SMALLER THINGS

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جمهورية مصر العربية
وزارة التربية والتعليم

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ABSTRACT

Despite overseeing two international seas and a major freshwater source, Egypt quarrels with the grand challenges of water pollution, diminishing clean water sources, recycling, and public health. This is a direct result of the unstable waste management measures, enabling industries to dispose of their wastes in rivers and seas. Among the most common of these wastes are plastics that degrade into microplastics under the effect of solar ultraviolet rays. Microplastics pollutes water, diminishes water sources, and impose health risks for both humans and marine organisms. Upon the research that was based on the purpose of study of solving the microplastic pollution in Egypt's freshwaters, the solution was chosen to be a gravel/sand/activated carbon/ceramic filter. To test the validity of the project, the design requirements were selected to be both water quality (neutral pH and low salinity [TDS]) and microplastic removal efficiency. The major finding of this project was the neutralization abilities of ceramic filters to overcome the weaknesses of activated carbon. As this document, hereby, will reveal in more detail, the results were astonishing and stellar, showing both efficiency and a significantly cleaner drinkable water. It was concluded that the project is valid and could be used in Egypt's locality.

Introduction

Egypt contributes with a large ecological footprint when considering the problems of water pollution, clean water sources, and recycling. These problems are commonly referred to as the Egypt Grand Challenges, a direct result of the inactive anti-pollution legalizations. The team attempts to create a filter made from cheap recycled materials to reduce the water pollution in Egypt and its related health hazards.

The problem to be solved chosen was microplastic pollution: *any polymerized plastic molecule in freshwater sources with a granule size below 5mm*. The extremes of this problem are highlighted by the fact that Egypt discards 0.25 million tons of macro– and microplastics annually to the Mediterranean Sea alone. This is equivalent to 44.1% of the total Mediterranean plastic deposits (see figure 1). The same figures could be used to stress the concentration of microplastics in freshwater (see figure 2).

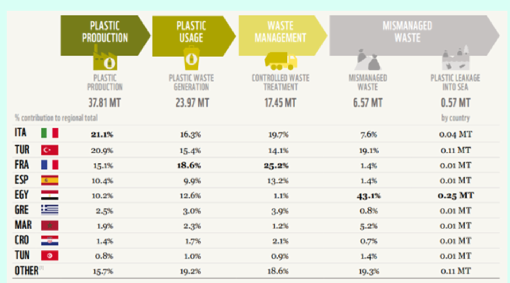


Figure 1 shows a comparison between the mismanaged wastes percentage of the countries of the Mediterranean.

Figure 2 illustrates the effect of Egypt and two other nations on the plastic leakage to nature. This highlights the effects on both saline and freshwater sources in Egypt.

To accomplish a valid project, the team researched two prior solutions: (1) sand filtration, and (2) ferrofluid coagulation. First, a sand filter uses sand grains of less than 1mm diameter to trap large particles in water. The sand is supported by a bed of gravel in a closed container in which water flows by the effect of gravity (see figure 3). The project showed strengths of availability and efficiency, while it showed weaknesses in the microplastic sizes it could remove (down to 15-microns). Second, ferrofluids use coconut oil and magnetite to adsorb microplastics to be removed under the effect of a magnetic field. Its strengths are the high efficiency (85%) and ease of use, while its weaknesses are the uncontrollable extraction of needed minerals.

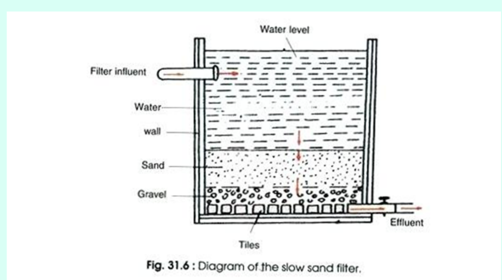


Figure 3 demonstrates a slow sand filter with layers made of sand and gravel to filter large particles of more than 100-microns. A sand filter consists of fine sand grains supported by a bed of rocks through which water flows.

