PERFORMANCE OF RAPID SAND FILTER DUAL MEDIA FOR MICROPLASTIC REMOVAL IN THE WATER: THE EFFECT OF MICROPLASTIC SIZE AND EFFECTIVE SIZE OF FILTER MEDIA

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Abstract

Microplastics (MPs) significantly damage the environment and human health, leading to a growing global concern. MPs have been detected not only in the natural environment but also in the drinking water treatment process. One of the configurations of the drinking water treatment unit is filtration. Only a few research studies have been published on microplastic removal in the water system. This study was conducted to determine the performance of a rapid sand filter (RSF) in removing microplastics in water with a variation in the effective size (ES) of silica sand and microplastic size. In this study, microplastics are artificially made with size variations of < 400 μm and >400 μm. The filtering uses two variations in the adequate size (ES) of silica sand, namely 0.4 mm and 0.7 mm. At the same time, anthracite is only a control variable with ES = 0.69 with a flow speed of 4 m / h and an observation time of 30, 60, 90, and 120 minutes. The results show that the filter media ES 0.4 has the highest efficiency values of 91.30% for the microplastic size MPs <400 µm and 95.80 % for the larger microplastic >400 µm. In addition, the average percentage removal of ES 0.7 mm was 77.24 % for the size of MPs <400 µm and 95.77% for the size of Mps >400 µm. Gaining insight into the mechanisms involved in removing microplastics from drinking water is essential for developing more effective techniques for eliminating them.

Keywords: *microplastic, rapid sand filter dual media, silica sand, drinking water*

Introduction

The global plastic production has increased by a factor of 560 in the last six decades. Plastic materials have greatly enhanced our daily lives due to their lightweight, excellent chemical stability, impressive durability, and competitive costs (Lastovina & Budnyk, 2021). Reports indicate that the annual production of plastic products in 2019 amounted to around 368 million tonnes, which is projected to increase to 500 million tonnes by 2025 (Huang et al., 2021). Only a minor proportion of plastics undergo recycling, while the overwhelming majority are later discharged into the ecosystem as waste plastic through multiple pathways (Y. B. Widianarko & Hantoro, 2018).

Microplastics (MPs) defined as plastic with a particle size of less than 5 mm (Ryberg et al., 2019; Shen et al., 2020), can be divided into 2 (two) sources, namely primary and secondary. Primary sources are microplastics that are deliberately made in microscopic sizes, while secondary microplastics are formed from degraded macro-sized plastics (Thushari & Senevirathna, 2020). Microplastics have been found to act as carriers for other harmful

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Received: 30 January 2024
Revised : 28 February 2024
Accepted: 16 March 2024
DOI: 10.23969/jcbeem.v8i1.12502

compounds, facilitating their movement in the environment. These harmful compounds adhere to microplastics in the environment through adsorption processes and can be consumed through inhalation or touch. Subsequently, desorption mechanisms liberate these substances after being consumed and can potentially cause toxicity and accumulate throughout the food chain (Verla et al., 2019). MPs easily penetrate the human body via the food chain due to their abundant quantity and small dimensions. MPs indicated a considerably higher risk to humans than big plastics. Several scientific studies have investigated the harmful impacts of microplastics (MPs) on organisms' biological processes and viability. As a result, MP pollution has gained global acknowledgment as an emerging environmental concern (Sutkar et al., 2023).

In addition, water sources contaminated with microplastics can also cause a decline in public health. A study conducted by (Mintenig et al., 2019; Pivokonsky et al., 2018) stated that microplastics can be found in water bodies and drinking water treatment processes where the number of microplastics reached up to >4,000 items per litre. Thus, it can be said that water treatment plants have to deal with the presence of new polluting agents (microplastics) in at least some of the areas that have been observed (Novotna et al., 2019). Generally, the treatment units used in drinking water treatment are pre-sedimentation, coagulation, flocculation, sedimentation, filtration and chlorination. Filtration is a method used to separate or filter water from solids and colloids through porous media. Based on this function, the filtration method can remove microplastics. According to research conducted by (Sembiring et al., 2021), rapid sand filter single media can be a promising technique to remove microplastic in water. The media used in the study was silica sand and could remove 85% - 97% of microplastics with a size of 200 µm.

