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ORIGINAL RESEARCH ARTICLE

Experimental investigation on Solar desalination system integrated with kanche marbles

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ABSTRACT

Water scarcity has been identified as one of the major challenges in the world today, thereby the necessity of developing simple and sustainable desalination technologies. The performance of this Modified Solar Still (MSS) using black-coated glass (kanche) marbles as sensible heat storage medium was experimentally compared with that of Conventional Solar Still (CSS) under climatic conditions of Somnath, Gujarat, India. The two identical, single-slope solar stills were operated in parallel with a basin area of 1 m². The MSS had higher water and glass cover temperatures in the basin throughout the day, which led to higher evaporation and condensation rates. The maximum distillate yield per hour for the MSS was 0.58L whereas the CSS yields 0.49L. Likewise, the amount of cumulative freshwater produced rose from 3.1 L/day in the CSS to 4.0 L/day in the MSS. The highest thermal efficiency of the MSS was 36.5% and for CSS it was 32%. The performance is enhanced due to better absorption and retention of solar energy by the black coated marbles and the MSS is a practical and economical solution for solar desalination applications, the main reason for this is attributed to the solar energy absorption and heat retention properties of kanche marbles.

Keywords: solar still; glass marbles (kanche); sensible heat storage; distillate yield; cost per litre; process innovation

1. Introduction

The demand for energy and freshwater has emerged as one of the key challenges in sustainable development globally[1,2]. There has been a large strain on traditional energy sources and water resources due to rapid industrialization, population growth and alteration in climatic conditions[3]. In such a scenario, solar energy has turned out to be a great alternative because of its renewable, accessible and eco-friendly properties. Solar energy, unlike fossil fuels, does not produce any harmful emissions and it offers a good alternative in solving energy and environmental issues[4]. Many parts of the world are becoming water-scarce due to insufficient safe drinking water in arid and semi-arid regions. Water in the oceans is abundant but due to its salinity can't be consumed directly by humans. Desalination technologies are the effective solution which remove dissolved salts from seawater and brackish water[5,6]. However, most of the conventional desalination methods consume significant energy input, which makes them more expensive and polluting[7,8].

Solar desalination is an innovative technology that integrates renewable energy with water treatment, providing sustainable solutions for water purification[9]. A solar still is a type of solar desalination technology that uses solar energy to evaporate saline water, and a transparent cover is used to condense and collect the purified water. A solar still is a type of solar desalination technology that involves harnessing the solar radiation to evaporate the saline water and a transparent cover to condense and collect the purified water[10,11]. The technology is very similar to that of the natural hydrological cycle and can be installed in remote areas without relying on an electrical grid[12]. To continuously enhance the thermal efficiency and freshwater production of solar still systems, innovative design modifications and energy enhancement techniques are continuously being made[13,14]. Singh et al.[15] showed that, shallowing of water had a significant impact on improving the freshwater productivity due to rapid heating and evaporation of water. Moreover, ANN based prediction and PSO optimization have successfully optimized the operating conditions for maximum performance of solar still. Sambare and joshi[16] employed passive sidewall aluminum reflectors and a PV-powered DC heater which greatly enhanced the thermal performance of the tubular solar still. The combined passive-active configuration enhanced evaporation rates, increased energy efficiency, boosted freshwater productivity to 6.86 L/m², and reduced the unit water production cost to 0.0137 $/L. Incorporation of composite nano-enhanced phase change material (nPCM) considerably enhanced the performance of solar still[17]. The advantages of the modified system were the increase of freshwater yield by 52.4% compared to the conventional still, improvement of the nocturnal productivity, energy exergy efficiency and significant contribution to the environment by reducing carbon emissions. Kantaoui et al.[18] conducted a balance analysis which showed that greater water mass in the basin resulted in reduced freshwater productivity, while higher PCM mass led to increased heat storage and overnight productivity. Elsaid et al.[19] combined the evacuated tube collectors with a tubular solar still, which showed that the water production and thermal performance were greatly improved. The modified system attained an energy efficiency of 63.84%, with a water production cost of 0.0277 $/L, which is an economically viable system. Esmaeili and Sheikholeslami[20] proved that conical and hemispherical covers are better for condensation and production of fresh water than trapezoidal covers. The improved conical cover design and internal baffle design led to a 30.6% increase in yield, a 3.6-year payback and better long-term profitability. Murugan et al.[21] experimentally investigated enhanced thermal conductivity floating wick materials in a double-slope solar desalination system and reported improved freshwater productivity and thermal performance.

