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Distilled water by solar desalination using PCM in environmental solution

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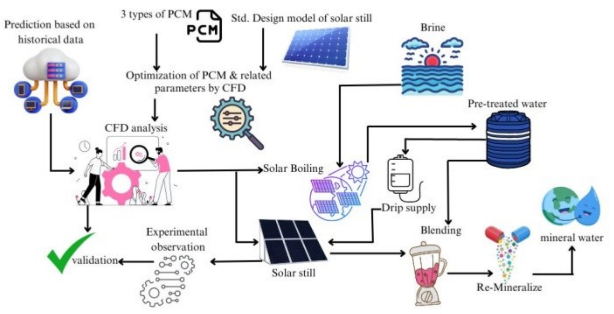
Graphical abstract



Abstract

By using a hybrid solar mineral water production setup to turn sea water into mineral water, this research intends to provide a comprehensive solution to the human need for drinking water. Before feeding seawater into the solar still, it also applies the proper pretreatment. In order to increase the rate of evaporation, this research maintains a thin layer of water. It also chooses or optimises the best PCM for night production and supports climatic fluctuations during day production. It chooses and refines the best absorber black coating for the basin in order to improve the quality and longevity of the absorption process. This article adapts the proper post treatment for fresh water to provide mineral water and has the necessary alterations to utilise the hybrid system anywhere there is feed water, if necessary. The computer-integrated data logger is used to properly infer real-time measurements. As a result, the hybrid effort increased both the yield of fresh water and the drinking water's quality. The highest yield was 6.273 kg per square metre per day in the winter and 9.715 kg per square metre per day in the summer. The design of the solar still with multiple trays, solar disc emphasis on the solar still, and cover cooling technique shall be supplemented the additional yield of fresh water from the sea water can further improve the system.

Keywords: Solar desalination, solar still, optimization, sea water, data logger

1. Introduction

Drinking water is most indispensable daily addition, especially in human life. Its quantity and quality decides the healthiness and sickness. Even at sickness it is basic daily addition. A huge demand of such precious one must be affordable to everyone. The technology which utilizes the abundant energy to derive it from an abundant worldwide source (sea water) will make it affordable to everyone. One of such wonderful invention is solar still. Even a computer also slow at the beginning of its invention so many innovative, unique augmentation approaches are still proposed in augmenting yield of solar still. The presentation of brief description about the solar still is must for better understanding to the readers, about the explaining the augmentation methods employed in this investigation. An Inside black coated metallic basin with slant opening and its surfaces thermally insulated well for avoiding the heat loss. The slant opening covers by a translucent roof of the greenhouse through with the sun radiation enters in the volumetric space of the basin. The radiation is converted into infrared by block coated surface. The infrared employed in heating and evaporating the brine. Then the water vapor condenses at inside of the glass cover by low air temperature at another side of the surface. The sloping glass cover and gutters at bottom edge end of the inclined glass cover as droplets. The heat and mass transfer is responsible for efficiency of the solar still. The better handling of heat and mass transfer of this system the efficiencies could be boot up speed very economically.

WHO (World Health Organization 2021) estimated that no access of drinking water for nowadays world population as 29%. Srithar & Rajaseenivasan (2018) reported a statistic of availability of water for drinking with respect sea water is 1% in the globe. So, the activity of compensation of such indispensable demands must be carried out rapidly by augmenting the existing water production system especially the conversion of sea water in to drinking water. The solar still employed to convert the sea water in to distilled water by means of solar energy (Miró *et al.* 2016). But the rate of production is found low. The various augmentation techniques recently reported to enhance the yield and quality.

The hybrid approach always leads to better yield (Abd Elbar & Hassan 2020) utilizes the opportunity of hybrid of the solar panel (for preheating brine), and the porous material (black steel wool fibers) for augmenting the evaporation rate with solar desalination system and achieved 3.534 kg water per square meter per day as maximum yield that was 38.07% excess than conventional solar still (Iqbal *et al.* 2021).

