RESERCH ARTICLE Open Access

Gema Lingkungan Kesehatan
Vol. 22, No. 2, 2024, pp 85-89
e-ISSN 2407-8948 p-ISSN 16933761
Doi: https://doi.org/10.36568/gelinkes.v22i2.139 Journal Hompage: https://gelinkes.poltekkesdepkes-sby.ac.id/

Performance of Hybrid Aeration-Pre-sedimentation Process in Microplastic Removal from Raw Water

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ABSTRACT

Plastic materials can degrade into small particles known as microplastics (MP) and nanoplastics (NP). The presence of MP has been detected in treated drinking water. Aeration and pre-sedimentation are preliminary treatment processes in Water Treatment Plants (WTP), which can potentially remove MP pollutants. This study aims to (1) determine the abundance and characteristics of MP in raw water samples and effluents from the hybrid aeration-pre-sedimentation process; (2) determine the efficiency of MP removal in the hybrid aeration-pre-sedimentation process. This study was conducted on a laboratory scale. Raw water samples (2.5 L) were collected from Kali Jagir Surabaya. The test reactor consisted of a cascade aerator (5 and 7 steps) and pre-sedimentation, operated in batch mode. Identification of MP abundance and characteristics (shape, size, color, polymer type) was conducted on samples before treatment (aeration influent) and after treatment (pre-sedimentation effluent). Sampling was performed in triplicates at 2 and 4-hour detention times. Test samples were extracted through oxidation with H_2O_2 and membrane filtration using PTFE (pore size 0.22 µm; diameter 47 mm). MP particles were observed using a Dino-Lite digital microscope. Polymer type was determined by FTIR testing. The results showed that the average abundance of MP in the influent sample was 8.5 particles/L, while in the effluent of the hybrid cascade aerator-pre-sedimentation reactors (5 and 7 steps), it was 1 and 6.5 particles/L, respectively. MP particles' dominant size and shape were 101-350 µm and fibers. Transparent and white colors predominated the MP particles. The polymer type of MP found in raw water samples was polyethylene (PE). The highest MP removal efficiency in the hybrid aeration-pre-sedimentation process with 2 and 4-hour detention times were 88% and 24%, respectively.

Keywords: Aeration-pre-sedimentation, Hybrid, Characteristics, Abundance, Microplastics

INTRODUCTION

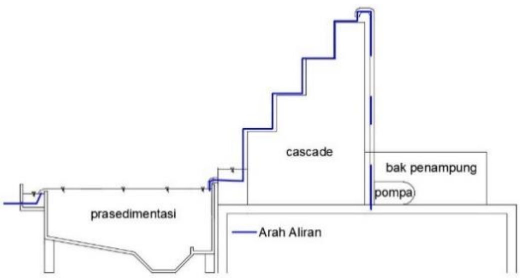
Global plastic production reached 400.3 million tons in 2022, with Asian countries contributing 19% of this production (Plastics Europe, 2023). The use of plastic products has the potential to generate plastic waste, which will degrade into microplastic (MP) and nanoplastic (NP) particles in the environment (Corcoran, 2022). Microplastic particles (MP) have become a new contaminant in the atmosphere and terrestrial and aquatic environments (Ali *et al.*, 2021). Previous research has shown that MP pollutants have been detected in aquatic environments, including surface waters (Elgarahy, Akhdhar and Elwakeel, 2021). The presence of MP in aquatic environments negatively impacts aquatic organisms, such as the ingestion of MP by these organisms (Sandra and Radityaningrum, 2021). Furthermore, these MP particles can enter the human body through the food chain (Elgarahy, Akhdhar and Elwakeel, 2021). Additionally, surface water contamination by MP leads to the contamination of raw water used for drinking (Shen *et al.,* 2021). Contaminants of MP in raw water have also been found to persist in the treated water from Water Treatment Plants (WTP) (Radityaningrum *et al.*, 2021); Shen *et al.,* 2021; Radityaningrum, Trihadiningrum and Soedjono, 2023). Consumption of drinking water contaminated with MP negatively impacts human health, as exposure to MP is toxic to human cells (Danopoulos *et al.*, 2022).

Raw water treatment is currently a viable solution for MP removal in drinking water production (Tang and Hadibarata, 2021). Conventional technologies (aeration, pre-sedimentation, coagulation-flocculation-sedimentation, filtration, and disinfection) are commonly used in most WTPs in Indonesia (Radityaningrum, Trihadiningrum and Soedjono, 2023). MP removal is possible in each unit of conventional technology used in WTPs (Na *et al.*, 2021). Previous research on MP removal in WTPs using conventional technologies has shown varying percentages of MP removal efficiency (Tang dan Hadibarata, 2021). The percentage of MP removal efficiency in drinking water treatment is influenced by the type of treatment technology and the main criteria of each technology (Radityaningrum, Trihadiningrum and Soedjono, 2023).

