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Slope Desalinator

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Abstract

Egypt, as a developing country, is incapable of achieving prosperity, where that is a direct result of the grand challenges that Egypt faces. The lack of water resources is one of the greatest grand challenges that implies the necessity of providing more water. The common, utilized sources of water such as the River Nile has the problem of being exhausted, where that made the project take the path of utilizing the underutilized water resources. The chosen resource is seawater, where it was chosen due to its great, unused quantity. The purpose of the study was to purify seawater to be used as water for agriculture. The prototype made use of thermal desalination in addition to the mineralization of the output water to be valid for agriculture. The design requirements were the pH and the TDS, where our prototype succeeded eventually as it produced the needed pH and TDS for agriculture, and the results were authorized by the Desert Research Center. That implied the availability of the prototype to be a real-life application and improve the drinking procedures in Egypt, relieving the usage stress on the River Nile and rainwater.

Introduction

As Earth's population increases, the demand for fresh water supplies increases. During the last 60 years, Egypt's population increased three times and the per-capita water share decreased from 2500m^3 to 700m^3, where the per-capita water share is expected to decrease to 500m^3 by the year 2050 **as shown in figure (1).** Those circumstances made improving clean water resources a must and a grand challenge to satisfy the needs of the growing population. Since the grand challenges are associated, more grand challenges such as urban congestion, arid areas, and pollution developed, emphasizing the importance of improving Egypt's water resources. It was necessary to work with water resources; however, the utilized water resources such as the River Nile and rainwater are exhausted, leading the study to make use of the underutilized water resources such as seawater, groundwater, and others. There are a lot of water uses, where the chosen use is agriculture as it uses 80%-85% of water resources in Egypt.There are a lot of prior solutions, where one of them is the Tampa Bay water desalination project in the Florida area **as shown in figure (2).** One of its positive points is effectiveness as output water is clear; however, it has the negative point of being expensive. Another prior solution is the wave-powered water desalination project in Green Island in western Australia. This prior solution had the extreme advantage of being a green water resource; however, it had the problem of requiring a large wave to start the process that decreases the availability as waves aren't that available. Following the prior solutions, a solution maintaining eco-friendliness, availability, and effectiveness was needed, and design requirements are the water quality parameters (pH and TDS). Moreover, the other design requirement would be the efficiency, which will be measured by comparing the output to input, so the most suitable solution was purifying water using thermal desalination. The prototype is a glass container that evaporates and, then, condenses the water vapor, where it mineralizes the water for agricultural use. That prototype satisfied the design requirements after the test plan. In the following sections, more details will be discussed.

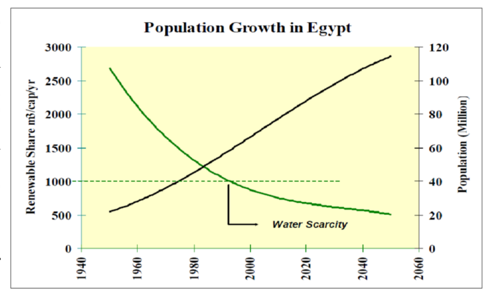


Figure (1): Earth's population and per-capita water share.

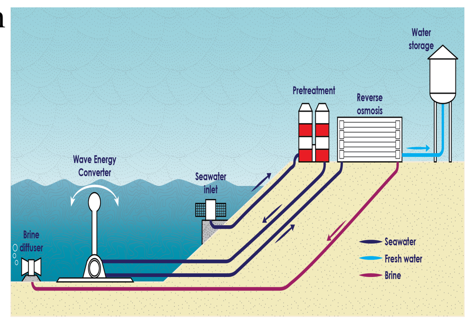


Figure (2): Illustration of the tampa bay water desalination project.

Materials & Methods

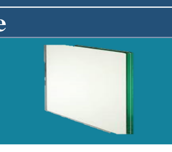
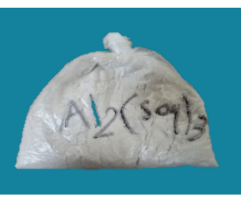
Material	Quantity	Description	Image
Standard Glass	8 faces of glass	6mm glass used to contain the water through boiling	
Simple immersion coil heater (1.5KW)	1 heater	A copper coil heater which is the main heat source	
Plastic Press Tap	1 tap	Makes the water flow out of the prototype	
Silicone Sealant	1 package	The main binding material for joining the glass faces of the prototype and filling the holes in the prototype.	
Aluminum sulfate $Al_2(SO_4)_3$	250 grams	Pretreatment step for lowering the boiling point.	
Himalayan (Pink) Salt	1 package of 400 grams	The type of salt used for mineralizing the distilled water to be valid for agriculture.	

