Effect of varying depth of water on performance of solar still

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Abstract:

This study experimentally investigates the effect of basin water depth on the performance of a single-slope solar still under the climatic conditions of Gandhinagar, Gujarat, India. Three basin water depths of **1 cm, 2 cm, and 3 cm** were examined to evaluate their influence on basin water temperature, distillate productivity, and thermal efficiency. Experimental observations revealed that water depth significantly affects the evaporation and condensation processes within the solar still. The lowest water depth of **1 cm** exhibited the highest basin water temperature, reaching approximately **69.5°C**, due to its lower thermal mass and faster heating characteristics. Consequently, the maximum daily freshwater production of **3.40 L/m²·day** was achieved at 1 cm depth, whereas the yields obtained at 2 cm and 3 cm depths were **2.95 L/m²·day** and **2.51 L/m²·day**, respectively. The corresponding thermal efficiencies were found to be **34.2%**, **29.7%**, and **25.3%** for 1 cm, 2 cm, and 3 cm water depths, respectively. Compared with the 3 cm depth, the 1 cm depth enhanced freshwater productivity by approximately **35.5%**. The results indicate that increasing water depth increases the thermal inertia of basin water, thereby reducing the water temperature rise and evaporation rate. Therefore, a shallow water depth of **1 cm** is recommended as the optimum operating condition for maximizing freshwater production and improving the overall performance of solar still systems under the climatic conditions of Gandhinagar.

Keywords : Solar still; water depth; distillate output; efficiency

1. Introduction:

Freshwater scarcity has emerged as one of the most critical global challenges due to rapid population growth, industrial development, urbanization, and climate change [1,2]. Although nearly 71% of the Earth's surface is covered by water, only a small fraction is available as freshwater suitable for human consumption. The increasing demand for potable water, particularly in arid and semi-arid regions, has intensified the need for sustainable and energy-efficient desalination technologies. Conventional desalination methods, such as reverse osmosis and multi-stage flash distillation, are effective but require significant energy input, operational costs, and infrastructure, limiting their applicability in remote and rural areas [3-5]. Solar desalination has gained considerable attention as an environmentally friendly and renewable solution for freshwater production. By utilizing abundant solar energy, solar desalination systems can convert saline or brackish water into potable water without the consumption of fossil fuels or the emission of greenhouse gases. Among various solar desalination technologies, the solar still is one of the simplest, most economical, and reliable systems. It operates on the natural hydrological cycle of evaporation and condensation, where solar radiation heats the saline water, causing evaporation, while the vapor condenses on a cooler transparent cover and is collected as distilled water [6-9].

Despite its simplicity and low maintenance requirements, the widespread application of solar stills is limited by their relatively low freshwater productivity. Therefore, numerous studies have focused on enhancing the thermal performance and distillate yield of solar stills through design modifications and optimization of operating parameters[10]. Among these parameters, basin water depth plays a crucial role in determining the thermal behavior of the system. Water depth influences the thermal capacity, heating rate, evaporation process, and overall freshwater production. A lower water depth generally promotes rapid heating and higher evaporation rates, whereas greater depths increase thermal inertia and reduce productivity [11-13]. Therefore, investigating the effect of basin water depth on solar still performance is essential for identifying optimal operating conditions and improving the efficiency of solar desalination systems for sustainable freshwater production [14-15].

2. Experimental setup:

Figure 1 : Experimental setup

The experimental investigation was conducted during **April 2022** in Surat, Gujarat, India (21.17°N latitude and 72.83°E longitude), a coastal city located in the western part of India. Surat experiences a tropical savanna climate characterized by high solar radiation, elevated ambient temperatures, and relatively moderate wind speeds during the pre-monsoon season. These meteorological conditions make the region highly suitable for solar thermal applications, including solar desalination and freshwater production through solar stills.

During the experimental period, the weather remained predominantly clear with minimal cloud cover, allowing uninterrupted solar energy availability throughout the day. The daily global solar irradiance varied between **720 and 980 W/m²**, with peak solar radiation reaching approximately **965 W/m²** during midday hours (12:00–14:00 h). The average daily solar radiation was observed to be around **820 W/m²**, providing sufficient thermal energy for water evaporation inside the solar still.

