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Solar De-salination of Water

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Abstract. Water is one of the most vital substances on Earth. Sustainment of life on this planet depends greatly on the availability of water. Water consumption is used not only for drinking but for purposes like agricultural irrigation, industrial raw material and domestic household purposes. Hence, the quality of water is an important matter. Solar de-salination is a technique that uses the Sun's radiant energy to de-salinate water. Due to its energy requirement, de-salinating seawater is generally more costly than freshwater, water obtained through bore wells also called Brackish water from rivers or groundwater. However, these sources may not be available in most of the places, like barren lands or may not be easily extractable, maybe even not a sustainable long term solution. The technique selected based on the evapouration and condensation rates to increase the efficiency, one must implement measures to enhance the evapouration and condensation rates of the capability. De-salination is a costly process majorly depending on its high energy requirements when as input power the whole system of de-salination either as fuel and electricity, following the century old traditions, modern day engineers have come up with a solution of harvesting the Sun's energy, hence the advent of solar de-salination of water.

Keywords: de-salination, parabolic trough base, potable water, reverse osmosis, solar energy

Introduction

The scarcity of drinkable (potable) water is a crisis over all parts of the world and is increasing at an exponential rate. Millions of peoples are affected by it. Though humans are blessed with enormous reservoirs of water, like oceans, rivers, glaciers and untapped groundwater, though we still lack the resources and intention to use it to solve the global crisis. If this problem continues to grow at this rate, we may not have enough drinking water for future generations. The causes associated with this problem are the growing population and global warming. Along with this, even if the modern methods are used, their energy requirement is very high. And with the growing energy demand and the decreasing fuel sources, like oil and its products, the likelihood of a sustainable and reliable energy source seems far fetched. As the modern sciences adapt more towards renewable sources, like wind, tidal and solar energy, the crisis for the lack of potable water needs to change its approach towards these sources (Srithar and Rajaseenivasan, 2018; Moradi and Mehrpooya, 2017).

Solar energy is free and clean to harvest. It can be coupled with a hybrid system to continue its operation for 24 h a day and it can also play a role in preserving the existing fuel reservoirs which can be used for other purpose. Pakistan is a country that is blessed with approximately 13-14 h of sunlight. This energy can be put to use for producing electricity, power cars and to de-salinate water.

Solar de-salination of water is a clean process that has zero effects on the environment. The process, raw materials and the products are all clean and have no damaging effect on the environment. This model can be used for a small rural settling where the availability of both clean water and readily available energy is a myth. This can also be scaled up to meet the demand of the urban household and the office demands. It can be optimized to perform efficiently in areas of low sunlight depending on the users inhabited in that region (Zhou *et al*., 2018; Gorjian and Ghobadian, 2015).

The UN estimates that 85% of the population lives on the driest and most barren parts of the planet. Access to clean water is not possible. The global crisis of lack of clean drinking water is no mystery to the people. It has been affecting generations for the past 10-15 years since the global population has drastically increased. As per the UN survey, 783 million people don't have access to safe and clean water and a huge amount of people die or get affected by water-related diseases, to be precise 6 to 8 million people annually.

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By 2050, the global population will jump up by 2-4 billion and will eventually increase the food and water demand by 70%. Pollution is another factor for the drop in the availability of clean water. Up to 90% of the wastewater in developing countries is not treated and globally, this figure is 80%. Solving this crisis will not only solve the world's potable water crisis but will also play a major role in dropping the damage done by the wastewater (Sathyamurthy *et al*. 2016; Sharon and Reddy, 2015).

Solar still was an outdated technology that was used a long time back. Modification for making the solar still cope with modern technology makes it competitive with other methods of solar de-salination. In comparison with other methods, solar stills don't harm the environment, nor do they require a huge amount of energy or space, nor do they prove to be expensive. Solar still of this scale can be put up in rural settings, can be scaled up for urban, without extraordinary knowledge of the operation, high cost or enormous space. This research aims to supply a household system with clean, potable water. This project aims to supply a healthy amount that would suffice the daily drinking needs. An approximate amount of water would be about 10 L/day. Also, the aim is to supply a sustainable source of de-salinated water (Amy *et al*., 2017; Morad *et al*., 2017).

