ANS ABDELTAWAB
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"EMBERS" FILTER

GRADE 11 - SEMESTER 2 - GROUP NO. 21204

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ABSTRACT

The rarity of water resources is considered as one of the most difficult challenges that faces Egypt. To address this issue, it was needed to address this issue by suggesting a solution that can purify wastewater and make it valid for irrigation purposes. Our design requirements is to achieve ≤500ppm salinity removal, turbidity ≤10 NTU, and adjust pH to 6.5–7.5. The targeted source of polluted water is dairy wastewater. The proposed solution is a three-stage purification system that treats the polluted water from three parameters: salinity, turbidity, and pH. The polluted water passes through various electrochemical and physicochemical treatments combined with moringa seed-based processing. The first stage applies electrocoagulation treatment using aluminum electrodes. The second stage utilizes materials such as sand and red bricks as a natural filter. The third stage applies ion-exchange treatment using an ion-trap sack containing biochar and moringa seeds. After each cycle, the parameters are measured by salinity, turbidity, and pH sensors, and then it is decided whether to proceed with more cycles or not based on the targeted irrigation thresholds. Two test plans were carried out to analyze the performance of the prototype and to improve it further. Our outcomes delivered impressive results. Salinity was lowered by 68.3 %, turbidity was lowered by 91.3%, and pH level was neutralized to become 6.7 pH. The total energy consumption of the prototype was 111,240 J/Cycle. Based on these data, the prototype managed to overcome these earlier stated issues effectively.

INTRODUCTION

Water shortage and contamination are considered among Egypt's most difficult challenges. The country's stress on its limited water sources increases due to population growth and agricultural demands. Egypt aims to manage water more efficiently and reduce the wastewater produced by factories, cities, and farming, as this aligns with the country's main goals, such as reusing waste, reducing pollution, and managing clean water sources. We seek to support this goal through this project by suggesting a new approach that treats wastewater by integrating innovative techniques into a system that treats dairy industrial wastewater and transforms it into irrigation-grade water.

The research on wastewater treatment methods shows several promising methods, such as electrocoagulation and biochar-based filters, but they often face issues with application scalability and resource-related problems. Recent research showed that there are specific parameters that influence the efficiency of electrocoagulation treatment, such as the electrode type, current density, and wastewater characteristics, which must be optimized if it were to be applied in real-world applications (Mousa et al., 2024). In addition, recent research demonstrates that using Moringa seeds, biochar, and sand in a specific order improves the removal of turbidity, pathogens, and heavy metals from contaminated water (Chaganti et al., 2024).

Because of the issues related to these conventional methods, we developed a hybrid system that applies electrochemical and physicochemical treatments using local, natural materials such as rice husks, eggshells, moringa seed powder, and biochar. These materials were selected due to their high adsorption capability, which makes them ideal for our treatment applications.

Our system is designed to reduce turbidity and salinity, adjust pH levels, and remove BOD, COD, and suspended solids with high efficiency. The treatment process includes three stages: (1) electrocoagulation using aluminum electrodes to remove heavy metals, oils, and organic compounds, (2) filtration through sand, eggshells, and crushed red bricks to remove suspended solids and balance pH, and (3) ion-exchange using an ion-trap sack filled with biochar and moringa seed powder to further purify the water. At the end of each cycle through the prototype, sensors are used to measure the turbidity, salinity, and pH of the treated water. The received data from the sensors is then compared to the targeted thresholds that make the water suitable for irrigation.

Our system is designed to treat dairy industrial wastewater and is intended to produce purified water suitable for irrigation. By using natural materials, following green engineering principles, and tackling real-world challenges, this project contributes to Egypt's goals of environmental sustaining.