The literature review shows that effective strategies to boost the productivity of solar stills involve the use of design changes, thermal energy storage materials, reflectors, evacuated tube collectors and optimization techniques. But little work has been done to study the long-term performance of solar stills with low-cost sensible heat storage materials under outdoor operating conditions. Furthermore, there are not many experimental tests available for comparing the performance of conventional and marble-assisted solar stills for a month-long period. So, the objective of the present study is to compare the thermal and productivity performance of the conventional solar still and modified solar still design using kanche marbles for one month period of experimentation. The goal is to assess how integration with marbles improves the freshwater yield, thermal characteristics and system efficiency.

2. Experimental setup

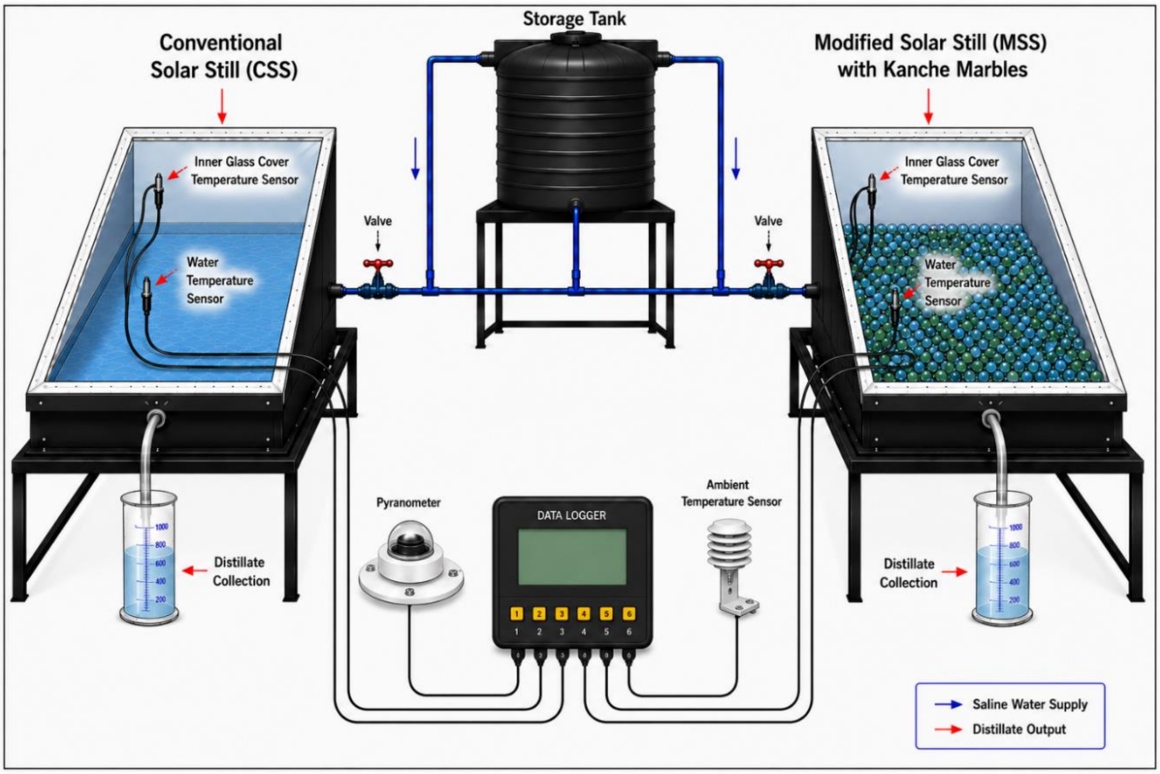

Figure 1. Schematic diagram of experimental setup.