The profound research allowed the team to choose a solution capable of solving the addressed problem, and thus, the grand challenges. The solution chosen is a two-stage filter made from gravels, sand, activated carbon, and kaolin clay (second stage). In the prototype, layers of the first stage are arranged with a filtration mesh for separation, then water is allowed to pass through kaolin clay pores to the insides of the filter and lastly to the faucet.

The design requirements were chosen to be both water quality in terms of pH and TDS levels, and microplastic removal efficiency. The project achieves both design requirements, it uses few cheap, mostly recycled/recyclable resources to filter large amounts of water from microplastic pollution while keeping its drinkability qualities. This is a result of the finely chosen materials described in the next section: materials and methods.

MATERIALS AND METHODS

Table 1:

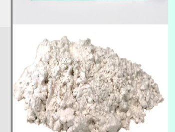
	Quantity	Description	Picture
Fine Sand	500 grams	Fine granular rocks divided into sizes of 1mm used to filter large particles down to 15-microns.	
Coconut Activated Carbon	450 grams	Coconut-based charcoal with small pores and high adsorption used to adsorb microplastics down to 10-microns.	
Cotton Cloth Mesh	4 sheets	A filtration mesh of pore size smaller than the diameter of fine sand to separate the layers of the filter.	
Gravels with Maifan Stones	750 grams	Fine gravel-sized stones of 6mm including neutral gravels and maifan stones.	
Glass Containers	2 containers	A container made from non-crystalline solid glass Used to contain and facilitate the movement of water through filtration layers	
Kaolin Clay	2 kilograms	A clay mineral used to make ceramic filters with small-sized pores made of kaolinite and quartz.	
Thin Hoses	2 hoses	A hollow tubing made designed to carry and transport fluids.	
Corn Starch	200 grams 10% of Kaolin CLay	Combustible material added to increase kaolin clay	
Water Pump	1, 12V	A device used to transfer water by the effect of pressure, operates at 12V and 0.6A.	

Table 1 showing the materials used.

Methods

First Stage

1. Build a container using glass sheets to house the first stage, leave it open wide from the top and separate the inners to two equal-sized chambers with a hole in the lower one (see figure 4)
2. Refine sand using a sieve of less than 2mm (see figure 5)
3. Refine gravels down to 6mm
4. Start by adding in the top chamber, in order, layers of mafian stones, activated carbon, refined sand, and gravels (amounts from table 1), each separated with a cotton mesh from the other layers (see figure 4)
5. Connect the bottom of the container to the next stage using a thin hose

Figure 4 shows the layers of the prototype arranged in order with cotton in between in a double-chamber container.

Second Stage

1. Bring 2,000 grams of moist kaolin clay and mix it with 200 grams of cornstarch
2. Start throwing (shaping) the clay by hand or using a potter's wheel to make a long cylinder open from one side
3. Once finished, leave it to dry for two days and then fire it at a temperature of 900–1150°C
4. Attach a funnel-like terminal plastic to finish the ceramic filter (see figure 6)
5. Build a container made of glass sheets slightly larger than the ceramic filter with two openings, one with the size of the funnel on the bottom and the other on the side
6. Attach the ceramic candle inside the container (see figure 6)
7. Connect the hole on the side to the previous stage using a pipe
8. Place the ceramic filter with the opening facing down and connect the funnel opening with a tube to a pipe and then to the faucet

Figure 5 shows the sieving of sand.

Figure 6 shows the ceramic filter installed in a glass container with a funnel opening

Test Plans

pH and TDS (each stage)

1. Take three samples of tap water and run the pH and TDS meters (see figure 7) on both filtered and unfiltered specimens
2. Repeat the process three times and take the average for accuracy and record the final result to measure the efficiency

Microplastics Removal Efficiency (TSS)

1. Add synthetic microplastics (handmade degraded microplastics or secondary microplastics) to distilled water and measure water volume*
2. Using TS (total solids) meter to calculate the total solids in aqueous solution. It is done before and after the filtration process, so TS before and after filtration process is calculated.
3. Take TDS value from the previous test plan
4. Calculate microplastic concentration by TSS (total suspended solids) value which indicates the amount of non-soluble materials in water
5. Use the TS value and TDS value to calculate TSS, as that TSS = TS-TDS

* distilled water used to ensure that all suspended content in water are microplastics

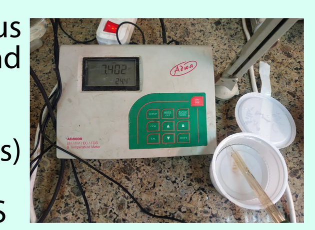


Figure 7 shows the pH/TDS meter in testing.

