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RECENT RESEARCH AND DEVELOPMENT ON WATER DESALINATION USING SOLAR STILL

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Abstract: Solar stills offer a straightforward yet potent method for purifying brackish or contaminated water using the sun's power, presenting an enduring approach to create safe drinking water in areas with limited resources. Over the past decades, extensive research has been devoted to enhancing the productivity, efficiency, and durability of solar stills through design modifications, integration with auxiliary components, and hybridization with other renewable technologies. This review synthesizes findings from experimental and theoretical studies, highlighting the evolution of single-basin conventional solar stills to advanced designs such as multi-effect stills, wick-type stills, pyramid and tubular configurations, and systems integrated with phase change materials (PCMs) and nanofluids. Finally, the challenges of low productivity will only be eliminated by focusing on hybridization.

Keywords: Solar, Solar still, Water Desalination, Solar Energy, Hybrid solar still

Introduction

Access to clean drinking water remains one of the most pressing global challenges of the 21st century, particularly in arid and semi-arid regions where groundwater salinity and freshwater scarcity are critical issues. According to international reports, billions of people face difficulties in accessing safe water, and this challenge is projected to intensify with population growth, urbanization, and climate change. Renewable energy-based water purification methods, especially solar distillation, have emerged as promising solutions owing to their simplicity, low maintenance, and environmentally friendly operation.

A solar still operates on the principle of natural evaporation and condensation, mimicking the hydrological cycle within a controlled setup. Solar radiation heats basin water, causing it to evaporate; the vapor then condenses on a cooler surface, producing distilled water. While the conventional single-basin solar still is the most widely studied, its limited productivity

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(typically 2–5 L/m²·day) has driven researchers to explore innovative designs and performance enhancement strategies.

SOLAR WATER DISTILLATION

Arunkumar *et al.* (2013) conducted research on PCM in black painted copper balls to increase solar still water temperature (Fig. 1). During the sunshine hours, PCM in copper balls melts and energy was stored in the form of liquid and the same heat was utilized by the water during off shine period while convection takes place between higher temperature PCM balls and water. The volume fraction of PCM in copper balls plays a significant role. The solar still with PCM and concentrator coupled to a hemispherical absorber increase the water temperature up to 93ºC. The saturated vapour temperature in the solar still was higher than inner cover temperature and equal to the solar still with and without PCM. Due to the thermal conductivity of copper balls, the heat stored was quickly released to the water by maintaining the thermal equilibrium. The percentage increase in yield with PCM (4.46 l/m^2/day) was 21.07% higher than without PCM (3.52 l/m^2/day).

Fig. 1: Concentrator-Coupled Hemispherical Basin Solar Still with Built-In PCM

Panchal and Shah (2013) developed a double basin solar still using locally accessible materials (Fig. 2) and black granite gravel of varying sizes as a heat storage material. Inner basin was directly connected with evacuated tubes to increase distillation output and outer basin expose to sun. The findings of the experiment demonstrated that connecting evacuated tubes to the inner basin's bottom side increased 56% (2.5 l/m^2 higher) daily distillate output and it reached up to 67% by using 30 mm average size black granite gravel.

Fig. 2: Pictorial view of double basin solar still with evacu ated tubes.

Obayemi *et al.* (2014) investigated on single slope solar stills with variable collector/inclination angle (Fig. 3) and compared with a rigid angle of collector/inclination conventional solar still. Experimental results between the 8.00 AM to 5.00 PM for a period of 5 days were carefully obtained at latitude of 11º 20′ in Samaru, Zaria, Nigeria, during an average period of solar radiation and analysed. Distillate peak yield occurred between 2.00 pm and 3.00 pm while minimum yield was obtained between 8.00 am and 9.00 am during the period of experiment. Traditional solar still produced an average yield of 1.366 l/day/m^2 as compared to variable collector solar still, (1.407 l/day/m^2). The efficiency of variable collector solar still was observed 42% while, in case of traditional solar still was 39%.

