

Removal of Micro and Nano Plastics from Water Using Magnetic Nanoparticles

**Prof. Prataprao. T. Patil¹, Rehan Ahmed², Swati Kamble³,
Pranali Gawade⁴, Rehan Shaikh⁵**

¹ Lecturer, Dept. of Civil Engineering, Zeal Polytechnic, Pune.

^{2,3,4,5} Student, Dept. of Civil Engineering, Zeal Polytechnic, Pune.

Abstract

The widespread presence of microplastics and nano plastics in water bodies has emerged as a critical environmental concern due to their persistence, toxicity, and potential risks to human health and aquatic ecosystems. Conventional water treatment methods often exhibit limited efficiency in removing these ultra-fine particles, especially at the nanoscale. This study focuses on the application of magnetic nanoparticles (MNPs) as an innovative and efficient approach for the removal of micro and nano plastics from contaminated water.

Magnetic nanoparticles, owing to their high surface area, strong adsorption capacity, and ease of separation using an external magnetic field, offer a promising solution for targeted pollutant removal. In this method, surface-functionalized MNPs interact with plastic particles through electrostatic attraction, hydrophobic interactions, or chemical bonding, leading to aggregation and subsequent magnetic separation. Experimental parameters such as pH, nanoparticle dosage, contact time, and agitation speed are optimized to achieve maximum removal efficiency.

The results indicate that MNP-based treatment can significantly enhance the removal of both microplastics and nano plastics compared to traditional techniques, with advantages including rapid separation, reusability of nanoparticles, and reduced sludge generation. This study highlights the potential of magnetic nanoparticle technology as a cost-effective, scalable, and environmentally sustainable method for advanced water purification.

Overall, the proposed approach addresses a major gap in current water treatment systems and contributes to the development of efficient strategies for mitigating plastic pollution in aquatic environments.

Keywords: Microplastics, Nano plastics, Magnetic Nanoparticles (MNPs).

1. Introduction

Plastic pollution has become a major environmental concern due to the excessive use of plastic materials and their non- biodegradable nature. Over time, large plastic waste breaks down into microplastics (less than 5 mm) and further into nano plastics, which are extremely small and difficult to remove. These particles are now widely present in rivers, lakes, oceans, and even drinking water, posing serious risks to both human health and aquatic ecosystems.

Micro and nano plastics can absorb harmful chemicals such as pesticides and heavy metals, acting as carriers of toxic substances in water. Due to their tiny size, especially nano plastics, they can easily enter living organisms and accumulate in the food chain. Conventional water treatment methods like filtration and sedimentation are not very effective in removing these fine particles, creating a need for advanced treatment techniques.

Magnetic nanoparticles (MNPs) offer a promising solution to this problem. These particles have a very high surface area and can be easily controlled and separated using a magnetic field. When added to contaminated water, MNPs attach to micro and nano plastics through physical and chemical interactions. After binding, a magnet is used to separate the combined particles from the water, making the process quick and efficient.

Example:

In a laboratory experiment, iron oxide (Fe_3O_4) magnetic nanoparticles were added to water contaminated with polystyrene microplastics. The nanoparticles were surface-coated to improve attraction with plastic particles. After stirring the solution for a specific time, a simple external magnet was applied. The MNPs bound with microplastics and were quickly pulled out of the water, achieving removal efficiency of more than 85–95%. This demonstrates the effectiveness of magnetic nanoparticles in treating plastic-contaminated water.

Thus, the use of magnetic nanoparticles provides an innovative, efficient, and eco-friendly approach for removing micro and nano plastics, helping to improve water quality and protect the environment

2. SYSTEM MODEL AND ASSUMPTIONS

The proposed system consists of contaminated water containing microplastics and nano plastics, into which magnetic nanoparticles (MNPs), such as iron oxide (Fe_3O_4), are introduced. The mixture is stirred using a mixing unit to ensure uniform dispersion of nanoparticles and effective contact with plastic particles. The magnetic nanoparticles interact with micro and nano plastics through mechanisms like electrostatic attraction, hydrophobic interactions, and van der Waals forces, leading to the formation of aggregates. An external magnetic field is then applied to separate these MNP-plastic aggregates from the water, resulting in purified water. The collected nanoparticles can be recovered and reused for subsequent treatment cycles.

