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Microplastic Eradicator

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Abstract

Upon the current situation that Egypt is confronted with—embodied in the several grand challenges, namely pollution, unclean water, public health problems, and deficiency of recycling—this project was established. This project investigates the consequential problem to be solved, the continuous increment in the amount of microplastic and its diverse threats on the vitality of water. To solve those, the main purpose of the study was set to be eradicating microplastics and their effects on the environment. Accordingly, the chosen solution was made to filter those contaminants from water. In order to successfully do so, design requirements were developed to guarantee the highest efficiency and quality of the prototype. Running the required tests, it was found that the testing results were satisfactory; they met the design requirements and have even exceeded the set expectations. They have also broadened the project's vision even more, ensuing some major findings: electricity is cheaper than chemicals in filtering microplastics. In brief, this project is granting Egypt (and the whole world) the opportunity to reduce the impacts of many grand challenges, most importantly, pollution. In the following sections, all of the above will be more elaborate.

Introduction

There is no doubt that Egypt, akin to several other countries around the globe, faces numerous severe grand challenges. Impeding the progress of Egypt's development, the grand challenges—i.e. pollution, unclean water, public health problems, and deficiency of recycling—are the main threats that are in serious need to be resolved. Of those challenges, one important problem to be solved surfaces: eradicating the spread of microplastics in waterbodies. More than 5 trillion plastic pieces weighing over 250,000 tons are afloat now, and this needs to be solved. Figure 1 shows the spread of microplastic relative to other sizes of plastics, posing a significant problem to both marine and terrestrial life.

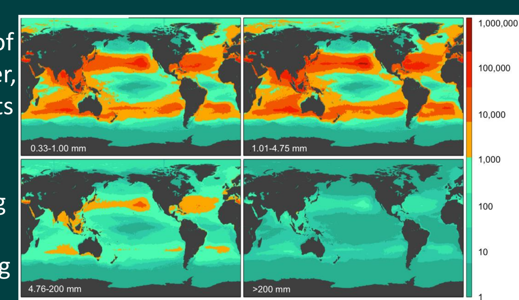


Figure 1 Model results for global count density classified by size

Accordingly, several techniques have been developed in order to solve this problem, most commonly reverse osmosis and nanofiltration. Reverse osmosis is the contrary of osmosis phenomena, where the solvent travels through a semipermeable from an area of high concentration to one of lower concentration by the application of a pressure higher than the osmotic pressure, filtering contaminates such as microplastics. The strengths of this technique are that that it does not use any chemical additives, which means water preserves its taste and quality, and it also removes other contaminants such as sodium, lead, and arsenic. The weaknesses are that (1) the high cost of the filtration units make them impractical, and (2) they need to be repaired every 6-12 months. A similar technique, nanofiltration uses reverse osmosis, but with a semipermeable membrane having extremely narrow sieves, filtering the finest particles of microplastics. The strengths are that it uses a smaller amount of energy and that the membranes have very tiny holes that pathogens such viruses and bacteria does not get through. A weakness is that pretreatment of water may be needed to reduce the number of membrane maintenances required.

After excessive research, and with the prior solutions in mind, the chosen solution was established to solve the problem further, with its design requirements being (1) achieving the highest efficiency in removing microplastics, (2) all of that while keeping the quality of water untampered with (preserving the original pH). Testing the prototype for those design requirements involves (1) measuring the efficiency by determining the amount of microplastics filtered and dividing it by the original amount of microplastics, and (2) measuring the pH of water before and after filtration to make sure they are within an optimum range from the original. For the design requirement to be met, numerous trials have taken place and the most efficient of them were chosen. It filtered water from microplastics using the scientific basis of electrocoagulation as the flocculation method and rapid sand filter as the filtering unit.

Succeeding to achieve these design requirements effectively, the chosen solution proved its efficiency and applicability to be implemented on the large, real-life scale. In the following section, the materials and methods used to develop this project are discussed.