Fig. 3: Single Slope Solar Still with Variable Collector

Ibrahim *et al.* (2015) developed and evaluated 0.36 m^2 solar still having submerged flat plate in water basin (Fig. 4) to increase output and compared with traditional solar still under the same test conditions. Comparatively, more distilled water was obtained from the solar still without submerged plate at 10 l of inlet raw water during the first day of experiment while the still with submerged flat absorber had more distillate during the second and third day of the experiment with 20 and 30 l inlet raw water respectively. The average efficiency was found about 82 % in both solar still having 0.75 l/day water output.

Fig. 4: Solar Still with Submerged Flat Plates

Deshmukh and Kolhe (2016) developed and evaluated double basin solar still with 10 evacuated tube and corrugated aluminium reflector under tube having basin size of 1000 × 330 × 380 mm and 1000 × 590 × 310 mm (Fig. 5). It had maintained constant water depth by similar water input and recorded hourly inner as well as outer glass temperature, ambient air temperature from 9 AM to 6 PM. Average productivity rate of water was 10 l/day in developed solar still, which was around 56% higher as compare to single basin solar still. Water pH and TDS were found 6.57 and 60ppm respectively. Payback period was found to be 137days for developed solar still.

Fig. 5: Double Basin Solar Still Augmented with Evacuated Tubes

El-Sheikh and Kishk (2016) evaluated the effect of external water cooling outside glass cover surface in 1.04 m^2 solar still. Four separate solar still of similar dimension were installed at same location (Fig. 6). The first still was used without cooling as a control. The other three solar stills were supported with a water pump to boost cool water over the glass cover surface and operated for one minute and stopped every 10, 15 and 20 minutes, respectively. It was reported that highest productivity was 4.2 l/day with 10 min interval gave 33.2% higher as compared to solar still without cooling. Farther, it was reported that solar still produced 4.21 l/day (with applying water cooling 1 min and stopped for 10 min) and 4.39 l/day (with applying water cooling 2 min and stopped for 10 min) distilled water output, whereas 3.24 l/day for without cover cooling solar still.

Fig. 6: Solar Stills with Cooling Arrangement for Glass Cover

Rahmanian and Farahbod (2016) represented the performance of a single basin solar still as a second stage of proposed zero discharge desalination processes to reach fresh water and also concentrated brine from the effluent waste water of the desalination unit of the Mobin petrochemical complex. Therefore, a solar desalination still was constructed after a pre-treatment unit to concentrate the softened wastewater to about 20 weight percent. The concentrated wastewater was as a suited feed for a forced circulation crystallizer. The results indicate the insolation rate was the most effective factor on the evaporation rate in the solar basin. The production rate of potable water increases to 5 l/m^2 day when the value of insolation rate was 24601.92 kJ/m^2 day on the June in Iran.

Agrawal *et al.* (2017) evaluated single sloped basin type solar still (Fig. 7) theoretical and practically. Different parameters such as basin water temperature, glass cover temperature, distillate output, evaporative, convective and radiative heat transfer coefficients and attenuation factor were changed with different water depth from 2 cm to 10 cm. The theoretical value of daily efficiency for 2 cm and 10 cm basin water depth was around

52.83% and 41.75% respectively and for the same basin water depth; experimental daily efficiency was around 41.49% and 32.42%, respectively. Distillate output was decreased from 4.26 to 3.24 kg/m^2/day for 2 to10cm basin water depth practically.