The enhanced the rate of freshwater yield from solar still through augmentation of thermal conductivity of the basin by adding nano alumina particles as it is cheap in its black coating. Abubakkar *et al.* (2021) hybrids the solar still as well as solar disc collector in such a way that the solar disc collector focuses its heat to solar still, but this combination yields 95ml excess collection per day was reported. Srithar *et al.* (2016) introduced enhanced triple basin system of solar still with preheating, triangular fins, and cover cooling arrangements, the same was hybrid with solar photovoltaic panel and parabolic dish concentrator in such a way that the parabolic dish concentrator positioned for focusing its concentration to solar still and the photovoltaic panel coupled for running the pump. The augmented method properly analyzed and reported that the use of charcoal in fins and cover cooling augmented from kg/m^2 per day to 16.94 kg/m^2 per day.

Khanmohammadi (2019) theoretically studied and proposed that the solar still performance could be enhanced by including the paraffin to store latent heat and suggested the glass wool to produce economical yield of 9.42 kg/m^2 per day. Essa *et al.* (2020) innovatively augmented the solar still evaporation by introducing the two rotating discs which are partially immersed in the brine to support to reduce the thinness of water inside the solar still. Various rotation speed was investigated. The yield improved from 2 to 3.5 kg/m^2 per day. (Parsa *et al*. 2020) introduced the silver nano particles in the brine to augmenting the evaporation rate and disinfect the hazardous contents to produces the healthier drinking water in hilly place and further improvement done and reported the yield of 6.025 kg/m^2 per day.

Parsa *et al.* (2020) highlighted in his review that the amplification of productivity and efficiency related are widely reported recently as per demand of the world in which nano technology plays important role and use of ZnO nano-rod shape offered improved efficiency of 38% and productivity of 30%. [16] Used Candle wax (tricosane) layer as latent heat storage and highlighted some fact that the use of PCM the day and night production of distilled water from the solar still is possible and length of off sunlight hours based on the quantity of PCM employed in that solar still. They used PCM in the filled tubes on solar still with different mass fraction.

The mass fraction is mass of PCM to mass of water (Sharshir *et al.* 2019). Bouzaid *et al.* (2019) proposed inclined cascade solar still with baffles for enhancing the yield. The investigation was carried out numerically and compared with an outcome. Mousa *et al.* (2019) achieved kg/m2 per day of yield in the solar still by means of 10 % volume fraction of Cuo-nano particles and Glaubers salt (PCM). Mahmoud *et al.* (2019) used a multi-stage stacked-tray system in solar still for increasing the desalination yield and achieved 8.100 kg/m^2 per day. (Chen *et al.* 2017) reported in his review that hybrid of energy technology also reported in the literature like hybrid of biomass energy and solar still in augmenting the production of fresh water.

The bubble column humidifier, humidification and dehumidification systems are founder better than packed type. In this paper handles a unique hybrid approach of disc type solar boiler, PCM embedding solar still, drinking water processing system, drip brine type top up for maintain the thin film of water etc are employed to augmenting the production to achieving the minimum or average rate of production per square meter for meeting single human drinking needs

2. Methods and materials

2.1. Augmenting effort

Apart from setting the optimal inclination angle of 45^o this investigation considered some augmentation strategies. The primary idea is introducing a device like a flywheel in the diesel engine which smoothes the pulses of energy supplied by the engine. That is supply energy when needed and absorbs the excess energy. It is also helps to smooth stop of the engine. Similarly, the phase changing material is one which absorbs the heat energy by melting and liberates the same by freezing. But the melting temperature of the PCM must optimized based n the application requirement. Secondly the PCM layers will serve as latent heat storage and such storage can used for increasing the yield by enabling the system by operating after sun set.

The concept of the boiled water reduces the boiling point (as salt content eliminated from it by boiling) there by augmenting the evaporation rate. The solar boiler fifthly the maintenance of thin film water in solar still amplifies the evaporation rate will be achieved by introducing the drip type top-up system and finally the cobalt pigment to anodized aluminum coating provides uniform black in colour as well as warned that number of chemical treatments is employed for pre treatment of brine and those treatment should not affects the final concentration. It insisted that to follow appropriate method of cleaning of membranes as it is affecting the incoming quality of water for treatment. The same filtered pretreated water from the tank supplied for blending process to concentrates the condensates from 1% to 10% as per direction of World Health Organization.

