

## Swietenia mahogani Fruit Shell-Based Carbon as a Filter Medium for Domestic Liquid Waste: A Preliminary Evaluation

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### Abstract

Domestic wastewater generated from daily household activities can degrade environmental water quality if discharged without adequate treatment. Filtration is one of the most widely applied preliminary treatment methods due to its simplicity and effectiveness in increasing water quality. Activated wood carbon (AWC) is widely used as an adsorbent in filtration systems. However, commercially produced AWC can be expensive, prompting interest in developing carbon from lignocellulosic waste such as mahogany fruit shells. In this study, mahogany shell carbon was prepared in both activated (AMC) and non-activated (NMC) forms, with activation performed using KOH, and evaluated alongside other common filtration media. The effectiveness of each filter configuration was assessed based on improvements in physical water quality parameters. The results showed that filters using zeolite, sand, and NMC provided balanced performance, achieving reductions in color, turbidity, and TDS while maintaining an adequate filtration rate. In contrast, the filter containing AMC exhibited extremely low permeability due to its fine particle size, resulting in poor filtration efficiency. These findings highlight the potential of NMC as a cost-effective filtration material for household-scale wastewater pretreatment.

*Keywords: Domestic wastewater, filtration, lignocellulosic waste, mahogany shell carbon.*

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## INTRODUCTION

Water is a basic human need and is essential for human life. However, in some areas, especially in densely populated urban areas, the need for abundant clean water also creates new problems such as used water waste from households, often referred to as domestic waste. Based on data from the 2023 Indonesian Environmental Statistics, an annual publication series by the Badan Pusat Statistik (BPS), in 2021 there were 6.160 villages/sub-districts in Indonesia had water pollution problems due to household waste. Household waste is the main source of water pollution in Indonesia. Household waste accounts for 58% of all causes of water pollution in villages/sub-districts in Indonesia. Water pollution is the main pollution problem (among water, soil, and air pollution), with 10.683 villages/sub-districts facing this problem (Statistik Lingkungan Hidup Indonesia, 2023).

Wastewater is often a major problem because it can cause environmental pollution and health problems. There are 9,066 polluted rivers in Indonesia as a result of household waste. The impact of this pollution can be seen from a physical aspect in the form of liquid and solid waste that causes unpleasant odors. One way to deal with household waste that pollutes the environment, especially liquid waste, is to treat it first so that it becomes waste that is suitable for disposal (Furqonati et al., 2024). Alternative way to treat waste so that it becomes suitable for disposal is through filtration (Sitasari & Khoironi, 2021). Filtration is a separation process that separates mixtures by creating a phase difference between solids and liquids through a filter medium. In filtration process, sample filtration rate occurs due to driving forces, such as pressure differences, for example due to differences in gravity, or rotational forces. Generally, filtration is carried out if the amount of dissolved solids is relatively small compared to the solvent or suspension (Oxtoby, 2016).

Sample Quality Standards. Based on Regulation of the Minister of Environment and Forestry of the Republic of Indonesia NO: P.68/Menlhk-Setjen/2016 on Domestic Waste Quality Standards, the category of water suitable for disposal must meet the permissible pH threshold value for liquid waste, which is 6 to 9. Indonesian Minister of Health Regulation No. 492/MENKES/PER/IV/2010 on Drinking Water Quality Requirements also categorizes water types based on the threshold values in Table 1.

Table 1. Water quality standards based on Indonesian Minister of Health Regulation No. 492 Year 2010.

| Parameter   | Maximum permissible level* |                  |                   |                  |
|-------------|----------------------------|------------------|-------------------|------------------|
|             | <sup>a)</sup> I            | <sup>b)</sup> II | <sup>c)</sup> III | <sup>d)</sup> IV |
| 1 TDS (ppm) | <500                       | <1000            | <1500             | 1000-2000        |
| 2 pH        | 6.5-8.5                    | 6.5-8.5          | 6.0-9.0           | 5.0-9.0          |

\*water classification categories based on usage, a)drinking water, b)clean water, c)fisheries water, and d)industrial.

From a physics perspective, water filtration can be understood as a transport process in porous media, where fluid flow rate, permeability, and adsorption mechanisms collectively determine filtration performance. The interaction between fluid dynamics and material properties, such as particle size, pore structure, and surface area plays a critical role in controlling both the filtration rate and the removal of contaminants. Water filtration systems generally consist of several important components that work synergistically to remove contaminants and ensure that the quality of the water produced meets standards (Solikhah et al., 2024). Based on research by Fitriandy (2023), Saputra (2023), Hidayat (2023), Prasetyo (2023), and Khairunnisa (2023), sand, gravel, and activated carbon are commonly used as the main components in water filtration systems. Sand and gravel are the most commonly used media in water filtration. Sand serves to remove coarse particles, while gravel

supports the structure and facilitates water flow (Timpua & Watung, 2021). Tests conducted by Timpua (2021) on filtration systems showed that sand of a certain size was able to filter up to 90% of suspended particles.

