ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25sep804

Study on Harnessing Ferrofluid Technology for Efficient Microplastic Extraction from Ocean Water and Optimization of Manufacturing Materials

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Publication Date: 2025/09/30

Abstract: This study aims to combat and analyse marine ecosystems that are seriously threatened by microplastic pollution, emphasizing the urgent need for efficient remediation techniques. In this work, we introduce a novel ferrofluid technology method for removing microplastics from ocean water. We should selectively capture microplastics by magnetic attraction by creating a ferrofluid mixture with oils, and magnetite nanoparticles. Additionally, the incorporation of strong magnets into water samples should be prioritized to enhance the effective removal of microplastics, enabling easier separation, filtration, and purification of samples. This approach highlights sustainable practices by recycling and reusing recovered pollutants, in addition to demonstrating high efficiency and selectivity in microplastic extraction. However, the safe handling and disposal of hazardous materials is to be guaranteed by the responsible management of ferrofluids per local regulations in advance. This overlooked strategy demonstrates the potential for fusing cutting-edge technology with environmental stewardship to support cleaner and healthier ecosystems while providing a viable remedy for microplastic pollution in aquatic environments.

Keywords: *Microplastic Pollution, Ferrofluid Technology, Extraction, Magnetite Nanoparticles, Sustainable Practices, Recycling, Environmental Stewardship, Water Remediation.*

How to Cite: Namya Bajaj; Manasa Raghavendran (2025) Study on Harnessing Ferrofluid Technology for Efficient Microplastic Extraction from Ocean Water and Optimization of Manufacturing Materials. *International Journal of Innovative Science and Research Technology*, 10(9), 2172-2177. https://doi.org/10.38124/ijisrt/25sep804

I. INTRODUCTION

Among the most commonly employed materials, plastics are most widely used across industries due to their light-weight, durability, and other properties. Nevertheless, when these plastics are disposed of, they are degraded into macro and microplastics, and these particles hence pollute the environment. Plastic use has increased from 1.5 million metric tons in 1950 to 350 million metric tons in 2017. Waste plastics often end up in aquatic ecosystems, contributing to the 8-11.5 million metric tons of plastic found in marine habitats. Microplastics, usually less than five millimeters, are the most common marine debris. They originate from various plastic goods and can easily pass into marine habitats. They accumulate in both terrestrial and marine ecosystems, with drinking water containing up to 93% of microplastic particles. Global micro-debris pollution in seas and oceans is predicted to reach 236,000 metric tons. Many species contain large amounts of microplastics, with about 80% of the microplastic pollution's origins identified. To impede these detrimental repercussions, an innovative and unique method of extraction of these particles can be put into practice that involves the usage of ferrofluids. Ferrofluids are colloidal liquids composed of tiny ferromagnetic or ferrimagnetic particles dispersed in a carrier fluid, exhibiting an attraction to the poles of a magnet. When put in water, the ferrofluid attracts microplastics, due to the non-polar nature of both (Designboom, 2019b, ll. 4–6). These microplastics, now bound with the ferrofluids, are then disposed of with use of a magnet.

II. MATERIALS AND METHODOLOGY

Key materials used to form the ferrofluids are oils and magnetite, which are used for their specific properties and functions:

➢ *Oils:*

Carrier fluids used for the manufacture of ferrofluids are generally oil in which magnetite nanoparticles are suspended and allowed to flow freely. Depending on the type of oil used, one can influence such characteristics of the ferrofluid as viscosity, thermal stability, and material compatibility. Oils can also prevent the nanoparticles from getting oxidized and

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breaking down. Hence, the recommended oil for ferrofluids is Grapeseed oil, since it contains a notably high percentage of Polyunsaturated Fatty Acids (PUFA), more so 70% as compared to other oils. For instance, peanut oil contains 32% PUFA. The increased PUFA content in grapeseed oil provides better magnetic response and dispersion of iron oxide nanoparticles and thus improved ferrofluid performance. Additionally, the environmental impacts of using grapeseed oil are also positive since grapeseed is obtained as a byproduct of wine production, hence preventing wastage of the material. Furthermore, grapeseed oil is somewhat better for de-stressing the environment. Therefore, the high PUFA content, suitable viscosity, and environmental points considered also make grapeseed oil the best fit for devising effective and environmentally sound ferrofluids, especially for large-scale microplastic removal from water.

