JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 25(12), 170–180
https://doi.org/10.12911/22998993/194094
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.09.18
Accepted: 2024.10.20
Published: 2024.11.01

Characteristics and Assess the Effectiveness of Microplastics in the Leachate Treatment Plants in Pathumthani, Thailand

Naphat Phowan[1], Kewalee Thongchang[1], Piyanuch Jaikaew[2*]

[1] Faculty of Environmental Culture and Ecotourism, Srinakharinwirot University, Bangkok, Thailand
[2] Faculty of Engineering, Department of Civil and Environmental Engineering, Srinakharinwirot University, Ongkharak, Nakhonnayok, Thailand
* Corresponding author's e-mail: piyanuchj@g.swu.ac.th

ABSTRACT

Thailand experiences plastic waste and microplastic contamination (MPs) caused by waste disposal and leachate treatment systems. MPs often escaped from the leachate treatment. This research collected leachate and sludge samples from the leachate treatment system. This research aimed to determine the amount and characteristics of MPs and assess the effectiveness of microplastics in the leachate treatment system. The research also aimed to determine the amount of heavy metals deposited on microplastics and assess the exposure to heavy metals from the soil surrounding the leachate utilization. The microplastic samples were analyzed using a Fourier Transform Infrared Spectrometer (FTIR) to determine the composition and the type of plastic. The heavy metals on microplastics and in the open dumpsite soil were analyzed using Inductively Coupled Plasma Optical Emission (ICP-OES). The study found that the efficiency of removing microplastics in the leachate treatment system was 77.55%. The microplastic content in all leachate sampling locations was 105 ± 11 pieces/l, and microplastics were found at a concentration of 65 ± 3 pieces/kg in the sludge. The detected size of microplastics ranged from 20 to 10 micrometers and fragment shapes were the most common. The composition of the most transparent microplastics was examined, with polyethylene found to be the most prevalent at 30.55%, followed by Polyester at 17.77%. Zinc was the most common heavy metal found, while Cadmium was not detected in either the wastewater or sludge samples on microplastics. Most MPs removed from the leachate accumulate in the sludge, which may pose a risk to the environment. Therefore, a way to deal with the sludge is needed to reduce the contamination of MPs.

Keywords: microplastics (MPs), heavy metals on microplastics, leachate treatment system.

INTRODUCTION

Thailand has an overall waste accumulation of approximately 27 million tons, with a substantial amount of plastic waste reaching around 4.7 million tons annually. The amount of municipal solid waste has increased by 3% compared to previous years, reaching 24.98 million tons, with just 25% identified as potentially recyclable [1]. The trend of plastic waste is progressively inclining annually, potentially attributed to urban expansion, population growth, and increased consumption. Plastic waste emerges from the degradation or fragmentation of large plastic pieces due to heat, and sunlight, resulting in micro-sized particles less than 5 millimeters, some invisible to the naked eye, commonly referred to as microplastics (MPs) [2]. Microplastic contamination can originate from various sources in the environment. These include primary microplastics originating from initial plastic applications, such as additives in cosmetics or industrial plastic pellets resembling microbeads, and secondary microplastics formed by the degradation, tearing, or weathering of large plastic pieces accumulated in the environment over time due to physical, chemical, and biological processes [3]. Consequently, these microplastics have the potential to infiltrate various environmental settings.

The contamination of MPs occurs through the disposal and usage processes. A considerable portion of plastic waste is directed to open dumpsites, a significant repository of plastic waste.

Microplastics can originate due to their small size, eluding proper wastewater treatment during the collection and transportation of solid waste and wastewater. Presently, there is uncertainty in the methods or guidelines for treating microplastics in wastewater treatment systems. However, in general, there are three stages: primary treatment, secondary treatment, and tertiary treatment. These may involve coagulants to facilitate the settling of some microplastics. Due to their challenging chemical and physical properties, microplastics tend to persist and remain suspended in the environment for extended periods. Moreover, microplastics can absorb other hazardous substances, notably heavy metals like cadmium, chromium, lead, and mercury. If not adequately treated and released into the environment, these toxic substances can contaminate soil layers, groundwater sources, and peripheral surface waters, potentially entering the food chain, and impacting both humans and the environment [4].

Reviewing research endeavors, most studies regarding MPs in wastewater treatment systems predominantly focus on quantifying the number and types of MPs in industrial wastewater treatment plants in foreign countries, exhibiting efficient MPs removal [5] However, information regarding the study of MPs in Thailand's wastewater or sewage treatment systems remains relatively scant. Therefore, the objective of this research is to investigate the quantity and characteristics of MPs found in the sewage treatment system, the concentration of heavy metals in microplastics, and assess the efficacy of microplastics removal from the sewage treatment system. The outcomes derived from this research will provide insights and recommendations to address these prevailing issues effectively.

MATERIALS AND METHODS

The study area

This study took place within the vicinity of the waste disposal area in Khlong Luang District, Pathum Thani Province. The geographic coordinates are X-axis: 14.140565 and Y-axis: 100.671892, encompassing a total area of 70 acres. The surrounding region is predominantly utilized for agricultural purposes and accommodates an average daily municipal solid waste capacity ranging between 500 and 1.000 tons per day. The sewage treatment capacity amounts to an estimated 3.000 cubic meters per day, employing an Activated Sludge (AS) system for processing municipal wastewater sludge [6].