Materials & Method

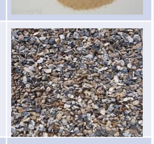
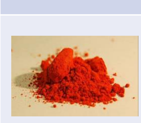
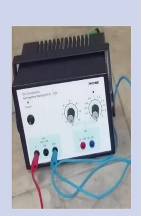
Name	Description	Illustration	Name	Description	Illustration	Name	Description	Illustration
Sand	25 cm × 25 cm × 5.5 cm of fine sand for the filtration of water in the rapid sand filter		Plastic Container	Plastic container was used to store water after it was electrocoagulated		Electrodes	Aluminum Electrodes of dimensions 11.5 cm × 20 cm × 1 mm was used for electrocoagulation	
Gravel	25 cm × 25 cm × 7 cm of gravel for the diffusion of the water in the rapid sand filter		Faucet	It was used to get the water out of the container				
Activated Carbon	25 cm × 25 cm × 1 cm of fine activated carbon grains for the microfiltration of the water in the rapid sand filter		Hoses	Hoses with 0.75-inch diameter was used to transfer water through containers		Water Tap Filter	It was used to make sure that there are no more macro particles that would ger in the water final product	
Cotton	1 pack of Cotton was used to collect the suspended particles from clogging the faucet and the tap filter		Nile Red Dye	A dye used to indicate suspended solids in water		Power Supply	It was used to stabilize an electric current and to control its properties	
Glass containers	25 × 30 × 25 cm^3 container was used for electrocoagulation 20 × 50 × 20 cm^3 container was used for coagulants settling 20 × 25 × 25 cm^3 container was used for the rapid sand filter		Crocodile Wires	It was used to connect electrodes with the power supply				

Table 1 The materials used

Method

Electrocoagulation Chamber

- First, glass was cut and assembled using silicon to form a 25 × 30 × 25 cm^3 container.
- Second, a wooden plate with length 25 cm was cut in a zigzag shape to hold the electrodes in the water and it was hanged in a longer plate of length 35 cm.
- Third, aluminum electrodes of dimensions 11.5 × 20 cm^2 were fixed to the zigzag shaped plate to be held during the coagulation, as shown in Figure 2.
- Fourth, crocodile wires were connected to the electrodes and the power supply to start the coagulation as shown in Figure 3.


Figure 2 Electrodes configuration

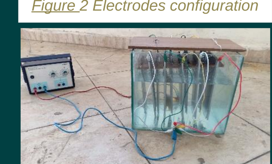


Figure 3 Final unit

Methods

Settling Chamber

- First, glass was cut and assembled using silicon to form a 50 × 20 × 20 cm^3 container.
- Second, four glass sheets were fixed inside the container as shown in Figure 4, where two sheets were fixed up, and two down.


Figure 4 Settling unit

Rapid sand filter Chamber

- First, glass was cut and assembled using silicon to form a 25 × 20 × 25 cm^3 container.
- Second, a faucet was fixed to the container wall to let water out when needed as shown in Figure 5, and a water tap filter was fixed to prevent sand from going inside the faucet.
- Third, activated carbon, sand and gravel were washed several times to make sure they are dust free.
- Fourth, 7 cm of gravel were put at the bottom, then a mesh was put to prevent sand from going between the gravel grains.
- Fifth, 5.5 cm of sand were put above the mesh, then another mesh layer was put to prevent activated carbon grains from mixing with sand grains.
- Finally, 1 cm of activated carbon were put above the mesh and they were covered by a cotton layer to distribute water on the whole filtering area as shown in Figure 6.

The final prototype is shown in Figure 7.

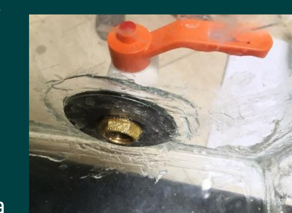


Figure 5 The faucet


Figure 6 Final rapid sand filter


Figure 7 Final prototype

Test Plan

To measure the efficiency of microplastic removal, two methods are employed:

First

1. Add a sample of microplastic to distilled water without any contaminants
2. Measure the TSS in water (C0)
3. Run the filtration
4. Measure the TSS in water again (C)
5. Calculate efficiency using the equation $\frac{C_0 - C}{C_0} \times 100\%$

