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Experimental Investigation of the Influence of Stone Bed Thickness and Glass Cover Inclination Angle on Solar Still Performance in Al Bayda, Libya

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A B S T R A C T

This study looks at how well a solar still worked in Al Bayda, Libya (32°27'N, 22°37'E) over a 10-day period in August when there was a lot of sunlight. The effect of stone bed thickness (0 cm, 1 cm, and 2 cm) and glass cover angle (22°, 27°, 32°, and 37°) on the water temperature and the amount of freshwater produced was carried out in this research. The results showed that, a 32° glass angle yielded the most water, 15% more than at 22° (10%), and more than 37°. A 1 cm stone bed significantly extended thermal storage and evaporation during low-radiation hours. The best mix of a 32° angle and a 1 cm stone bed increased the amount of fresh water produced each day by 20% compared to the usual setup. The most productive time was between 12:00 and 14:00. These results suggest a cheap way to improve the design of solar stills in dry areas, potentially increasing freshwater production in Libya's AL Jabal AL Akhdar Region.

Keywords: Solar still, stone Bed thickness, Glass cover Inclination, Water purification, freshwater production

* Introduction

The paper must be formatted according to the JOMS. (9 points, the introduction should explain the nature of the problem including previous work and purpose, delete and type). This document is a template for Microsoft word doc, docx versions and MUST be written by Times New Roman

In regions with limited freshwater resources, such as Libya, water scarcity remains a critical challenge. Solar distillation has emerged as an effective and sustainable method for utilizing solar energy to produce potable water . This process relies on evaporating water and subsequently condensing the vapor to remove impurities, offering a viable solution to address water shortages.

The performance of solar stills is influenced by several design parameters, including the thickness of the stone bed and the inclination angle of the glass cover. These factors significantly affect heat retention, evaporation rates, and condensation efficiency. While previous research has demonstrated that adjusting these parameters can enhance water yield, their combined effects under specific climatic conditions remain insufficiently explored. Further investigation is necessary to optimize these design elements and improve the efficiency of solar stills across diverse environmental settings. A deeper understanding of solar distillation mechanisms can contribute to the development of more effective solutions for providing clean drinking water in water-scarce regions .

This study aims to assess the performance of a solar still in the Green Mountain region, Al Bayda, Libya. This location, positioned at latitude 32°27′N and longitude 22°37′E, receives substantial solar radiation, making it an ideal site for solar distillation experiments. The research investigates various stone bed thicknesses (0 cm, 1 cm, and 2 cm) and glass cover inclination angles (22°, 27°, 32°, and 37°) to determine the optimal configuration for maximizing freshwater yield .

*** Methodology**

1- Experimental Setup

To explore practical ways of enhancing solar still efficiency, we designed an experimental setup that allowed for controlled adjustments to key parameters. The schematic representation of the experimental solar still setup is presented in Fig. 1. The system consisted of: -

1- A transparent glass cover with adjustable inclination angles (22°, 27°, 32°, and 37°) to study its impact on condensation efficiency.

2- Stone beds of varying thicknesses (0 cm, 1 cm, and 2 cm) placed at the basin bottom, serving as a thermal storage medium to regulate heat retention and evaporation dynamics.

3- Thermocouples strategically positioned within the setup to monitor temperature variations throughout the experiment.

4- A graduated collection system designed for precise measurement of daily freshwater yield, ensuring accurate performance evaluation.

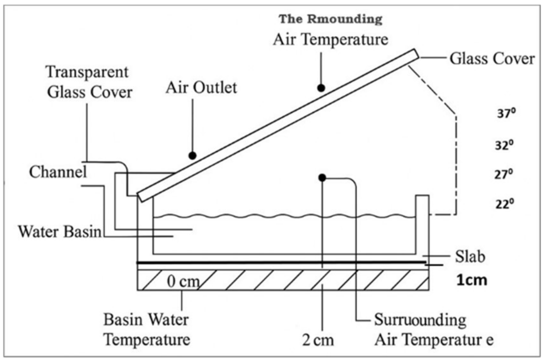


Fig1. A schematic representation of the experimental solar still setup. It shows the adjustable glass cover, the slab zones at the bottom of the basin, and the thermocouple locations

2- Study Location

The study was conducted in the Green Mountain region of Al Bayda, Libya, at area characterized by high solar radiation and moderate humidity levels, which are ideal conditions for testing solar distillation systems. The region's geographic coordinates (latitude 32°27′N, longitude 22°37′E) are within a favorable solar belt, making it a promising site for solar-based desalination. To ensure the reliability of results, the experiment was conducted over three months, accounting for seasonal climatic variations and their influence on system performance.

3- Performance Evaluation

The effectiveness of the solar still was assessed through a set of critical performance parameters, including: -

1- Daily freshwater yield, providing a direct measure of system efficiency.

2- Basin water temperature, influencing the rate of evaporation.

