Synthesis and Evaluation on the Performance of Ferrofluid in Wastewater Treatment

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Abstract

Water contamination is created by industrial and agricultural development and is a primary source of water pollution. Iron oxides and magnetite are examples of IONPs with a high surface area and adsorption capacity that can easily bind to numerous molecules, allowing them to remove pollutants such as turbidity, metals, organic debris, and bacteria from aqueous effluents. To further understand the interaction of magnetite with bacterial cells, functional groups on the surface of bacteria were investigated. Ferrofluids are a simple and environmentally friendly method of removing harmful germs from water streams. The ideal cell: magnetite ratio was 1:50, which removed bacterial cells from E. coli, P. putida, and M luteus with 94.8% and 99.7%, respectively. In addition, The removal efficiency of ferrofluid alone was found to be the highest at 98% among all the other combinations tested in effective turbidity decrease. The most important details of the study are that magnetite has a maximum efficiency of 98% decrease in turbidity ., and that effective removal of most metals from water using magnetite and magnetic separation was achieved at 300 mg/l magnetite. Finally, the study looked at the capabilities of various types of oils to act as carriers and how they can increase microplastic removal effectiveness. The best formulation for ferrofluid preparation was discovered to be 1:2.5 (volume of oil) utilizing lubricating oil, which successfully eliminated 99% of microplastics from aqueous medium.

Keywords: Drinking water treatment; Environmental assessment; Microplastics; Remediation strategies; Removal technology.

1. Introduction

Freshwater scarcity and water pollution have become increasingly acute in recent years across the world. At the moment, unsafe and unreliable sources of drinkable water account for around 3.1% of yearly mortality, or over 1.7 million people globally. More than 57% of the world's population is expected to endure year- round water shortage by 2050[1].The fundamental reason for a lack of clean drinking water sources is water pollution.

The importance of industrial and agricultural growth in any developing country causes water contamination with harmful organic pollutants and metals such as copper (Cu), and zinc (Zn) [2, 3].

One of the most critical difficulties that few people are aware of, which can lead to oxidative stress, DNA damage, and inflammation, among other health problems including cell death. Microplastics are to blame. Microplastics are abundant in water. In fact, a person who only drinks bottled water would absorb over 130,000 microplastic particles each year from that source alone. Microplastics are polluting the ocean, freshwater, and land, and research suggests that these microplastics are consumed by animals, including humans. The increased usage of plastics in a variety of forms and applications has resulted in an exponential rise and dispersion of microplastics throughout the environment [4,5] .The sources of this microplastic pollution include the direct production of microplastics or the breakdown of macroplastics, as well as products such :Personal care items, synthetic textile fibers, and rubber tires are examples of such materials. These polymers are widely mixed or paired with chemical additives like phthalate and polybrominated biphenyls, and they can be found in the environment, water, and food [6, 7].

These plastic contaminants are likely to have harmful health effects when swallowed or inhaled. Particulate matter concentrations above a certain threshold diminish light penetration and biological productivity, as well as recreational value and habitat quality, and cause lakes to fill up faster[8] .Excessive sedimentation in streams can impair habitat areas for fish and other aquatic animals. Some pollutants, most notably metals and bacteria, can find a home in particles[9].

Drinking water with high turbidity, or cloudiness, is both aesthetically and physically uncomfortable. In turbidity, pathogens can find food and shelter. If the causes of high turbidity are not removed, they can encourage the regeneration of bacteria in the water, resulting in waterborne illness outbreaks that have caused substantial cases of intestinal sickness across the world. Although turbidity is not a direct indicator of health risk, several studies show a significant relationship between turbidity decrease and protozoa elimination. Turbidity particles provide "safety" for bacteria by reducing their exposure to disinfectant attack. Bacterial survival is hypothesized to be enhanced by microbial adherence to particulate particles.

Water pollution and poor sanitation have been linked to the spread of diseases such as cholera, diarrhea, typhoid, and polio. When water and sanitation services are absent, inadequate, or poorly maintained, people are exposed to preventable health dangers. This is especially true in health care facilities, where a lack of water, sanitation, and hygiene services exposes both patients and personnel to infection and sickness. Infections affect 15% of hospitalized patients globally, with the proportion much greater in low-income countries[10]

Magnetite, also known as Iron (II, III) oxide, is a naturally occurring and high-grade ferromagnetic substance having the chemical formula Fe_3O_4. Well-crystallized magnetite is thermodynamically stable and responds strongly to external magnetic fields. Magnetite (Fe_3O_4) and Maghemite (γ-Fe_2O_3) are the only non-toxic magnetic minerals approved for medical use due to their remarkable oxidative stability [11]. Pure magnetite possesses a unique point of zero charge (PZC) at pH 6.5 [12], making it negatively charged and suitable for absorbing positively charged species like cations. Powdered magnetite may effectively remove arsenic (III) and

arsenic (V) from water. According [11], reducing particle size from 300 to 12 nm boosts arsenic removal effectiveness by around 200 times. The "Sirofloc process" uses regenerable magnetite to remove charged species from water, resulting in decolorization [13]. Magnetite's surface can absorb charged biological stuff from water, including bacteria [14].