Second

1. Prepare 6 microscope slides of water, 3 unfiltered and 3 filtered, as shown in Figure 8
2. Take a picture of each slide under the microscope
3. For the unfiltered slides, calculate the number of pixels in which microplastic particulates occur to exist as C0
4. For the filtered slides, calculate the number of pixels in which microplastic particulates occur to exist as C
5. Calculate efficiency using the equation $\frac{C_0 - C}{C_0} \times 100\%$
6. Take the average


Figure 8 Slide preparation

To measure water quality the following is done:

1. Measure any water quality indicative property (such as pH shown in Figure 9) before the filtration
2. Run the filtration
3. Remeasure that same indicative of water quality
4. Make sure changes are in an optimum range


Figure 9 Measuring the pH of water

Results

Negative Results

While constructing the project, negative results were faced, where some unintended errors took place, which led to the reconstruction of some parts of the prototype. For instance, while working on the rapid sand filter, the materials were arranged based only porosity. However, after adding water during the test, the materials were mixed because of the difference in specific gravity, heavy materials went down and the light up.

Results

Three tests were done to ensure efficiency in removal of microplastic and the quality of resultant water, which are the design requirements.

TSS Test

To measure the amount of microplastic removal, a TSS (Total Suspended Solids) apparatus by the name of ZS-680 SS Concentration Controller (shown in Figure 10) was used. It measured any undissolved solids suspended in water, which includes microplastics. Employing the test plan, the initial reading of the TSS in the contaminated water was 92 mg/L. Moreover, the filtered water showed a TSS of only 12 mg/L, making the removal efficiency $\frac{92-12}{92}$ = 87.0%.


Figure 10 TSS Apparatus

Microscope Test

Another test that was employed to measure the amount of microplastic removed was the microscope test. Therein, the number of microplastic pixels were 16489 for every 190080 pixels (illustrated in Figure 11(a)). With the filtered water, this number was reduced to only 1172 pixels for every 144622 pixels on average (illustrated in Figure 11(b)), showing a removal efficiency $\frac{\frac{16489}{190080} - \frac{1172}{144622}}{\frac{16489}{190080}}$ = 90.7%.

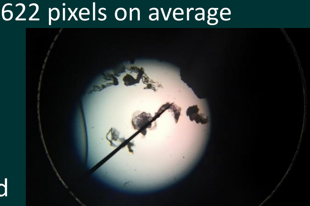


Figure 11(a) Contaminated water


Figure 11(b) Filtered Water

pH Test

To measure water quality, a pH test was executed, whereby the acidity and alkalinity was made sure not to fall out of the optimum range. Providentially, the pH of water before and after the filtration has been measured to be in the range 7-8, as shown in Figure 12

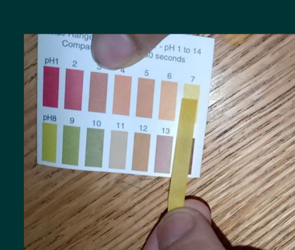


Figure 12 pH of water

Final

Results are collected in Table 2.

Test	Unfiltered	Filtered
TSS	92 mg/L	12 mg/L
Microscope	0.088 mp pixel / white pixel	0.008 mp pixel / white pixel
pH	~7-8	~7-8

Table 2 Collected Results

Analysis

As affirmed in the results section, the project has achieved its design requirement, removing microplastics and resulting in water that is usable and highly unpolluted. Next will be explained why that is so.

Electrocoagulation Chamber

Overview

An electrocoagulation unit (illustrated in Figure 13) is an electrolytic cell made up of an anode and a cathode. When a potential is applied from an external power supply, the anode material (metal M) undergoes oxidation, as shown in Equation 1 and Equation 2. Water may also be oxidized forming hydronium ion and elevated oxygen, while the cathode will be subjected to reduction, as shown in Equation 3 and Equation 4 (where Z is the number of electrons transferred in the anodic dissolution process per mole of metal).

