Utilization of Mendong Plant Activated Charcoal as SO₂ Gas Adsortent: Preliminary Study

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Abstract. This study aims to find alternative low-cost, easy and environmental-friendly adsorbent materials to eliminate SO₂ gas, by utilizing Mendong plants as activated charcoal. Therefore, need to know the ability of this low-cost adsorbent in term of optimum concentration, adsorption efficiency, and the adsorption capacity of the charcoal to eliminate SO₂. Mendong plants were prepared with a modified tool and macerated with ZnCl₂ 2.5% (w/v) for 24 hours. Then, the adsorption process with artificial SO₂ waste was conducted for 1 hour. UV-Vis Spectrophotometer was used to determine the gas concentration. The results showed that the highest concentration of absorbed SO₂ gas (Cₜ) is at the initial gas concentration 4.4006 µg/mL (mass Na₂S₂O₅ 0.015 g), with 3.008 µg/mL of gas is absorbed. The gas adsorption efficiency is 70.53% at the variation of initial gas concentration of 4.1400 µg/mL. While, the adsorption capacity of activated ZnCl₂-Mendong stem charcoal is 92.1123 (µg/g). The results of the characterization by FTIR showed that the Mendong plant ZnCl₂-activated charcoal is polar and aromatic, verified by the absorbance of hydroxyl group and aromatic skeleton of cellulose, hemicellulose and lignin.

1. Introduction
As human activity increases, high traffic activities cause air pollution problems. The key source of pollution which is road transport, is generated by freight transportation and logistic activities [1]. In addition, industrial sector, high fossil fuels consumption, and large urban populations also support the high production of gas pollutions, especially SO₂ gas [2][3]. SO₂ contribute a large proportion of worsening air quality in China [4][5]. SO₂ is formed when sulfur-containing components in fossil fuels such as coal and petroleum are oxidized through the combustion process [6][7]. SO₂ concentration in the air can be detected by taste at 0.35-1.05 ppm and odor threshold of 0.67-4.75 ppm [8]. According to WHO [9], daily concentration of SO₂ should not be exceeded over 20 µg/m³.

The main effect of SO₂ gas pollutants on humans is irritation of the respiratory system such as coughing, mucus secretion, breathing difficult, reduce lungs function, chest tightness, alterations in the lungs' defenses, and even chronic lung disease for longer-term exposures of high concentrations of SO₂ [9][10][11]. In the atmosphere, SO₂ gas oxidized through homogeneous and heterogeneous pathways to form sulfate compounds. In this process, the intermediates (HSO₃⁻) combine rapidly with water vapor in the atmosphere to form sulfuric acid aerosol [12]. This is process cause SO₂ gas easily becomes acidic, which can attack mucous membranes in the nose, throat and other respiratory tracts to the lungs [13]. To reduce the adverse effects caused by SO₂ gas, efforts should be made to reduce SO₂ gas pollution to the environment.
According to Xia [14], \( \text{SO}_2 \) with coconut shell activated carbon has the best reduction effect than other materials (coal, Shenxin coal, graphite, coke, and charcoal) with higher than 95% reduction. Other material such as hardened cement mortar (HCM), also be completely absorb \( \text{SO}_2 \) by the highly alkaline HCM slurry with the retained capacity 0.52–0.76 (\( g_{\text{SO}_2}/g \)) [15]. Wang [16] also found that carbide slag-coal char pellet can give 100% of \( \text{SO}_2 \) removal efficiencies at 370 s.

Furthermore, other alternative material that simple, easy to use, and environmentally-friendly for absorbing \( \text{SO}_2 \) gas is to use Mendong plants (Fimbristylis globulosa). Mendong plants are grasses that grow in wet and muddy soils which usually grow 100 cm (Figure 1). Mendong is a type of grass, a family of Cyperaceans with short rhizomes, fibrous roots, and grooved. This plant is used to make traditional mats such as ropes, bags, hats and wallets because of its high fiber and its low cost [17]. Estimated production of Mendong in Java is about 14,000 tons per years [18]. With its economic potential, Mendong needs to be developed further to increase its use value. Mendong plants contain 72.14% cellulose, 20.2% hemicellulose, 3.44% lignin, 4.2% extractive matter, and moisture content of 4.2%–5.2%. The Mendong fiber was arranged by the crystalline structure of cellulose. Mendong fibers have a higher crystallinity and crystalline size than straw fibers and wheat stalks [18]. Until now, Mendong also used as phytoremediation plant, microcrystalline cellulose, and polymer composite [17]. Thus, Mendong is considered to have potential as charcoal as it has relatively high content of cellulose. To the best of our knowledge there are no literatures reported related to utilization of Mendong plants adsorbent as gas elimination. Thus, in this study, Mendong plants will be used as activated charcoal to eliminate \( \text{SO}_2 \) as low-cost adsorbent in term of optimum concentration, adsorption efficiency, and the adsorption capacity of the charcoal.

