

Integrated Iron Rods Impact on Enhanced Output of Conic Solar Still

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Abstract – This experimental study investigated the performance of modified solar stills (MSS) incorporating structural iron rods in the still basin. The experiment, conducted on September 13, 2024 at the University of El Oued, southeastern Algeria. Three identical conical solar stills: CSS, an MSS₀ with 0 cm rod spacing, and an MSS₁ with 1 cm rod spacing. Results indicate a negligible impact of the modifications on internal glass temperature, with all stills peaking around 43–43.5°C. However, the presence of iron rods significantly enhanced water temperature and distillation output. Both MSS₀ and MSS₁ achieved peak water temperatures of approximately 60°C, notably higher than the CSS's peak of 55°C. This thermal advantage translated directly into increased distilled water production. Hourly output data showed MSS₀ and MSS₁ consistently producing around 93-95 ml during peak hours (12:00-14:00h), compared to the CSS's 88 ml. Cumulatively, MSS₀ yielded the highest total output at approximately 740 ml, followed by MSS₁ at 720 ml, both substantially exceeding the CSS's 600 ml. These findings highlight the effectiveness of integrating iron rods to improve solar still efficiency, with MSS₀ demonstrating marginally superior overall performance.

Keywords: Modified solar still, Water temperature, Solar distillation, Cumulative output.

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I. Introduction

The scarcity of potable water is a global challenge, particularly in arid and semi-arid regions. In many areas, including the El Oued region of southeastern Algeria, groundwater often contains high mineral concentrations, rendering it unsuitable for drinking according to World Health Organization (WHO) standards [1, 2]. Solar distillation emerges as an environmentally friendly, economical, and straightforward solution for water purification, leveraging abundant solar energy to produce fresh water through vaporization and condensation [3, 1]. Despite its inherent advantages, conventional solar stills typically suffer from low productivity, prompting extensive research into various enhancement techniques [3, 4].

Researchers have explored numerous modifications to conventional solar still designs to boost their efficiency

and output. One critical aspect is the glass cover, which influences both light transmission and heat retention. Studies have shown that the thickness of the glass cover significantly impacts performance. For instance, an experimental investigation in El Oued, Algeria, revealed that a glass cover thickness of 3 mm was optimal, leading to the highest distilled water production of 3.15 kg and an energy efficiency of 30.71%, with a daily average exergy efficiency of 2.46% [5]. Conversely, increasing the glass thickness was found to decrease both productivity and efficiency [5]. Similarly, the tilt angle of the glass cover plays a crucial role in maximizing solar absorption and condensate runoff, with optimal angles varying seasonally. In Ouargla, south Algeria, a 30° tilt angle was most effective in autumn (3.517 Kg.m⁻²) and winter (3.633 Kg.m⁻²), while 20° proved optimal in spring (5.224 Kg.m⁻²) and summer (4.527 Kg.m⁻²) [6].

Further investigations into glazing configurations have yielded mixed results. While double glazing is often employed in solar collectors for improved insulation, its application in solar stills can be detrimental. Experimental studies have demonstrated that using a double-glazed cover with a 1 cm insulated air chamber minimized a distiller's yield by 56.52% compared to a conventional single-glazed still [7]. Another comparison showed an even more drastic reduction of 88.63% (approximately nine times lower) in productivity with double glazing versus single glazing, strongly advising against its use for single-slope solar stills [8].

A wide array of materials and innovative system designs have been investigated to enhance solar still performance, primarily by improving heat absorption, energy storage, or evaporation rates.

