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A Novel Magnetic System with Carbon Nanotubes to Remove Microplastics from Water

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Türkiye

Biography

Ayse Pelin Dedeler is a senior at Izmir Cakabey Schools and an incoming freshman at Stanford University. She is interested in how STEM can contribute to solving global challenges, particularly interested in the areas of sustainability and physics. In her free time, she hikes, builds Lego, and reads the latest articles on physics. Ayse Pelin is very interested in academia, having already published 2 articles.

As an advocate for the environment, Ayse Pelin has been invited to speak on environmental issues and promote sustainability at prominent conferences and panels throughout her high school career. She delivered a talk on the environment at the Union of Municipalities of Turkey Science Congress and spoke on “The Effect of Microplastics on Global Warming” at The National Polar Sciences Symposium.

In addition to her speaking engagements, Ayse Pelin played a formative role in organizing the CakaMUN (Model United Nations) conference on the theme of ”Climate Action” as Deputy Director General. She has also served as President of the Student Council, organizing environmental awareness events, and was the Editor of the School’s Newspaper— which was distributed online in order to reduce paper waste.

Growing up by the shore, Ayse Pelin developed a profound love for marine life. During the Covid-19 pandemic, she began a daily coastal cleanup routine. However, she soon realized that to make the cleanup efforts truly effective, she needed to address the presence of microplastics that couldn’t be removed by hand. After a field trip to a water treatment facility, where she discovered that traditional filters were also not effective in removing microplastics from water, she then determined to develop a novel solution to microplastic pollution. Using magnetic technology to remove microplastics from water, she has attended many science fairs including Regeneron ISEF. After 3 years of improving her project, Ayse Pelin is now excited to be entering the Stockholm Junior Water Prize.

Acknowledgment

I would like to acknowledge all who have contributed to the development of this project. Their support has been essential to the project’s successful completion. I would like to thank Prof. Dr. Yavuz Öztürk for providing me access to the laboratory at Ege University, which enabled me to initiate this project. I would also like to extend my gratitude to Prof. Dr. Can Erkey from Koç University for their mentorship and provision of resources, particularly in conducting spectroscopic measurements. I also want to thank the robotics club at my school for providing me the tools I needed to construct the machine prototype. Last but not least, I want to thank my family for supporting me and allowing me transform my room into a mini lab. The accomplishments of the project were greatly influenced by everyone who provided me with feedback and gave support.

Contents

1 Abstract

Microplastic pollution due to inadequate water treatment has become an emerging issue, posing a global threat to marine life. Effective and eco-friendly removal solutions of microplastics (MPs) are urgently required. This study aims to develop a magnetic removal method that utilizes nano-adsorbents to capture MPs and remove them from the water via magnetic force. Magnetic carbon nanotubes(M-CNT) which intended to adhere to the surfaces of MPs were achieved by synthesizing multi-walled carbon nanotubes with magnetite (Fe_3O_4) nanoparticles. Due to the strong hydrophobic properties of carbon nanotubes M-CNTs successfully adhere to the surfaces of MPs. Numerous experimental parameters affecting MPs adsorption by M-CNTs were tested, including amount of adsorbent, contact time, salinity of water, and MP polymer type. The polymers included in this experiment (PET, HDPE, LDPE) were chosen based on the plastic varieties that generate the most waste globally. The obtained M-CNT material was added to beakers containing artificial seawater where the M-CNT material adsorbed on MPs and the composites were separated from aqueous solutions using neodymium magnets. The subsequent UV/VIS spectrometer findings of cleansed water samples are used for Beer-Lambert Law calculations which later demonstrated a 98% success rate for MPs removal. By thermal treatment at 35°C and washed with considerably low amount of EtOH, M-CNTs can be cleaned of MPs and once again be utilized in MP removal from the water. For real-life applications of M-CNT, a magnetic machine is designed with 3D printing and Lego parts. The machine's magnetic field can be turned on and off by realigning diametrically magnetized disc magnets with servo motors and the NXT brick. This attains the dual goals of moving M-CNTs through the machine and continuously removing microplastics from water. Hence, a novel approach for removing microplastics with unique nanomaterials from aqueous environments has been proposed.

Keywords: Microplastics, Magnetic Carbon Nanotubes, Switchable Magnetic Technology

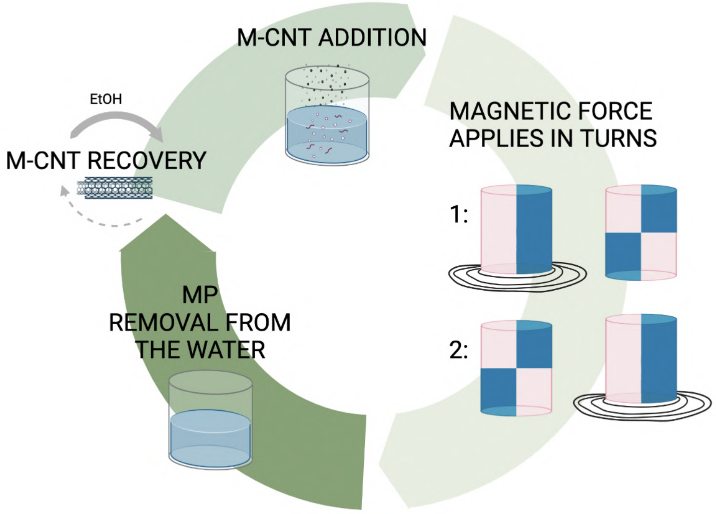

Figure 1: Graphical Abstract

List of abbreviations: Microplastics (MPs), Carbon Nanotubes (CNT), Magnetic Carbon Nanotube (M-CNT), High-density polyethylene (HDPE), Low density polyethylene (LDPE), Polyethylene terephthalate (PET).

2 Introduction

2.1 Microplastics

”Microplastics” defined as plastics with a diameter of less than 5 mm that are formed through the breakdown of macroplastics or generated by abrasive usage in industry, are an emerging environmental problem [1]. The number of plastics in the ocean offshores nowadays has been calculated around 5.25 trillion pieces and 92% of these plastics are below 5 mm [2]. Microplastics can enter water bodies, including oceans, lakes, rivers, and even drinking water. Microplastics can enter water bodies via various ways, such as inadequate waste management, accidental spills, and incorrect disposal of plastic-based products (Figure 2). Colorless and transparent plastics or microplastics found in water resources can turn into a serious hazard as invisible garbage [3].

