Effectiveness of Cloth Mask with Sugarcane Bagasse Activated Carbon Filter

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Abstract. The Covid-19 pandemic has causes an increase in the amount of medical mask waste, and an alternative that can be done to reduce waste is using cloth masks with additional mask filters. The purpose of this research is to know the effectiveness of cloth masks with activated carbon filters in reducing pathogenic and increasing users’ comfort level when using the mask. This research method was experimental research. The research design was a completely randomized design (CRD) with one treatment in the form of concentration variations activator of KMNO₄, which are 5%, 10%, and 15%. Bacterial Filtration Efficiency and Pressure Drop test data were analyzed by using one-way ANOVA on SPSS series 24 software and ImageJ software for the SEM test. The result of this research shows there is no significant (P value > 0.05) difference in each activator concentration variation. The activator with 15% concentration sample has the highest efficiency in filtering bacteria, which is 37.5%. The result of the pressure drop is there was no significant (P value > 0.05) difference between the three mask samples and the activator with 5% concentration sample is a mask sample with a mean of 3.675 mmH₂O/cm² (< 4.08 mmH₂O/cm²). Based on the results of the study, cloth masks with activated carbon filter are considered less effective in reducing bacteria with a percentage of filtration ability below the ASTFM F2101-14 standard of 95%, and only mask with 5% concentration are comfortable enough to use, due to having a value below the EN14683 standard: 2019 which is < 4.08 mmH₂O/cm².

INTRODUCTION

The current worldwide COVID-19 pandemic is caused by the Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) virus that attacks the respiratory system. This virus has the potential for rapid spread because it can spread through droplets [1]. Based on data from the Ministry of Health, confirmed positive cases of Covid-19 until August reached 581,686,197 cases [2]. The high rate of spread of SARS-CoV-2 at this time caused the Indonesian Government to require the use of masks for the entire community to reduce the spread of the virus [1].

The use of masks recommended by the Government is proportional to the amount of mask waste generated [3]. This is evidenced by the recorded data of essential Personal Protective Equipment (PPE) waste consisting of medical masks and surgical gloves reaching 49,000 tons or 56% of the total global PPE waste [4]. Therefore, an appropriate solution is needed, such as using environmentally friendly and efficient masks to prevent exposure to SARS-CoV-2 by using cloth masks with additional filters. Cloth masks can be one of the solutions to prevent SARS-CoV-2 transmission without increasing medical waste because it can be used repeatedly. However, the effectiveness of cloth masks in filtering microorganisms is still lacking when compared to medical masks [5]. For this reason, WHO recommends adding a filter placed between 2-layer cloth masks. Additional filters in cloth masks increase the filtration ability of masks, especially in reducing microbes. An activated carbon filter is one of the common filters for masks on the market [4].
Activated carbon serves as a mask filter due to its good microorganism adsorption ability with amorphous properties consisting mostly of free carbon [6] (Maulana, 2017). The ability of activated carbon can improve performance in absorbing particles and polluting gases [7]. Bhimaraju et al (2020) found that cloth masks with activated carbon filters have better PM 2.5 filtration ability than ordinary medical masks [8]. Activated carbon for filter is made from plant waste that has a high carbon content, for example, Ramos (2021) who made an activated carbon filter from coconut fiber [9]. One other waste that can be utilized for activated carbon filters is bagasse. Bagasse is an organic material with a high content of cellulose, lignocellulose, and hemicellulose compared to flax and jute plants [10]. Activated carbon from bagasse has been widely used for metal adsorbents and dye waste [11][12]. The availability of bagasse is quite abundant [7]. Bagasse has the potential to be used as activated carbon because it contains lignin-cellulosic biomass with high carbon content [13]. Based on the results of the study, bagasse is effective in adsorbing Ca$^{2+}$ and contains 35.01% cellulose, so it has the potential to increase adsorption power by making it an additional filter in masks [14]. Therefore, activated carbon filters from bagasse can be used as an addition to cloth masks to increase the effectiveness of particle filtration, especially for microorganisms.

Until now, there has been no research related to the effectiveness of cloth masks with activated carbon filters in filtering microorganisms. This is important as a determinant of the quality of the mask. In addition, pressure difference testing is needed to determine whether the mask is tight or not when worn. Therefore, this study aims to determine the level of effectiveness using the Bacterial Filtration Efficiency (BFE) test and the comfort level of mask users, as well as cloth masks with bagasse-activated carbon filters.