2.2. Post treatment of condensate

The Blending and Re-mineralization is the post treatment of condensate as the collected condensates of solar still are poorly buffered and contain insufficient minerals. The collected condensates from solar still are antagonistic to store in tanks or transport over pipes as they are made up of cement or metals. So condensates are to be habituation tackle this issue. The recommended practice of conditioning of condensates is, blending the condensate with semi treated or source water a little that is 1% to 10%. In this research, the brine is initially filtered and boiled by means of Solar Dish Collector and stored in the diathermic vessel (tank) and from 1% to 10% concentration permitted as per recommendation World Health Organization (WHO) with condensate. The bacteria, viruses, parasites, and protozoa were killed initially by boiled at solar boiler and cooled at diathermic vessel.

The re-mineralization is the process of including / augmenting the mineral content in condensate. The world health organization experts and health experts recommend that content of magnesium and calcium in drinking water like 5 mg and 15 mg of calcium and magnesium per percentage of sea water. The recommended dosage of alkalinity and hardness in the condensate of solar still is carbon dioxide (CO_2) 44 milligrams per litter and calcite ($CaCO_3$) is 100 milligram per litter. The addition of bromide would likely protract to respond with outstanding antiseptic during distribution as well as storage. Blending with minerals like chlorides of potassium, sodium as well as and other salts with condensate as directed by the WHO.

2.3. Phase changing material selection

The phase changing materials (PCM) are widely employed in thermal storage system as it absorbs heat energy by melting and liberate the same by freezing. As it has high density, comparatively PCM occupies less space and can use the dual purpose of heat transfer medium and thermal storage. Classified the PCM commercially available PCMs. The application of PCM ranged between super heating and sub cooling purposes. According to the operating Range solar still and solar boiler and melting temperature selected in 50^{o}C 60^{o}C and 70^{o}C. But commercial availability is S50, S58 and S70. Here s stand for Salt Hydrate PCMs and then following two digits are melting temperature. According to proposed application, the range of PCM is suitable for Positive Temperature 7^{o}C to 117^{o}C. The Salt Hydrate PCM of type S72, S89 and S117 were preferred for the analysis.

3. Thermal storage and numerical optimization

3.1. Modeling and analysis on solar still

The standard model is with principal parts including PCM packaging. The CAD model of the solar still created with SOLIDWORKS software and defined boundary conditions. For the purpose of simulating the system and analysing the hybrid performance of PCM and Solar still, the PCM limitations were also added, and attributes were defined in the CAD geometry. For the examination of computational fluid dynamics, the average local solar data were taken into consideration. Unsaturated latent heat model alone should be used to define this modelling. This system highly number of times steps in to hydration of system plays in limitations. In order to overcome these issues of latent heat conditions were set which time in travel in 1 hour. The basin, glass and water temperatures, as well as three different PCM, are all included in this system. To install this first reason, three PCM materials can be used as frame works. These materials should have saltwater qualities. Additionally, the impacts of this system's induction of the evaporation process in a laminar flow model at the latent heat temperature were deduced. While doing the dynamic investigation, the PCM's phase shifted from liquid to solid and was taken into account in the simulation. It was presumpted that the CFD model's problem specification contained the only resistance that existed. This formation's turbulent kinetic energy equation is defined at the basin's bottom. The system's PCM package will store the extra heat as latent heat and return it if there is a change, even if it takes a day or more. Glass temperature is taken as the condensate temperature. For a better understanding of the PCM's heat storage and condensing rate, this internal heated force is being assessed. For water infiltration of the outer layer and heat loss to the surroundings, the free slip barrier was established.