This research also employed the rapid sand filter (RSF) method, considering the observed efficacy of the single-media rapid sand filter conducted in a previous study. This is because the reactor and media used in rapid sand filters are easy to design, easy to obtain and have an affordable price. RSF is made to eliminate contaminants physically and is usually run for a short time with media filters (Chabi et al., 2024). Quartz sand and grainy activated carbon are used in media filters to clean water. In addition, rapid sand filters can filter water faster, wash it easier and have high effectiveness because the media used has low porosity.

The previous study (Sembiring et al., 2021) used a single-media rapid sand filter with silica sand filter media. The result showed that the performance of RSF single media could remove the microplastic up to 95 %. In this study, a dual media filter was chosen because, in general, it can provide better water results than single media. Silica sand can filter solids in water, while anthracite can filter solids and reduce turbidity and odours that organic substances can cause. However, there needs to be more research elucidating the process of eliminating microplastics through the utilization of dual media. This study aims to determine the optimal size of dual media rapid sand filter media for the removal of microplastics and to investigate the impact of filter media size and microplastics size on their removal efficiency.

Research Methodology

Rapid sand filter preparation

This reactor has a height of 100 cm, a length of 15 cm, and a width of 15 cm. The media used in this reactor are gravel with a thickness of 10 cm, silica sand (ES = 0.3 - 0.7 mm) with a thickness of 30 cm and anthracite (ES = 1.2 - 1.8 mm) with a thickness of 40 cm. This study has a submersible pump to drain water from the inlet drum to the reactor. The water flow speed is regulated using a faucet connected to a pipe and flowmeter. This reactor can be seen in Figure 1. Before the filtration test, the media filter was analyzed, washed and dried to ensure the absence of impurities in the media filter.

Filtration Test

The primary investigation was carried out utilizing a reactor depicted in Figure 1.

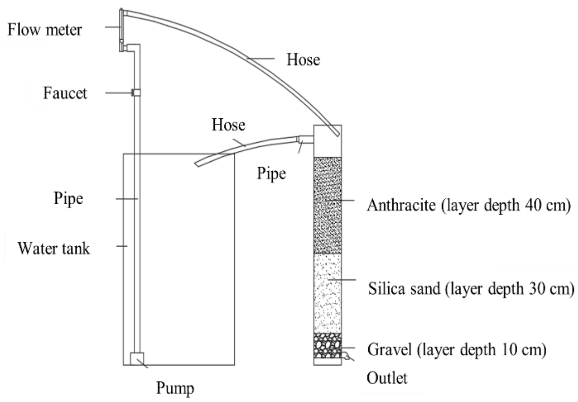

Figure 1. Schematic of rapid sand filter used in this study.

Water from the sample tank was transferred to the storage tank via the submersible pump; the water was subsequently introduced into the reactor via the filter media at the outflow. The contaminated water used in this study was made artificially by mixing artificial microplastics with clean water sourced from municipal water supply system. The initial elevation of the water surface over the filter medium was 5 cm. The continuous flow method will be used to flow the water sample continuously for 120 minutes for each variation of effective size (ES) of silica sand, at a loading rate of 4 m/h. One liter samples will be taken from the inlet and outflow at time intervals of 0, 30, 60, 90, and 120 minutes. To evaluate the optimum size of the media filter and to see the performance of the rapid sand filter, there were two variations of silica sand effective size (0.3-0.5 mm & 0.51-0.7 mm. The microplastic size also adjusted at (<400 µm & >400 µm) represents the smaller and bigger size.

Microplastic Identification

The present study used artificial microplastic samples from plastic bags (LDPE) and shampoo containers (HDPE). Both plastics are then pulverized using a grater and blender so that there is a smaller size. The plastic bag will be in the form of a film, while the shampoo container will be in the form of fragments.

During 2 h running filtration test, influent and effluent samples were collected using a glass bottle with a volume of 500 mL. After the filtration, the samples were filtered using Whatman GF/C paper with the assistance of the vacuum filter. Whatman GF/C paper is used because it has pores measuring 1.2 µm; hence, it is very appropriate if used to filter microplastics (Wulandari et al., 2021). After the water sample was drained, the filter paper was transferred to a petri dish and placed in an oven at 70° C for 1 h. The filter paper was marked with a line into eight sections to facilitate identification. The dried filter paper was then identified the number and size of microplastics using a light binocular microscope with a lens magnification of 10× (total magnification 100×). The unit of the number of microplastics observed is the number of microplastics per liter of sample.