The ambient temperature ranged from **27.5°C during the early morning hours to 40.2°C in the afternoon**, while the average daytime temperature was approximately **34.8°C**. Such high ambient temperatures contributed to rapid heating of the basin water and enhanced the evaporation process. The relative humidity varied from **48% to 76%**, with an average value of approximately **62%**. Although higher humidity can reduce the evaporation potential, the prevailing high solar intensity compensated for this effect and supported effective freshwater production.

Wind speed during the experiments ranged from **1.1 to 4.3 m/s**, with an average value of approximately **2.6 m/s**. Moderate wind velocity facilitated convective cooling of the glass cover, thereby improving the condensation rate of water vapor. Furthermore, the average sunshine duration during April was approximately **9–10 h/day**, ensuring prolonged exposure of the solar still to solar energy.

Overall, the combination of high solar irradiance, elevated ambient temperature, moderate wind speed, and extended sunshine hours created favorable operating conditions for the solar still. These climatic parameters significantly influenced the thermal performance, evaporation rate, and freshwater productivity of the system during the experimental investigation.

3 Result and discussion:

3.1 Variations of solar intensity:

Figure 2 shows the hourly variation of solar radiation during the experimental investigation conducted in Surat, Gujarat, during April 2022. Solar radiation is the primary energy source responsible for heating the saline water in the basin and driving the evaporation-condensation process inside the solar still. The intensity of solar radiation increased gradually from the morning hours as the sun rose higher in the sky. At 08:00 h, the solar intensity was approximately 220 W/m² and increased steadily to about 450 W/m² at 09:00 h and 650 W/m² at 10:00 h. Further increases in solar radiation were observed during midday, reaching approximately 820 W/m² at 11:00 h and 920 W/m² at 12:00 h. The maximum solar intensity of nearly 965 W/m² was recorded around 13:00 h (See figure 2)

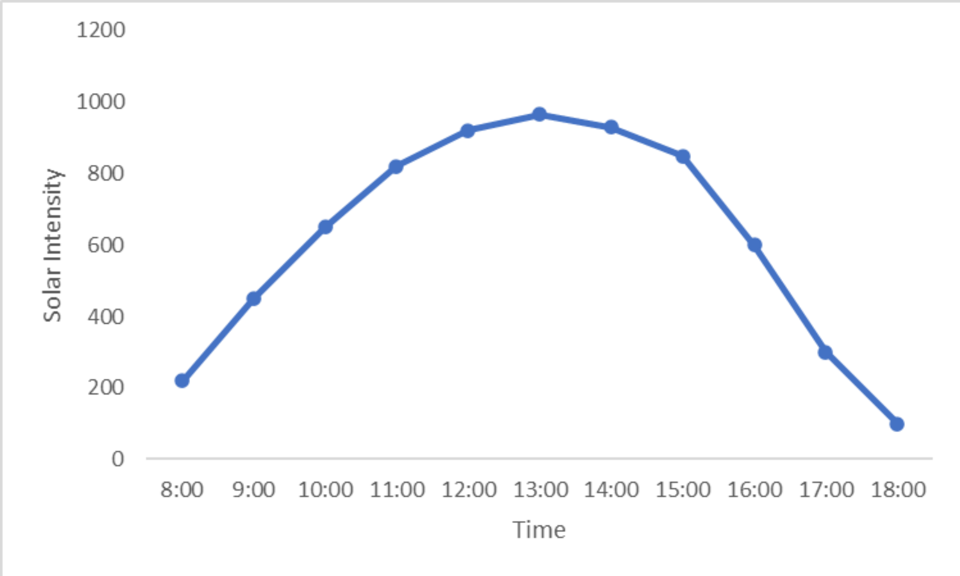

Figure 2 : Time vs solar intensity

Following the peak period, solar radiation gradually decreased due to the reduction in solar altitude angle. The solar intensity declined to approximately 850 W/m² at 15:00 h, 600 W/m² at 16:00 h, and below 300 W/m² after 17:00 h. The observed variation significantly influenced the thermal performance of the solar still. Higher solar radiation increased heat absorption by the basin liner and saline water, leading to elevated water temperatures and enhanced evaporation rates. Consequently, the highest distillate production and thermal efficiency were achieved during periods of maximum solar intensity. These findings clearly indicate the strong dependence of solar still productivity on available solar energy.