Safety Precautions

1. Dealing with any chemicals and/or chemical reactions must be done in a laboratory under the supervision of a responsible lab supervisor while wearing appropriate apron, gloves, googles, and lab coat.
2. No produced water can be drunk at any circumstances until proven to be drinkable through lab tests.

RESULTS

Negative Results

At first, the prototype construction was obstructed due to problems with the separation of the layers of the first stage. A few types of filtration mesh were used including fibers, silk, and polyester. Fibers would disassociate into water, and polyester and silk increased microfiber contents. The best two types of mesh were settled on to be either cotton cloth of a filtration membrane of 0.5mm or slightly lower/higher. Both separate the layers effectively, are stable, and builds appropriate flow rate.

Positive Results

Upon testing, the project's prototype showed outstanding results, sufficient to fulfil both design requirements of water quality and microplastics removal efficiency. Doing so, the project is capable of solving the capstone challenge of microplastic pollution in water sources, and thus, the grand challenges in Egypt of recycling, water pollution, and lack of water sources. Results outlined in table 2 and figure 8.

The water had a final pH of 7.268±0.01 pH, TDS of 0.28±0.01mg/mL, a TSS of 0.36±0.01mg/mL, TS of 0.64±0.01mg/mL, turbidity clearance efficiency of 97.3±1%, and microplastic removal efficiency of 91.8±1%.

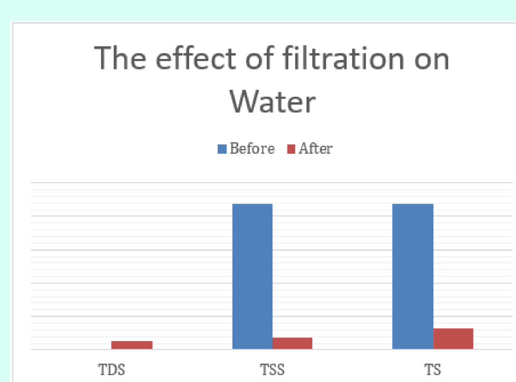


Figure 8 shows the effect of filtration on water in a stacked graph. Blue is for before, red for after.

	Before	First Stage	After
pH Level	~7.000±0.01	7.402±0.01	7.268±0.01
TDS	~0±1mg/mL	—	0.28±0.01 mg/mL
TSS	~4.39±1mg/mL	—	0.36mg/mL
TS	~4.39±1mg/mL	—	0.64mg/mL
Microplastics Removal Efficiency	—	—	91.8±1% down to 1-micron

Table 2 shows the final results obtained from the average of three different experimenets on distilled water. Only the pH level was measured directly after the first stage.

ANALYSIS

Precise scientific bases were used to ensure that the project (figure 4 & 6) is capable of achieving the design requirement. Doing so, the project solves the problem of microplastic pollution in water and, thus, the respective grand challenges formerly addressed. These bases are discussed in the following:

Microplastics

Microplastics are plastics of size range from 1nm to 5mm. The microplastics either come from primary or secondary sources. Primary microplastics are manufactured with a diameter within the microplastic size range, while secondary microplastics are large plastics degraded by the sun ultraviolet rays. Microplastics, in the project, are removed using mechanical straining through layers of sand and gravel, cross-flow filtration in the Kaoline Clay filter, and adsorption through the activated carbon and sand.

Porosity and Permeability

Two key concepts in the design of this filtration method are porosity and permeability (ES1.12). Porosity is defined as the volume of pores in a body, while permeability is the amount of liquid flowing through the body. During filtration, pore size defines the minimum size trapped by a filter. For permeability, a suitable flow rate is defined as a one that supplies enough of the liquid while giving the liquid the needed exposure time.