The collect samples

It was conducted using an integrated sampling method [7]. Random sampling locations are illustrated in Figure 1. Samples were collected simultaneously or in close succession from each designated location and combined into a single sample. At each sampling location, 1 liter of wastewater and 1 kilogram of sediment were collected. The sampling location included: wastewater inlet junction (Inlet: S1), aerated lagoon wastewater (Aeration Pond: S2), sedimentation Pond wastewater (Sedimentation Pond: S3), wastewater discharged into the environment (Outlet: S4), sediment from the sedimentation pond (SS). The preliminary analysis of the wastewater samples was carried out using field parameters measuring equipment, encompassing various water quality parameters. Subsequently, a pH, dissolved oxygen (DO), and electrical conductivity (EC) meter model HQ40D

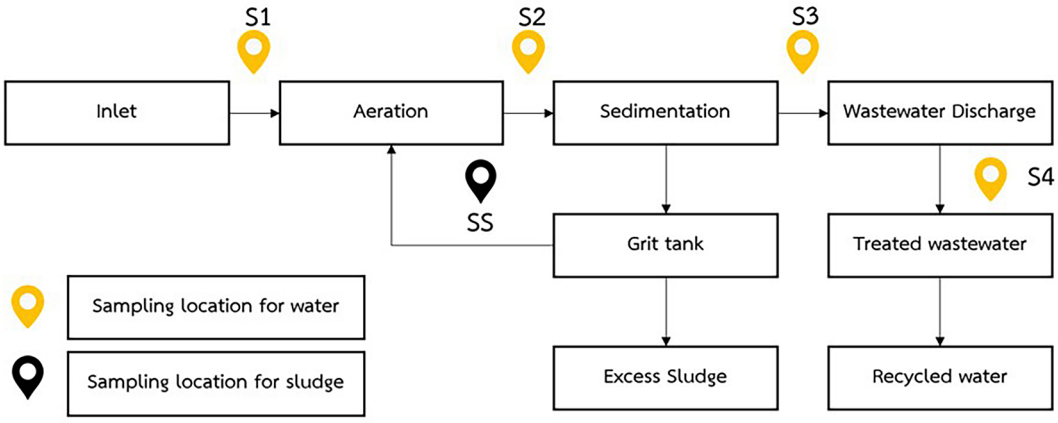

Figure 1. Schematic of the wastewater treatment system and sampling locations for wastewater and sediment

were submerged into the wastewater samples for measurement. The obtained wastewater samples were analyzed to determine the quantity of oxygen that microorganisms require to decompose organic matter present in water (BOD), following the standard method of APHA. The quantity of oxygen that chemicals utilize to decompose organic matter in water (COD) was determined using the Closed-reflux, Titrimetric method. The analysis also included the measurement of Suspended Solids (SS) and total dissolved solids (TDS) by Gravimetric method [8]. Each analysis was conducted in triplicate, and the results were recorded.

Analysis of microplastics

Preparation of wastewater and sludge samples

Wastewater and sludge samples were prepared separately. The wastewater sample comprised 1 liter, while the sludge sample was 1 kg. The sludge sample was then placed in a hot air oven at 70 °C for 72 h. Afterward, it was sieved through screens with sizes of 5.0, 1.0, 0.5, and 0.05 mm. MPs larger than 0.5 mm were separated since they contained significant plastic debris and organic matter. To degrade the organic substances, present in the sample, hydrogen peroxide (30%), ACS grade, (CARLO ERBA Reagents, Germany) was used, and the reaction was accelerated at a temperature of 60 °C. The density separation was then performed using sodium chloride (NaCl), ACS grade, (Merck, Denmark). It was added to each beaker and continuously stirred for 24 h to allow for sedimentation. Afterward, the clear water from the top was filtered using an air-filtering apparatus, employing glass fiber filter paper GF/C with a pore size of 0.45 µm. Finally, the filtered material was dried in a hot air oven at a temperature of 65 °C for 4 h. NOAA Technical Memorandum NOS-OR&R-48 (NOAA Marine Debris Program, National Oceanic and Atmospheric Administration U.S. Department of Commerce) [9].

Study of characteristics and components of microplastics

The dried filter paper was used for counting and conducting a morphological analysis of microplastics, including their color, shape, and size. This analysis was performed using a Nikon SMZ1270 stereo microscope equipped with the NIS-Elements D software, providing a Live View image at magnifications ranging from 0.63 to 8.0×. Additionally, the components of the microplastics were analyzed using a Fourier-transform infrared spectroscopy (FT-IR) machine, the PerkinElmer Spectrum Two model, operating within the wave number range of 400–4000 cm^{-1}.

Analysis of heavy metals on microplastics

Preparation of samples for determining heavy metals on microplastics

To determine heavy metals in microplastics, the filter paper containing the retained MPs was fragmented into small pieces, approximately 0.5 g, and subjected to microwave digestion. The digestion process was performed using an Aqua regia solution consisting of hydrochloric acid fuming 37% (Merck, Germany) and Nitric acid 65% (Merck, Germany) in a ratio of 3:1. The fragmentation was carried out at a temperature of 175 ± 5 °C. The resultant solution from the digestion was left to cool and filtered through a 2.5-µm filter paper to separate the clear part. The volume was adjusted to 50 mL using deionized water (DI) and stored in a refrigerator at 4 °C before analyzing the concentration of heavy metals on microplastics. Analysis, an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) model PQ9100 Elite, manufactured in Germany, was used. Standard solutions with concentrations of 1.000 µg/mL were prepared in Nitric acid 65% (Merck, Germany), Hydrochloric acid 37% (Merck, Germany), and DI water at concentrations of 0.1, 0.3, 0.5, 1, and 2 mg/L. Suitable conditions for analysis were determined, as shown in Table 1, creating a graph of standard concentrations with different Intensity values. The X-axis represents Intensity, and the Y-axis shows the concentration of heavy metal. The R-square value was determined to be 0.999 for all parameters of heavy metals. The analysis focused on measuring nine trace metals, including lead (Pb), cadmium (Cd), nickel (Ni), manganese (Mn), copper (Cu), chromium (Cr), zinc (Zn), iron (Fe), and arsenic (As) contamination.