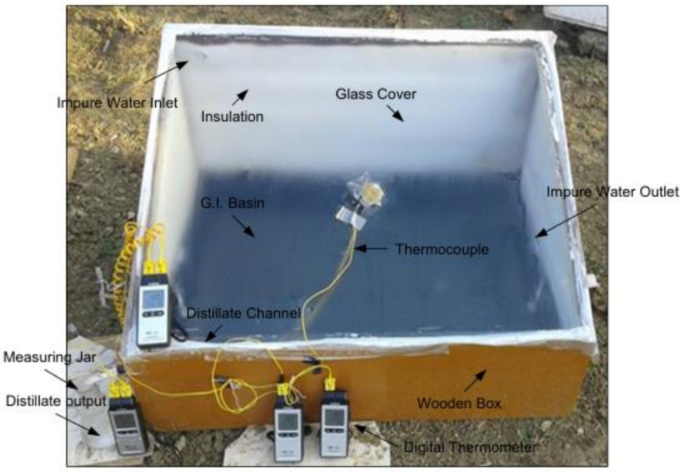

Fig. 7: Single Basin Single Slope Solar Still

Sadiq and Jassim (2017) evaluated theoretically and practically active double slope 1m^2 solar still using evacuated tube heating pipe (Fig. 8) for Basrah climate, Iraq. The computer program was used to calculate the water productivity and other parameters such as heat transfer coefficient and heat flux of the system theoretically then compared with the experimental results relative to local Basrah climate. The water productivity increased with the increasing of solar intensity and wind velocity. As compare to conventional system 43.5 per cent more productivity was obtained in developed solar still. The degree of agreement between theoretical and experimental results was observed about 90%.

Fig. 8: Heating Pipe Evacuated Tube Solar Still

Karthikeyan *et al.* (2018) found from the experimental analysis that increasing the ambient temperature from 25°C to 47°C, the productivity increased in the range as 12 to 23%, which shows that the system performed more distillation at higher ambient temperatures. This experimental result showed that combination of sponge cubes and top cover cooling distillation method would have better performance compared to other methods. Because, normally stepped absorber solar still got 12 % improvement of distilled yield and also by using sponge cubes and jute wicked balls, it got only 6.07 % improvement of distilled yield from normal methods. But using top cover cooling method combined with sponge cubes method had better performance by improvement of 16.28 % of distilled yield from normal methods.

Hoque *et al*. (2019) fabricated a pilot-scale solar still (Fig. 9) with an effective surface area of 0.214 m^2 with mild steel sheet. At first, solar still productivity was evaluated by varying basin water amount by 3, 3.5, 4 and 4.5 l synthetic water. Experimental investigations showed a decrease in water production with an increase in basin water amount. The optimum basin water amount was found to be 3.5 l at which distillate production was maximized. The effect of salt concentration was assessed by synthetic solutions with 2000, 5000 and 8000 ppm total dissolved solids. An inverse relation was found between salt concentration and freshwater production. Lastly, real seawater was fed to the basin and an average freshwater production of 2.38 l/m^{2}day was obtained with a removal efficiency of 99.87, 99.83, 99.78 and 99.81% for turbidity, chloride, TDS and electrical conductivity respectively.