Aeration and pre-sedimentation are preliminary treatment processes contributing to MP removal in WTP production water (Tang and Hadibarata, 2021). The percentage of MP removal efficiency in WTPs using aeration and pre-sedimentation ranges from 16.5% to 98.4% (Tang and Hadibarata, 2021). Aeration and pre-sedimentation processes are preliminary treatments that impact the reduction of pollutant loads in subsequent treatment stages. Therefore, efforts should be made to optimize these processes to achieve high removal efficiency. The main criteria of the treatment process influence the effectiveness of the treatment process in achieving high pollutant removal efficiency. This study focuses on MP removal in the hybrid aeration-pre-sedimentation process for water treatment. The objectives of this study are (1) to determine the abundance and characteristics of MP in raw water samples and effluents from the hybrid aeration-pre-sedimentation process; (2) to determine the efficiency of MP removal in the hybrid aeration-pre-sedimentation process. This research is important because MP removal in the hybrid aeration-pre-sedimentation process is a preliminary treatment that positively impacts the quality of drinking water production. The novelty of this research is the ability of the hybrid aeration-pre-sedimentation process to remove MP from raw water.

RESEARCH METHODOLOGY

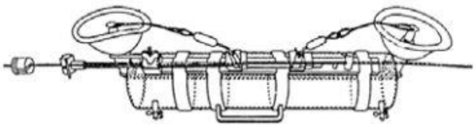
This study was conducted on a laboratory scale using test reactors consisting of a cascade aerator (5 and 7 steps) and pre-sedimentation (Figure 1). The reactors were operated in batch mode. Raw water samples were taken from Kali Jagir Surabaya, with a volume of 2.5 L. Raw water sampling was performed using a Van Dorn Sampler, with a volume of 1 L (Figure 2). The test parameters included the abundance and characteristics (shape, size, color) of microplastics (MP) in the water samples. Sampling points were at the inlet of the cascade aerator (before treatment) and the outlet of the pre-sedimentation (after treatment). Sampling was performed in triplicate at 2 and 4-hour detention times.



(a)

(b)

Figure 1. Test Reactor: **(a)** Schematic of the hybrid aerator cascade-pre-sedimentation reactor; **(b)** Documentation of the hybrid aerator cascade-pre-sedimentation reactor



(a)

(b)

Figure 2. Van Dorn Sampler: **(a)** Schematic of the device; **(b)** Documentation of the device

MP extraction from the test samples began with oxidation using H2O2 (Wu *et al.*, 2020). Following this, membrane filtration was performed using PTFE (pore size 0.22 µm; diameter 47 mm) (Masura *et al.*, 2015). The separation of MP particles (from the extraction) from the filter membrane was done manually using tweezers. MP particles were then observed using a Dino-Lite digital microscope. The classification of MP shapes observed included fibers, films, fragments, and pellets (Anderson *et al.*, 2017). MP size categories (1-100 µm, 101-350 µm, 351 µm-1 mm, and >1 mm-5 mm) were modified from previous research classifications (Frias and Nash, 2019). MP colors were transparent, white, gray, black, brown, red, and blue (Peng *et al.*, 2018). MP polymer types were determined through FTIR testing. MP abundance and characteristics were determined based on the average values from two replicates.

RESULTS AND DISCUSSION

The raw water samples' average abundance of microplastics (MP) was 8.5 particles/L. This value is lower than findings from previous research, which reported an MP abundance of 16.05 particles/L in Kali Jagir Surabaya (Radityaningrum *et al.,* 2023). This discrepancy may be due to differences in sampling locations and times. The average MP abundance in the effluent from the 5-step and 7-step cascade aerators and pre-sedimentation, taken at 2 and 4-hour detention times, is shown in Table 1.

Table 1
MP Abundance in Aerator Influent and Effluent of Aerator and Pre-sedimentation

Raw Water Sample (Aerator Influent) (particles/L)	Aerator Cascade Effluent (particles/L)				Pre-sedimentation Effluent (particles/L)	
	5 *Step*		7 *Step*			
	t: 2 hour	t: 4 hour	t: 2 hour	t: 4 hour	t: 2 hour	t: 4 hour
8,5	2,67	3,67	5,5	6,67	**1**	**6,5**

Table 1 shows that the average MP abundance in the effluent of the hybrid aeration-pre-sedimentation process for 5-step and 7-step aerators is 1 and 6.5 particles/L, respectively. The MP shapes identified in the raw water samples include fibers, pellets, films, and fragments (Figure 3).

