Global NEST Journal, Vol 25, No X, pp 142-149

Integrated design of stepped solar still with internal glass reflector for environmental desalination

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Received: 30/06/2023, Accepted: 15/09/2023, Available online: 27/09/2023
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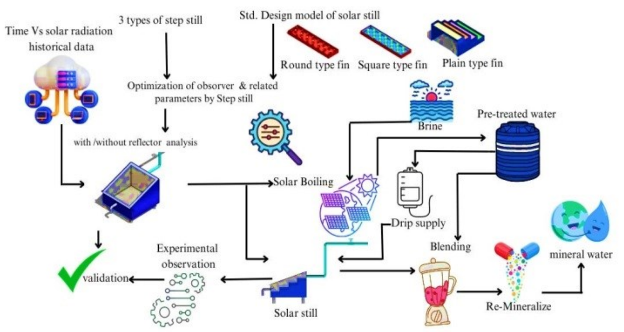
https://doi.org/10.30955/gnj.005215

Graphical abstract



Abstract

Water, a scarce resource that is necessary for the survival of all life on earth and also for economic, environmental sustainability, and social progress, is becoming increasingly difficult to come by. Recent research analysis revealed that reflector, absorber, and evaporator were the three distinct components of equipment employed in solar stills. The 1x1 m^3 specification was used to examine this experiment. Using absorbers, reflectors, and evaporators, this study developed three distinct conceptual stages. The initial phase includes cloth, stone, and waste steel used in the absorber process. Using a reflector, a secondary stage experiment compared using with and without glass. The stepped type absorber with mild steel, plain round, and square fin type trays are all dealt with in the territorial stage of the evaporator process. To assess the improved desalination system, an analysis between an enhanced stepped solar still and a plain stepped solar still is made. It increases the concentration of solar radiation on the water and simultaneously enhances the heat transfer and leads to 30% enhancement of efficiency.

Keywords: Desalination, solar still, reflector, absorber, evaporator, solar radiation

1. Introduction

Due to environmental pollution, the amount of water available in this world is decreasing as the population rises. Because this world is surrounded by water on three sides and land on one, the water source we require is not present in the required quantity, and the necessary tools or products have not yet been discovered. While it is true that we will not be able to stop the world's excessive population growth by the year 2030, the drinking water conditions that this requires must be resolved by at least 7% or else we will face several drinking water issues. This drinking water can be quickly retrieved from the sun in freshwater or marine environments without the use of electricity, according to many books and common application goods.

The most fundamental need is for freshwater, which also serves industrial, residential, agricultural, and trade-specific needs in addition to those of animals, plants, and humans. About 97% of the water on the Planet is in five seas, and the remaining 2% is frozen into ice in the polar regions. As a result, just around 1% of the total amount of water on the Planet is freshwater fit for human use. Additionally, many regions of the world have less freshwater accessible due to rapid industrial developments and significant population expansion. In dry areas of the world, desalinating, moving, and providing freshwater remain the key issues. The water quality utilized for agriculture and drinking in India falls short of WHO standards. The widespread use of solar stills may be explained by the fact that the bulk of Iraq's dry regions sees significant gains from solar radiation. A solar still is a tool employed in the sunlight distillation process, which turns impure water into fresh water using solar thermal energy. Solar stills don't need an external power source of any kind. The fundamental processes of solar distillation are the evaporation of water and vapor deposition. The main issues with solar stills are their expensive cost, big necessary surface area, poor thermal effectiveness, and limited rate of water supply.

Researchers show how the suggested water desalination system will operate between August and September 2020 depending on factors like high-frequency, water elevation, and hot air (Abdelaziz *et al.*, 2022). Some variables, such as the speed of the wind and water saltiness are deemed to have minimal effects on the operation of the system in comparison to the other variables. The effect of water salinity on salty water surface stress which quickly encourages 100% relative humidity, is where it works. Examines the potential of combining reverse osmosis with desalination by heat innovations in hybrid designs (Alhaj, M., & Al-Ghamdi, S. G. 2019). This article develops tools to support decisions for the best placement of solar desalination units depending on several geographical criteria and evaluates the ecological effects of solar distillation on a life process basis rather than only by taking into account carbon dioxide emissions. (Feria-Díaz *et al.*, 2021). Desalted water found in this experiment is 47% less than that from traditional desalination using thermal energy. With 69% of the installed capacity worldwide, reverse osmosis techniques are more prevalent at the intermediate and rural scale in single plant processes, particularly for the generation of fresh water. When compared to other renewable energy sources, it has reduced intermittency and higher reliability, making it a source with enormous promise for desalination procedures. But there are currently no studies demonstrating the economic viability of this technology, which is still in the early stages of research.

