 https://doi.org/10.1051/e3sconf/202561203001

Effect of UV-degraded microplastics on Dissolved Air Flotation (DAF) removal

Sovannary Pit[1], *Jirawat* Sangpreedeekorn[1], *Theerayut* Phengsaart[2], and *Dao* Janjaroen[1*]

[1]Department of Environmental and Sustainable Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330, Thailand
[2]Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330, Thailand

Abstract. Microplastics (MPs) are ubiquitous environmental pollutants that cause significant effects on the aquatic ecosystem and human health, including challenging water treatment systems due to their small particle size and high environmental persistence. This study aims to investigate the effect of ultraviolet (UV) radiation on two types of MPs, polypropylene (PP) and polystyrene (PS), by using the dissolved air flotation (DAF) process. In this work, MPs in the size ranges (300-500 μm) were subjected to controlled UVC exposure to simulate environmental weathering. After 30 days of irradiation, the results show that the removal efficiency of aged PP increased to 40.67%, while the unaged PP was only 35.12%. Similarly, pristine PS had a removal efficiency of 14.66%, which substantially improved to 31.33% after UVC degradation. The increase in UV-aged MPs can be attributed to surface modifications, such as increased surface roughness and the formation of more oxygen-containing functional groups, which modified their interactions with air bubbles in the DAF process and hence affected their removal efficiency. These findings indicate that UV exposure significantly enhances the DAF process in removing MPs, providing a promising approach for improving MP mitigation in water treatment systems.

1 Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as a significant environmental concern due to their widespread presence in marine, freshwater, and terrestrial ecosystems. Their small size and large surface area allow them to absorb pollutants, creating complex contamination and facilitating long-distance transport, which increases their toxicity [1-3]. As these MPs accumulate in aquatic environments such as wastewater or surface water [4], understanding and improving their removal from water systems is paramount. Among the available techniques, Dissolved Air Flotation (DAF) has been recognized as a promising method for reducing the environmental impact of MPs. DAF is a water treatment technology that purifies water by removing suspended substances, including oil or solids. The effectiveness of DAF relies on its ability to attach fine air bubbles to particles, raising their buoyancy and facilitating removal at the surface of water [5].

* Corresponding author: dao.s@chula.ac.th

However, the removal efficacy of DAF can vary considering based on the physical and chemical properties of the MPs, which may be altered by environmental factors such as mechanical fragmentation, ultraviolet (UV) irradiation, thermal degradation, and biodegradation [6]. However, UV light is considered the most common source of polymer degradation [7]. The aging process induced by UV exposure causes significant changes to the surface properties of MPs, such as increased surface roughness, alterations in hydrophobicity, and the formation of new functional groups [8, 9]. For instance, MPs can absorb light through benzene rings or impurity chromophores such as carbonyl and unsaturated bonds, which may experience structural bond cleavage, free radical generation, and simultaneous degradation [10, 11]. These alterations may impact the interaction between MPs and air bubbles during the flotation process, potentially influencing the removal efficiency of aged MPs compared to their pristine MPs [11].

Given the widespread use of plastics like Polypropylene (PP) and Polystyrene (PS) in various industries, including packaging, consumer goods, and food storage, these materials are among the most common types of MPs found in aquatic environments due to significant amounts of MPs during use and disposal. The degradation of these plastics under environmental conditions, primarily through UV exposure, further complicates their removal from water systems.

This study aims to address the knowledge gap regarding the removal efficiency of UV-degraded MPs using DAF process. Specifically, the research focuses on two plastic types, PP and PS, and investigates the effect of UVC radiation on their morphologies and chemical changes of MPs and subsequent removal efficiency in the DAF process. By simulating environmental weathering conditions in the laboratory, this work provides valuable insights into the impact of aging on MPs and their behavior in water treatment systems. Understanding the changes induced by UV degradation and their effects on removal efficiency is crucial for optimizing DAF and other water treatment technologies to mitigate the environmental and health risks posed by plastic pollution.

2 Methodology

2.1 Sample preparation

Two common plastic materials, PP and PS, were selected from plastic straws and cutlery for this study. These materials were selected due to their widespread application in consumer products, making them a major contributor to plastic pollution. PP and PS polymers were broken down into the smaller particle by a grinding machine. After grinding, MPs were sieved into size ranges of 300-500 μm before being subjected to UV irradiation experiments.