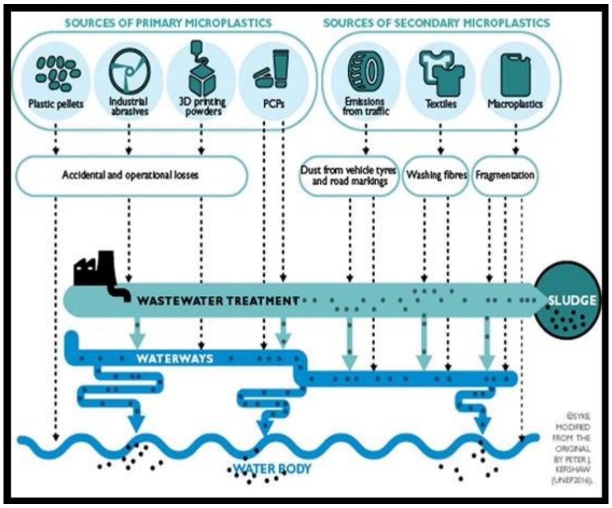

Figure 2: Schematic diagram of how sources of micro plastics mix into the aquatic environment [4].

The need for disposable masks, gloves, and disinfectant bottles which has increased with the COVID-19 pandemic, exacerbates the existing plastic problem and thus, affects the environment. The plastic materials that have been used during the pandemic now reached the seas. While the degradation of a disposable mask in the water ecosystem takes an average of 450 years like all plastic types, it will never decompose, but turn into microplastics [5]. The increasing amount of microplastics in water bodies has raised concerns not only due to their possible negative impact on aquatic ecosystems but also on human health. Microplastics can enter the food chain, and now they have been found in the human blood and respiratory system [6].

In this project it is aimed to produce magnetic nanomaterials that are effective and sustainable for capturing microplastics, as well as a magnetic microplastic removal machine for cleaning microplastics from environmental water sources.

2.2 Why Magnetic Removal?

Water treatment has a key role in maintaining the quality of our water supply. The need for new, effective pollutant removal methods has become vital as there is inadequate access to clean water, with water scarcity occurring globally [7]. Traditional methods such as filters, coagulation, and flocculation have been widely used in water treatment processes. But the traditional methods have their shortcomings. For example, filters are time-consuming, often get clogged, and are expensive. Also, absorbent losses happen in filters. Whereas coagulation and flocculation require the use of hazardous chemicals, such as coagulants or flocculants, which can introduce additional pollutants or pose risks to the ecosystem if not properly managed. In the past decade, with the emergence of nanotechnology and nanomaterials research, we have been able to develop nano-adsorbent materials for capturing pollutants such as heavy metals and dyes [8]. The magnetic removal process with magnetic nano-adsorbents is a promising alternative, offering several distinct advantages over conventional techniques [9]. Compared to filters, in the magnetic removal process, there are no adsorbents lost, and it’s faster, easier, and cheaper. In contrast to coagulation and flocculation, in the magnetic removal method, there are no chemicals left in the water because the adsorbent is being collected with magnets. And because the material is collected, it can be reused in the water treatment process after sent for recovery. This provides a sustainable and eco-friendly water treatment solution.

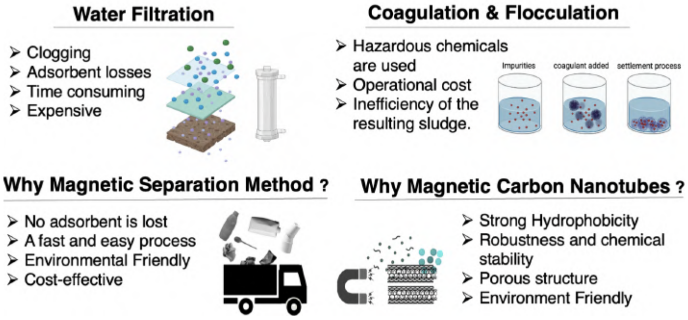

Figure 3: Limitations of current microplastic removal systems.

3 Material and Method

3.1 Materials

The chemicals used in the study include:

- Carbon Nanotubes:
  - Type: COOH functional multi-walled carbon nanotubes (Nanograph, Turkey)
- Ferric Chloride Hexa-hydrate:
  - Chemical Formula: FeCl3·6H2O
  - Purity: Aldrich 97
- Ferrous Chloride Tetra-hydrate:
  - Chemical Formula: FeCl2·4H2O
  - Purity: Aldrich 98
- Ammonium Chloride:
  - Chemical Formula: NH4OH
  - Purity: Aldrich 28–30
- Ethanol
- Distilled Water

The analytical methods employed for the analysis of M-CNTs and the characterization of M-CNTs-adsorbed MPs are as follows:

- X-ray Diffraction (XRD) Analysis:
  - Instrument: BRUKER D2 PHASER diffractometer
- Scanning Electron Microscopy (SEM):
  - Instrument: ZEISS EVO LS15
  - Accelerating voltage: 3.00 kV
- Fourier Transform Infrared Spectroscopy (FTIR):
  - Instrument: Thermo Scientific iS10 FT-IR
- Ultraviolet-Visible Spectroscopy (UV-Vis):
  - Instrument: SHIMADZU UV-3600 - UV-VIS-IR

These analytical methods were utilized to investigate various aspects of M-CNTs, including their crystal structure (XRD), morphology (SEM), chemical composition (FTIR), concentration (UV-Vis). The combination of these techniques provides valuable insights into the properties and behavior of M-CNTs and their interaction with adsorbed microplastics (MPs).

3.2 Obtaining Microplastics

To be used in the experiments, secondary type microplastics were obtained by sanding disposable plastic covers containing PET, HDPE, and PP (Figure 4). Primary type microplastics were obtained from facial cleansing products containing microbeads. To extract MPs, the product was first dispersed in water and then, transferred into a syringe and filtered on a 20-μm membrane several times.

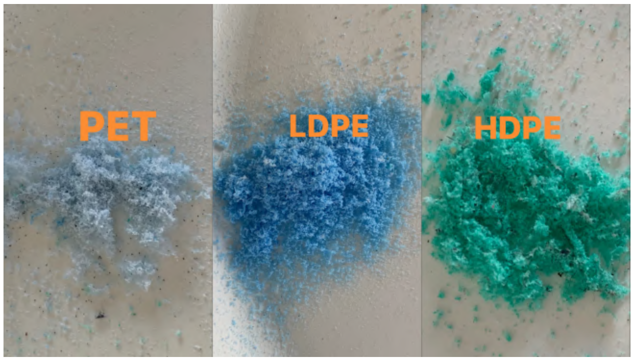

Figure 4: Different types of secondary microplastics obtained with sandpaper.

