

Identification and characterization of microplastics in a drinking water treatment plant

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ABSTRACT

Microplastics, defined as plastic particles ranging from 1 μm to 5 mm, have become an emerging concern in drinking water supply systems due to their persistence, resistance to degradation and potential implications for human health. Previous studies have shown that conventional water treatment processes may be limited in their ability to remove micro- to submicron- sized particles, particularly in tropical regions with high pollution loads. This study aimed to identify and characterize microplastics at difference stages of the drinking water treatment plant in Palembang, South Sumatera. Samples were collected from the Ogan River at four treatment stages at water treatment plant A (WTP A): intake, coagulation-flocculation, sedimentation and reservoir. The samples were filtered using a Whatman GF/F filter paper, subjected to oxidation with 30% H_2O_2 , and analyzed using an optical microscope for morphological observation as well as Fourier transform infrared (FTIR) spectroscopy for polymer identification. Microplastics were detected at all stages, with highest concentrations observed in raw water, and an overall removal efficiency of 69.4%. Fragment were dominant form (> 93%) followed by fiber, film, and pellets. FTIR analysis indicated that polyvinyl chloride (PVC) was more prevalent in raw water; polyethylene terephthalate (PET) and polystyrene (PS) were observed during the flocculation stage, while PET, polypropylene (PP) and polyethylene (PE) were detected in treated water. These finding suggest that conventional treatment processes are more effective in reducing denser polymers such as PVC, whereas lighter polymers such as PET and PP may persist through treatment. This highlights the potential need for complementary advanced treatment technologies, such as nanofiltration or activated carbon adsorption, to further improve drinking water quality.

Keywords: microplastic, water treatment plant, drinking water.

INTRODUCTION

Plastic plays a central role in modern life because it is light, strong, and durable. Since 1959, global plastic production has increased steadily, with cumulative total production estimated to exceed 8.3 billion tons (Geyer et al., 2017). However, most of these materials end up as persistent waste that resists to degradation, thereby contributing to environmental pollution as microplastics and nanoplastics (Andrady, 2017; Enfrin et al., 2019).

Microplastics are plastic particles ranging between 1 μm and 5 mm (Koelmans et al., 2019; Sarkar et al., 2021) and based on their origin, they are classified as primary and secondary microplastics. They are now found across various ecosystems, including the seas, rivers, soil, air and even within human body (Xu et al., 2020; Zhang et al., 2020).

Microplastics exert multifaceted environmental effect, functioning as carrier of additives and persistent organic pollutants that pose ecological risks (Hahladakis et al., 2018). The

interactions between microplastics and microorganisms may facilitate the attachment and growth of pathogenic biofilms (Rummel et al., 2017). Some studies have even reported accumulations of microplastics in biological tissues, such as in fish, river sediments and marine organisms (Hermsen et al., 2017; Anbumani and Kakkar, 2018; Wang and Wang, 2018).

The human exposure to microplastics is not confined to environmental compartments, as recent evidence confirms their detection in human blood and placental tissue (Leslie et al., 2022; Ragusa et al., 2021). Further studies revealed that the exposure to polystyrene microplastics may provoke inflammatory response in immune cells and disrupt endocrine functions (Sharma and Chatterjee, 2017). Therefore, the occurrence of microplastics in drinking water has emerged as significant global health concern (Revel et al., 2018).

The sources of microplastics in inland waters are highly varied, including the degradation of microplastics, synthetic fibre from laundry and discharges to industrial waste (Koelmans et al., 2019; Li et al., 2018a). Rivers have been identified as significant transport pathways carrying microplastics from terrestrial environment into marine system (Jambeck et al., 2015; Zhang et al., 2018). In fact, atmospheric investigation also indicates that airborne microplastic particles can undergo deposition and subsequently re-enter aquatic system (Zhang et al., 2020).

Recent studies have increasingly emphasized the role of drinking water as one of the primary pathway of human exposure to microplastics. Research conducted in Europe shows the presence of microplastics in drinking water, though at lower concentration compared to raw water (Bäuerlein et al., 2022; Pivokonsky et al., 2018a). The studies also reported the efficiency of microplastic removal varied between 60–80% (Shen et al., 2020). Nevertheless, small sized particles (<100 µm) continue to pose major removal challenges due to their ability pass through in conventional treatment process (Na et al., 2021).

Investigation on microplastics in drinking water supply systems are still limited; studies in Surabaya revealed a microplastic contamination characterized in drinking water, with fragment and fibre as dominant types (Radityaningrum et al., 2023). This finding highlights that microplastics have become a real issue in drinking water system in Indonesia. Consequently, further regional data from another regional required to

provide a more comprehensive understanding. Palembang as one of major cities in Sumatera has several drinking water treatment plants for the water sourced from Musi River and its tributaries. These rivers affected by domestic, industrial, transportation activities, which could contribute to microplastic pollution. The presence of fragments from plastic bags and PET, as well as fibers from household waste, are presumed to be the primary sources of pollution in urban water bodies (He et al., 2021; Li et al., 2018b). Additionally, polymers are commonly found in drinking water, such as PS, PET, and PP are also most widely produces plastic globally (Geyer et al., 2017).