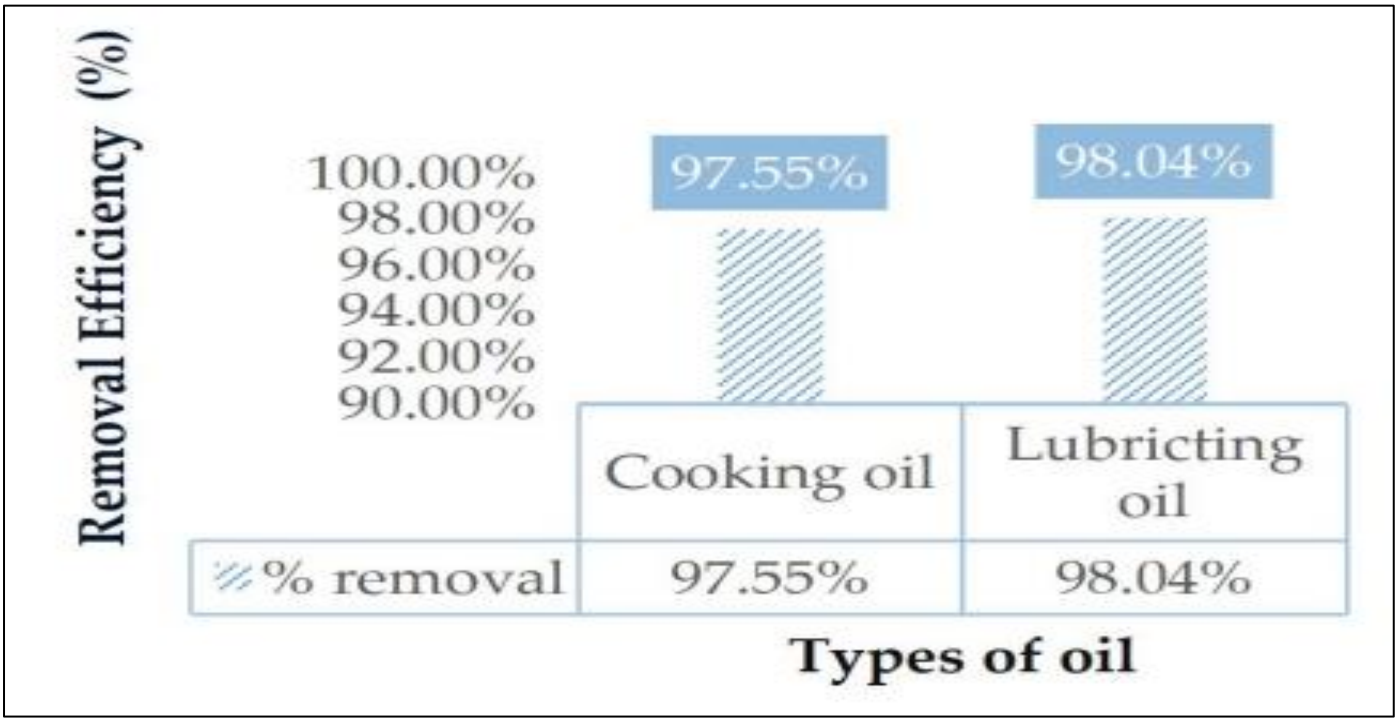

Fig 1 Type of Oil and Efficiency for Removal (Oil Volume: 2.5ml, Magnetite: 0.5g/L Sample) (Ibrahim, 2023)

Although grapeseed oil is a kind of cooking oil, we have to consider the oil's after-effects on the water sample. Lubricating oil contains toxic substances, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and additives that can contaminate the water sample. It is estimated that just one gallon of used lubricating oil can contaminate up to 1 million gallons of water. While cooking oil has its adverse effects it is more sustainable for the environment, in comparison with lubricating oil. It is also to be noted that the margin of removal efficiency is only 0.49%, hence making cooking oils (specifically Grapeseed oil), the superior option of the two.

➤ *Magnetite:*

The presence of magnetite (Fe_3O_4) nanoparticles are the fundamental component for the manufacturing of ferrofluids, due to their ability to convey the ferromagnetic properties of ferrofluids. When exposed to a magnetic field, the magnetite particles within the ferrofluid align themselves along the field lines, imparting magnetic properties to the ferrofluid. These magnetic properties have practical applications, such as using magnets to extract microplastics from water samples.