The integration of thermal storage materials within the solar still basin has shown considerable promise for improving productivity, especially for extending operation into nighttime hours. For instance, using a black zinc plate (48x48 cm, 0.2 cm thickness) as a sensible thermal storage material resulted in a 1.54 times improvement in productivity compared to a reference distiller [9]. Similarly, incorporating industrial coal debris led to a 25.76% improvement in accumulative productivity and an increase in average thermal efficiency from 27.98% to 34.79% [10, 11]. Economic analyses consistently indicate shorter payback periods for such modified systems. Coupling a solar still with a sensible heat storage tank improved daily distilled water production by 27.70% and maintained a stable thermal efficiency of 60-61% during the night phase [12]. Natural and industrial waste materials have also been explored as cost-effective enhancements. Natural charcoal blocks yielded an 8% improvement in solar still output [13]. The introduction of palm fibers significantly enhanced distilled water production, with improvement rates of 11.9% (40g), 24.5% (80g), and 35.6% (120g) depending on the amount used [14, 15]. Aluminum wastes, due to their high thermal conductivity, showed a 33.72% improvement in productivity when incorporated into solar stills [16]. Furthermore, palm stems led to a remarkable 53.01% improvement in pure water production, with the still containing 9 palm stems yielding the highest output of 5080 ml [17]. The local Saharan plant *Cladium mariscus* in its dry state improved water production by 33.27% [18]. Conversely, some materials have shown limited or negative impacts. The addition of natural sand dunes decreased distilled water productivity by 1.46 times [19], while sand from Illizi city yielded a negligible 0.67% improvement [20]. Using a new absorber designed with multilayer composite

materials resulted in a slight decrease of 3% in freshwater production [21]. The inclusion of plastic fins had a negative effect, decreasing distiller output by 8.8% [22].

sophisticated materials and system configurations. Phase Change Materials (PCMs), particularly organic PCMs, have shown significant promise for increasing distillate yield by storing latent heat. Reviews highlight enhancements up to 143.78% with lauric acid in active solar stills and up to 124.74% with soy wax in passive stills [23]. Experimental studies confirm these benefits, with a 2 kg mass of paraffin wax (RT54HC) leading to a 27.7% increase in freshwater production [24]. Macro-encapsulated PCMs have demonstrated energy efficiency improvements of 28–99% and exergy efficiency increases of 21–129%, with peak productivity reaching 2500 ml m⁻²d⁻¹ [25]. The integration of nano-enhanced phase change materials (NePCM), often combined with other modifications, can lead to productivity increases ranging from 14.58% to 318% [26]. The use of different types of carbon in the absorber of traditional solar stills has also yielded impressive results. Activated carbon led to the highest improvement of 79.39%, followed by graphite (57.58%), coal (50.30%), and wood charcoal (18.18%) [27].

Beyond material innovation, various system modifications have been explored. Integrating a single external mirror improved productivity by 42% to 45% with an efficiency of 35%, and an estimated payback period of 23 days [28]. A solar distiller assisted by a concentrator system (SDACS) showed significantly higher hourly and accumulated water outputs, along with improved thermal and exergy efficiencies [29]. External reflecting mirrors angled at 25° enhanced cumulative daily water output by 33.67% in a conical solar still [30]. Innovative condenser designs and basin modifications are also being explored. A multi-cavity built-in condenser increased freshwater harvested by up to 83.5%, resulting in a 16.7% overall productivity upgrade and a 55.96% improvement in net daily productivity compared to conventional stills [31]. The strategic placement of plastic fins of varying diameters (e.g., 0.5 cm) in the basin can increase surface tension and achieved a 41.4% improvement in water production (6176 ml/m²/day) over a reference still (4368 ml/m²/day) [32]. It's worth noting that another study on plastic fins showed a negative effect on output [22]. Integrating floating aluminum fins (FAF) with multiple cylindrical external condensers (MCEC) resulted in an 80.36% higher average daily yield and a 163% improvement in exergy efficiency [33]. More complex designs include a novel tubular solar still with a rotational absorber, ultrasonic atomizer, and

hygroscopic fabrics (cotton and jute). The rotational absorber increased yield by 18%, and jute fabric significantly outperformed cotton, achieving a 90% productivity improvement and an optimal 97% increase (6795 mL/m²) with 49% thermal efficiency [34]. A modified pyramidal solar still integrating a pulsating heat pipe (PHP), PCM, and fins achieved a 94.96% higher yield and 31.51% higher energy efficiency compared to a conventional pyramidal still [35].