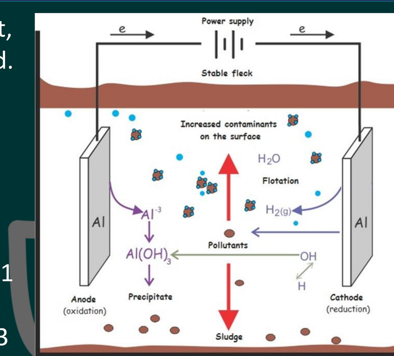


Figure 13 Overview of electrocoagulation

$$M_{(s)} \rightarrow M_{(aq)}{}^{Z+} + Ze^-$$
Equation 1 Oxidation half-reaction

$$2H_2O_{(l)} \rightarrow 4H^+{}_{(aq)} + O_{2\,(g)} + 4e^-$$
Equation 2 Oxidation of water

$$M_{(aq)}{}^{Z+} + Ze^- \rightarrow M_{(s)}$$
Equation 3 Reduction half-reaction

$$2H_2O_{(l)} + 2e^- \rightarrow 2H_{2\,(g)} + 2OH^-{}_{(aq)}$$
Equation 4 Electrolysis of water

With its simple design and easy operability, this technology removes metal, colloidal solids, suspended particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric metal hydroxide species. Those species neutralize the electrostatic charges on suspended solids to facilitate agglomeration or coagulation and the subsequent separation from the aqueous phase.

Microplastic Suspension

Microplastic's presence in water can be explained using the phenomenon of colloidal stability. Due to the occurrence of repulsive electrical charges on the surface of the particles, they remain in the dispersed state. Given that their total surface area is large compared to their mass and size, the gravitational forces of colloids are often neglected compared to the surface phenomena of the fluid. The particles remain suspended and stable due to the fact that they carry a similar charge (acquired as per triboelectric effect between the particle and water, as explained in physics), usually negative, so repulsion arises. In order to destabilize this suspension, the repulsive forces are to be overcome and instead interaction forces should dominate. One way is to neutralize this charge and consequently break suspension by using oppositely charged particles that get attracted to the surface of the colloids forming an electric double layer as illustrated in Figure 14.

The electric double layer consists of an inner section (stern layer), where ions of opposite charge bond to the surface of colloidal particles, and an outer section (ion diffuse layer or slipping plane), where the ions enter and leave freely as per diffusion. This double layer creates a repulsive field around it, which is dictated by its extent (as the thickness of the double layer increases, the repulsive forces also increases, and vice versa).

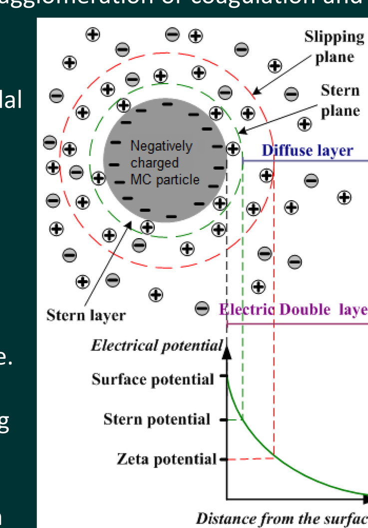


Figure 14 Electric double layer illustration

Microplastic Destabilization

To overcome those repulsive forces, adding counter charged ions to the solution by the oxidation of the anode is done. Those metal ions are provided by the oxidation reaction at the cathode, which results in Al3+ ions. By doing so, the metal ions will diffuse through the double layer and adhere to the particle, causing higher counter ion concertation around the particle. This in turn reduces the layer thickness and repulsive forces, making room for the van der Waals forces to appear and predominate, and resulting in particles coming easier together forming larger flocs.

At appropriate pH values, Al^{3+} continues to react to form $Al(OH)_3$, which is finally polymerized to $Al_n(OH)_{3n}$, conforming to Equation 1 (with Z = 3), and to the equations Equation 5 and Equation 6:

$$Al^{3+}{}_{(aq)} + 3H_2O_{(l)} \rightarrow Al(OH)_{3\,(s)} + 3H^+{}_{(aq)}$$
Equation 5 Aluminium ions' transformation

$$nAl(OH)_3 \rightarrow Al_n(OH)_{3n}$$
Equation 6 Polymerization of aluminum hydroxide

When those polymerized molecules reach higher molecular weight and longer chain lengths, the obtain the ability to form "bridges" between the particles. Those bridges result in larger particles and hence better destabilization. Moreover, as some insoluble metal hydrates precipitate, they cause sweep coagulation, where they entrap colloidal particles, falling with them.