RESULTS AND DISCUSSION

Physical and chemical characteristics of water in the wastewater treatment system

The analysis of the basic physical and chemical characteristics of water in the wastewater

Table 1. Parameters and setting of ICP-OES PQ9100 Elite

Parameter	Settings
Power	1200 W
Plasma gas flow	12.0 L/min
Auxiliary gas flow	0.50 L/min
Nebulizer gas flow	0.60 L/min
Nebulizer	Concentric nebulizer, 2.0 mL/min, Borosilicate glass
Pump rate	2.0 mL/min
Sample introduction	Teledyne ASX-560

treatment system from four sampling locations, namely the Inlet (S1), Aeration Pond (S2), Sedimentation Pond (S3), and Outlet (S4), revealed that the average temperature of wastewater in the treatment system ranged between 33.2 ± 0.10 and 35.3 ± 0.10 °C. The pH value was within the range of 6.45 ± 0.02 to 7.07 ± 0.16, while the EC was between 1.451 ± 1.00 and 2,847 ± 1.15 µS/cm. DO levels ranged from 0.13 ± 0.05 to 3.79 ± 0.18 mg/L. The BOD varied between 152.5 ± 9.17 and 353.06 ± 2.10 mg/L, and the COD ranged from 411.66 ± 7.63 to 1.420 ± 4.50 mg/L The total suspended solids (SS) in the water varied between 271.66 ± 7.63 and 965.83 ± 64.08 mg/L. Additionally, the TDS ranged between 7,617.77 ± 276.83 and 8,733.33 ± 65.65 mg/L, as shown in Table 2.

Microplastic contamination in the wastewater treatment system

From samples taken from wastewater and sludge in the wastewater treatment system, as shown in Table 3, it was found that at the inlet location (S1), there were 49 ± 1 pieces/L of MPs. Meanwhile, at the Aeration Pond (S2), there were 32 ± 4 pieces/L of MPs, indicating a reduction in MPs from the inlet to the aeration tank by approximately 34.69%. At the Sedimentation Pond (S3), there were 24 ± 1 pieces/L of MPs, showcasing a 25% reduction in MPs from the aeration tank to the sedimentation pond. This reduction might be due to the longer retention time and aeration aiding in better flocculation of MPs, possibly allowing for more effective settling in the sedimentation pond at the outlet (S4), the concentration decreased further to 11 ± 5 pieces/liter, indicating a reduction in MPs from the sedimentation tank to the outlet by approximately 54.17%. The overall reduction in MPs from the inlet to the outlet was approximately 77.55%, as illustrated in Figure 2. These findings are consistent with Zhang et al. [10], which evaluated MPs' removal efficiency in a wastewater treatment system using advanced treatment processes (Ultrafiltration, Nanofiltration, and Reverse osmosis), showing removal efficiencies ranging from 16.67% to 75%. Additionally, analyzing the MPs quantity in sludge samples from the wastewater treatment system, it was found that the concentration of MPs in the sedimentation tank's sludge was 65 ± 3 pieces/kilogram [11]. This suggests that the MP concentration in the effluent decreased due to the mechanism of microbial floc formation in the secondary treatment process. MPs tend to settle at the bottom of the tank alongside microbial flocs due to the Earth's gravitational force and density.

The size distribution of MPs found in the wastewater treatment system and sediment is categorized into 5 sizes: > 500 µm, 200–500 µm, 100–200 µm, 20–100 µm, and < 20 µm, as shown in Table 4.

The study on the size of MPs in wastewater samples showed that the percentage distribution of MPs in various sizes found in different

Table 2. Physical and chemical characteristics of wastewater in the treatment system

Parameter	Wastewater treatment system			
	Inlet (S1)	Aeration pond (S2)	Sedimentation pond (S3)	Outlet (S4)
pH	7.07 ± 0.01	6.94 ± 0.46	6.45 ± 0.02	7.07 ± 0.16
EC (µS/cm)	2.847 ± 1.15	1.673 ± 13.78	1.451 ± 1	1.455 ± 2.51
Temperature (°C)	34.43 ± 0.02	34.73 ± 0.01	35.3 ± 0.1	33.2 ± 0.1
DO (mg/L)	0.13 ± 0.05	2.67 ± 0.15	2.78 ± 0.01	3.79 ± 0.18
BOD (mg/L)	353.06 ± 2.10	152.5 ± 9.17	237.3 ± 9.64	221.5 ± 3.95
COD (mg/L)	1.420 ± 4.50	721 ± 7.63	411.66 ± 7.63	382.67 ± 28.30
SS (mg/L)	705 ± 77.94	965.83 ± 64.08	826.66 ± 51.07	271.66 ± 7.63
TDS (mg/L)	8,391.11 ± 143.65	8.420 ± 293.19	8,733.33 ± 65.65	7,617.77 ± 276.83

Table 3. Quantity of microplastics (MPs) in wastewater and sludge

Sampling location	Water MPs quantity (pieces/L)	Sludge MPs quantity (pieces/kg)	Removal efficiency (%)
Inlet (S1)	49 ± 1	-	-
Aeration pond (S2)	32 ± 4	-	34.69
Sedimentation pond (S3)	24 ± 1	-	25
Outlet (S4)	11 ± 5	-	54.17
Sludge (SS)	-	65 ± 3	-

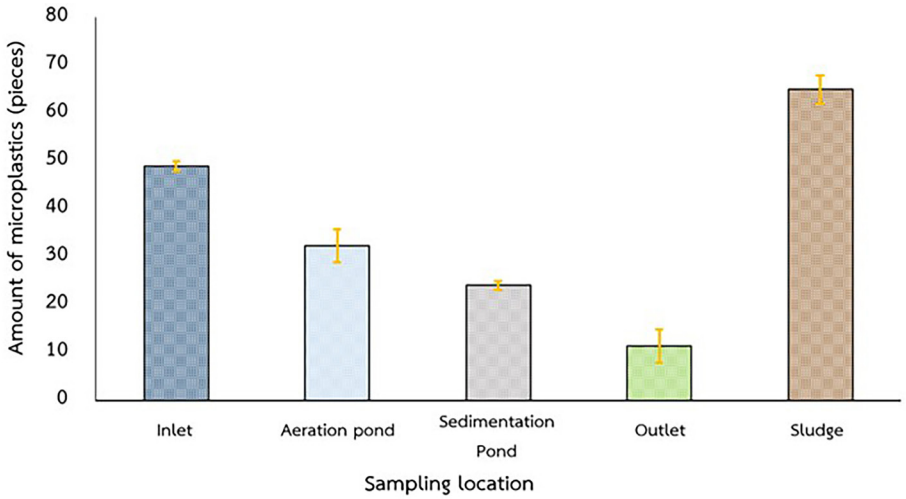

Figure 2. Quantities of MPs found in the wastewater treatment system at each location