This necessitates the rapid and effective removal of toxins and contaminants from aquatic environments by technological innovation. In recent decades, nanoparticles have emerged as one of the most versatile tools. Nanoparticles (NPs) have a huge surface area. As a result, they are more effective in binding to a wider range of molecules.[15,16,17,18] Magnetite nanoparticles (MNPs) have the additional advantage of being superparamagnetic. As a result, MNPs have the added control of altering nanoparticle concentration simply by utilizing a magnet. Recently, MNPs were reported to have been created for wastewater treatment. The use of a magnetic field after purification to eliminate nanoparticles simplifies, reduces costs, and makes handling safer. There is presently no way to detect microplastics in wastewater treatment. The idea was that this extraction procedure would remove turbidity, heavy metals, microorganisms, and up to 95% of microplastics from samples [19, 20,21].

2. Methodology

2.1. Supplies

All the chemicals and reagents used in this study were of analytical grade without further purification excluding specified ones and deionized water used in preparing the solutions. Ferromagnetic (Fe_3O_4) and alum ($Al_2(SO_4)_3$) . H_2PO_4 , NaOH, $FeCl_3$, NaCl, $Cu(NO_3)_2$, $ZnSO_4H_2O$, $MgCl_2$, and $CaCl_2$. Bromophenol blue powder (BBP) was used as the drying agent.Polyethylene terephthalate (PET) as microplastic. The types of oil, namely lubricating oil, was used as liquid carriers , standard lab equipment (beakers, flasks, graduated cylinders, etc.), ALNiCo (Aluminum Nickel

2.2. Sampling of water

The water used to evaluate magnetite's capacity to reduce turbidity came from a nearby source. The samples were kept in cold storage at 4 degrees Celsius and brought to room temperature before testing. When the water was acquired, the pH was noted. When the tests were carried out, the pH was adjusted to the desired values using stock solutions of NaOH (0.1M) and H_2SO_4 (0.1M). The pH of the water samples was 5.6. The pH of 5.6 was borrowed from the CSIRO division since it is the pH at which magnetite's electrostatic attraction to organic materials is greatest [22].The water was examined for microorganisms including bacteria and viruses. Which revealed the presence of Pseudomonas putida, Escherichia coli, and Micrococcus luteus bacterium strains. E. coli, P. putida, and M. Luteus have been found to have dry weight percentages of 31.4%, 48.4%, and 34.9%, as discussed in [23,24] . These rough dry weight figures were used to calculate the amount of magnetite needed for the studies.

2.3. Factorial design of experiments

Preliminary investigations identified the range of magnetite concentrations utilized for water treatment.

Magnetite, alum, and poly acrylamide were utilized at various quantities. The turbidity control factorial design was a partial factorial design with 5 variables. Table 1 contains a chart showing the values utilized. P = Polyacrylamide, A = Commercial grade Alum: Aluminum sulfate Al2 (SO4)3, 26.8% Wt. in water (10 mg/l and 60 mg/l), M =Magnetite (100 mg/l to 300 mg/l), the numbers in brackets indicate the top and lower limits of the concentrations utilized for the suitable combination The letter N indicates that no chemical was added and acts as a control. The letters L and H indicate its lower and upper concentration limit .

Table 1: Combinations used to determine the removal efficiency of M = magnetite , L = alum and P = polyacrylamide, L= Lower limit of concentration , H = Higher limit of concentration and N = No chemical

Combination	A	P	M
1	LA	LP	HM
2	HA	LP	HM
3	LA	HP	HM
4	HA	HP	HM
5	NA	NP	HM

The setup utilized for water sample treatment. A 1L sample of untreated raw water was combined with 0.5 mL of oil and magnetite as ferrofluid A total of five different combinations of alum, polyacrylamide, and magnetite were employed. Positive controls included no contaminants and negative controls included clean deionized water (turbidity = 0.01NTU).

The sample was pushed through a magnetic field after treatment to capture the flocs generated, and the clear water was collected in a collecting jar. To maintain uniformity, the volume of water used as a sample was kept.

2.4. Measurements of turbidity in water samples

A Digital Direct reading field turbidity meter was used to test the turbidity of a water sample. The turbidity of the sample was evaluated in triplicate before and after magnetite treatment.