MATERIALS

Table 1. *Materials Used*

NAME	SOURCE	USAGE & DESCRIPTION	PRICE	AMOUNT	PHOTO
Moringa seeds	Farm waste	natural coagulant to help remove suspended and impurities	-	500g	
Eggshells	restaurant waste	Used to balance the pH percent in the final filtration stage.	-	250g	
Red brick	school yard	crushed and used as part of the physical filtration layer	-	3 Blocks	
rice husk (biochar)	Farm waste	Absorbs odor and removes pollutants through adsorption	10 L.E	500g	
Fine Sand	School Yard	Used as a layer on the physical filtration stage	-	500g	
Aluminum Rods	Recycled	for conducting he electricity into the electrocoagulation stage.	-	2 rods	
Solenoid valves	RAM Electronics	Automatically controls water flow between stages	900 L.E	4 pieces	
pH sensor	RAM Electronics	Measure the pH percent in water from scale 0 to 14.	1700 L.E	1 piece	
TDS sensor	RAM Electronics	Measure the Total Dissolved Solids(TDS) in water	750 L.E	1 piece	
Turbidity Sensor	RAM Electronics	Measure the cloudiness in the water	850 L.E	1 pieces	

Methods

Before constructing the prototype, all safety precautions were taken into consideration, including: **(1)** Using masks, gloves, coats, and googles while treating with the wastewater avoiding some diseases infection. **(2)** Treatment stages construction process was in both of chemistry lab and FabLab. **(3)** The Arduino connection was in the welding area in FabLab.

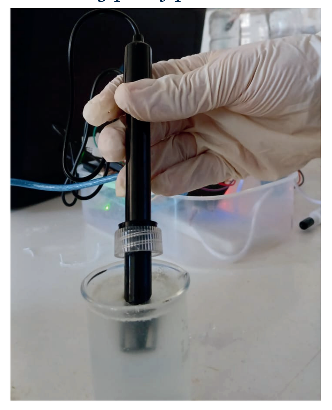

Fig 1: *measuring pH of polluted water*

Stage 1- Natural coagulation & electrocoagulation. The first stage of the treatment stages combines electrocoagulation with natural coagulation, it removes total dissolved solids (TDS), turbidity, BOD and COD into flocs, making it easily to tackle in the second stage.

- 2 aluminum electrodes were submerged into the bottom of the plastic jar, placed at a fixed distance apart and connected to a 12V DC isolated power supply via a relay to ensure safety.
- the jar is filled with wastewater and electrocoagulation is applied for 30 minutes.
- Afterward, some of Moringa oleifera seeds powder were added to the water, it works as a natural coagulant to leave the flocs formation.
- After electrocoagulation application, the mixture was left undisturbed for an additional 15 minutes, just for allowing the flocs to settle at the bottom of the jar. After the first stage the treated water will flow through the solenoid valve into stage 2.

Fig 2: *electrocoagulation stage*

Stage 2- Physicochemical filtration (Adsorption & physical layers). A multi-layer filter was constructed using the following components:

- Some red bricks and the fine sand were added as the base layer of the filter, supported with filter paper, just for ensuring no sand flow with water.
- Some of powdered eggshells were added into the filter, it works as a pH neutralizer.
- The composition of biochar and moringa seeds were added as the final layer of the filter, it was washed before using for ensuring there no color settles from the biochar. After the first stage the treated water will flow through the solenoid valve into stage 3.

Fig 3: *filtration stage*

Stage 3 - bio-polishing sack. The third stage called the polishing stage, a piece of cheesecloth sack was filled with a mixture of biochar, powder eggshells and crushed moringa seeds. This stage worked as the final adsorption, pH neutralizing and organic matter treatment.

- A rectangular shape of cheesecloth fabric was used as the supporter of the third stage, filling it with the filter components.
- The cheesecloth was filled with the mixture of the biochar, powder eggshells and crushed moringa seeds. For pH regulation, turbidity removal, and organic matter removing.

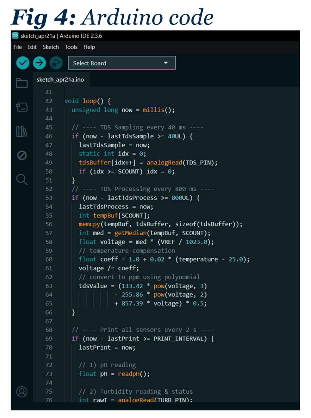

Fig 4: *Arduino code*

After passing the water through the 3 stages, the parameters are measured by salinity, turbidity, and pH sensors, and then it is decided by the Arduino code whether to proceed with more cycles or not based on the targeted irrigation thresholds.