Activated carbon plays a role in absorbing odors, tastes, organic compounds, and heavy metals from water metals (Arissunarso, 2019; Salamah, 2008; Sari & Sari, 2021). Activated carbon is carbon that has been processed so that the pores in the carbon are open (Mifbakhuddin, 2010). Research by Faradila et al. (2023) shows that activated carbon can remove up to 95% of harmful organic compounds and improve the taste of water. Activated carbon is recognized as one of the most effective adsorbents due to its high surface area and ability to bind various organic contaminants. However, commercially produced activated carbon can be expensive, prompting interest in developing alternative materials from agricultural or natural waste (Danbature et al., 2024). In recent years, activated carbon from biomass has been developed by researchers because biomass is a renewable resource and is cheaper. Activated carbon can even be made from biomass waste such as nut shells, solid waste from grain pressing, pulp, fruit peels, and so on (Salamah, 2008).

In this context, lignocellulosic waste such as mahogany fruit shells offers potential as a low-cost filtration material. Mahogany fruit shells represent a potential low-cost precursor for activated carbon production (Indriyani, 2022). Their rigid and lignocellulosic structure allows them to be converted into porous carbon through carbonization and chemical activation (Magoling & Macalalad, 2017; Tsai & Tsai, 2023). When converted into carbon, its porous structure may influence both flow behavior and adsorptive capacity, making it relevant to the study of filtration processes in environmental physics. However, the relationship between material characteristics, filtration performance, and resulting water quality parameters has not been fully explored.

Therefore, this study aims to evaluate the performance of mahogany shell-based carbon, in both activated (AMC) and non-activated (NMC) forms, as a filtration medium for domestic wastewater. The analysis focuses on the relationship between filtration media properties and measurable water quality parameters, including physical characteristics, total dissolved solids (TDS), and pH, as well as filtration performance indicators such as filtration rate and permeability. This approach allows the filtration system to be analyzed not only as a practical treatment method but also as a physical system governed by fluid flow and material interactions. Based on this objective, the research is guided by the following questions:

- a. RQ1 :How do different filtration media affect the physical properties of domestic wastewater, including color, odor, and turbidity?
- b. RQ2 :How do filtration media characteristics influence key water quality parameters, specifically TDS and pH?
- c. RQ3 :How do material properties such as particle size and permeability influence the overall filtration performance and effectiveness of the system?

## METHOD

**Preparation of Mahogany Fruit Shell-Based Carbon.** The research began with the process of making non-activated mahogany fruit shells-based carbon (NMC) and continued with the carbon activation process using an alkaline solution. In the making of activated mahogany fruit shells-based carbon (AMC), we use chemical activation by utilizing potassium hydroxide (KOH) solution, which is carried out at the Integrated Laboratory of the Faculty of Mathematics and Natural Sciences, UNNES. The process of making AMC follows the procedure below.

1. The mahogany fruit shells are processed into NMC. After cooling, the carbon is ground until it passes through a 100 mesh sieve.
2. A KOH solution with a concentration of 3 N was prepared.
3. The carbon was soaked in the KOH solution with a ratio of 1:3 and stirred using a magnetic stirrer. The soaking process was carried out for 4 hours.

4. The carbon is neutralized after the soaking process in the KOH solution.
5. The soaked carbon is drained and dried at a temperature of 100oC for 1 hour.
6. The AMC is then stored in a tightly sealed plastic container until it is used as a component of water filters.

Carbon is generally divided into two types: powdered form carbon and granular form carbon. Both types of carbon were used in the experiment. Activated wood carbon (AWC) and NMC used are in granular form, and AMC used is in powdered form.

**Filtration Device Setup.** The mechanical filtration processing method will be applied in this study. The filtration device was made using 2-inch diameter PVC pipes equipped with valves to open the flow of waste filtration. A detailed diagram of the device is illustrated in Figure 1. The wastewater source will be channeled through the filtration pipe. The water will flow through several filter components. The water that has passed through the filtration stage is then collected in a storage container at the bottom of the filtration pipe. Figure 2 shows the documentation of the device that is ready for use for filtration with variations in the filter material arrangement as described in Figure 3. In addition, the mass, volume, and particle size diameter of all filter media used in the system were measured prior to assembly to ensure comparability between filter configurations. The material specifications and quantities used in the device are detailed in Table 2.