The performance of solar stills is highly dependent on local climatic conditions. A comparative study in the El-Oued region of southeast Algeria demonstrated that the amount of distilled water produced in summer (1127 ml/day) was more than nine times that produced in winter (119 ml/day), underscoring the significant influence of factors like solar radiation, ambient temperature, and humidity on distiller productivity [36]. Beyond specific modifications, the general challenges and research methodologies in solar distillation have been discussed, emphasizing its potential as a simple, economic, and environmental technique despite historical low productivity issues [3]. The concept of using heat flow through glazing as an indicator of pure water productivity has also been proposed [4]. Reviews further highlight the promising application of thermoelectric modules integrated with solar stills for potable water production from groundwater, with potential for electricity generation [37]. Research continues to investigate the use of various materials, including rubber and its thickness [38], metal plates and refractory plates [39], and date and olive kernels as energy storage materials [40]. For instance, olive kernels increased cumulative water production by approximately 226%, and date kernels by 176% [40].

The role of nanoparticles in nanofluids, PCMs, and nanocoatings is actively reviewed for their potential to enhance thermal performance and productivity, especially when combined with other techniques like glazing cooling and modified absorbers [41]. Computational tools like Ansys Workbench are also being utilized to analyze parameters and the impact of heat-absorbing materials such as steel balls, tin pieces, and lead balls, with steel balls yielding the highest production rate of 1770 mL/m²/day [42]. Innovations like rotating wick solar stills with different wick configurations and materials (jute, cotton, coir) have shown significant thermal efficiency improvements (up to 74.3% with external reflectors and glass cooling) and lower distillate costs [43]. Finally, the overarching influence of surface tension in enhancing performance through designs like plastic fins continues to be a focus [44].

The objective of this work was to evaluate the impact of incorporating iron rods within the basin of a solar still on its thermal and productive performance under the specific environmental conditions of El Oued, Algeria. The novelty of this study lies in systematically investigating the effect of iron pole spacing (0 cm and 1 cm) on key performance indicators – internal glass temperature, water temperature, and hourly and cumulative distillate output – providing specific quantitative data to assess the practical benefits of such a modification.

II. Methods and Materials

On September 13, 2024, an experiment was conducted at the University of El Oued, East and South Algeria. We took three similar conical solar stills and exposed them to the sun under the same conditions. We used the first still as a control (CSS), while in the second still (MSS₀), we placed iron rods in solar still basin with 0 cm between the rods, as shown in Figure 1. The rods were attached to each other with no space between them. In the third still (MSS₁), we placed the same two rods, leaving a space of 1 cm between them.

The objective of the experiment was to determine whether the presence of rods in the still increases its efficiency. The specific objective was to determine the effect of the distance left between the rods on the productivity of the solar still. The experiment was conducted on a sunny, windless day. The three stills were equipped with thermal sensors, and all results were taken at the end of an hour throughout the experiment.



Figure 1. Experiment Preparations

III. Results and discussion

III.1. Solar radiation and Ambient temperature

Figure 4 illustrates the water temperature (T_{water}) over time for the control solar still (CSS) and two modified stills (MSS_0 with 0 cm pole spacing, MSS_1 with 1 cm pole spacing). All stills started around 29°C at 07:00 h. The peak water temperatures were observed around midday. The CSS peaked at approximately 55°C between 12:00h and 12:30h. In contrast, both modified stills, MSS_0 and MSS_1 , achieved significantly higher peak temperatures. MSS_0 reached its maximum of approximately 60°C around 12:30h, while MSS_1 peaked slightly earlier, around 12:00h, also reaching approximately 60°C. This demonstrates that the addition of iron rods, regardless of spacing, effectively increased the maximum water temperature achieved by the stills.

