Motor vehicle exhaust carbon monoxide and hydrocarbon emission content reduction by banana peel activated carbon

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Abstract. Air pollution caused by motor vehicle exhaust emissions produced gases such as carbon monoxide (CO) and hydrocarbon (HC) that are dangerous for health of living things. Those gases can be adsorbed with activated carbon made from agricultural waste such as banana peel because it has quite high lignocellulose content and available in large amount in Indonesia. Activated carbon from banana peel in this research was used the AC made in previous studies which has 617 mg/g and 614 mg/g surface area for chemically activated AC and chemical and physical activation combined respectively. The characterization of activated carbon was done by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) tests which resulted that the pore on AC surface was visually clear and the AC contained up to 88% of carbon, respectively. Chemical-activated carbon with H2SO4 6 N was capable of adsorbing 40.46% CO and 31.51% HC respectively. While physical-chemical activated carbon with H2SO4 6 N was capable of adsorbing 56.27% CO and 42.63% HC. The banana peel waste was proven to be a promising adsorbent raw material to reduce pollutant contents in environment.

1. Introduction
The level of air pollution continues to increase every year. The effects are very dangerous for human health or surrounding environment [1]. The long-term effect from direct or indirect exposure will cause several dangerous diseases including cancer. The causes of air pollution are industrial exhaust, natural disaster, construction development, but the recognizable large source of air pollution is from transportation. The motor vehicle emits many types of gases as a result of complete and incomplete combustion in the engine, such as carbon monoxide, carbon dioxide, water vapor, hydrocarbon, nitrogen oxides, sulfur oxides etc.
The number of motorcycles has continuously increased in Indonesia [2]. The total of motorcycles had reached 113 million units in 2017 and this amount will increase gradually year by year because motorcycles are Indonesian most popular vehicles [3]. The main concern is the carbon monoxide (CO) and hydrocarbon (HC) amount which are higher than the safe limit in Air Quality Index (AQI) or The Pollutant Standard Index (PSI). These gases are very dangerous because they have toxins effect in the human body. The CO can bind the haemoglobin and cause the oxygen loss [1]. The same danger applies too with HC, this gas can cause respiratory system infection and even cancer [4]. By knowing the danger of these gases and many motor vehicles producing them in Indonesia, a solution is needed to reduce the emission levels of these gases. There are several ways to reduce pollutant content in exhaust gases emission, and the most popular and developed one is using adsorbents. Many types of adsorbents such as silica gel, alumina, zeolite, bauxite,
and activated carbon can be used [5]. But due to its high adsorption ability and other advantages, activated carbon become to most used adsorbent in these matters. Activated carbon has large pore volume which related to its ability to adsorb large amount of pollutant [4].

The surface characteristics of AC is mainly influenced by its raw material. The precursor material such as coal and wood still maintained but nowadays the have been replaced by renewable sources such as agricultural wastes which contains high lignocellulose components [5]. Previous research has been used raw material such as durian peel wastes [6], palm shells [7], coffee grounds [8] and others. The high number of banana peel wastes is because banana is one of Indonesian favorite fruits. Furthermore, other processing during production of foods, such as banana chips and fried bananas also contribute to this number [9]. The need of cellulose content in raw material is found in banana peel which resulted this waste will be a good material for AC production [7][10]. The banana type used was peel of ripe Kepok Banana.

The AC can be produced within three main steps, dehydration, carbonization, and activation [11]. The preparation of the AC was done in previous study [12]. Therefore, this paper aims to test the activated carbon made from banana peel waste adsorption capability to reduce exhaust CO and HC emission content from motor vehicle.

2. Material and Methods

2.1 SEM and EDX Tests

Scanning Electron Microscopy (SEM) test has aims for illustrating the surface structure of the sample, which was activated carbon. The test was examined by JEOL JED-2300 Analysis Station. 0.1 gram of sample was used in dry condition and without any pretreatment. The picture magnification was set at 1500x.

Energy Dispersive X-ray Spectroscopy (EDX) test was executed simultaneously with SEM test. EDX test was used for analyzing elemental composition of the tested activated carbon. The device for this method was the same with SEM, JEOL JED-2300 Analysis Station. The analysis power was examined at 20 kV with energy range of 0-20 keV.

2.2 Activated Carbon CO and HC Emission Adsorption Capability Test.

This stage aims to test the adsorption capability of activated carbon from banana peel against CO and HC emission content on motorcycle. The selected test vehicle is one of the 2014 automatic transmission motorcycles. The exhaust gas emitted by the motorcycle was measured using a gas analyzer. Both chemical and physical-chemical activated carbon were tested for their adsorption capability to reduce CO and HC emissions in motorcycle using an adsorption test tube as shown in Figure 1.