**Wastewater Sources.** The domestic wastewater used in this study consisted of liquid waste generated from dishwashing activities in households. The wastewater in each batch was different because it depended on the wastewater supply. Three wastewater batches were used in this study. The visible physical properties and parameters of the wastewater are presented in Table 3.

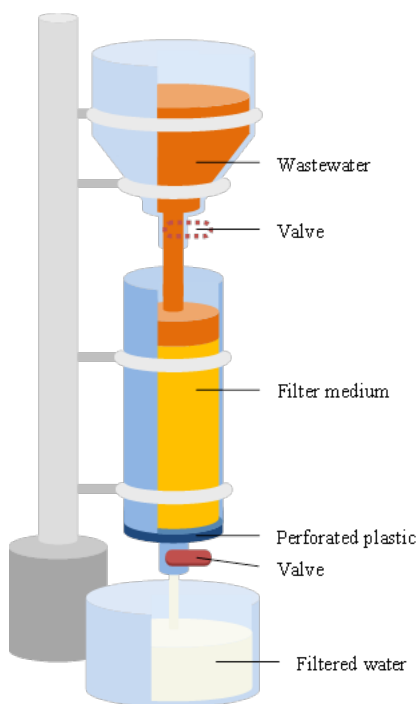


Figure 1. Illustration of the wastewater filter system.



Figure 2. Domestic wastewater filtration device.

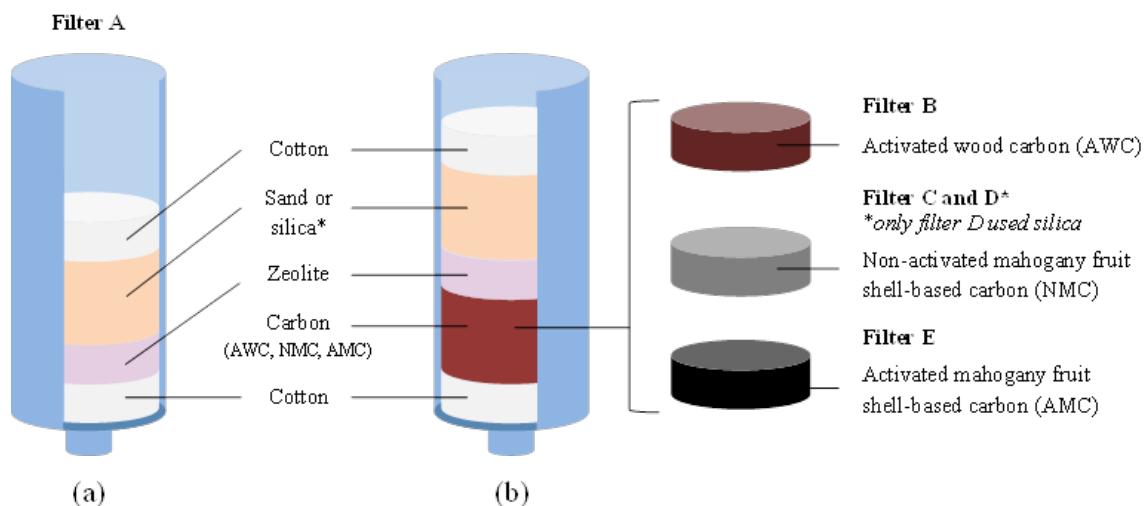


Figure 3. Composition of water filter medium with variations (a) without carbon, (b) granular AWC, granular NMC, granular NMC but using silica, and powdered AMC.

Table 2. Mass density,  $\rho$  and particle size,  $d$  of the filtration media used.

|                               | $m$<br>(gr) | $V$<br>(cm <sup>3</sup> ) | $\rho$<br>(gr/cm <sup>3</sup> ) | $d$<br>(mm)                               |
|-------------------------------|-------------|---------------------------|---------------------------------|-------------------------------------------|
| Activated wood carbon         | 254         | 438.90                    | $5.79 \times 10^{-1}$           | $2.5 \times 10^{-1} - 5.0 \times 10^{-1}$ |
| Activated mahogany carbon     | 254         | 438.90                    | $5.79 \times 10^{-1}$           | $< 1.5 \times 10^{-1}$                    |
| Non-activated mahogany carbon | 110         | 438.90                    | $2.51 \times 10^{-1}$           | $1.0 \times 10^{-1} - 2.0 \times 10^{-1}$ |
| Zeolite                       | 253         | 219.45                    | 1.15                            | 1.0 - 3.0                                 |
| Sand                          | 488         | 438.90                    | 1.11                            | $5.0 \times 10^{-1} - 2.0$                |
| Silica sand                   | 634         | 438.90                    | 1.44                            | $5.0 \times 10^{-1} - 2.0$                |
| Cotton                        | 16          | 438.90                    | $3.65 \times 10^{-2}$           | -                                         |