III.2. Radiation and Ambient temperature evolution

This figure details the hourly progression of Solar Radiation and Ambient Temperature throughout the experimental day, crucial environmental parameters influencing solar still performance. Both factors demonstrated a typical daily cycle, beginning around 250 W/m² solar radiation and 29.5 °C ambient temperature at 07:00, steadily increasing to reach their peaks in the early afternoon. Solar radiation peaked at approximately 1000 W/m² around 13:30-14:00, closely followed by the highest ambient temperature of about 44 °C. As the afternoon advanced, both parameters gradually declined, ending at approximately 800 W/m² solar radiation and 32.5 °C ambient temperature by 18:00. This clear representation of the energy input and surrounding thermal conditions highlights the fluctuating yet significant solar potential available for distillation during the experiment.

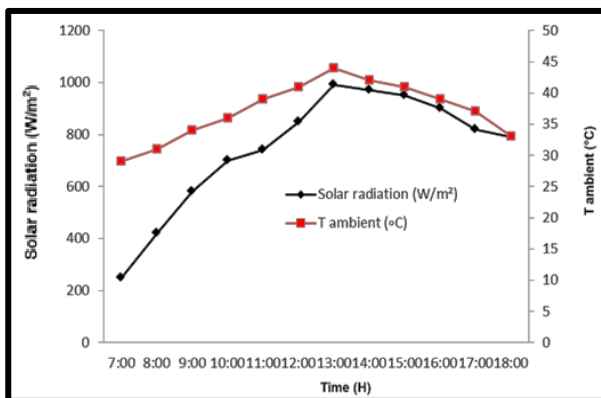


Figure 2. Radiation and Ambient temperature

III.3. Internal glass temperature

Figure 3 demonstrates the internal glass temperature ($T_{\text{glass_int}}$) over a day for three solar stills: a control still (CSS) and two modified stills (MSS_0 with 0 cm pole spacing, MSS_1 with 1 cm pole spacing). All three stills began at approximately 28.8°C at 07:00h, with temperatures rising steadily to a peak of around 43–43.5°C between 12:00h and 13:00h. Subsequently, the temperatures gradually decreased, reaching approximately 38°C by 19:00h. Throughout the experiment, the internal glass temperatures of all three stills remained remarkably similar, with only minor variations, indicating that the iron pole modifications had a negligible effect on the internal glass temperature profile compared to the conventional solar still.

The amount of heat received by the glass (internal face) is evacuated by the conductivity which passes through it:

$$\frac{M_g C_{p_g} dT_{gi}}{A_g dt} = Q_{r.w_gi} + Q_{c.w_gi} + Q_{evap} - Q_{c.gi_ge} \quad (1)$$

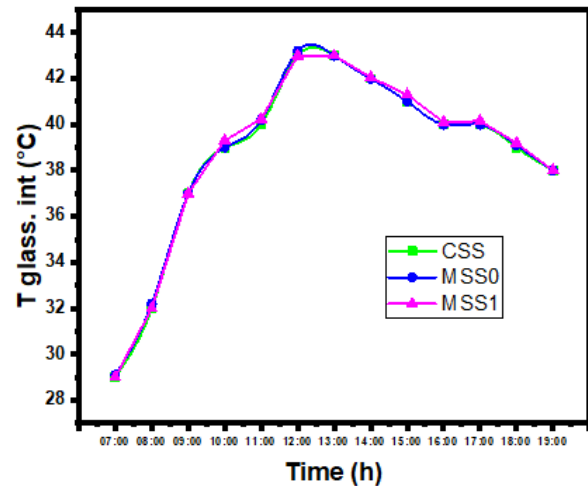


Figure 3. Internal glass temperature

III.4. Water temperature evolution

Figure 4 illustrates the water temperature (T_{water}) over time for the control solar still (CSS) and two modified stills (MSS_0 with 0 cm pole spacing, MSS_1 with 1 cm pole spacing). All stills started around 29°C at 07:00 h. The peak water temperatures were observed around midday. The CSS peaked at approximately 55°C between 12:00h and 12:30h. In contrast, both modified stills, MSS_0 and MSS_1 , achieved significantly higher peak temperatures. MSS_0 reached its maximum of approximately 60°C around 12:30h, while MSS_1 peaked slightly earlier, around 12:00h, also reaching approximately 60°C. This demonstrates that the addition of iron rods, regardless of spacing, effectively increased the maximum water temperature achieved by the stills.