The Electrodes

The choice of electrode materials carries some consequences. Two choices are the most extensively used: iron and aluminum. Iron is the first plausible choice, being the most abundant and the least expensive of the two. However, several problems arise with iron: (1) iron exhibits the buffer effect in a weaker manner than aluminum, leaving effluent water with 9 or 10 pH value, even if the initial pH is acidic; (2) iron(II) ions are highly soluble and, therefore, less capable of destabilizing a colloid by $Fe(OH)_3$; (3) iron requires aeration of water to increase the dissolved oxygen concentration and, consequently, iron(II) oxidation; and (4) iron requires the pH to be 7.5 or higher to increase iron(II) oxidation rate. To avert those downsides, and with their advantages in mind, aluminum electrodes were chosen.

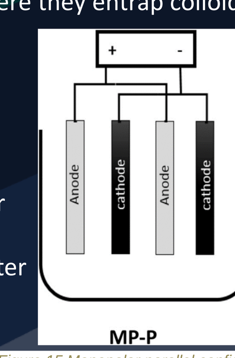


Figure 15 Monopolar parallel configuration

According to most authors, aluminum results in more efficient destabilization and, thus, removal of particles. Also, because the Lewis acidity of aluminum ions at the cathode balances the formation of OH^- at the anode, the aforementioned buffer effect takes place, which results a final pH between 7 and 8.

Apart from the material, other were taken into consideration. First, MP-P (Figure 15) electrodes configurations has been deemed by many authors as the most efficient configuration: monopolar electrodes are less costly than bipolar electrodes, and attaching them in parallel results in a better distribution of charges, consequently better destabilization. Second, AC power supply was used in favor of DC current (which causes passivation of the cathode), resulting in a better current efficiency and a better electrode life. Third, current density, as it increases, results in more coagulations agents (aluminum ions), and consequently better particle flocculation. However, there exists a certain limit in above which a higher chance of wasting electrical energy in heating the water thereby reducing current efficiency. So, a 21.7 mA/cm^2 current density was used. Finally, the distance between each two electrodes was minimized to be 2 cm in order to maximize floating by hydrogenation.

Electrode Dissolution

$$m = \frac{ItM_w}{ZF}$$
Equation 7 Faraday's law

As explained in chemistry, Faraday's law (stated in Equation 7) can be employed to measure the rate of dissolution of the anode.

The terms of Faraday's law are I (the current in A), t (time of the operation in s), M_w (the molecular weight in g/mol), F (Faraday's constant being 96485 C/mol), Z (the number of valency), and m (the mass of anode dissolved in g). This law can be used to predict an estimated time by which the cathode will be used up.

Settling Chamber

The settling chamber gives the coagulated material the chance to mix and collide more. These collisions make the van der Waals forces predominate between them, resulting in larger flocs and coagulants, easing their filtration in the rapid sand filter. The path that the water takes is illustrated in Figure 16.

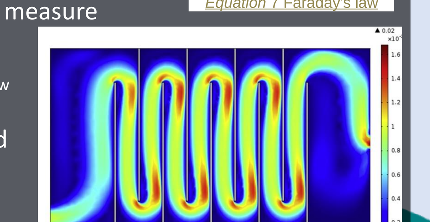


Figure 16 Flow path

Rapid Sand Filter

Sand bed filters work by providing the particulate solids with chances to adhere to the surface of a grain. As water flows the porous sand along a winding route, the particulates get closer to the grains and collide with them. The layers are arranged based on specific gravity to diminish the danger of mixing. In the following, each layer will be talked about thoroughly.

Activated Carbon

With the least specific gravity, activated carbon was put first, causing physical adsorption (illustrated in Figure 17), a property dependent on the van der Waal forces between its high surface area and the particulates, to the smaller particles, any odor- or test-making molecules and such.

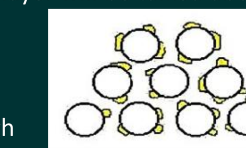


Figure 17 Illustration of physical adsorption

Sand Grains

Next come the Sand grains, providing the process of mechanical straining (illustrated in Figure 18), which is dependent on the porosity of sand, so that larger particulates resulted from coagulation or flocculation processes not penetrate the small pores between the grains, making the medium only permeable for water.