Moreover, the implementation of strong magnets is integral to the extraction procedures in this study. By creating a powerful magnetic field on the ferrofluid containing magnetite nanoparticles, the microplastics present in water samples can be easily captured and separated from the solution. The efficacy of employing high-intensity magnets relies on the generation of a focused magnetic field, allowing for the selective separation of microplastics from water.

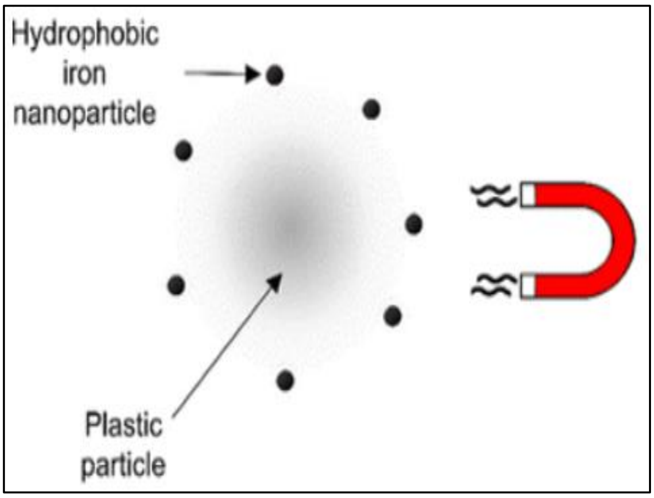

Fig 2 Diagrammatic Representation of the Working of Magnetite Powder (Grbic et al., 2019, fig. 1)

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The method of extraction of microplastics from the ocean water is comprehensively explained as follows:

- *Collection of Ocean Water:*

The samples of ocean water are taken using appropriate instruments that include cisterns or tanks that are used to collect marine water to get the actual representation of the water.

- *Collection of Household Contaminated Water from Wastewater Treatment Plants:*

While Wastewater Treatment Plants, clean other larger pieces of physical wastes and several other chemical and biological waste, partnership with WTPs can provide a formal and easier set-up to carry out this project. Researchers found that an average 6 kg load of laundry releases more than 700,000 microscopic plastic fibers into wastewater. These plastic fibers come from synthetic (= plastic) textiles like polyester (PlanetCare, n.d.). Hence, by doing so, we prevent harmful wastewaters from entering ocean waters incipiently. This can be done in parallel with the previous step.

- *Spectrometry Analysis:*

To measure the concentration of microplastics in a given sample, a visible light spectrometer should be utilized. The spectrometer analyzes the spectra of light passed through samples using the software Spectragryph, applying the Beer-Lambert law to determine the concentration of each sample. With relevance to microplastic analysis, the Beer-Lambert Law allows us to estimate the concentration of microplastics in a water sample by measuring the amount of light absorbed at specific wavelengths, considering the inherent light absorption properties of different types of plastic.

- *Preparation of Ferrofluid Mixture:*

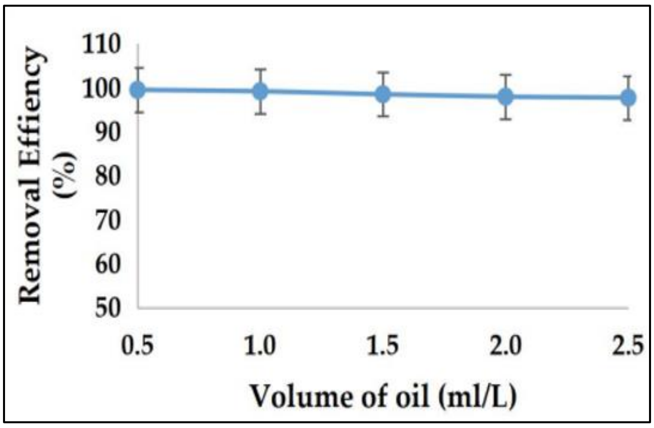

Fig 3 Efficiency of Different Oil Volumes (Ibrahim, 2023).

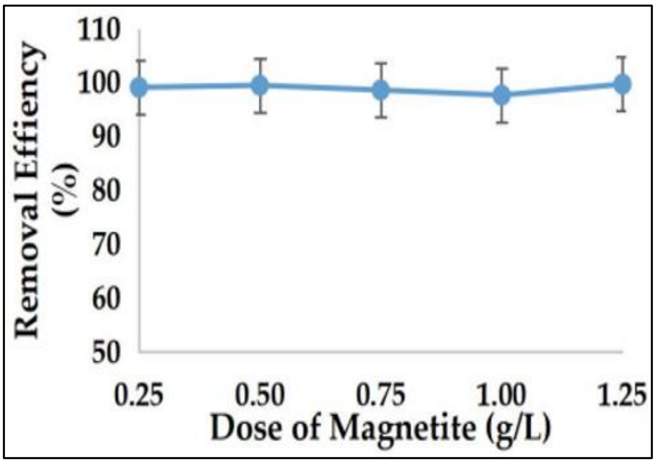

Fig 4 Efficiency of Different Magnetite Volumes (Ibrahim, 2023).