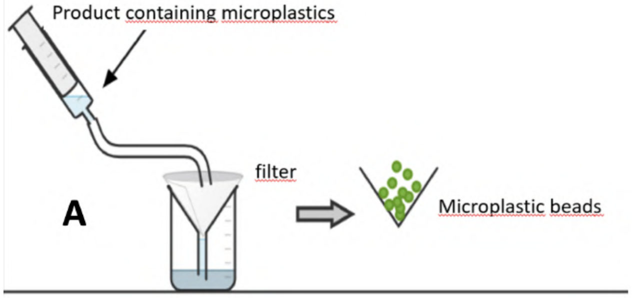

Figure 5: The schematic representation of how the microbeads obtained from cosmetics.

3.3 Magnetite (Fe_3O_4) Synthesis

A solution of ferric chloride 0.0125 M was added to a ferrous chloride solution 0.0125 M and a solution 1 M of ammonium hydroxide. 50 ml of ammonium chloride was added to volume of 200 ml of deionizated water in a bottom round flask, and the mixture was stirred for 10 min at 800 rpm. Afterwards, 10 ml of ferrous chloride 0.0125 M and 20 ml of ferric chloride 0.0125 M were added; immediately a black precipitate appeared, which aged for 10 minutes and later filtered. Poured in a petri dish particles dried at 45°C for 4 hours [10].

3.4 Magnetic Carbon Nanotubes (M-CNT) Synthesis

Magnetically feature carbon nanotubes (M-CNT) were synthesized using Fe_3O_4 nanoparticles with ferromagnetic characteristics, and (COOH) functionalized carbon nanotubes (CNT-COOH). Because the M-CNT material will be used in water treatment process, the synthesize procedure was aimed to be performed as simple as possible.

In a solution of 40 mL deionized water and ethanol (1:1, volume ratio), Fe_3O_4 nanoparticles (50 mg) and CNT-COOH (200 mg) were dispersed. The mixture was ultrasonicated for 1 hour and then shaken for 12 hours at room temperature. Particles were dried at 50°C for 16 hours [11].

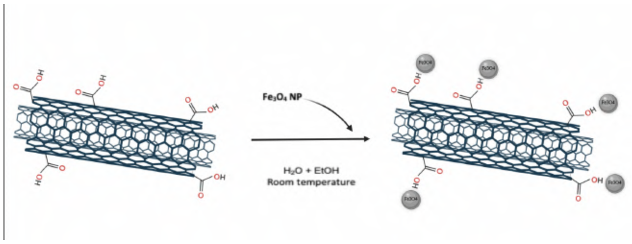

Figure 6: Schematic Illustration of the Procedure for the Preparation of M-CNT

3.5 Calculation of the Final MPs Concentration and Removal Efficiency

UV/VIS spectrophotometer is used to record the spectra of cleaned water samples. Beer-Lambert Law was one of the methods that has been used in this project to show the successful removal of MPs.

$$A = \varepsilon l c \tag{1}$$

where:

A is amount of light absorbed

ε is the molar absorbance coefficient, which varies with wavelength, but not with concentration

ℓ is the thickness of the sample

c is the concentration of the absorbing species

• Extinction coefficient of MPs are calculated using the following equations;

$$\alpha = \frac{2.303 \times A}{l} \tag{2}$$

$$k = \frac{\alpha \lambda}{4\pi} \tag{3}$$

where:

α is absorption coefficient, λ is the wavelength

k is extinction coefficient

• The microplastic removal efficieny (%) is calculated according to the following equation, where C_0 is the initial concentration of MPs:

$$RemovalEfficiency(\%) = \frac{Co - C1}{Co} \times 100 \tag{4}$$

3.6 Microplastic Removal Experiments

The magnetic microplastic removal method steps can be seen in figure 7. M-CNTs are added to to contamined water, and after M-CNTs are adsorbed by MPs they are removed by sweeping a magnet inside a glass tube. In order to observe the effects of various conditions on removal process, different test groups were prepared. First of all, to determine the effect of salinity on the removal process, two groups of mediums are prepared: distilled water and simulated seawater. Simulated seawater contains 35g NaCl and 1L deionized water, which was prepared according to a previous study [12]. In seperate petri dishes of 40 mL water and simulated seawater, 10mg MP and 10mg M-CNT is added to both. Later the studies continued in simulated seawater environment. To test M-CNTs ability to be adsorbed by different types of microplastics PET 01 HDPE 02 are weighted in balance 20mg are added into 40mL simulated seawater environment. For determining the optimal ratio of M-CNTs to be adsorbed by MPs a constant rate of 10 mg MP/ 40mL simulated seawater in petri dishes are prepared and respective amounts of 2.5, 5, 10, 15, 20 mg of M-CNTs are added. MPs in each of the test environments were removed by mixing with the help of a glass tube that contains a neodimyum magnet inside it (Figure 7).

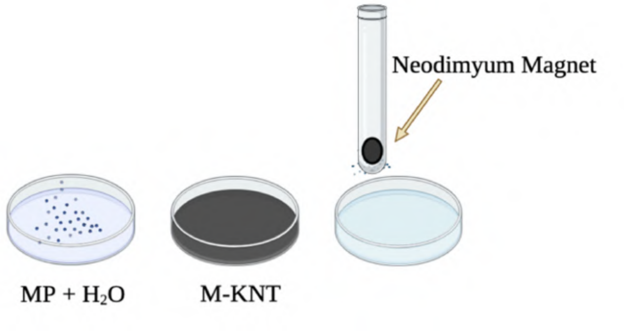

Figure 7: Schematic representation of M-CNT addition and magnetic removal from aqueous suspension containing microplastics.

3.7 Magnetic Water Treatment Machine Design to Remove Microplastics

The attraction force that switchable magnets produce is correlated with their ”flux” field. The steel piece surrounding the magnets is altered to prevent this attraction force from affecting the exterior. The pole locations can be changed by 180-degree rotation of the neodymium magnet. As a result, the magnetic field from one magnet passes into the other magnet after passing through the steel wall. As seen in Figure 8, this enables the switching of the magnet’s ”flux” field as desired. Main principle is that the steel compartment’s outside cannot be affected by the changed ”flux” field in any way. This means that the magnet can be activated and deactivated when necessary, ensuring that its magnetic influence is contained within the compartment [13] [14].