First Stage

The first stage consists of four layers of maifan stones, neutral gravels, activated carbon, and refined sand (see figure 4). This stage works under the effect of gravity, traps large particles and removes taste and odor. Neutral gravels of large effective sizes are used to balance the volume flow rate and to trap large pollutants.

Pollutant	Percent Removal	Pollutant	Percent Removal
Fecal coliform	76	Total Organic Carbon (TOC)	48
Biochemical Oxygen Demand (BOD)	70	Total Nitrogen (TN)	21
Total Suspended Solids (TSS)	70	Iron, Lead, Zinc	45

Table 3 shows typical removal efficiencies of sand filtration layer.

The sand filtration layer is made of refined sand of diameter below 1mm. This filter layer is supported by a bed of GAC. The pore sizes of the sand layer are typically <100-microns. Sand filtration has an efficiency of 90% down to 0.5-microns; however, only 5% of which are actually 0.5-microns particles; the rest are >15-micron particles. It also has a 70% efficiency removal of microplastics (and other suspended solids, see table 3). This lowers the turbidity created by the GAC. Sand also has little or no effect on both TDS and pH levels.

The next layer is a layer of granular activated carbon (GAC) extracted from coconut shells. GAC is designed to have low-volume pores that increase the surface area (>1000m2/g) to increase the adsorption rate. Adsorption of microplastics in GAC is operated through London Dispersion forces. London dispersion forces induce temporary dipoles in microplastic atoms (see figure 9). Despite being the weakest force, it is highly sensitive to distance and additive (the sum of all contact forces between atoms), making it the best for adsorption.

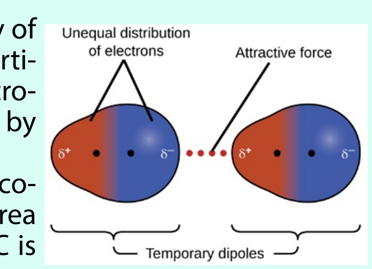


Figure 9 demonstrates the temporary dipole moment of neutral atoms forming the London dispersion force.

GAC also removes most large microplastics >10-microns in water, taste and odor, chlorine, heavy metals, radon, and sediments. However, it increases turbidity up to 200% and acidity up from pH 7.8 through pH 3.3. This is treated with maifan stones, sand, and kaoline clay (see figure 10).

The filtration of GAC is affected heavily by the acidity: the more acidic the solution is, the higher efficiency it provides. Thus, maifan stones are placed after GAC to ensure that the alkalinity it provides does not interfere with the functionality of GAC. Maifan stones (mostly plagioclase feldspar) are a 6mm in diameter mineral used to increase the alkalinity of water to overcome the extreme acidity created by the GAC.

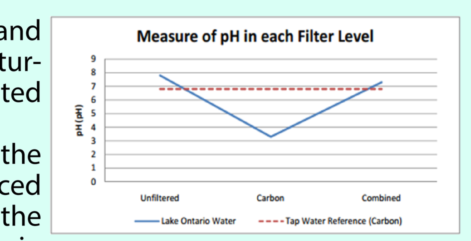


Figure 10 showing the effect of activated carbon and activated carbon combined with kaoline clay filter effects on water pH level.

Kaolin Clay Filtration

Clay is formed from the erosion/weathering of igneous rocks. Clay is selected for this type of filtration due to its small pore size because it is smaller than sand, slit, or gravels.

Kaolin ceramic clay filtration is composed of kaolinite/quartz clay combustible material, and water. Kaolinite is a type of weathered orthoclase feldspar. It is also a layered silicate mineral with aluminum and hydroxide groups in its composition ($Al_2Si_2O_5(OH)_4$).

In the process, Kaolin has low pore size (<0.02-micron) that expands with heat, while the combustible material burns completely leaving voids and pores to ensure uniform porosity. After experiments, at temperature of 1150°C and with 10% combustible material at 300-micron creates a porosity of 1-micron (matching theoretical results, see figure 11).