Figure 2. Kanche marbles used in the experiment.

The experimental test rig with the basin fabrication area of 1.0 m² was fabricated and evaluated under climatic conditions of Somnath, Gujarat and comprised of two identical single slope asymmetric solar stills

Conventional Solar Still (CSS) and Modified Solar Still (MSS). The structural frames were made up of high-density galvanized iron sheets insulated with glass wool of 50 mm thickness (k = 0.038 W/m·K), to drastically reduce the parasitic thermal transfers to the ambient surroundings. The most effective glazing solution employed was highly transparent 4 mm thin low-iron tempered glass which was tilted at 20° (which is the optimized angle, corresponding to the local latitude of Somnath 20.8880° N 70.4013° E) to enhance the amount of solar radiation captured during daytime and to allow the condensate to drain into the collection troughs by gravity. The high absorptivity matte black thermal paint (α = 0.95) was applied to the internal basins to absorb the maximum amount of solar flux. The MSS basin is filled with a single layer of optimized, spherical glass (kanche) marbles, 20 mm in diameter, with matte black paint. The standard water level in the MSS basin is 2 cm. This design utilizes the thermal mass of the water, reducing the total heat storage needed for the first phase change and providing passive sensible heat storage (SHS) matrix. Calibrated K-type thermocouples were strategically positioned at multiple points to measure the temperatures of the water, inner glass cover and ambient temperatures. The global solar irradiance was measured by a high precision pyranometer during the diurnal cycle. **Figure 1** shows a schematic of the experimental setup, and **Figure 2** shows the kanche marbles used in the experiment.

The experiments were carried out by fabricating two solar stills of identical size of 1 square meter each, one is Conventional Solar Still (CSS) and the other is Modified Solar Still (MSS) with a monolayer of black coated marbles for Sensible Heat Storage (SHS). Daily simultaneous comparative experiments were carried out in Somnath, Gujarat during April, 2025. Solar irradiance, ambient and internal temperatures, distillate yield were systematically recorded for each hour after sunrise and before late evening (07:00 to :18: 00 IST). Readings have been taken from 1st April to 30th April during sunshine days but only 11th April 2025 taken for the results and discussion.

3. RESULTS AND DISCUSSION

This section shows the result and discussion of the research work carried out at Somnath, Gujarat on solar still. Research has been conducted during 1st April to 30th April, 2026. But, readings of 11th April 2026 has been used for the analysis.

