 2021; Durán et al., 2022; Kosheleva et al., 2019; Nguyen et al., 2021; Ratan et al., 2018; Sujino et al., 2022). The agricultural waste such as wheat straw, corn cobs, stalks and rice husks have potential as precursors in the synthesis of activated carbon. Chemical activators and temperature pyrolysis also affect the formation of activated carbon. The reagents that are often used as chemical activators include NaOH, H3PO4, KOH, H2SO4, and ZnCl2. The advantage of chemical activation is that the operating temperature and pressure conditions are relatively lower. In addition, the effect of using chemicals can increase the number of pores in the product (Adegboyega et al., 2015; Geng et al., 2014). Meanwhile, the pyrolysis temperature required for the formation of activated carbon is between 400–900 °C. In addition, several other literatures report that the activation temperature has an important role to develop the porosity and surface functional groups obtained on activated carbon (Kosheleva et al., 2019; Tripathi et al., 2016). The porosity of activated carbon is mostly microporous (<2 nm) and mesoporous (2-50 nm) (Foong et al., 2020). Lu and Li (Lu & Li, 2019) have conducted an analysis related to the porosity of activated carbon from banana peels. The results obtained that the average pore diameter and total pore volume were 2.11 nm and 0.32 cm3/g. The formation of porosity from the converting banana peels into activated carbon is influenced by chemical activation (Jain et al., 2016).

Many carbon applications including catalyst and adsorbent used activated carbon made from natural resources due to several considerations: the high availability and low price, and the utilization of waste to the added value material. Besides, activated carbon can reduce harm to the environment and human health compared to synthetic catalysts (Frazier et al., 2015). Activated carbon can also be obtained from fruit peels (Jothi Ramalingam et al., 2015). Banana peel is one of the abundant waste with high carbon content and can be transformed into activated carbon through feasible method such as heating at 400–500 °C. Kharirah et al. (Kharirah et al., 2021) have reported that the elemental content (% wt) of activated carbon derived from banana peels is the most dominant, namely carbon and oxygen of 78.15 and 10.52 %, respectively. Borhan et al. (Borhan et al., 2015) also analyzed the content of activated carbon from banana peels using SEM-EDX. The results showed that the elemental content (% wt) of carbon and oxygen found in the activated carbon samples from banana peels were 60.18 and 25.19 %, respectively. This indicates that banana peel waste is able to become prospective activated carbon because it has a carbon content in the range of 50 – 80 % (Borhan et al., 2015). In Madura Island, banana peels could be utilized as exhaust gas adsorbent for a whole year. The present study aims to use of banana peel as the source of activated carbon. The addition of activated carbon of banana peel is expected to enhance the adsorption capacity of catalytic converter to lower the hazardous gas emission, as well as increase the strength and thermal stability. In addition, the influence of the catalyst layer was also investigated for the purpose of optimization.

### 2. Materials and Methods

#### 2.1 Materials and tools

The materials used in this study include banana peel waste which originated from Madura Island, Indonesia. Activator NaOH was purchased from Merck, cassava starch was obtained locally, demineralized water, stainless steel plate and copper plate. The tools used in this research include single cylinder diesel engine Yanmar TF 70 LY-DI, tachometer, oven, drilling machine, electric welding, grinder, furnace, beaker glass, hotplate stirrer and gas analyzer.

#### 2.2 Methods

##### 2.2.1 Activated carbon preparation

Synthesis of activated carbon following the research conducted by Neolaka et al. (Neolaka et al., 2021). Banana peels were cut into small pieces and dried under sunlight to remove the moisture. Carbon was achieved after the calcination of dried banana peels at 400 °C for 1.5 hours. Afterwards, carbon was crushed and sieved using 150-mesh. The activation of banana peel carbon was carried out by adding of NaOH 3 M under stirring condition at 600 rpm for 2 hours. This activation was followed by washing it with demineralized water to reach neutral pH value. To remove the water, activated carbon was dried in the oven at 110 °C for 2 hours. This procedure is illustrated in Figure 1.

##### 2.2.2 Activated carbon characterization

The crystallinity and identification phase of activated carbon were carried out by powder X-Ray diffraction (XRD) using a Bruker D2 Phaser with Cu-Kα radiation. The diffractograms were collected at 40 kV and 40 mA, and in steps of 0.05 over the range of 5°< 2θ< 80°. The morphology and elemental content of activated carbon were analysed using Scanning Electron Microscopy-Energy Dispersive X-Ray (SEM-EDX) by Instrument Phenom Desktop. The functional group was studied by Fourier Transform Infrared (FTIR) Nicolet Avitar 360 IR. The porosity of activated carbon was determined by nitrogen adsorption using a Quantachrome Novatouch Lx4.