Variations of water and inner glass cover temperature:

Figure 3 illustrates the hourly variation of basin water temperature and inner glass cover temperature during the experimental period. Both temperatures followed a trend similar to the solar radiation profile. During the morning hours, the basin water absorbed solar energy and its temperature increased continuously. The water temperature rose from approximately 30°C at 08:00 h to about 42°C at 09:00 h and 55°C at 11:00 h. As solar radiation intensified, the basin water temperature continued to rise and reached a maximum value of approximately 69.5°C at 13:30 h for the 1 cm water depth.

The inner glass cover temperature also increased throughout the day but remained lower than the basin water temperature. The glass temperature increased from approximately 28°C in the morning to a peak value of nearly 56°C during the afternoon hours. The temperature difference between the basin water and the inner glass cover played a crucial role in the evaporation and condensation processes. A larger temperature difference promoted rapid vapor generation and efficient condensation on the glass surface. The maximum temperature difference of approximately 13–15°C was observed during peak sunshine hours, resulting in enhanced freshwater production.

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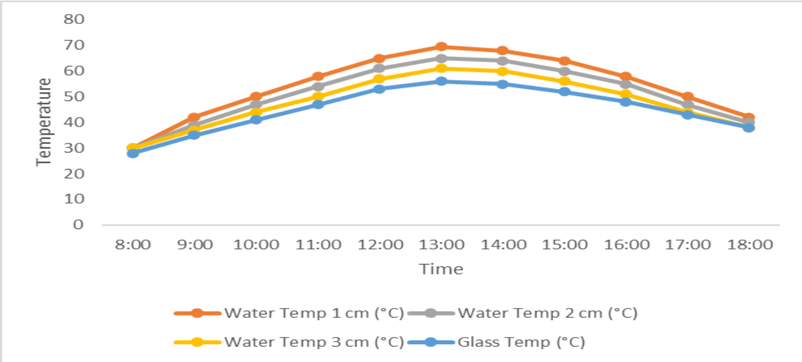

Figure 3 : Time vs water and inner glass cover temperature

After 14:00 h, both temperatures gradually decreased because of declining solar radiation. The lower water depth exhibited higher temperatures due to its reduced thermal mass and faster heating rate. Therefore, shallow water depths are advantageous for improving evaporation and overall solar still performance.

Variations of distillate output:

Figure 4 presents the hourly variation of freshwater productivity obtained from the solar still. The distillate output closely followed the trend of basin water temperature and solar radiation intensity. During the early morning period, freshwater production was negligible because the water temperature was insufficient to initiate substantial evaporation. The hourly distillate yield remained below 0.05 L/m²·h before 09:00 h. As solar radiation increased and the basin water became warmer, evaporation intensified, leading to higher freshwater production.

The hourly distillate output increased progressively from approximately 0.10 L/m²·h at 10:00 h to 0.25 L/m²·h at 11:00 h and 0.38 L/m²·h at 12:00 h. The maximum productivity of approximately 0.48 L/m²·h was observed between 13:00 h and 14:00 h, corresponding to the highest solar radiation and basin water temperature. During this period, the evaporation rate was maximum because of the large temperature difference between the basin water and glass cover.

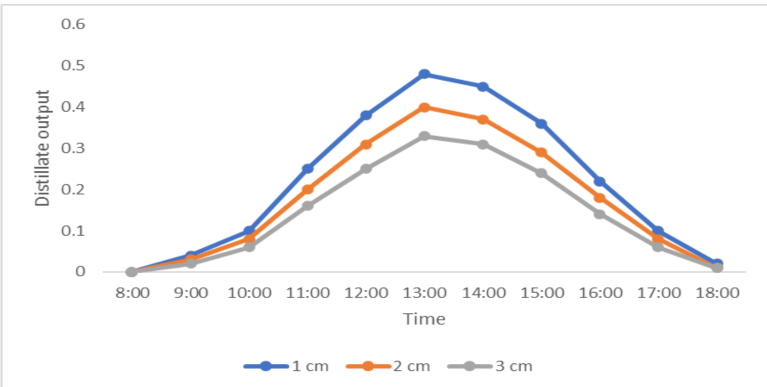

Figure 4 : Time vs distillate output

After the peak period, freshwater production gradually declined as solar radiation and water temperature decreased. The productivity dropped to approximately 0.22 L/m²·h at 16:00 h and became very low near sunset. The cumulative daily freshwater yield reached approximately 3.40 L/m²·day for the 1 cm water depth. The higher productivity obtained at lower water depth is attributed to rapid heating, increased evaporation rate, and improved thermal utilization. These results demonstrate the significant influence of water depth on solar still productivity

Variations of thermal efficiency

Figure 5 shows the hourly variation of thermal efficiency of the solar still under different operating conditions. Thermal efficiency is an important performance indicator that represents the fraction of incident solar energy effectively utilized for freshwater production. During the early morning hours, thermal efficiency was relatively low because most of the absorbed solar energy was consumed in heating the basin water and the structural components of the solar still. At 09:00 h, the efficiency was approximately 10%, indicating limited evaporation activity.

