Proceedings of the 12th International Conference on Fluid Flow, Heat and Mass Transfer (FFHMT 2025)
July 15, 2025 - July 17, 2025 | Imperial College London Conference, London, United Kingdom
Paper No. 101
DOI: 10.11159/ffhmt25.101

Experimental Investigation of Using Porous Bodies to Enhance the Solar Still Performance

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Abstract - The demand for good quality drinking water is increasing. Indeed, the population is increasing rapidly, and the water needs of industry and agriculture are increasingly high. The drinking water crisis strongly revives interest to rapidly develop desalination techniques that are cheaper, simpler, and more robust, more reliable, if possible less energy consuming and environmentally friendly. The desalination of sea and brackish water using solar energy is the most profitable and where the most urgent demand is that drinking water be distributed by droppers. To answer to the water deficit in the world, various technical processes have been developed, in recent decades to demineralize sea and brackish water. Solar stills are a promising solution for addressing the lack of water in areas with limited water resources. To effectively utilize solar stills to address water scarcity, many strategies were used to improve water production, energy efficiency, and overall system reliability. Using porous bodies within a solar still can be an effective way to enhance the performance and efficiency of the solar still. In this paper, the effect of using rocks in solar still was investigated. Different experiments were performed under the same real climate conditions, and the solar still's performance was enhanced and compared in the two cases: conventional solar still and solar still with porous bodies. The results have shown that the incorporation of porous bodies can lead to significant improvements in the water production rate, and overall performance of the solar still system. The experimental findings showed that the incorporation of porous bodies led to the most significant improvements in the solar still's water production and thermal efficiency, with increases of up to 30% compared to the control still. Findings from these studies can inform the design and optimization of integrated solar-driven water treatment systems, contributing to the development of sustainable and cost-effective solutions for water desalination and purification.

***Keywords*:** Solar still - Porous bodies - Performance - Experimental studies - Real climate conditions.

1. Introduction

The demand of clean water is globally increased while the major water resources on earth are seas and oceans. These resources provide water with high concentration of salt which is not suitable for human consumption. The other resources such as lakes, rivers and underground water supply fresh water that doesn't match the global standard of drinking water due to the existence of bacteria and viruses. The traditional systems of producing drinking water operating by using fossil or hydrocarbon fuels in their distillation processes. It is a way to meet the demand of the drinking water but it is not friendly for the environment due the exhaust that brings to the air the carbon dioxide and monoxide gases. To keep the environment clean in producing drinking water, the thermal energy used in the distillation can be provided by solar energy. Solar still is one of the methods that can produce drinking water using solar energy as its thermal energy for its distillation process. Solar still is a device that has metallic tank enclosed by a glass cover. The basin water in the solar still is heated due to Sun ray that penetrate through the cover. The fresh water is produced by the condensation of the water vapor due to the temperature difference between the water vapor and the inside surface of the cover. The solar still known as low productivity and efficiency comparing with other solar distillation systems. Recently, many researchers have conducted studies to improve the efficiency of the solar still and its production of water by modifying the design of the solar still for different operational conditions.

