

Daily Output Improvement of Solar Stills Using Nanomaterials

Subjects: [Water Resources](#)

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Solar stills play a crucial role in the rate of production and thermal performance in solar desalination. Several experimental modifications have been attempted to enhance the productivity of solar stills. One of the modifications proposed in recent studies involves the inclusion of nanomaterials in the base fluid used in solar stills. The addition of nanomaterials has been reported to increase the production rate. Common examples of nanomaterials used to enhance the productivity of different types of solar stills include Al_2O_3 , CuO , ZnO , and TiO_2 .

solar still technology

nanomaterials

desalination

nanofluid

productivity

1. Effects of Al_2O_3 Nanofluid on Solar-Still Performance

Sahota and Tiwari ^[1] investigated the effect of Al_2O_3 on the yield performance of a passive double-slope solar still (DSSS). Al_2O_3 nanoparticles were added to the base fluid (water) at two different masses of 35 and 80 kg. The passive DSSS with the nanofluid worked as follows: Solar radiation penetrates the solar still through the transparent condensing cover. The radiation is first absorbed by the nanofluid and then by the blackened surface. A plasmon-resonance absorption band of metallic nanoparticles is clearly observed near the infrared spectrum. The mixture of metallic nanoparticles in the base fluid absorbs solar radiation. A common effect of energy transfer between the nanoparticles and the basin liner is that it increases the temperature of the nanofluid in the solar still. Sahota and Tiwari ^[1] developed and implemented a methodology to calculate the changes in hourly and daily yields resulting from the passive DSSS at 0.04%, 0.08%, and 0.12% concentrations. The findings showed an increase in the heat-transfer coefficient with an increase in the concentration of nanoparticles. One reason for this is that nanofluids directly absorb solar radiation, and the rate of absorption increases with solar intensity. Another reason is that the basin liner also transfers thermal energy to the nanofluid, resulting in an increase in temperature. Overall, the daily yield of the solar still increases with increasing concentration of Al_2O_3 nanoparticles in the base fluid.

Zhang et al. ^[2] studied the effects of Al_2O_3 and TiO_2 nanoparticles on reducing the energy demand within solar collectors. The investigation involved the application of two methods to facilitate the better use of solar energy. The first was a phase-change material (PCM), which was used to absorb the solar radiation, eliminating potential summer radiation problems. The second approach depended on the absorption of the solar radiation and its conversion into a source of heat to generate sanitary hot water. The findings showed that the use of nanoparticles resulted in the reduction in energy consumption within the solar collectors. In the PCM method, energy consumption was reduced by 44% on hot days, which was equal to a 267 kWh drop. On cold days, the reduction

was 48%—equivalent to 2419 kWh. Year-round analysis revealed that the energy consumption was reduced by 2686 kWh with the use of the nanoparticles in solar collectors.

Farajzadeh et al. [3] conducted experimental and numerical studies on the effect of Al_2O_3 on the thermal efficiency of flat-plate solar collectors. First, they determined the maximum efficiency and thermal loss of collectors with water following the American Society of Heating, Refrigerating, and Air-Conditioning Engineers methodology. The maximum efficiency of the solar still with water was 0.9, while the thermal loss was 21.2. This was followed by another experiment in which the solar still was filled with Al_2O_3 along with water. The maximum efficiency of the solar still with this mixture was 0.9, while the thermal loss was reduced to 13.74. These findings showed that Al_2O_3 did not substantially improve the maximum efficiency of a solar still but can be beneficial in reducing thermal loss. However, the authors failed to explain the reasons for the decrease in the heat loss when Al_2O_3 nanoparticles were introduced.

Faridani and Ameri [4] analysed the possibility of using Al_2O_3 nanoparticles to enhance the performance of basin solar stills. They used $\gamma\text{-Al}_2\text{O}_3$ nanoparticles to effectively produce pure water in the presence of a mixer. Three analyses—Fourier-transform infrared spectroscopy, X-ray diffraction, and scanning electron microscopy—were used to verify the nanoparticles. The quantity of $\gamma\text{-Al}_2\text{O}_3$ nanoparticles, initial depth of water, intensity of solar energy, and temperatures of the glass, bottom, and brine were analysed. The results showed a distillate yield of approximately 60.03% with a 0.3 mass% of $\gamma\text{-Al}_2\text{O}_3$. The tests with nanoparticles also showed an increase in the glass, bottom, and brine temperatures. Overall, the application of $\gamma\text{-Al}_2\text{O}_3$ nanoparticles improved the performance of the still because of the better thermal characteristics of saline water.