2.5. Calculations of magnetite dosages used in experiments.

Magnetite (Iron (II, III) Oxide) (MW = 231.53 g/mol) was utilized. Depending on the dry weight of the cells, the cells and the necessary amount (by% Wt.) of magnetite added to solutions were estimated. This was done to establish a direct relationship between magnetite concentration and bacteria.

The dry weight of the cell pellet was kept precisely proportionate to the weight of magnetite supplied to produce a direct link between cell concentration and magnetite added. The term cell: magnetite ratio refers to the ratio of dry cell weight to magnetite weight. For example, if the cell: magnetite ratio is 1:5, it indicates that 5 g of dry magnetite was supplied for every 1 g of cells (dry weight percent). The following ratios were employed throughout this study: 1: 0, 1: 1, 1: 5, 1: 10, 1: 50, 1: 100, and 1:200. Because the dry weight of each culture varies, the magnetite added to the solutions was weight commensurate.

2.6. Mixing of bacterial cells and magnetite

For adsorption to occur, 0.5 ml of oil was added to the solution containing the bacterial cells. To maintain uniformity, the sample volume was kept constant at 50 ml for all tests. At room temperature, all magnetite-containing solutions were manually mixed. Following mixing, the magnetite was allowed to settle using a permanent magnet (AlNiCo 14" x 3", average strength 1.8 T, and maximum at 2.3 T), and the supernatant was examined for live cells. To test the effect of a permanent magnet on bacterial cells, negative controls were also studied. The magnetic field settling was only around 5% max and 1% min, which is most likely due to aseptic method inaccuracy. The positive control for this experiment was to see if magnetite added any microorganisms to the solutions, and none were found.

2.7. Microplastic suspension preparation

PET was used as a microplastic in this work to create synthetic wastewater. A grinding machine was used to cut and grind the PET into little bits. The ground microplastics were sieved through a mesh size of 2 mm. Smaller microplastic particles were captured whereas larger ones remained on the mesh. Synthetic wastewater was created by dissolving microplastics in distilled water and stirring it before use.

2.8. Ferrofluid synthesis and its application for microplastic extraction

To synthesize ferrofluid, two kinds of oil, cooking oil and lubricating oil, were employed as liquid carriers. To generate ferrofluid, about 2.5 mL/L of oil was added to the microplastic solution, followed by 0.50 g/L magnetite powder. After rapidly agitating the solution, a magnet was submerged in it to capture the ferrofluid-containing microplastic, which was subsequently extracted from the solution. The quantity of microplastic retained in the water after adsorption by ferrofluid was then evaluated using the remaining water sample, and its removal effectiveness was calculated. The experiment was repeated with several types of oil to measure their removal effectiveness. After that, experiments were carried out with various amounts of oil (0.5, 1.0, 1.5, 2.0, and 2.5 mL/L) and doses of Fe_3O_4 powder (0.25, 0.50, 0.75, 1.0, and 1.25 g/L). The correlation between the two variables was determined using statistical analysis of the t- test.

2.9. Specifications of magnets used

High strength ALNICO (Aluminum Nickel Cobalt) disk magnets were employed to settle magnetite. The dimensions were 14" x 3.5" (thickness x diameter) and the strength at the poles was 2.3 T (1Tesla = 10000 Gauss). A gauss meter was used to measure the average strength, which was roughly 1.8T.

2.10. Statistical Analysis of data

To assure the correctness, reliability, and repeatability of the factorial design results, a statistical analysis of the factorial design was performed. Statistics were evaluated using Regression analysis in Microsoft Excel 2021 to solve data for factor significance. Before doing the regression analysis, all the data were normally distributed. The regression was performed with a 95% confidence level (P0.05).

Figure 1: Shows the extraction process

2.11. Extraction method

1. Magnetite powder is added to the test tube.
2. Necessary amount of oil was added to thetest tube .
3. The stoppered tube was inverted 20 times toallow the magnetite and oil to adhere to the suspension.
4. The stopper was removed, and the ferro-fluid containing the suspension was extracted in a tiny test tube using magnets.
5. The magnets were then extracted from the suspension, and the ferrofluid was evacuated from the tube by withdrawing the magnets from within the tube.

