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MICROPLASTICS FROM PAINT INDUSTRIES: AN EMERGING THREAT TO ENVIRONMENT AND ITS TREATMENT POSSIBILITIES

Sumbal Zaheer
Muzammil Anjum
Azeem Khalid

Microplastics From Paint Industries: An Emerging Threat to Environment and Its Treatment Possibilities

By

Sumbal Zaheer[1], Muzammil Anjum[1], Azeem Khalid[1]

Abstract

Plastic pollution has emerged as a significant global environmental issue, with microplastics recognized as persistent contaminants in aquatic and terrestrial ecosystems. Among the contributors to this pollution, the paint industry plays a notable role by discharging toxic paint particles—such as antifouling and anticorrosive coatings—into water bodies during industrial activities. Paint formulations typically comprise polymeric materials, including polyesters, polyurethanes, polyacrylates, and epoxies, along with various additives like heavy metals and biocides. Primary microplastics are intentionally incorporated into paints to enhance functionality and durability, while secondary microplastics are generated through mechanical abrasion and degradation of painted surfaces. These microplastics are resistant to conventional wastewater treatment technologies, necessitating the development of advanced remediation strategies. Among the emerging techniques, electrochemical treatment has shown considerable promise as a sustainable and effective method for the degradation of microplastic pollutants in paint industry effluents. This process utilizes electrical current to initiate oxidative reactions capable of breaking down complex polymeric structures into less harmful compounds. This paper reviews the sources and ecological impacts of paint-derived microplastics and explores potential mitigation strategies, emphasizing the effectiveness of electrochemical processes. It also underscores the importance of multidisciplinary research, integrated environmental management frameworks, and regulatory interventions. The study evaluates the performance of electrochemical treatment in reducing microplastic concentrations and improving the overall quality of wastewater discharged from the paint industry.

Keywords: Microplastics; Paint industry; Ecological Impacts; Electrocatalysis; Environmental sustainability

[1] Department of Environmental Sciences, PMAS Arid Agriculture University, 46300-Rawalpindi, Pakistan
Corresponding Email: sumbalzaheer11@gmail.com, muzammilanjum@gmail.com

Introduction

In early 1900s, the synthesis of plastic for the first time was considered as a milestone as it improved the quality of life in many ways. We have been using plastic in almost every product we made. In 1907 plastic production was started at industrial level, this industry began to grow in 1920. There has been a sharp increase in production and use of plastic since 1940s (Pilapitiya & Rantnayake, 2024). 2 million tons of plastic was produced in 1950, this level reached upto 368 million tons in 2019. Plastic production has increased 180 times since 1950. In 2022, at global level 400.3 million tons plastic was produced. This number is expected to rise rapidly in the future (Rafey and Siddiqui, 2021).

Plastic have replaced many other materials that are used in the production of goods like metals, paper, wood as they are light in weight, durable, can easily bend into different shapes and is less costly. Previous studies have shown that use of plastic in any product lowers its production cost and increase the profit especially in chemical, oil and manufacturing industry (Fayshal et al., 2023). Use of plastic in almost every industry is the dominant anthropogenic activity that cause a lot of disturbance in nature (Rafey et al., 2025).

The use of plastic in almost every industry is increasing the emerging microplastic pollution. The particles of synthetic plastic polymer that are less than 5 mm are considered as microplastics (Hartmann et al., 2019). They are further divided into primary and secondary microplastics. Primary microplastics are the beads, pallets and fibers that are intentionally used in textile and cosmetics industry. Secondary microplastics are formed due to breakdown of large plastic particles (Bikker et al., 2020). As per the previous studies, more than 100 million microplastics are present in oceans, out of which 51 trillion microplastics having size less than 5mm are floating on the surface (Agamuthu et al., 2029).

Among all the industries that are releasing microplastics in the environment, paint industry is the leading industry. In 2021, the worth of global paint industry was 160 billion dollars and it is expected to reach 245 billion in 2029 (Fanf et al., 2024). Paints contain different pigments, binders, colours and additives that are made up of plastic polymers (Wiesinger et al., 2018). Binders provide adhesion to the paints and contain synthetic polymers like acrylics, vinyl and polyesters. These paints are termed as plastic based paints (Elkins, 2019). Moreover, water-based acrylics contain polystyrene, polyethylene and polyurethanes along with some co-polymers like eposxies and alkyls (Gaylarde et al., 2021). Due to increasing use of these paints,

microplastic pollution is growing as an emerging threat to the nature and public health (Hartmann et al., 2019).

This short review aims to provide insights about the role of paints in increasing microplastic pollution. This review on microplastics and their impacts on public health can help raise awareness about this emerging issue and consumer choice. Along with the impacts, eco-friendly and sustainable solutions to deal with this problem is also highlighted in this review.