Apart from the health-related concern, microplastics also exert ecological effects that can alter ecosystem balance. They disrupt symbiosis of marine organism, such as corals and algae (Okubo et al., 2018) as well as affect terrestrial system (De Souza Machado et al., 2018). The observation emphasizes the urge need for comprehensive research of microplastic contaminants across different environmental matrices, including water treatment system (Barbier et al., 2022; Gallowaya and Lewisa, 2016; Koelmans et al., 2022; Sarkar et al., 2021).

To mitigate these effects, various advanced technologies have been explored, including nanofiltration, adsorption using active carbon, and the use of functionalized materials as adsorbents (Enfrin et al., 2019). Moreover, the enzymatic degradation of plastics by specific microorganisms has also investigated (Wei and Zimmermann, 2017). Nevertheless, the large scale implementation of these technologies remain limited by operational and economic challenges (Guo et al., 2022; Popova et al., 2023).

On the basis of previous studies, microplastics have been extensively detected in freshwater ecosystem that potentially enter to drinking water supply system (Horton et al., 2017). Nevertheless, the research on microplastics in drinking water treatment particularly in tropical regions such as Indonesia, remains limited. Therefore, this study concentrates on the drinking water treatment in Palembang, which utilizes raw water from Ogan River. Specifically, the objectives of the research were to identify and characterize the occurrence of microplastics at different stages of water treatment in Palembang, Indonesia, including their abundance, morphological, characteristic, and size distribution using optical microscopy, as well as to qualitatively assess polymer-related characteristic of microplastics using FTIR spectroscopy.

Through this objective, the findings of this study are expected to make more substantial contributions to advancing the microplastics mitigation effort in Indonesia, particularly in Palembang and to enrich the existing body of knowledge on the effectiveness of drinking water treatment system in reducing microplastics (Horton et al., 2017; Sun et al., 2019a; Zhou et al., 2021).

MATERIALS AND METHODS

Sampling location

Raw and treated water samples were collected from a water treatment plant (referred to as WTP A) located in Palembang Indonesia, which receives its raw water from the Ogan River one of the tributaries of the Musi River (Kurniawati, 2023), and has a maximum capacity 800 L/s and supplies clean water to residents in certain areas of Palembang City. The water treatment plant (WTP) uses a conventional process consisting of coagulation-flocculation, sedimentation, filtration and disinfection process before distribution.

Sampling was conducted once in February 2025 under normal operating condition of the drinking water treatment plant during the rainy season. At WTP A (Figure 1), samples were collected from the raw water intake (inlet), the outlet of the Coagulation-flocculation process, the sedimentation outlet, and the outlet the treated water Reservoir outlet (after under going filtration-balancing process). The volume of each sample was 1 L, considering by the residence time of each process unit within the WTP. The samples were placed in glass bottles and stored at 4 °C prior to analysis (Pivokonsky et al., 2018; Mintenig et al., 2019). Therefore, the quantitative data presented in this study represent microplastic concentration at the time of sampling and are not intended to describe long term or seasonal variability.

Laboratory treatment of water samples

The water samples collected from each treatment stage were transported to the laboratory for microplastics analysis. Before microplastics identification, the laboratory analysis was carried out beginning with the degradation of organic matter to remove organic contaminants to prevent interference during microscopic observation and FTIR analysis. A sub sample of 250 ml from each water

sample was subjected to chemical digestion using hydrogen peroxide (30% H₂O₂ solution), which was added in an amount of 20 ml and stirred for 30 min, then left for 24 h at room temperature until H₂O₂ completely evaporated, when visible organic residues remained, the digestion procedure was repeated until complete oxidation was achieved. After digestion, the samples were filtered using a vacuum filtration system equipped with glass microfiber filters (Whatman GF/F) with nominal pore size of 0,7 µm. Following filtration, the filters were transferred to clean a petri dish handle using metal forceps, dried in the oven at 30 °C for 30 minutes. After drying, the retained particles were carefully examined under an optical stereo microscope for visual identification, morphological characterization and particle size estimation. Size classification was based on the particle retained on the filter and visually identifiable under the applied magnification and lighting condition. The filter covered with aluminum foil until further analysis.

All glassware was rinsed with aquabidest pre-filtered through a 0.45 µm membrane, and procedural blanks were processed alongside samples to monitor laboratory contamination. This sampling preparation and handling procedure follows commonly applied approaches in the microplastic studies conducted in drinking water treatment system (Pivokonsky et al., 2018).

Identification of microplastics

After the treatment of raw and treated water samples, the filtered samples were visual examined with optical microscope (Nikon Eclipse E100LED MV R) to observe the shape and abundance of microplastic particles, serving as the initial step for microplastic classification (Koelmans et al., 2019). The number of microplastic particles per L samples was manually counted while particle size measurements were performed using the ImageJ software.