It deals with the economic feasibility and efficiency of solar vapor generation (SVG)which is used to produce clean water. This experiment makes use of the inherent qualities of evaporation structures, which has the advantages of being cheap and eco-friendly (Guan *et al.*, 2021). Multiple channels for transporting water in plants are a well-known structural engineering technique that is a good structure for SVG water supply. From a material standpoint, cellulose-based parts are excellent candidates for SVG systems because of their high hydrophilic properties and low heat conductivity for systems made of composites to meet this challenge. It emphasizes information about worldwide energy use and the general operating principles for different desalination plants (Kumar *et al.*, 2022). As a result, the current study examines current distillation and purification methods for water and also challenges with water supply and potential areas for further research and development.

Lim *et al.* (2021) create high-performance, dynamically stable, and resilient Seawater Reverse Osmosis (SWRO) materials to reduce SWRO's energy usage and startup costs. To close the gap between common wisdom and actuality, the author of this study integrates SWRO membrane production methods from both academic research articles and patents. In this study, the environmental impacts of several standards were compared and evaluated using the Life Cycle Assessment software. Multi-stage flash facilities working in Qatar's desalination sector with an upgraded MSF distillation setup (Mannan *et al.*, 2019). The lengthening of environmental evaluations in Chile's desalination business is the subject of this article. As a result, the findings revealed that Chile's environmental evaluation procedure has significantly increased in length over time (Sola *et al.*, 2019)

Its principal objective is to act as a grid-scale absorber that may produce drinkable water from excess power while also providing electrochemical energy through an inverse operation when there is a deficit of electricity. These charge-transfer procedures also make a wide range of environmental uses possible (Srimuk *et al.*, 2020). The experiment looks at how to use a biomimetic 3D evaporator to improve the power consumption, evaporation percentage, and long-term viability of photothermal substances at high levels of salinity (Wu *et al.*, 2020).

One of the best ways to handle the water issue in isolated dry places is with solar stills. Because of its reduced productivity, this item is not very well-liked. Increasing productivity can be achieved, for example, by lowering the basin's volumetric capacity for heat (Murugavel, K. K., & Srithar, K. 2011). It has been noted that the incorporation of water nanoparticles, cover cooling, and solar collectors significantly increases the output of solar still water (Srithar, K., & Rajaseenivasan, T. 2018).

The efficiency of the solar still is increased in this work by using a tiered solar still. In this research, the idea of merging a stepped solar still and a collector is presented (Alaudeen & Srithar 2014). In this work, a double basin solar still's performance was attempted to be optimized (Gnanaraj & Christopher D. S. 2017). The R&D community developed stepped solar still as a solution to this problem to boost production per unit area where the area of the basin is minimized through the use of small trays. However, there is still room for improvement in stepped solar (Muftah, A. F., Sopian, K., & Alghoul, M. A. 2018). In an intention to increase the solar still productivity, a new hybrid solar desalination system was developed by combining an inclined solar still with a single basin solar still and hot water storage tank. This integrated system was fabricated and tested with different geometry of new absorber plate configurations (flat, grooved and fin shaped absorbers) under actual climatic conditions. The different new absorbers used in this experiment, increases the surface area of water available for evaporation inside the inclined still. (Samuel hanson R. & Kalidasa murugavel K. 2017)

It was demonstrated that there was an ideal amount for the collector's area and saline water's mass velocity that would maximize the use of energy. It evaluated the efficiency of an inclined copper-stepped solar still with inclined trays to increase the efficiency of a system. This intends to increase production by the use of a refrigeration system that uses vapor pressure. As a result, the rate of unprocessed water evaporation, vapor condensate, and water-based production per square meter of still surface will all rise. Desalination explores the current state of global energy utilization by focusing on the key issues with the production and use of green energy, introducing concepts and frameworks of environmentally friendly growth, and determining the course of energy development.