2.2 UV irradiation experiments

In the aging process, 0.5 g PP and PS MPs were added to a glass beaker with 20 mL of distilled water. The mixtures were irradiated at room temperature with four UVC lamps at 254 nm wavelength in the custom-made UV chamber for 30 days. After the desired exposure, all the MPs were filtrated using filter paper and dried for 48 h at 50 ºC before further analysis. Every two days, distilled water was replenished to prevent drying of samples. The same procedure was followed for control samples kept in the dark condition by wrapping the beakers with aluminum foil. Additionally, all of MPs photoaging experiments were repeated in triplicate.

2.3 Dissolved Air Flotation

The air flotation test was conducted in a column of 77 cm in height and 6 cm in diameter. The bottom of the flotation cell was fitted with a permeable substance for air bubbling. The setup included an air compressor, flow meter, and a tall flotation cell, as depicted in **Fig. 1**. According to the methodologies referenced in [12], the experiment involved pressurizing 1500 mL/min of recycled water at 10% using an air compressor, which was then agitated to ensure the air is almost completely dissolved in the system. After 5 minutes of flotation, the treated water was collected at the bottom of the flotation column.

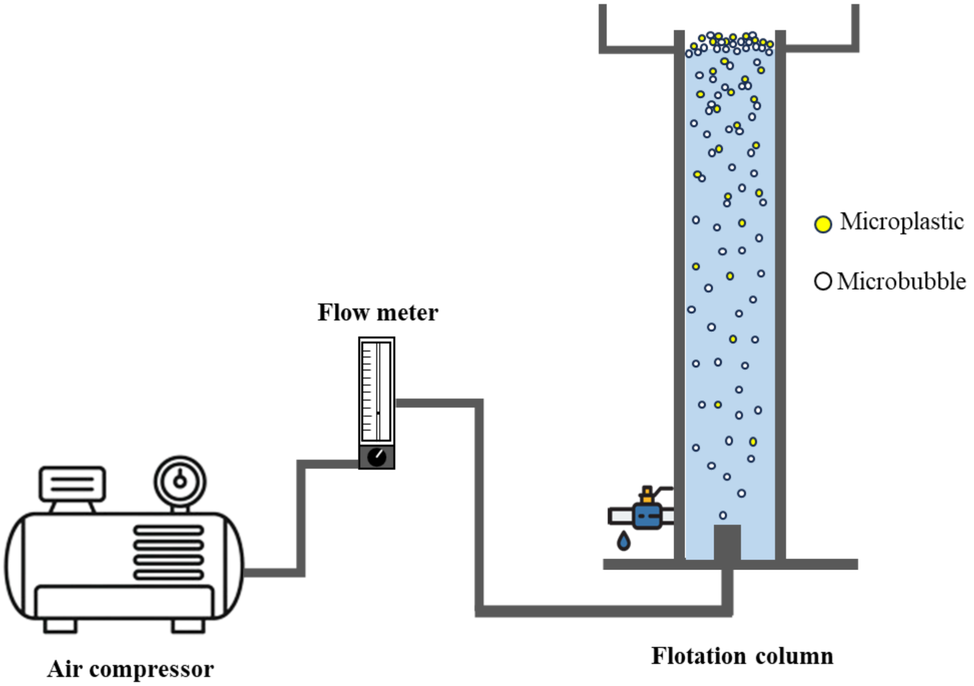

Fig. 1. Dissolved Air Flotation setup

2.4 MPs characterization

The surface morphologies of pristine and photoaged MPs were characterized by scanning electron microscopy (SEM) (JEOL JSM-IT300, Japan). Functional groups were observed by Fourier transform infrared (FTIR) spectroscopy (LUMOS II, Bruker, Germany). Additionally, the aging MP samples were analyzed for hydrophobicity, zeta potential, and size distribution.

3 Results and Discussion

3.1 The characterization of MPs

The FTIR analysis was performed to detect any modifications in the chemical functionality of the PP and PS MPs before and after UV degradation due to its capacity to detect the presence of functional groups and bonds at particular bands, as shown in **Fig. 2**. As illustrated in **Fig. 2a**, major auto peaks were observed on aged PP (at 2973-2855, 1454, 1374 and 1043 cm^{-1}), mainly assigned to the C-H vibration of aromatic rings, C-H deformation, skeletal vibrations and tensile vibration of C-O, respectively. After continuous irradiation of UVC for 30 days, PP produced a new absorption peak at 1796 cm^{-1}, representing the formation of C=O, which may be related to the formation of carbonyl groups.