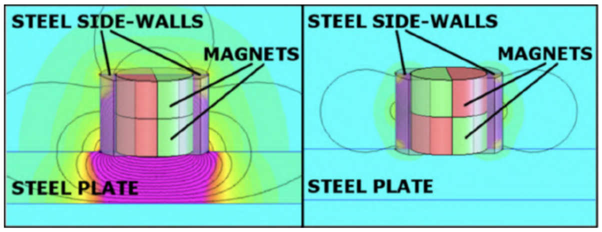

Figure 8: Working principle of magnets of which magnetic feature can be opened and closed. [15]

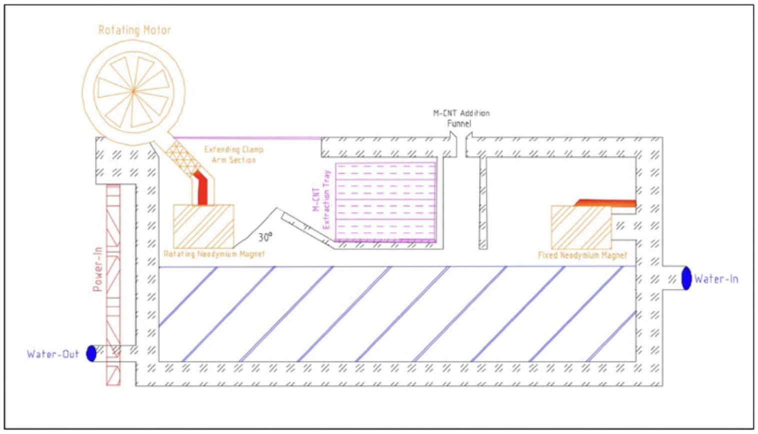

Figure 9: AutoCAD illustration of the proposed water treatment system.

Steps of the magnetic water cleaning machine (figure 9) to remove MPs are:

- Take the incoming polluted water into the compartment
- Add M-CNTs into the MP contaminated water
- Activate the first magnet’s magnetic field.
- Activate the second magnet’s magnetic field, creating a pumping effect between two magnets thus increasing M-CNTs interaction with MPs
- Lift magnets up from the water on the y-axis, removing MP adsorbed M-CNT carriers
- Release the cleaned water from the compartment
- Deactivate the magswitches’ magnetic fields; which will drop the MCNTs adsorbed MPs on the extraction tray.
- Send MCNTs adsorbed MPs for recovery

4 Results and Discussion

4.1 Structural and Characterstic Analysis of MPs and M-CNTs

4.1.1 XRD Analysis

M-CNT was structurally characterized using spectroscopic approach and evidence. Phase and crystalline structure of cubic Fe_3O_4 and M-CNTs were confirmed by XRD measurement. XRD model was used to determine the coating of magnetic Fe_3O_4 particles on CNTs, Fe_3O_4 2θ = 30.3°, 35.0° [16] was checked to show the characteristic diffraction peaks. The peak taken at 2θ = 35.3° indicated the presence of Fe_3O_4. In the XRD model, 2θ = 26.5° characteristic peak of M-CNTs was detected which confirmed that the nanostructure of CNTs were well preserved during the magnetic synthesis [17].

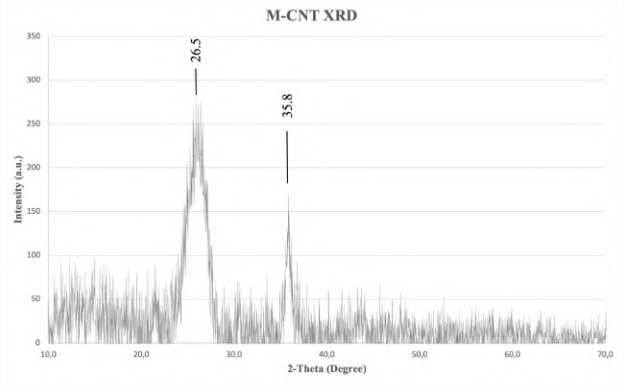

Figure 10: XRD pattern of the M-CNTs.

4.1.2 FTIR Anlysis

An average of 50 scans were collected for each spectrum measurement at FTIR. As can be seen in figure 11 fingerprint peaks of M-CNTs were determined as 2360° and 1510°. Also, the FTIR spectra of M-CNTs showed band at 1683 cm-1 indicating clear mode of C=O vibration of the carboxyl group (COOH) [18]. After showing the characteristics of M-CNTs, the spectra of high-density polyethylene (HDPE) and polyethylene terephthalate (PET) microplastics were taken in FTIR, the vibration frequencies of various bonds in the molecules were measured, and information about the functional groups in the molecule was obtained. Fingerprint peaks of HDPE plastic were determined as 2915° and 2850° (Figure 12).

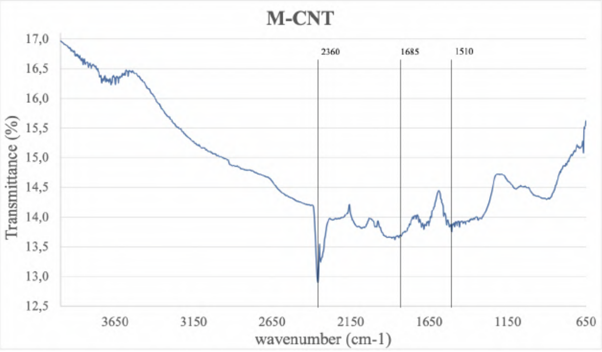

Figure 11: The FTIR fingerprint peaks of the M-CNT.

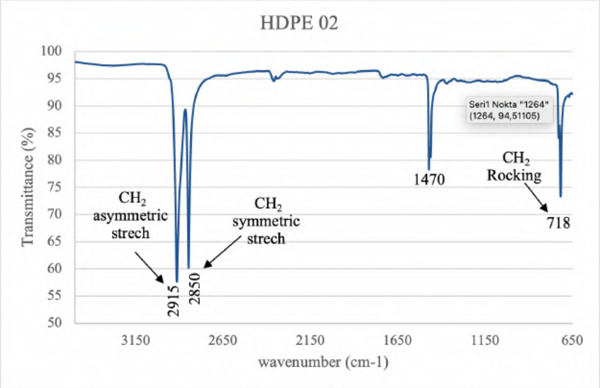

Figure 12: FTIR fingerprint peaks of HDPE MPs

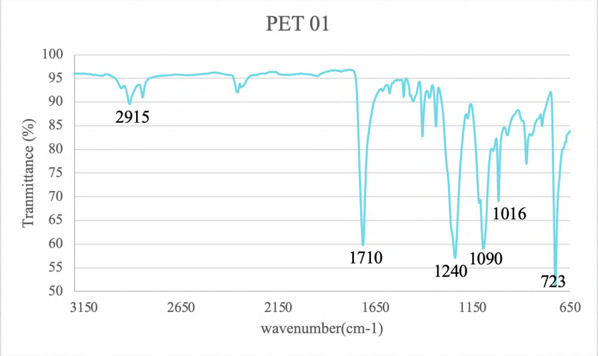

Figure 13: FTIR fingerprint peaks of PET MPs

4.1.3 SEM Analysis

Scanning Electron Microscope (SEM) has been used to investigate the morphology of the prepared M-CNT materials. Figure 14 & 15 shows the SEM images of the M-CNT. According to Figure 14 Fe_3O_4 clusters are attached to the CNTs surfaces. The diameter size of M-CNT is determined to be between 11 and 13nm.

