PERFORMANCE INVESTIGATION OF SINGLE-SLOPE SOLAR STILLS WITH DRIPPING ARRANGEMENT AND NANO ZrO_2 PARTICLES

by

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Original scientific paper
https://doi.org/10.2298/TSCI221105248V

In many parts of the world, fresh drinking water is in short supply. The solar still produced a daily output of only 3 L, but it was used in providing a sustainable supply of clean drinking water. The climate of Kanyakumari district, Tamil Nadu, India was tested from 8.30 a. m. to 5.30 p. m. on April 2023 using a modified solar still (MSS) for the experiment. The effectiveness of a MSS has been increased over that of a conventional solar still (CSS) by using as nanoparticle of ZrO_2 and a dripping arrangement of water. The yields of MSS and CSS were determined experimentally to be 2.22 L per m^2 and 3.39 L per m^2, respectively. It was found that the CSS and MSS had thermal efficiencies of 25% and 35%, respectively. It has also been noticed that the MSS in its modified form has increased efficiency by 52.5%. Water costs 0.95 Rs per L under the CSS and 0.75 Rs per L under the MSS, as determined by their respective economic analyses. Solar still using nanomaterials and dripping arrangement improved output. It has also been noticed that the MSS in its modified form has increased efficiency by 52.5%.

Key words: *nanomaterial, solar still, thermal efficiency, fresh water, ZrO_2*

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Introduction

The most important substance on Earth is water. The search for drinkable water presents a challenge in underserved areas. It is generally accepted that water makes up about 75% of the Earth's surface, and that saltwater makes up a sizable proportion of the planet's total water content. Several techniques have been used to turn seawater into potable water. Solar desalination holds great promise for solving the water shortage problem. Due to its low cost and convenience of use, a solar still can be used to purify salty, brackish, or unclean water. Solar still treats wastewater such as brackish or salt water for reuse as drinking water. A shallow, water-proof basin is its main component. The body is warmed by the Sun, which is absorbed by the black exterior of the tank. The evaporation rate is increasing as the water temperature rises. Evaporated water accumulates at the top of a relatively dry, sloping, transparent bottle. In the measuring jar located below the distilling trough, the condensed water is stored as potable water.

Designed solar still with stair-shaped absorber plate and dimples for surface area. Compared MSS to traditional inclined solar still. The MSS showed 18.80% performance level and 3.34% higher efficiency [1]. Adding reflectors, jute fabric, and a new glass angle to a traditional solar still increases its output. Productivity rise by 72.18% when the solar still was modified, and efficiency went up by 41.51%. With a 10° slant, water flow and solar radiation were both enhanced [2]. Using coffee-based colloid as eco-friendly alternative to inorganic nanoparticles for solar stills. The MSS outperformed the CSS [3]. To optimise the efficiency of solar stills, researchers are experimenting with a cylindrical parabolic concentrator equipped with a focal pipe and an oil heat exchanger [4]. Designed solar still with fins and PCM-based energy storage. The MSS cost-effective with shorter pay-back period [5].

Increased water temperature and cumulative productivity by 10.8% compared to CSS. Improvements in CPL, energy efficiency, and reducing CO_2 emissions [6]. Using the staggered pin finned absorber in the paraffin wax bed of the upgraded single-basin solar still may increase the yield from the CSS by as much as 24.26% [7]. Increased distillate water output of up to 97.8% was achieved using MSS with multiple sets of coaxial pipes. Distillate water from modified stills cost between 1.65 Rs per L and 1.98 Rs per L [8]. The upgraded condenser in a single-slope solar still increased output, energy, and exergy while also showing significant gains in economic efficiency. Enhanced energy and exergy efficiency, decreased unit cost, and additional carbon credit [9]. Productivity was boosted in MSS by the use of a parabolic trough solar collector, a separation unit, and external condensers [10].

Banana stem was usedin solar desalination for collecting solar energy. Camphor-soothed banana stems used to accelerate evaporation process. Carbon credits obtained, yielding 934 ml at 36.35% efficiency. The MSS cost: USD 0.0503 per liter [11]. The MSS with *V*-shaped floating wicks for improved heat absorption. Higher evaporative surface area led to higher productivity [12]. The MSS with microparticles doped in black paint-coated absorber. The Cu, Al, and tin coatings increased full-day water yield by up to 33.13%, 22.18%, and 11.53%, respectively [13]. The PCM or external condenser improved productivity by about 35% and 44%, respectively. Costs of distilled freshwater for CSS, MSS-PCM, and MSS-EC: 2.40 Rs per L, 1.98 Rs per L, and 1.82 Rs per L [14]. The price per collected litre of freshwater was found to be lower when sand and wire mesh were used [15].