The stages carried out refer to the technical guidelines and provisions of Crawford and Quinn (2017) on the identification of microplastics based on the SCS (Size and Colour Sorting System) technique, namely determining the size of plastic, determining the color of microplastics, and determining the number of microplastics.

Effectiveness of Microplastic Removal

At this stage, the effectiveness is seen based on the number of initial microplastics or at minute 0 and those that pass the filtration process. The removal effectiveness can be calculated using the following equation.

$$\%R = \frac{C_{in} - C_{out}}{C_{in}} \times 100\% \quad (1)$$

R is the removal efficiency percentage (%), C_{in} is the initial microplastic number, and C_{out} is the final microplastic number after passing through the media filter.

Results and Discussion

Media Filter Analysis

Sieve analysis is first carried out to determine the filter media that suits the design criteria of the dual media rapid sand filter method. The parameters to be known are effective size (ES) and uniform coefficient (UC), or uniformity coefficient of the filter media. The graph provided data on each filter media's effective size (ES = D10) and uniformity coefficient (UC = D60/D10) values. Table 1 displays the findings of the filter media investigation.

Table 1. Filter media properties

Parameter	**Silica sand 20-40 Mesh**	**Silica sand 8-16 Mesh**	**Anthracite 8-16 Mesh**
ES (mm)	0.59	0.7	0.63
UC (mm)	1.34	1.2	1.8
Particle Density (g/cm^3)	2.60	2.70	1.46
Porosity	0.4	0.4	0.5

The characteristic of media used in this study suits the RSF design criteria established by (Reynolds & Richards, 1996) and (Tchobanoglous et al., 2003) regarding sand porosity, ES, and UC values. The filter media uniformity value, denoted as UC and represented by the ratio D60/D10, is determined by the ES value (D10), which represents the size of the upper filter media deemed most efficient at segregating impurities that traverse the filter media. Design criteria for RSF have been set by (Reynolds & Richards, 1996); the UC value is less than 1.7 mm and ES values range from 0.35 to 0.70 mm. Silica and anthracite may be utilized as the filter medium in this investigation, according to the outcomes of the sieves' analysis by the design criteria. The RSF design criterion for filter media porosity is 0.42–0.47 (Sembiring et al., 2021). Therefore, according to Table 1, the two sand media variations met with the RSF filter media category. Particle density is an indication of the density of soil particles (Blake, 2008). The design criteria for porosity in silica sand is 0.4. Meanwhile, the design criteria for anthracite media porosity are 0.5. Based on Table 1, all particle densities of the media filter have met the design criteria.

Filtration test

The ES used in this study were 0.3-0.5 and 0.51-0.70. In the first step, the number of microplastics with two different (size <400 µm and >400 µm) with silica sand effective size variation of 0.4 was monitored as the function of the running test. The samples were taken with 0, 30, 60, 90, and 120 minutes observation times. The percentage of MPs is calculated by comparing the number of incoming MPs (inlet) with the number of MPs removed after the filtration procedure (outlet). The samples that have been obtained are then filtered using Whatman GF/C paper for the number of microplastics using a microscope. The observation results of the identification of the number of microplastics can be seen in Figure 2, while the number of microplastics per litre is displayed in Figure 3.

The percentage of microplastic removal tends to fluctuate for each measurement, that is, 30, 60, 90, and 120 min. Nevertheless, with a reduced ES and increasing the size of the microplastic, the removal efficiency of the microplastic reached the maximum level. The filter media has the highest efficiency is the 0.4 mm filter media size with average efficiency values of 61.74% - 91.30% for the microplastic size MPs <400 µm and 71.8 % - 95.80 % for the larger size of microplastic >400 µm. In addition, the average percentage removal of ES 0.7 mm was 77.24 % for the size of MPs <400 µm and 95.77 for the size of Mps >400 µm. The removal percentage of microplastic with the variation of ES and size is shown in Figure 4.

Generally, the larger size of microplastic >400 μm has the most excellent removal efficiency compared to smaller microplastic <400 μm, which means that larger microplastic sizes are most retained in the pores of the filter media or its surface. This is in line with the statement of (Chubarenko et al., 2016), which states that the large particle size of microplastic is directly proportional to the removal percentage. According to the results, the average size of artificial microplastics that still pass through the filter media ranges from $\leq 100\ \mu$m and $\leq 200\ \mu$m for the effective size (ES) of 0.4 and 0.7, respectively.