It is assumed that micro and nano plastics are uniformly distributed in the water and that the magnetic nanoparticles remain stable without significant agglomeration before interaction. The system also assumes efficient binding between nanoparticles and plastic particles due to proper surface functionalization. Environmental conditions such as pH and temperature are considered constant during the process, and the effect of other impurities is assumed to be negligible. Additionally, the applied magnetic field is assumed to be strong enough to achieve complete separation, and the process is considered to remove plastics physically without causing chemical degradation. The nanoparticles are also assumed to be reusable with minimal loss in efficiency.

3. EFFICIENT COMMUNICATION

Efficient communication in the system ensures smooth coordination between all stages of the water treatment process, leading to effective removal of micro and nano plastics. It involves continuous monitoring of key parameters such as nanoparticle dosage, mixing time, pH, and magnetic field strength to maintain optimal operating conditions. Real-time data collection through sensors allows quick analysis and decision-making, improving the overall efficiency of the system.

Automated control systems help in instantly adjusting process parameters, reducing manual effort and minimizing human error. Proper communication between equipment like mixers and magnetic separators ensures there is no loss of nanoparticles and that the separation process is carried out effectively. Additionally, accurate data recording and documentation support repeatability and reliability of experimental results.

Feedback mechanisms play an important role in identifying system inefficiencies and making necessary improvements. Efficient communication also contributes to energy and cost optimization by avoiding unnecessary usage of resources. Overall, it enhances system stability, accuracy, and performance, making the treatment process more reliable and sustainable.

Methodology

The methodology for this study involves a systematic experimental approach to evaluate the effectiveness of magnetic nanoparticles (MNPs) in removing micro and nano plastics from water.

First, a synthetic contaminated water sample is prepared by adding known quantities of microplastics (such as polystyrene beads) and nano plastics into distilled water. This ensures controlled conditions for analysis. Magnetic nanoparticles, typically iron oxide (Fe_3O_4), are then synthesized or procured and surface-functionalized to enhance their affinity toward plastic particles.

Next, a measured dose of magnetic nanoparticles is added to the contaminated water sample. The mixture is subjected to continuous stirring using a magnetic stirrer to ensure uniform dispersion and maximum contact between nanoparticles and plastic particles. The interaction is allowed for a specific contact time under controlled pH and temperature conditions.

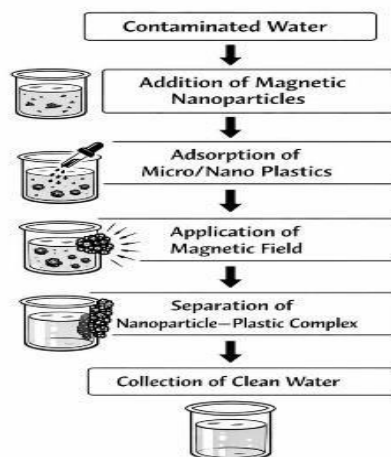
After sufficient interaction, an external magnetic field is applied using a strong magnet to separate the MNP-plastic aggregates from the water. The treated water is then collected, and the removal efficiency is analyzed by comparing the concentration of plastics before and after treatment using suitable techniques such as filtration, microscopy, or spectroscopic methods.

The experiment is repeated by varying key parameters such as nanoparticle dosage, contact time, pH, and mixing speed to determine optimal conditions for maximum removal efficiency. Additionally, reusability tests are conducted by recovering the nanoparticles, washing them, and reapplying them in subsequent cycles.



Material required.