Table (1): The used materials in the prototype.

1- A simple 3D design was created on sketch up to help in the imagination of the prototype.

2- Both the suitable dimensions of the glass container and the required angle were calculated to fit the design requirements, and the shapes have been determined: A- Two trapezoid faces with dimensions 0.62 m, 0.64 m, 0.17 m, and 0.45 m and an area of 0.17775 m^2. B- Two rectangular faces with dimensions 0.17 m and 0.2 m and an area of 0.034 m^2. C- One rectangular face with 0.62m and 0.2m and an area of 0.124 m^2. D-Two rectangular faces with 0.08 m and 0.43m and an area of 0.0344 m^2.

3-The faces have been sealed together as shown in figure (3) to maintain coherence, and the holes have been filled with silicon to prevent any water from leaking.


Figure (3): the faces of the prototype were sealed together.

4- Two output vents were made on the trapezoid sides to lower the temperature difference across the container.

5- The two 0.08 x 0.43 faces were sealed opposite to the holes at a 45-degree angle.

6- The heater was isolated by silicon and then put in the bottom of the container in order to evaporate water.

7- The roof of the prototype has been prepared to condense the water and direct it into the collecting part of the prototype as shown in figure (4)

8- The Plastic Press Tap has been sealed in the collection part of the prototype.

9- An initial volume of 5.6liters of water was added to cover the coil, preventing it from being harmed.

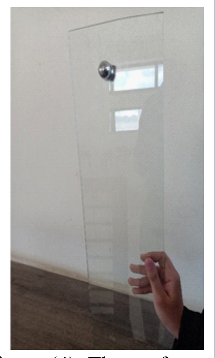


Figure (4): The roof was prepared to collect water into the container

Test Plan

1- 5.6 seawater liters of known TDS and pH were put in the pretreatment container as shown in figure (5), and (20-30mg/L) of aluminum sulfate ($Al_2(SO_4)_3$) were added to the container, and it was left for 45 min until precipitates appeared.

2-One liter, which is the required quantity for the test plan, has been added.

3- The heater was turned on to start heating, and the prototype was covered by its roof.

4- After condensation, pink salt was added to the distilled water then TDS and pH were measured.


Figure (5): the pretreatment container of aluminum sulphate.

Results

Negative Results:

Through the first test plan, some cracks had occurred in the roof of the prototype. After some scientific investigation, it was concluded that the cracks were because of the difference in both the pressure and temperature between the inside and the outside of the prototype, where that lead to adding some holes in the prototype to undergo some of the condensation processes out of the prototype.

Positive Results:

Due to the incapability of providing more than one seawater container, the test plan was conducted using samples of pH = 7.8 and TDS of 10000mg/L. The results which are shown in table (2) give us a pH of 7.1, TDS of 56mg/L, and time of 29 mins before mineralization, where those results are not suitable for agriculture. That's why mineralization with Himalayan salt was crucial, where mineralization gave a pH of 6.94 and a TDS of 579mg/L.

Measurable quantity	pH	TDS	Loss rate	Time
Seawater	7.8±0.01	10000±10	-	-
Before Mineralization	7.1±0.01	56±10	12%	29
After Mineralization	6.94±0.01	579±10	-	-

Table (2): The results of the prototype before and after mineralization.

Analysis

Heater Coils

Heater coils, which are used in the vaporization step, work through a process is known as resistive or joule heating. **As mentioned in the third learning outcome in physics,** when an electric current flows into a material that has some resistance, it creates heat. As electrons pass through the conductor, they are scattered and, in the process, lose energy to the surroundings. This energy is given off as heat. This amount of dissipated heat can be calculated in terms of power. Power is defined as energy per time. So, this means that the amount of heat is the rate of energy converted to heat in the used conductor. This means that the rate of transmission of heat in the water, where Power = Intensity × Voltage. This formula means that a current of one ampere through the conductor across a voltage drop of one volt that results in one watt of heat. Another formula can be derived from this equation in terms of ohm's law by substituting the V by R×I, which means power =I^2× R.


Figure (6): The used coil heater.

The heating element in the coils must have some special characteristics. The best material is nichrome. Nichrome consists of 80% nickel and 20% chromium. It has a relatively high resistance, which increases the temperature as much as possible. Another feature of this material is the layer of chromium oxide. This layer prevents the coil from breaking or burning out. The heating coil can also be made from copper. It has a high heat conductivity.