A stepped solar still is the standard design for the solar still. It has a few drawbacks, such as producing less distilled water per unit of area due to lower water temp and poor efficiency, etc. Numerous research projects have been ongoing up to this point to increase the output of the solar still. From the literature survey,that there was no data has been found about the integration of glass reflector in the walls of the still. From this aspect, this research work gets importance in the contemporary desalination technology to meet the economical and environment friendly system. To enhance the distillation, all the sides of the basin are made to be fixed with internal reflecting mirrors. Solar radiation reflected in all sides of the basin by the internal glass reflectors absorbed on the basin liner. The internal reflectors are to be remarkably increase the distillate productivity.

2. Materials and methods

2.1. Experimental setup

The experiment was conducted at Sethu Institute of Technology, Kariapatti, Virudhunagar, Tamilnadu, India. Figure 1 shows how the main experiment set up stepped solar still. This experiment size is 1x1 m^3 and everything inside is made of galvanized steel with 1.2 mm thickness and black powder coated. It has a square shape and its interior is considered innovative and is an internally positioned glass reflector with an angle of 11x11m^2 at the top position. A steel box with a surface area of 1.2 x 1.2 m^2, a height of 0.59 m at one side, and a height of 0.6 m at another side makes up the setup. Saw dust accumulated at the steps' base. This will stop heat from escaping through conduction.

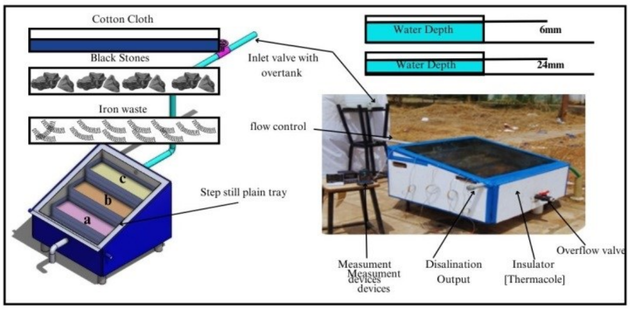


Figure 1. Stepped solar still

The experimental set-up is properly instrumented to determine the temperatures at various still locations as well as the amount of distillate, total sun radiation, and solar air heater. When water is poured to a depth inside the still's basin, the stepped solar still with an internal glass reflector generates more desalinated water. Thus, the deeper the saline water is within the basin, the better the outcomes. In this paper, a stepped solar still with internal reflectors was studied experimentally and theoretically. The findings show that, during testing, the improved stepped solar still with internal reflectors had a daily productivity that was almost 75% higher than that of a standard still.

The goal of this research is to enhance the efficiency of the staged tray desalination system using regulators and observers in a single-sided solar desalination prototype model. Stepped solar still with an internal glass reflector has subsequent trays of inclined collectors which is shown in Figure 2. The top of this style stepped solar still featured a 1.2 m^2 surface fitted with a 5 mm thick glass to gather solar energy. It has the traditional basin's absorber plate attached to it. The glass cover is angled 11 degrees and faces north, which corresponds to Madurai, Tamil Nadu's latitude.

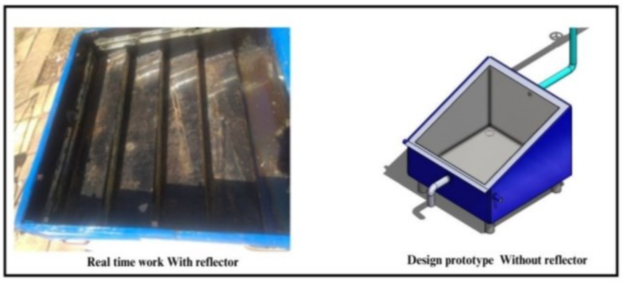


Figure 2. Stepped solar still with internal glass reflector

2.2. Principle of solar distillation

The solar option is the least expensive of all the available technologies, and it can be utilized everywhere without too many issues. This method would be helpful for many enterprises, aside from acquiring fresh water, to transform their liquid wastewater into solid trash for easier disposal. The fundamental principle of solar extraction is to admit radiation from the sun through a transparent lid to a shallow, wrapped brine basin. The fluid vapor also collects the radiation that is transferred into the still; as a result, the heat within the still fluctuates repeatedly, causing it to continue to evaporate. A measurement of the radiation that enters is the fluid vapor that is created in the still. In this context, a calculation of the still's efficiency and an attempt is made to calculate the radiation that the still receives while it is in operation using a readily observable measure, such as relative humidity.