Microplastics in Paints: Classification and Sources

Paints are the most dominant source of microplastics that are released into sea and oceans. As compared to the textile fibres and tyre dust, 58% of the microplastics that ends up in our marine ecosystem come from paints alone. It is equal to 1.9 million tons of plastic particles that are released into our environment **(**Paola Paruta and Boucher 2022). Due to use of petroleum as raw material for production of different types of paints, this issue is rapidly increasing causing great damage to our environment (Moyo et al., 2024). Due to improper disposal of paints, polymer particles get discharged. Moreover, due to weathering of dried plastic coatings also contribute to this cause (Faber et al., 2021).

Binders are the key components in water based and non-aqueous paints that contain polymer backbone polystyrenes, polyethylene and chlorinated rubber binders (Gaylarde et al. 2021). Other than binders, microbeads and microfibers are also added into paints to enhance their properties and durability (Faber et al., 2021). These also contribute to release of microplastic during the life cycle of paints. Due to many physical properties like shipping, road marking and external surfaces. As per the literature, the major concentrations of these microplastics are ended up into sea, oceans and coastal regions (Imhof et al., 2016).

- **Mechanisms of Microplastic Release**

Furthermore, in urban areas road markings are considered as a source of microplastics as paints from road markings enters into terrestrial waterways and oceans. They also contain all the basic polymers including polyamides. As per the research conducted in 2016 by Magnusson et al, 504 tons of MPs enters into oceans from road markings in Sweden (Magnusson et al., 2016). These paints particles are identified as major fraction of microplastics (Gaylarde et al., 2021). At global level 588 ktons of paint is used for road markings, which in total accounts for 7% of the MPs release in oceans (Boucher et al., 2017).

Building coatings, which is used in buildings and during construction work is also contributing factor in MPs pollution. These paints are used for decoration as well as to prevent corrosion. Due to UV-irradiation, the paint particles are released as MPs and enter into nearby water bodies with rainwater (Gaylarde et al., 2021). Moreover, old paint when replaced by new one also enters into seas and cause marine pollution. Figure 1.1 is illustrating the sources and transport of paint derived microplastics into oceans.

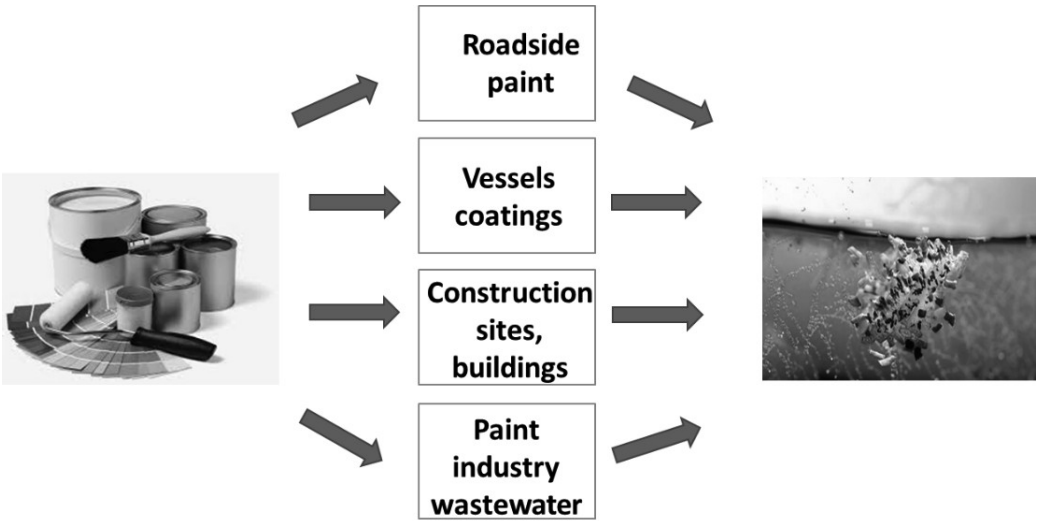


Figure-1.1: Pathway of paint derived MPs into oceans (acquired and modified from Gaylarde et al., 2021).

Environmental Fate and Transport

These paint particles are transported as airborne particulates into fresh water bodies and oceans (Horton et al., 2017). All the plastic debirs from land enters into lakes and oceans directly through littering at beach, aquaculture and fishing activities. 80% of the land based based that enters into water bodies is plastic (Li et al., 2016; Cole et al., 2011).

Due to their high durability, they can persist in the marine ecosystem for long period of time. Some MPs are lighter in weight so they float on the surface of water. Some are even denser than the sea water, so the become part of the seabed. They can be easily ingested by the sea animals (Smith et al., 2018).