In the afternoon, as solar intensity decreased, the water temperatures in all stills began to decline. The CSS showed a more consistent decline, reaching approximately 44°C by 19:00h. MSS₀ maintained a higher temperature for longer, remaining above 55°C until after 16:00h and finishing at approximately 52°C by 19:00h. MSS₁'s temperature dropped more sharply than MSS₀ in the late afternoon, falling from 55°C at 14:00h to approximately 44°C by 19:00h, similar to the CSS at the end of the day.

Overall, the data indicates that both MSS₀ and MSS₁ achieved higher peak water temperatures compared to the CSS, with MSS₀ maintaining elevated temperatures for a longer duration in the afternoon. This suggests that the iron rods enhance the thermal performance of the solar stills by increasing water temperature, particularly around solar noon. However, the 0 cm spacing (MSS₀) appeared to retain heat more effectively in the later hours compared to the 1 cm spacing (MSS₁).

The heat exchange between the water and the inside of the glass, the same quantities of heat are found respectively by convection, radiation and evaporation is given by:

$$\frac{M_w C_p w dT_w}{A_w dt} = \alpha_w \tau_g G + Q_{c.b.w} - Q_{c.w.g} - Q_{evap} - Q_{r.w.g.i} \quad (2)$$

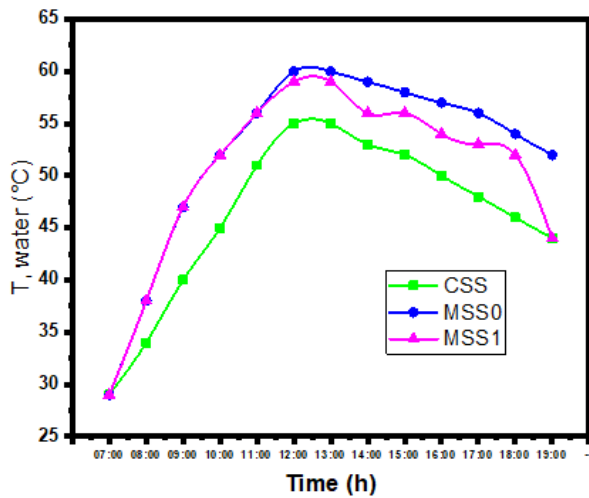


Figure 4. Water temperature

III.5. Hourly output evolution

Figure 5 shows the hourly distilled water output (ml) for the control solar still (CSS) and two modified stills (MSS₀ and MSS₁). Starting low at 09:00h (22-25 ml), all stills increased output with rising solar intensity. During peak hours (12:00-14:00), CSS reached about 88 ml, while both MSS₀ and MSS₁ significantly outperformed it, consistently producing around 93-95 ml. As the day progressed, output declined for all. However, MSS₀ and

MSS₁ generally maintained a higher hourly output than CSS throughout the afternoon, ending around 35 ml by 19:00h compared to CSS's 15 ml. This indicates that the iron pole modifications in MSS₀ and MSS₁ consistently led to a greater hourly water production than the conventional CSS.

