ENERGY ANALYSIS OF SOLAR STILL USING INDUSTRIAL AND NATURAL COAL: AN EMPIRICAL STUDY SOUTHEASTERN ALGERIA

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ABSTRACT

The global issue of drinking water scarcity has become a pressing concern, affecting populations worldwide. Even in the Algerian desert regions, notably the El Oued region in southeastern Algeria, the challenge of drinking water shortages persists despite the abundant presence of underground saline water. This study explores the viability of solar distillation as a cost-effective solution, leveraging renewable energy, specifically solar energy, to convert saltwater into potable water. As solar energy is inherently intermittent, the need for energy storage arises to optimize water production. This scientific study presents a comprehensive investigation into the performance of three solar still configurations: SSR (Reference Solar Still), SSM1 (Solar Still with natural coal), and SSM2 (Solar Still 2 with industrial coal). The research evaluates their water productivity and thermal efficiency to discern the impact of natural and industrial coal on the distillation process. The experimental results reveal a significant disparity in water productivity among the three solar stills. SSM2, featuring industrial carbon in its water basin, outperforms both SSR and SSM1 with a remarkable distilled water output of 366ml. In contrast, SSR yields 271ml, and SSM1 produces 297ml. Thermal efficiency, a crucial parameter reflecting the utilization of solar energy, also exhibits notable differences. SSM2 demonstrates superior thermal efficiency at 14.986%, surpassing both SSR (11.25%) and SSM1 (12.57%).

Keywords: Distilled Water; Solar Still; Solar Energy; Solar Distillation.

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INTRODUCTION

In the face of escalating water scarcity, desalination has emerged as a crucial technology, particularly in regions with limited freshwater resources. Countries like Algeria are investing strategically in desalination to provide a sustainable solution for safe drinking water, concurrently addressing water scarcity and promoting sustainable development. Technological advancements are driving down the cost of desalination, expanding its accessibility globally. Drawing insights from the works of Khechekhouche et al. (2020a, 2020b), Miloudi et al. (2022), Sefaoui et al. (2021), Sadasivuni et al. (2022) and Zair et al. (2021), highlighting its potential as a practical and equitable means to ensure water security.

Electricity from photovoltaic cells extends its utility beyond solar stills, finding application in water treatment and energizing remote communities. Hybrid solar stills, offering an efficient solution for water purification in resource-constrained areas, are a focus of ongoing research and development. The work of researchers like Kabeel et al. (2018), Kamlesh et al. (2020), propels the evolution of these systems toward wider availability and accessibility.

Solar stills, crucial for water desalination and purification, hinge on the harmonious interplay of solar radiation intensity, glass thickness, and the angle of the glass cover. The efficiency of these devices is intimately connected to the solar radiation they receive, making regions with abundant sunlight particularly favorable for their operation, as higher radiation intensity enhances the evaporation rates crucial for water distillation Khechekhouche et al. (2017a, 2019a, 2020 c), Panchal et al. (2019a), and Thakkar et al. (2020). Simultaneously, the thickness of the glass cover emerges as a pivotal factor, necessitating a delicate balance. While thicker glass provides improved insulation, thereby minimizing heat loss to the surroundings, finding the optimal thickness is paramount to ensuring equilibrium between insulation and the ability to transmit sunlight for effective energy absorption Khechekhouche et al. (2019b, 2020f). The angle at which the glass cover is positioned further influences the performance of the solar still, as the proper orientation facilitates maximum solar energy absorption by ensuring sunlight reaches the still's surface at an optimal angle. Strategically adjusting this angle based on geographical location and seasonal variations contributes to efficient water vaporization and condensation processes Cherraye et al. (2022).

Researchers continually explore novel designs and materials to elevate the efficiency and productivity of solar stills. The use of diverse still shapes and sizes, such as parabolic troughs or Fresnel lenses, proves instrumental in concentrating solar energy onto the absorber surface, consequently enhancing distillation efficiency. Investigating advanced materials like carbon nanotubes for absorber and insulation layers showcases a commitment to improving overall efficiency, leveraging their excellent thermal conductivity. In a bid for innovation, researchers are also integrating solar stills with other renewable energy sources like wind turbines or solar photovoltaic panels. This integration aims to provide a more reliable and consistent energy source for water purification. These pioneering approaches, as highlighted by Patil et al. (2020), Shah et al. (2023) and Ho et al. (2022), hold immense promise for the future of solar distillation technology. Their potential impact extends towards addressing the critical issue of water scarcity in various parts of the world.