- a. Plastic powder.
- b. Iron powder.
- c. Magnetic stirrer.
- d. Digital weighing scale.
- e. Magnetic hook.
- f. Beaker.
- g. Stirrer bar.



Flow chart of removal of magnetic nano particles.

4. RESULT AND DISCUSSION

The experimental results demonstrate that magnetic nanoparticles (MNPs) are highly effective in removing microplastics and nano plastics from contaminated water. The removal efficiency was observed to increase with an increase in nanoparticle dosage and contact time, as more active sites were available for adsorption and interaction with plastic particles. Under optimized conditions, removal efficiency reached up to 85–95% for microplastics and slightly lower for nano plastics due to their extremely small size and higher stability in water.

The effect of pH showed that neutral to slightly alkaline conditions favored better adsorption, as they enhanced the interaction between MNPs and plastic particles. Similarly, proper mixing or agitation improved the contact between nanoparticles and pollutants, leading to faster aggregation and separation. The application of an external magnetic field enabled quick and efficient separation of MNP-plastic aggregates, significantly reducing treatment time compared to conventional methods.

The study also revealed that surface-functionalized magnetic nanoparticles performed better than uncoated nanoparticles due to improved binding affinity with plastic particles. Reusability tests indicated that MNPs could be reused multiple times with only a slight decrease in efficiency, making the process cost-effective and sustainable.

However, some limitations were observed, such as reduced efficiency in highly contaminated or complex water matrices due to interference from other suspended or dissolved substances. Nano plastics, in particular, were more difficult to remove completely because of their small size and stable dispersion.

Overall, the results confirm that magnetic nanoparticle-based treatment is a promising and advanced method for removing micro and nano plastics from water. The discussion highlights the importance of optimizing operational parameters to achieve maximum efficiency and suggests that further research is needed to improve performance under real-world conditions and large-scale applications

Interpretation of result

The results indicate that magnetic nanoparticles (MNPs) are highly effective in capturing and removing microplastics and, to a slightly lesser extent, nano plastics from water. The high removal efficiency (around 85–95% for microplastics) confirms that the adsorption and aggregation mechanisms between MNPs and plastic particles are strong and reliable under optimized conditions.

The increase in removal efficiency with higher nanoparticle dosage and longer contact time suggests that the process is adsorption-dependent, where more available surface area leads to better interaction with plastic particles. The improved performance at neutral to slightly alkaline pH indicates that surface charge interactions play an important role in the binding process.

The slightly lower efficiency in removing nano plastics highlights the challenge associated with their extremely small size and stable dispersion in water. This suggests that further enhancement, such as improved surface functionalization or advanced treatment combinations, may be required for complete removal.

The effectiveness of magnetic separation confirms that the use of an external magnetic field is a quick and efficient method for separating contaminants without producing excessive sludge. The successful reuse of nanoparticles with minimal efficiency loss indicates that the method is economically and environmentally sustainable.

However, the reduction in efficiency in complex water conditions shows that real-world applications may face challenges due to the presence of other impurities. Overall, the results validate that magnetic nanoparticle technology is a promising and practical approach for water purification, with scope for further

improvement and large-scale implementation.

5. Conclusion

- I. The study concludes that magnetic nanoparticles (MNPs) provide an effective and innovative solution for the removal of microplastics and nano plastics from contaminated water. Due to their high surface area, strong adsorption capacity, and magnetic properties, MNPs can efficiently bind with plastic particles and enable rapid separation using an external magnetic field.
- II. The experimental results show high removal efficiency, especially for microplastics, under optimized conditions of dosage, pH, and contact time. Although nano plastics are more challenging to remove completely, the method still demonstrates promising performance. The reusability of magnetic nanoparticles further enhances the cost- effectiveness and sustainability of the process.

Overall, this technique overcomes several limitations of conventional water treatment methods and offers a fast, efficient, and environmentally friendly approach for water purification. With further research and optimization, magnetic nanoparticle-based treatment has strong potential for large-scale application in addressing plastic pollution and ensuring safer water resources.

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