Table 3. Wastewater physical properties and parameters.

| Wastewater batch | Visible physical properties description                                     | Physical parameters |                              |
|------------------|-----------------------------------------------------------------------------|---------------------|------------------------------|
|                  |                                                                             | TDS<br>(ppm)        | Acidic-base<br>level<br>(pH) |
| 1                | Odorous, oily, dissolved large particle seen, cloudy.                       | 773.5               | 4.30                         |
| 2                | Odorous, oily, dissolved large particle seen, cloudy and brownish in color. | $114.0 \times 10$   | 3.80                         |
| 3                | Odorous, oily, dissolved large particle seen, cloudy and brownish in color. | $195.0 \times 10$   | 5.40                         |

#### Sample and Data Collection.

After the wastewater passed through each filter device, the filtered wastewater was collected and its volume was recorded over a fixed time interval to determine the filtration rate. A 100 mL subsample was taken from each filtrate batch for further analysis of physical water quality parameters. Testing Procedures. The samples obtained through filtration were then observed and analyzed for their visible physical properties. In addition, wastewater samples were measured in the laboratory based on the parameters of total dissolved solids using a Total Dissolved Solid (TDS) meter and acidity levels using

a pH meter after being calibrated. Each measurement was performed twice for every sample to ensure reliability and consistency.

#### **Filtration Rate and Darcy's Law Calculation.**

Filtration rate is an essential parameter for evaluating the performance and practicality of a filtration system. It represents the volume of water that can pass through a filter per unit of time and reflects the permeability and structural characteristics of the filter media. The filtration rate of the device is measured using Darcy's Law on fluid flow through porous media. Darcy's Law states that the rate of fluid flow through porous media is proportional to the hydraulic pressure gradient and the permeability of the media, as shown in equation (1).

$$Q = -k \cdot A \cdot \frac{\Delta h}{L} \quad (1)$$

and

$$k = \frac{V \cdot L}{A \cdot \Delta h \cdot t} \quad (2)$$

with:

- V : Volume of water flowing (m<sup>3</sup>)
- L : Length of material passed through (m)
- A : Cross-sectional area of material (m<sup>2</sup>)
- Δh : Height difference of hydraulic (m)
- t : Flow time (s)
- k : Permeability coefficient (m/s)
- Q : Filtration flow rate (m<sup>3</sup>/s)

## **RESULTS AND DISCUSSION**

This section presents the experimental findings in accordance with the research questions posed in this study. First, it discusses the influence of filter media composition on the physical properties of domestic wastewater (RQ1). Second is the influence of filter media composition on the quality parameters (RQ2). Lastly, it discusses how material properties, such as particle size and permeability, affect the system's overall filtration performance and effectiveness (RQ3).

#### **Effect of Filtration on Physical Properties.**

To address RQ1, the effect of filtration media on the physical properties of wastewater was analyzed. The filtration experiments were conducted using several filter configurations composed of zeolite, sand, silica sand, and different types of carbon media shown in Figure 3. The samples tested in this study can be seen in Figures 4 and 5. Based on the observations, it can be seen that the type of material used in the water filter greatly affects the filtration results, both in terms of the filtration rate and the physical properties of the filtered water. The visible physical properties of the samples are presented in Table 4.



Figure 4. Documentation of wastewater samples and filtration results, in order (left to right) are waste 1, B1', C1', D1' (back row), waste 2, B2, C2, and D2 (front row).



Figure 5. Documentation of wastewater samples and filtration results, with (left to right) waste 3, B3, C3, D3, A3 (back row), E3', and A3' (front row).

The observation data in Table 4 shows that all filtration results, both with and without carbon, are odorless and visually clearer after treatment. This indicates that the filtration system effectively improves the physical quality of wastewater. The clarity of the samples can be attributed to the presence of silica sand and beach sand, which function as mechanical filters that remove suspended particles and reduce turbidity. Silica sand and beach sand can reduce cloudiness caused by large particles (Timpua & Watung, 2021). Research by Gupta (2009) and Ahmad (2016) explains that silica sand is widely used in water treatment plants to reduce turbidity and filter fine particles. In addition, this medium is durable and has a high filtration capacity.