Table 4. Size of microplastics (MPs)

Sampling location	MPs size (µm)				
	> 500	200–500	100–200	20–100	< 20
Inlet (S1)	3	3	2	22	19
Aeration pond (S2)	2	3	4	13	10
Sedimentation pond (S3)	2	3	3	9	7
Outlet (S4)	1	1	2	3	4
Sludge (SS)	4	11	13	25	12
Total	12	21	24	72	52

sampling locations within the wastewater treatment system and sludge is as follows:

At the wastewater inlet, MPs sized 20–100 µm were the most common (44.89%), followed by < 20 µm (38.77%), > 500 µm and 200–500 µm (both 6.12%), and 100–200 µm (4.08%). In the aeration tank, 20–100 µm MPs dominated (40.62%), followed by < 20 µm (31.25%), 100–200 µm (12.50%), 200–500 µm (9.37%), and > 500 µm (6.25%). In the sludge tank, 20–100 µm MPs were most prevalent (37.5%), followed by < 20 µm (29.16%), 100–200 µm and 200–500 µm (both 12.5%), and > 500 µm (8.33%).

The effluent or discharged water samples exhibited MPs predominantly in the size range of < 20 µm at 36.36%, followed by MPs sized 20–100 µm at 27.27%, 100–200 µm at 18.18%, > 500 µm at 9.09%, and 200–500 micrometers at 9.09%. In the case of the sludge samples, the most prevalent MPs were in the size range of 20–100 µm, accounting for 38.46%, followed by sizes < 20 µm at 18.46%, 100–200 µm at 20%, 200–500 µm at 16.92%, and MPs larger than 500 µm at 6.15% like in Figure 3. These results indicated similar distribution patterns of MPs in different size categories across various sampling locations. Smaller

particles were reduced at the inlet, aeration tank, and sludge tank while larger particles increased. Conversely, in the aeration tank, smaller MPs increased while larger particles decreased [12]. Moreover, MPs can break down under physical and chemical actions, such as wind waves, microorganisms, and UV radiation [13]. Studies have shown that larger particles can break down due to the turbulence generated in the aeration tank [14] and the interaction with organic matter during bio-reactions, exposure time, and the concentration of chemicals added [15].

The investigation identified five types of microplastics (MPs) – fibers, fragments, pellets, flakes, and films – from samples collected at four wastewater locations and one sludge sample. Fragments were the most prevalent, constituting 29.31% of the samples and predominantly found in wastewater. The next most common types were fibers, pellets, films, and flakes, with flakes being the least abundant at 6.12% in the inlet location. Across all sampling sites including the aeration tank, sludge tank, effluent, and sludge samples fragments and fibers consistently remained the most abundant MPs. These findings align with He et al. [16], who also identified five MP types in landfill waste and found that up to 99.36% of plastic particles in wastewater, the size of 77.48% microplastics was between 100 and 1000 µm. The widespread presence of broken plastic pieces is likely due to the accumulation of plastic waste over 30 years in the landfill, leading to small-sized plastics through weathering processes like exposure to air, UV radiation, sunlight, chemicals, and environmental elements (Figure 4) [17].

From the investigation at the sampling locations in the wastewater treatment system and sediment, various colors of MPs were identified. These include transparent, red, blue, black, pink, white, brown, green, and others, as shown in Figure 5. The most prevalent color found was transparent, accounting for 22.77%, followed by white at 15.56%, blue at 15%, black at 13.33%, red at 8.89%, other colors at 7.78%, green at 7.22%, pink at 6.11%, and brown at 3.33%, respectively. The addition or incorporation of color during plastic production provides specific properties to plastics, such as flexibility, softness, durability, and electrical conductivity [18]. This addition enhances aesthetics, adds value, and suits the particular type of plastic used in various applications. The color of MPs can indicate the source or origin of the plastic waste. For instance, transparent and white MPs are the base colors in the primary manufacturing process in the industry, which may fade or change due to weather conditions and exposure to sunlight, hence being more commonly found. The blue color might come from bottle caps or packaging materials, while black-colored plastics are commonly utilized in agricultural applications, such as agricultural film covering soil [19]. The characteristics of each type of plastic in

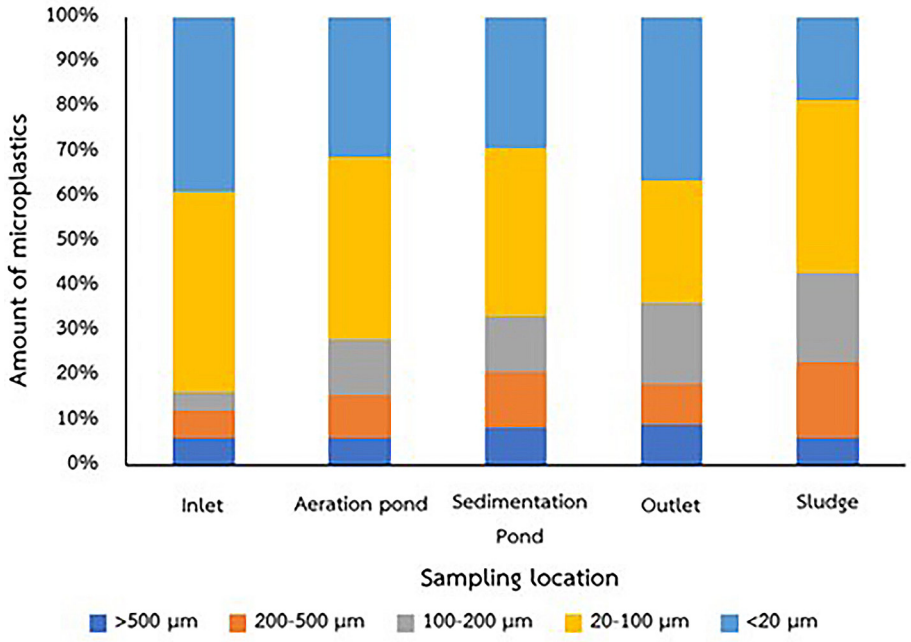

Figure 3. Sizes of MPs found in the wastewater treatment system at each sampling location