Energy efficiency, exergy efficiency, and productivity increased by significant percentages. Cost of distillate production: Rs. 1.73 per L, pay-back period: 12 months, credits earned: Rs. 13050 [16]. The MSS yielded 64% more distillate than CSS, with reduced cost per liter and improved thermal efficiency [17]. Modification of solar still with sisal fibers for glass cover cooling improved the energy-economic performance, lowered glass temperatures [18].

The MSS exhibited the increased water and reduced glass temperatures, higher productivity, and lower cost per liter. Improved CPL and pay-back period compared to CSS [19].

Salt water drip system using a copper sheet layer in the solar still's basin with a single slope [20]. The MSS with ZnO nanoparticles and dripping arrangement for improved solar still performance. Economic analysis indicated lower water cost for MSS [21]. Copper sheet layer and water-dripping arrangement in a solar still with a single basin and a single sloping wall. Dripping salt water from a basin of calcium stones dramatically increased yields [22]. Solar stills are being investigated, with the use of a cooling and dripping arrangement to store thermal energy in marble chips and sandstones. Sandstones and cooling arrangement positively affected distillate output [23].

Modelling thermal asymmetry in a single-slope basin-type solar still using sponge liners of varying thickness and color was proposed. To prevent the sponge from drying out during the day's hottest parts, a special dripping arrangement was used andobserved the performance enhancement [20]. Thermal modelling based on energy balance equations and computer program for analytical solutions. There is a strong correlation between numerical and experimental findings [24].

According to the results of the previous analysis, the CSS has a lower productivity compared to the water and glass covers. It has been found that the condensation temperature can be reduced by letting water slowly drop over a glass cover. The enhanced thermal conductivity of water has also been linked to the nanomaterials' ability to raise water temperature. Nanomaterials have been studied extensively in solar stills by many scientists. The ZrO_2 nanomaterial, however, has received little attention. However, no one has actually put the nanomaterial and dripping arrangement notion into practise yet. To that end, this study aims to conduct an experimental examination of a MSS that incorporates nanomaterials and a dripping arrangement, and to compare the results to those obtained with a CSS. The paper's discussion of the yield differences between MSS and CSS. Finally, this study also provides an example of an economic evaluation of the MSS and CSS.

Materials and methods

Solar still was used and experiments have been done both with and without adjustments to compare performance under varying situations. Changes made to the still are referred to as a MSS, while keeping things as they were is known as a CSS. In the current experiment, the water level is held at 2 cm throughout. Figure 1 shows schematic representation of the MSS and CSSused in this study.

Figure 2 displays a SEM image of the ZrO_2 used in this experiment. With a basin area of 1000 mm × 1000 mm and sidewall heights of 30 mm and 70 mm, it is still possible to reach kanyakumari latitude. Solar still was made out of galvanised sheeting that was 4 mm thick. Both the inside and outside of the basin were insulated with glass wool. The basin liner was held in place over the insulation with the help of a wooden plate that is 30 mm thick and rests on the outside of the solar still. The insulation had a thickness of 60 mm. The CSS applied a black coating to the basin's interior base and walls to maximise the collection of solar heat. A glass sheet around 23° from the horizontal seals the top of the bowl. In order to maximise absorption, the underside is black. Also, the white interior of the vertical walls improves their reflectivity.

The dripping apparatus is a plastic tube that measures 0.5 m in length and 1 cm in diameter. The 25 holes in the tube are evenly spaced at 0.2 cm to allow water to flow into the dripping arrangement. In addition, the main tank is linked to the water supply through dripping tubing. Dripping water from the storage tank would fall on the glass cover of solar