MATERIALS AND METHOD

The method of this research is experimental. The research design is completely randomized design (CRD) with one treatment in form of concentration variations activator of KMNO$_4$, which are 5%, 10%, and 15%, and all tests were repeated twice. Material and tools of this research area bagasse, KMNO$_4$, glacial acetic acid, distilled water, filter paper, chitosan, Staphylococcus aureus bacterial inoculum, spunbond cloth, erlenmeyer, measuring pipette, dropper, beaker glass, funnel, stirring rod, scale, stove, pot, oven, mesh sieve 300, spatula, chopper, brush, spray bottle, and scissors. Bacterial Filtration Efficiency (BFE) test data refers to ASTM-F2101-14 standard with efficiency ≥ 95% and pressure drop test data refers to EN14683:2019 standard with <4.08 mmH$_2$O/cm$^2$. Bacterial Filtration Efficiency and Pressure drop test data were analyzed by using a one-way ANOVA test on SPSS series 24 software and ImageJ software for the SEM test.

RESULTS AND DISCUSSION

Scanning Electron Microscope (SEM)

The morphology of bagasse-activated carbon was observed by Scanning Electron Microscope (SEM) with SNE 4500 M type. SEM test results showed an overview based on the shape, density, and porosity parameters on the surface of activated carbon powder. The shape of particles can be seen based on the objective description of the image. The density of activated carbon powder can be seen from the density in the SEM analysis image. The porosity of activated carbon can be known by calculating the area of pores on the carbon. The value obtained from analyzing the porosity level and surface area of each test sample at each magnification is calculated using the following formula [15].

$$\varphi = \frac{A_T}{A_{TP}} \times 100\%$$

Where $\varphi$ is the sample's porosity level, AT is the total surface area of the analyzed sample, and ATP is the total analyzed pore area of the sample based on porosity analysis performed using ImageJ. The results of the calculation mean value of porosity area is shown in Table 1.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Magnification ± SD</th>
<th>500 x</th>
<th>1000 x</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>0.002185 ± 0.001337</td>
<td></td>
<td>0.003279 ± 0.001339</td>
</tr>
</tbody>
</table>
Table 1. Mean of porosity area value of activated carbon (%) (cont.)

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Magnification ± SD</th>
<th>500 x</th>
<th>1000 x</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0.002189 ± 0.001337</td>
<td></td>
<td>0.003279 ± 0.001339</td>
</tr>
<tr>
<td>15%</td>
<td>0.003273 ± 0.001336</td>
<td></td>
<td>0.003272 ± 0.001336</td>
</tr>
</tbody>
</table>

Following are the results of the SEM test analysis as seen from the shape, density, and porosity parameters. Figure 1 shows the results of the SEM test of activated carbon powder with a concentration of 5% observed with 500x and 1000x magnification.

![Figure 1](image1.png)

**FIGURE 1.** SEM test results of activated carbon powder, a) 5% concentration repeat 1 (500x), b) 5% concentration repeat 2 (500x) c) 5% concentration repeat 1 (1000x), d) 5% concentration repeat 2 (1000x)

From the results shown in Fig. 1, the shape of activated carbon particles at a concentration of 5% observed with 500x and 1000x magnification in the first repetition is dominated by a long cylindrical shape, there is also a fracture or flake box. While in the second repetition, the shape is elongated cylindrical with irregular breaks. Figure 1 shows that at a concentration of 5%, both observed with 500x and 1000x magnification have high density, both in the first and second repetition. Based on the data shown in Table 1, the average percentage of pore area of activated carbon powder at 500x and 1000x magnification can be seen. The mean value of pore area at 5% concentration shows a value of 0.003278%. Next, SEM test results of activated carbon powder with a concentration of 10% concentration are shown in Fig. 2.

![Figure 2](image2.png)

**FIGURE 2.** SEM test results of activated carbon powder a) 10% concentration repeat 1 (500x), b) 10% concentration repeat 2 (500x) c) 10% concentration repeat 1 (1000x), d) 10% concentration repeat 2 (1000x)
The shape of activated carbon powder with a concentration of 10% with 500x and 1000x magnification in the first repetition is dominated by flat, short shapes, smaller, and irregular fractures. It is also the same in the second repetition, with flat and short shapes. Furthermore, at a concentration of 10%, the density level is quite high but a little more tenuous in the first and second repetitions. Based on data shown in Table 1, a mean value of pore area of 10% concentration activated carbon powder observed with 500x, and 1000x magnification shows a value of 0.003276%.

FIGURE 3. SEM test results of activated carbon powder a) 15% concentration repeat 1 (500x), b) 15% concentration repeat 2 (500x) c) 15% concentration repeat 1 (1000x), d) 15% concentration repeat 2 (1000x)

In carbon powder observed with 500x and 1000x magnification at 15% concentration, carbon particles are dominated by the shape of wider and shorter flakes in the first repetition, while in the second repetition, the particle shape is wider. The density of 15% concentration carbon powder shown in Fig. 3 shows that density is low and looks more tenuous than 5% and 10% concentrations in both the first and second repetition. The porosity measure in Table 1 shows that carbon powder with 15% concentration shows a value of 0.003272%.