3.1. Variations of time vs Solar intensity (11/04/2025)

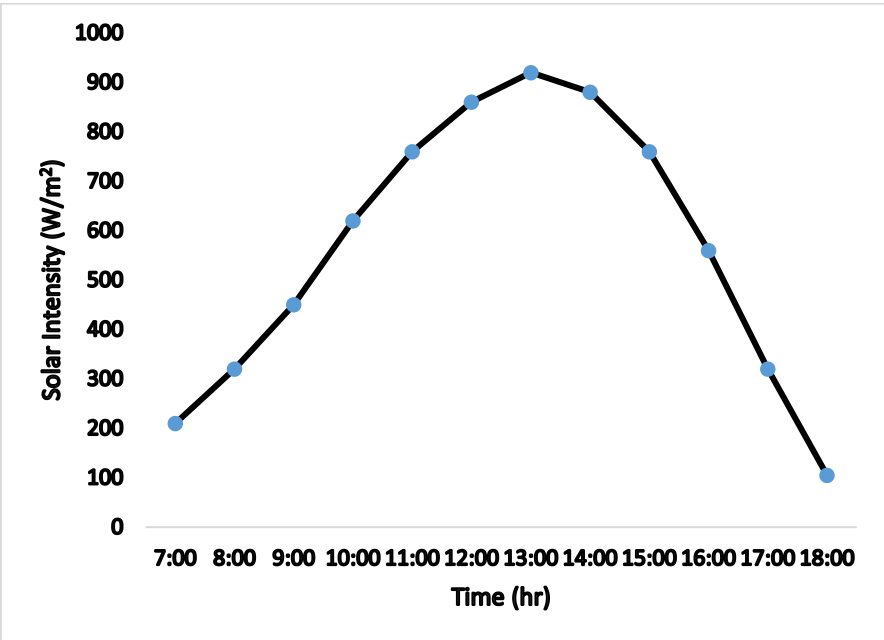

Figure 3. Variations of Time vs Solar Intensity (11/04/2025).

The variation of the global solar intensity I(t) W/m^2 with time on hourly basis during the experimental testing period (11th April 2025) in Somnath, Gujarat is shown in **Figure 3**. The intensity of the sun was in a typical parabolic trend with a low of 210 W/m2 at 07:00 IST, and rising steadily with clear sky conditions. The peak intensity of the solar resource in the globe was 920 W/m2 around 13:00 IST, which is due to the high intensity of the sun in the region during the peak summer month. After 13:00 IST, the solar flux slowly decreased reaching 105 W/m2 by 18:00 IST and nearing towards zero during night. The two distillation systems were mainly driven by this solar profile.

3.2. Hourly Variations of Water and Inner Glass Cover Temperatures (11/04/2025)

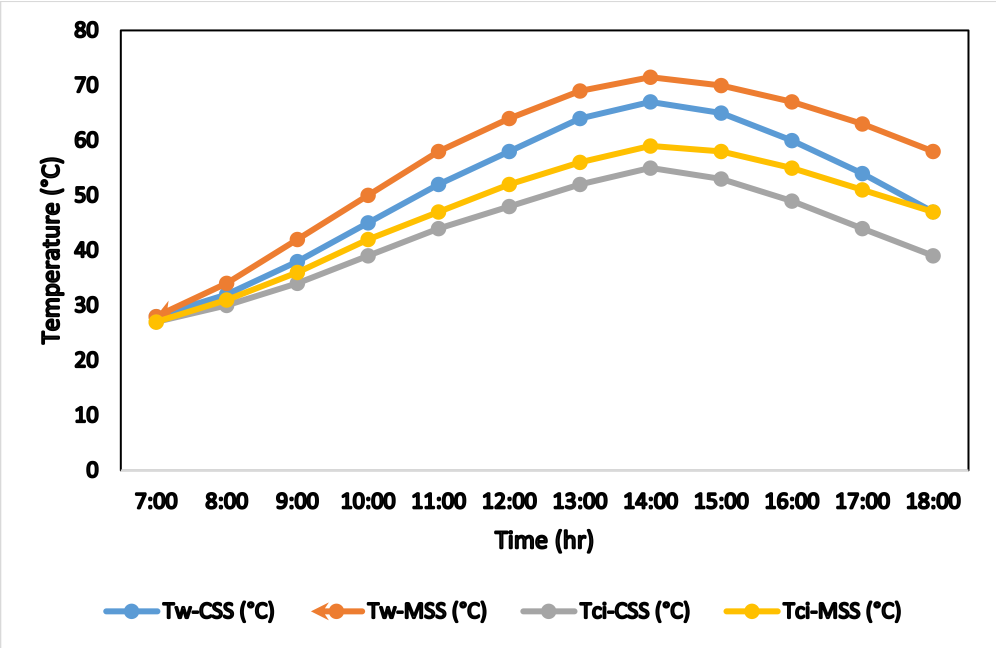

Figure 4. Variations of time vs water and inner glass cover temperature (11/04/2025).