The integration of Phase Change Materials (PCMs) into a solar still proves beneficial for efficiency improvement. PCMs store heat during daylight hours, releasing it during periods of low solar radiation. This sustains a higher temperature within the still, fostering increased rates of evaporation and condensation, consequently boosting freshwater production. The use of PCMs in solar stills remains an active area of research and development, offering various types of PCMs, each with distinct advantages and disadvantages. Crucial factors influencing PCM selection include melting point, thermal conductivity, and cost (Ajdari et al. (2022) and Panchal et al. (2018a, 2019b, 2021).

The performance of solar stills is significantly influenced by the materials chosen for their construction. Materials with high thermal conductivity, such as metals like aluminum, Zinc, sponge or Iron, enhance heat transfer within the still, leading to faster and more efficient evaporation Bellila et al. (2022a), Khechekhouche et al. (2019b, 2020d, 2020e). Conversely, materials with low thermal conductivity, like insulation materials such as foam or fiberglass, aid in reducing heat losses, thereby improving overall efficiency Khechekhouche et al. (2023, 2020g), Khamaia et al. (2022). Solar stills have also employed natural materials like marble, palm fibers, coal and many others, promoting effective heat transfer. The selection of materials hinges on various factors, including thermal properties, availability, cost, and durability Kermerchou et al. (2022), Sadoun et al. (2022), Djaballah et al. (2022), Panchal et al. (2018b), Bellila et al. (2022b).

The importance of this study lies in its contribution to the advancement of solar distillation technology. By studying the influence of natural and industrial corbon on the performance of solar stills, the study seeks to identify strategies to optimize water production and energy efficiency. This knowledge is crucial for the development of more efficient and sustainable solar distillation systems, particularly in regions where access to clean water is a pressing concern.

METHODOLOGY

In May 2023, a comprehensive experiment unfolded at the University of El Oued in southeastern Algeria, involving a trio of identical conventional solar stills each measuring 0.5 x 0.5 meter. The experimental setup maintained a consistent saltwater level of 1 cm in all three stills. To capture nuanced temperature variations, thermocouples were strategically positioned on either side of the glass cover. One of these thermocouples was submerged in water, while another was exposed to the open air, ensuring accurate recording of ambient temperature fluctuations.

The solar stills were designated as follows: the first operated as the SSR reference still, providing a baseline for comparison, while the second was the modified solar still (SSM1), enhanced with 50 grams of natural charcoal. The third still, labeled SSM2, was another modified variant, featuring 50 grams of industrial charcoal in its water basin, as visually depicted in Figure 1. This innovative configuration facilitated a meticulous comparative analysis of results with the reference solar still (SSR).

Throughout the experimental period, meticulous measurements of temperature and the quantity of pure water were diligently recorded at hourly intervals. This multifaceted approach aimed to capture and analyze the dynamic interplay of variables, providing a comprehensive understanding of the solar stills' performance under various conditions.