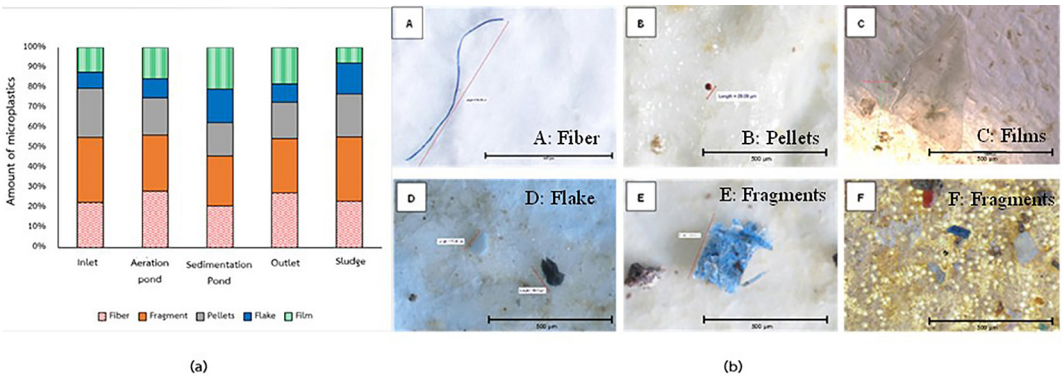

Figure 4. (a) Shapes of MPs found in the wastewater treatment system at each sampling location, (b) examples of MPs shape are found in the wastewater treatment system and sludge. A: fiber B: pellets C: films D: flake E-F: fragments

Figure 6(F)-6(I). FTIR Spectrum Graph of MPs in the wastewater treatment system and sludge within the wave range of 400–4000 cm^{-1}, classified according to wavelength as follows: Polyethylene (PE) Similar to HDPE and LDPE : ~720–2915 cm^{-1} [20, 21], polyvinyl chloride (PVC): ~600–2975 cm^{-1} [22], polypropylene (PP):~840–2950 cm^{-1} [20], polyester (PES):~720–2850 cm^{-1} [20, 22], PS:~690–3080 cm^{-1} [23], nylon: ~1180–3500 cm^{-1} [24], polyamide (PA): ~1180–3300 cm^{-1} [20, 21] (Figure 7). The FT-IR analysis of plastic components in wastewater and sludge identified eight types: polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyester (PES), polyamide (PA), low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polystyrene (PS). Polyethylene was the most prevalent, with 15 pieces per liter (30.61%) at the inlet and 4 pieces per liter (36.36%) at the outlet, while HDPE was the least common, found at only 2 pieces per liter (4.08%) at the inlet. No PA, LDPE, or HDPE was detected at the outlet, due to the properties are heavier than water found in sediment. These findings align with research by Talvitie et al. [12], which studied the characteristics of MPs in wastewater treatment systems and identified 12 different types of polymers, with polyethylene being the most prevalent, followed by polyester (20%) and polyamide and acrylic (11.1%) [13]. The origin of plastic waste, temperature, UV light exposure, and environmental conditions in the study area resulted in different quantities of MPs. The smaller the identified MPs, the more severe the threat to the environment and their accumulation in the food chain. For example, in the sludge sample, polyethylene was most prevalent at 17 pieces/kg (26.15%), followed by polyester at 14 pieces/kg (21.53%), and high-density polyethylene was the least at 2 pieces/kg (3.07%). Polyethylene is the most widely produced and

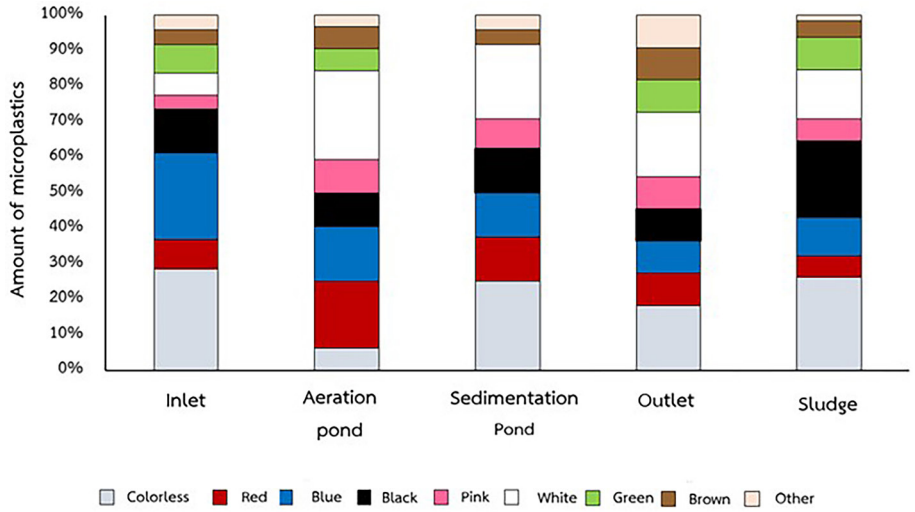

Figure 5. Colors of MPs found in the wastewater treatment system at each sampling location