2.12. Analysis of microplastics in water media

To determine the concentration of microplastics and bacterial cells remaining after extraction. The major instrument used to test the efficiency of the microplastic extraction procedure was microscopy. Adobe Photoshop was used to identify how many pixels were coated with plastic using a specific color range that selects any pixel in this color or within this range, which was then used to calculate the percent decrease in plastics and bacterial cells.
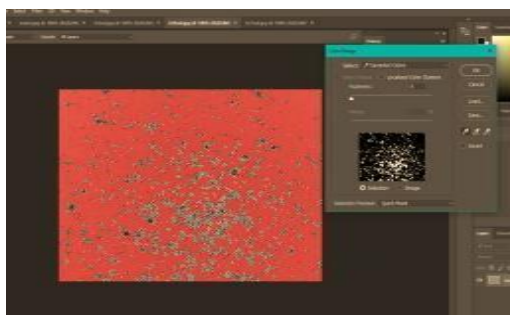

Figure 2: Shows % decrease was counted on Adobe Photoshop

2.13. Removal Efficiency in Microplastic Suspension

For each of the four distinct quantities of oil utilized in each extraction, three extractions were performed. For each extraction, to produce a meaningful result, Means and standard deviations were derived from them, allowing for the computation of standard error and a final hypothesis test.

The microscope findings were computed by determining the percentage of each picture that was covered by

plastic (dividing the number of pixels covered by plastic by the total number of pixels and multiplying by a hundred). The percentage drop was then determined based on this.
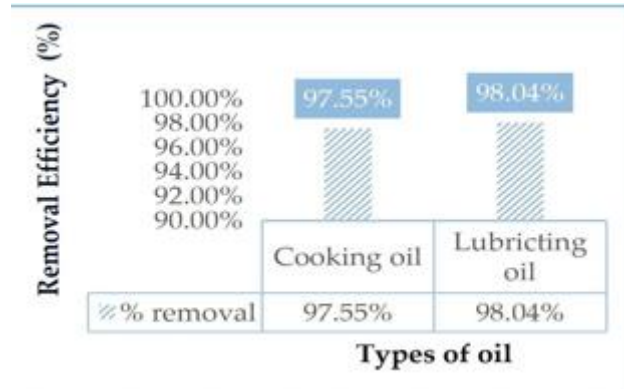

Figure 3: Removal efficiency of microplastic using ferrofluid based on different types of oil (Oil volume: 2.5ml, magnetite: 0.5g/L sample)

The results showed that all types of oil employed in ferrofluid synthesis performed admirably, with all oil types achieving > 95% microplastic removal effectiveness. The lubricating oil, on the other hand, had the maximum removal effectiveness of 98.04%.

Several quantities of lubricating oil were utilized to assess their efficacy for microplastic removal in the second parameter tested, and the findings are presented in Figure 3. According to the results, ferrofluid with a concentration of 0.5 mL/L of oil had the maximum removal effectiveness of 99.5%
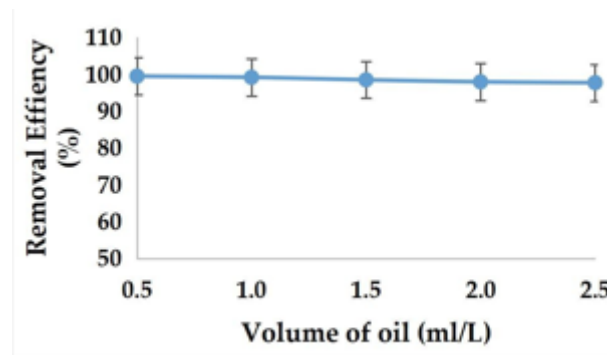

Figure 4: Removal efficiency based on different volumes of oil

The dose of magnetite was changed using lubricating oil at a constant volume of 0.5 ml/L to discover the optimum quantity of iron oxide on ferrofluid efficiency. According to the results, 0.25 g/ L of iron oxide had the lowest removal effectiveness of 99.11%, and increasing the iron oxide dose enhanced the removal efficiency up to 99.72%. Also, there was no significant variation in microplastic removal effectiveness when the magnetite concentration was varied between 0.25 and 1.25 g/L.
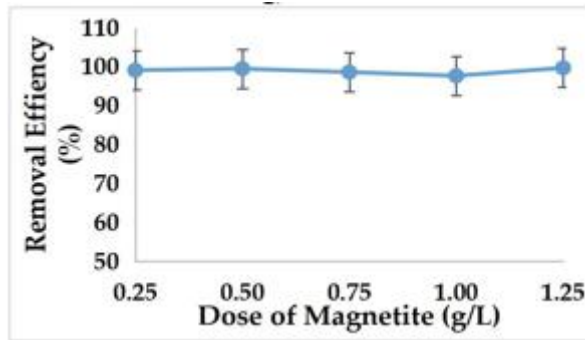
Figure 5: .Removal efficiency based on different dosages of magnetite