##### 2.2.3 The preparation of catalytic converter using activated carbon coated with copper

The design of the catalytic converter was depicted in figure 2. The Activated carbon formed was then coated with copper like a sandwich as shown in the Figure 2. The catalyst (copper coated activated carbon) was drilled to form a hole and then covered in stainless steel chase. As for the overall dimensions of the catalytic converter, it is shown in Figure 3.

##### 2.2.4 Catalytic converter activity

The activity of the catalytic converter was tested in an engine diesel Yanmar TP 70 LY-DI equipped with a gas analyzer (Figure 4). The performance was defined by the decrease of CO, NO, and NOx emission. The analysis was conducted over varied catalytic converter including without catalyst (WC), one layer of catalyst (C1), two layers of catalyst (C2), and three layers of catalysts (C3). The percentage of efficiency of gas emission was formulated as follows,

\[
\text{% Efficiency} = \frac{C_{in}-C_{out}}{C_{in}} \times 100 \%
\]

where \(C_{in}\) represents emission gas concentration without a catalytic converter, and \(C_{out}\) with catalytic converter.
Bananas were obtained from the Madura region, Indonesia.

Banana peels were dried under sunlight.

Banana peels were carbonized at 400 °C for 1.5 hours using a furnace.

The sample was filtered using filter paper and washed with aquademin until the pH was neutral.

The sample was activated using NaOH 3 M by stirring for 2 hours at room temperature with 600 rpm.

The sample was sieved using a 150-mesh sieve.

The sample was heated at 110 °C for 2 hours using an oven.

Activated carbon sample from banana peel waste.

**Fig. 1** Preparation of activated carbon from banana peel waste

**Fig. 2** Catalytic converter design with three catalysts (a), two catalysts (b), and one catalyst (c)
3. Results and Discussion

3.1 Activated carbon characterization

Analysis using XRD was used to determine the phase of the activated carbon sample from banana peel waste. Activated carbon samples were analysed with 2θ between 5°-80° using Cu-Kα radiation. Figure 5 describes the diffractogram of activated carbon from banana peels. The presence of carbon was confirmed by peaks at 2θ = 26.81° and 32.07°. These features also confirmed amorphous phase of activated carbon. The activated carbon showed a widening diffractogram peak at 2θ between 10° – 30°. These peaks are the characteristic of porous materials with good porosity (Neme et al., 2022).

Microstructure data of activated carbon samples using XRD analysis based on data parameters 2θ, crystal size (Å), intensity and FWHM (Full-Width at Half Maximum) are shown in Table 1. The data were obtained from the two highest peaks in activated carbon samples from banana peels. The first peak at 2θ = 26.81° with crystal size of 3.32 Å, FWHM value at 0.187°, and intensity at 2130 cps. The second highest peak at 2θ = 32.07° with a crystal size of 2.79 Å, FWHM value is 0.333° and intensity is 1164 cps. The FWHM value provides information about the crystalline homogeneity of the synthesized activated carbon. Good material quality was indicated by the relatively smaller FWHM value in accordance with the sample crystal structure and homogeneous lattice (Sujiono et al., 2020).

The morphology and EDX spectrum of activated carbon is illustrated in Figure 6 and 7. The micrographs showed irregular sheet-like and rough surface with particle size about 30 µm. Some pores and structural channels were also examined. Table 2 shows that the highest elemental contents of activated carbon based on EDX results, namely carbon and oxygen, were obtained at 78.36 and 18.50 %, respectively.