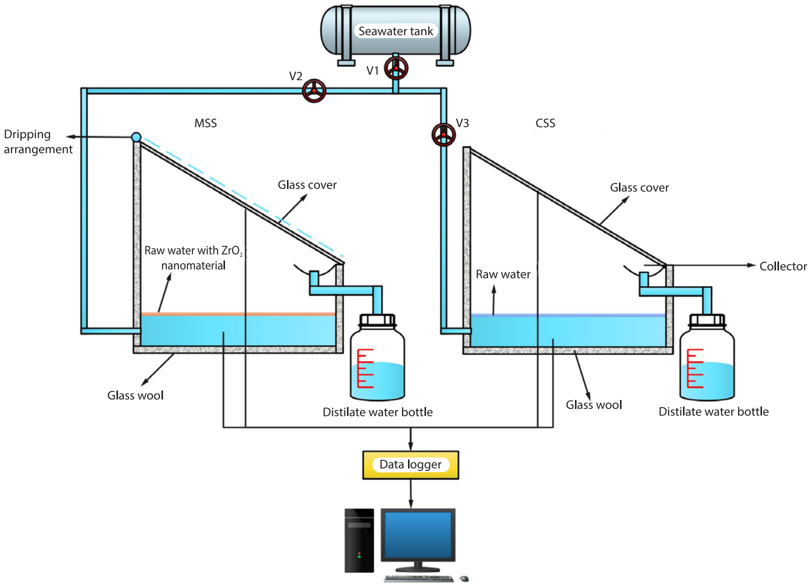

Figure 1. Diagrammatic representation of the MSS and CSS

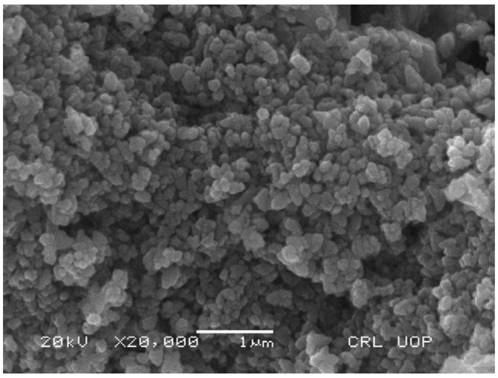

Figure 2. The SEM image of aggregated ZrO_2 nanoparticles

still, because of the density difference. In the present study, water constantly drips over the glass cover from the dripping pipe. Each solar plate's cover and top sheet was sealed with isolating and adhesive tape to prevent vapour from escaping the basin into the air. Condensation that accumulates on the inside of the glass tank walls drains down a plastic tube in the bottom channel and into a jar that is secured to the drain. Nanoparticles of ZrO_2 are being used in this study of solar stills.

Based on the trials, different devices were utilised to measure different parameters. Water and glass temperatures in solar stills, as well as room temperature, were measured using thermocouples of the *k*-type accurate to within 1 °C. The thermocouples were used to provide the readings for a digital temperature display. Distillate water was collected and measured in a bottle that contained exactly 1000 mL less than 10 mL. The solar radiation was measured between 0 W/m^2 and 1592 W/m^2 using a solar metre.

In this analysis, we accounted for the uncertainty that can arise from using instruments in trials. The instrument manufacturer or supplier will have gathered most of these figures from the equipment data sheet. Table 1 summarises the uncertainties associated with the instruments used in current studies.

Result and discussion

This research contrasts the performance of MSS and CSS in the climate of Kanyakumari, Tamilnadu, India. Two days in April 2023 were chosen because they had an average solar intensity that was similar to that of the MSS and the CSS. Therefore, normal daytime data were collected on April 6th and 10th to evaluate MSS and CSS.

Table 1. The study of experimental equipment uncertainties

Device	Accuracy	Measuring range	% of uncertainty
Thermocouples [°C]	±1	0–1000	0.082
Bottle for collecting distilled water	10 mL	0-10 l	0.0001 mL
Solar meter [Wm^{-2}]	±150	0-2000	0.926.0

Hourly profile of ambient temperatures and solar radiation

On a typical day (06/04/2023), the solar radiation profile and hourly ambient temperatures are shown in fig. 3. The average solar radiation during the experiment is 408-913 W/m^2, and the temperature ranges from 3551 °C. Higher solar temperature radiation was strongest between 12.30 p. m. and 1.30 p.m. Solar light levels are maximum in the morning and lower in the afternoon. Radiation from the sun decreases dramatically after midday, and the temperature outside reduces as a result.

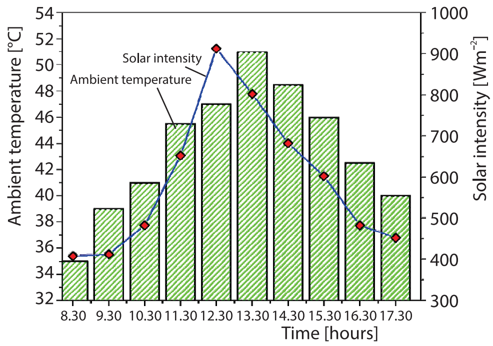

Figure 3. Hourly averages of ambient temperature and solar radiation

Hourly differences of solar intensity, internal glass cover and water temperature on MSS and CSS