2.14. Turbidity in water samples

The turbidity of the water sample samples was assessed before and after magnetite treatment. The water sample alone was utilized as the positive control in this experiment, with an initial turbidity of 115.2 NTU (Nephelometric Turbidity Units) at room temperature. The negative control was pure deionized water with a turbidity of 0.01 NTU (99.99%).
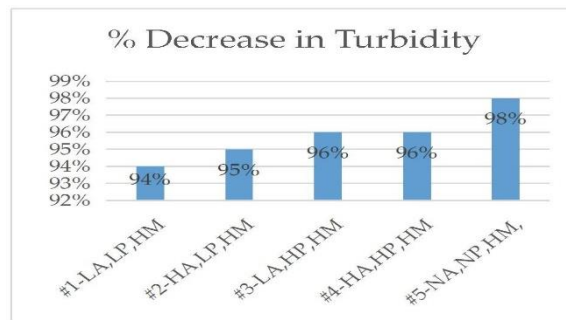

Figure 6: Percent turbidity removed based on different combinations of A= Alum, P=Polyacrylamide and M=ferrofluid.**(refer to Table 1)**

The removal effectiveness of magnetite and oil alone (#5 in Figure 6) was determined to be the greatest of all the combinations evaluated, at 98%. The runs #1 through #4 reliably reduced up to 96% of the turbidity of magnetite and oil alone .

Table 2: Results from Regression analysis on results obtained using MS Excel, 2021 Blue cell highlights the P value of magnetite as a significant factor (P < 0.05)

Multiple R	0.923	Alum	0.365
R Square	0.851	Polyacrylamide	0.133
Significance F	0.093	Magnetite	0.075

Magnetite exhibits no significant difference according to regression analysis (P=0.075, P>0.05, see table 2). The intercept in table 2. statistically explains why the impact of magnetite is not significant (P = 0.075, P>0.05). Other metrics, such as Multiple R and R square, explain the regression analysis's accuracy. R square 0.85 indicates that the regression analysis is 85% accurate. With 95% confidence, the significance Of parameter indicates that the likelihood of anticipating the incorrect P-value is 9.3%. This suggests that the regression analysis is 93% accurate overall.

2.15. Bacterial Absorption

This experiment was designed to determine the quantity of magnetite necessary for the adsorption of bacterial cells in a non-buffered 0.85% by weight saline solution (Figure 5). For this experiment, the positive control was settling by magnetic field alone, which was 0.3%, 1.1%, and 2.8% (mean value stated) for E. coli, P. putida, and M. luteus, respectively. A negative control was utilized to ensure that the magnetite was not polluted in any way, and the results for all three cultures were 0%.
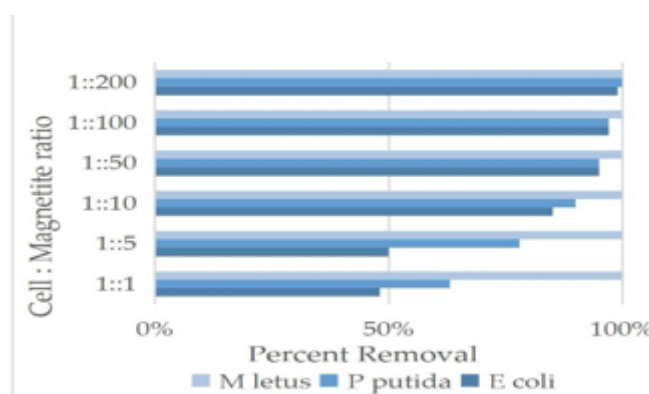

Figure 7 : Effect of magnetite concentration as a function of percentage removal of M. luteus, P. putida and E. coli by adsorption to magnetite in 0.85% saline at pH 7.5. Values are average of triplicates with +/- one standard deviation

The optimal cell: magnetite ratio was 1:50, which eliminated bacterial cells from E. coli, P. putida, and M luteus with 94.8%, 99.7%, and 100%, respectively. The adsorption percentage increases from 99% to 100% when the cell: magnetite ratio increases from 1:10 to 1:200. All previous tests indicate that magnetite has a high capacity for bacterial adsorption (Gram negative - E. coli and P. putida and Gram positive - M. luteus).

2.16. Removal of heavy Metals

Figure 8 shows the treatability performance of ferrofluid and alum for the removal of hazardous metals (Al, Cu, Zn, Fe, and Mg) from TE at a dose of 50 mg/L and a pH of 5.
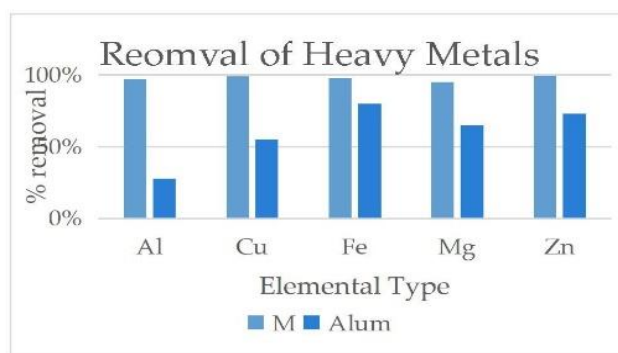

Figure 8: Shows the absorption of heavy metal using ferrofluid

According to the data, the ferrofluid system removes more than 95-99% of the original elements concentration compared to 40-80% for alum. The elements are seen to be in the following order: Zn > Cu > Fe > Al > Mg for the ferrofluid system, and Fe > Zn > Mg > Cu > Al forthe coagulated system containing alum.