During the experiment, the hourly change in the water temperature within the basin (Tw) and condensing inner glass cover temperature (Tci) for the Conventional Solar Still (CSS) and for the Modified Solar Still (MSS) are shown in **Figure 4**. The thermal behavior of both systems was similar, with the temperature rising steadily from 07:00h to 14:00h as the solar intensity also increased, and then decreasing towards the evening. The water temperature in the MSS throughout the day was always higher than that in the CSS. MSS increased from 28°C at 07:00 h to a maximum value of 71°C at 14:00 h; the CSS reached a maximum temperature of 67°C at 14:00 h.

Water temperature in the higher end of the basin in the MSS is higher due to better absorption of solar energy and better retention of heat, which improved the evaporation process inside the still. The inner glass cover temperature also increased in a similar manner, attaining the maximum temperature of 59°C and 55°C for the MSS and CSS, respectively, at 14:00 h. During much of the operating period, the MSS was 3-5°C warmer than the CSS. Evaporation condensation rate was higher in the MSS due to the greater temperature difference between the basin water and the glass cover, which led to increased freshwater productivity. Both Tw and T_{ci} slowly dropped after 14:00 h due to the decrease in solar radiation, but the MSS remained higher for longer. The results again indicate that the modification had a positive impact on the thermal behaviour of the solar still and resulted in an improvement of distillate output, over the conventional solar still.

3.3. Hourly Distillate output profile (11/04/2025)

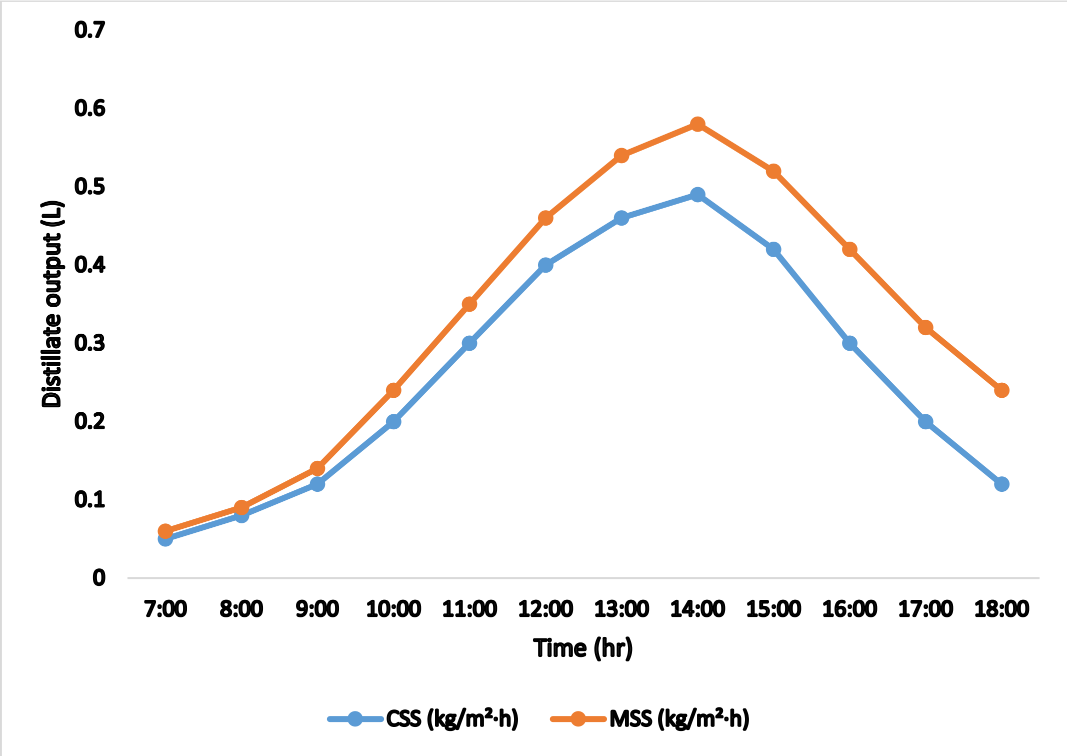

Figure 5. Variations of hourly distillate output vs time (11/04/2025).