Figures 4 and 5 show the average solar intensity, I, glass cover temperature, T_{ci}, and water temperature, T_w, for MSS and CSS. The water and air temperatures inside the glass have various solar responses at different times of day, figs. 4 and 5. Both lows occurred between 1300 and 1400 UTC, when Sun radiation was at its lowest. The white painted wall in the MSS reflects the solar light. As a result, the MSS has access to a far larger pool of solar power. The GHG are accumulating rapidly in the atmosphere, and the evaporation of MSS was greater than that of CSS. The peak of the water temperature curve was seen to be mid of the day, as depicted in fig. 4. Between 8.30 a. m. and 13:30 p. m., the covers become colder as water moves over the glass, increasing condensation. The storage capacity and thermal conductivity of water nanoparticles are both improved. In both SS incidents, the solar intensity and the ambient temperature dropped after midday. After midday, nanoparticles evaporate as their heat is transferred to the water as depicted in fig. 5.

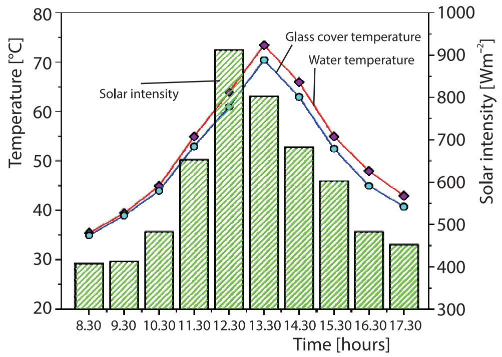

Figure 4. Differences in solar intensity, internal glass cover, and water temperature occur typically every hour during the day in a CSS

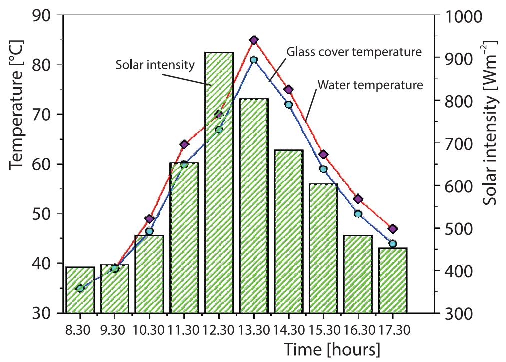

Figure 5. Solar intensity, glass inside cover and water temperature MSS hourly differences

The absence of nanoparticles on the white-lacquered walls allows for a slower rate of evaporation, even when the CSS increases and the energy density of the basin water increases. A higher energy capacity was available in CSS with black lacquered walls because the absence of nanoparticles slows down the rate of evaporation.

Comparison of hourly yield for MSS and CSS

Figure 6 depicts the results of a comparison of the hourly output of the MSS and CSS. Since the experiment started at 8:30 a. m. in the morning, there was no difference in the outcomes between 0 a. m. and 8:30 a. m.. After midday, when solar radiation decreases, yields for both stills begin to fall. Water's warming effect on the glass counteracts that of the nanoparticles as it passes through the cover. This causes a temperature shift, which in turn causes condensation and boosts MSS efficiency. The daily average experimental yield of MSS and CSS is depicted in fig. 7. The combined yield of MSS and CSS was determined to be 3.39 L per m^2 and 2.22 L per m^2, respectively. The ZrO_2 nanoparticles were employed in MSS dripping set-up. The dripping set-up can reduce the internal glass cover temperature by 1° or 2°. Adding ZnO_2 nanoparticles to the water at a concentration of 0.1% by volume and a size of 30 nm increased its thermal conductivity. Dripping and nanomaterials both contributed to an increase in MSS yield, which is a proven fact.