Table 4. Observation data on wastewater filtration result.

| Sample*          | Description                                                                                                        |
|------------------|--------------------------------------------------------------------------------------------------------------------|
| B <sub>1</sub> ' | Odorless, non-oily, no dissolved large particle seen, clear and colorless.                                         |
| C <sub>1</sub> ' | Odorless, non-oily, no dissolved large particle seen, clear but brownish in color.                                 |
| D <sub>1</sub> ' | Odorless, non-oily, no dissolved large particle seen, clear but blackish in color.                                 |
| B <sub>2</sub>   | Odorless, non-oily, no dissolved large particle seen, clear and colorless.                                         |
| C <sub>2</sub>   | Odorless, non-oily, no dissolved large particle seen, clear but slightly yellowish in color.                       |
| D <sub>2</sub>   | Odorless, non-oily, no dissolved large particle seen, clear but slightly yellowish in color.                       |
| A <sub>3</sub> ' | Odorless, non-oily, no dissolved large particle seen, clear but brownish in color.                                 |
| E <sub>3</sub> ' | Odorless, non-oily, jet black.                                                                                     |
| A <sub>3</sub>   | Odorless, non-oily, no dissolved large particle seen, clear but brownish in color (clearer than a <sub>3</sub> '). |
| B <sub>3</sub>   | Odorless, non-oily, no dissolved large particle seen, clear but slightly yellowish in color.                       |
| C <sub>3</sub>   | Odorless, non-oily, no dissolved large particle seen, clear but yellowish in color.                                |
| D <sub>3</sub>   | Odorless, non-oily, no dissolved large particle seen, clear and colorless.                                         |

\*The letters preceding the sample numbers correspond to the variations in filter material used in Figure 2, and the apostrophe (') indicates that sample came from the filter was used for the first time.

In addition to turbidity reduction, the removal of odor is associated with the presence of zeolite, which has a high adsorption capacity due to its porous structure. Zeolite is widely used to remove odor-causing substances such as ammonia (NH<sub>3</sub>) and hydrogen sulfide (H<sub>2</sub>S), as well as other organic and inorganic compounds (Widiastuti, 2011). Previous studies have shown that zeolite effectively reduces ammonia content and adsorbs sulfur-based compounds responsible for unpleasant odors (Wang and Peng, 2010; Li and Bowman, 2001). This indicates that the filtration media effectively removed odor-causing compounds. These results indicate that each filtration medium plays a distinct role in the overall filtration process. Differences in filtration performance are more evident in filters containing carbon media. Filters B, C, and D, which use AWC and NMC, show a more significant reduction in color compared to filter A without carbon. These results are reinforced by the statements in the studies by Salamah (2008) and Arissunarso (2019), which state that activated carbon media are better at reducing color parameters in wastewater. Mifbakhuddin (2010) states that activated carbon is carbon that has been processed so that its pores are open, thus activated carbon has high absorptive power. The activation process increases the adsorption capacity of carbon by opening its pore structure, resulting in higher absorptive power. This is reflected in filter B, which demonstrates better color removal than filters C and D.

However, not all carbon-based filters perform equally. In filter e, the use of powdered AMC results in the release of fine particles into the filtrate, increasing the measured TDS and affecting water clarity. This behavior is related to the application characteristics of powdered carbon, which requires different handling compared to granular carbon forms. The operational procedures for the adsorption process differ for powdered carbon and granular carbon. Powdered carbon is usually dissolved in the sample until contact occurs, then left to settle (Masduqi & Assomadi, 2012). Based on the statement by Masduqi and Assomadi (2012), filters with AMC in powdered form should be treated differently from other filters due to the significant difference in the size of the adsorption media particles. This suggests that correct use of carbon-based media contribute to improving water quality beyond turbidity reduction, particularly in removing dissolved substances that are not captured by sand filtration alone. These results demonstrate that the filtration process involves multiple mechanisms, including adsorption and mechanical filtration, which collectively determine the effectiveness of the system.

#### Effect of Filtration on Quality Parameters.

To address RQ2, tests were also conducted using a TDS meter and pH meter. While visual improvements are evident, quantitative analysis using TDS and pH measurements is necessary to further evaluate filtration performance. The test results for each sample are presented in Table 5 and 6. The TDS results show that filter devices A, C, and D produced a consistent reduction in dissolved solids across repeated filtrations, indicating stable media performance. Filter B with granular AWC achieved the most noticeable reduction, suggesting a strong initial ability to lower TDS. In contrast, filter E with powdered AMC exhibited markedly higher TDS levels in the filtrate, demonstrating ineffective removal and possible leaching of dissolved material from the fine activated carbon media.