Polymer-related characteristics of selected microplastic particles were examined using Fourier transform infrared spectroscopy (FTIR-ATR, Shimadzu). Following filtration using glass microfiber filters (Whatman GF/F, nominal pore size 0.7 µm), areas of the filter containing visually identified particles were observed under the optical microscope. Due to the entrapment of particles within the glass fiber matrix of the GF/F filters, individual particle isolation was

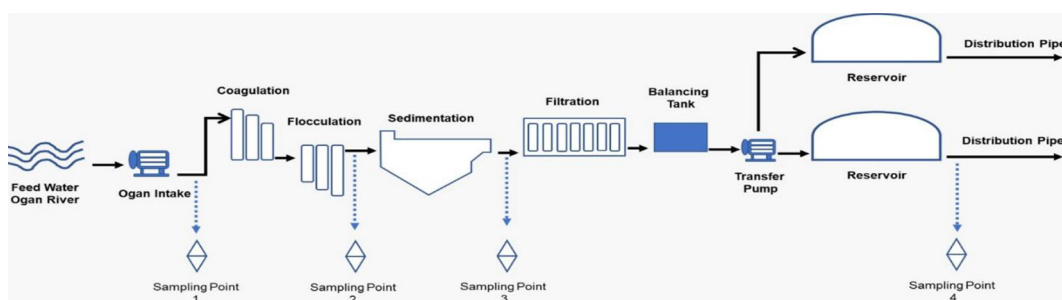


Figure 1. Schematic diagram of water treatment plant process WTP A and sampling point

not feasible; therefore, small sections of the GF/F filters containing the observed particles were carefully cut and directly analyzed using FTIR-ATR. FTIR spectra were acquired using standard ATR operating conditions as provided by the instrument, covering the mid-infrared range of approximately 4500–500 cm^{-1} . Accordingly, FTIR results were interpreted qualitatively as indicative of polymer related spectral features.

Quality assurance and quality control

To minimize potential contamination during microplastics analysis, strict quality assurance and quality control (QA/QC) procedures were applied throughout all stages of the study, from sample preparation to analysis. All glassware was rinsed with aquabidest water and covered with aluminum foil when not in use. The use of plastic laboratory equipment was avoided during the analytical procedures. The samples and membrane filters were consistently covered with aluminum foil during preparation and were only uncovered during analysis to minimize the deposition of airborne microplastic particles. Researchers wore cotton laboratory coats and nitrile gloves throughout all analytical procedures to reduce contamination from synthetic fibers. Procedural blanks were prepared using filtered aquabidest water and processed alongside the samples following the same digestion, filtration, and analytical procedures to detect potential contamination originating from the laboratory environment and analytical processes. During visual inspection and FTIR analysis, membrane filters were analyzed immediately after opening, and exposure time to laboratory air was minimized. These QA/QC procedures followed established guidelines for microplastics analysis (Masura et al., 2015; Hermsen et al., 2018).

Data analysis

Microplastic abundance data presented in this study were obtained from repeated measurements. For each treatment stage, three replicate samples were collected at the same sampling point under comparable operational conditions and within the same sampling period. Therefore, the reported values represent average concentrations. Data variability was assessed using relative standard deviation (RSD) as an indicator of analytical consistency between replicates. The quantification of microplastics was conducted on the water intake, on the outlet of the coagulation-flocculation and sedimentation processes, as well as from treated-water reservoir after the filtration, balancing and disinfection stages. The microplastics removal efficiency of treatment process was calculated using the following equation:

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

where: C_{in} and C_{out} represent the microplastic concentrations (particle/L) in the influent and effluent streams.

Descriptive analysis was employed to provide an overview of morphology, size distribution and polymer composition of the identified microplastics. A comparative literature review was conducted to identify the similarity of the present finding with previous studies on microplastic occurrence.

RESULTS AND DISCUSSION

Abundance of microplastics at different treatment stages

The observations showed that microplastics were detected at all treatment stages of WTP A, as presented in Table 1. Microplastics analysis for

a 250 ml sample was conducted using a Nikon Eclipse E100LED MV R microscope, where the highest concentration was found at the intake, reaching 3372 particles L⁻¹, and this value gradually decreased to 2940 particles L⁻¹ after coagulation-flocculation process, 1956 particles L⁻¹ at sedimentation outlet, and 1032 particles L⁻¹ at the outlet reservoir after final filtration and balancing. The gradual reduction shows that the conventional treatment process was able to reduce most of the microplastic concentration with a total efficiency of 69.4%. This finding is consistent with the results reported by Pivokonsky et al., 2018 who observed microplastics removal efficiencies in two water treatment plants ranging from 60–80% in Chechia. This study also showed that microplastic concentrations in raw water (1.471–3.605 particles L⁻¹) decreased to 338–628 particles L⁻¹ after treatment, with fragments being the dominant morphology throughout the treatment stages. Similarly, Radityaningrum et al., (2021) also reported removal efficiencies of 54% and 76% at two conventional water treatment plants in Surabaya, further confirming that conventional processes are partially effective in reducing microplastics in raw water.

Values represent mean concentrations from three replicate samples. Relative standard deviation was 5.3% (intake), 4.3% (coagulation–flocculation), 4.68% (sedimentation), and 9.05% (reservoir).

The high concentration of microplastics in raw water sourced from the Ogan river indicates significant pollution input from domestic activities and household waste. This result corresponds well with previous studies by Li et al., 2018, who stated microplastics are widely present in freshwater systems, including rivers and drinking water sources, dominated by domestic wastewater.

Overall, the total efficiency of microplastics removal at WTP A reached 69.4%. The concentration decreased gradually across the treatment

stages, with 13% removal after coagulation-flocculation, 33% during sedimentation, and 47% at the reservoir outlet after passing through the filtration and balancing stages.