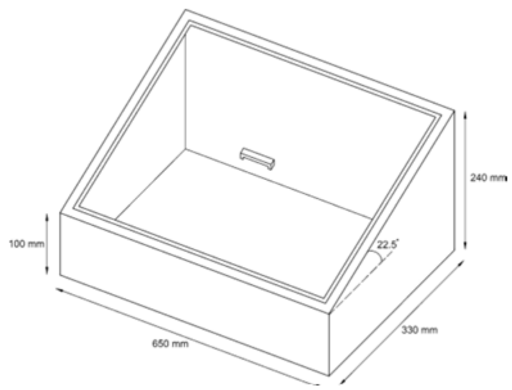

Fig. 9: Pilot-Scale Solar Still

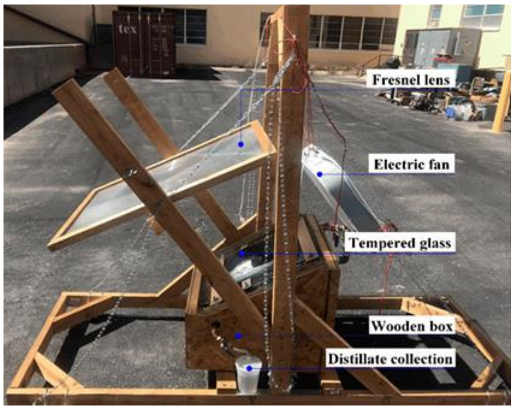

Fig. 10: Fresnel Lens Enhanced Solar Still

Jhonsan *et al.* (2019) conducted study on 0.2 m^2 single basin solar still having an external movable Fresnel lens (FRL) on front side (Fig. 10) to increase the effective solar heat input. It was reported 1.3 and 8.3 kg/m^2 distilled water output without and with FRL from 8 to 5 pm which was 638% higher. Productivity was increased with increasing water depth but distilled water output decreased with increasing water depth from 2 to 10 cm. A mathematical model was developed using energy balance equations for glass, water and absorber plate to predict the glass temperature, water temperature, productivity with respect to solar intensity and time using excel.

Alwan *et al.* (2021) modified available commercial solar still by placing a rotating hollow cylinder inside a solar distiller and integrating the solar still with a solar heater (Fig. 11) and evaluate economic analysis of solar still. Modified solar still produced 12.5 l/m^{2}day, which was 400% more distillate water yield compared to a commercial solar still (3.1 l/m^{2}day). The costs of producing a liter of distilled water from the conventional and modified solar stills were 0.0282 and 0.0268 $/l, respectively. TDS, pH and electrical conductivity of distillate water produced by the modified solar still was around 13 ppm, 6-8.5 and 8.7 µs/cm respectively.

Hameed (2022) evaluated the performance of single slope solar still with a square cross-section hollow fin (25 × 25 × 25 mm) using 2 mm thick galvanized iron attached to an absorber plate and cooling the glass cover (Fig. 12). The cooling mechanisms under consideration were of two types: continuous water spray and pulsed glass cooling (30 s/30 min), (30 s/20 min), (30 s/10 min), and (30 s/5 min). It was reported that enhancement in productivity of 3.12 l (40% more) with fin as compared to 1.87 l without fins in solar still. It was reported the 36.7% higher water output was achieved by the integration of single slope solar still with a square cross-section hollow fin with glass cooling by spraying at 30 s/10 min as compare to without fins and colling in solar still. It was also reported that the combination of both mechanisms had enhancement of 61.3% in contrast to that of a conventional single slop solar still.