As solar radiation increased throughout the day, the basin water temperature rose significantly, resulting in higher evaporation rates. Consequently, thermal efficiency improved steadily and reached approximately 22% at noon. The highest thermal efficiency of around 34.2% was recorded between 13:00 h and 14:00 h, coinciding with peak solar intensity, maximum water temperature, and highest freshwater productivity. During this period, a greater portion of the absorbed solar energy was converted into latent heat of evaporation, leading to efficient freshwater generation.

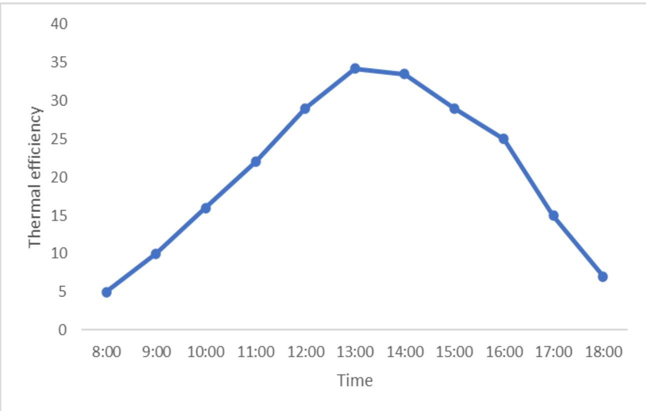

Figure 5 : Time vs thermal efficiency

Following the afternoon peak, thermal efficiency gradually decreased because of the reduction in solar radiation and evaporation rate. The efficiency declined to approximately 25% at 16:00 h and further reduced below 15% during the late afternoon hours. The 1 cm water depth consistently exhibited superior thermal efficiency compared with deeper water levels due to its lower thermal inertia and faster heating characteristics. The results indicate that reducing basin water depth enhances energy utilization, promotes evaporation, and improves the overall thermal performance of solar desalination systems

3. Conclusion

An experimental investigation was conducted to evaluate the effect of basin water depth on the thermal performance and freshwater productivity of a single-slope solar still under the climatic conditions of Surat, Gujarat, during April 2022. Three different water depths, namely 1 cm, 2 cm, and 3 cm, were examined to determine their influence on solar still performance. The experimental results demonstrated that basin water depth is a critical operating parameter affecting the evaporation-condensation process, thermal efficiency, and freshwater production.

The solar radiation reached a peak value of approximately 965 W/m² during midday, which significantly influenced the thermal behavior of the solar still. The basin water temperature increased with solar intensity and attained a maximum value of approximately 69.5°C for the 1 cm water depth. The higher temperature difference between basin water and inner glass cover enhanced evaporation and condensation rates, resulting in improved distillate productivity. The maximum daily freshwater yield of approximately 3.40 L/m²·day was achieved at the 1 cm water depth, whereas lower yields were obtained at 2 cm and 3 cm depths due to increased thermal inertia. Similarly, the highest thermal efficiency of about 34.2% was observed for the 1 cm water depth.

The major findings of the present study are summarized as follows:

- The 1 cm water depth exhibited the highest basin water temperature, reaching approximately 69.5°C, due to its lower thermal mass and faster heating characteristics.
- The maximum freshwater productivity of approximately 3.40 L/m²·day was obtained at 1 cm water depth, which was significantly higher than the productivity achieved at 2 cm and 3 cm water depths.
- Thermal efficiency increased with increasing solar radiation and reached a maximum value of approximately 34.2% during peak sunshine hours for the 1 cm water depth.
- Increasing basin water depth reduced the evaporation rate and overall system performance because a larger portion of the absorbed solar energy was utilized in heating the additional water mass rather than producing evaporation.
- Based on the experimental findings, a shallow basin water depth of 1 cm is recommended for achieving enhanced thermal performance and freshwater production in solar still systems operating under climatic conditions similar to those of Surat, Gujarat.

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