The hourly productivity of distillate of the Conventional Solar Still (CSS) and Modified Solar Still (MSS) is shown in the **Figure 5** at similar operating conditions. A clear upward trend in both systems in the morning hours to a peak in the afternoon hours and then decreasing towards the evening is obvious in both the freshwater production. The CSS and MSS generated around 0.05L and 0.06L, respectively, at 07:00 h. As the amount of solar radiation increased, the water temperature of the basin also increased, leading to increased evaporation rate and vapor generation. At 13:00 h the hourly productivity of the CSS reached 0.46 L with a best value of 0.49 L at 14:00 h. Likewise, the MSS performed better with hourly distillate production rising from 0.06 L at 07:00 h to 0.53 L at 13:00 h and peaking at 0.58 L at 14:00 h. This suggests the increased productivity of the MSS is due to better thermal energy absorption and better evaporation-condensation in the modified system.

Both systems reduced the hourly distillate production gradually after 14:00 h because of the decrease in the solar intensity and the basin water temperature. But the MSS maintained higher freshwater production during the experimental period always. After 18:00 h, the MSS was producing around 0.24 L while the CSS was producing about 0.12 L. The improved performance was due to better heat retention, lesser thermal losses, and greater difference in the temperature of the water in the basin and the glass cover which allowed a continuous evaporation and condensation process. The overall MSS showed an average productivity improvement of about 20-22% over CSS, which is well established that the modification works efficiently for enhancing the thermal and desalination performance of solar still.

3.4. Cumulative Distillate output profile (11/04/2025)

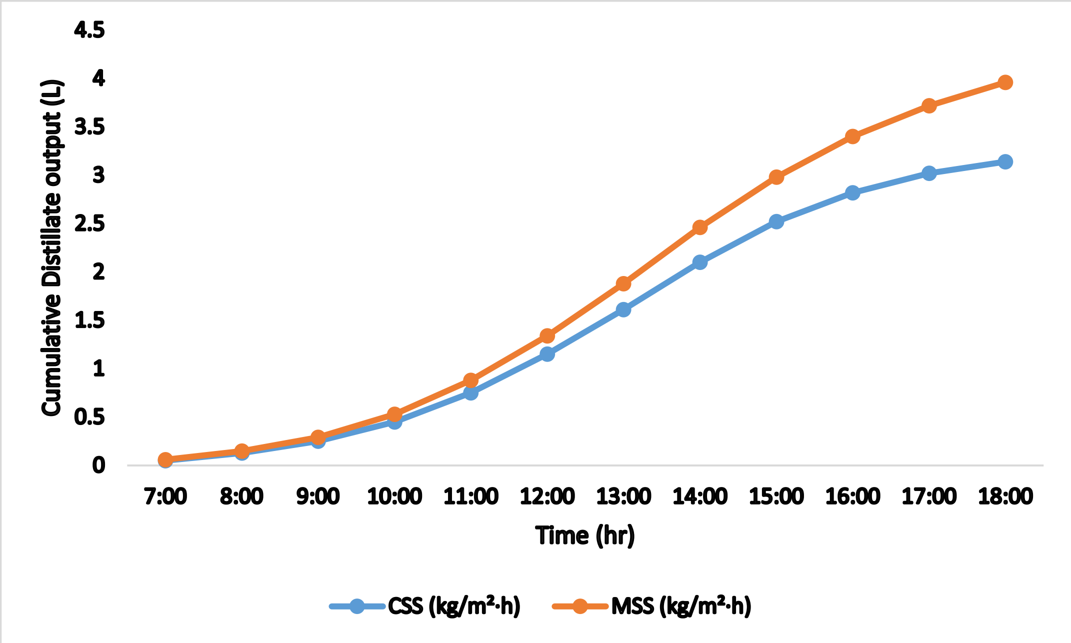

Figure 6. Variations of Time vs cumulative distillate output (11/04/2025).