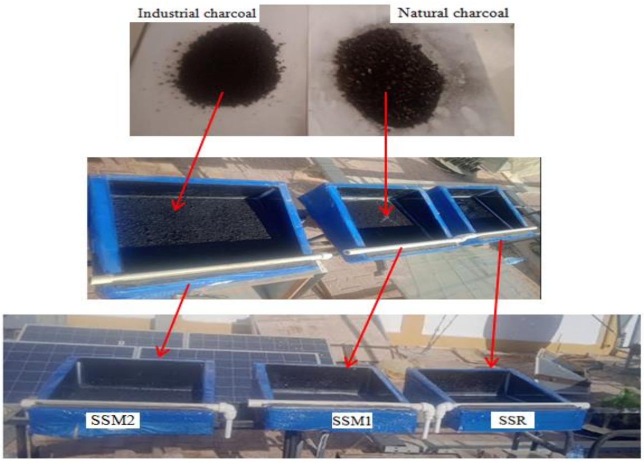

Figure 1: Experimental set-up

RESULTS AND DISCUSSION

Solar radiation

Solar radiation stands as a pivotal determinant in the realm of solar distillation, exerting a profound influence on the distillation process. This intricate interplay is vividly depicted in Figure 2, illustrating the dynamic evolution of solar radiation and ambient temperature in comparison to the real-time experiment. The rhythm of solar radiation unfolds normal, commencing its ascent between 8:00h and 12:00h. As the sun ascends, solar radiation steadily intensifies, reaching its zenith between 13:00h and 14:00h. A crescendo is achieved, with the radiant energy peaking at an impressive 1001 W/m^2 during this solar zenith. However, as the day progresses, the solar radiation undergoes a gradual descent, tapering off to a value of 530 W/m^2 by 16:00h, signifying the waning influence of the sun on the distillation process.

Simultaneously, the ambient temperature mirrors this solar dance, mirroring the rhythm of solar radiation. The temperature ascends in tandem with increasing radiation, culminating at a noon-time peak of 35°C at 2:00 p.m. Subsequently, as solar radiation diminishes, the ambient temperature undergoes a decline, settling at a value of 32°C by 16:00h.

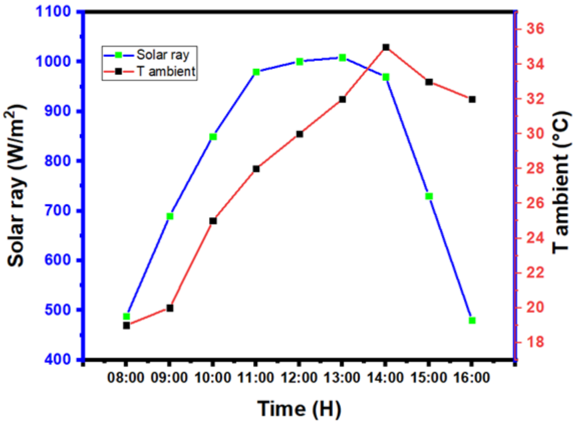

Figure 2. Solar radiation and ambient temperature

Water temperatures

Figure 3 offers a dynamic representation of the fluctuating water temperatures within the three solar stills, providing a real-time overview of how the experiment unfolded.

Remarkably, the water temperature inside SSM1 reaches an impressive 50°C, while SSM2 exhibits an even higher temperature, peaking at 52°C. In contrast, solar SSR still records a slightly lower but remarkable maximum temperature of 49°C. It is crucial to emphasize that these peaks occur synchronously between 13:00h and 14:00h. The noticeable difference in water temperature highlights the substantial impact of incorporating charcoal into the solar still design. The improved absorption and thermal retention capabilities of charcoal significantly contribute to raising the water temperature in SSM1 and SSM2, exceeding the temperature of the reference SSR solar still.

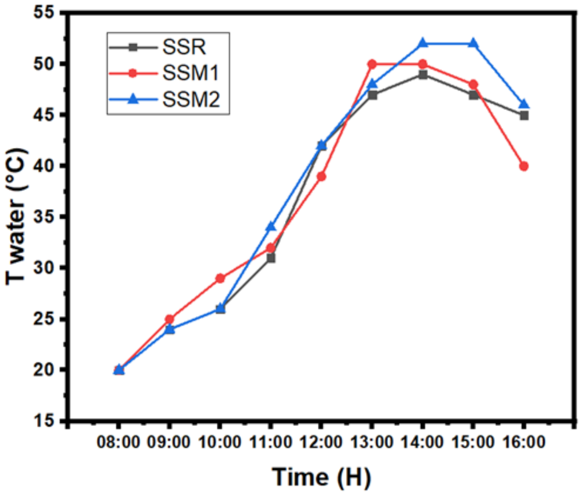

Figure 3. Water temperatures

External temperature

Figure 4 illuminates the real-time variations in the maximum external temperatures across the solar stills, revealing a value of 35°C for all three configurations. This observation underscores a fascinating aspect of the experiment, where the external temperature, representing the ambient conditions surrounding the solar stills, remains uniform across the SSR, SSM1, and SSM2. Despite the distinct internal temperature variations and water temperature disparities influenced by the presence of charcoal, the external environment exerts an equal thermal influence on all three solar stills.