Morphological and size distribution of microplastic particles

The morphological analysis of microplastics at every treatment stage in WTP A (Table 2) shows that most of the particles were in the form of fragments (Figure 2). In the intake stages, fragments reached 98.3% of the total particles, decreasing to 93.4% in the final reservoir stage. This pattern is consistent with the research conducted by (Pivokonsky et al., 2018b) who stated that fragments were the predominant morphology in two different drinking water treatment plants in the Czech Republic. Generally, fragments originated from the fragmentation of single use materials such as plastic bags, PET and food packaging commonly used in daily life (Sun et al., 2019b; Wang and Wang, 2018). Fibers were found in smaller proportions (0.4–1.6%), but they showed fluctuation across treatment stages, increasing in the flocculation process and decreasing after sedimentation. This pattern shows that part of synthetic textile fibers were retained during floc formation, while fine microsized particles could still pass during the filtration process. Fibers mainly originate from domestic waste, especially from the washing of polyester (Cai et al., 2020) or nylon, and are ultimately released into rivers.

On the basis of Table 3, the size distribution of microplastics at different stages of WTP A is dominated by particles smaller than 100 µm. In the intake stage, the 5–100 µm fraction accounted for the largest proportion indicating that medium sized microplastics initially enter the treatment system at relatively high quantities. However, after coagulation-flocculation, sedimentation and at the reservoir after filtration, the < 5 µm fraction becomes the dominant size group. This shift reflects the greater reduction of 5–100 µm particles during treatment and the persistent presence of ultrafine particles (< 5 µm), which remain largely unaffected by conventional processes.

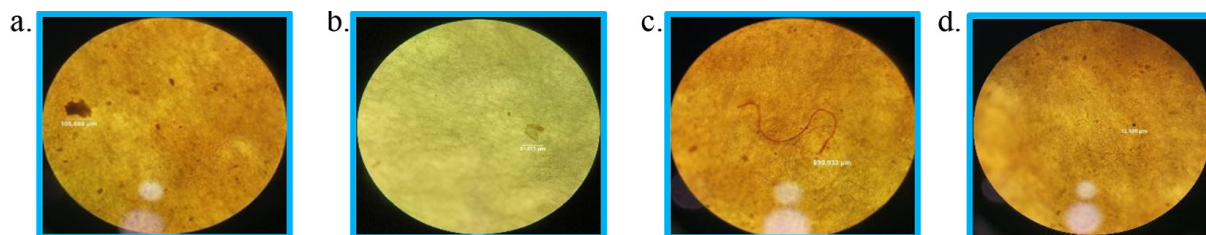
This dominance of particles smaller than 100 µm reflects a size-selective removal mechanism during conventional water treatment. Larger and medium-sized microplastics (5–100 µm) are more efficiently removed through coagulation–flocculation and sedimentation due to their

Table 1. Microplastic abundance (particles/L) at different treatment stages of WTP A

Treatment stages	Particles/250 ml	Abundance (particles/L)
Water intake	843	3372
Coagulation-flocculation	735	2940
Sedimentation	489	1956
Reservoir	258	1032

Table 2. Morphological distribution of microplastic particles in WTP A

Type	Intake	Coagulation-flocculation	Sedimentation	Reservoir
	Particles/250 ml	Particles/250 ml	Particles/250 ml	Particles/250 ml
Fragment	829	721	468	241
Film	5	3	19	13
Fiber	5	11	2	4
Pellet	4	-	-	-
Total	843	735	489	258

**Figure 2.** Morphological types of microplastic: (a) fragment, (b) film, (c) fiber, (d) pellet

higher mass as well as greater probability of collision and incorporation into flocs. In contrast, particles smaller than 5 μm exhibit limited aggregation potential and low settling velocities, causing them to persist and become proportionally dominant in the later treatment stages (Na et al., 2021). This observation is consistent with the finding of (Enfrin et al., 2019) who reported that physical and chemical treatment processes can promote microplastic fragmentation, generating fine and ultrafine particles that are hydrodynamically stable and increasingly difficult to remove. These fragmented microplastics behave similarly to colloidal particles, making them less responsive to gravity-driven separation and conventional filtration mechanisms.

As shown in Figures 3 and 4, the visual trend confirms the transition in dominance from the fine-sized fraction (5–100 μm) at intake to the ultrafine fraction (<5 μm) in the later stages of treatment. This behavior aligns with previous research indicating that microplastic removal efficiency decreases substantially for particles smaller than approximately 10–20 μm due to their low mass and reduced likelihood of forming stable flocs during coagulation and settling (Na et al., 2021). Similarly, Bauerlein et al., (2022) reported that microplastic particles <20 μm exhibit markedly lower removal efficiency and tend to persist in treated water owing to limited sedimentation and filtration behaviors. The persistence of ultrafine

particles also supports the micrometer-scale colloidal behavior described by Gigault et al., (2018), who demonstrated that ultrafine microplastics display pronounced Brownian motion, extremely low settling velocities, and enhanced mobility, limiting their removal through gravity-driven processes (Prata, 2018), reported that microplastic particles smaller than 50 μm can bypass sedimentation and sand-filtration units in wastewater treatment systems, while Enfrin, et al., (2019) highlighted that microplastic fragmentation produces fine particles that are hydrodynamically stable and increasingly difficult to remove.