Fig. 11: Modified Solar Still

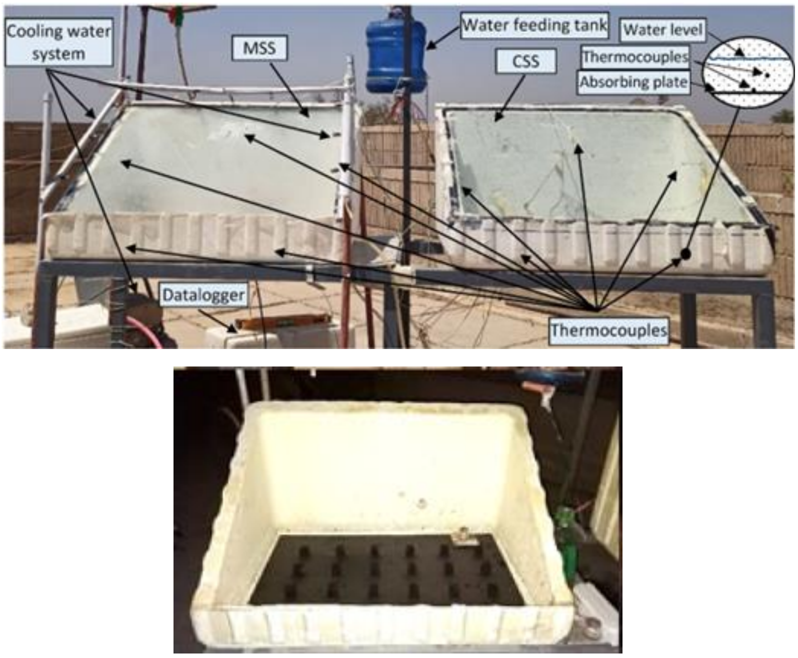

Fig. 12: Modified Solar Still and Absorber Plat with Square Fin

Murugan *et al.* (2022) developed and tested 0.5 m^2 single basin and a stacked solar still (two basins stacked together, Fig. 13) based on thermodynamic and economic analysis in the month of March 2020. The average daily productivity obtained from the single basin and stacked still were 1.416 l/day and 1.913 l/day respectively. The energy and exergy efficiency of the stacked solar still was higher than the single basin solar still due to lower energy loss in the stacked solar still. Economic feasibility was carried out by calculating the cost of the distilled water per litre and observed that the cost per litre of distilled water produced from a single basin solar still is 29.9% higher than the stacked solar still. The payback period of the stacked solar still was 540 days, whereas it was found 459 days for a single basin solar still.

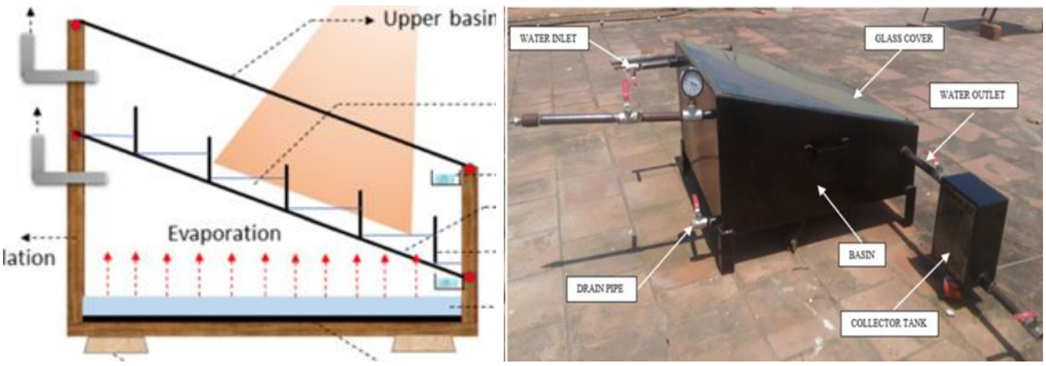

Fig. 13: Stacked Solar Still

Panchal *et al.* (2024) applied toner waste powder mixed black paint on basin plate of 0.5 m^2

solar still to evaluate its effect on distillate output and energy-exergy efficiency. Observations of water temperature, inner glass cover temperature, distillate output, wind speed and solar intensity were recorded every hour during experimental days. Distilled water output was recorded 1.09 (55.71% higher) l/day in solar still having tonner waste powder mixed color on basin plat, whereas 0.7 l/day was recorded in in solar still having only black color on basin plat at 2 cm water depth.

Recommendations for future work

Solar still technology, despite its simplicity, has undergone decades of refinement and innovation. While the conventional single-basin design remains the foundation, productivity enhancements have been achieved through design modifications, integration with evacuated tubes, reflectors, nanofluids, and phase change materials. The distilled water produced consistently meets potable standards, confirming its effectiveness in providing safe drinking water. Nevertheless, issues such as scalability, durability of materials, and economic competitiveness with other desalination technologies remain challenges. Future research should prioritize hybrid systems combining solar distillation with other renewable energy technologies, the use of advanced materials with superior thermal properties, and life-cycle assessments of large-scale implementations. Field studies and pilot-scale demonstrations are essential to bridge the gap between laboratory experiments and real-world applications. In conclusion, solar stills remain an environmentally friendly, low-cost solution for water purification, and continued research is necessary to optimize their performance and expand their adoption in water-scarce regions.

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