Furthermore, MPs are of great concern as they act as carriers of other toxic pollutants as well. Their absorption capacity is very high and they can as mean of transport of various contaminants in the environment (Kinigopoulou et al., 2022). Due to weathering, the cracks on the microplastics surface ae

formed. These cracks are the place where other contaminants can accumulate on the surface of MPs (Liu et al., 2022). When hydrophobic contaminants are drawn to the hydrophobic surface of microplastics, they accumulate on these particles, a process known as absorption. Additionally, microplastics can enhance the adherence and transmission of contaminants by forming hydrogen bonds with their polar functional groups (Rafa et al., 2024).

Effects on Aquatic Animals and Humans

MPs digested by fish, mussels, mammals and shellfish pose a serious threat to their lives (Gundogdu et al., 2020). Due to the compounds, they contain, MPs can have an impact on aquatic animals' gut microbiome (Smith et al., 2018). They may build up in aquatic animals' digestive systems, obstructing their passages and reducing their capacity to consume and process food (Cole et al., 2013). This can be hazardous to aquatic species and potentially result in their death. In addition to this, MPs may also carry hydrophobic organic chemicals that also pose a serious threat to living organism in the water bodies (Hartmann et al., 2017). Apart from this, paint particles from ships and vessels when enter into the marine environment, can prevent the growth of algae and invertebrates (Soroldoni, et al., 2017). Figure 1.2 is showing how paint particles enter into marine environment and the impacts they cause on marina organisms.

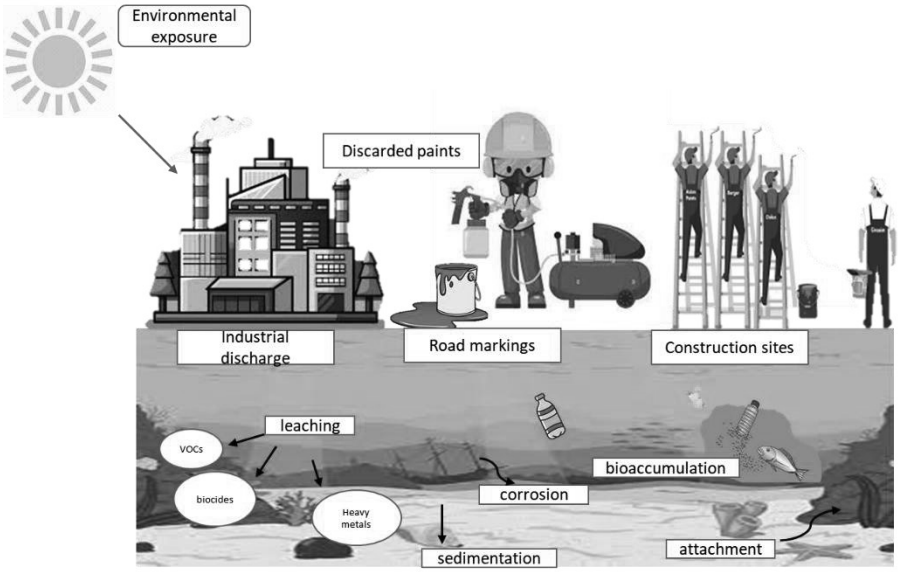


Figure-1.2.: Pathways and Effects of Paint-Derived Microplastics in Marine Environments (acquired and modified from Forero-López et al., 2024)

Humans can come in contact with MPs through air, food water and skin. MPs travel from one organism into another and become accumulated in food chain. Inhalation and ingestion of MPs can lead to reproductive and heart diseases like hypertension, oxidative stress, inflammation and blockage in heart (Zhao et al., 2021). Furthermore, depending on the particular size of MPs, different effects are seen in human body. MPs with size less than 5 µm can affect spleen, lymph nodes and blood circulation by accumulating inside the body. Microplastics between 5-10 µm can accumulate in the organs like liver, kidney and brain and effect their function (Prietl et al., 2014).

Current Mitigation Technologies

There are many methods for degradation and removal of microplastics. Physical degradation, chemical degradation and degradation using microorganism are the three major processes used (Shah et al., 2008). In addition to primary microplastics, secondary microplastics are also formed due to large plastic fragments. In order to save our environment from secondary microplastics, source control measures such as collection of plastic related waste from river side was practiced in past. This practice also prevents plastics from entering into water bodies (Sutkar et al., 2023). Furthermore, the traditional wastewater treatment methods are not efficient in completely removing MPs from industrial wastewater. They have shown 70-80% efficiency but due to small particles size of MPs, millions of them escape into water bodies (Sun et al., 2019).

Moreover, the standard and most practiced filtration and sedimentation techniques are also unable to fully capture the MPs due to their small size (Ziajahromi et al., 2017). The coagulation method offers benefits like low cost and easy operation, but it also has drawbacks like coagulant residues and possible secondary contamination. Remaining metal coagulant after treatment would cause additional ecological toxicity (Gao et al., 2023).