Results

Two test plans were carried out to evaluate the performance of the purification system. Our chosen parameters were salinity (ppm), turbidity (NTU), and pH level. These parameters, in addition to power consumption and water volume, were observed and recorded each cycle.

Each cycle lasted about 1 hour and 30 minutes, with sensor readings recorded before the treatment and at the end of stage 3.

Trial 1:
In trial 1, we tested the prototype with 1.5 liters of dairy wastewater sample. The wastewater processed through 5 cycles. Our findings were recorded as follows: salinity dropped from 1505 ppm to 620 ppm, turbidity decreased from 92 NTU to 23 NTU, and pH level increased from 3.9 to 6.4. After the 5 cycles, The water volume decrease from 1.5 liters to 1.43 liters. In addition, power consumption was measured after each cycle to be an average of 111,240 J/Cycle.

Table 2. *Trial 1 – Parameter Readings per Cycle*

Cycle	Salinity (ppm)	Turbidity (NTU)	pH
1	1505	92	3.9
2	1400	75	4.5
3	1300	60	5.2
4	1000	40	5.9
5	620	23	6.4

Trial 2:
In trial 2, we tested the prototype with 2 liters of dairy wastewater sample. The wastewater processed through 6 cycles. Our findings were recorded as follows: salinity dropped from 1524 ppm to 483 ppm, turbidity decreased from 93 NTU to 8 NTU, and pH level increased from 3.8 to 6.7. After the 6 cycles, The water volume decrease from 2 liters to 1.91 liters. The average power consumption per cycle didn't change 111,240 J/Cycle.

Table 3. *Trial 2 – Parameter Readings per Cycle*

Cycle	Salinity (ppm)	Turbidity (NTU)	pH
1	1524	93	3.8
2	1350	70	4.3
3	1200	50	5.0
4	900	30	5.6
5	600	15	6.2
6	483	8	6.7

Analysis

Succeeding collecting results, a deep-down analysis of the results must be done to ensure the problem is mitigated, Egypt Grand Challenges are faced, and finally, the concept of "Recycle and Feedback" was achieved. And our prototype met all the design requirements, including reducing the salinity percentage by less than 500ppm, using natural filters materials, treating at least 3 different water quality parameters (Salinity, Turbidity, pH, COD, and BOD), and using at least 3 different techniques of water treatment (Chemical, physicochemical, biological).

Stage 1- electrocoagulation & natural coagulation method.

The electrocoagulation method is done by utilizing 2 aluminum electrodes to work as the current conductors in the wastewater. The current conductors are connected to an adaptor with 12 volts and 2 amperes. This method worked as the TDS, turbidity, and organic matter removal. The stage employs electrochemical and biochemical concepts of wastewater treatment, this method uses electrolytic cell as the base of electrochemical process, using both of anode and cathode electrodes and connecting them to electric current. At the anode Aluminum oxidation occurs by this reaction equation:

$$2Al\,(S) \rightarrow 2Al^{3+}\,(aq) + 6e^-$$

Simultaneously at the cathode, the aluminum reduction take place:

$$6H_2O + 6e^- \rightarrow 3H_2\,(g) + 6OH^-\,(aq)$$

So, the overall reaction combining these 2 processes together:

$$2Al\,(s) + 6H_2O \rightarrow 2Al(OH)_3\,(s) + 6OH^-\,(aq)$$

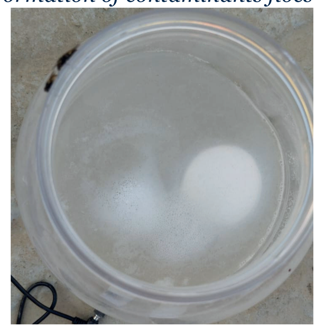

Fig 5: *formation of contaminants flocs*

The generated Aluminum hydroxide ($Al(OH)_3$) acts as the coagulant by 2 mechanisms, which are the charge neutralization ($AL(OH)_3^+$) that repels the negatively contaminants, and the $AL(OH)_3$ flocs and that enmeshes particles. The moringa seed (natural coagulant) enhances this process by its positively charges proteins through forming contaminants flocs when sticking to negative contaminants = contaminants flocs.