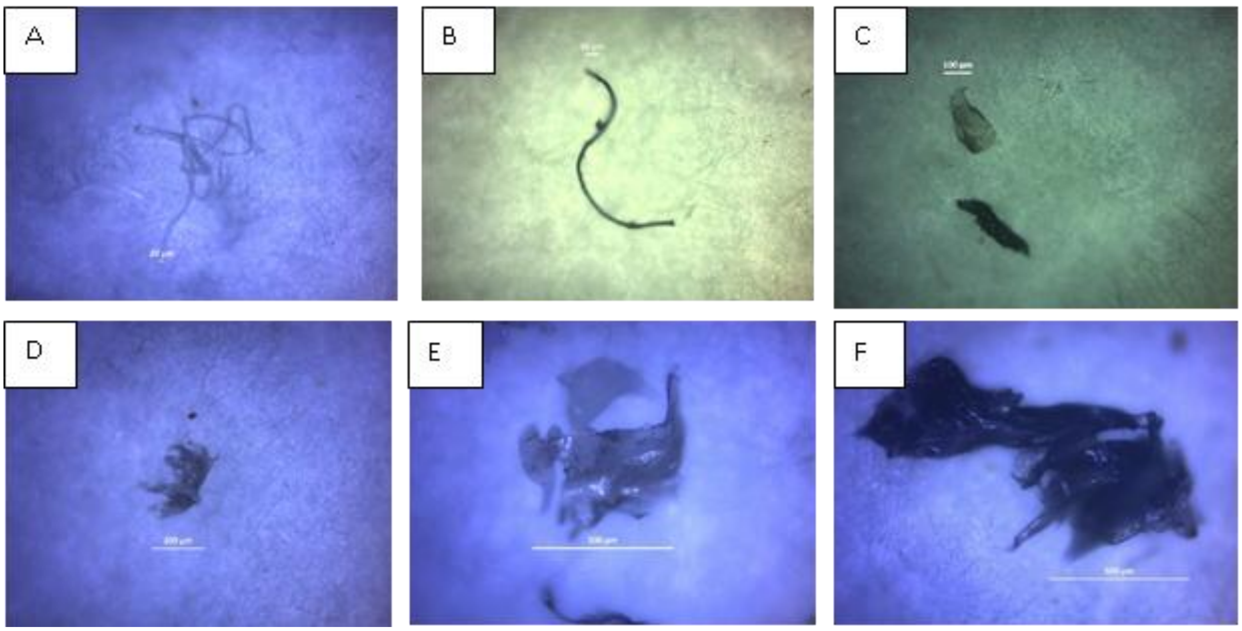

Figure 2. Microplastic in the microscope observation (A)(B)(C) Microplastic with size <400 µm (D)(E)(F) Microplastic with size >400 µm

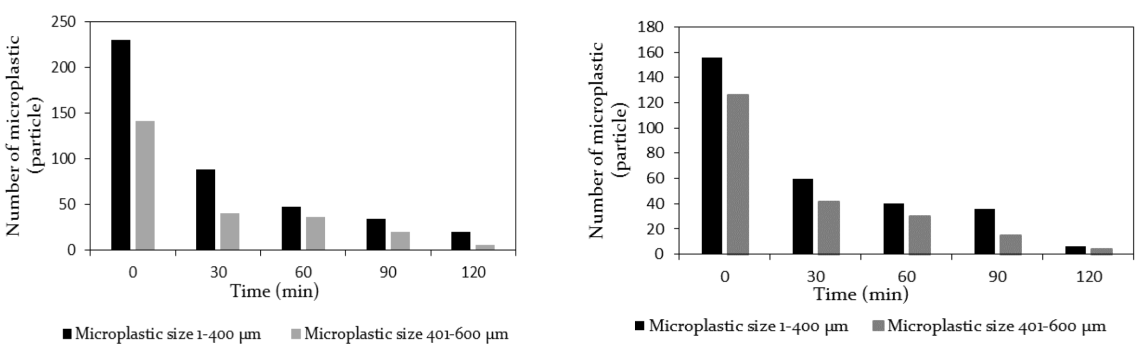

Figure 3. Number of microplastic after filtration test as the function of time (a) ES = 0.4 mm (b) ES= 0.7 mm

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According to the results, the average size of artificial microplastics that still pass through the filter media ranges from ≤ 100 μm and ≤ 200 μm for the effective size (ES) of 0.4 and 0.7, respectively.