Table 1

<table>
<thead>
<tr>
<th>2θ (°)</th>
<th>d (Å)</th>
<th>Intensity (cps)</th>
<th>FWHM (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.81</td>
<td>3.32</td>
<td>2130</td>
<td>0.187</td>
</tr>
<tr>
<td>32.07</td>
<td>2.79</td>
<td>1164</td>
<td>0.333</td>
</tr>
</tbody>
</table>
The nitrogen adsorption-desorption isotherm of activated carbon from banana peels is shown in Figure 8a. In this figure, it can be seen that the nitrogen adsorption-desorption isotherm of activated carbon occurred in the adsorption of high amounts of nitrogen molecules at a relative pressure of $P/P_0$ of zero to relative pressure of $P/P_0$ was 0.2. Then, there was a slight increase in the volume of nitrogen molecules adsorbed at a higher relative pressure $P/P_0$ ($P/P_0 > 0.3$) which indicated the occurrence of mesoporous filling. The solid surface would be covered by nitrogen molecules to form a single layer (monolayer). The presence of pores on the solid surface would have the effect of limiting the number of layers on the adsorbate and the phenomenon of capillary condensation occurs (Nugraha et al., 2021). This capillary condensation would cause hysteresis. Hysteresis loops could occur due to incomplete condensation resulting in a metastable adsorption phase (Carraro et al., 2019). In Figure 8a, a hysteresis loop was observed during desorption at a relative pressure of $P/P_0$ 0.4-1. Based on the pattern of nitrogen adsorption-desorption above, it can be generally concluded that activated carbon shows a type IV adsorption profile which is characteristic of meso-sized pore solids with the size of 2-50 nm as presented by the pore size distribution in Figure 8b. The activated carbon sample showed meso-sized pores with the observed peak of the pore size distribution at a pore diameter of about 2-4 nm to be exact at 3.1 nm.

The functional group of activated carbon was investigated by FTIR, as described in Figure 9. FTIR characterization of activated carbon samples recorded at wave numbers between 500 to 4000 cm$^{-1}$. The FTIR spectra of activated carbon samples showed several peaks at 3387, 1580, 1378 and 1035 cm$^{-1}$. The presence of hydroxyl group was confirmed by the broad peak at 3387 cm$^{-1}$, as a result of the reaction between NaOH and carbon on the surface (Rawal et al., 2018; Soleimani & Kaghazchi, 2014; Waly et al., 2021). The peak observed at 1580 cm$^{-1}$ is the C=O stretching vibration which was associated with the carboxylic acid (Freitas et al., 2019; Li et al., 2019). The sharp peaks at 1378 cm$^{-1}$ assigned the vibration of C=C bonding from aromatic ring and the indication of carbon activation by NaOH (S. Zhang et al., 2013). The feature at 1035 and 875 cm$^{-1}$ represented the vibration of C-O group and C-H aromatic, respectively (Saleh, 2018; Tran et al., 2023).

### Table 2
The composition of activated carbon analyzed by EDX

<table>
<thead>
<tr>
<th>Element</th>
<th>Elemental Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>78.36</td>
</tr>
<tr>
<td>Oxygen</td>
<td>18.50</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.82</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.75</td>
</tr>
<tr>
<td>Fluorine</td>
<td>0.53</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.45</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.43</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.10</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.08</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.0</td>
</tr>
</tbody>
</table>
The characterization results of activated carbon using FTIR in the study are the same as the research conducted by Neolaka et al., Rawal et al., and Mendez et al. (Méndez et al., 2022b; Neolaka et al., 2021; Rawal et al., 2018). O–H and C–O stretching vibrations obtained from activated carbon samples play an important role as pollutant absorbers (Shu et al., 2017).

3.1 Catalytic converter activity

The catalytic converter was tested in diesel engine with the alteration of speed in the range of 100-1500 rpm within 100 intervals. Aside from that, the catalyst layers were also varied for the optimization process. The result was rationalized by the efficiency percentage of NO, NOx, and CO. The activity of catalytic converter on the NO and NOx emission tests is described in Figure 10 and 11. The nitrogen oxide was formed by the reaction between oxygen and nitrogen from air at high temperature during the combustion of the fuel as mentioned in scheme 2 (Ilkiliç, 2009). Aside from the combustion, the fuel contained nitrogen oxide (NOx). Overall, the application of catalytic converter decreased the emission of NO. Unsurprisingly, the highest NO emission was generated by the absence of catalytic converter with 201 ppm at 1100 rpm. In contrast, the lowest NO emission of 134 ppm at 1300 rpm was exhibited from the application of three layers of catalyst (C3). More layers of catalyst provided sufficient active sites to accommodate the reduction of NOx to N2. Moreover, the presence of activated carbon leads to more adsorption of exhaust gases.

Generally, the NO emission depleted as the engine speed increased over catalytic converter C2 and C3. However, the emission rose when the rotation was 1300 rpm. Similar trend was also observed in Figure 11. This phenomenon occurred owing to the complete combustion at 1300. Afterwards, the emission then continuously increased due to the higher supply of air at high rotation of the engine.