Every nook and cranny was filled with solar energy devices used for home and commercial purposes. By offering incentives, aid, and loans with lower interest rates, the Indian government's Ministry of Non-Conventional Energy Sources (MNES) promotes citizens and business owners to promote the usage of solar energy equipment.

3. Instrumentation

3.1. Types of trays used in this experiment

There are three types of trays are used in this experiment. They are plain, round fin tray, and square fin tray which is shown in Figure 3 (a, b, c) Iron sheet measuring 3 mm thick is used to make these trays. Two different types of fins with square and circular cross sections are introduced in the stepped tray for increasing the heat transfer area and simultaneously heat transfer rate. The augmentation of the heat transfer rate leads to enhances productivity. Using various basin materials such as black painted iron chips, stones used for heat absorption, and also cotton cloth on water retaining will lead to augmenting productivity. The improved stepped solar still's coupled effect of components for the basin and fins improve overall efficiency and effectiveness while lowering the price of filtered water. A part of the glass gutter affixed to the glass bottom directs the water and condenses on its surface to the collecting trough for storage. Through a conduit, the retention tank with a 25 L capacity provides feed water. At the tank's inflow, there is a gate valve. The contaminated brackish water from the basin is collected in a drain tank made of plastic. To regulate the water level in the basin, a valve is linked between the drain tank and the basin. In stepped solar still the heat energy from solar radiation is absorbed by the absorber plate. Productivity increases by flowing water over the trays through the stepped solar still. These plates are filled with various basin materials such as black painted iron chips, stones and two different types of fins with square and circular cross-sections. The trays get heated up and evaporate the saline water and form water vapors. The vapor condenses under the glass cover and is collected separately.

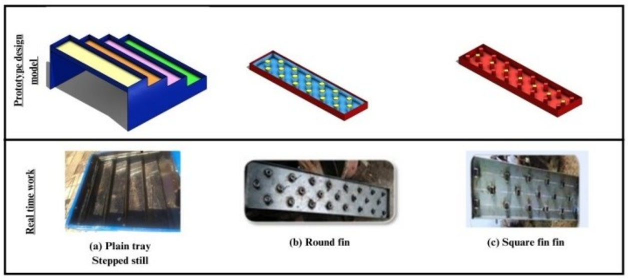


Figure 3. (a) Plain Tray (b) Round Fin Tray (c) Square Fin Tray

4. Experimental procedure

From April to June, the experiment was conducted in Madurai, Tamil Nadu. The base of the tray is divided into three absorbers that can be increased by heat transfer into the tray and water. Hourly monitoring of the performance took place between 9 am and 6 pm (Indian Standard Time). At first, an experiment was started with a cotton-type fabric material as the external radiations absorb and increase the heat to improve the evaporation through the circulation process of the material in the water. Second, for the same purpose of water evaporation, black powder coated on naturally existing paving stones is used to absorb solar radiation and promote overheating. Third, this prototype was found to place steel chips, which are unwanted iron scraps in a waste management system, in areas exposed to solar radiation that are incorporated into the trays. The height of this prototype is 160 m, so only the interior of the glass reflector in this basin can be used for the required observation water. The below table provides the characteristics of measuring instruments. An important part of this experimental process is the Fin Trays, whose design and dimensions are planned and evaluated the better performance. Finally, examining the purity of the supply water and the clean water produced by the solar still, it was found that there had been notable increases in terms of factors like accuracy, range, and% error in this workflow of architecture diagram as shown in Figure 4.

5. Analysis of experimental prototypes

A 25-liter tank is used, and the minimum flow rate of water is discharged by gravity pressure in this tank. The prototype of a step-shaped tray, which is integrated with the plane in the center of the image below in positions A and B, C, is the main output of this research. This prototype uses some devices to determine their functions in positions A, B, and C on different sensor devices validated in the node.