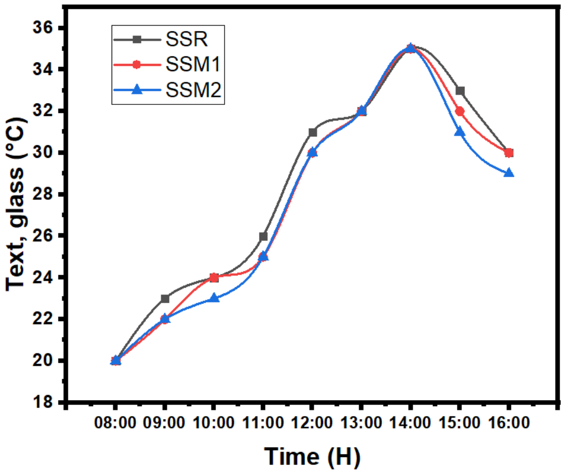

Figure 4. External temperature

Internal temperature

Figure 5 meticulously details the internal temperature dynamics of the glass cover during the solar distillation experiment, providing nuanced insight into the thermal behavior within the solar stills. The temporal evolution of the internal lateral temperature of the glasses is revealed, revealing remarkable trends throughout the experimental timeline. As the Figure 3 illustrates, a distinctive trend emerges, highlighting a gradual increase in internal temperatures. The maximum of these temperatures is clearly observed between 13:00h and 14:00h, a temporal alignment with the maximum values of solar radiation and ambient temperature, as previously indicated. In particular, during this crucial period, solar stills display their maximum internal temperatures. Specifically, the solar SSR still reaches an impressive 48°C, while the modified solar stills, SSM1 and SSM2, follow closely behind with internal temperatures of 47°C each.

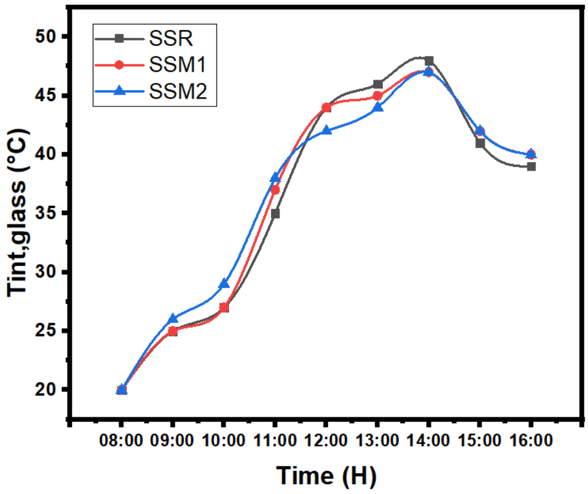

Figure 5. Internal temperature

Water temporal output

Figure 6 remarkably captures the variations in pure water production over the course of each hour, presenting valuable insights into the temporal output of the solar distillation process. Notably, the data reveals distinct hourly trends, with the solar SSR still recording a maximum hourly production of 51 ml of pure water. Beyond this output, the SSM1 solar still presents commendable performance, reaching a maximum hourly rate of 55 ml. However, the most remarkable achievement is attributed to the SSM2 solar distiller, which surpasses its counterparts by producing an impressive flow rate of 71 ml of pure water per hour.