The highest NOx emission test results were obtained without using a catalytic converter, which was 211 ppm at 1100 rpm. Meanwhile the lowest NOx emission gas content was attained when using a catalytic converter with three catalysts (C3), namely 140 ppm at 1300 rpm. This showed that the more the number of catalysts used, the lower the gas emission content produced from the diesel engine. NOx formation was influenced by the flash point, combustion duration and oxygen concentration (Kataria et al., 2019). The reduction process occurs in the presence of a copper metal catalyst coated with activated carbon. Gases such as NO and NOx are reduced from the catalytic converter.

\[
\text{NO}_x \rightarrow \text{N}_2 + \text{O}_2 \tag{2}
\]
Figure 12 describes the comparison of CO emission of exhaust gas resulting from the engine with the presence and absence of catalytic converter. The use of catalytic converter mainly resulted in lower CO emission. The highest was resulted from combustion over the WC sample, with 484 ppm at 1100 rpm. Conversely, the lowest emission of 304 ppm at 1300 rpm was produced from sample C3 with three layers of catalyst.

Carbon monoxide was generated by the incomplete combustion of hydrocarbon in the combustion chamber (Ganesan et al., 2021). The high performance of copper metal was associated with the presence of intra and inter-particle porosity in the catalyst and high dispersion of copper particles on the catalyst surface (Subhashish Dey & Dhal, 2019). The number of oxygen species adsorbed on the surface of copper played an important role for the catalytic conversion of CO emission. In such a manner, the CO emission content produced after passing through the catalyst of activated carbon coated with copper decreases. The catalytic converter captured the CO molecules to enable the oxidation proceeded. The oxidation reaction for the formation of CO emission is an exothermic reaction, especially a catalyst combustion reaction which is better known as catalytic oxidation reaction. If there is not enough oxygen in the air, incomplete combustion will occur so that the carbon in the fuel will produce CO emission gas. The metal catalyst alloyed with copper and activated carbon will accelerate the gas reaction by forming weak bonds between the gas and metal atoms on the surface of the catalyst. So that the catalytic converter using activated carbon coated with copper is able to convert harmful pollutants such as CO emission gas to be converted into CO2. Eventually, the CO was converted to less hazardous CO2 and released to the air. The presence of copper coated activated carbon which has high porosity and excellent metal dispersion could enhance the oxidation process. The CO emission declined as the engine rotation increased to 1300. At this point, complete combustion had taken place.

Compared to CO and NO, the highest CO2 emission was produced from C3 samples, as illustrated in Figure 13. The CO2 was produced by two processes, the result of hydrocarbon combustion and the oxidation of CO on the catalytic converter. Subsequently, CO2 emission trend differed from NO and CO emission. Figure 13 also presents that the highest CO2 emission content is obtained at C2 and C3, which is 2.7 % at 1500 rpm, while the lowest CO2 emission content is obtained in the WC is 2 % at 1000 rpm. The engine speed significantly affected the formation of CO2. Such high speed permitted more air to the combustion chamber and provided more oxygen for fuel combustion (Abed et al., 2018). The susceptible mole ratio of oxygen-hydrocarbon created a complete combustion and produces more CO2. The reaction of CO2 production is mentioned in the following scheme 3 (Jeyakumar et al., 2020).