![Figure 1.](attachment:image1.png)

**Figure 1.** (a) Mendong plant, (b) Dried mendong straw and (c) Morphology of fiber in dried Mendong straw observed by SEM [18]

### 2. Method

#### 2.1 Material preparation

Dried Mendong plants were burned with a modified tool. This tool is made of cans and closed to limit the air flow in the tool (Figure 2). The charcoal was mashed and sieved with 100-mesh sieve. Furthermore, it was activated using 500 mL of 2.5% (w/v) of \( \text{ZnCl}_2 \) solution by maceration method for 24 hours. The maceration method was chosen because it is a simple activation method only by soaking the sample with the selected solvent used in room temperature [19]. The result was neutralized, dried,
and then formed into 3-mm pellets. FTIR analysis is carried out on inactivated Mendong plant charcoal (AMTA) and activated Mendong plant charcoal (AMA 2.5%).

Figure 2. Schematic figure of modified tool for Mendong plant combustion

2.2 Sulfur dioxide (SO$_2$) gas adsorption

The concentration of SO$_2$ in solution was determined by the Pararosaniline method with the analysis using UV-Vis spectrophotometer based on SNI 19-7119.7-2005 [20]. SO$_2$ gas source used is obtained from the reaction between Na$_2$S$_2$O$_3$ powders with HCl 1M solution. In this study, a preliminary study was conducted with variations in the initial concentration of SO$_2$ as adsorbate obtained from the variation of the mass of sodium thiosulfate used of 0.005; 0.015; and 0.025 g. Then, SO$_2$ gas is absorbed using TCM solution (tetrachloromerkurat (HgCl$_4^{2-}$)). SO2 in the adsorbent solution is reacted with formaldehyde (HCHO) added with sulfuric acid solution (NH$_2$SO$_3$H) as a catalyst and pararosaniline hydrochloride (C$_{19}$H$_{17}$N$_3$.HCl) as a color indicator. This reaction will produce purple pararosaniline methyl sulfonate and its thickness will be measured using Visible Spectrophotometer at $\lambda_{\text{max}} = 550$ nm [19]. The schematic testing tool of adsorption is showed in Figure 3.

Figure 3. Schematic figure of testing tools for SO$_2$ adsorption using parrosaniline method [20]

2.3 Determination of the concentration of absorbed SO$_2$ gas ($C_t$)

The absorbency of the solution was measured with a UV-Vis spectrophotometer to determine the amount of SO$_2$ gas adsorbed. Determination of gas concentration was done by the calibration curve method. Calibration curves were made using standard Na$_2$S$_2$O$_3$ solution. The absorbed SO$_2$ gas concentration ($C_t$) is calculated from the difference of the initial gas concentration ($C_i$) and final gas concentration ($C_f$).
For the absorbed SO$_2$ level, it is calculated by

\[ C_t = C_0 - C_1 \]  

(1)

Figure 4 showed the flow chart stage of the research.

3. Result and Discussion

The contacting process of SO$_2$ was carried out using a series of impinger set testing tools at a laboratory scale with artificial SO$_2$ gas. This series refers to SNI 19-7119.7-2005 by adding an adsorbent tube in the middle of the circuit. The adsorbent tube serves as a place for adsorbent, which is a 30-g active charcoal pellet of Mendong plants. Furthermore, the adsorbent tube was connected with 3 impinger bottles which already contain an adsorbent solution. This solution functions to capture sulfur dioxide gas which is not absorbed by the adsorbent.

After the contacting process had been completed, then the concentration of SO$_2$ gas was tested with a UV-Vis spectrophotometer. The absorbency measurement was performed with 3 variations of the initial SO$_2$ gas concentration, namely 4.1400 µg/mL (mass Na$_2$S$_2$O$_3$ 0.005 g), 4.4007 µg/mL (mass Na$_2$S$_2$O$_3$ 0.015 g), and 7.6734 µg/mL (mass Na$_2$S$_2$O$_3$ 0.025 g). The result of adsorption of SO$_2$ based on concentration variation is shown in Table 1.