Table 5. Total dissolved solid (TDS) in 100 mL of domestic wastewater sample.

| Filter device | TDS**<br>(ppm)    |                   |                   |                  |                   |                   |
|---------------|-------------------|-------------------|-------------------|------------------|-------------------|-------------------|
|               | $\overline{pF}$   | $\overline{F}$    | $\overline{pF}_1$ | $\overline{F}_1$ | $\overline{pF}_2$ | $\overline{F}_2$  |
| a             | $195.0 \times 10$ | $559.5 \times 10$ | -                 | -                | $195.0 \times 10$ | $147.0 \times 10$ |
| b             | 773.5             | 537.5             | $114.0 \times 10$ | 239.5            | $195.0 \times 10$ | 781.0             |
| c             | 773.5             | 872.5             | $114.0 \times 10$ | 935.0            | $195.0 \times 10$ | $145.5 \times 10$ |
| d             | 773.5             | 784.0             | $114.0 \times 10$ | 939.5            | $195.0 \times 10$ | 731.0             |
| e             | $195.0 \times 10$ | $680.5 \times 10$ | -                 | -                | $195.0 \times 10$ | -                 |

\*The sample filtered using pre-washed filter device.

\*\*The number doesn't indicated the wastewater batch used in the samples

The reduction in TDS is associated with the adsorption of dissolved ions onto the surface of the carbon material. This reduction indicates effective adsorption of dissolved ions onto the porous carbon surface, which is governed by surface area and pore structure characteristics. Filters with higher surface area and more accessible pore structures exhibited greater TDS reduction. Conversely, filters containing very fine particles showed unstable TDS values, likely due to the release of suspended carbon particles into the filtrate, which increased measured dissolved solids.

Asadiya's (2018) research shows that a zeolite-activated carbon composition with a ratio of 1:1 is effective in reducing the TDS content in samples. According to Pamuji (2014), the combination of zeolite and activated carbon media is a good combination for water filtration because the difference in pore size between zeolite and activated carbon affects the filtration ability of the two media. Zeolite is a mineral that has selective cavities or pores for filtration. The pore size for the filtration process possessed by zeolite is relatively smaller than the pore size possessed by activated carbon (Asadiya, 2018). The pore size of activated carbon, which is relatively larger than the pore size of zeolite media, allows activated carbon to absorb nonpolar compounds. Meanwhile, zeolite media with its pore size can perform filtration or ion exchange on polar molecules such as organic material dissolved in samples (Utama, 2017; Asadiya, 2018).

In addition to affecting TDS, zeolite and carbon also affect pH changes in the samples. The pH test results for each sample are presented in Table 6. The pH results show that all filter devices, which equally incorporate zeolite, caused an increase in the pH of the wastewater due to the alkalizing nature of the mineral. However, filters that combined zeolite with carbon (filters B, C, and D) demonstrated better overall performance, producing more stable and moderated pH values across repeated filtrations. In contrast, filter E, which uses powdered AMC without proper treatment, showed irregular and highly acidic pH values, indicating unstable performance. These trends suggest that while zeolite alone can adjust pH, the integration of carbon enhances the stability and suitability of the treated water.

Table 6. Acid-base level in 100 mL of domestic wastewater sample.

| Filter device | Acid-base level** |            |                   |             |                   |             |
|---------------|-------------------|------------|-------------------|-------------|-------------------|-------------|
|               | (pH)              |            |                   |             |                   |             |
|               | $*p\bar{F}$       | $*\bar{F}$ | $\overline{pF_1}$ | $\bar{F}_1$ | $\overline{pF_2}$ | $\bar{F}_2$ |
| A             | 5.40              | 5.90       | -                 | -           | 5.40              | 6.05        |
| B             | 4.30              | 4.65       | 3.80              | 5.05        | 5.40              | 6.10        |
| C             | 4.30              | 9.40       | 3.80              | 4.65        | 5.40              | 6.70        |
| D             | 4.30              | 9.95       | 3.80              | 4.50        | 5.40              | 6.40        |
| E             | 5.40              | 10.95      | -                 | -           | 5.40              | -           |

\*The sample filtered using pre-washed filter device.

\*\*The number doesn't indicated the wastewater batch used in the samples.

In initial filtration with NMC and AMC can be observed that there are still many dissolved carbon particles, indicated by a change in the color of the waste to black. Table 6 shows that dissolved carbon greatly affects the acid-base level of the sample. The adsorption process in activated carbon can cause changes in water pH, especially if the activated carbon is new and contains residues that have not been completely removed (Mifbakhuddin, 2010). Ariyani et al. (2020) research shows that the use of carbon in water filter can increase water pH. Similar to activated carbon, zeolite can also affect the acid-base level of the sample. The use of zeolite can affect the pH of water, especially if the water contains ions that can interact with zeolite. Research by Heriyana and Mugisidi (2016) shows that adding zeolite media in the filtration process can increase the pH of wastewater so that it approaches the pH value in accordance with wastewater quality standards.