Aluminum Sulphate and Boiling Point Elevation:

During the process of water filtration, large particles, suspended in water, settle out of the solution quickly; however, the smaller particles – small and medium-sized – take a long time to settle out and, sometimes, do not settle out completely. That's why, aluminum sulfate ($Al_2(SO_4)_3$) is used to react with the smaller particles, primarily bicarbonates (formed from the reaction of carbon dioxide with pure water), and form precipitates that sink, reaching the bottom of the container. In addition to making filtration easier, aluminum sulfate is beneficial regarding the act of maintaining the boiling point from elevation. $\Delta T_b = K_b \cdot m_{solution}$


Figure (7): The precipitates of the aluminum sulphate

According to the equation of boiling point elevation, **studied in the second learning outcome of chemistry**, the boiling point of a non-volatile solution increases in proportion to the molality of the solute and is a constant relative to each solvent. By getting more solutes out of the solution, the boiling point approaches the normal value. That enables the solution to boil faster, saving energy and making our prototype faster and more efficient.

Heat Energy

Heat energy is the energy required to cause an increase in the temperature of an object, where the amount of heat energy is calculated by the following equation is $H=msd\theta$. H is the required heat energy, m is the mass of the object, s is the specific heat of the object, and $d\theta$ is the needed change in temperature. Water has a specific heat of 1Ꞇg^{-1}°C^{-1} and the test plan requires the boiling of 6.6 liters of water (equal to 6600g), where the room temperature during the test plan was 20°C and the boiling point of water is 100°C, so the needed heat energy, as mentioned in the fourth learning outcome in mechanics, is equal to: 6600×1×80=528000Ꞇ =2209152J, and since power = energy per time, where the power of our coil heater is 1.5KW. Therefore, time = energy divided by the power = 1473 seconds = 24.5minutes. This is the required time to make the water heats by the electric coil heater, which is approximately the same as the test's time.

Thermal Expansion

The overall thermal expansion of a certain material is a direct result of the change in the average separation between its smallest building units, atoms or molecules, where the expansion is equal to: $\Delta A = \gamma A_0 \Delta T$, where ΔA is the change in area (expansion), γ is the coefficient of the area expansion, A_0 is the initial area of a glass surface, and ΔT is the change in the temperature of the glass. For illustration, at the boiling point of water (100°C) at initial temperature of 20°C, $\gamma\Delta T$= 18 x 10^{-6} x 80 = 1.44 x 10^{-3}. That's why, each of the glass faces would have a new area equal to 1.44 x 10^{-3} of the initial area. For example, the face of length 0.2m, width 0.17m, and area 3.4 × 10^{-2} m^2 will have an area increase of 1.44 x 10^{-3} × 3.4 × 10^{-2}= 4.76 x 10^{-5} m^2, applying this to all of the other faces. This expansion can be decreased by lowering the temperature difference. This will help in maintaining the materials and avoiding any destruction of the used glass.

Glass

Glass is mainly composed of organic materials like silica (SiO_2) and soda (Na_2O). Glass is the best choice for health. It is an inert substance that does not react with water or any other substance under the ordinary conditions, so it is the best choice for water containers. Since it has a low coefficient of expansion 9 x 10^{-6}, it can be used to boil and evaporate water under certain circumstances and specific adjustments that decrease the pressure inside the container.

Adhesion and Cohesion

The reason behind our condensation ideas is cohesion and adhesion forces. Cohesion and adhesion forces are very important properties of water. **As mentioned in the first learning outcome in geology**, Cohesion is the attraction of a water molecule to another water molecule. Adhesion is the attraction between water molecules and other substances. These forces drive the movement of the water droplets on the condensation roof. As the water droplets accumulate together and attract each other by cohesion, and they are also attracted to the glass by the adhesion force without falling down again into the container. This causes the droplets to start sliding until it reaches the collecting container.