Hence, in its preparation, there is a defined amount of ferrofluid mixture that is made through the process of synchronizing nanoparticles made of magnetite or iron oxide into the carrier fluid for the study. This mixture will be used to capture and interact with microplastics existing in ocean water systems. The best formulation for ferrofluid preparation was discovered to be 1: 2.5 (volume of magnetite to volume of oil) (Ibrahim, 2023). The mean ratio of the water sample to ferrofluid is 5 grams : 0.1 grams, respectively. Using these values we can manufacture and reuse the ferrofluids, utilizing only the required amount of the same.

- *Treatment Process:*

The calculated and measured quantity of ocean water (containing microplastics) is then flowed into a chamber with the ferrofluid solution. The microplastics are substantiated with magnetite particles in the ferrofluid, and the mixture is agitated gently.

Consequently, debris made of clusters of microplastics coated on the ferrofluid is obtained on the water surface due to the magnetic nature of magnetite. When microplastic particles come into contact with these nanoparticles, they adhere due to Van der Waals forces.

- *Magnetic Separation:*

By introducing a magnet, the magnetite nanoparticles (along with the adhered microplastics) are drawn toward it, allowing for easy separation of microplastics from the ferrofluid suspension. Hence, it is easier to segregate microplastics from the ferrofluid suspension.

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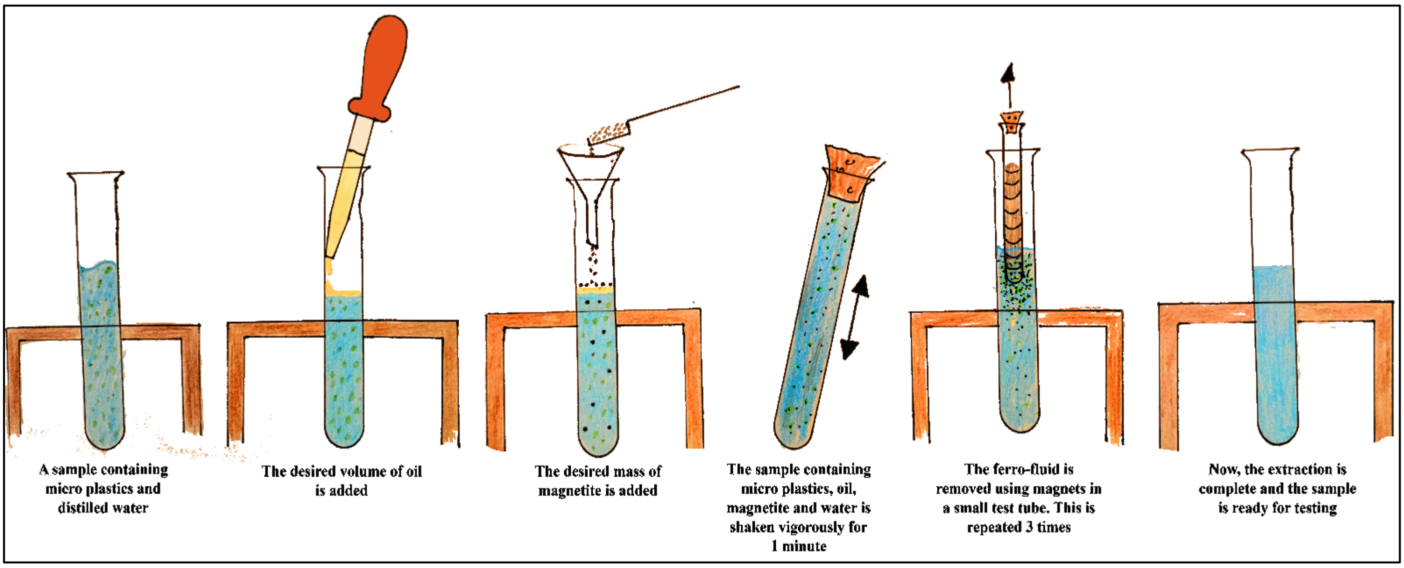

Fig 5 Diagrammatic Understanding of the Process of Extraction of Microplastics from Water Sample (Fionn Ferreira Google Science Fair Ireland Education $50,000 Prize for Ocean Microplastics Cleaning, n.d.-b, fig. 2)

➤ *Separation of Clean Water and Filtration and Purification:*

After using the ferrofluid method to separate microplastics from water, the remaining water in the second cistern can undergo further filtration and purification. An effective method that can be utilized is membrane filtration.