### Comparative Performance of Filter Configuration.

To compare the overall performance of the filtration configurations, the key physical parameters, including carbon particle size, filtration rate, and permeability were summarized in Table 7. This summary provides a consolidated view of how each filter behaves in terms of flow characteristics and pollutant removal efficiency, allowing the strengths and limitations of each media combination to be clearly identified. Filtration rate is a key indicator of filter performance because it reflects the permeability of the media and the practicality of the filtration process. A fast filtration rate suggests high media permeability, while a slow rate may indicate clogging, compaction, or the presence of fine particles.

Table 7. Summary of physical performance of filters.

| Filter | Carbon particle size*<br>(mm)             | Filtration rate<br>(mL/s) | Permeability<br>(k) |
|--------|-------------------------------------------|---------------------------|---------------------|
| A      | -                                         | $3.49 \times 10^{-1}$     | Moderate-fast       |
| B      | $2.5 \times 10^{-1} - 5.0 \times 10^{-1}$ | $6.71 \times 10^{-2}$     | Slow                |
| C      | $1.0 \times 10^{-1} - 2.0 \times 10^{-1}$ | $6.73 \times 10^{-3}$     | Very slow           |
| D      | $1.0 \times 10^{-1} - 2.0 \times 10^{-1}$ | $6.73 \times 10^{-3}$     | Very slow           |
| E      | $<1.5 \times 10^{-1}$                     | $4.26 \times 10^{-3}$     | Very slow           |

\*The filtration rate only depends on the carbon particle size because the other component made from exact same size material.

To address RQ3, the relationship between particle size, permeability, and filtration performance was analyzed using Darcy's Law. Data on water filtration rate calculations using Darcy's Law are presented in Table 8. Darcy's law states that the flow rate of fluid through a porous medium is proportional to the hydraulic pressure gradient (Bear & Bachmat, 1990). This statement is reinforced by the results of research conducted by Triatmojo et al. (2020), which shows that water flowing through porous media is only affected by hydrostatic pressure. Fluid flow rate analyzed using the concept of Darcy's law is steady state flow, so that the debit is not affected by changes over time.

Table 8. Water filtration rate.

|   | $k$<br>$\times 10^{-6}$<br>(m/s) | $A$<br>$\times 10^{-4}$<br>(m <sup>2</sup> ) | $L$<br>$\times 10^{-2}$<br>(m) | $Q$<br>(cm <sup>3</sup> /hour) |
|---|----------------------------------|----------------------------------------------|--------------------------------|--------------------------------|
| A | $1.78 \times 10^2$               | 19.64                                        | 0.64                           | $12.55 \times 10^2$            |
| B | $3.42 \times 10$                 | 19.64                                        | 0.89                           | $24.16 \times 10$              |
| C | 3.43                             | 19.64                                        | 0.89                           | 24.22                          |
| D | 3.43                             | 19.64                                        | 0.89                           | 24.22                          |
| E | 2.17                             | 19.64                                        | 0.89                           | 15.33                          |

Based on the data in Table 8, it can be seen that filters using powdered AMC have lower permeability compared to filters using granular NMC. The shape of the granules affects the size of the pores and the surface area of the media formed (Arissunarsa, 2019). The AMC used has finer particles, with a mesh size of 100, compared to NMC. Filter e exhibited an extremely slow filtration rate because the AMC carbon used was ground to a very fine size, causing the particles to pack densely and significantly reduce pore space. The high micro-porosity created during chemical activation also increased water retention within the carbon's internal structure. Together, these factors decreased the permeability of the filter media, resulting in severe

flow rate resistance and very low filtration rate. This finding is consistent with research by Nindya and Suparno (2016) that stated that the size of carbon particles affects the filtration rate.

However, permeability is not solely determined by the shape and size of the media particles. The data in Table 8 shows that filters using activated carbon have higher permeability than non-activated carbon filters. The process runs faster because the pores in activated carbon are larger than those in non-activated carbon (Arissunarto, 2019). This finding is reinforced by research by Mifbakhuddin (2010), which states that activated carbon is carbon that has undergone various processes so that the pores in the carbon are open, thus activated carbon has a higher absorption capacity. Consequently, waste flows more easily in activated carbon media. These differences in permeability and adsorption characteristics not only affect filtration rate but also influence the overall quality of the treated water. Therefore, it is important to evaluate whether the filtered wastewater meets established environmental standards. In accordance with regulations issued by the Indonesian Ministry of Health and Ministry of Environment and Forestry, the results of household waste filtration can be categorized as shown in Table 9.