3. Discussion

3.1. Types of oil

For the preparation of ferrofluid, two types of oil (cooking oil and lubricating oil) were employed, and their efficiency in removing microplastics from aqueous media are shown in Fig. 1. The results showed that all types of oil employed in ferrofluid synthesis performed admirably, with all oil types achieving > 95% microplastic removal effectiveness. The lubricating oil, on the other hand, had the maximum removal effectiveness of 98.04%.

This might be owing to the oil's great stability, which is made up of a full blend of hydrocarbons (molecules composed of only hydrogen and carbon atoms). Cooking oil, on the other hand, is not a full hydrocarbon since it contains fat molecules, which are made up of tri-esters .Tri-esters are chemical compounds made up of three hydroxyl groups (-OH) known as glycerol, three fatty acid molecules with long hydrocarbon chains (R), and a carboxylic acid group (-COOH). This study's findings are consistent with those of Khan et al., who stated that ferrofluids produced with lubricating oil as a carrier fluid displayed more stable qualities than ferrofluids created with paraffin oil or sunflower oil as a carrier fluid. The high stability features of ferrofluid in lubricating oil may be attributable to the solvent's refractive index or dielectric constant. After interacting with a neodymium magnet,

the ferrofluids made using cooking oil generated modest and low spikes.

However, in the presence of a magnetic field, the lubricating oil-based ferrofluid created significant and obvious spikes, coagulating additional microplastics together. Used oil, on the other hand, has a higher viscosity due to external variables like impurities or temperature, whereas fresh unused oil base is a transparent, free-flowing liquid. The high viscosity of heavy oil has a significant impact on capillary penetration of the oil into the tiny polymer pores that function as oil sorbent material. This is further confirmed by Darcy's law, which indicates that when oil has a high viscosity, pores can become clogged, inhibiting polymer adsorption. Higher viscosity liquids take longer to travel through the holes than lower viscosity ones. The rate of absorption varies with the viscosity of the oil. In summary, heavier oils absorb more slowly than light oils. The adsorption capacity of oil reduces as its viscosity rises . As a result, unused oil had a greater microplastic removal effectiveness than used oil because less viscous oil attracted more microplastics, allowing for the efficient extraction of significant numbers of microplastics together with oil by magnetite powder.

3.2. Effect of different volume of oil

 The increase in the volume of oil appears to have affected the removal efficiency. These findings are comparable with those of Aboul- Gheit et al.in [25], who discovered that the absorption efficiency of plastic particles towards oil is best when the plastic to oil ratio is between 0.5-2.

The absorption of plastics on the oil becomes less efficient as the volume of oil supplied increases, thus decreasing the extraction efficiency of microplastics using oil-based ferrofluid. If oil can trap all microplastics, magnetite can remove a significant amount of microplastics floating in water. This outcome can also be explained by a solid's hydrophobicity and oleophilicity. Because of the absence of interaction between water and oil molecules, hydrophobic materials restrict water absorption and hence improve oil sorption capacity. Strong hydrophilic particles will stay distributed in the aqueous solution phase, whereas strong hydrophobic particles will remain in the oil since the oil phase is the only one that wets them. The tight cohesiveness between the oil matrix and the polymer matrix assures structural integrity and oil absorption uniformity. In practice, it will be stable under ocean conditions such as waves, wind, and sunshine, and it will be easily removed from the water's surface by creating a magnetic field.

3.3. Effect on different dosages of iron oxide

 When the magnetite concentration was between 0.25 and 1.25 g/L. Just a little quantity of magnetite is required to create ferrofluid with significant electro-positivity, which may cause quick aggregation with oil and microplastic suspension in water media. With the addition of an external magnetic field, the interparticle interaction has a major influence on the fluid's characteristics because the magnetic dipole interaction forces activate the particles' agglomeration behavior. This phenomenon may be observed when the fluid's viscosity varies. Fig. 3. This discovery is consistent with [26] , that proved increasing magnetic field intensity enhances thermal conductivity constantly to a certain amount. The efficiency of ferrofluid on thermal conductivity revealed the magnetic field strength of the ferrofluid in this study. The thermal conductivity increased as the

dosage of magnetic particles increased. Based on the results, the removal effectiveness of ferrofluid became high at 1.25 g/L magnetite dose, while increasing the magnetite concentration was projected to diminish the removal efficiency.