In membrane filtration, a thin film or a membrane with very narrow channels effectively separates water from other substances by preventing the water from passing through the membrane. Precisely sized pores allow water molecules to pass while blocking contaminants, which may be the aftermath of using ferrofluids. This ecological approach offers high-efficiency purification for various analyses, solidifying its role in responsible ocean water sample processing.

➤ *Recovery and Disposal of Ferrofluids:*

The ferrofluid mixture, now devoid of microplastics, can be reused for further extractions, or other applications. When the efficiency of the mixture diminishes over time, it is to be disposed of safely following local regulations for handling hazardous materials.

Following ferrofluid-based microplastic capture, centrifugation offers a high-throughput separation strategy. The centrifuge rapidly spins the mixture, forcing the denser ferrofluid (with microplastics) outwards, while the lighter water solution remains in the center. This efficient technique allows for easy retrieval of the ferrofluid containing the captured microplastics.

➤ *Further Treatment of Microplastics:*

The separated microplastics are collected and sent for recycling to organizations that specialize in repurposing plastic for various applications such as clothing production, manufacturing, lithium-ion batteries, 3D printing, etc. The retrieved microplastics can also be repurposed for this project itself.

III. RESULTS

This study investigated the feasibility of employing ferrofluids for the extraction of microplastics from ocean water. Microplastic pollution poses a significant threat to marine ecosystems, necessitating the development of efficient remediation strategies. Our research explored the potential of ferrofluids to capture these tiny plastic fragments, offering a promising solution for microplastic removal.

A key finding of this study involved the development of an optimal ferrofluid formulation. Grapeseed oil, a sustainable byproduct rich in polyunsaturated fatty acids (PUFAs), was selected as the carrier fluid due to its ability to enhance the magnetic response and dispersion of magnetite nanoparticles, the essential magnetic component within the ferrofluid. Furthermore, the utilization of grapeseed oil aligns with environmentally conscious practices by repurposing a waste product from the wine industry. The optimal ratio of magnetite to grapeseed oil was determined to be 1:2.5, establishing a foundation for future large-scale applications.

The magnetic properties of ferrofluids are critical for the process of microplastic capture. When introduced into the water sample containing microplastics, the ferrofluid interacts with these particles due to their shared non-polar nature. Gentle agitation facilitates this interaction, leading to the formation of microplastic clusters coated on the ferrofluid. The subsequent application of a strong magnet creates a focused magnetic field, effectively drawing the magnetite nanoparticles (and the attached microplastics) towards it. This magnetic separation offers a significant advantage – the easy retrieval of the captured microplastics from the water sample. This retrieval process facilitates further analysis or, as emphasized by this research, responsible recycling initiatives.

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Following the ferrofluid-based separation, the remaining water might still contain trace amounts of the ferrofluid. To address this, we explored ecological purification techniques such as membrane filtration. This method utilizes a thin membrane with precisely sized pores, allowing water molecules to pass through while effectively blocking contaminants. This two-step approach ensures a clean and microplastic-free final product, solidifying responsible ocean water sample processing practices. A significant advantage of this method lies in the reusability of the ferrofluids. Once depleted of microplastics, the ferrofluid mixture can be redeployed for further extractions, maximizing its efficiency and minimizing waste generation. However, when the effectiveness of the ferrofluid diminishes, proper disposal becomes crucial. Strict adherence to local regulations for handling hazardous materials is paramount to ensure responsible environmental management.

In prior research conducted, for each plastic tested, the results obtained were an average of 87.6% ± 1.1% extraction. The method used was most effective on fibres obtained from a washing machine, and least effective on polypropylene plastics (PlanetCare, n.d.). This is to be viewed in a positive light since these results declare that the majority of microplastic particles can be segregated from the water sample, giving hope for cleaner oceans.