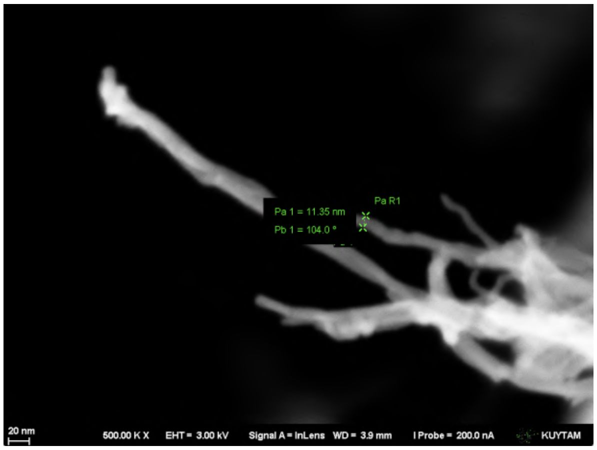

Figure 14: SEM image of M-CNT

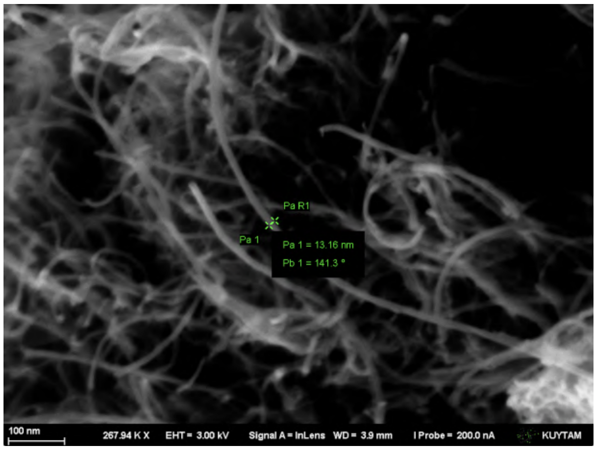

Figure 15: Structure and morphology of the M-CNT.

4.2 Removing Microplastics from Water with M-CNT

The experiments were carried out in 40 mL of artificial seawater in petri dishes. A base clean water is prepared to be used as reference for later comparison, and a control group with no M-CNT treatment is prepared with 10 mg of MPs. For MPs removal experimental groups, the following quantities (in mg) of M-CNT are used: 2.5, 5, 10, 15, and 20. The effect of quantity of M-CNTs on MP removal is investigated.

UV/VIS spectrophotometer was used to record the spectra of cleaned water samples in the range of 300–1000 cm-1, and the baseline (Io) is set as artificial seawater. In Figure 16 The dark blue line at the bottom is the control group, being non-treated MP polluted water sample. And the grey line at the top in 100% transmission rate is the base sample— non polluted artificial seawater. As demonstrated in Figure 17, the removal efficiency of MPs improved as the ratio of MCNTs utilized to clean MPs increased.

Table 1: Experimental Groups

	M-CNT Amount (mg)	MP Amount (mg)	Water (mL)
Base	-	-	40
Control	-	10	40
Ex.1	2.5	10	40
Ex.2	5	10	40
Ex.3	10	10	40
Ex.4	15	10	40
Ex. 5	20	10	40

The water cleaned with 20 mg of M-CNT had a 1.2± 98% transmission rate on average. The optimal ratio of M-CNTs to MPs is determined as 2:1. The transmission measurements of the water cleaned by optimal ratio of M-CNTs to MPs can be seen in Figure 18.

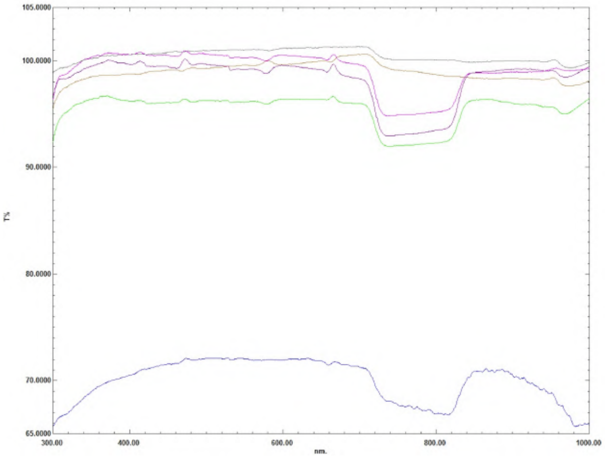

Figure 16: Transmittance spectrum of the samples cleaned with diffrent ratio of M-CNT to MPs.

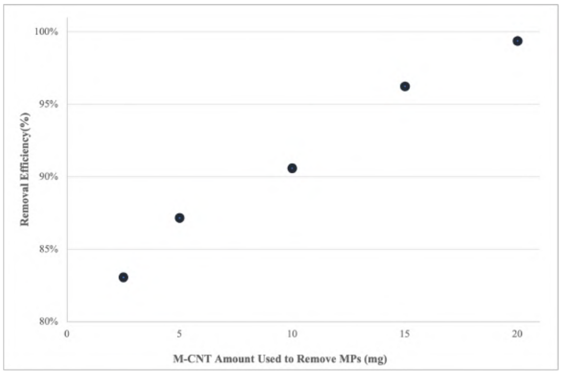

Figure 17: Absorbance spectrums recorded at different times at MPs Removal Process

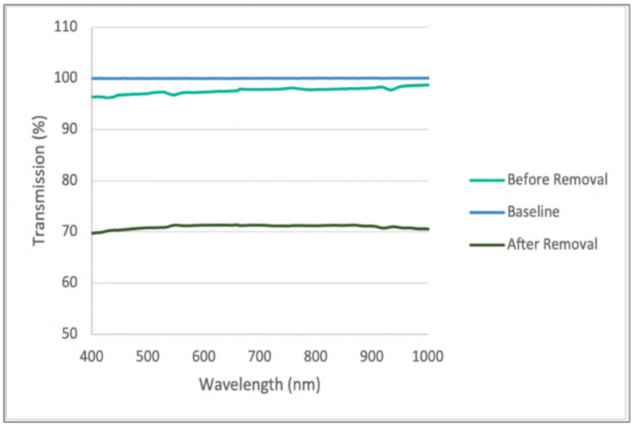

Figure 18: Transmittance spectrum of clean water (baseline), polluted water and the samples cleaned with optimal ratio of M-CNT to MPs.