Several enhancements have been carried out in solar stills for increasing its productivity. Different configurations of solar stills have been conducted to evaluate the performance in producing freshwater out of brackish water. The study shows in the results that the maximum amount of fresh water obtained by the tubular solar still coupled pyramid solar still due to the concentrator effect. The results point out that the productivity fully depends on the temperature of the climate and the water temperature[1].Studies have been conducted applying V-corrugation to the basins in order to increase the exposed area to the sun ray to gain high energy for increasing evaporation and decreasing the amount of saltwater existing in basins at the same water depth of solar stills without V-corrugated basins[2], [3]. Results has shown that using a V-corrugated basin instead of the flat basin improved the daily productivity, exergy, and thermal efficiencies by 133 %, 23.48 %, and 55.12 %, respectively[4]. A study has investigated the modified hemispherical solar still (with and without external condenser). It used copper oxide Nano fluid and Copper ships sandwiched between wick material and has shown it best performance comparing with different material of nano fluid in terms of daily productivity and thermal performance. Its results show that daily yield, thermal and exergy efficiency of 4.7 L/ m^2, 46.63 %, and 2.38 % which exceeded the ordinary design by ratios of 48.73 %, 48.74 %, and 167.42 %, respectively[5].A study has investigated the octagonal-pyramid solar still which its results showed that the productivity of the octagonal-pyramid solar still has increased more than twice than that of the conventional still. The maximum productivity are obtained when the depth of water inside the basin h =5cm and angle of inclination of glass cover θ =30°[6].This study were examining double slope U-shaped solar distiller(DSUD) using ZnO/nZVI nanoparticle for enhancement the performance of the still.DSUD performance was enhanced JPAC, ZnO/JPAC, and nZVI/JPAC, with ZnO/JPAC showing 66.35% better productivity at an absorption wavelength of 264 nm. BET analysis confirmed that ZnO/JPAC has higher stable thermal conductivity due to its absorption of solar light compared to JPAC and nZVI/JPAC. It shows that he DSUD produced 7.253L/m^2 per day in the winter and 8.957 L/m^2 per day in the summer, despite production of 51.05%, suggesting a higher ability to adapt to both winter and summer[7]. A study showed that solar stills with activated carbon could produce up to 58% more distilled water than conventional designs without porous materials. Temperature profiles in solar stills with porous bodies consistently show higher water surface temperatures, which correlate with increased evaporation rates. Continuous monitoring indicates that these stills achieve peak temperatures that enhance distillation efficiency[8]. While porous materials can improve performance, their long-term durability under harsh environmental conditions remains a concern. Studies highlight the need for materials that can withstand prolonged exposure to water and UV radiation without degrading [9].The incorporation of porous materials may complicate maintenance and cleaning processes. Clogging and fouling can reduce efficiency, necessitating the development of designs that facilitate easy cleaning [10] ,[11] tested experimentally different thicknesses of porous material incorporated in solar still. They found that the stepped solar still with a thicker porous bodies has higher freshwater productivity and efficiency, and the temperature in the chamber is affected by the presence of porous material as compared to the conventional still.

This study investigates the impact of incorporating porous bodies into solar still designs on their performance in terms of water distillation efficiency. By comparing traditional solar stills with this enhanced by natural rocks, distillate water production and thermal efficiency are evaluated.

2. Experimental setup

Experiences are conducted in order to compare the performance of a conventional solar still with a modified design to determine which configuration yields more distilled water and operates more efficiently under similar conditions. The solar still used in our experiments is a simple basin made of transparent glass, a flat cover, and a shallow water reservoir. Experiments were conducted in the summer season of 2023 on the roof of the College of Engineering building at Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia (24.7136° N, 46.6753° E). The schematic views of the in site experimental setup is illustrated in Fig. 1. Solar still used in these studies is made of carbon steel plate with a surface of 1 m^2. The solar still used in our experiments is made of 10 mm galvanized steel. The basin water coated black paint to increase radiation absorption. Glass covers with an inclination of 32° and thickness of 6 mm were used as a condensation surface. The sidewalls of the solar still were insulated using 5cm Styrofoam thick layer.

The experiments were conducted for a period from 1 May to 10 May 2023, between 8:00 AM and 6:00 PM. The temperatures inside the solar still were recorded every 60 min. At the end of each working day, the total water production and solar radiation were evaluated. In the modified Solar Still, porous bodies were introduced in the basin to show improved performance due to enhancements in heat retention and sunlight utilization. In the modified still a layer of natural rocks is used as porous bodies to enhance the efficiency and durability. Added rocks provide stability for the solar still structure, especially in outdoor applications where wind and other environmental factors can be a concern.