![Figure 1. Adsorption test tube scheme](image)

The adsorption test tube consists of the outside tube and the inner tube. The outer tube had a length of 50 cm and a diameter of 3.8 cm. The outer tube acts as a motorcycle exhaust connector with sampling probe gas analyzer. Meanwhile, the inner tube had a height of 3 cm and a diameter of 3 cm. The inner tube containing 5 grams of activated carbon that was tested. Both circle sides of the tube were covered with 2 layers of mask fabric (spun bond nonwoven) so that exhaust gas out of the exhaust can enter and exit through the inner tube. In addition to the inner tube and outer tube, on the test tube of adsorption is
also required seal/rubber at the end of the inner tube in order that there is no motorcycle exhaust gas go to the sampling probe without passing the inner tube that containing the activated carbon. The adsorption test tube was connected to the probe portion of the gas analyzer and motorcycle exhaust during retrieval of the CO and HC emission content. To measure the initial CO and HC emission content of the motorcycle exhaust, the adsorption test tube was used in the absence of inner tube that containing activated carbon. After the initial exhaust gas emission content have been measured, the inner tube containing the activated carbon was inserted into the outside tube. Measurement of CO and HC emission content had been executed every minute for 10 minutes. The amount of exhaust gas emissions that was successfully adsorbed can be calculated based on the difference of the initial gas emission content with the emission content of gas at minute-n as shown in Eq. 1.

\[
\% \text{ Gas Adsorption} = \frac{(G_0 - G_n)}{G_0} \times 100\% \tag{1}
\]

Information:
\(G_0\) = Initial gas emission content [% or ppm]
\(G_n\) = Gas emission content at minute-n [% or ppm]

3. Results and Discussion

3.1 SEM and EDX Tests

SEM test describes visual appearance of AC external surface. Figure 2 (a) and (b) consecutively shows structure of external surface of two activated carbon tested.

(a) (b)

**Figure 2.** Surface structure of (a) chemical activated Carbon; (b) physical-chemical activated carbon

Based on Figure 2 (a) and (b), it was known that pore formation for both types of activated carbon were not-fully developed. However, pore formation in physical-chemical activated carbon was more developed than chemical activated carbon. The pores in physical-chemical activated carbon was clearer visually and sufficiently dispersed than the chemical activated carbon.

In Figure 2 (a), it can be seen that some of pores in the activated carbon surface were still blocked and the formation of pore holes that were less close to the round shape, which were opposite with Fig. 2 (b). Thus, the structure of physical-chemical activated carbon was better than chemical activated carbon. This is due to the physical activation process of physical-chemical activated carbon which is not present in the chemical activated carbon. The nitrogen gas that flows on the physical activation plays a role in pushing and removing impurities that cover the surface of the carbon pores [7]. In addition, the physics activation by the nitrogen gas stream also helps prevent excessive oxidation to the carbon pore structure due to excess oxygen gas around the carbon during carbonization process.

Meanwhile, EDX test resulted elemental composition of two types of activated carbon tested as shown in Table 1.
Table 1. Activated carbon elemental composition

| Element | Chemical activation | Physical-chemical activation |
|---------|---------------------|-----------------------------|
| C       | 87.90               | 84.72                       |
| O       | 11.21               | 14.05                       |
| S       | 0.89                | 1.23                        |

In Table 1, it can be seen that the two activated carbon types tested each contain carbon (C), oxygen (O), and sulfur (S) elements. No other element distinguishes the two types of carbon tested because of the only different treatments between both types of carbon was simply the process of physical activation using nitrogen gas that went through and was not left behind in the activated carbon. The dominant element present in both types of activated carbon was C. Both meet the requirements of minimum carbon content standards on activated carbon in accordance with SNI 06-7370-1995, which is 65% of the total mass. The carbon content of both types of activated carbon is above 80%, indicating that banana peel has many carbon atoms derived from lignocellulose in banana peel.

It was also known from Table 1 that both types of activated carbon contain different amounts of oxygen element. In addition, both types of activated carbon also contain sulfur elements caused by the use of \( \text{H}_2\text{SO}_4 \) solution as the chemical activation agent in this paper. However, the sulfur and oxygen content of the physical-chemical activated carbon was slightly greater than the chemical activated carbon because there were more ions from \( \text{H}_2\text{SO}_4 \) that enter the gaps of the physical activated carbon layer during the chemical activation than the not yet activated carbon.