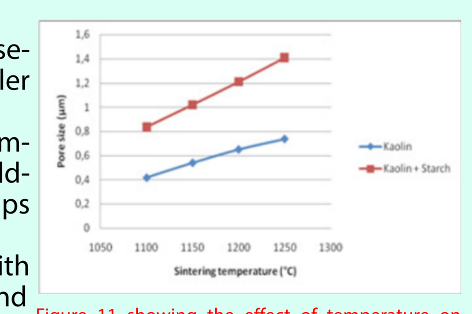


Figure 11 showing the effect of temperature on kaoline clay filter during the firing process.

In the project, the kaolin clay filter is designed in the shape of a cylinder to facilitate cross-flow filtration (demonstrated in figure 12). Due to the small pore size of the filter, this method is used to decrease the clogging rate.

In practice, this filter removes 95 to 99.99% of all compounds down to 1-micron. This is almost all the microplastics in the water and most bacteria and organic compounds. It also neutralizes acidic water, lowers turbidity, removes carbon added by GAC, and creates appropriate mineral content in water. The device has a lifetime of up to five years; however, the device requires regular cleaning.

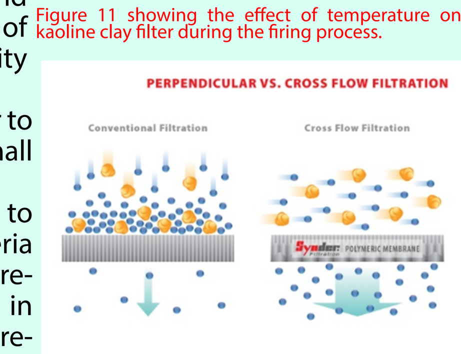


Figure 12 demonstrates the difference between perpendicular filtration and cross flow filtration.

Calculations and Testing

The scale of pH (CH2.02) is a logarithmic scale that describes the acidity of a solution: 7 is neutral, 14 is most alkaline, and 0 is most acidic. Volume flow rate (PH1.09) is the average measure of flowing liquid in cubic meters per unit time.

Total dissolved solids (CH2.01) describe the amount of minerals in a solution in parts per million. Total suspended solids is the net amount of solids that does not dissolve in water. In the case of distilled water with microplastics, TSS = microplastic concentration. TS is measured by summing TDS and TSS. To measure either of those, a filtration method is used. In the filtration method, a filter paper and borosilicate glass are dried in a desiccator then a sample of 25mL is passed through the filter paper in a funnel to the glass. The filter paper and the glass are dried in an oven at 105 degrees. The change in mass of filter paper equals is used in equation 1 to find TSS; the change in the mass of the glass is used in the same equation to measure TDS.

$$\frac{\Delta \, Mass\ of\ Filtration\ Paper}{Volume\ of\ Sample} \times 1000\ mg\backslash L$$

Equation 1 used to calculate total suspended solids and total dissolved solids from the filtration method.

Learning Transfer

Chemistry (2.01): Concepts of filtration, ion exchange resins, TDS, dissolved oxygen, distillation, biological treatment, and analysis were used in the idea selection and design requirement validation.
Chemistry (2.02): Water properties and types of water filtration systems were used in the selection of ideas.
Earth Science (2.04): Ideas of water treatment systems and water pollution were used to create the clay filter.

CONCLUSION

Following the intensified research, backed up by the help of experts in the field of chemistry and water purification, the team created a valid project that satisfies both design requirements of water quality and microplastics removal efficiency (down to 1 micron). Additionally, the project was able to match the solution requirements of water turbidity, water hardness, cost-effectiveness, availability, eco-friendliness, and durability. Even more, after the stellar results of the test plan and using the scientific bases in the analysis, the project could be declared a legitimate method to clean microplastics from freshwater, overcoming the problems of the prior solutions. This project could be used as a household filter in Egyptian houses and water treatment centers to solve the problem of microplastic pollution and the previously-described grand challenges.