Additionally, **Fig. 2b** showed the comparison between the pristine PS and PS aged for 1-month irradiation. Peaks at 1026, 1371 and 1665 cm^{-1}, the tensile vibration of C-O, phenolic hydroxyl (C-OH) and carbonyl group (C=O) were observed, respectively. The stretching band in the range of 3600-3100 cm^{-1} are attributed to the O-H stretching vibration and adsorption peaks at 3080-2630 cm^{-1}, which is due to the C-H vibration of aromatic rings [13]. However, the aged PS MPs exhibited a few changes as the virgin one, possibly owing to the overlap of absorption peaks [14]. Therefore, the above preliminary results proved that the PP and PS were aged after UVC irradiation, and new oxygen-containing functional groups were generated and were compatible with [15] and [16] that UV light can promote aging MPs, resulting in modification in the MPs characteristics, which can influence in removal MPs processes.

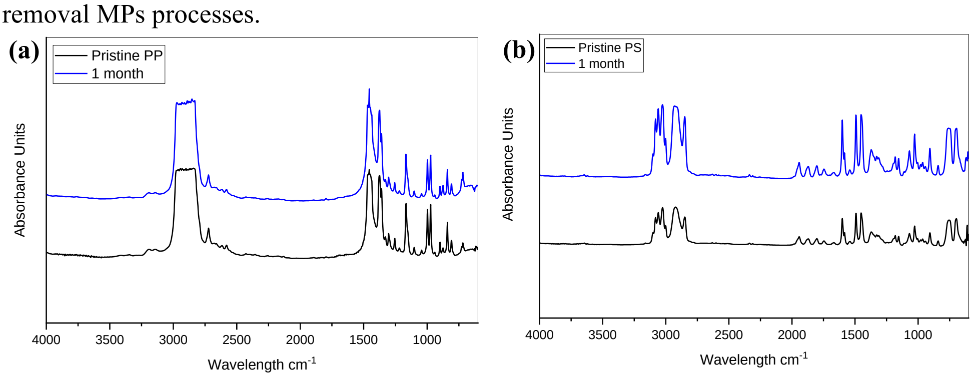

Fig. 2. The comparison of FTIR spectra of **(a)** pristine PP and aged PP **(b)** pristine PS and aged PS under UVC radiation for 30 days

3.2 Removal of UV-degraded MPs by DAF

In the DAF process, the removal efficiency of both aged MPs was higher than the pristine MPs as exhibited in **Fig. 3**. This change in physicochemical properties of PP and PS is evidenced by enhanced surface roughness, increased hydrophobicity, and increased oxygen-containing functional groups with aging time under UVC degradation. For PP, the removal efficiency in its pristine form was recorded at 35.12%. However, after exposure to UVC light, the efficiency increased to 40.67%. Similarly, PS MPs showed a removal efficiency of 14.66% in their original state, which significantly increased to 31.33% following 30 days under UVC treatment. The substantial improvement in this study shows that the removal of aged PS compared to PP MP, suggested that aged PS shows a higher increase in removal efficiency when considering the percentage increase from their baselines due to the loss of hydrophobicity, more pronounced changes in surface properties under the UV exposure [16], enhancing its interactions with air bubbles.

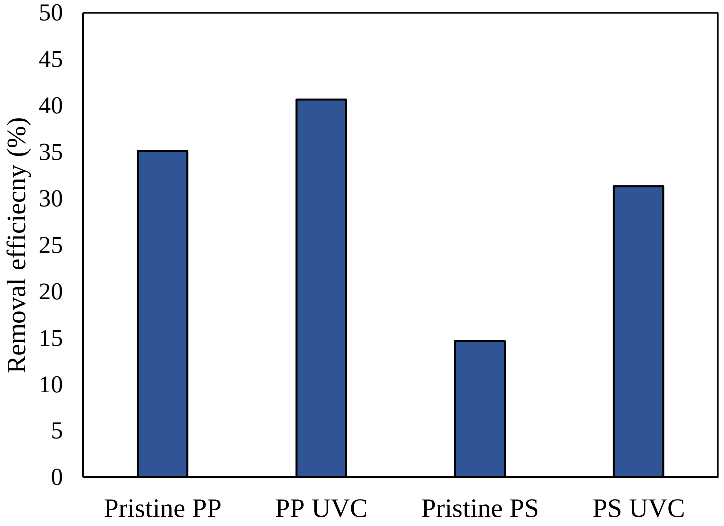

Fig. 3. Removal efficiency between Pristine and Aged MPs under UVC exposure using the DAF process