The removal efficiency seems to be directly connected to any variations in the mass of FeO added. According to the findings of this investigation, as the mass of FeO grew, so did the removal efficiency.

3.4. Turbidity Control with Magnetite

The initial step in comparing the efficacy of magnetite to conventional turbidity control strategies such as flocculation by coagulant and polymer was to control turbidity in a water sample. In natural water, colloidal organic stuff is often negatively charged as stated in [27]. It was expected that if magnetite is positively charged at a pH lower than its PZC (6.5 to 7) it will be able to electrostatically adsorb colloidal clay in natural water. For these comparisons, the coagulant and polymer utilized were alum and polyacrylamide, respectively. One of the most extensively utilized turbidity control strategies is alum and polymer flocculation [27].

The aforementioned results closely corroborate previous experiments in which 10000mg/l of pretreatment magnetite achieved 99.63% turbidity control from the Yarra River in Victoria, Australia (raw water turbidity in excess of 190 NTU) in [27] .Earlier research employed a very high concentration of pretreatment magnetite (0.5 to 2% v/v = 5000mg/l to 20000mg/l) to reduce turbidity by more than 99% in [28]. This study employed magnetite concentrations ranging from 100 mg/l to 300 mg/l, with a maximum effectiveness of 98% at 300 mg/l magnetite. This implies that magnetite has the best efficiency when compared to the other treatment options. It's worth noting the difference in removal effectiveness between alum + magnetite (#2 = 95%)and polyacrylamide + magnetite (#3 = 96%). There is virtually no change, implying that magnetite responds faster than the compounds themselves.

3.5. Adsorption of bacterial cells

The controls indicate a 2.8% elimination when exposed to a magnetic field, suggesting that the species (M. luteus) was influenced by the magnetic field. According to research, an applied static magnetic field causes the dissociation of ion protein complexes on the surface of bacteria, resulting in an anti-bacterial action [29]. The experimental conditions were kept quite identical to the preliminary experiment, with the exception of the pH, which was neutral (7.5) in this case. At room temperature, the suspending solution was Standard 0.85% by weight saline.

It is worth noting that the concentration of magnetite is slightly related to E. coli and P. putida adsorption. The percentage elimination increases from 50% to 100% as the cell: magnetite ratio increases from 1:1 to 1:200, following a pattern (approximation). The increase in percent elimination was approximately.25 percent for each unit concentration of magnetite. M. luteus has a very high removal efficiency when compared to the other two strains, achieving above 99% removal under all circumstances evaluated. The adsorption capacity plateaus from cell: magnetite ratios of 1:1 to 1:200, with no discernible proportionality connection detected. There is no significant difference in E. coli removal efficiency when the cell: magnetite ratio is increased from 1:1 to 1:5,

however there is a 15% increase in P. putida removal efficiency. M. luteus, on the other hand, has a 99% clearance rate, which is exceptionally high in comparison. The adsorption percentage of M. luteus does not change significantly; it remains in excess of 99% at a 1:1 ratio and is 99.9% at the maximum cell: magnetite ratio of 1:200. P. putida is removed more than E. coli at lower magnetite doses (up to a 1:10 ratio), although E. coli removal rises marginally at higher magnetite doses (1:50 and above ratio). Such little discrepancies in removal efficacy might have stemmed from an error in weighing magnetite or measuring magnetite interaction time with bacterial cells, and so went unnoticed. There have been no previous studies that have examined magnetite's adsorption capabilities for the three strains employed in this investigation. With 4% v/v magnetite and a pH of 4.0, studies on other species show 98.07% adsorption of Escherichia coli in [14].

This magnetite concentration is about comparable to (assuming water density = 1000 kg/m3) 40 gm/l, which is considerably high in comparison to the values 70 examined in this work .The conversion for concentrations from a cell: magnetite ratio of 1:50 is about 44 mg/l (SG= 5.1), while the conversion for concentrations from a cell: magnetite ratio of 1:200 is approximately 180 mg/l. There is no pH correction in this experiment, and the pH was measured to be 7.5, which is a contradiction because it is extremely near to magnetite's PZC (6.5-7). [28] studied the adsorption of E.coli bacteriophage T7 and found that a magnetite concentration of 500 mg/l and a mixing duration of 30 minutes at 100 RPM resulted in 99% elimination. Even at 500 mg/l, the quantity of magnetite utilized for bacteriophage T7 adsorption is substantially higher than the maximum cell: magnetite ratio of 1:200 (about 180 mg/l for E. coli).