RECOMMENDATIONS

Antibacterial Ceramic Balls

Our first recommendation is using Microporous Antibacterial Ceramic Ball (CM-BMP10 — see figure 13) as a phase for removing bacteria and microorganisms in our filter instead of using a ceramic filter. Micro-porous Antibacterial Ceramic Balls contain silver ions all over micropores' particular area. Silver ions kill bacteria and prevent bacterial growth by moldering organic compounds that shape bacteria, like bacterial cell membranes. The balls could even resolve bacterial residues. As to the same functions of adsorption and filtration of bacterial microorganisms compared to activated carbon, Microporous Antibacterial Ceramic Balls have more merits as they have higher efficiency and raw material abundance. So, the project will achieve better water quality in real life if this was added. Bio-ceramic balls, however, come at a high cost of up to 100USD per cubic meter and is not readily available in Egypt, so it was dismissed and replaced with a chlorinator.

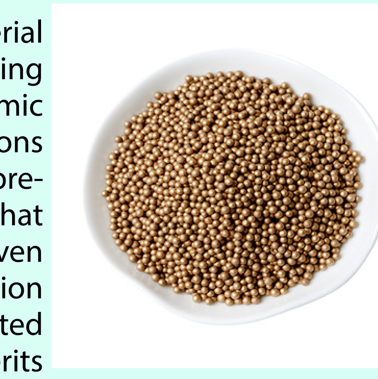


Figure 13 shows the antibacterial ceramic balls plated with silver.

Ultra-Folded Activated Carbon

Our third recommendation is the ultra-high surface area porous activated carbon (AS) derived from Asphalt. It has a surface area 3851 m2/g, which is 4.7-fold larger than that of Activated carbon (AC), which leads to a 4-fold higher maximum adsorption capacity. Figure 14 compares between the AS and AC Also, the surface functionality of AS is similar to that of AC. However, the high cost and the industrial demands to manufacture something like the AS make it impossible to be afforded in our project.

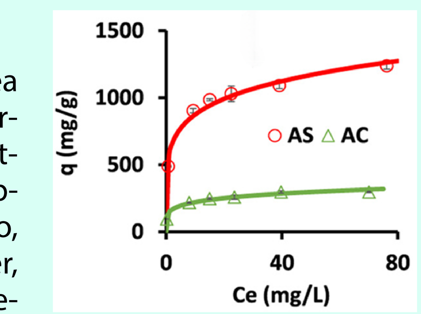


Figure 14 shows the relation between q or the amount adsorbed in comparison with the Ce or the equilibrium concentration of the solution.

Microplastic Recycling

Microplastics could be extracted through backflushing (see figure 15) of water through the stages of the filter. It is recommended to follow the process of backflushing with distillation to extract the microplastic. Melting the plastics, it could be later used to create plastic straws, cups, and/or other minimal plastic bodies. Other ways of doing that are alum coagulation. These methods were not used in the prototype because they make water undrinkable and harmful to human and marine life. Another method is flat polymer microfiltration of size below 1-micron. However, this method is extremely slow and inefficient.

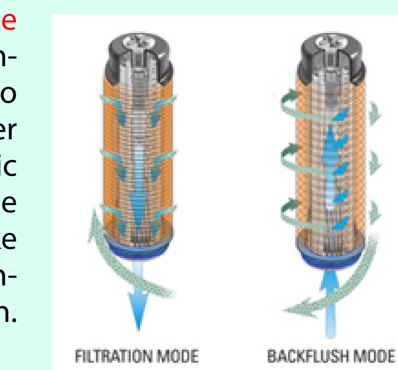


Figure 15 demonstrates backflushing in filtration cleansation.

Real Life Application

The project could be applied in real life in one of two ways: (1) a household filter, or (2) a water treatment system. In the first, a water household is recommended to be installed along an aquafilter automated pitcher container. The first stage is recommended to be replaced every 6000L, while the second must be cleaned regularly for clogging. If used in a water treatment system, it is recommended to be made on a larger scale with a pressure device to increase the volume flow rate. For both cases, it is preferred to use the order of activated carbon followed by sand and gravel. This enhances backflushing used to clean the filter and support the sand body during the process.

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