In addition, Wu et al., (2022) found that the removal efficiency for particles $\leq 20 \mu\text{m}$ in drinking water treatment plants in China was only about 80%, while coagulation–sedimentation and sand filtration processes only reduced this fraction by 42.8% and 25.8%. Therefore, fine sized microplastic fractions become the most persistent component in treated water due to their low density, high dispersibility and limited removal by conventional processes (Na et al., 2021; Wu et al., 2022). This finding indicates that conventional treatment processes act primarily as size-selective barriers rather than complete removal system. As larger particles are progressively removed, fine and ultrafine microplastic become proportionally enriched in residual fraction, even if their absolute concentrations are partially reduced. Consequently, particles smaller than 5 μm represent the

Table 3. Size distribution of microplastics at different stages of WTP A

Size range (µm)	Intake	Coagulation-flocculation	Filtration-sedimentation	Reservoir
	Particles/250 ml	Particles/250 ml	Particles/250 ml	Particles/250 ml
<5 µm	351	429	270	152
5–100 µm	486	282	214	100
101–500 µm	3	18	5	5
>500 µm	1	1	0	1
Total	843	735	489	258

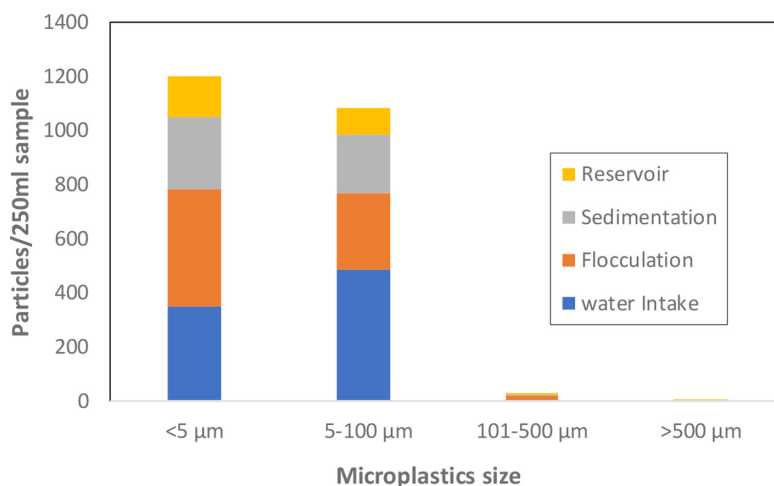


Figure 3. Microplastic size distribution at different treatment stage of WTP A

most persistent size fraction in the final treated water (Gigault et al., 2018; Prata, 2018).

Overall, these results reveal a structural limitation in the current treatment sequence: while larger particles are efficiently removed, ultrafine (<5 µm) and fine (<20 µm) fractions remain insufficiently addressed and persist into the final treated water. This finding underscores the need for complementary advanced treatment processes such as membrane-based technologies, adsorption media, or post-treatment polishing to more effectively target the ultrafine fraction. Beyond process limitations, the persistence of particles smaller than 5 µm may also be relevant from a human exposure perspective, as particles in this size range have been reported to exhibit higher bioavailability and a greater potential to interact with biological barriers (Hwang et al., 2020; Wright et al., 2020). Although toxicological effects were not evaluated in this study, the presence of ultrafine microplastics in treated drinking water highlights the importance of further investigation into their potential health implications (Leslie et al., 2022). Future investigations are

planned to include repeated sampling over time in order to better capture variability and improve uncertainty estimation.

Identification of microplastic polymers based on FTIR analysis

Fourier transform infrared spectroscopy (FTIR-ATR) was used to examine the polymer-related spectral features of microplastic particles collected from different stages of the drinking water treatment processes at WTP A. The observed absorption peaks in the FTIR spectra were interpreted to indicate the presence polymer types (Coates, 2000; Primpke et al., 2018). Similar FTIR-based approaches for polymer identification in environmental microplastic samples have been reported in previous studies (Chen et al., 2020; Simon et al., 2018). FTIR analyses were conducted on small sections of GF/F filters containing visually identified particles, rather than on individually isolated microplastic particles. As a result, the recorded spectra may reflect composite signals

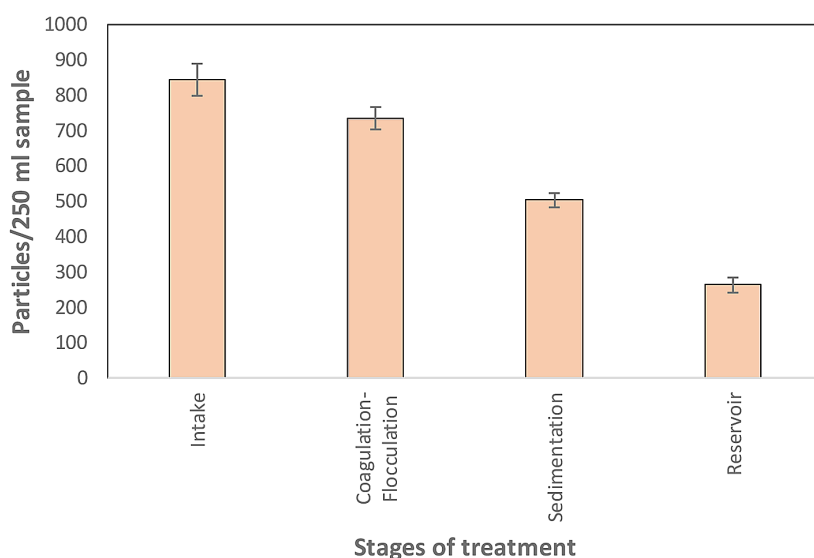


Figure 4. Microplastic forms distribution at different treatment stages of WTP A

from multiple particles, along with potential contributions from the glass fiber filter matrix. Accordingly, the FTIR results are interpreted qualitatively as indicative of polymer presence, rather than as definitive or quantitative identification at the individual particle level.