Earlier investigations on the use of magnetite to adsorb microbes were undertaken at pH levels ranging from 4 to 5 [30][31]. The studies in this paper were carried out at a pH of 7.5, which is extremely near to magnetite's point of zero charge (PZC) (Ranges between 6.5 to 7.0, average value considered 6.7). According to this knowledge, the electrostatic interaction between magnetite and bacteria will be of relatively low amplitude, and so will not be a dominating mechanism for adsorption for this reason some additional work was completed to determine the mechanisms for adsorption.

The cell: magnetite ratio of 1:50 was chosen for subsequent studies since the clearance percentage for all three strains was greater than 90% at this ratio (Figure 5). If this ratio is exceeded, the amount of magnetite required for treatment will be increased for a very little gain in efficiency, rendering it an economically unviable alternative.

Formerly, it was assumed that the bacterial surface is negatively charged, and the magnetite surface is positively charged, resulting in electrostatic adsorption. However, because the point of zero charge for magnetite lies between 6.5 and 7.0 as discussed in [32] the degree of electrostatic interaction is quite low. However, the surface density charge will fluctuate when the pH of the sample changes. The surface charge density of bacteria would have altered as a function of pH, as found in research testing the influence of pH on microbe adsorption.Since the putative removal process is so complicated, there is yet no clear proof or hypothesis that explains the sort of interaction between magnetite and bacterial species. Bacterial surfaces are extremely complex, making it difficult to pinpoint the most likely adsorption process. These advances prompted researchers to search for hydroxyl functional groups on the surfaces of bacterial cells.

3.6. Heavy metals removal with magnetism

According to the data, the ferrofluid system removes more than 95-99% of the original elemental concentration. The findings are consistent with research conducted in [33] to investigate the efficacy of magnetite for metal removal in the presence of a magnetic field. Experiment results on the efficient removal of metals such as calcium, copper, nickel, and zinc under the influence of a magnetic field revealed that raising the magnetic field and reducing the flow velocity resulted in increased separation. The most important conclusion to be derived from the results is that most metals, up to 95 percent, were effectively removed from water using magnetite and magnetic separation.Natural magnetite was employed in batch settings to remove actinide and heavy metals from wastewater, with greater than 90% removal efficiency routinely achieved similar to the achieved percentage in [34]. This is based on the magnetic characteristics and magnetic power of the elements. The process of cationic exchange and hydroxide production on the surface of the ferrofluid was used to magnetically remove heavy metals.

3.7. Limitation

This study has some potential limitations. While this study revealed the efficacy of magnetite-based ferrofluids in eliminating pollutants, it had certain drawbacks.(1) the study only included three bacterial strains: E. coli, P. putida, and M. luteus. This small scope may limit the findings' applicability to real-world circumstances.(2) the reliance on controlled laboratory environments to conduct studies. While these settings are necessary for initial characterization, they may not fully replicate the intricacies found in genuine aquatic habitats, limiting the application of the results. (3) the study concentrated on short-term removal efficiency and did not consider the long-term stability, durability, or economic viability of magnetite-based ferrofluids in continuous water treatment systems. This lack of investigation raises concerns about the feasibility of using ferrofluids on a bigger scale. To address these limitations, future studies should increase the sample size by including more bacterial strains and environmental circumstances. Real-world experiments are critical in determining long-term stability and economic viability. Exploring alternate carrier oils and microplastic removal technologies may also improve ferrofluid performance.

4. Conclusion

Ferrofluids are an alternative method of removing pathogenic microorganisms from water streams. They are composed of iron oxides and adsorption capacity, which can bind to many molecules and remove contaminants from aqueous effluents such as turbidity, metals, organic matter, and bacteria. The method is simple and sustainable and can be used to remove three model bacteria Escherichia coli, Pseudomonas putida and Micrococcus luteus. The optimal cell: magnetite ratio was 1:50 and could remove bacterial cells up to 100%. The most important details of the phrase's magnetite, ferrofluid, iron oxide, removal, and efficiency are that magnetite has a maximum efficiency of 98% decrease in turbidity and is the most effective removal of most metals from water at 300mg/l.

This study focused on the ability of several types of oils as carriers and how they may improve the removal

efficiency of microplastic. The optimum formulation for ferrofluid preparation was found to be at a ratio of 1:2.5 (volume of oil: dosage of magnetite) using lubricating oil which has successfully removed 99% of microplastic from water media.The results conclude that magnetite has great potential for it to be used as a disinfectant/disinfectant aid and serves as a good alternative to full disinfection of water treatment plants. And his study also inferred that the ferrofluid prepared with standard optimum formulation was effective in removing microplastics , heavy metals , and decreasing turbidity .

Acknowledgements

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