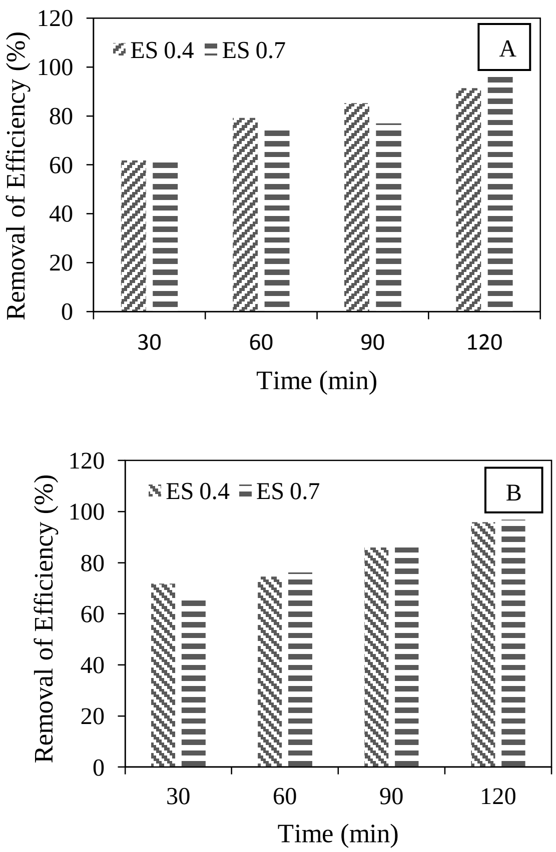

Figure 4. The Removal efficiency of RSF under (A) size of microplastic <400 µm and (B) size of microplastic >400 µm

Mechanism of Microplastic Removal in the Rapid Sand Filter

According to the experiment's result, the most retained microplastics are sizes >400 μm with a filter media size of 0.44 mm, and the average size of microplastics that still pass through the filter media is ≤200 μm through the filter media is ≤200 μm. The particulate removal process in filtration has three mechanisms: transportation includes the process of brown motion; the ability to stick includes the process of mechanical straining; and the ability of repulsive forces or collisions between particles. Most particulate removal is caused by physical processes where relatively large particulates will be trapped between sand grains when passing through the filter media, commonly referred to as the mechanical straining process. Then, smaller particles will adhere to the surface of the sand grains caused by the van der Waals force effect co, commonly referred to as physical adsorption. The principle of this process is due to the difference in charge between the surface of the suspended particles around it so that there is an attractive force.

According to (Sembiring et al., 2021), revealed that if the particles have a size larger than the size of the void in the filter, the particles will be removed through straining, while if the particle size is smaller than the void, then the particles will be removed when it contacts and attached to the filter media due to the van der Waals forces.

Besides the van der Waals force, particle attachment can also occur due to sedimentation due to sedimentation or deposition, where the process settles suspended particles that are smaller than the pores in the filter media than the pores on the surface of the grain. This happens when particles have a higher density than the density of water. Indirectly, particles settle due to the force of gravity and adsorb to the surface of the filter media (Cescon & Jiang, 2020). The mechanism process of mechanical straining and adsorption of microplastic attached to the media filter is illustrated in Figure 5. The removal mechanism in filtration works simultaneously. Therefore, effective transportation of a particle is not seen from one particle only but for all particles.

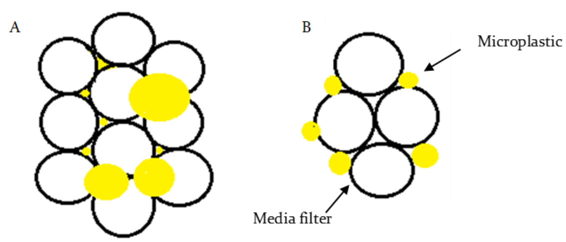

Figure 5. Mechanism process of (A) Mechanical straining and (B) Physical adsorption

Conclusions

The performance of rapid sand filter dual media in removing microplastic was investigated. It showed that RSF can be one of the methods to remove the microplastic via physical process. The variation in silica sand's effective size and microplastic's size will affect the removal efficiency of microplastic in water. Based on the result, the maximum removal percentage using a rapid sand filter is 95.77 % under ES 0.4 mm, and the microplastic size is more significant than 400 µm. This success is attributed to the mechanical straining and adsorption to the sand matrix.

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