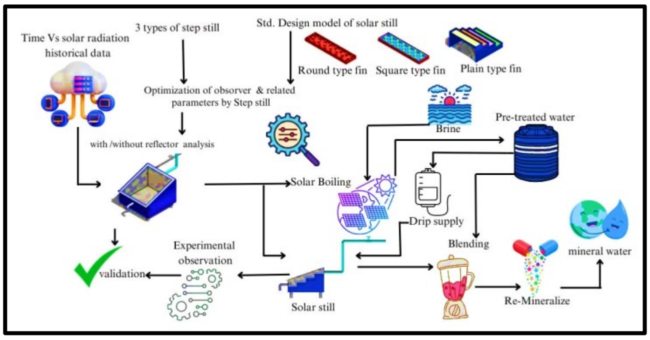


Figure 4. Architecture experimental works

That is, the wire thermocouple installation, solar power meter, radiation meter, the anemometer is all standardized instruments used to detect velocity and flow rates in their measurements through nodes using digital technology with sensors. In this, the critical internal measurements are driving flow maintained at 4 mm and 24 mm water for a whole day from 6:00 to 18:00 for about 12 hours from two liters desalinated yield obtained by solar distillation. This experiment validates the Sethu Institute of Technology in Virudhunagar with this latitude outdoor location and it will distinguish it from different angles using the sensors. Solar radiation and material passion, tray plate, temperature of water treatment wind air velocity, and glass reflector measurements are taken depending on factors such as angle and can be further classified by their factors as shown the Figure 5 final desalination process.

a. Combined formation A and B and C by alternating with accelerate the performance.
b. Its performance can be varied by increasing its angle of the glass reflector.
c. Adding the latent heat observation can vary depending on the nature of black stones and the use of waste iron scrap.
d. Depending on the water used, performance will vary depending on whether light distilled water or bore well water is used, seawater or liquid water from other waste sources, or industrial wastewater.

6. Results and discussion

There are many aspects of the parameters that can be considered for the components of this research paper. An important part, of which three types of trays are plain, square fin, and round fin. Apart from that, the main focus of this research produced by the installation of the internal reflector glasses, which can be considered an important innovation of this paper. It was found that solar radiation can be absorbed in the prototype with or without reflectors. This desalination process can take place between 6:00 am and 6:00 pm in its solar experiment, and it captures solar radiation once per hour, depending on the heat transfer in the reflector. In the outlet distilled water TDS, salinity, are observed through transparent measurements. The performance in this experiment can be seen with the observed values of solar radiation in desalinated and with and without the results of this study.

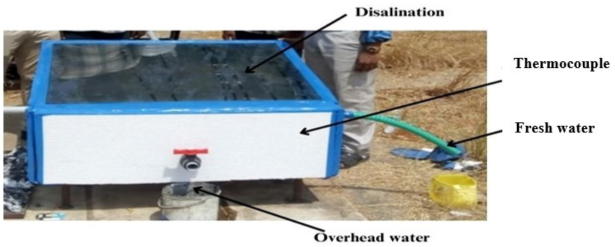


Figure 5. Experimentation system output

6.1. Comparison of solar radiation with atmospheric temperature

In this improvisation study, water was first sampled at a neutral temperature, which can be considered a liquid compound. Because at least 300 feet of water is available, the temperature of the well water was first determined. Next, the solar radiation in the atmosphere is measured from morning to evening, especially on May 18, 2023. These radiation measurements were detected by a refractor using a thermometer, which is considered the main equipment in the experiment of the prototype, which is very hot between 11 clocks and 2.30 the clock during this time is about 32 degrees Celsius to 36 degrees Celsius To be specific, the amount of solar radiation will be so much in this month value is 0–923 W/m^2. Based on this value, researchers have created below a graphical representation of Figure 6 of the comparison of solar radiation with atmospheric temperature.

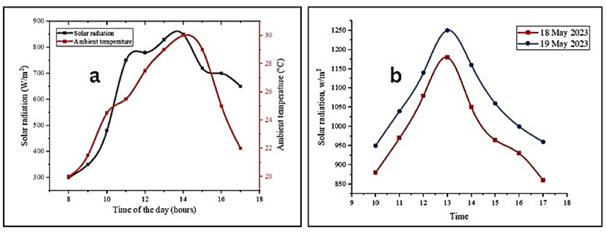


Figure 6. Hourly variation of atmospheric temperature and sun radiation at (a) daytime with (b) measurement date

6.2. Effect of temperature on the external components

In this study, the prototypical step still solar was used to measure the water depth and compare it in two different ways. (Figure 7) This research continues inventively in three alternative designs, including plain tray, round fin, and square fin, for Case Studies 1: 6 mm and Case Study 2: 24 mm. The readings of the air temperature as shown in Figure 4 are compared in this experiment with and without internal and external reflectors.