Intake

The FTIR spectrum of the raw water sample (Figure 5) exhibited distinct absorption peaks at 964 cm^{-1} , 692 cm^{-1} , and 616 cm^{-1} , which are associated with CH_2 rocking and $\text{C}-\text{Cl}$ stretching vibrations characteristic of polyvinyl chloride (PVC). These absorptions fall within the diagnostic fingerprint region of PVC, particularly around $\sim 960\text{ cm}^{-1}$ for CH_2 rocking and $600\text{--}700\text{ cm}^{-1}$ for $\text{C}-\text{Cl}$ stretching, as consistently reported in previous FTIR studies (Shimadzu Corporation, 2012; Veerasingam et al., 2021). The assignment of functional group vibrations was guided by standard infrared spectral interpretation references (Coates, 2000). The presence of these characteristic peaks indicates that PVC is a prominent polymer type detected in the raw water sample. In addition, a weak carbonyl ($\text{C}=\text{O}$) absorption band near 1715 cm^{-1} was observed, which is commonly associated with polyethylene terephthalate (PET), suggesting the possible presence of PET particles at lower relative abundance (Araujo et al., 2018).

The occurrence of PVC-related signals in the raw water is consistent with typical urban plastic inputs, such as domestic waste and water

distribution infrastructure, which are frequently reported as sources of PVC contamination in surface water systems (Andrady, 2017).

Coagulation-flocculation

After the coagulation-flocculation process, new absorption bands were detected near at 1715 cm^{-1} ($\text{C}=\text{O}$ stretching) and 1240 cm^{-1} ($\text{C}-\text{O}$ stretching), corresponding to the characteristic functional groups of PET. Although these peaks were not automatically identified by the software, their presence was clearly observable in the FTIR curve (Figure 6), suggesting that PET-related spectral features became more discernible at this stage. This observation is consistent with previous reporting characteristics of PET absorption bands at 1715 cm^{-1} and 1240 cm^{-1} attributed to carbonyl and ester stretching vibration of aromatic ester group (Kim et al., 2025; Chen et al., 2020), and is agreement with FTIR-based microplastic identification approaches described by Primpke et al., (2018).

In addition, a weak band observed around 1512 cm^{-1} , is consistent with aromatic $\text{C}=\text{C}$ stretching vibration that have been reported for polystyrene (PS), (Ghosal et al., 2018). Generally, these results suggest a relative decrease in PVC-related spectral features after the coagulation and flocculation stage, while the signals associated with lighter and more flexible polymer, such as PET and PS, may remain detectable in the analyzed samples.

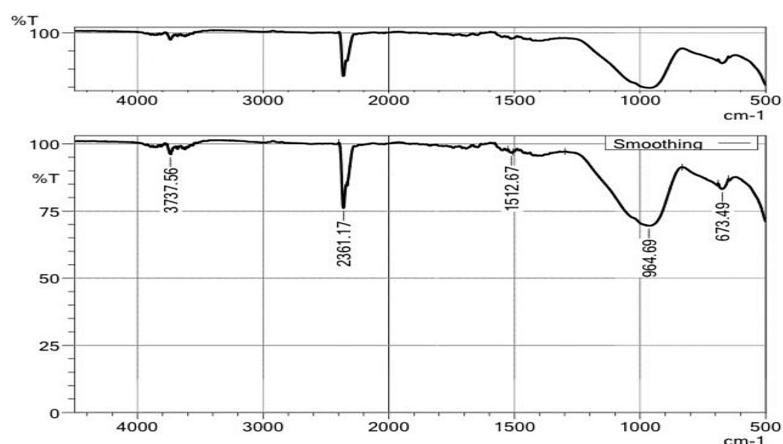


Figure 5. Spectrum of the intake sample

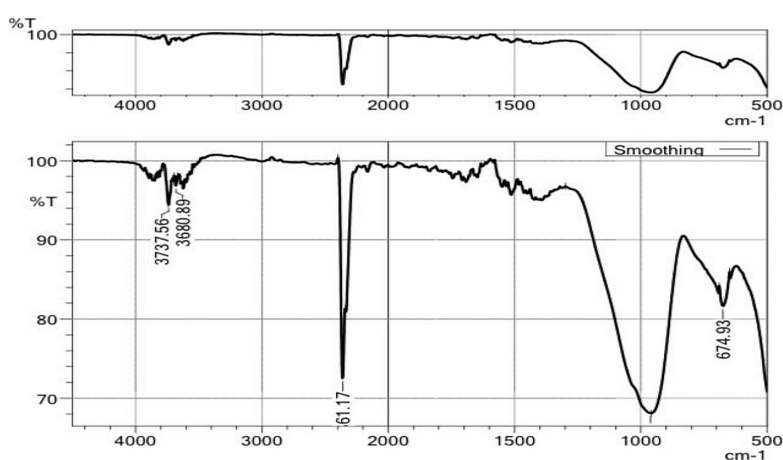


Figure 6. Spectrum of the coagulation-flocculation sample

Sedimentation

During the sedimentation stage, the characteristic of PET-related absorption bands at 1715 cm^{-1} and 1240 cm^{-1} remained clearly visible, indicating the continued detectability of these particles at this treatment stage. Although the automatically labeled spectrum displayed a distinct band at 1512.67 cm^{-1} (Figure 6), manual examination of the FTIR spectrum revealed faint absorption around 1715 cm^{-1} and 1240 cm^{-1} , the bands that are typically associated with the carbonyl (C=O) and ester (C-O) stretching vibration of PET. Although these features were not automatically labeled by software, their presence is consistent with PET-related spectral features reported in previous studies (Kim et al., 2025). These observations suggest that PET-associated microplastic signals remained detectable after the sedimentation process, whereas spectral features previously associated with heavier

polymers such as PVC became less apparent at this stage. This trend is consistent with the finding of Pivokonsky et al., (2018), who reported that higher density polymers such as PVC tend to be more efficiently removed during sedimentation and earlier treatment stages.