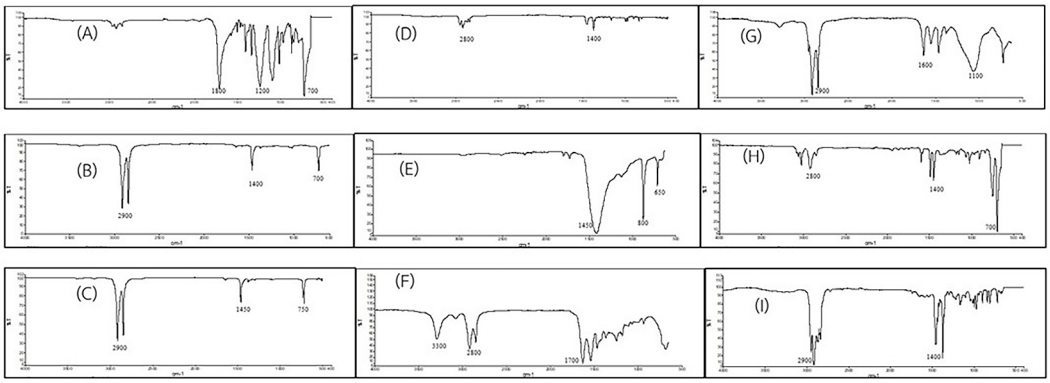

Figure 6. FTIR spectrum graph of MPs in the wastewater treatment system and sludge within the wave range of 400–4000 cm^{-1}, (a) polyester, (b) high-density polyethylene, (c) low-density polyethylene, (d) polypropylene, (e) polyvinyl chloride, (f) nylon, (g) polyamide, (h) polystyrene, (i) polyethylene

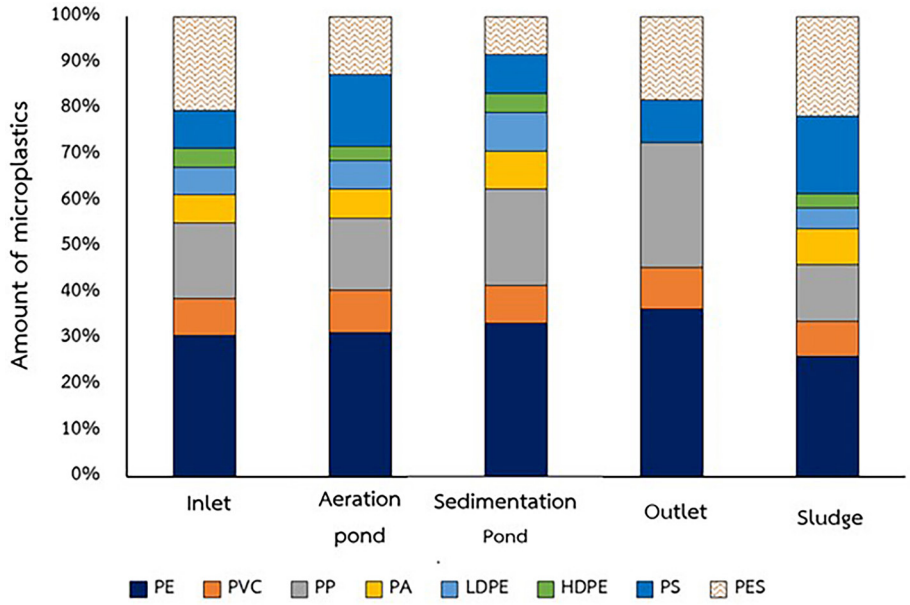

Figure 7. Components of MPs found in the wastewater treatment system at each sampling location

used polymer globally [14] and often originates from the breakdown of small plastic pieces in landfill sites or small-sized cosmetics particles with abrasive properties. This finding corroborates Hongprasith et al. [15], which measured MP pollutants in wastewater and sludge from various wastewater treatment systems in Thailand. The research concluded that microplastics (MPs), especially fiber types, accounted for the highest proportion (32–37%) and were primarily composed of polymers such as polystyrene, polypropylene, and polyethylene. These plastics mainly originated from everyday items like boxes, children's toys, bags, ropes, food packaging, cable coatings, medical plastics, or electrical wire covers.

The study on the heavy metal content of microplastics at each sampling location is presented in Table 5. In the sampling location of the incoming water into the system, the highest concentration detected was 22.177 ± 0.23 mg/L for cadmium, followed by iron at 0.532 ± 0.01 mg/L. The lowest concentration detected was for arsenic at 0.043± 0.01 mg/L, and chromium was not found. At the air-filled replenishment pit sampling location, the highest concentration observed was 21.98 ± 0.11 mg/L for cadmium, while iron showed a lower concentration at 0.116 ± 0.01 mg/L. Chromium was not detected at this location. In the sedimentation pond sample, the highest concentration of heavy metals was 20.150 ± 0.03 mg/L for cadmium, followed by iron at 0.013 ± 0.01 mg/L and copper

at 0.007 ± 0.01 mg/L, respectively. Chromium, magnesium, nickel, arsenic, lead, and cadmium were not detected at this sampling location. In the effluent sample leaving the system, the highest concentration detected was 19.70 ± 0.10 mg/L for cadmium, followed by iron at 0.007±0.02 mg/L. Nickel, magnesium, copper, arsenic, iron, and cadmium were not detected at this location. In the study of heavy metal content on microplastics in the sediment, the highest concentrations found in the sediment samples were 26.687 ± 0.03 mg/L for cadmium, followed by iron at 1.760 ± 0.01 mg/L, copper at 0.175 ± 0.01 mg/L, and chromium at 0.170 ± 0.14 mg/L. Nickel, lead, copper, manganese, arsenic, and cadmium were found in smaller quantities, ranging from 0.075 ± 0.01 to 0.003 ± 0.01 mg/L. Chromium was not found in the sediment samples.