IV. DISCUSSION

This research unveils the exciting potential of ferrofluids as a potential game-changer in the fight against microplastic pollution. It stands as a testament to the power of merging cutting-edge technology with a deep respect for our environment. This approach offers a promising solution for tackling the ever-growing issue of microplastics in our oceans, a problem that threatens the health of these vital ecosystems.

One of the key takeaways from this study is the development of an optimal ferrofluid formulation. We opted for grapeseed oil, a sustainable byproduct rich in polyunsaturated fatty acids (PUFAs), as the carrier fluid. This choice not only yielded superior results in terms of magnetic attraction and nanoparticle dispersion but also aligned with environmentally conscious practices by repurposing waste from the wine industry. It's a win-win for both effectiveness and sustainability. The 1:2.5 ratio of magnetite to grapeseed oil established in this study provides a foundation for future large-scale applications, paving the way for broader implementation.

The magnetic properties of ferrofluids are truly what make them shine in the capture process. When introduced into the water sample, the ferrofluid interacts with the microplastics due to their shared non-polar nature. A gentle agitation facilitates this interaction, leading to the formation of microplastic clusters coated on the ferrofluid. The subsequent application of a strong magnet creates a focused magnetic field, effectively drawing the magnetite nanoparticles (and the attached microplastics) towards it. This magnetic separation offers a significant advantage – the easy retrieval of the captured microplastics from the water sample. This retrieval process not only facilitates further analysis but also, as emphasized by this research, opens doors for responsible recycling initiatives.

Following the ferrofluid separation, there's a chance trace amounts of the ferrofluid might remain in the water. To address this, we explored ecological purification techniques such as membrane filtration. This method utilizes a thin membrane with precisely sized pores, allowing water molecules to pass through while effectively blocking contaminants. This two-step approach ensures a clean and microplastic-free final product, solidifying responsible ocean water sample processing practices.

A significant advantage of this method lies in the reusability of the ferrofluids. Once depleted of microplastics, the ferrofluid mixture can be redeployed for further extractions, maximizing its efficiency and minimizing waste generation. However, when the effectiveness of the ferrofluid diminishes, proper disposal becomes crucial. Strict adherence to local regulations for handling hazardous materials is paramount to ensure responsible environmental management.

This research truly delves into the exciting potential of ferrofluids. It embodies the power of merging cutting-edge technology with environmental stewardship. This approach offers a promising solution for tackling the escalating issue of microplastic pollution in our oceans, ultimately contributing to cleaner and healthier marine environments.

There are, of course, areas where further exploration is warranted. The reusability limitations of ferrofluids and potential regeneration techniques remain a topic of interest. Future research should explore methods to extend the usable lifespan of the ferrofluids, thereby minimizing waste generation and maximizing cost-effectiveness. Additionally, investigations into the scalability of this method for large-scale microplastic remediation efforts are crucial for real-world application. Furthermore, assessing the economic feasibility of implementing ferrofluid technology is essential for widespread adoption.

By addressing these considerations, future research can further refine and solidify the potential of ferrofluids as a powerful tool in combating the global challenge of microplastic pollution. We are optimistic that this approach can play a significant role in restoring the health of our oceans for generations to come.

V. CONCLUSION

This research shows promise for using ferrofluids to remove microplastics from ocean water. The authors created a new ferrofluid using grapeseed oil, a waste product, as the carrier. This ferrofluid effectively clumps microplastics in the water, which can then be removed with a magnet. The leftover ferrofluid can potentially be reused after microplastic removal.

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The study highlights several advantages of this method. First, it is environmentally friendly by reusing waste products. Second, the magnetic separation allows for easy retrieval of microplastics for further analysis or recycling. Third, the ferrofluid itself can be reused, minimizing waste.

The authors call for further research to improve the reusability of the ferrofluid, develop methods for large-scale application, and assess the cost-effectiveness of this approach. If these challenges can be addressed, ferrofluids could become a valuable tool for combating microplastic pollution in our oceans.

ACKNOWLEDGEMENTS

We would like to acknowledge the pivotal role of our educators in fostering scientific inquiry and research excellence. We would like to extend our heartfelt appreciation to the dedicated teachers who contributed to the successful realization of this research endeavor. Special gratitude is expressed to our school, Gems Modern Academy, Dubai, for its invaluable support, and to our Principal Mrs. Nargish Khambatta for her instrumental role in providing the platform for this impactful scientific exploration. We would also like to acknowledge the invaluable assistance and guidance provided by our teacher, Dr. Vimaldeep Kaur.

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