The cumulative distillate productivity of Conventional Solar Still (CSS) and Modified Solar Still (MSS) in the experimental period is shown in **Figure 6** With operating time, the freshwater yield of both systems rose continuously thanks to the progressive evaporation/condensation of saline water. The cumulative output was relatively low during the early morning hours (07:00-10:00 h) due to lower intensity of the sun and water temperature in the basin. The CSS and MSS produced only 0.45 L and 0.50 L, respectively, by 10:00 h. During the increase in solar radiation, water in the basin gained more thermal energy and the basin's evaporation rate rose, resulting in a significant increase in cumulative productivity. The freshwater production was found to be significantly increased between 12:00 h and 15:00 h.

The performance of modified system is better than the CSS as the cumulative yield of the modified system was 2.50L and 3.00L for the CSS and MSS respectively at 15:00 h. Throughout the experimental period, the MSS always had higher cumulative productivity than the CSS. This improvement is due to the enhanced ability of the solar energy to be absorbed by the modified configuration, the improved heat transfer characteristics and the continued evaporation-condensation process inside the modified configuration. Despite the gradual reduction in solar intensity in the late afternoon period, the MSS produced freshwater at a relatively higher rate compared to the other periods, because of better thermal energy retention and heat losses during the late afternoon. After 18 h (at the end of the experiment), the cumulative distillate production of the MSS was about 4.0 L, while that of the CSS was about 3.1 L. This equates to an overall productivity improvement of almost 29%. From the results, it can be seen that the modification was able to improve the thermal performance, as well as the production hours of the solar still, and also significantly increase the production of freshwater when compared to the conventional solar still.

3.5. Time vs thermal efficiency (11/04/2025)

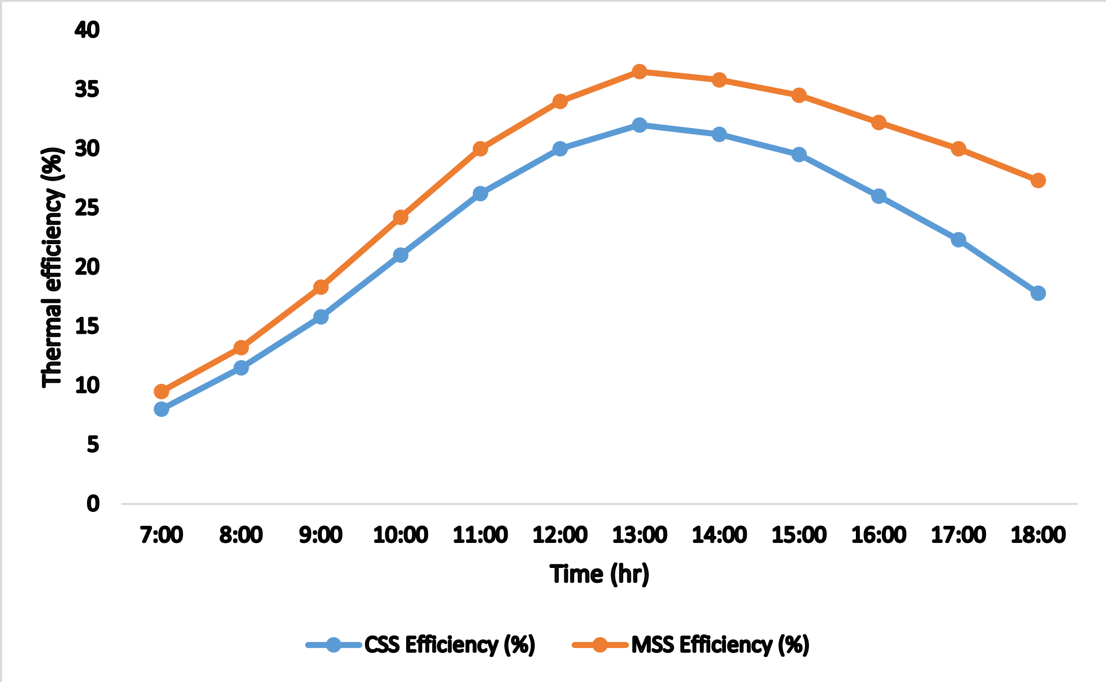

Figure 7. Variations of Time vs. Thermal efficiency (11/04/2025).