This investigation's goal is to evaluate how well embedding works with solar still. According to the literature, the operating temperature of the solar still will often be greater than 70oC. Therefore, a temperature above 70oC is required for PCM melting. The observation period lasted for 12 hours, from 7 am to 7 pm. Modelling using computational fluid dynamics took into account the absence of slip in the overall system. Following simulation, the volume percent was determined to be between 0.27 and 0.67 for the condensate of the brine. Figure 1a displays the volume fraction at the collecting site. Figures 1b and 1c, respectively, show the space inside and the volume fraction on the glass surface. Contoured plots were created. This semi-structured model's contour plots were created using ANSYS 14.5 Workbench Solver, and 1854242 Nodes were discovered by Tet-Mesh analysis in the simulation and experiment.

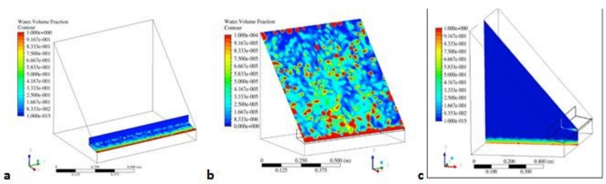


Figure 1. Volume fraction at (a) collection point (b) glass (c) interior space

The mass flow analysis aids in determining the PCM performance between 5 PM and 10 PM or later. The analysis's findings were compiled and presented. With mass flow, a mixture of temperature and flow velocity, the PCM support can be further examined. Based on the findings of the investigation, the S117 type PCM was determined to be at ease when defined environmental and solar data were taken into account. As a result, it was advised to embed S117 type PCM in the solar sill and solar boiler as a single unit with concentric shell PCM to be filled in between the Shell on all sounded sides except glass side. The mass flow with a mixture of temperature and velocity was shown in Figure 2 together with a manufactured PCM. Integrated solar still.

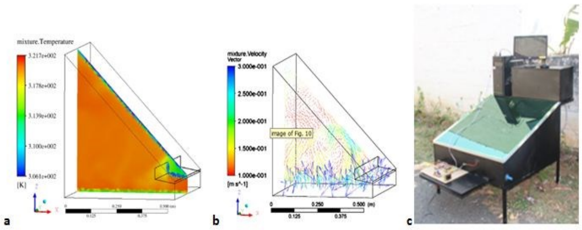


Figure 2. Mass flow with mixture of (a) temperature (b) velocity (c) fabricated solar still

4. Experimentation

4.1. Experimental setup

The fabrication of the solar still basin. Between the basin and the insulation, the S117 PCM packing can be placed. As instructed by manufacturer requirements, the S117 PCM was packaged. The concentric vessel was then mounted inside the glass-covered, insulated basin box. The Quality checks were made to ensure the fabrication quality. The setup can be altered to solar still without PCM by replacing the space by insulation materials. The fabricated Solar Still With and Without PCM alteration setup and Computer assisted SCADA – serial port. The solar still is equipped with sensors and measuring devices for experimentation. The Solar still fabricated with alteration facility without embedding and with PCM embedding to investigate the proposed augmentation effects. The Data logger is integrating all sensors to computer. For example, the inside temperature in the solar still is measured by T-type thermocouple which is integrated to SCADA – serial port. The data logger used for inferring multiple measurements like the PCM temperature, inside space temperature, water temperature. Glass temperature, solar flux, beam radiation, useful heat gain, inlet heat temperature, ambient temperature and outlet temperature. The sensors were employed and integrated for this purpose.

4.2. Experimentation

Experimenting with plans includes the alternative day inquiry on the traditional sola still and embedded PCM configuration. Boiled brine is drip-fed into the solar still to maintain the thin layer of water. Maintaining the volume flow rate at the same level as the evaporation rate. For the optimum coverage and longevity, Rust-Oleum Brand Flat protective enamel was applied to the absorber. The sensors offered a variety of measurements, and they linked those measurements with a data logger and a computer to produce direct readings.