Water temperature, rate temperature, and material temperature are stepped yet desalinated substances. To collect the data, the outer glass reflector temperature takes mostly between 12:30 pm and 2:30 P.M. Under these circumstances, solar intensity decreased and the vapor temperature increased to conduct this stepped-still solar performed in the experiment. While, excess solar energy through this observation component is contained in this heat transfer bore well water mainly through the inner and outer reflectors, basins, and trays.

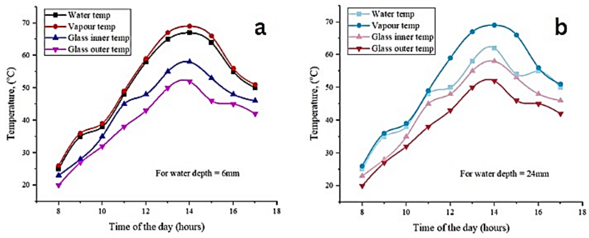


Figure 7. Hourly observation of temperature variations (1) [Internal components] vs. time of the day (B) with water depth = 6 mm and 26mm

6.3. Effect of basin materials and internal components

In this section, the stepped solar still is presented, in which the internal components can be seen using cloth and stones, and iron scraps placed on the conceivable basin. The accumulation of stones and pebbles in the basin and step bowls increase the water temperature and evaporation rate. (Figure 8). To increase the contact area of water, cloth materials are used at the basin. Due to the capillary action of water, the water retention capacity is increased by using cloth material. The productivity of the stepped solar still increases with the increase in the area of the plate by providing fins. The evaporation rate of water still depends on the absorber area of water. The increase in the heat transfer rate leads to an increase in productivity.

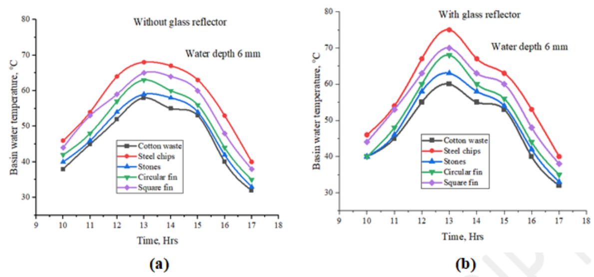


Figure 8. Temperature enhancement with (a) without glass reflector (b) with reflector

The use of various basin materials such as black painted iron chips, stones for heat absorption, and also cotton cloths for water retention led to an increase in productivity. (Figure 9). The combined effect of the new type of stepped solar still with fins and basin materials augments the overall performance and productivity and reduces the cost of purified water.

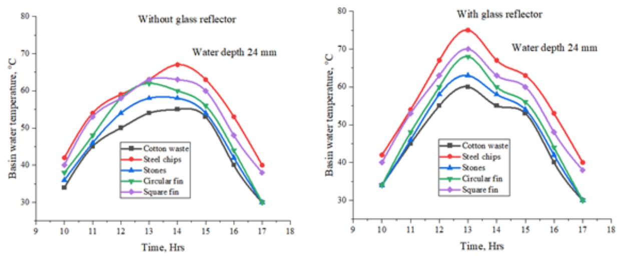


Figure 9. Effect of Time Vs Temperature (Tray with Basin Material and fined tray)

6.4. Performance enhancement of water depth on productivity

As shown in the above sections, the results of the experiment vary depending on the location of water depth and its effects. In this study, water depth in the drive is compared with case study 1: 6 mm, case study 2: 24 mm, and their experimental results. Plain and Round Square fins with internal and external, which can be considered as the main innovation in the drive, is the most important component of a single-stepped solar desalination system.