The only raw material put into the process is the feed water. Its properties may vary with varying locations and sources. The source of feed water could be sea, river and brackish water. The properties like hardness, total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD) and mineral contents vary in all. Brackish water has a higher salinity than freshwater but is much lesser than seawater. Brackish water is either found in estuaries or underground aquifers. There are two product information i.e. potable water and brine. Potable water is self-explanatory and be used at hand but also stored for future use for cooking. Brine is used for culinary purposes, refrigeration fluid, water softening and purification, de-icing (Kuang *et al*., 2019; Al-harahsheh *et al*., 2018).

Materials and Methods

The selection of a de-salination method (plant) is truly difficult. It depends upon time requirement, financial feasibility, area, location, ergonomics of the system, operability, portability, scale of the project, type of feed, resources present and future scope of modification. The process selected is a conventional solar still with two external modifications to its system. The modifications, namely are a solar parabolic trough collector and a shell and coil condenser.

Equipment design and sizing. The vessel made up by acrylic, which provides strength and a cheap source of making a vessel. The volume occupation dimensions of the vessel were 24″ × 12″ × (10″ × 7″). The angle of the glass inclination was 14°. The volume of the vessel was 33 L. This process uses two ball valves from which two were of 0.25 inches. One will control flow to the vessel and the other will be used to regulate flow back to the feed tank. The piping made by stainless steel (SS) which makes the project resistant to corrosion to it is durable for a long period. Straight pipes used of stainless steel of 10S schedule and the pipe used of 0.25″ (nominal dia). The temperature gauges used installed one in the parabolic reflector and the other in the vessel. In this process, we use a centrifugal pump to pump brackish cooling water to the condenser and the vessel. The absolute power utilization of the pump 0.5 hp that is 372.85 watts.

The parabolic trough collector is an external non-electrical heater. A heating fluid is circulated through the reflector to first gain heat from the sun and then transmit, through conduction by the feed in the vessel. The heating fluid in this system is water. The condenser used a shell and coil condenser. The base of the parabolic trough condenser was made of wood to give the structure a solid shape, make the structure cost-efficient, durable in sunlight without gaining a lot of temperatures and ease of turning the trough to incorporate the maximum amount of sunlight.

The shell of the condenser was made up of stainless steel (SS) and the coil was made of copper tubes. Tube sizes of condenser, the nominal size is 0.75 inch, outer dia is 21 mm, inner dia 19 mm, flow area 2.84E-04 m^2, thickness 2.00 mm, thermal conductivity 342 Kcal/h.m.°C. The exchanger dimension details were outside dia of inner cylinder 'B' 0.13 m, inside dia of the outside cylinder 'C' 0.26 m, inside dia of coil 'D' 0.019 m, average dia of Helix 'Dh' 0.195 m, outside dia of coil 'Do' 0.021 m and distance between two coils 'P' 0.0315 m. The flow rate of fluid in the shell and coil side condenser was 300 and 2 Kg/h, respectively. The inlet and outlet temperature of the shell side was 35.0 and 35.66 °C. The inlet and outlet temperature of the coil side was 120.0 and 25.0 °C. The heat capacity of fluid in the shell and coil side condenser was 0.963 and 1.001

Kcal/Kg. °C, respectively. The thermal conductivity of the fluid in shell and coil side condenser was 0.570163 and 0.570077 Kcal/h/m.°C, respectively. The viscosity of the fluid in the shell and coil side condenser was 2.7 and 1.4544 Kg/m/h, respectively. The density of the fluid in the shell and coil side condenser was 1020 and 907 Kg/m^3, respectively. The shell and coil condenser parameter was the number of turns 11, overall heat transfer coefficient (U) 30.94 Kcal/h/m^2.°C, heat (Q) 190 Kcal, the height of the cylinder 36 cm, length of the coil 14.38 ft, heat transfer coefficient of inside coil based on outer dia of the coil (D_o) 74.64 Kcal/h/m^2.°C, heat transfer coefficient of the outside coil (h^o) 79.385 Kcal/h/m^2.°C, equivalent dia 0.2876 m, LMTD 35.80 and area 0.17 m^2.