Stage 2- physicochemical stage.

Stage 2 is a combination between 2 main filtration concepts, the physical filtration using (red bricks & sand) acting as mechanical barrier for tackling the TDS and flocs from the first stage, and the adsorption concept using eggshells and the biochar.

- Red bricks & sands (physical filtration), acts as a particle removal by following the sieving mechanism, with decreasing the pore size downward.
- Eggshells (CaCO3 – pH stabilization & adsorption), it dissolves in acidic water while neutralize pH (6.5–7.5), preventing the acidity issues via this reaction:

$$CaCO_3(s) + H^+ \rightarrow Ca^{2+} + HCO_3^-$$

- Biochar & moringa seeds (chemical adsorption), it removes the COD and BOD via the surface adsorption and ion exchange.

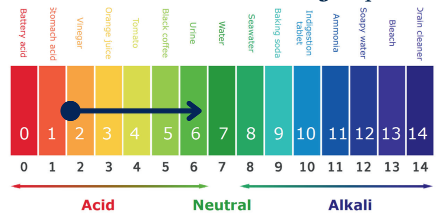

Fig 6: *pH scale*

Stage 3- BIO polishing (final treatment).

The third stage works as polishing step, for ensuring that the water meets the standard for the agricultural use. By combining biological and chemical mechanisms to remove the survived contaminants from both first 2 stages. Using the cheesecloth sack structure as the base of the filter, filling it with the biochar, eggshell powder, and powdered moringa seeds. The total reactions on this stage through 2 steps:

- pH neutralization by the reaction:

$$CaCO_3(s) + H^+ \rightarrow Ca^{2+} + HCO_3^-$$

- BOD and COD adsorption following the reaction:

Biochar+Organics Biochar-Organics
(X-X means electrostatic bonds)

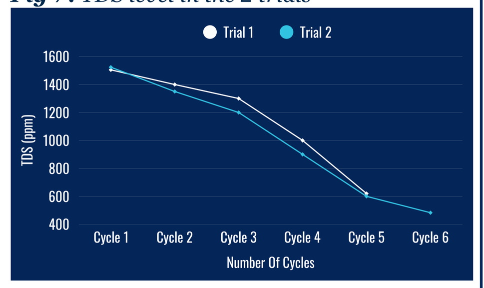

Fig 7: *TDS level in the 2 trials*

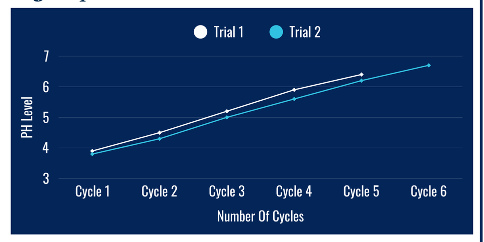

Fig 8: *pH level in the 2 trials*

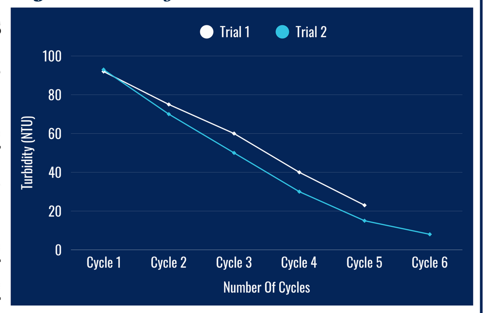

Fig 9: *Turbidity level in the 2 trials*

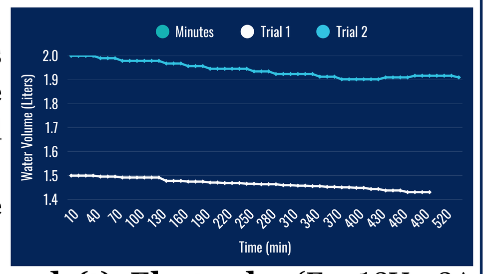

Fig 10: *Water Volume in the 2 trials*

Fig 7 shows the reduction of the TDS level in both of the 2 trails that we conducted. In the first trial, the TDS was reduced from 1505 ppm to 620 ppm. In the second trial, the TDS was reduced from 1524 ppm to 483 ppm.