Moreover, new absorption bands were observed near 1452 cm^{-1} and 1373 cm^{-1} are consistent with polypropylene (PP)-related CH_2 bending and CH_3 deformation vibration (Primpke et al., 2018b) (Figure 7).

Reservoir

Figure 8 shows the FTIR spectrum of the water reservoir effluent after the sedimentation-filtration processes, exhibiting relatively stronger absorption band at 1715 cm^{-1} (C=O stretching) and 1242 cm^{-1} (C-O stretching), which are commonly associated with PET (Cecon et al., 2022; Kim et al., 2025). Additional absorption

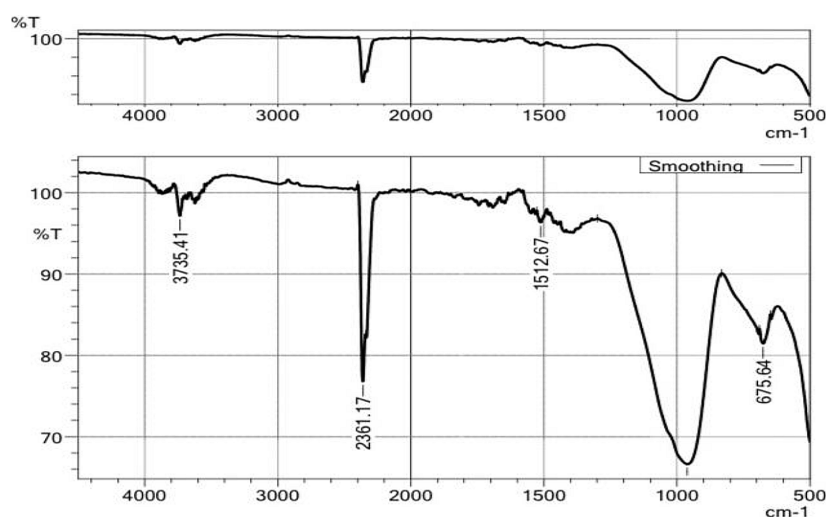


Figure 7. Spectrum of the sedimentation sample

bands observed between 1450–1370 cm^{-1} are consistent with PP with related CH_2/CH_3 deformation vibrations (Primpke et al., 2018), while a weaker band near 2915 cm^{-1} (CH_2 asymmetric stretching) is indicative of polyethylene (PE)-related spectral features (Coates, 2000). The occurrence of PET-related spectral features in the reservoir sample was consistent with previous FTIR-based studies of treated drinking water, which reported the persistence of PET signatures after conventional treatment processes (Lujic et al., 2025).

The persistence of PET and PP signals in the final treated water is consistent with the dominance of fine and ultrafine microplastic fractions ($<100 \mu\text{m}$, particularly $<5 \mu\text{m}$) observed at the later stages of treatment. At these size ranges, PET and PP particles tend to interact less efficiently with coagulant flocs, which can be attributed to their relatively low mass and surface characteristics. Consequently, a portion of fine PET and PP particles may remain suspended during treatment and pass through filtration units, allowing their polymer signatures to still be detected by FTIR in the treated water (Enfrin et al., 2019; Wu et al., 2022). Previous studies have shown that PET and PP microplastics are often removed less efficiently during conventional drinking water treatment, especially when present as fine or fragmented particles (Na et al., 2021; Pivokonsky et al., 2018b). In addition, treatment processes may promote further fragmentation, producing smaller PET and PP particles with increased stability in the water column, which contributes to their

persistence after coagulation and sedimentation (Enfrin et al., 2019).

In contrast, the absorption features in the 600–00 cm^{-1} , typically assigned to C-Cl stretching vibration of PVC, were less apparent in the reservoir sample, suggesting that PVC-related spectral features were reduced during earlier treatment stages. This observation is consistent with Pivokonský et al. (2018), who reported that PET, PP, and PE were among the most frequently detected polymer types in treated drinking water.