In developing countries, especially in Pakistan, due to lack of monitoring methods and standards protocols to monitor and detect microplastics in wastewater before releasing them in water bodies is a huge challenge. WWTPs cannot degrade them alone, so we need advance treatment methods to mitigate this emerging issue.

Emerging Technologies and Sustainable Alternatives

From the past few decades, due to inefficiency of traditional WWTPs to control MPs, various advance treatment methods or combination of various methods have been used. Electrooxidation, electro-Fenton, photoelectrochemical, and electrochemical technologies are some of these

procedures. Combining these methods give efficient results by lowering the cost and reducing reaction time (Malinović, et al., 2022).

One eco-friendly way to reduce microplastics in the environment is to use efficient electrocatalytic process to degrade MPs present in wastewater (Tohfa et al., 2019). Electrocatalytic degradation uses electric current to convert the microplastics in less harmful products by reducing their molecular weight. These byproducts can be further utilized in organic synthesis. Thus, from an economic, energy, and environmental standpoint, the electrocatalytic process utilizing electrical energy sources is becoming a more and more appealing choice (Bratovcic, A, 2019). Furthermore, during hydrogen evolution reaction, water splits into hydrogen and oxygen, this hydrogen can be used as a source of energy.

Moreover, the recent advancement in use of aerogels as catalysts is gaining much attention due to their wide applications and recyclable nature. Their highly porous property combine with high absorption capacity makes them suitable catalysts in electrocatalysis (Maleki & Hüsing, 2018). Recent literature review suggested that one of the effective and efficient aerogels is polysaccharide based natural aerogel in comparison with others. In addition, the bioproducts made by these aerogels are environment friendly and can be degraded easily, making these aerogels best option for degradation of pollutants via electrochemical methods (Inamuddin et al., 2021).

- **Research Gaps and Future Directions**

The data regarding the release of microplastics from paint industry along with their impacts on marine ecosystem is still not fully available. This cause hurdles in assessing their impacts on humans and environment. Traditional WWTPs are not designed in a way to treat the emerging contaminants especially originating from paint industry. Due to their small size, MPs are also pass the filtration plants. There are some studies on advanced treatment methods for pollution control but studies specifically on treatment of paint industrial wastewater is still under way.

Analysis of paint industrial wastewater to detect and quantify MPs is a big challenge due to diverse polymers present in them. The lack of standardised analytical methodologies hinders the evaluation of treatment systems and environmental monitoring. Current Environmental regulations also do not address emerging contaminants from paint industries. Due to this gap, the implementation of strategies to mitigate the issue and implementation of industry-specific standards is limited in our country.

To address the rising concern about microplastic contamination from the paint industry, future research should focus on full characterisation of paint-derived microplastics in order to better understand their physicochemical characteristics, degradation processes, and ecological interactions. Electrochemical treatment system advancements, such as electrode material and reactor design optimisation, are required for successful pollutant degradation. Electrochemical technologies can be used with traditional treatments such as coagulation-flocculation and membrane filtering to improve removal efficiency even more.

Standardized analytical procedures for microplastic identification and quantification are urgently required to ensure regulatory compliance and scientific uniformity. Furthermore, strong legislative frameworks must be built to govern paint-derived microplastics, including clear standards for acceptable amounts and monitoring. Finally, raising public awareness and involving the paint sector in sustainability projects will be critical for promoting eco-friendly methods and lowering long-term environmental repercussions.

Conclusion

Untreated wastewater from paint industries represents a significant environmental concern due to its high load of microplastics, which are not only intrinsically toxic but also capable of adsorbing other hazardous pollutants such as heavy metals and organic contaminants. These microplastics, both primary and secondary, originate from the formulation processes and degradation of paint materials, contributing substantially to aquatic microplastic pollution. Furthermore, paint industry effluents commonly contain resins, synthetic polymers, heavy metals, and biocides, all of which pose serious ecological and health risks. Among the various treatment approaches, electrochemical oxidation has emerged as a promising and environmentally sustainable method for the remediation of such complex effluents. This process involves the in-situ generation of reactive oxygen species (ROS), which facilitate the oxidative breakdown of high-molecular-weight polymers into smaller, less toxic, and more biodegradable compounds, thereby improving overall water quality. Nevertheless, to effectively mitigate the environmental impact of microplastics from paint industry discharges, the implementation of advanced treatment technologies, in conjunction with robust regulatory frameworks, targeted mitigation strategies, and industry-specific guidelines, is essential. Further research into electrochemical methods, particularly their integration with other advanced treatment technologies, may offer

scalable and efficient solutions for addressing microplastic pollution in paint industry wastewater.

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