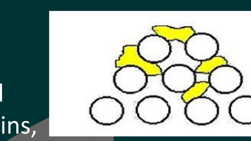


Figure 18 Illustration of mechanical straining

Gravel Particles

During filtration, the gravel ensures a smooth and diffused flow and avoids the sand layer being disturbed during backwash.

Meeting the design requirement

The prototype clearly shows how the design requirements was met, being highly efficient, and producing high quality water. Having a high efficiency, as stated in the design requirement, the project helps solve the problems to be solved, and thus contributes to the diminishing of the related grand challenges. They also evidently help the world filter one of the most hurtful kinds of pollution, and that is microplastics.

Conclusion

Regarding all the required scientific analyses, reasoning, and tests that have taken place, the results show that the project have successfully fulfilled its design requirements and that it is implementable in real life. They also show that the project is capable of resolving the specific problem, and thus, help eliminate the related grand challenges.

Recommendations

Better Test: Raman Spectrometer

In order to get more accurate results, an apparatus by the name of Spectrometer (shown in Figure 19) can be used to measure the concentration of microplastics in water. This apparatus sends a spectrum that has units of relative wave number shift (cm^{-1}). Quantized vibrational modes within the molecule have different energies, leading to peaks in different places on the spectrum, akin to a fingerprint for each material. This results in more accurate and effective results, measuring only microplastics and allowing for more types of water to be measured. With all those advantages, however, a Raman spectrometer is more expensive compared to the methods used


Figure 19 A spectrometer

The Efficient Sufficient: Cationic Polymer and Aeration

Increasing the efficiency of the project is essential. As such, two methods are proposed that accomplish this feat. The two methods play part during the flocculation phase, enhancing it, but each with its different technique. Cationic polymer increases the bridging effect between the particles, causing larger, more stable flocs to form. PolyDADMAC (shown in Figure 20) is an example of such cationic polymer. Efficiency can also be increasing by aerating the water. This results in better steering of the flocs, more collisions, and thus bigger flocs that are easier to filter.

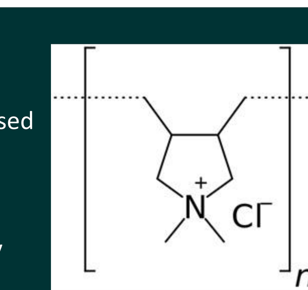


Figure 20 Dadmac monomer

Water, Drinkable: Chlorination

A final stage is required to construct a device that filters wastewater to drinkable water, and it is chlorination. Chlorination (illustrated in Figure 21) is the disinfection process wherein chlorine or a chlorine compound such as solid calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite solution (NaOCl) are added to the water. This causes germs and other microorganisms to die, preventing the spread of waterborne diseases such as cholera, dysentery, and typhoid, which leaves water that is drinkable and not unhealthy.

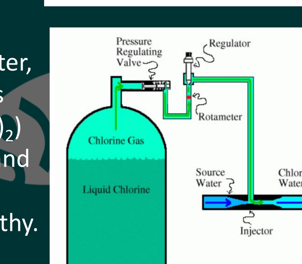


Figure 21 Chlorination illustration

Recycling or Incineration: the Hydrocyclone

Based on the ratio of their centripetal force to fluid resistance, the hydrocyclone (shown in Figure 22) classifies, separates, or sorts particles in a liquid suspension. This device can be implemented after the electrocoagulation in order to achieve two things: (1) mixing (and hence larger flocs) and (2) an effluent with the larger flocs in it, allowing the ability of the microplastic particles to be more easily retained. The retained materials can then be incinerated to generate electricity or firstly separated based on density and then each group melted together. The inability to create such an intricate device was the reason behind hindering the progress towards its implementation.

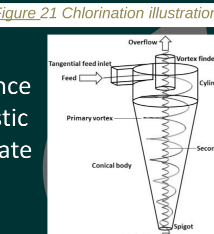


Figure 22 A hydrocyclone

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