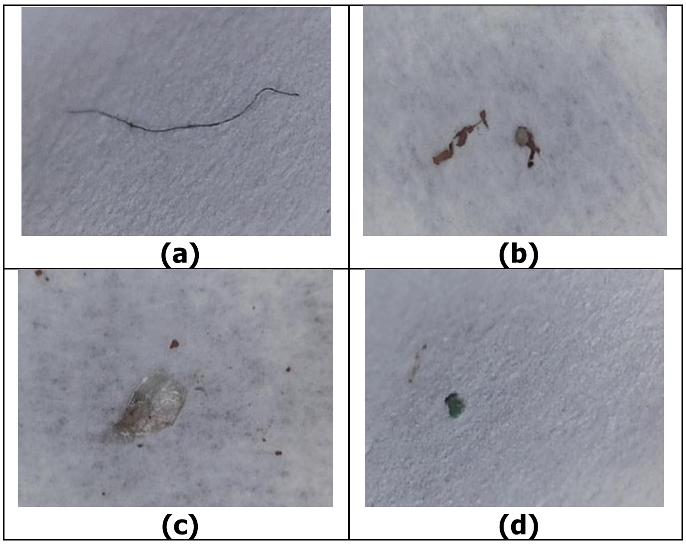


Figure 3. Identified MP Shapes
(a) Fiber; **(b)** Pellet; **(c)** Film; **(d)** Fragment

Based on the findings, fibers are the most dominant form of microplastic (MP) in raw water from Kali Jagir Surabaya. The physical characteristics of fibers resemble threads or strands (Hiwari *et al.*, 2019). Pellets are MP particles from toiletries products (Fendall and Sewell, 2009). Film-shaped MPs are suspected to come from decomposed transparent plastics (Lassen *et al.*, 2015). The identified fragment MP particles were dark green, likely because the particles were still coated with organic material, obscuring the microplastics' color. Fragments typically come from large, undecomposed plastic waste particles (Cole *et al.*, 2011). The average percentage of MP abundance based on shape is shown in Figure 4.

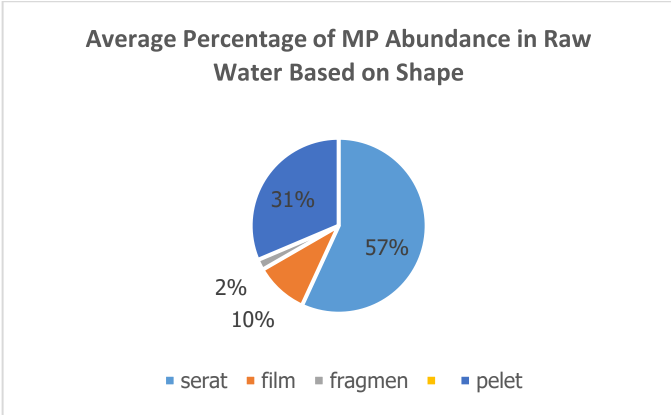


Figure 4. Average Percentage of Identified MP Abundance Based on Shape

Figure 4 shows that the highest and lowest average percentages of MP abundance are fibers (57%) and fragments (2%). This differs from previous research in Kali Jagir Surabaya, where the lowest percentage of MP abundance was found in films (0.3%) (Radityaningrum et al., 2023).

The average percentage of MP abundance based on size groups is shown in Figure 5.

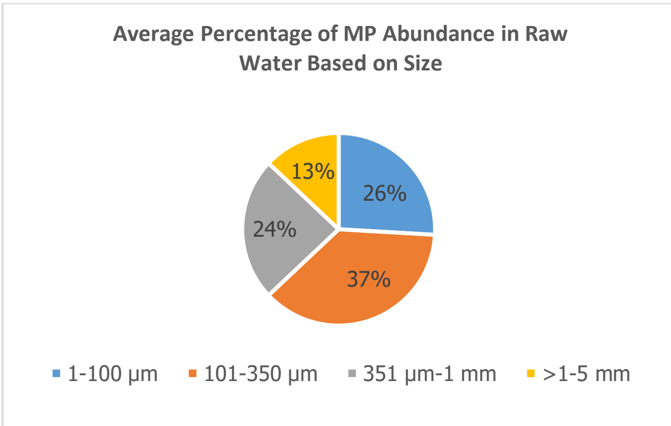


Figure 5. Average Percentage of Identified MP Abundance Based on Size

The highest and lowest average percentages of MP abundance based on size are 101-350 µm and >1-5 mm. This contradicts previous research, where the abundance of MPs sized 101-350 µm was the lowest (Radityaningrum et al., 2023).