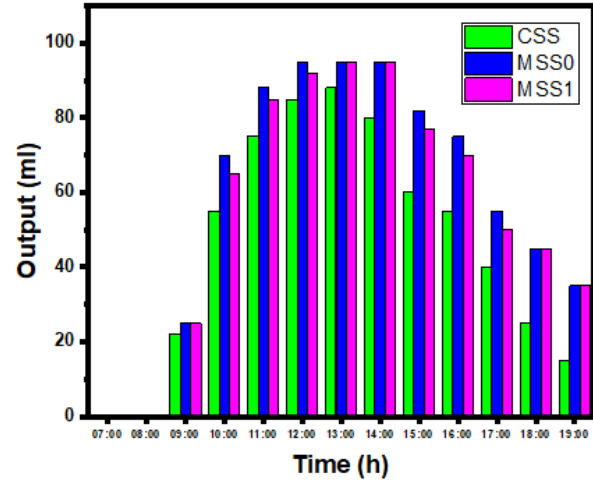


Figure 5. Hourly output

III.6. Cumulative output evolution

This line graph illustrates the cumulative distilled water output for the control solar still (CSS) and two modified stills (MSS₀ and MSS₁) over the day. Starting from minimal output at 07:00, all stills showed increasing production. However, MSS₀ and MSS₁ consistently outperformed CSS throughout the experiment. By 19:00h, CSS had produced approximately 600 ml, while MSS₀ achieved the highest output at around 740 ml, and MSS₁ reached about 720 ml. This demonstrates that the iron pole modifications in MSS₀ and MSS₁ significantly enhanced the total water distillation compared to the CSS.

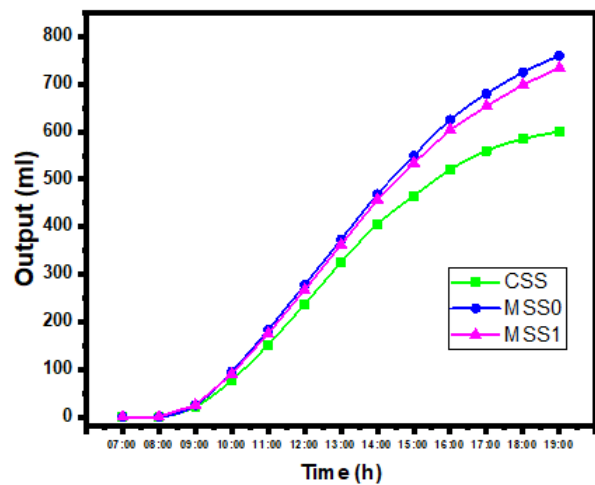


Figure 6. Cumulative output

IV. Conclusion

This experimental investigation conclusively demonstrates that the integration of iron rods into the basin of a solar still significantly enhances its thermal and productivity performance. While the internal glass temperature remained largely unaffected by the modifications, peaking consistently around 43–43.5°C across all stills, the water temperature showed a marked improvement in the modified stills. Both MSS₀ and MSS₁ achieved a peak water temperature of approximately 60°C, a substantial increase compared to the CSS's peak of 55°C. This enhanced heat absorption and transfer directly contributed to a notable increase in distilled water output. During peak solar hours (12:00h–14:00h), MSS₀ and MSS₁ consistently outperformed the CSS, producing around 93–95 ml hourly, compared to the CSS's 88 ml. Furthermore, the cumulative daily output underscored the superior efficiency of the modified designs: MSS₀ yielded approximately 740 ml, MSS₁ produced 720 ml, both significantly exceeding the CSS's total of 600 ml. These results strongly suggest that the simple and cost-effective addition of iron rods can lead to a substantial improvement in solar still distillate production, with the 0 cm spacing configuration (MSS₀) showing a slightly better overall performance in terms of total yield.

Nomenclature

Symbol	Description	Unit
A_g	Surface area of the glass	m ²
A_w	Surface area of the water	m ²
C_{pg}	Specific heat of the glass	J/(kg·K)
C_{pw}	Specific heat of the water	J/(kg·K)
m_{ew}	Mass of water evaporated	kg
M_g	Mass of the glass	kg
M_w	Mass of the water	kg
$Q_{c,b-w}$	Convective heat flow between the bottom of the still and the water film	W/m ²
$Q_{c,gi-ge}$	Heat flow by conduction through the glass	W
$Q_{c,w-gi}$	Convective heat flow between the water film and the glazing	W/m ²
Q_{evap}	Evaporative-condensation heat flux between the water film and the glazing	W/m ²
t	Time	s
G	Solar radiation	W/m ²
T_{gi}	Temperature of the glass (inside)	K
T_w	Temperature of the water	K
α_w	Absorptivity of the water	/
τ_g	Transmissivity of the glass	/

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism

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