For optimization two measures were taken, first was the pre-heating of the feed water. The feedwater would evapourate more quickly if its temperature were already near its boiling point. To raise the temperature, the condenser are runs a vapour stream in its tubes, to condense the vapour and also to preheat the feed water, the feed water is run into the shell for completing these two purposes. The second measure was the vapour collection or the vapour suction from the vessel to it would collect quickly move through the condenser. A fan system is installed at the vapour outlet to create suction into the vessel to enable more formation of water vapours and to ensure their removal quickly. The entire system are rests on mild steel (MS) frame to ensure strength and assurance in a solid structure. The structures dimension was of 30″ × 30″ × 98.4″.

Parabolic trough. The activity of any sun oriented thermal vitality collector can be depicted as a vitality balance between the sun based vitality absorbed by the collector and the thermal vitality lost from the collector. If no elective component is given to evacuation of thermal vitality, the collector receiver heat loss must rise to the retained sun oriented vitality. The temperature of the receiver increments until the convective and radiation heat misfortune from the receiver equivalents the retained sun based vitality. The temperature at which this happens is named the collector stagnation temperature. For control of the collector temperature eventually cooler than the stagnation temperature, dynamic expulsion of heat must be utilized. This heat will be then accessible for use in a solar energy framework. The rate at which heat is effectively expelled from the collector determines the collector working temperature. For evacuation of a huge division of the absorbed sun powered vitality as valuable heat, the measure of heat lost from the receiver must be kept little (Al-harahsheh *et al*., 2018; Shalaby *et al*., 2017).

Receiver heat loss can be decreased by working the collector close to the surrounding temperature (for example with low temperature level plate collectors) or by developing the collector to such an extent that heat loss at raised temperature is diminished. The most widely recognized method for decreasing receiver heat loss at raised temperatures is to lessen the size of the hot surface since heat loss is legitimately corresponding to the area of the hot surface. Concentrating collectors decrease the region of the receiver by reflecting the light occurrence on a huge zone over an absorber of a little area. With diminished heat loss, the concentrating absorber can work at raised temperatures and still give critical amounts of valuable heat vitality.

A second purpose behind utilizing concentration in the structure of solar collectors is that reflective surfaces are typically more affordable than the receiver. Hence, a lot of modest reflecting surface area can be put in a field, focusing the incident solar energy on littler absorbent surfaces. Though, concentrating collectors must track the sun's movement over the sky, adding expense to the development of a concentrating collector framework.

The concentrating collectors have reflecting surfaces that need less material and are less difficult than flat plate collectors. The absorber territory of a concentrator framework is littler than that of the flat plate framework for the equivalent solar energy collection. Heat lost to the surrounding per unit of sunlight based vitality collecting zone is not as much as that of a flat plate. The working liquid can accomplish higher temperatures in concentrating collectors (Shirazi *et al*., 2016; Arunkumar *et al*., 2015).

The conductive losses in collectors depicted as heat transfer happens through adjacent surfaces by conduction; this can be limited by setting protecting materials instead of good conductors of heat. Convective heat losses because of steal away heat by some medium like air from the surface can occur in these sorts of devices. This can be limited by shutting all the air holes. Radiative losses from the absorber can be forestalled by the utilization of spectrally specific absorber coatings. Therefore, specific absorber coating decreases heat losses and increment collector efficiency. The size of the reflector is collector aperture area 2.52x106 mm^2, collector aperture 1200 mm, aperture to length ratio

0.57, rim angle 180° and receiver diameter 30 mm (Pouyfaucon and García-Rodríguez, 2018; Reif and Alhalabi, 2015).

The trough base, consists of 5 such pieces joined together by horizontal pieces of wood to form a collective base of 2.1 m. For the sizing of the parabolic base, we used the parabolic equation to determine the height at equal intervals on the horizontal axis. The equation for this specific parabola turns to be $x^2 = 1.1112*y$. The heights of the base were recorded at equal intervals and their height was calculated. Table 1 indicates both the values, on the negative axis (left) and the positive axis (right), to determine the heights.