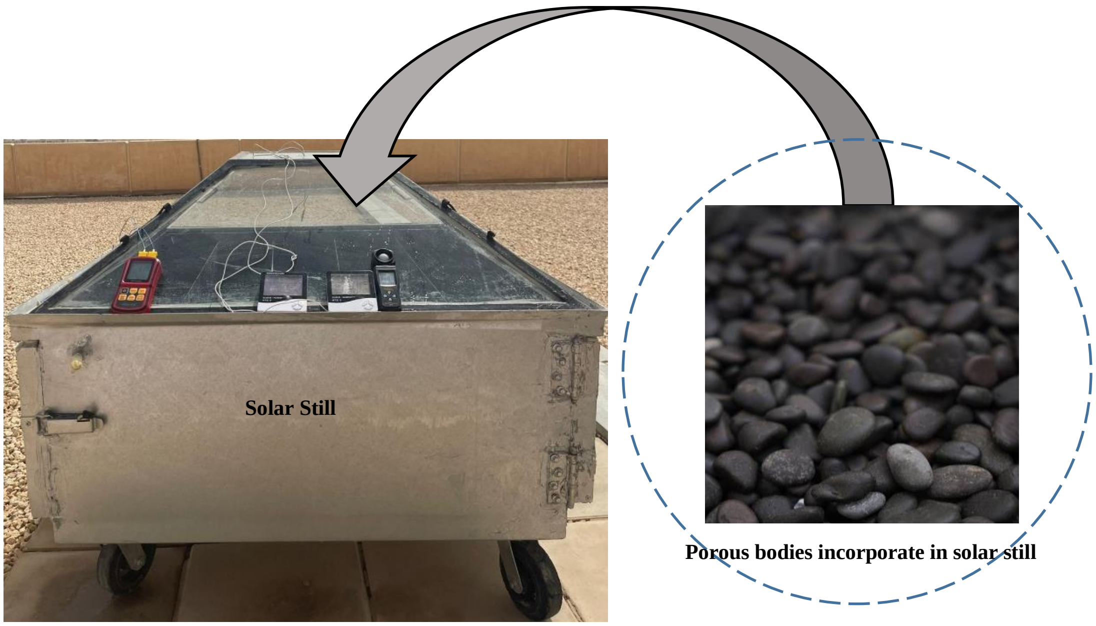

Fig. 1: Experimental setup

3. Solar radiation in the experiment site

Riyadh, the capital of Saudi Arabia, is known for its high levels of solar radiation due to its geographical location and climate. Understanding solar radiation in Riyadh is essential for optimizing solar energy applications, including solar stills. The region has a desert climate characterized by hot summers and mild winters, with minimal cloud cover throughout the year. The consistent and high solar radiation levels throughout the year in Riyadh provide significant potential for solar energy utilization, making it an attractive location for solar power projects. This data can inform the design and implementation of solar energy systems effectively.

Riyadh receives an average of about 500 to 700 W/m² per day of solar radiation, making it one of the sunniest locations in the world. A significant portion of the solar radiation is direct due to the clear skies and low atmospheric obstruction. While the level of diffuse radiation is lower compared to direct radiation, it still contributes to the total solar energy available. During the summer months (May to September), solar radiation levels peak, often exceeding 700 W/m² per day. In winter (December to February), solar radiation decreases, averaging around 400 to 500 W/m² per day, but remains significant compared to many other regions.