On the basis of Figure 9 showing overlaid FTIR spectral curve of all treatment stages (intake, coagulation-flocculation, sedimentation and reservoir after filtration as well as balancing), qualitative changes in polymer-related spectral features can be observed during the treatment process. The spectra indicate that PVC-related signals are more prominent in raw water, while PET and PS-related features become more apparent during the coagulation-flocculation stage. In contrast, the final treated water at the reservoir outlet is characterized by the spectral features associated with PET, PE, and PP. This trend is supported by presence of characteristic PET absorption bands near 1715 cm^{-1} (C=O stretching) and 1240 cm^{-1} (C–O stretching), as also observed in recent spectroscopic studies on PET (Cecon et al., 2022; Kim et al., 2025). These patterns suggest a relative reduction of PVC-related spectral features during coagulation-flocculation-sedimentation process were signals associated with lighter and more flexible polymers, such as PET, PE and PS may persist up to the reservoir stage. These findings align with the previous studies by Pivokonsky et al.,

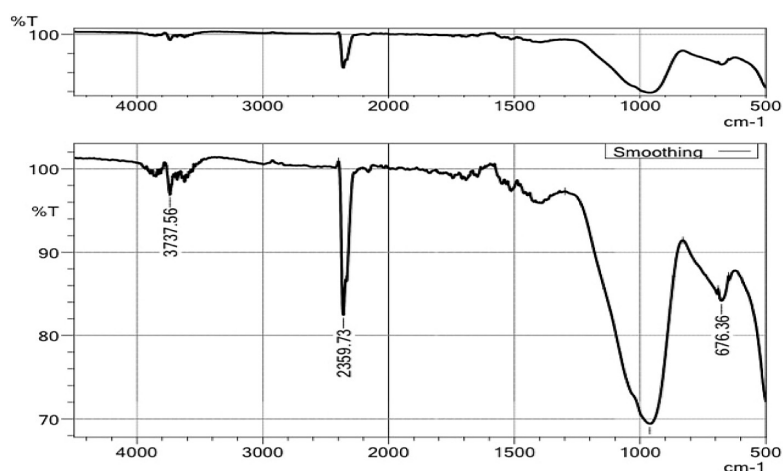


Figure 8. Spectrum of the reservoir sample

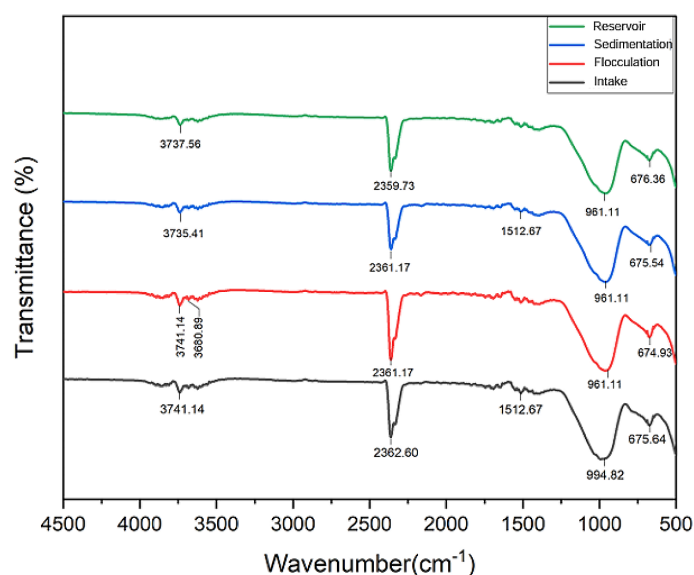


Figure 9. FTIR spectral curve of microplastics at different water treatment stages

2018, Primpke et al., 2018, and Chen et al., 2020) which reported removal efficiency of microplastic strongly depends on particles size and density. Deformation bands attributed to CH_2/CH_3 group of PP were observed in $1450\text{--}1370\text{ cm}^{-1}$ (Primpke et al., 2018), while absorption near 2915 cm^{-1} region corresponds to CH_2 asymmetric stretching of polyethylene (PE). The absence of distinct absorption features in the $600\text{--}700\text{ cm}^{-1}$ region, typically assigned to C–Cl stretching of PVC, further suggests that PVC related material were largely removed during earlier treatment stages (Coates, 2000; Primpke et al., 2018).

Taken together, the FTIR results, when considered alongside the particle size distribution, suggest that polymer persistence in treated water is closely related to particle size. Larger

and denser polymers tend to be removed more effectively during the earlier treatment stages, whereas fine-sized PET and PP particles remain detectable in the final treated water, reflecting the combined influence of particle size and polymer properties on microplastic removal in conventional drinking water treatment systems (Na et al., 2021; Pivokonsky et al., 2018b).

CONCLUSIONS

Microplastics were detected at all stages of drinking water treatment process at WTP A in Palembang City, indicating that these particles persist from raw water intake to treated water. Conventional treatment processes achieved an

overall microplastics removal efficiency of 69.4%, showing a substantial reduction, but not complete elimination. Fragments were the most frequently observed morphology, and particles smaller 100 μm dominated across all stages, with ultrafine particles ($< 5 \mu\text{m}$) persisting in treated water.

The presence of microplastic particles smaller than 5 μm is of particular concern due to their potential relevance for human exposure. Although toxicological effects were not assessed in this study, the detection of fine microplastics emphasized the need for further research on their behavior, fate, and potential exposure pathways in drinking water systems, as well as the need for treatment approaches capable of addressing ultrafine particles.

FTIR analysis provided qualitative evidence of polymer-related spectral features, with PVC-related signals more apparent in raw water and PET-, PP-, and PE-related functional groups observed in treated water. The spectral trends suggest that heavier polymers are more effectively reduced during early treatment stages, whereas lighter and more flexible polymers tend to persist through conventional treatment processes. The continued presence of fine and buoyant microplastic particles highlights the need for improved treatment strategies to further enhance drinking water quality.

On the basis of these findings, complementary advanced treatment technologies, such as granular activated carbon (GAC) filtration or membrane-based processes, may be considered to improve the removal of fine and ultrafine microplastics that persist after conventional treatment systems.

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