Process description. The feed water is stored in a tank, which is obtained from a bore-well, as shown in Fig. 1. The water is given ample time to the solid suspends settle down. An improvement to this can be the installing of bag filters to ensure the filtration from particles. This feed water, free from suspended particles, is now pumped through the feed pump into the vessel. The water will now store into the vessel unit, the vapourization of the water occurs. The circulation pump is now activated to enable the circulation of the feed to enable heating through reflectors into the vessel. As soon as the vapor formation starts, the fan is activated to suck the vapors from the vessel and into the condenser.

As some vapours move into the condenser, some of the vapours condenses in the fan system, an outlet removes such condensed vapours and transfers it into the clean water storage tank. As the vapours move into the condenser, the feed pump re-directs the fluid back to its feed tank. This ensures the pre-heating of the feed water and so do the vapours condense.

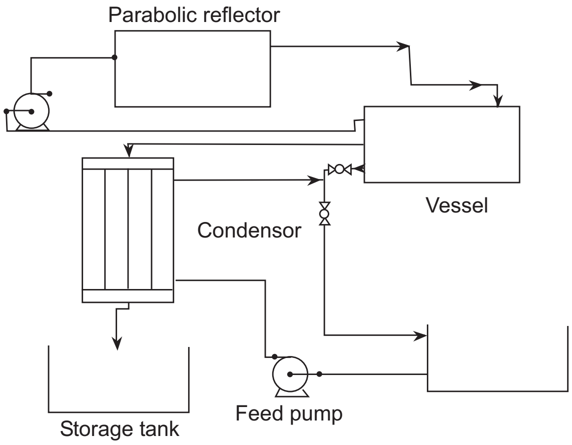

Fig. 1. Process flow diagram.

Until the tank is empty, the feed water is not directed to the vessel, until then it will only circulate through the system. Valves are installed for such purpose, one valve is controls the flow of feed water into the vessel system and the other ensures the circulation of the heated feed water to and fro the system (Chaichan *et al*., 2016; Pugsley *et al*., 2016).

Results and Discussion

The water demand has been increasing day by day, there are many techniques for de-salination of water, but we selected the most economical method for de-salination. The modified solar still technique is used in this research. The advantage of this technique was the less amount of energy used in the system (Shahzad *et al*., 2017; Caldera *et al*., 2016; Maleki *et al*., 2016). It also conducted a different water quality test for the test brackish water and our output distilled water.

The results of the test performed for brackish feedwater pH 6.9, TDS 3200 ppm, Turbidity 4.78 NTU, COD 77 ppm, BOD 12 ppm, DO 0.69 ppm and hardness 375 ppm. The brackish feed water was allowed to be heated by three mediums parabolic reflector, direct heating from the sun and pre-heating as the feed brackish water is being used as the cooling medium in condenser. The vapours generated in the vessel are transferred to the condenser *via* exhaust fan of 1400 rpm (0.3Hp). The vapours are cooled in the external condenser with the help of brackish feed water. The insulation and water-proofing of the vessel are being done by the silicon, the silicon traps maximum heat inside not allowing too much heat loss. The operating condition of feed is brackish water, heating mediums parabolic reflector, direct heating from the sun and pre-heating, temperature sensor type is analog, cooling water flow rate is 28 l/min, water temperature is 20 °C and out 40 °C, the water Flow rate in parabolic reflector is 15 l/min. Water de-salination is being carried out at different weather conditions, having different experimental arrangements.

Table 1. Parabolic trough heights

x (m)	-0.48	-0.4	-0.32	-0.24	-0.16	-0.08	0	0.08	0.16	0.24	0.32	0.4	0.48
y (m)	0.21	0.14	0.09	0.05	0.02	0.01	0.00	0.01	0.02	0.05	0.09	0.14	0.21

Solar still without a parabolic reflector and external condenser in cloudy and sunny weather. In these experiments, a collector was installed inside the vessel. The glass surface through which sun rays were allowed to enter in the vessels acts as a condensing surface, due to the difference in the temperature the vapours were cooled and fell in the collector. The water collected in the cloudy weather conditions was about 0.5-0.8 l/day and sunny weather conditions were about 1-1.2 l/day. Fig. 2(a) and 2(b) shows the results in cloudy conditions and sunny condition.