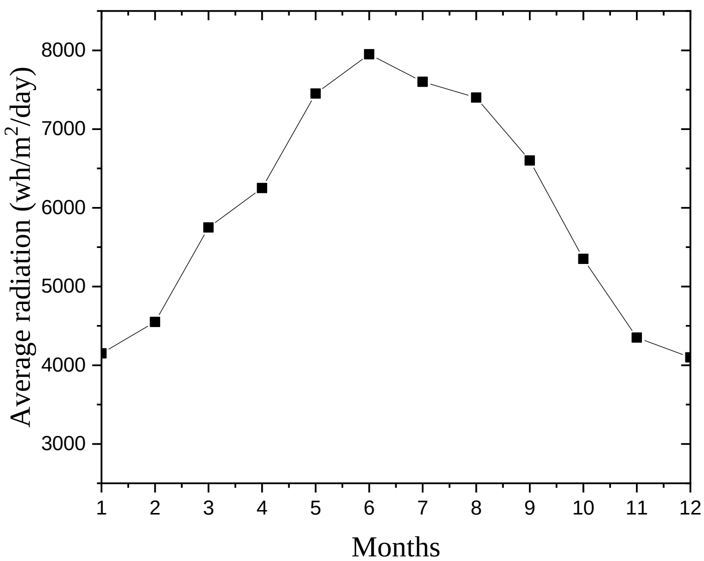

Fig. 2: Monthly Average solar radiation in Ryadh_KSA

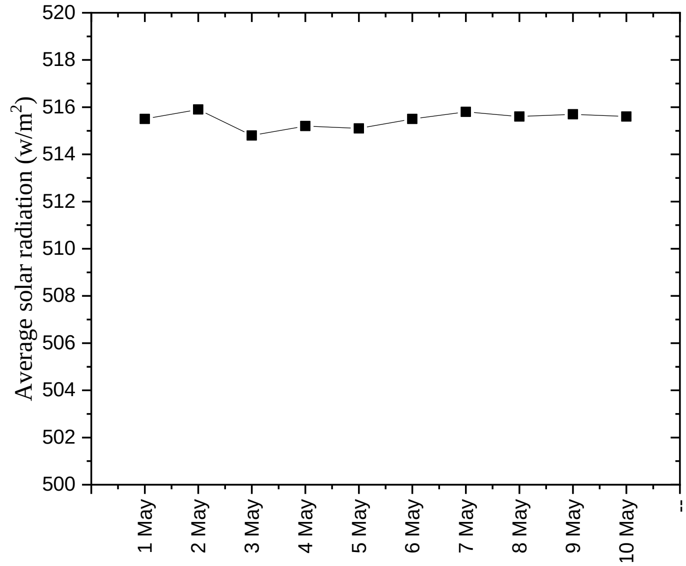

Fig. 3: Average solar radiation during experiment days

4. Results and discussion

Experimental measurements of temperature in the solar still provide critical insights into the thermal performance and efficiency of this system. By examining temperature profiles at various points within the still, we can understand the factors influencing evaporation and condensation processes. Thermocouples are used to measure temperature at different locations within the solar still. Sensors are placed at the water surface (evaporation zone), Mid-height of the chamber, condensation surface (glass in) and the base of the still (absorber).

Experimental results in the conventional still (figure 5.a) shows a clear gradient, with the highest temperatures recorded at the absorber surface, decreasing as you move up to the condensation surface and walls. During peak solar radiation hours, water surface temperatures exceed 55°C, significantly enhancing evaporation rates. The temperatures at the chamber reaches 50°C, indicating effective heat transfer from the water surface. The condensation surface records lower temperatures along the still, which are crucial for effective water collection. Variations in solar radiation throughout the day lead to corresponding changes in temperature. Peak temperatures are observed between midday and 17 PM. Higher surface temperatures correlate with increased evaporation rates, contributing to higher water yields.

In the modified solar still the integration of porous bodies significantly influence temperature measurements throughout the system (figure 5.b). Porous bodies provide a larger surface area for heat transfer, leading to more uniform temperature distribution across the evaporation surface. By minimizing localized high-temperature areas, porous materials prevent thermal inefficiencies associated with uneven heating. Experimental measurements show that the incorporation of porous bodies raise the temperature at the water surface by more than 5°C compared to conventional design without porous bodies. Porous bodies facilitate better heat absorption and retention, leading to higher temperatures that boost evaporation rates. Porous bodies can act as thermal reservoirs, storing heat and releasing it gradually. This property helps maintain elevated temperatures even during periods of low solar radiation. The ability to retain heat allows the still to continue operating effectively during cloudy days or at night, enhancing overall water yield. The temperature gradient between the evaporation and condensation surfaces is critical for maximizing distillation efficiency. Porous bodies help maintain this gradient by improving heat management.