The characteristics of MP particles in the raw water samples based on color are shown in Figure 6.

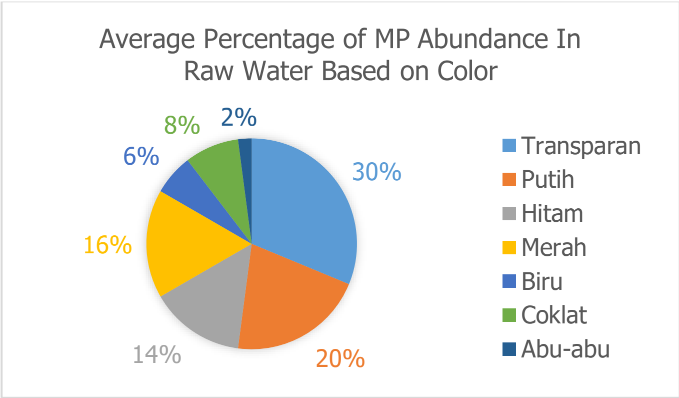


Figure 6. Average Percentage of Identified MP Abundance Based on Color

The dominating colors of MP particles are transparent (30%) and white (20%). The MPs' colors likely originated from the original color of the plastic material before fragmentation occurred.

Based on FTIR testing, the polymer type of MP identified in the raw water samples is polyethylene (PE) (Figure 7).

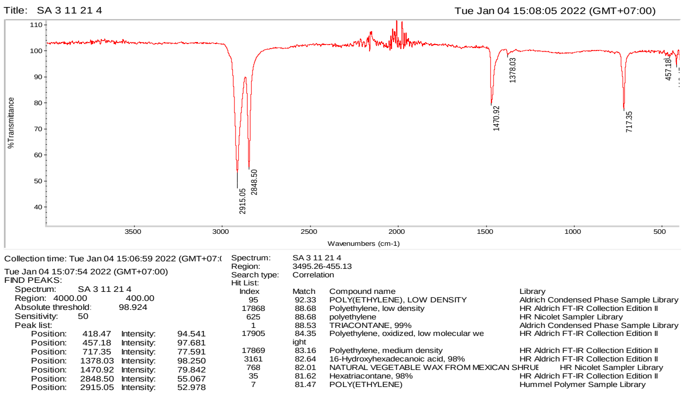


Figure 7. FTIR Test Spectrum for Raw Water Sample

The identified polyethylene (PE) polymer in the raw water samples is consistent with previous research findings in Kali Jagir Surabaya (Radityaningrum et al., 2023).

Regarding the performance of the hybrid aeration-pre-sedimentation process in removing MP pollutants from raw water, the removal efficiency percentages achieved at 2 and 4-hour detention times were 88% and 24%, respectively. Previous research conducted on a field scale in several WTPs using conventional technology in Indonesia showed pre-sedimentation removal performance ranging from 37% to 68% (Mar'atusholihah, Trihadiningrum and Radityaningrum, 2020 ; Radityaningrum *et al.*, 2021). Additionally, this performance is consistent with the findings of Tang and Hadibarata (2021), where the MP removal efficiency in aeration and pre-sedimentation units ranged from 16.5% to 98.4%. The design criteria of each unit influence MP removal efficiency in the hybrid aeration and pre-sedimentation process (Pivokonsky *et al.*, 2018). Therefore, further research is needed to identify factors that significantly affect the performance of water treatment processes in MP removal.

CONCLUSION

The study found a significant presence of microplastics (MP) in the raw water from Kali Jagir Surabaya. The identified MP particles were predominantly fibers, with sizes ranging from 101-350 µm, and were mostly transparent or white. The polymer type of the MP found in the raw water samples was polyethylene. The hybrid aeration-pre-sedimentation process removed MP contaminants from the raw water with an efficiency of up to 88%.

RECOMMENDATIONS

MPs are a new contaminant in raw water, so further research on MP removal in water treatment processes is necessary. Future studies could involve laboratory-scale experiments using artificial microplastic pollutants to explore the mechanisms of MP removal in each water treatment unit. Research can also examine other design criteria variables for each water treatment process. The results of future studies could serve as a basis for improving the provision of clean drinking water by relevant stakeholders.

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