4.3 Spectral Analyses of MP Removal Process

4.3.1 Absorbance Graph and Beer-Lambert Law

In order to perform Beer-Lambert Law calculations, the molar extinction coefficient must be known. The molar extinction coefficient of HDPE MPs used in this project was experimentally determined and graphed according to the Equations 4 and 2 utilizing HDPE absorbance values recorded at FT-IR. Molar extinction coefficient is greater where the absorption is more intense therefore peak at 825 nm (ϵ = 289.09) is selected to calculate the Beer Lambert law. Utilizing the Equation 4 concentration of MPs before removal and after removal has been calcultated. Subsequently, utilizing Equation 4 the removal efficiency of MPs has been found as 98% successful.

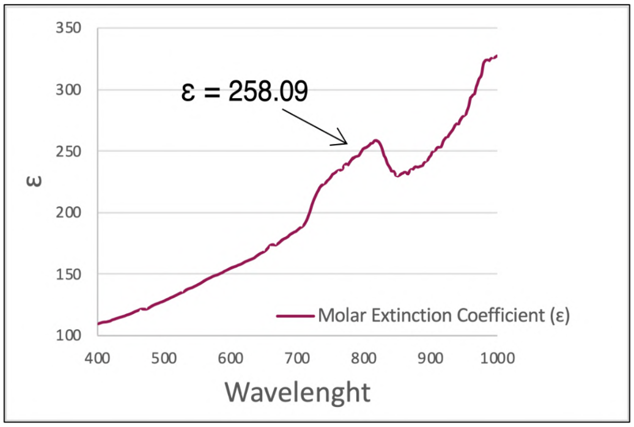

Figure 19: The molar extinction coefficient (ϵ of HDPE MPs used in this experiment.

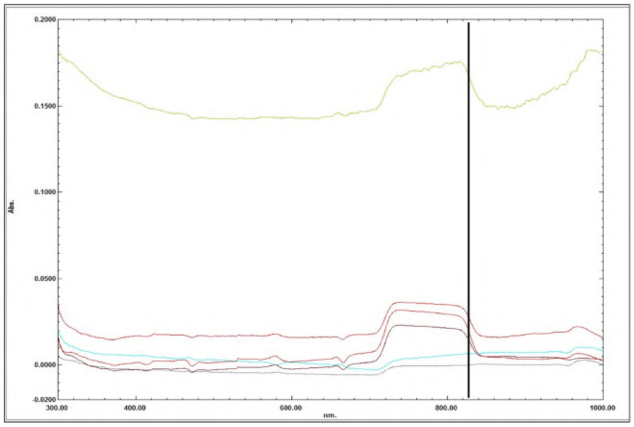

Figure 20: Absorbance graph of MPs removal process of samples cleaned with diffrent ratios of M-CNTs.

4.3.2 M-CNT Adsorbed MP Bulk Analysis

Previous FTIR analyses, as shown in Figure 12, provided the vibration frequencies for HDPE MPs at 2915° and 2850°, and for M-CNTs at 2360° and 1510°, as depicted in Figure 11. Subsequently, after the M-CNTs were utilized for the MP removal process, a solid sample of M-CNTs with adsorbed MPs was subjected to FTIR analysis within the wavelength range of 4000nm-650nm. The acquired spectra in Figure 21 revealed the presence of peaks corresponding to both M-CNTs and HDPE, indicating the successful adsorption of MPs onto M-CNTs and the occurrence of temporary dipole interactions.

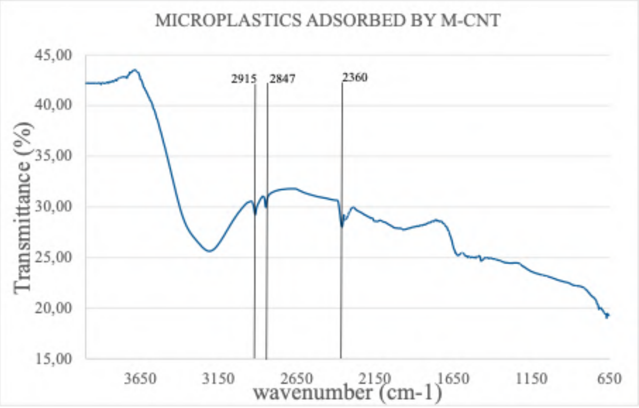

Figure 21: M-CNT adsorbed MPs FTIR spectrum

4.4 Recovery of M-CNTs

For the M-CNT material to be reused in removing microplastics from water, it has to be recovered from MPs. First, the magnetic force was removed and the M-CNT-adsorbed MPs were placed on a glass slide (Figure 22), and their image was recorded with a microscope (Figure 24.a). It can be seen in the bulk that MPs are dominantly present. The bulk waited at room temperature for 5 minutes thus hydrophobic interactions among the MPs and M-CNTs decreased because they were outside of the water. A magnet in a glass tube is passes through the slide (Figure 23), while attracting the M-CNTs, the microplastics remained on the slide. The M-CNT material was collected by the magnet and was examined under the microscope (24.b). In figure it was observed that even in dry conditions the M-CNT material was still adsorbed on some microplastics. To recover M-CNTs the material is dried for 10 minutes in an oven heated to 35°C. Afterward, the particles were washed one round with 20 ml of ethanol and examined under the microscope again (Figure 24.c). Ethanol was preffered due to being known as a polar medium and the MP, M-CNT interaction was based on non-polar, hydrophobic interactions. It was observed that the M-CNT material was recovered from microplastics and could be reused to clean polluted water.

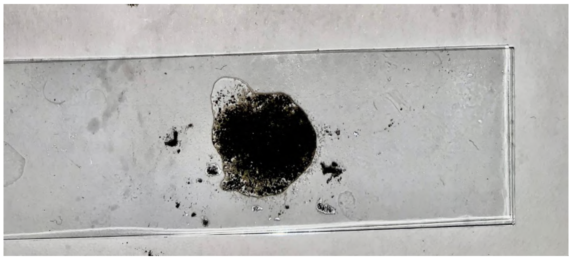

Figure 22: M-CNT adsorbed MPs bulk on a glass slide.