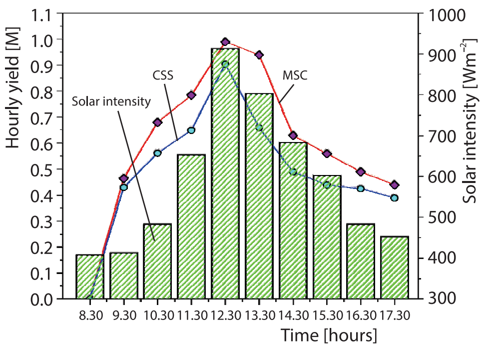

Figure 6. Hourly yield comparison between MSS and CSS

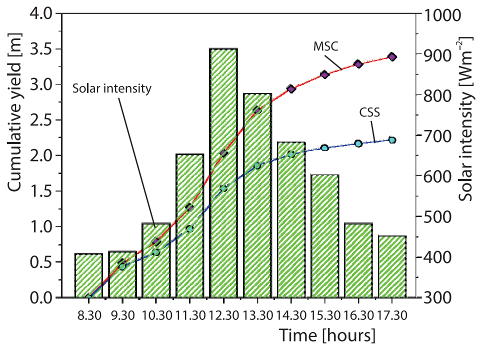

Figure 7. Comparison of cumulative yield for MSS and CSS

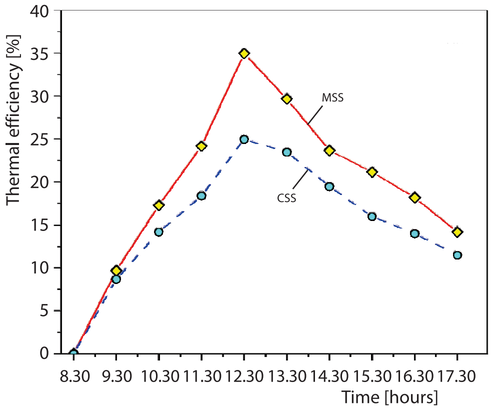

Figure 8. Thermal efficiency comparison of the MSS and the CSS

Comparison of thermal efficiency for MSS and CSS

Figure 8 shows how the MSS and CSS compare on a typical day of experimentation. During the early morning hours of 8:30 a. m. and 10:30 a. m., both MSS and CSS thermal efficiency follow a similar pattern, however MSS efficiency departs from CSS efficiency. Changes in the MSS thermal efficiency curve can be traced back to the introduction of nanomaterials and the installation of a water-dripping mechanism. The thermal efficiency of the two stills clearly varies with output, despite the fact that their combined surface area remains unchanged.

The yield of MSS was also improved by the use of Nanomaterials and the water-dripping arrangement, making it more advantageous than CSS. Therefore, MSS has higher thermal efficiency than CSS. The MSS and CSS obtained their maximum thermal efficiencies of 35% and 25%, respectively, at 01:30 p. m. on a typical trial day. Thermal efficiency was defined [17]:

$$\eta = \frac{q}{I \times A} \tag{1}$$

Economic analysis

An economic analysis of the MSS and CSS, tab. 2 displays the costs of the individual parts, yielded a cost per litre (CPL). The sum totals for MSS and CSS were calculated to be 7200 INR and 6900 INR, respectively. Existing assumptions on life expectancy, *n*, and interest rates, *I*, remain unchanged at 12 years. The CRF used in this analysis is based on the work of Kabeel and Abdelgaied [4, 8], from which it is generated. The differences between MSS and CSS are displayed in tab. 3.

Table 2. Estimated price of MSS and CSS for current study

Sr. number		MSS	CSS
1	Glass cover	1200	1200
2	Mild steel plates	2500	2500
3	Black chrome paint	500	500
4	Silicon seal	600	600
5	Stand	1200	1200
6	Dripping and nanomaterial cost	300	–
7	Fabrication cost	900	900
Total		7200	6900

Table 3. Price for different components/fabrication cost, yield, CPL, and thermal efficiency increment are compared between the CSS and MSS

Sr. No.	Particular	CSS	MSS
1	Price of different components/fabrication cost	6900	7200
2	Yield [L]	2.22	3.39
3	Thermal efficiency increment [%]	25	35
4	CPL (INR)	0.95	0.75

$$CRF = \frac{[i\left(1+i\right)^n]}{(1+i)^n - 1} \tag{2}$$

$$\text{Annual fixed cost is represented by} = \left(CRF \times F\right) \tag{3}$$

Consequently, 0.75 and 0.95 Rs per L were discovered by the CPL of the MSS and CSS, respectively.

Conclusions

After these three major changes:

– The following findings were achieved while using MSS with white colored walls.
– A drip system for the MSS.
– The addition of ZrO_2 nanoparticles into the MSS basin (0.10 wt.%).

The conclusions are as follows.

- The efficiency of MSS has been improved with the use of ZrO_2 nanoparticles and water dropping on white walls and glass.
- Potable water yielded by the MSS and CSS on a typical testing day was 2.22 L and 3.39 L, respectively.
- The MSS and CSS CPL for a typical testing day in Kanyakumari, Tamilnadu, India was 0.95 Rs per L and 0.75 Rs per L, respectively.
- During a typical trial day, MSS and CSSachieved thermal efficiencies of 25% and 35%, respectively. As a result of the Nanoparticles and dripping arrangement, MSS achieves roughly 33.33% more efficiency than CSS.

Acknowledgment

The authors would like to acknowledge the Researchers Supporting Project (No. RSP2023R373), King Saud University, Riyadh, Saudi Arabia.

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Paper submitted: November 5, 2022
Paper revised: September 20, 2023
Paper accepted: September 30, 2023