3- Glass cover temperature and condensation rate, determining how effectively vapor was converted back into liquid.

4- Thermal storage capacity of the stone bed, affecting heat retention and prolonged evaporation cycles.

By analyzing these factors, the study aimed to uncover practical insights into how minor design adjustments could lead to significant improvements in solar distillation performance.

* Results

1- Effect of Stone Bed Thickness

The findings highlighted the important role of thermal storage in optimizing evaporation rates. The introduction of a stone bed significantly influenced the system's ability to retain heat and sustain evaporation. The 1 cm stone bed yielded the best performance, increasing freshwater output by 20% compared to a conventional still and 12% more than the 2 cm stone bed. The 2 cm stone bed, although effective in heat retention, absorbed excessive energy, reducing the temperature gradient necessary for efficient evaporation, ultimately lowering water yield.

2- **Effect of Glass Cover Inclination**

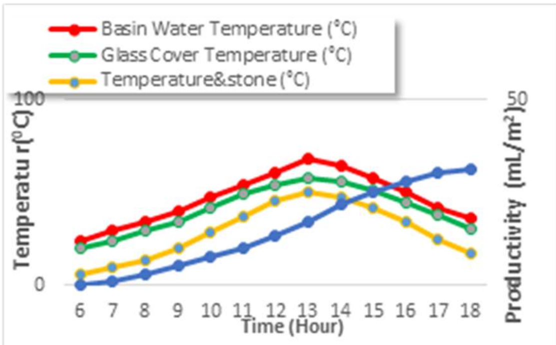
The angle of the glass cover proved to be a crucial factor in determining condensation efficiency. A 32° inclination produced the highest water yield, surpassing the 22° inclination by 15% and the 37° inclination by 10%. At 22°, water droplets tended to accumulate on the glass surface, creating a barrier that hindered further condensation. At 37°, excessive heat loss diminished condensation rates, leading to lower overall efficiency.

3- **Combined Influence of Stone Bed and Glass Inclination**

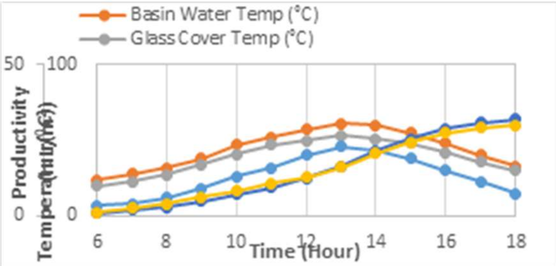
The combination of a 1 cm stone bed and a 32° glass cover inclination yielded the most effective configuration, increasing freshwater production by 20% compared to conventional solar stills without a stone bed. This finding highlights that integrating thermal storage with an optimized condensation surface can significantly improve system performance. The performance of the optimal 1 cm stone bed with a 32° inclination was monitored throughout the day, as shown in Figure 2.

4- **Hourly Productivity Analysis**

Water production patterns followed a predictable trend influenced by solar intensity and the thermal storage effect of the stone bed. The peak productivity occurred between 12 PM and 2 PM, when solar radiation was at its highest, which driving maximum evaporation. Water output gradually declined in the late afternoon, but thanks to the heat-retaining capacity of the stone bed, evaporation continued even as solar intensity decreased. No unexpected fluctuations were observed, though ambient temperature and humidity levels had a slight impact on condensation efficiency. The daily yield, temperature variations, condensation rate, and water storage were recorded throughout the experiment, as shown in Figure 3.



(Fig 2. Performance of optimal 1cm stone bed and 320 Inclination Throughout the day)



(Fig3. Cumulative Water Storage Over Time During Daily Operation)

5- Statistical Analysis using ANOVA

Statistical analysis confirmed that both stone bed thickness and glass cover inclination had a significant impact on freshwater yield ($p < 0.05$). The F-values of 8.42 and 10.15, respectively, highlight the strong influence of these parameters on evaporation and condensation efficiency. Regression analysis revealed a strong positive correlation ($R^2 = 0.89$) between the optimal configuration and water production, reinforcing the effectiveness of these design adjustments. Furthermore, no signs of multicollinearity or statistical anomalies were detected, ensuring the reliability and robustness of the results.

* Discussion

1- Effect of Stone Bed Thickness

The inclusion of a stone bed significantly improved the system's ability to retain heat, allowing for continued evaporation even when solar intensity declined. Among the tested configurations, the 1 cm stone bed proved to be the most effective, striking a balance between heat retention and controlled release. However, increasing the thickness to 2 cm resulted in excessive heat accumulation, diminishing the temperature gradient essential for efficient evaporation. These findings align with the observations of A. F. Mohamed [7], who demonstrated that a moderate stone bed thickness enhances solar still efficiency, whereas excessive thermal retention hinders the performance.