Figure 23: M-CNTs are being separeted from MPs after the removal procces to be recovered

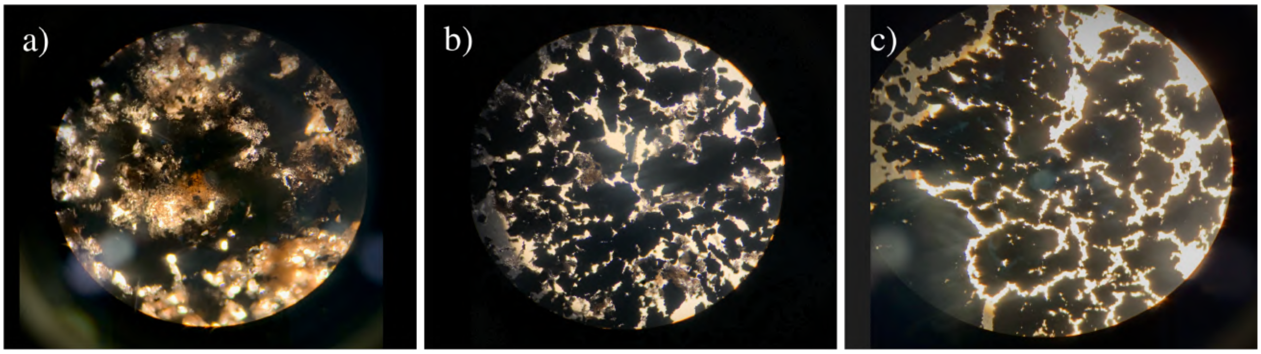

Figure 24: Microscope image of: a) M-CNT adsorbed MPs bulk b) M-CNT after being separated from MPs with magnetic force c) M-CNT after recovery.

4.5 Magnetic Microplastic Removal Machine

For real-life applications of the synthesized M-CNTs, a magnetic water-treatment machine was build. For the microplastic polluted water be cleaned by M-CNTs, the magnets within the machine must be actively controlled. The machine will contain: 2 switchable magnets, a robotic system to move these magnets in and out of the water, a water pump, 3D designed & printed body, and a M-CNT extraction tray. The robotic mechanism is built to activate and deactivate the magnetic field of neodymium magnets, by rotating the magnets' handlebars and switching the disc magnets inside it. For this purpose, the motor's activation sequence is programmed to complete the MPs removal process. The NXT block is used as the brain of the LEGO®-built system. NXT is a computer-controlled LEGO brick with programmable, intelligent decision-making features [19]. The pseudo code plan can be seen in Figure 25.b.

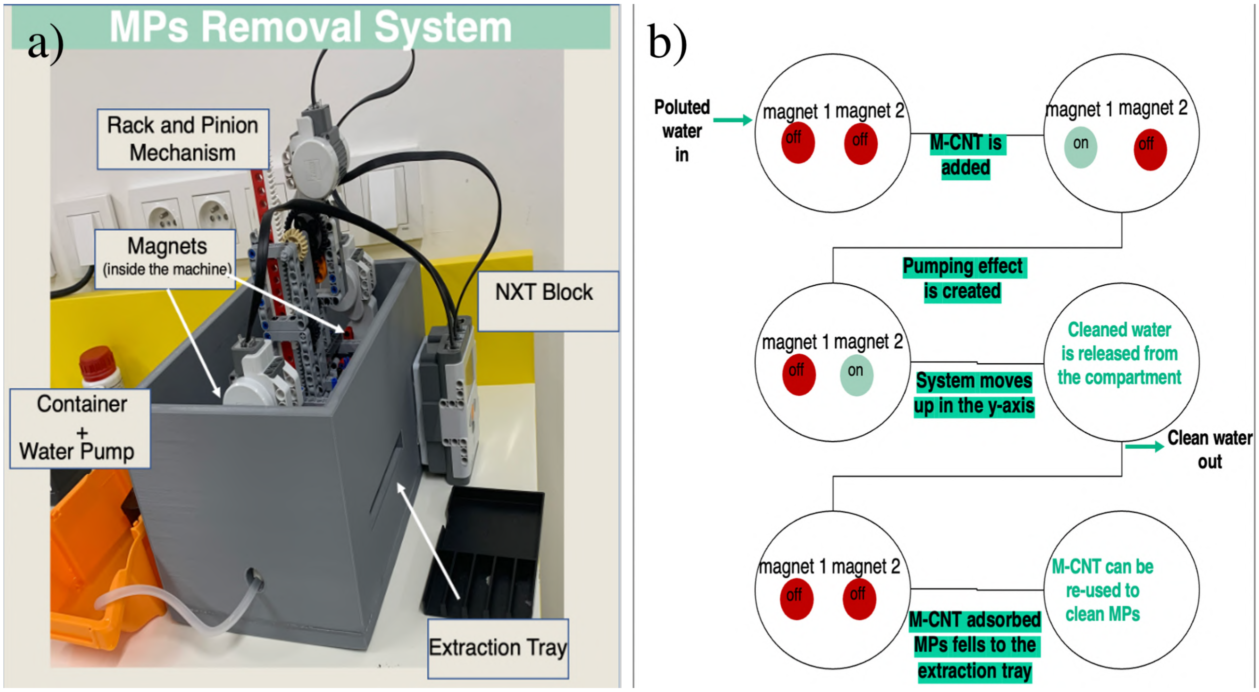

Figure 25: a) The magnetic microplastic removal machine. b) Pseudo code of machine's internal mechanism.

The motor's activation sequence is programmed to complete the MPs removal process (Figure 26). For controlling the interactive servo motors, the NXT contains three output ports designated A, B, and C. The A and B motors are utilized to rotate the primary cogwheels that are fixed to the magnets, with the C motor performing the y-axis movement and carrying both magnets in and out of water.

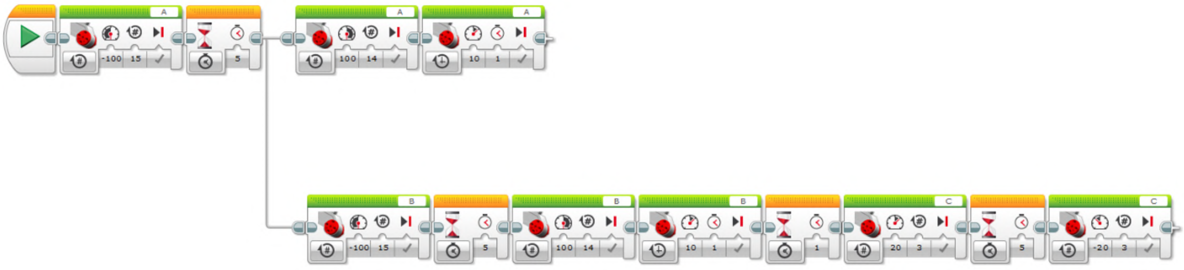

Figure 26: The written codes in NXT brick to programme the machine.