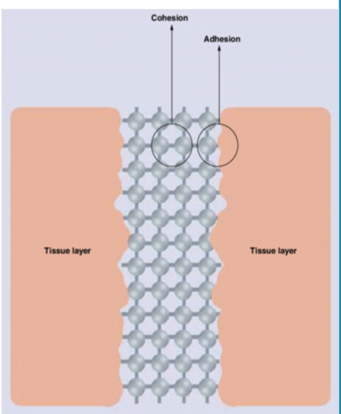


Figure (8): Adhesion vs Cohesion forces

TDS and pH measures:

There are a lot of aspects that determine the quality of water. The TDS and the pH are the most important in our project. The TDS is the measure of the total dissolved metals in the water. It is measured by the TDS sensor, which measures the electrical conductivity. By measuring the electrical conductivity, it is easy to determine the percentage of the TDS. The other quality aspect is pH. **As studied in the third learning outcome in chemistry**, pH scale is a scale that differentiates between acids and bases by considering the difference in the concentration of the H+ ions in the solution. A solution with a pH of 7.0 is neutral (neither basic nor acidic), where acidic solutions have a pH lower than 7.0 and basic ones have a pH higher than 7.0. The pH is measured using a device called a pH meter that is an electronic device with a solution of a known pH and a probe. The known-pH solution is in a special glass membrane that permits the passage of H+, and the probe could be inserted to a solution of unknown pH and the difference in the pH scale causes an electric potential to occur which is registered on the meter.

Conclusion

To sum up, the problem of the lack of water resources in agriculture could be solved through the desalination of seawater, utilizing seas as water resources. A prototype that desalinates water through heating it proved its effectiveness by achieving the design requirements of water quality (pH of 6.94 and a TDS of 579mg/L) and efficiency (88% output-to-input ratio), implying the ability of the prototype to be made at a large scale and solve the problem of seawater in Egypt.

Recommendation

Real-life usage:

The prototype collects and purifies water at a rate of 880 mL every 28 minutes with a TDS of 581mg/L and pH of 6.97, which is suitable for most crops except the most sensitive crops (ranges from 0 to 300ppm). As an assumption, if 100 square meters of oranges – one of Egypt's most consumed crops – were planted. They are needed to be covered by an average of 1.5 inches of water. That means that our area will a total of 63 L/h. So, by calculations, the production rate of the solution must be 35.8 bigger than the prototype. As the prototype produces 1.76 L/h. A crop like oranges will require an average of 63 L/h in a given area of 100 m^2. Another important thing is location. Since the solution involves the desalination of seawater to produce water for agricultural uses, a place with an adequate saltwater supply will be suitable. Egypt has access to two coastlines: the Mediterranean Sea and the Red Sea. As the Red Sea is one of the saltiest seas in the world with a TDS of 41 ppm, the Mediterranean Sea is a better choice to increase its effectiveness. The chosen place was Alexandria due to the access to the Mediterranean Sea and the availability of the required materials of the solution, which lowers the cost of transportation.

Pyrex Glass

The Pyrex glass (borosilicate) will be a good recommendation as it has a lower expansion coefficient of 3.3× 10^{-6} which is lower than the glass used in our prototype. this will make the project more durable which is one of the solution requirements.


Figure (9): Pyrex Glass Photo

Trace Mineral Drops

The distilled water, which is pure, must be mineralized to be valid for agricultural use. That implies the necessity of adding minerals to it, whereas in the prototype, the use of Himalayan or pink salt is necessary. We recommend the usage of trace mineral drops to make the pure water better for agricultural use and health. The trace minerals drop have higher minerals' concentration with less sodium chloride concentration.

Wave Electricity

$P = \frac{\rho g^2}{64\pi} H^2_{m0} T_e$, where P is the wave energy flux per unit of wave-crest length, H_{m0} is the significant wave height, T_e is the wave energy period, ρ is water density, and g is the acceleration by gravity.

The output energy gained from the wave-powered desalination is mainly affected by two factors, which are the wave height and the wave energy period. The average wave height in the Mediterranean Sea is 0.75 m. which is a sufficient height to generate 0.806058 KW in a wave period of 3 seconds. This means a production of 23214.24 KW per day supposing that the wave rate would be constant. Such a production will be sufficient for any desalination planet without a significant cost.


Figure (10): Wave Powered desalination project.

Literature Cited

Zumdahl, S. S., Zumdahl, S. A., & DeCoste, D. J. (2017). Chemistry (10th ed.). Cengage Learning.

Serway, R. A., & Jewett, J. W. (2018). Physics for Scientists and Engineers (MindTap Course List) (10th ed.). Cengage Learning.

Chang, R. (2009). Chemistry (AP CHEMISTRY CHANG) (10th ed.). McGraw-Hill Education.

Negm, A. M. (2018). Conventional Water Resources and Agriculture in Egypt (The Handbook of Environmental Chemistry, 74) (1st ed. 2019 ed.). Springer.

Benbow, A., Carpenter, M., & Hoover, M. (2021). Earthcomm : Project-based Space and Earth System Science (2nd Ed.) ; Teacher's Edition, Volume 1, Chapters 1–4 (2nd ed.). It's About Time.

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