Fig 8 shows the neutralization of the pH level in the 2 trails. In the first trial, the pH increased from 3.9 to 6.4. In the second trial, the TDS was reduced from 3.8 to 6.7.

Fig 9 shows the reduction of the turbidity level in the 2 trails. In the first trial, the turbidity decreased from 92 NTU to 23 NTU. In the second trial, the turbidity was reduced from 93 NTU to 8 NTU.

Fig 10 shows the volume of the water across the cycles of the 2 trails. In the first trial, the water volume decreased from 1.5 liters to 1.43 liters. In the second trial, the water volume reduced from 2 liters to 1.91 liters For calculating the energy consumed by the prototype , by following joule's first law (E= VIT):

E (energy) = Voltage(V) x current(I) x Time in seconds(t). Electrodes (E = 12V x 2A x 2400s = 57,000 Joules). **Water Pump** (E = 12V x 0.7A x 900s = 7,650 Joules). **Solenoid valve** (E = 12V x 3.2A x 1200s = 46.080 Joules) Total Energy consumption per cycle is 57,600 (EC) + 7,560 J (Pump) + 46,080 (Valves) = **111,240 J/Cycle.**

Table 4: *Connections to our learning outcomes*

LEARNING OUTCOME	CONNECTION
ME.2.05	The pumps and electrodes for electrocoagulation draw and use power within the system. Consequently, by understanding how power is supplied to different devices in the system, an energy-efficient wastewater treatment system can be designed.
MA.2.06	Learning about limits and continuity has aided my ability to optimize my wastewater treatment system by allowing me to look at gradual processes, such as the purification process, and see what happens as time goes on (and as the type of water changes).
MA.2.10	Analyzing sensor data (e.g., turbidity, pH, salinity) is needed to detect patterns or outliers of real-time system readings.
PH.2.08	This understanding provides the basis for the explanation of the electrocoagulation process, where electromagnetic fields or currents are used to effect the process.
ME.2.08	The work, energy, and power relationship must be applied to ensure the requisite energy for the components of the system.

Conclusions

The multi-stage wastewater treatment system successfully reformed the wastewater into agriculturally reusable water. Using locally available waste materials and natural materials, making it both effective and environmentally sustainable.
While addressing Egypt's grand challenges of security of water and pollution, the prototype has met the design requirements by:

- Salinity reduction from 1524 ppm to 483ppm (below 500 ppm threshold)
- Lowering turbidity from 93 NTU to 8 NTU(>90% removal)
- Using 100% natural and recycled materials.
- Incorporating 3 different treatment techniques (chemical, physicochemical, biological)

The prototype has addressed 4 different sustainable development goals (SDGs), which are:

Recommendations

In a view of improving the effectiveness and efficiency of the wastewater treatment plant being proposed, some improvements are recommended.

1- It is recommended that the system is tried out on different types of contaminated water, including farm and industrial wastewater. This will ensure the efficiency of the system under different situations as well as its adaptability for different environments.

2- The prototype must be strengthened so that it becomes durable and simple for maintenance as well as operation.

3- The inclusion of another phase of disinfection, where methods like UV light or activated carbon can be used. This will kill harmful microorganisms and render the water purer and better suited for applications like consumption by animals or irrigation.

4- it is suggested that solar power be utilized for running the system. This would eliminate the use of regular electricity, lowering the energy cost, render the system sustainable, and open the possibility of running the system even in locations where electricity is unavailable.

These improvements will make Egypt able to attain its goals of reducing pollution, increasing water sources, and recycling waste by utilizing and sustainable solutions.

Literature Citation

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