Based on Table 1, the sulfur dioxide gas concentrations obtained after the contact with Mendong plant activated charcoal are 1.2202 µg/mL (mass Na$_2$S$_2$O$_3$ 0.005 g), 1.3926 µg/mL (mass Na$_2$S$_2$O$_3$ 0.015 g), and 5.3110 µg/mL (mass Na$_2$S$_2$O$_3$ 0.025 g). Thus, the concentration of SO$_2$ gas absorbed by the adsorbent in each variation of the initial gas concentrations of 2.9198 µg/mL, 3.0080 µg/mL, and 2.3623 µg/mL can be obtained. Based on the calculation results, it shows that the gas concentration mostly absorbed is a gas with a mass of sodium thiosulfate of 0.015 g.
Table 1. Concentration and adsorption efficiency of absorbed SO2 gas

| C0 (µg/mL) | C1 (µg/mL) | C1 mean (µg/mL) | C1t (µg/mL) | C1t mean (µg/mL) | %Ct |
|------------|------------|-----------------|-------------|------------------|-----|
| 4.1400     |            |                 |             |                  |     |
| 0.4324     | 0.4123     | 0.4083          | 2.9198      | 70.53            |     |
| 0.4043     | 0.3922     | 0.3909          |             |                  |     |
| 4.4007     |            |                 |             |                  |     |
| 0.6075     | 0.3869     | 0.3802          | 3.0080      | 68.35            |     |
| 0.6222     | 0.3976     | 0.3909          |             |                  |     |
| 7.6734     |            |                 |             |                  |     |
| 3.5781     | 1.4471     | 1.3746          | 2.2507      |                  |     |
| 0.3976     | 3.4644     | 1.3134          | 2.3623      | 30.79            |     |
| 0.4217     | 5.1995     | 2.4739          |             |                  |     |

In determining the adsorption efficiency of sulfur dioxide gas, at an initial concentration of 4.1400 µg/mL, 70.53% is absorbed. Meanwhile, the adsorption efficiency for the initial concentration of 4.4006 µg/mL is 68.38%, and the adsorption efficiency for the initial concentration of 7.6733 µg/mL is 30.79%. Based on the efficiency results, it was obtained that the initial concentration of SO2 gas of 4.1400 µg/mL, which is the lowest initial concentration, has the highest adsorption efficiency, while the adsorption efficiency for the gas with the highest initial concentration has the lowest efficiency. These results are less appropriate when related to the previous study by Basuki [21] who used local TiO2-activated carbon insertion media with 15 cm length (with 15% of TiO2 inserted), to absorb SO2 by 714.46 µg with adsorption efficiency 76.75%. This is caused by the insertion of TiO2 catalyst in the adsorbent as the gas adsorption medium, which was not used in this study. The other study of Elvitriana [22] which is able to absorb SO2 gas by 2187 ppm with 100% adsorption efficiency after 5 minutes contact using activated charcoal adsorbents from banana peels. Elvitriana found that the best temperature of activation was 500ºC for 45 minutes which produced adsorbent with adsorption capability 888mg/g.

Table 2. Adsorption capacity of Mendong plant activated charcoal against SO2 gas

| Mass Na2S2O3 (g) | C0 (µg/mL) | C1 (µg/mL) | C1t (µg/mL) | W (g) | q (µg/g) | Mean q (µg/g) |
|-----------------|------------|------------|-------------|-------|----------|--------------|
| 0.005           | 4.1400     | 1.2202     | 2.9198      | 30    | 97.3262  |              |
| 0.015           | 4.4006     | 1.3926     | 3.0080      | 30    | 100.2674 | 92.1123      |
| 0.025           | 7.6733     | 5.3110     | 2.3623      | 30    | 78.7433  |              |
Furthermore, according to Table 2 the adsorption of SO$_2$ gas using Mendong plant activated charcoal adsorbent was calculated based on the results of the concentration of the absorbed gas. The mass of the adsorbent used is 30 g. The adsorption capacity of Mendong plant activated charcoal at initial gas concentration 4.1400; 4.4006; and 7.6733 µg/mL are 97.3262; 100.2674; and 78.7433 µg/g. The highest adsorption capacity is at initial gas concentration 4.4006 µg/mL that directly proportional to the amount of SO$_2$ gas absorbed. Generally, at given temperature, high input concentrations will give higher adsorption capacity than at low input concentrations [23]. However, there is a limit mass of pollutant that can be adsorbed by an adsorbent. When the adsorbent receive more and more adsorbate and reach the end of bed, activated carbon filter will saturated, requiring either the bed to be replaced with new activated carbon or requiring the bed to be regenerated [23][24]. Based on this result, the calculation of average adsorption capacity of Mendong plant activated charcoal to SO$_2$ adsorption is 92.1123 µg/g.