Measurement errors were prevented by using average reads for the analysis. The average of three separate days of the week was taken into account for the combined observations of the ambient temperature from morning 9AM to afternoon 4PM. In Figure 3a, the ambient temperature profile over time is graphically analysed and displayed. The ambient temperature ranges from 30 to 34 degrees Celsius. Similar observations were made of the absorber temperature, output temperature, and inlet temperature between the hours of 9 AM and 4 PM. As boiled and cooled water was fed to the solar still, the input temperature fluctuated from 29°C to 33.2°C (Figure 3b). By reducing the boiling point of the brine, the boiled, cooled water lowers the evaporation temperature and increases the output of fresh water. The Figure 3c graphically analyses and displays the output temperature profile over time. The output temperature ranged from 34 to 70 degrees Celsius. In Figure 3d, the temperature profile of the absorber is graphically analysed and displayed. The temperature of the absorber ranged from 80°C to 142°C. The extra heat was stored in latent heat storage and used to produce fresh water at night.

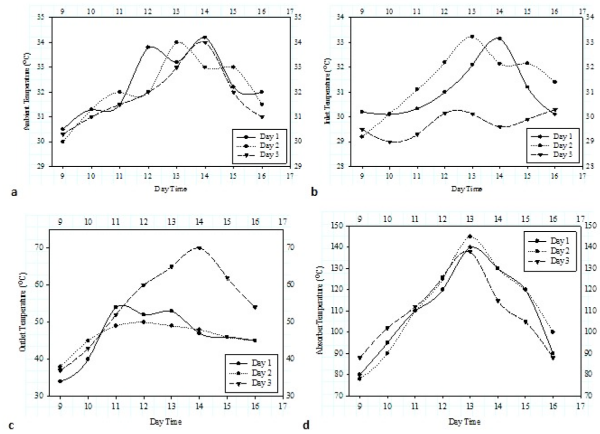


Figure 3. Temperature distribution over day (a) ambient (b) inlet (c) outlet (d) absorber

The measurement of input energy is crucial since it helps to better understand the nature of production, such as slow, fast, or medium speed. The combined observations of solar flux, usable heat gain, and beam radiation were made between the hours of 9 a.m. and 4 p.m. These observations are represented visually in Figures 4a to 4c. The average values of these three parameters are presented in comparison in Figure 4d.

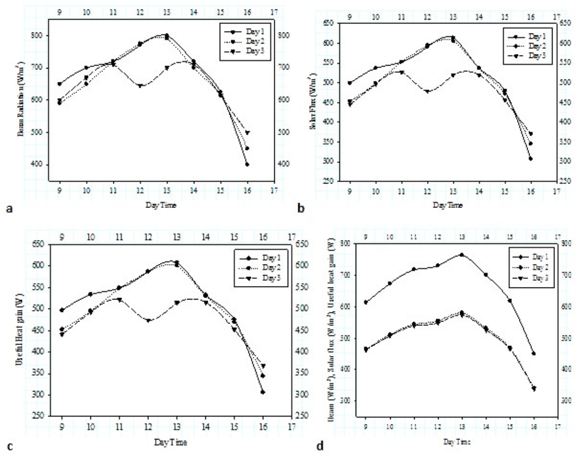


Figure 4. Day time profile of (a) beam Radiation (b) solar flux (c) useful heat gain (d) average performance

5. Results and discussions

5.1. Winter yield analysis

Further the evaluation is expended to freshwater yield performance of augmented solar still. The ultimate aim is to augment the freshwater yield of solar still. So the fresh water yield analysis is presented here. The observations of freshwater yield in winter are presented in the Figure 5a. The values are freshwater yield average of 5 different days of winter season (beginning middle end and two inter mediate on the winter season) on specific time. The observations are the quantity water collected from the augmented solar still in Kg per square meter similarly the CFD simulated fresh water yield also presented with same unit. In the simulated (CFD) observation, the average of past winter data employed. The performance evaluated and comparatively furnished in graphical form in the Figure 5. The actual performance of the augmented solar still in winter and higher than the expected performance (CFD simulation results)