Further support, Zubair et al. [8] highlighted the impact of different absorbent materials on evaporation rates, showing that materials with excessive heat retention could reduce the effective temperature gradient. Similarly, Hameed and Masood [9] emphasized the importance of phase change materials (PCMs) in controlling heat storage, a concept that parallels the role of stone beds in stabilizing temperature fluctuations. These insights reinforce that thermal storage must be optimized rather than maximized to maintain steady water production. The findings of this study align with these conclusions, and underlining the importance of precisely balancing heat retention and dissipation to sustain efficient evaporation.

2- Effect of Glass Cover Inclination

The inclination of the glass cover played a key role in regulating condensation efficiency. The 32° inclination provided the optimal balance, effectively facilitating drainage while minimizing heat loss. In contrast, the 22° inclination led to droplet accumulation, obstructing further condensation, while the 37° inclination caused excessive cooling, leading to heat dissipation and reduced water yield.

These results are consistent with the findings of Nabil and Fawzy [10], who investigated how different glass cover materials influence condensation rates in solar stills. Their study suggested that condensation performance is closely linked to inclination angle and surface properties. Additionally, Al-Sulaiman [11] examined how climatic conditions and basin materials interact, demonstrating that excessive cooling can lower evaporation efficiency. The current study's findings support these observations, further emphasizing the need for careful design considerations to maximize condensation efficiency. The carefully calibrated inclination angle is essential for maximizing freshwater production.

3- Combined Influence

The best performance was achieved with a 1 cm stone bed and a 32° glass cover inclination, demonstrating a 20% increase in freshwater production compared to a conventional solar still without a stone bed. This combination effectively enhanced both evaporation and condensation processes, leading to improved water yield.

These findings suggest that refining these parameters can offer a cost-effective and practical solution for small-scale desalination applications. Future research could explore the feasibility of scaling up this design for larger systems or integrating it with other renewable technologies for enhanced performance.

4- Hourly Productivity Trends

The recorded hourly water yield trends reinforced the strong influence of solar intensity and thermal storage on system performance. Peak water production occurred between 12 PM and 2 PM, coinciding with maximum solar radiation. Notably, the stone bed's ability to retain heat sustained evaporation rates even in the late afternoon, leading to more consistent water output.

These observations are in agreement with the findings of Ranjan et al. [12], who investigated the influence of environmental factors on solar stills. Their study demonstrated that solar radiation patterns and material-based heat storage mechanisms play a crucial role in maintaining steady water yield. A graphical representation of these trends would provide a clearer visualization of the system's daily performance cycle.

5- Statistical Validation

The statistical analysis confirmed the reliability and significance of the experimental results. ANOVA testing indicated a strong impact of both stone bed thickness and glass cover inclination on water yield, with F-values of 8.42 and 10.15, respectively. Additionally, regression analysis ($R^2 = 0.89$) demonstrated a strong correlation between the optimized parameters and freshwater production.

These findings align with the statistical results presented by Sharma and Purohit [13] and Awan and Ali [14], who used regression analysis and numerical simulations to predict solar still efficiency. Their studies showed that well-optimized designs consistently outperform conventional setups, validating the modifications proposed in this research.

Furthermore, Riaz and Shah [15] emphasized that statistical validation is critical in assessing the effectiveness of solar desalination techniques. The current study's findings reinforce this perspective, showing that careful experimental design and statistical analysis can significantly improve the accuracy and reliability of solar still performance assessments.

No statistical anomalies were detected, reinforcing the credibility of these findings and validating the effectiveness of the proposed design modifications.

*** Conclusion**

This study demonstrated the crucial role of optimizing stone bed thickness and glass cover inclination in improving solar still efficiency. The optimal configuration is a 1 cm stone bed combined with a 32° glass cover inclination, resulted in a 20% increase in freshwater yield compared to conventional designs. These findings underscore the importance of thermal storage and condensation efficiency in enhancing solar distillation performance. Looking ahead, further research could explore additional refinements, such as alternative stone materials and improved structural designs, to further optimize water production under different climatic conditions. The integration of solar stills with other renewable energy technologies may also provide a promising pathway for improving water access in arid and semi-arid regions.

1- Recommendations and Future Work

To build on these findings, future studies should consider: -

1- Investigating different stone materials with higher thermal conductivity to further enhance heat retention.

2- Exploring multi-stage condensation techniques to improve water recovery efficiency.

3- Implementing real-time monitoring and automation systems to optimize performance and adapt to changing weather conditions.

4- Assessing the economic feasibility of large-scale deployment, particularly in regions like Al Bayda, where water scarcity remains a pressing challenge.

By continuing to refine solar distillation technologies, we can move closer to sustainable and practical solutions for providing clean drinking water in water-stressed communities.

2- Abbreviations and Acronyms

Table of Abbreviations: -

Abbreviation	Definition
ANOVA	Analysis of Variance
R^2	Coefficient of Determination
cm	Centimeter
°	Degree (Angle)
AM	Ante Meridiem (Before Noon)
PM	Post Meridiem (After Noon)

3- Acknowledgement

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