\[
\text{CO} + \text{O}_2 \rightarrow \text{CO}_2 \\
\text{HC} + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2
\]
The emission of each gas over C3 samples was profoundly analyzed in depth regarding how much efficiency the reduction of CO, NOx and NO emissions, as shown in Figure 14. In terms of engine speed, the emission of all gases declined as the function rotated. Higher speed also produced more combustion and consumed more fuel. Therefore, the emission also reached higher. Regarding the catalyst layers, the higher number of catalysts lowered the gas emission efficiency. Catalysts provided more active sites to accommodate exhaust gas and transformed them to less dangerous gasses. Nevertheless, to a certain degree the adsorption reached maximum level when the active sites were covered with the gases. This phenomenon was followed by the gas desorption caused by the weakened interaction. This indicated that the adsorption rate and mechanism were affected by the physical electrostatic force. The adsorption capabilities on emissions from diesel engines shows with different types of catalyst. The use of catalysts that have adsorption capabilities on emissions from diesel engines shows a very effective performance. The highest efficiency of reducing CO emission concentration is using Co-ZSM-5 Zeolites as catalyst. Zeolite-based catalytic converter has better performance. Based on research that has been carried out by Rajakrishnamoorthy et al. (2020), the concentration of CO emissions was significantly reduced at all levels of load conditions using Co-ZSM-5 zeolites as catalyst. The use of zeolite-based catalysts such as natural zeolite is also able to reduce the concentration of SO2 emissions up to 94% (Hamid & Wilujeng, 2021). The highest NOx emission reduction efficiency was obtained using a copper oxide catalyst (Venkatesan et al., 2017). The NOx compound was significantly decreased when the engine was left running with the catalytic converter at all loads. The results revealed that the reduction efficiency of NOx emission concentration is 61% at full load. The manufacture of the catalytic converter in this study uses a combination of materials that can reduce gas emissions through adsorption and materials with catalytic properties, although most studies still classify metal filters for catalytic converters into several elements such as copper, titanium, and aluminium. The expected advantage by combining these two properties is the creation of an optimal material that can reduce gas emissions from diesel engine. In addition, all the supporting materials for making the catalytic converter in this study came from Indonesia with easy availability and low cost. In such a manner, the combination of copper coated activated carbon can reduce CO and NOx emissions by around 49% and 31%. The activating group on the surface of activated carbon can interact as an adsorption media because it has a porous crystal structure and high thermal stability. The catalytic converter in this study is effective to decrease the concentration of emissions from diesel engine when compared to the previous studies.

Table 3
Comparison of previous research related to catalytic converters

<table>
<thead>
<tr>
<th>No</th>
<th>Catalysts used in catalytic converter</th>
<th>Emission reduction efficiency value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silicon dioxide and alumina</td>
<td>CO: 33 %</td>
<td>HC: 83 %</td>
</tr>
<tr>
<td>2</td>
<td>Cu-ZSM-5 Zeolites</td>
<td>CO: 87 %</td>
<td>NO: 56 %</td>
</tr>
<tr>
<td>3</td>
<td>Natural zeolites</td>
<td>CO: 42 %</td>
<td>NO: 59 %</td>
</tr>
<tr>
<td>4</td>
<td>Activated charcoal</td>
<td>CO: 33 %</td>
<td>NO: 13 %</td>
</tr>
<tr>
<td>5</td>
<td>Aluminum oxide and titanium dioxide</td>
<td>CO: 50 %</td>
<td>HC: 58 %</td>
</tr>
<tr>
<td>6</td>
<td>Activated carbon from banana hump</td>
<td>CO: 25 %</td>
<td>NO: 27 %</td>
</tr>
<tr>
<td>7</td>
<td>Copper oxide</td>
<td>CO: 21 %</td>
<td>NO: 61 %</td>
</tr>
<tr>
<td>8</td>
<td>Fly ash</td>
<td>CO: 34 %</td>
<td>HC: 32 %</td>
</tr>
<tr>
<td>9</td>
<td>Copper coated activated carbon</td>
<td>CO: 49 %</td>
<td>NO: 31 %</td>
</tr>
</tbody>
</table>
4. Conclusion

A catalytic converter was successfully prepared from activated carbon from banana peel coated with copper. The FTIR confirmed the potential utility of activated carbon for exhaust gas adsorption with the carboxyl and hydroxyl functional group. Diffractogram affirmed the porous phase and low crystallinity of activated carbon. The uniformly porous surface was verified by SEM-EDX, as well as the presence of carbon and oxygen as the main elements. In line with the finding, analysis using nitrogen adsorption-desorption showed the presence of meso-sized pores. The application of activated carbon in catalytic converter could decline gas emission, which decreased along with the amount of catalyst layers. The highest efficiency was obtained from C3 samples at 1100 rpm with the following efficiency value CO: 48.76 %, NOx: 31.27 % and NO: 29.35 %.

Acknowledgments

The authors would like to thank the Ministry of Education, Culture, Research, and Technology that has provided research funding Direktorat Akademik Pendidikan Tinggi Vokasi (DAPTV) scheme Penelitian Dosen penula (PDP) in 2022.

Author Contributions: AH: Supervised the study, acquired funding, conceptualization, reviewed and edited the manuscript, WBU: performed the experiments and data analysis, MF: performed the experiments and data analysis, resources projects, IDF: project administration and editing, ZR: supervision, writing—review, A: reviewed and edited the manuscript, AML: writing—review, editing and validation. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References