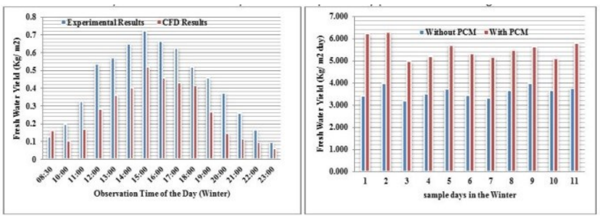


Figure 5. Fresh water yield on winter (a) expected and actual with augmented solar still (b) effect of PCM embedding on winter

5.2. PCM performance on winter yield

The PCM performance could be evaluated by considering all other augmenting effort expect PCM embedding that is simply described as solar still without PCM embedding case. The solar still with PCM embedded case is complete consideration of all augmenting efforts including PCM embedding. Single set up is designed for dual observations so alternate days are considered for analysis and the samples used for entire winter season. The results are analyzed and comparatively presented in the Figure 5.

5.3. Summer yield analysis

Further the evaluation is expended to freshwater yield performance of augmented solar still in the summer were observed. The freshwater yield reported here is average of 5 different days of summer season (beginning middle end and two inter mediate on the summer season) on specific time. The statistics of observations are the quantity water collected from the augmented solar still in Kg per square meter. Similarly, the CFD simulated fresh water yield also presented with same unit. In the simulated (CFD) observation, the average of past summer data employed. The performance evaluated and comparatively furnished in graphical form in the Figure 6. The actual performance of the augmented solar still in summer and higher than the expected performance (CFD simulation results).

5.4. PCM performance on summer yield

The PCM performance could be evaluated by considering all other augmenting effort expect PCM embedding that is simply described as solar still without PCM embedding case. The solar still with PCM embedded case is complete consideration of all augmenting efforts including PCM embedding. Single set up is designed for dual observations so alternate days are considered for analysis and the samples used for entire summer season (Date of observations presented for reference).

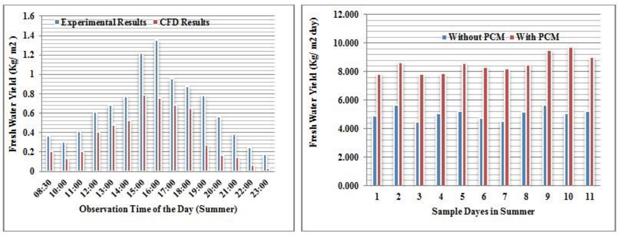


Figure 6. Fresh water yield on summer (a) expected and actual with augmented solar still (b) effect of PCM embedding on summer

5.5. The integrated solar mineral plant

The optimized PCM type S117 is used as latent heat storage for solar boiler as well as solar still. The brine is filled in the brine tank through filter. The basic filtered brine is supplied to PCM embedded solar boiler. The PCM employed here to compensate the solar radiation variation as well as work beyond the sun set time to maximize the yield. The boiled water periodically disposed to the diathermic vessel (pretreated water tank). In this tank boiled water get cooled to environment temperature. The action of boiling and natural cooling of brine killed the bacteria, viruses, parasites, and protozoa within. The Pretreated water tank supplies brine to the solar still to produce condensates as well the blender to concentrates the condensate. The condensate has low hardness and mineral content. The quality of the condensate to be enhanced to meet the supplements supplied through natural drinking water. Such care activities are blending and re-mineralization. The setup established with guidelines WHO. The freshwater yield from the augmented solar still is further post treated to convert it into quality healthy mineral water. The resultant waters are tested and found good quality and tasty mineral water production ensured.

6. Conclusion

By considering indispensable, urgent and best requirement of converting the seawater to mineral water for happy living of world family members is discussed in this article.

The hybrid approach includes

1. Introduced pretreatment of solar disc collector for boiling the filtered brine.
2. Boiled water allowed to cool and simultaneous supply for solar still
3. Augmented evaporation rate by introducing the drips top up system of brine to maintain the thin film of water with neglected heat loss in solar still.
4. Augmented evaporation rate by supplying of boiled cooled pretreated water supply to solar still.

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