Thermal efficiency of the Conventional Solar Still (CSS) and Modified Solar Still (MSS) were plotted against time as shown in the **Figure 7** below and were seen to vary throughout the day. Ref.[22] used for the equation to determine the thermal efficiency. Thermal efficiency of both systems gradually rose with incident solar radiation, basin water temperature and evaporative heat transfer rate throughout the morning hours. The average CSS values were found to be between 8% and 07:00 h and 32% at 13:00 h, while the maximum MSS efficiency has been observed to be > 36.5% at 13:00 h. The reason for its superior performance is due to increase in the absorption of solar energy and better heat transfer properties in the basin of MSS.

The modification promoted better heat retention and higher water/condensing surface temperature differential which enhanced the evaporation process. This caused a greater proportion of the sun's absorbed energy to be used for latent heat of vaporization, which resulted in improved thermal efficiency during the daytime operation period. After the maximum period of solar radiation, the thermal efficiency of both systems slowly decreased because of the decrease in the intensity of the solar radiation and in the water temperature of the basin. But the efficiencies of the MSS were higher than that of the CSS throughout the experiment. The CSS and MSS efficiencies were around 18% and 27.5% respectively at 18:00 hr. This behaviour suggests that the MSS had a higher thermal inertia which allowed it to store and access thermal energy more efficiently in the late afternoon. An improved thermal performance may also be related to lower convective and radiative heat losses and higher evaporative mass transfer coefficient. The efficiency gap between the two systems increased after noon, implying that the changes have played a significant role in maintaining the evaporation under reduced solar radiation. The average thermal efficiency improvement of the MSS over the CSS was approximately 15-20%, indicating the efficiency of using the MSS for increasing energy utilization and freshwater production in solar desalination systems.

4. Conclusion

An experimental work was conducted to assess the thermal and productivity performance of a Conventional Solar Still (CSS) and Modified Solar Still (MSS) coupled with black coated glass (kanche) marbles in climatic condition of Somnath, Gujarat, India. From the experimental observations and analysis the following conclusions can be drawn:

1. The intensity of the sun was found to be in the normal diurnal pattern, increasing from 210 W/m² in the morning to a peak of 920 W/m² at 13:00 h before it gradually reduced towards sunset
2. The thermal properties of MSS was better than other samples throughout the experimental period. The highest water temperature (71°C) in the modified system (MSS) was obtained compared to the CSS (67°C), showing better solar absorption and heat storage system in MSS.
3. The increased temperatures helped to improve evaporation-condensation processes and increase the production of fresh water.
4. The maximum distillate yield per hour of the MSS was 0.58 kg/m2·h and 0.49 kg/m2·h for the CSS. This is about an 18.4% improvement in the hourly freshwater production.
5. The total freshwater yield yielded by the MSS is about 4.0 kg/m2 while for the CSS it is about 3.3 kg/m2 for the same number of operating days, which is an overall improvement in productivity of about 21.2%. Compared to the CSS, the maximum thermal efficiency of the MSS achieved was 36.8%, which was much higher than the CSS's 32.1%.
6. Furthermore, the MSS achieved higher efficiencies in the late afternoon because of its better thermal energy storage and retention ability. The use of glass marbles in the MSS led to better performance by improving the absorption of solar energy, the sensible heat storage, thermal losses and maintaining evaporation-condensation activity even with reduced solar radiation.

The proposed modification is simple, low cost, environmentally friendly, and it is not required to put any external energy, that is a practical solution for achieving higher performance of the solar desalination. Overall, the modified solar still was shown to have better thermal efficiency and freshwater production than the conventional solar still. The results have confirmed that the use of black coated glass marbles as sensible heat storage medium is an effective solution in improving the solar desalination system and can be used to make sustainable freshwater in a remote, coastal and water-lacking area.

Conflict of interest

The authors declare no conflict of interest.

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