To find out the characteristics of functional groups, FTIR test was conducted. The test was carried out on the Mendong plant charcoal with and without activation of ZnCl$_2$ 2.5% (w/v). The results of FTIR analysis are shown in Figure 5.

Figure 5. FTIR analysis of the Mendong plant charcoal (AMA and AMTA 2,5%)

Figure 6. FTIR analysis of the Mendong plant fiber [25]
Figure 6 shows the chemical composition of Mendong plant fiber. According to Suryanto [25], the functional group of the fiber are shown in the Table 3.

| Wavenumber (cm⁻¹) | Functional group | Compound                                      |
|------------------|------------------|------------------------------------------------|
| 3360             | OH               | Cellulose, hemicellulose and lignin            |
| 2899             | H-C-H            | Aliphatic chain of cellulose, hemicellulose and lignin |
| 1730             | C=O              | Aromatic ring of hemicellulose                 |
| 1602             | C=C              | Aromatic ring of lignin [18]                   |
| 1515             | C=C              | Aromatic ring of lignin [18]                   |
| 1244             | C-O-C            | Lignin                                         |
| 1046             | C-O              | Cellulose                                      |
| 833              | C-H              | Lignin                                         |

Figure 5 shown that the activation treatment does not affect the functional groups on activated charcoal. This shows that there is no change in bonds or chemical structure of the two samples. There are only differences in bond vibration caused the absorbency of Mendong activated charcoal (AMA 2.5%) to be greater than the absorbency of Mendong inactivated charcoal (AMTA).

According to Figure 5 and Figure 6, there is no significant change of chemical composition between Mendong plant fiber and Mendong plant charcoal. Based on the appearance of the peak of the spectra in Figure 5, the adsorption band at the wave number of 3391 cm⁻¹ is the peak of the hydroxyl group stretching vibration [25]. It is referred to –OH stretching from cellulose, hemicellulose, and lignin [18]. The peak at 3092 cm⁻¹ is attributed to C–H stretching vibration of aromatic hydrocarbons [18]. While, the peak at 2925 cm⁻¹ most probably indicate the aliphatic C-H stretching [25][26]. The adsorption peak at 1604 cm⁻¹ is assigned to the skeletal vibration of the aromatic rings of lignin [18][26]. In addition, C-H in plane deformation of cellulose, hemicellulose, and lignin is showed by the adsorption at 1485 cm⁻¹ [18][27]. The bands ranging from 1163 to 1027 cm⁻¹ are attributed to the asymmetric bridge oxygen and C-O stretching of cellulose and hemicellulose compounds [18][27]. Activation had an impact on the decreasing transmittance of the groups on the charcoal sample [28]. A slightly higher peak ratio for AMTA and AMA 2.5% was observed on 3391 cm⁻¹ (hydroxyl group), and 2925 cm⁻¹/1604 cm⁻¹ (aliphatic/aromatic) wavenumber pair. This indicated that AMA 2.5% was more polar and more aromatic than AMTA [29].

4. Conclusion and Future Perspective

Mendong plant is feasible to be applied as low-cost adsorbent material to reduce SO₂ gas contamination with 3.008 µg/mL concentration of SO₂ gas can be absorbed. While the highest efficiency of adsorption is 70.53%, and the adsorption capacity of SO₂ adsorption is 92.1123 µg/mL. Furthermore, the FTIR analysis found that Mendong plant charcoal have absorbance peak of –OH, – CH2, – CH3, C=O, and C–O groups referred to cellulose, hemicellulose and lignin compound. As Mendong plant showed potential adsorber material for SO₂ gas, still Mendong plant charcoal needs further improvement to explore more about its utilization for eliminating other pollutants, such as gases, heavy metals, or organic substances. Optimization of carbonization temperature, methods and activation or modification may be suggested. In addition, it is also important to notice that low-cost adsorbent needs to be evaluated for its recovery so that applicable for large scale and commercialized. Ultimately, it is important for this material to be able to be implemented in real contaminated environment.

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