Results of microstructure characterization using a Scanning Electron Microscope (SEM) tool show that bagasse-activated carbon powder from three concentration variations is generally dominant in the form of irregular rectangular fractures with more pore characters. This can occur possibly because this activated carbon comes from bagasse which also has long fibers with flakes or fractures formed from the combustion process. In addition, this is evidenced by research conducted by Mohamed et al. in 2015, which shows that activated carbon from bagasse has more pores [16].

Activated carbon powder has a different density level according to concentration variation. For example, from three concentration variations, activated carbon with the highest density level is at a concentration of 5%, and the lowest density level is at a concentration of 15%. This can occur possibly due to differences in the number of activator chemical compounds that can affect the density of activated carbon powder particles. Based on research conducted by Erawati & Fernando in 2018, the selection of activators and the concentration level of activator administration affect the density produced by activated carbon [17].

The porosity structure of activated carbon powder is seen based on the area of pores found on the carbon surface. The expansion of pores on carbon can be caused by the carbonation process and activation of carbon with activator chemical compounds [18]. According to research conducted by Mulyati in 2018, forming new pores can cause a reduction in carbon mass due to the activation process with chemical compounds [19]. From the calculation of the porosity area of activated carbon powder, the largest is found in activated carbon powder with a concentration of 5%.

SEM test results on activated carbon filters show an overview based on the diameter and length parameters of filter fiber. Results of the SEM test of activated carbon filters were then measured for diameter and fiber length and adjusted to scale in the image, which is 50 µm at 500x magnification and 30 µm at 1000x magnification. Finally, the diameter and length results that have been measured are calculated using the formula [20].

\[ D_0 = \frac{M}{D_{temp}} \times 2.3 \quad \text{and} \quad L_{real} = L_{temp} \times M \]
With $D_0$ being the diameter of the sample being sought, $M$ being the comparison scale or magnification used, $D_{temp}$ and $L_{temp}$ are the diameter and length obtained from the SEM test, and $L_{real}$ is the actual length or sample being sought. The value of 2.3 used in sample diameter calculation is the SEM test coefficient value to convert the value from the test value to the actual value. The following mean value data of the diameter and length of activated carbon filter fiber can be shown in Table 2.

<table>
<thead>
<tr>
<th>Magnification</th>
<th>500x ± SD</th>
<th>1000x ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>Diameter (µm)</td>
<td>5%</td>
</tr>
<tr>
<td>5%</td>
<td>109.86 ± 33.69</td>
<td>122.76 ± 0.66</td>
</tr>
<tr>
<td>10%</td>
<td>470.42 ± 74.83</td>
<td>509.17 ± 22.39</td>
</tr>
</tbody>
</table>

Figure 4 shows SEM test results of activated carbon filters with 5% concentration observed with 500x and 1000x magnification.

Table 2 shows the results of the mean diameter and length of activated carbon filters with 500x and 1000x magnification. At 500x magnification, 5% concentration has a filter fiber diameter of 86.04 µm and a fiber length of 525.33 µm.

![Image](image1.png)

**FIGURE 4.** SEM test results of activated carbon filter a) 5% concentration repeat 1 (500x), b) 5% concentration repeat 2 (500x), c) 5% concentration repeat 1 (1000x), d) 5% concentration repeat 2 (1000x)

![Image](image2.png)

**FIGURE 5.** SEM test results of activated carbon filter a) 10% concentration repeat 1 (500x), b) 10% concentration repeat 2 (500x), c) 10% concentration repeat 1 (1000x), d) 10% concentration repeat 2 (1000x)
Based on the results of the mean value of diameter and length of activated carbon filters with 500x and 1000x magnification. A carbon filter with 10% concentration has a filter fiber diameter of 35.78 µm and a fiber length of 204.7 µm.

![Image](image.png)

**FIGURE 6.** SEM test results of activated carbon filter a) 15% concentration repeat 1 (500x), b) 15% concentration repeat 2 (500x), c) 15% concentration repeat 1 (1000x), d) 15% concentration repeat 2 (1000x)

Based on data in Table 2, the results of the mean diameter and length of activated carbon filters with 500x and 1000x magnification. A carbon filter with 15% concentration has a filter fiber diameter of 39.86 µm and a fiber length of 305.6 µm. Morphological characterization of sugarcane bagasse activated carbon filters were analyzed based on the diameter and length of fibers in each sample observed using a Scanning Electron Microscope (SEM) tool at 2 types of magnification, 500x and 1000x. Analysis results show that samples have different diameters and lengths based on concentration variation.