Table 9. Categories of waste filtration results in accordance with Indonesian Minister of Health Regulation No. 492 Year 2010 and Indonesian Minister of Environment and Forestry Regulation No. 68 Year 2016.

| Sample | Indicator*       |     |       |     |    | Description                |
|--------|------------------|-----|-------|-----|----|----------------------------|
|        | Odor             | Oil | Color | TDS | pH |                            |
| 1      | B <sub>1</sub> ' |     |       |     |    | Not yet ready for disposal |
|        | C <sub>1</sub> ' |     |       |     |    | Not yet ready for disposal |
|        | D <sub>1</sub> ' |     |       |     |    | Not yet ready for disposal |
| 2      | B <sub>2</sub>   |     |       |     |    | Not yet ready for disposal |
|        | C <sub>2</sub>   |     |       |     |    | Not yet ready for disposal |
|        | D <sub>2</sub>   |     |       |     |    | Not yet ready for disposal |
| 3      | A <sub>3</sub> ' |     |       |     |    | Not ready for disposal     |
|        | E <sub>3</sub> ' |     |       |     |    | Not ready for disposal     |
|        | A <sub>3</sub>   |     |       |     |    | Ready for disposal         |
|        | B <sub>3</sub>   |     |       |     |    | Ready for disposal         |
|        | C <sub>3</sub>   |     |       |     |    | Ready for disposal         |
|        | D <sub>3</sub>   |     |       |     |    | Not yet ready for disposal |

\*The colored table indicates that the sample was meet the standards such as odorless, non-oily, colorless, TDS<1500 ppm, and neutral pH.

The study showed that different media combinations produced varying levels of improvement in domestic wastewater quality. Filters using zeolite, sand, and granular NMC provided the effective reduction in color, turbidity, and TDS while maintaining an acceptable filtration rate. Meanwhile the filter used powdered AMC, with its very fine particle size, resulted in extremely slow filtration rate and limited improvement. Compared with Indonesian wastewater quality standards, only some combinations brought the filtrate closer to acceptable limits, emphasizing that media composition and permeability strongly influence overall performance. The results showed that filters using zeolite, sand, and granular NMC provided balanced performance, achieving significant reductions in color, turbidity, and TDS while neutralized pH and maintaining an adequate filtration rate. The device's overall performance is demonstrated in Table 10.

Table 10. Device's overall performance summary based on the observation and laboratory measurement.

| Filter device | Physical indicator* | Physical performance* | Description                                                                                                                 |
|---------------|---------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------|
| A             |                     |                       |                                                                                                                             |
| B             |                     |                       | The AWC works best, significantly reducing TDS, effectively neutralizing pH, and maintaining an acceptable filtration rate. |
| C             |                     |                       |                                                                                                                             |
| D             |                     |                       | The NMC has an impact on TDS reduction, neutralized pH, and an acceptable filtration rate.                                  |
| E             |                     |                       |                                                                                                                             |
|               |                     |                       | The powdered type carbon did not suit this kind of filtration mechanism. Fine carbon particles blocked the mechanism.       |

\*The colored table indicates that the filters meet the standards to filtered domestic wastewater save for disposable.

As a secondary observation of the study, it was determined that there is a difference in performance between the new and used devices. The filtration results are divided into two main categories: initial filtration, when the device has never been used and has never been exposed to water, and repeated use, when the filter has been washed and used multiple times. There is a significant difference between the two groups. A filter that has never been used or washed will produce poor filtration results. Water filters need to be washed before use. This removes dust, dirt, and other particles that may be present in the filter or the filter material. Washing the water filter before use removes any residues or chemicals remaining from manufacturing process (Roni et al., 2020). In addition, cleaning the filter regularly can improve filtration efficiency (A. M. Sari & Rinawati, 2021)..

## CONCLUSION

This study evaluated the performance of various filter media combinations in improving the physical quality of domestic wastewater. The results showed that filters using zeolite, sand, and granular NMC provided balanced performance, achieving significant reductions in color, turbidity, and TDS while maintaining an adequate filtration rate. In contrast, the filter containing powdered AMC (100-mesh) exhibited extremely low permeability due to its fine particle size, resulting in slow filtration rate and poor filtrate clarity. These findings emphasize the importance of media characteristics in filtration systems. In particular, particle size and pore structure govern both permeability and adsorption capacity, which together control flow behavior and contaminant removal efficiency. Granular carbon materials are therefore more suitable for packed-bed filtration systems than powdered forms. Overall, the most effective configuration achieves a balance between sufficient permeability and strong adsorption capability, making it applicable for simple domestic wastewater treatment. Future studies should focus on optimizing material properties, particularly particle size distribution, to improve filtration consistency and performance. In addition, further investigation into the interaction between fluid flow and porous media structure would provide deeper insight into the physical mechanisms governing filtration efficiency. It is also recommended to ensure that all filter components are thoroughly washed prior to use in order to remove fine dust or residual particles that may affect the filtration performance and interfere with the accuracy of the measurements.

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## DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

## CONFLICTING INTEREST STATEMENT

The authors states that there is no conflict of interest in the publication of this article.

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