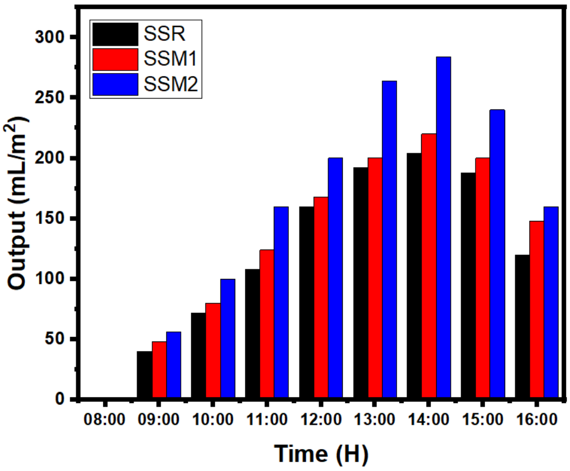

Figure 6. Water temporal output

Accumulation water

Figure 7 provides a comprehensive visualization of the accumulation patterns of pure water from the three distinct solar stills over the course of the experiment, shedding light on a critical aspect of their performance. Notably, the data discloses distinctive outcomes, underscoring the impact of design modifications on the distilled water yield. A key observation arises from the total quantity of pure water amassed by each solar still during the 8-hour experimental duration. The SSM1 solar still, enriched with natural charcoal in its water basin, demonstrates a remarkable efficiency, yielding a total of 297 ml of pure water. Following closely, the SSM2 solar still, featuring industrial carbon, surpasses its counterparts by collecting a noteworthy 366 ml of pure water. In contrast, the SSR solar still, lacking the charcoal component, registers a slightly lower total yield of 271 ml.

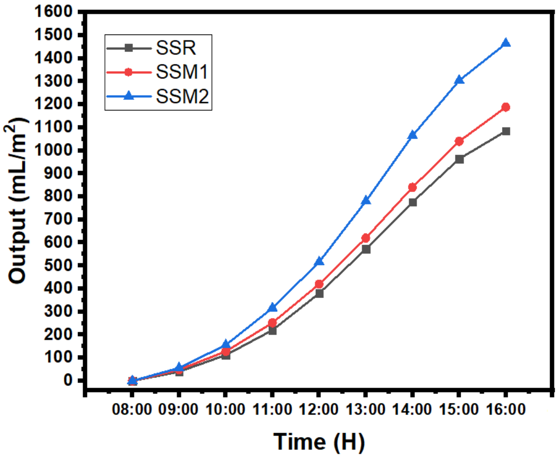

Figure 7. Accumulation water

Thermal efficiency

Figure 8 unfolds the thermal efficiency trends exhibited by the three solar stills over the experimental timeline, spanning from 8:00h to 16:00h. However, as the experiment unfolds, distinctive performance nuances come to light. A notable observation emerges, highlighting the consistent superior performance of SSM2 in comparison to SSM1, and the benchmark SSR still. This trend persists throughout the entirety of the experiment, gaining prominence as the clock approaches 16:00h. Remarkably; MSS2 establishes itself as the frontrunner, showcasing a sustained edge in thermal efficiency over its counterparts. The quantitative analysis of thermal efficiency further substantiates these observations. The average efficiency across the three distillers is quantified as 11.25% for the SSR, 12.57% for MSS1, and an even more impressive 14.86% for MSS2. This performance gradient reaffirms the significant impact of the modifications incorporated into the distillers, notably the inclusion of innovative design elements.

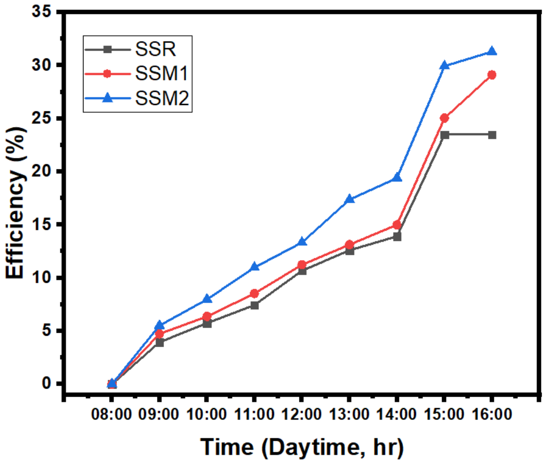

Figure 8. Thermal efficiency

CONCLUSION

The experimental data obtained from the solar stills SSR, SSM1, and SSM2 provides valuable insights into their respective performances in terms of water productivity and thermal efficiency.

- The distilled water productivity results clearly indicate that SSM2 outperforms both SSR and SSM1. The solar still SSM2 achieved an impressive output of 366 milliliters, surpassing the productivity of SSR (271 ml) and SSM1 (297 ml).
- Furthermore, when considering thermal efficiency, SSM2 once again emerges as the superior performer. With a thermal efficiency of 14.986%, SSM2 surpasses both SSR (11.25%) and SSM1 (12.57%). The higher thermal efficiency of SSM2 indicates a more effective utilization of solar energy for the distillation process, resulting in increased water production.

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