The diameter of activated carbon filter fiber is known to have the best size at a concentration of 5%, both observed with a magnification of 500x and 1000x. An activated carbon filter with 5% concentration is considered to have the best diameter size because it is the smallest, so it is thought to have better adsorbing power. This is proven by research conducted by Erawati & Fernando (2018) which states that the smallest carbon size has good adsorption power at the smallest particle size. In addition, other studies mention that variations in activator chemical compounds can affect particle size and the adsorption power of activated carbon [17].

**Bacterial Filtration Efficiency (BFE)**

Results of statistical tests on bacterial filtration efficiency can be seen in Table 1 and Table 2.

<table>
<thead>
<tr>
<th>Variation</th>
<th>df</th>
<th>Sum of Square</th>
<th>MS</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>0.073</td>
<td>0.037</td>
<td>3.339</td>
<td>0.173</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>0.033</td>
<td>0.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>0.106</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

df = degree of freedom; Sum of square, ms = mean square

Based on the ANOVA test results shown in Table 1, the significant results are above 0.05. This means that there is no significant difference in the BFE test results for each activator concentration variation. The mean value of the BFE test in Table 2 indicates that the activator with 15% concentration has the highest efficiency in filtering bacteria, which is 37.5%. Meanwhile, the activator with 5% concentration has the lowest efficiency in filtering bacteria, which is 11.5%.
According to research by Sato et al in 2016, masks made of non-woven materials and activated carbon have a BFE efficiency of 97.4%, almost the same as N95 masks [21]. This can occur due to the ability that activated carbon has in resisting bacteria, hence pores of activated carbon are smaller than the geometric dimensions of bacteria [22]. However, based on BFE test results, the bacterial filtration efficiency of the three mask variations was not above 50%. The value obtained is even very far from the EN14683: 2019 standard, which is ≥ 95%. This is likely because the fabric used for the outer layer of the mask is cotton fabric, not polyester fabric, or other non-absorbent fabrics. Non-absorbent fabrics have hydrophobic and electrostatic properties that can increase filtration ability, making them suitable for the outside of masks that may have contact with droplets [23]. In addition, the manufacture of activated carbon mask filters in this study has not been standardized, so there may be a decrease in quality in the absorbent properties of activated carbon.

### Pressure Drop

The results of statistical tests on pressure drop can be seen in Table 5.

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>448,307</td>
<td>2</td>
<td>224,154</td>
<td>1,118</td>
</tr>
<tr>
<td>Within Groups</td>
<td>601,385</td>
<td>3</td>
<td>200,462</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1049,692</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results showed that there was no significant difference between the three mask samples (Sig. > 0.05). Pressure difference is an objective measure of airflow resistance and breathability. The lower the pressure difference value, the easier it is for mask users to breathe. Based on EN14683:2019 standard, the size of a pressure difference for type I masks is < 4.08 mmH$_2$O/cm$^2$. The mean value of the pressure drop can be seen in Table 6.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Mean (mmH$_2$O/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 5%</td>
<td>3.6750</td>
</tr>
<tr>
<td>Sample 10%</td>
<td>24.8400</td>
</tr>
<tr>
<td>Sample 15%</td>
<td>14.7700</td>
</tr>
<tr>
<td>Std. error</td>
<td>14,15845</td>
</tr>
</tbody>
</table>

Pressure difference is an objective measure of airflow resistance and breathability. Lower the pressure difference value makes it easier for mask users to breathe [24]. Based on the EN14683:2019 standard, the size of pressure difference for type I masks is < 40 Pa/cm$^2$ or < 4.08 mmH$_2$O/cm$^2$. Table 6. is the result of the pressure difference test on the mask sample. When referring to the EN14683: 2019 standard, the 5% sample is a mask sample that meets the standard for the pressure difference with an average of 3.6750 mmH$_2$O/cm$^2$ which is below 4.08 mmH$_2$O/cm$^2$. A factor that causes different pressure drops in each fabric mask is the fabric and thickness level of the mask filter. The difference in mask filter thickness is influenced by carbon concentration which causes the viscosity level of the mask filter before printing. This is likely due to the non-standardized mask manufacturing process.
CONCLUSION

Based on the results, three variations of cloth masks were considered less effective in reducing organisms with a percentage of filtration ability below the ASTM F2101-14 standard of 95%. From the results of the pressure drop test, it can be seen that cloth masks and activated carbon filters with a concentration of 5% have a value that meets the EN14683 standard: 2019, which is below 4.08 mmH2O/cm². Further research is needed for quality control for the manufacture of activated carbon filters in terms of filter size.

ACKNOWLEDGMENTS

The authors would like to thank the Directorate General of Learning and Student Affairs (Ditjen Belmawa) for providing financial assistance in the implementation of the research. Authors would also like to thank Physics Study Program of Universitas Negeri Jakarta and the Air Quality Laboratory of the Faculty of Civil and Environmental Engineering, Bandung Institute of Technology for assisting this research.

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