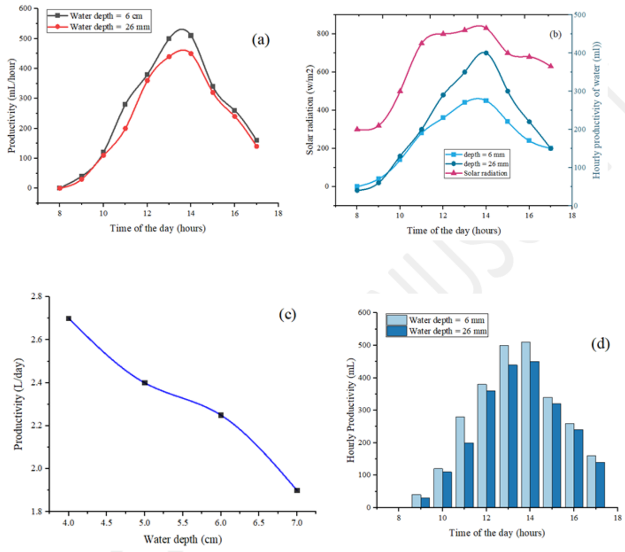


Figure 10. Productivity varies with water depth and time. Productivity with daytime (**a**), solar radiation with daytime (**b**), productivity per day with water depth (**c**), and Bar diagram of hourly productivity at different water depths (**d**).

The latent heat of the water is stored by this component using sun radiation. In addition to these findings, the experiment's absorber included cotton cloth block stone and iron waste. In these two case studies of water, the maximum power at 2 p.m. was taken into consideration together with intensity, as indicated in the Figure. It was found that the intensity of solar radiation only gradually increased near the water's surface. (Figure 10) In addition, with the thermal equation, the option is the transfer of coefficient is greater than the lower depth. Comparison of Trays and Fins With the observer, which includes two types of case studies, research through this active experimentation found that the above step yields a higher percentage of productivity than the case study.

6.5. Performance enhancement stepped solar still

The overall available performance of solar still is maximum at the plain and modified stepped still. However, the inclination of the glass cover and the location of the latitude of solar detection may depend on the place. In this, the efficiency of stepped solar still increases more and more time. (Figure 11) Also, the performance is a novel step still greater as shown in Figure 6. This figure compares the energy efficiency reflected by the stepped solar still with and without integrating the internal glass reflector wall. Its productivity of performance enhancement modified stepped solar still is about 30% higher when compared to conventional stepped still.

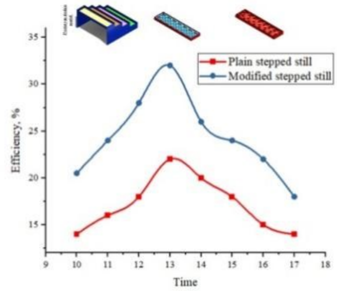


Figure 11. Efficiency of the stepped solar stills

The integration of glass wall reflector in the stepped solar still gives the productivity from 20% to 33%

6.6. Performance enhancement productivity analysis of stepped solar still vs basin materials

The fin type with absorber solar still shows performance enhancement when comparing the productivity of water to conventional stepped solar stills, and as shown in Figure 12, the stepped type with fin and tray has no more heat losses than the system of the conventional stepped model. Since internal glass mirrors utilize the energy reflected from every side of the still wall, their installation improves performance significantly.

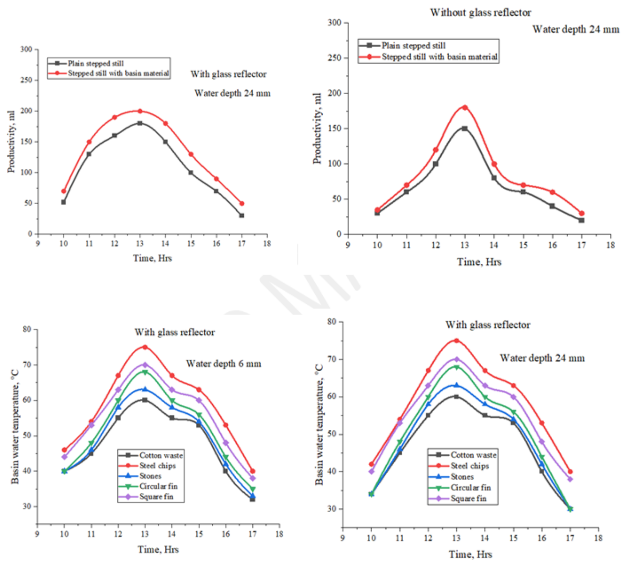


Figure 12. Effect of Time vs Temperature (Tray with Basin Material and fined tray)

7. Testing for water quality

Several factors, including the salinity and TDS, were used to evaluate the purity of the borewell or groundwater and the output water that was taken from the solar still.