In Table 5, the highest concentrations of heavy metals were found in the water inlet and decreased accordingly. Conversely, microplastics in sludge showed similarly high quantities of heavy metals, specifically zinc, and iron. These elements are natural elements commonly found in food and vegetables. Factors leading to variations in the concentration of heavy metals on microplastics at each sampling point include the number of microplastics, their properties such as surface characteristics, age, and the type of polymers. Naqash, et al. [26] found that microplastics exposed to weathering, degradation, and photooxidation over a long duration in natural environments resulted in a negatively charged surface. This property allows microplastics to attract and adsorb positive ions of metals from the environment, leading to varying concentrations of heavy metals.

Analyzing the concentration of heavy metals on microplastics at each sampling point using One-way ANOVA, significant statistical differences were observed (0.05 level), except for cobalt. The studied heavy metal quantities in microplastics from food packaging, finding varying contamination levels. The most contaminated microplastics were from foam, followed by water bottles. The most prevalent heavy metals included zinc, followed by copper, cadmium, chromium, and cobalt. Heavy metals found on microplastics mostly originated from plastics that had additives; for instance, colored plastics had a higher tendency to release contained heavy metals compared to clear and dense plastics.

Additives modify the properties of plastics during the blending process, which subsequently affects the properties of plastic pellets during production. Plasticizers, modifiers of mechanical properties, such as polyethylene and lubricants [18], help enhance flexibility and softness. Sarkar et al. [19] studied the occurrence and removal of microplastics carrying heavy metals in natural wastewater treatment systems. They discovered high concentrations of toxic heavy metals (lead, cadmium, chromium, copper, nickel, cobalt, and zinc) on microplastics predominantly originated from polyethylene terephthalate (PET) and polyethylene. The concentration of heavy metals in microplastics varied depending on the external solution's pH value.

The reduction in heavy metal concentrations in microplastics might be due to coagulation with chemicals or sedimentation in sludge, ion exchange, absorption, or membrane filtration Khalid et al. [25] mentioned that the decrease in heavy metal concentrations in microplastics

Table 5. Concentration of heavy metals on microplastics in wastewater and sludge

Heavy metals	Sampling location					
	Inlet	Aeration pond	Sedimentation pond	Outlet	Sludge	Sig.($p < 0.05$)
Zn	22.177 ± 0.23	21.98 ± 0.11	20.150 ± 0.03	19.70 ± 0.10	26.687 ± 0.03	0
Fe	0.532 ± 0.01	0.116 ± 0.01	0.013 ± 0.01	0.007 ± 0.00	1.760 ± 0.01	0
Cu	0.274 ± 0.02	0.114 ± 0.01	0.007 ± 0.00	ND	0.175 ± 0.01	0
Ni	0.240 ± 0.01	0.025 ± 0.01	ND	ND	0.075 ± 0.01	0
Cr	0.264 ± 0.01	0.053 ± 0.15	ND	ND	0.170 ± 0.14	0
Mn	0.043 ± 0.01	0.015 ± 0.01	ND	ND	0.004 ± 0.00	0
Pb	0.050 ± 0.02	0.023 ± 0.01	ND	ND	0.012 ± 0.00	0.248
As	0.034 ± 0.01	0.013 ± 0.01	ND	ND	0.003 ± 0.00	0
Cd	ND	ND	ND	ND	ND	-

Note: *ND = NOT detected.

might result from chemical flocculation or settling in sedimentation tanks, ion exchange, or adsorption through membrane filters.

CONCLUSIONS

This study investigated the efficiency of MPs removal in the wastewater treatment system at an open landfill site in Pathum Thani province. Analysis of the basic characteristics of leachate from four points revealed that temperature and pH fell within the water quality standards. Still, parameters such as DO, BOD, COD, EC, SS, and TDS exceeded the permissible limits set for effluent discharge from industrial and factory areas as per the Royal Gazette announcement on March 29, 2017.

The efficiency of various processes in removing MPs from the leachate system showed that the average number of MPs entering the system was 49±1 pieces/L. The aerated lagoon had an efficiency of 34.69% in removing MPs, with an average of 32 ± 4 pieces/L. The settling pond had an average of 24 ± 1 pieces/L and a removal efficiency of 25%. At the point of water discharge from the system, the average MP count was 11 ± 5 pieces/L with a removal efficiency of 54.26%. MPs with sizes ranging between 20–100 m were predominantly found at each sampling point.

Overall, the removal efficiency of MPs in the treatment system was 77.55%. Additionally, an average of 65±3 pieces/kilogram of MPs was found in the sludge, mainly within the 20–100 μm size range. The observed MP shapes included irregular pieces, fibers, spheres, films, and flakes. A variety of colors were also detected, with clear MPs being the most prevalent, followed by transparent white, dark red, green, pink, brown, and other colors. The investigation of MP types revealed eight polymers, with PE and polyester being the most predominant at 30.55% and 17.77%, respectively. The most prevalent heavy metals found on MPs were zinc, iron, copper, chromium, nickel, cobalt, magnesium, and lead, in decreasing order. Cadmium was not detected in both leachate samples and sludge.

Statistical analysis showed significant differences in the concentrations of heavy metals on microplastics at each sampling point except for cobalt. Most heavy metals in microplastics originated from plastic manufacturing processes. The surface properties of MPs that allowed the absorption of pollutants led to the accumulation of heavy metals in microplastics.

External factors such as seasons, weather conditions, and rainfall might affect the concentration of microplastics. Most microplastics entering the leachate treatment system accumulated in the sludge, posing a risk of environmental contamination. Therefore, advanced technologies and methods are necessary to improve MPs removal efficiency and manage sludge effectively, reducing environmental contamination in subsequent soil environments.

The outcomes derived from this research will provide insights and recommendations to address these prevailing issues effectively. To ensure that leachate from the treatment system, which may be absorbed into the soil, will not release pollutants that may directly or indirectly affect the environment.