3.2 Activated Carbon CO and HC Emission Adsorption Capability Test

The adsorption capability test was performed on both types of activated carbon tested with a total time of 10 minutes each. Measurement of motorcycle exhaust CO and HC emission content was done every minute. Therefore, resulted graph of motorcycle exhaust CO and HC emission content relation to time as shown in Figure 3 and Figure 4.

Based on Figure 3 and Figure 4, there are decreases in motorcycle exhaust CO and HC emission content after the inner tube containing the activated carbon was inserted into the adsorption test tube. The decreases were caused by the adsorption most of the CO and HC gases emission by activated carbon.

![Figure 3. Effect of time on CO gas emission content](image-url)
Figure 4. Effect of time on HC gas emission content

The decrease in exhaust gas emissions for both CO and HC gases takes place significantly up to the second minute. This was because at the time of transition between the initial condition and the condition in the second minute, activated carbon that has not yet adsorbs any gas can adsorbs CO and HC gas freely. In those minutes, physical-chemical activated carbon was shown reducing motorcycle exhaust CO and HC content more significantly compared to chemical activated carbon. This proves that the adsorption capacity of the physical-chemical activated carbon on motorcycle exhaust emissions was greater compared to chemical activated carbon.

In the meantime, from the third to tenth minute onwards, the decrease in CO and HC emission content occurred tend to be stable and not changed much as in the first or second minute. This is because in the third minute onwards, the pores of activated carbon had been filled with molecules of CO and HC so that there was a decrease in the adsorption of activated carbon so the reduction was not as big as the application at the beginning of the test. Although at some time there was an increase in CO and HC exhaust emission content than the previous minutes, but the increase was not too significant that it remained stable as in the previous minutes. Until the tenth minute, the level of exhaust emissions measured by the gas analyzer had not reached the measured emission level of the initial exhaust gas. It shows that until the tenth minute the activated carbon had not been surfeited. The percentage of CO and HC gas that was successfully adsorbed by activated carbon was calculated using Eq. 1 and the results can be seen in Figure 5 and Figure 6.

Figure 5. Effect of time on CO gas adsorption

As shown in Figure 5 and Figure 6, the percentage of adsorbed gas by physical-chemical activated carbon was greater than the chemical activated carbon throughout the time of the test. This proved that the adsorption capability of physical-chemical activated carbon was greater compared to chemical activated carbon. The greater the adsorption capability of the activated carbon is proportional to the amount of CO and HC pollutant gas that can be adsorbed by activated carbon.
Based on both graphs in Figure 5 and Figure 6, it can also be seen that the adsorption percentage of motorcycle exhaust HC emission was smaller when compared to the adsorption percentage of motorcycle exhaust CO emission. The average adsorption percentage of HC gases by chemical activated carbon was 31.51%, smaller than the adsorption percentage of CO gases that was 40.46%. Meanwhile, the average adsorption percentage of HC gases by physical-chemical activated carbon was 42.63%, also smaller than the adsorption percentage of CO gases that was 56.27%. Previous study using banana peel adsorbents resulted 35% of CO had been reduced in 5 minutes [13] which is lower than this research. Another way to increase the amount the yield of adsorption, the physical activation using microwave can be used which resulted the high CO adsorption yield up to 97.64% [14].

One of the factors influencing the adsorption pattern of activated carbon is the selectivity of activated carbon in the adsorption of gas pollutant molecules [15]. Activated carbon tends to more easily adsorb gas with a simple molecular structure than gas with a complex molecular structure. HC gas emitted as motor vehicle exhaust emission is a collection of complex hydrocarbon compounds, so that the absorption of HC exhaust carbon by activated carbon is also not as much as CO gas adsorption. A gas with a mixture of complex compounds such as HC causes HC gas tends to have a larger relative molecular mass than CO gas so that the number of HC gas molecules that can diffuse into the pores of activated carbon is less than that of CO. So, this research was proven that the AC made from banana peel wastes success and effective to remove hazardous pollutant [16].

4. Conclusion

It can be concluded that activated carbons made from banana peel waste were succeed to reduce motor vehicle exhaust CO and HC emission content. The chemical activated carbon was capable of adsorbing 40.46% CO gas and 31.51% HC gas respectively. While the physical-chemical activated carbon was capable of adsorbing 56.27% CO gas and 42.63% HC gas. It shows physical-chemical activated carbon had better adsorption capability than chemical activated carbon. The additional physical activation method in the making process of activated carbon can helps to remove impurities that cover carbon pores and increase the adsorption capability.

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