7.1. Total dissolved solids (TDS)

Water from a borewell was used for this study. The rainwater that seeps deep into the earth and becomes stuck between the layers of rock is typically the source of borewell water. The depth of the borewell affects the amount of impurities in this water supply. Borewell water often has a TDS level of 500 ppm or greater, which gives the water an extremely salty flavor and makes it challenging to drink. Reverse osmosis (RO) is an effective purification method for treating borewell water. TDS is determined by adding the calcium and copper hardness of the specimen. The greatest way to lower the TDS in drinking water would be to use a RO water purifier, and data gathered shows that using a solar still improves the water quality. RO removes even tiny particles from water by squeezing them through a thin membrane with minuscule pores. Atoms smaller than 0.0001 microns are the only ones that can get through. TDS levels below 300 are regarded as great for drinking, however, they are not always deemed to be acceptable levels.

7.2. Salinity in water

Whenever it rains, a little salt is left behind on the ground. Salt is left behind in the landscape, but water is removed by plant transpiration and evaporation. This concentrates salt over time. Evaporation may directly increase the salinity of groundwater in areas where it is close to the surface. Less than 0.6 parts per thousand (ppt) is the allowable salinity for fresh water. In some cases, quick recharge following flooding can drain out or dilute salty groundwater, reducing its salinity. Large-scale changes in borewell water salinity take decades or longer to manifest. Since human consequences are rarely a problem, borewell water salinity is often only sometimes evaluated. So, using the water produced by the solar still aids in reducing salt and has no salinity. As a result, the water quality of the solar system's still output is drinkable.

8. Economic analysis

The net cost of the system is approximately 340$ for a modified stepped still therefore, the fixed charges cost 35$ for the novel stepped still the operator and the maintenance costs are 8$ and 6$ then the total cost is 49$ for the modified stepped and conventional still, the average product of water 31 liters per day for modified stepped still finally, the cost of distilled water per liter is 0.045$ for modified novel stepped still.

9. Conclusion

The idea of using solar stills to obtain clean water was found to be particularly interesting due to its technological and commercial benefits, including its low cost of development, manufacturing, and technology. This study examines the productivity-boosting effects of a redesigned stepped solar still with several internal glass wall reflectors. An efficient evaporation and absorption surface is provided by the embedded glass reflector, increasing still production. Performance investigation was carried out using various operating circumstances in the Stepped Solar Still. Fins and other basin components were added to broaden the exposure area.Using various basin materials such as black painted iron chips, stones used for heat absorption, and also cotton cloth on water retaining will lead to augmenting productivity. In which the tray with steel chips leads to the highest basin temperature. This article chooses from a variety of permutations the basin material that performs the best and the fin designs that work best. The maximum output capacity is shown by the water depth of 6 mm. The improved stepped solar still combined impact from components for the basin and fins to improve overall efficiency and effectiveness while lowering the price of filtered water. The following findings are presented in light of the current experimental study: Since the warmth from a solar-powered air heater is directed into a stepped solar still, the temp of the saline water rises, enhancing the production of fresh water. The internal glass reflector method has shown to be a reliable and straightforward solution for increasing the output of stepped solar stills. Up to 30% more productivity is gained from the stepped solar still when a glass wall reflector is integrated. The system's overall cost and area demand are both decreased by the suggested design. As a result, TDS levels were below 300 while using a solar still, which is considered to be excellent for drinking. Drinkable fresh water is produced by the solar system when the salinity is less than 0.6 parts per thousand (ppt). Examining the output water and feed water quality produced by the solar still, significant improvements were found. The improved stepped solar still's coupled effect of components for the basin and fins improves overall efficiency and effectiveness while lowering the price of filtered water. Distilled water's quality fully complies with WHO guidelines. To scale up the procedure on a commercial scale, especially in nations like India that get a lot of direct sunlight, more study is required.

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