Acknowledgments

The researchers would like to express gratitude for the Science, Research and Innovation Fund for fiscal year 2024, Grant No.114/2567 Srinakharinwirot University for support provided this study. In addition, the Faculty of Environment Culture and Ecotourism and the Faculty of Engineering, Srinakharinwirot University, for the generous provision of facilities, particularly the laboratories, which played a crucial role in ensuring the successful execution of the research endeavors.

REFERENCES

1. Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., and Russell, A.E. 2004. Lost at Sea: Where Is All the Plastic, Science, 304, 838–38.
2. Fu, L., Li, J., Wang, G., Luan, Y., and Dai, W. 2021. Adsorption behavior of organic pollutants on microplastics, Ecotoxicology and Environmental Safety, 217, 112207.
3. Paisanpong, T. 2023. Microplastics contamination of aerated lagoon wastewater treatment and stabilization pond wastewater treatment. The Public Health Journal of Burapha University, 17, 1–14.
4. Alijagic, A., Suljevi, D., Fo˘cak, M.,, Sulejmanovi, J, Sehovi, E., Sarndahl, and E., Engwall, M. 2024. The triple exposure nexus of microplastic particles, plastic-associated chemicals, and environmental pollutants from a human health perspective, Environment International, 188, 108736.

5. Zhang, Z., Su, Y., Zhu, J., Shi, J., Huang, H., and Xie, B. 2021. Distribution and removal characteristics of microplastics in different processes of the leachate treatment system. Waste Management. 120, 240-47.
6. Polruang, S., Khongkwanmueang, A., and Asokbunyarat, V. 2022. A study of quantity, shape, and size of microplastics in a wastewater treatment plant in Bangkok.The Proceedings of 60th Kasetsart University Annual Conference, Bangkok. 329–337.
7. He, P., Chen, L., Shao, L., Zhang, H., and Lü, F. 2019. Municipal solid waste (MSW) landfill: A source of microplastics -Evidence of microplastics in landfill leachate. Water Research, 159, 38–45.
8. De Falco, F., Di Pace, E., Avella, M., Gentile, G., Errico, M.E., Krzan, A., ElKhiar, H., Zupan, M., and Cocca, M. 2021. Development and performance evaluation of a filtration system for washing machines to reduce microfiber release in wastewater. Water, Air, & Soil Pollution, 232(10), 406.
9. Masura, J., Baker, J.E., Foster, G.D., Arthur, C., Herring, C. 2015. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48.
10. Zhang, Y., Kang, S., Allen, S., Allen, D., Gao, T., and Sillanpää, M. 2020. Atmospheric microplastics: A review on current status and perspectives. Earth-Science Reviews, 203, 103118.
11. Li, X., Chen, L., Mei, Q., Dong, B., Dai, X., Ding, G., and Zeng, E.Y. 2018. Microplastics in sewage sludge from the wastewater treatment plants in China. Water Research, 142, 75–85.
12. Talvitie, J., Mikola, A., Koistinen, A., and Setälä, O. 2017. Solutions to microplastic pollution - Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Res, 123, 401–407.
13. Sirivithayapakorn, S. 2019. Types and distribution of microplastic in seawater and bottom sediment in Chao-Phraya River mouth area.Science and Technology Research Projects. Natural Science Program, Kasetsart University.
14. Europe P. 2018. An analysis of European plastics production, demand, and waste data. Available at: https://plasticseurope.org/wp-content/uploads/2021/10/2018-Plastics-the-facts.pdf. Retrieved 25 February 2023.
15. Hongprasith, N., Kittimethawong, C., Lertluksanaporn, R., Eamchotchawalit, T., Kittipongvises, S., and Lohwacharin, J. 2020. IR microspectroscopic identification of microplastics in municipal wastewater treatment plants. Environmental Science and Pollution Research, 27(15), 18557–18564.
16. He, P., Shao, L., Zhang, H., Chen, L., Lu, F. 2019. Municipal solid waste (MSW) landfill: A source of microplastics? -Evidence of microplastics in landfill leachate.Water Research, 159(4), 38–45.
17. Tobudde, I., Tobuddee, I., Tangkananurak, M.K., Wararam, W., and Sirivithayapakron, S., 2021. Heavy metals concentration in microplastic packaging and the releasing capability of releasing heavy metals from microplastic particles of plastic containers in synthetic marine water. Srinakharinwirot University (Journal of Science and Technology, 13(25), 149–161.
18. Kang, H.C., and Geckeler, K.E. 2000. Enhanced electrical conductivity of polypyrrole prepared by chemical oxidative polymerization: effect of the preparation technique and polymer additive, Polymer, 41(18), 6931–6934.
19. Sarkar, D.J., Das Sarkar, S., Das, B.K., Sahoo, B.K., Das, A., Nag, S.K., Manna, R.K., Behera, B.K., and Samanta, S. 2021. Occurrence, fate, and removal of microplastics as a heavy metal vector in natural wastewater treatment wetland system, Water Research, 192, 116853.
20. Coates, J. 2000. Interpretation of Infrared Spectra, A Practical Approach. In: Meyers, R.A. (Ed.), Encyclopedia of Analytical Chemistry. Wiley.
21. Pavia, D.L., Lampman, G.M., Kriz, G.S., Vyvyan, J.R. 2008. Introduction to Spectroscopy. Brooks/Cole.
22. Stuart, B.H. 2004. Infrared Spectroscopy: Fundamentals and Applications. Wiley.
23. Silverstein, R.M., Webster, F.X., Kiemle, D.J. 2005. Spectrometric Identification of Organic Compounds. Wiley.
24. Smith, B.C. 2011. Infrared Spectral Interpretation: A Systematic Approach. CRC Press
25. Khalid, N., Aqeel, M., Noman, A., Khan, S.M., and Akhter, N. 2021. Interactions and effects of microplastics with heavy metals in aquatic and terrestrial environments, Environmental Pollution, 290, 118104.
26. Naqash, N., Prakash, S., Kapoor, D., and Singh, R. 2020. Interaction of freshwater microplastics with biota and heavy metals: a review. Environmental Chemistry Letters, 18(6), 1813–1824.