First, the magnetic fields of both magnets are deactivated, and the M-CNT material is added to the incoming MPs-contaminated water. Later, magnet no. 1 is engaged, attracting the MPs that have been bonded to the surfaces of the M-CNTs. Following that, the field of magnet no. 1 is deactivated, and the field of magnet no. 2 is engaged, causing a pumping effect through the machine. This mobility also enables the M-CNTs to interact with MPs and collect additional MPs from the water. Finally, both magnets are engaged, and the entire system moves up along the y-axis, removing M-CNTs adsorbed MPs from water. The water has now been cleaned and released from the compartment.When the magnets are held still in the positive y-axis a tray is inserted beneath them and the magnets deactivate. The M-CNTs and MPs are no longer in control of the magnetic field and thus fall on the tray and are sent for recovery.

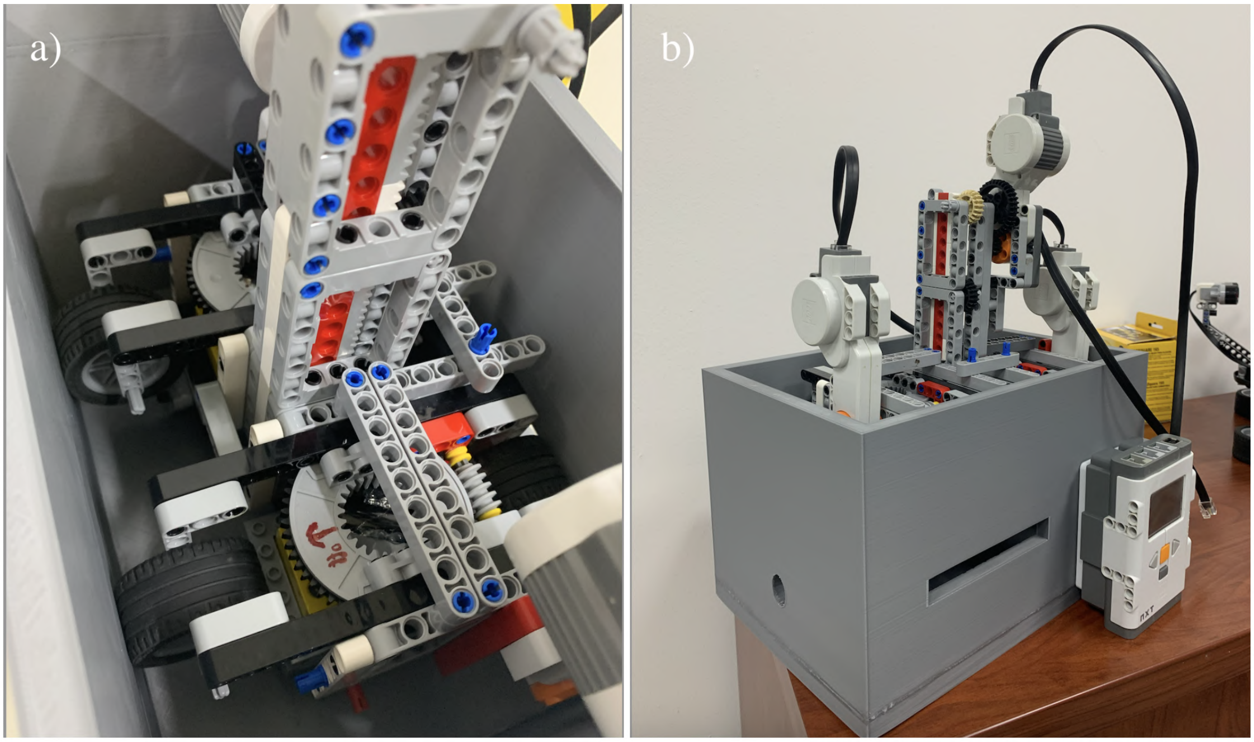

Figure 27: a) The mechanism development for turning manual magnets into an autonomous system. b) The constructed machine for M-CNT applications

Steps of the cleaning process can be itemized as the following:

- Contaminated water is sent in the machine via an arduino water pump.
- M-CNT material is added to the incoming water.
- Magnets go down into y-axis, into the water.
- Magnetic fields of the magnets are periodically activated, causing a pumping effect through the machine. This mobility also facilitates the M-CNTs to interact with MPs and collect more MPs from the water.
- The magnets go up in the y-axis, out of the water.
- Cleaned water is released from the machine.
- The magnets are held still in the positive y-axis and an extraction tray is inserted beneath them.
- The magnets get deactivate thus the M-CNTs and MPs are no longer in control of the magnetic field and fall on the extraction tray.
- Particles on the extraction tray are sent for recovery.

5 Applications & Recommendations

- The developed technology can be incorporated into water treatment facilities to prevent MPs from entering marine ecosystems.
- The designed machine can be mounted on ships to extract MPs from the oceans.
- It is well known that microplastics from washing machines enter the environment and pollute the marine ecosystem significantly. This MPs removal method can be used on washing machine's sewages to prevent synthetic fiber pollution.

6 Conclusion

M-CNTs developed in this project exhibited adherence to the surfaces of all common MPs in artificial seawater. With the application of magnetic forces, the M-CNTs can completely remove MPs within 10 minutes. The adsorption of M-CNTs by MPs were caused due to the strong hydrophobicity of MPs, temporary dipole interactions and electro-static force. The UV/VIS spectrometer findings of cleansed water samples are subejcted for Beer-Lambert Law calculations which demonstrated a 98% success rate for MPs removal. The used M-CNTs can be recovered by thermal treatment at 35°C and washed with considerably low amount of EtOH, and once again be utilzed to remove MPs.

A machine for the real-life applications of M-CNT is developed in which the dual goals of moving M-CNTs through the machine and continuously removing microplastics from water is achieved. Results recommend that M-CNT can be used as efficient, cost-effective, and eco-friendly material to remove microplastics. Hence, MPs removal from water has been investigated by merging nanomaterials with unique surface qualities, and a system that offers a lot of technical potential in terms of cleaning microplastics in aquatic environments has been developed.

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