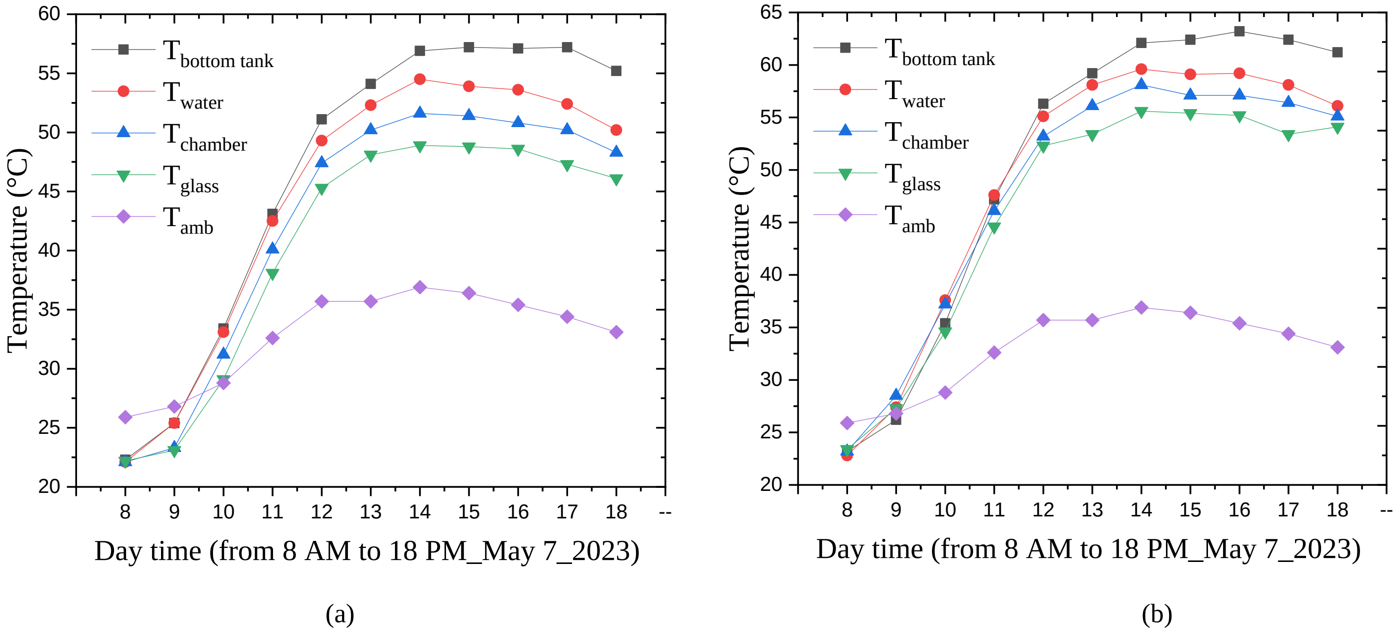

Fig. 5: Temperature variation in the solar still– (a) without porous bodies– (b) with porous media

Incorporating porous bodies into solar still designs significantly impacts distillate water production by enhancing evaporation rates, improving thermal efficiency, and increasing overall water yield. Experimental results (figure 6) have demonstrated that solar stills with porous bodies produce 30% more distilled water compared to traditional design. This increase is attributed to both enhanced evaporation rates and prolonged operational efficiency. Improved heat management not only boosts evaporation but also enhances the condensation process, leading to more effective collection of distilled water.

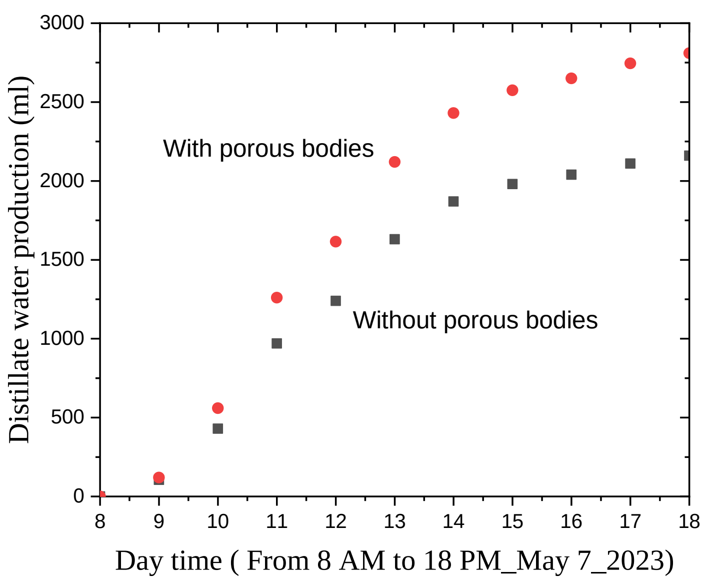

Fig. 6: Daily distillate water production

4. Conclusion

The comparative analysis between conventional solar still and this enhanced with porous bodies reveals significant advantages for the latter in terms of distillate water production and overall efficiency. Solar stills incorporating porous bodies consistently demonstrated a marked increase in distillate water production, with improvements of about 30%. This enhancement is primarily due to the increased surface area for evaporation and better heat retention properties of the porous materials. The presence of porous bodies contributes to higher evaporation rates by maintaining elevated temperatures at the water surface. This results in more effective utilization of solar energy, leading to faster distillation processes. Higher average temperatures and better heat retention contribute to longer operational periods, even under variable solar conditions.

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