4 Conclusion

This research illustrates how UV degradation significantly changes the characteristics of PP and PS MPs, which promotes their removal efficiency in the DAF process. After the UV exposure, the removal efficiencies of both MPs improved, with PP increasing from 35.12% to 40.67% and PS rising from 14.66% to 31.33%. These improvements are ascribed to the surface modifications induced by UVC radiation, including increased roughness, brittleness, color changes, and the formation of oxygen-containing functional groups. These modifications enhance the interaction between MPs and air bubbles in the DAF process, consequently leading to more effective removal from water. The findings suggest that the incorporating of UV treatment as a preliminary step in water treatment could increase the efficiency of MP removal, potentially providing a solution to the growing of MP pollution in aquatic environments. Further studies should focus on various MP types under different simulated environments and the development of advanced treatment technologies by investigating on other factors such as varying pH, pressure and flow rate in DAF treatment to receive higher efficiency.

References

1. Cui, Q., et al., *Microplastics generation behavior of polypropylene films with different crystalline structures under UV irradiation.* Polymer Degradation and Stability, **199**: p. 109916. (2022)
2. Wang, T., et al., *Interactions between microplastics and organic pollutants: Effects on toxicity, bioaccumulation, degradation, and transport.* Science of The Total Environment, **748**: p. 142427. (2020)

3. Luo, H., et al., *Environmental behaviors of microplastics in aquatic systems: A systematic review on degradation, adsorption, toxicity and biofilm under aging conditions.* Journal of Hazardous Materials, **423**: p. 126915. (2022)
4. Hoellein, T.J., et al., *Longitudinal patterns of microplastic concentration and bacterial assemblages in surface and benthic habitats of an urban river*. Freshwater Science, **36**(3): p. 491-507. (2017)
5. Edzwald, J.K., *Dissolved air flotation and me.* Water Research, **44**(7): p. 2077-2106. (2010)
6. Andrady, A.L., *Microplastics in the marine environment.* Marine Pollution Bulletin, **62**(8): p. 1596-1605. (2011)
7. Liu, P., et al., *New insights into the aging behavior of microplastics accelerated by advanced oxidation processes.* Environ. Sci. Technol., **53**: p. 3579. (2019)
8. Cai, L., et al., *Observation of the degradation of three types of plastic pellets exposed to UV irradiation in three different environments.* Science of The Total Environment, **628-629**: p. 740-747. (2018)
9. Liu, P., et al., *Effect of weathering on environmental behavior of microplastics: Properties, sorption and potential risks.* Chemosphere, **242**: p. 125193. (2020)
10. Wang, X., et al., *UV-induced aggregation of polystyrene nanoplastics: effects of radicals, surface functional groups and electrolyte.* Environmental Science: Nano, **7**(12): p. 3914-3926. (2020)
11. Ouyang, Z., et al., *The photo-aging of polyvinyl chloride microplastics under different UV irradiations.* Gondwana Research, **108**: p. 72-80. (2022)
12. Heang, V., *Effect of microplastic and coagulant types on microplastic removal in landfill leachate by using Dissolved Air Flotation (DAF) process*, in *Department of Environmental Engineering*, Chulalongkorn University. (2022)
13. Mao, R., et al., *Aging mechanism of microplastics with UV irradiation and its effects on the adsorption of heavy metals.* Journal of Hazardous Materials, **393**: p. 122515. (2020)
14. Liu, P., et al., *Simulation of natural aging property of microplastics in Yangtze River water samples via a rooftop exposure protocol.* Sci Total Environ, **785**: p. 147265. (2021)
15. Wu, X., et al., *Photo aging of polypropylene microplastics in estuary water and coastal seawater: Important role of chlorine ion.* Water Res, **202**: p. 117396. (2021)
16. Meera, G., et al., *Coagulation studies on photodegraded and photocatalytically degraded polystyrene microplastics using polyaluminium chloride.* Waste Management, **170**: p. 329-340. (2023)