Solar still with parabolic reflector and external condenser. The reason for installing the parabolic reflectors was to increase the evapouration and condensation process of the solar still to obtain the output water up to 8-10 l/day. The water collected was about 2.5 l/day. The reason we're not able to obtain the calculated results was the vapour's loss in the systems. More waterproofing needs to be done to increase the efficiency of the facility. Fig. 3 portrays the temperature versus time of solar still with parabolic reflector and external condenser.

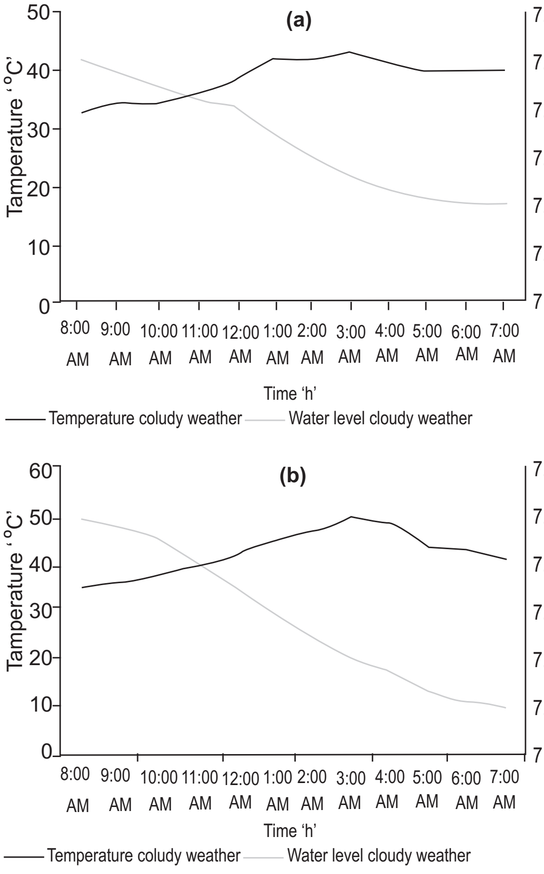

Fig. 2. Results at **(a)** cloudy conditions **(b)** sunny conditions.

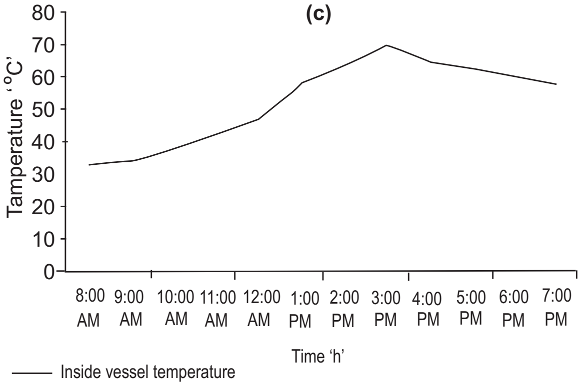

Fig. 3. Temperature versus time of solar still with parabolic reflector and external condenser.

Conclusion

The conversion of brackish water into de-salinated water by solar energy was successfully done in this research. The temperature, TDS level, and other parameters required were achieved for successful de-salination. The research also entailed the successful sizing and fabrication of a water de-salination apparatus. The technique selected is based on the evapouration and condensation rates to increase the efficiency of the facility, one must implement measures to enhance the evapouration and condensation rates of the facility. There are some recommendations to increase the efficiency of the facility by using the Helical Copper tubes inside the vessel as the heating medium. The need for research in de-salinating the water through solar energy is increasingly becoming crucial. Although the world's non-renewable resources will still suffice for decades to come, man's ability and knowledge has surpassed the point that he can rely solely on estimates. Today the world needs clean and healthy water that should fulfill the needs of each living organism alive. Pure water is the main constituent of a healthy ecosystem.

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Conflict of Interest. The authors declare no conflict of interest.

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