Negm et al. [5] investigated the effect of Al_2O_3 on the efficiency of a thermosyphon flat-plate solar collector and found that the efficiency of solar collectors could be increased using nanofluids such as Al_2O_3 as the working fluid. They observed an increase in the efficiency when using nanofluids as the working fluid compared with that of designs that used distilled water alone. Al_2O_3 –water nanofluids have been found to be suitable for improving the efficiency of solar collectors.

Shoeibi et al. [6] studied the effects of nano-enhanced PCM on the performance of solar stills. The Al_2O_3 nanoparticles used in the study were at concentrations of 0.3 wt%. Al_2O_3 was mixed in paraffin wax to enhance the thermal properties of PCM. The study indicated a 49.5% increase in the productivity of solar stills when Al_2O_3 nanoparticles were used at 0.3 wt% concentration. Moreover, the Al_2O_3 nanoparticles could reduce the melting point by 1.8 °C at a concentration of 0.1 wt%. The nano-coating also increased the rate of water production of the solar still by approximately 5.7%. Overall, the study showed an improved performance of the solar still with the addition of Al_2O_3 nanoparticles.

Chaichan and Kazem [7] investigated the productivity improvement of a single-slope solar distillator using a PCM and Al_2O_3 nanoparticles. They added nano- Al_2O_3 to the wax of one of the distillates used in the study to enhance the thermal conductivity of paraffin wax. The addition of Al_2O_3 to paraffin wax resulted in a substantial increase in the rate of heat transfer and enhanced the distillate yield to approximately 60.53% compared with that of the simple

distiller yield recorded after sunset. Muraleedharan et al. [8] reported the design and construction of a modified active-solar-distillation system (MSDS) and compared its performance parameters with those of a conventional solar still. The heat-transfer fluid was an Al₂O₃ Therminol-55 nanofluid (nHTF), and different parameters—including the temperature of the saline water, hourly yield, and total yield—were compared. The experiment showed that the hourly yield of the MSDS with an nHTF of 0.1% was 45–250.27% more than that of the conventional solar still. The total yield of the MSDS with 0.1% nHTF was much higher at 12.190 L/m²/day compared with the 3.48 L/m²/day reported for the conventional solar still. Daily efficiency of the MSDS varied depending on the concentration of the nanofluid, but the maximum efficiency was 53.33% for an nHTF concentration of 0.1%. Thus, an MSDS system using a nanofluid showed higher productivity and better cost-effectiveness than those of a conventional solar still using only water.

Rashidi et al. [9] numerically tested the significance of a nanofluid used in stepped solar stills. The glass cover and bottom surface had constant temperatures of 30 °C and 40 °C, respectively. An unstable Al₂O₃–water nanofluid flow was used in the simulation. The nanoparticles were then added to the base fluid. Employing higher concentrations of the nanofluid led to higher rates of evaporation and condensation and quantities of water generated by the device. The results showed an increase in hourly productivity because of increasing the solid volume fraction of nanoparticles. Elevating the percentage concentration of Al₂O₃ from 0% to 5% resulted in a 22% increase in the hourly productivity.

Choudhary and Subudhi [10] reported turbulent natural convection in an enclosure full of a water-based Al₂O₃ nanofluid. The nanoparticles were spherical and had a mean diameter of 40 nm, and they were mixed with distilled water to prepare the nanofluid at a concentration of 0.01 and 0.1 vol%. The resulting nanofluids remained stable for >24 h. There was an increase in Ra, suggesting an increase in heat transfer because of the use of nanomaterials in the enclosure. Bellila et al. [11] used an Al₂O₃ nanofluid to enhance the productivity of a hemispherical solar still. The improvement in the yield of the solar distiller ranged from 105.8% to 121% across different volume concentrations of the nanoparticles. Tuly et al. [12] evaluated the use of Al₂O₃ in a modified DSSS and found a 21.5% increase in the augmented productivity.

The effects of Al₂O₃ on the performance of solar-still desalination systems is summarised in **Table 2**.

Table 2. Summary of the effects of Al₂O₃ on the performance of a solar-still desalination system.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Sahota and Tiwari [1]	Experimental	Al ₂ O ₃	Passive double slope solar still (DSSS)	0.04, 0.08, and 0.12	At 0.12% concentration, the yield was enhanced by 12.2% and 8.4% for 35 kg and 80 kg base fluids, respectively.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Zhang et al. [2]	Experimental	Al ₂ O ₃	Solar collectors	-	Energy consumption reduced by 44% and 48% on hot and cold days, respectively.
Farajzadeh et al. [3]	Experimental	Al ₂ O ₃	Flat plate solar collector	-	No major reduction in maximum efficiency. Use of nanoparticles reduced thermal loss from 21.2 to 13.74.
Faridani and Ameri [4]	Experimental	γ-Al ₂ O ₃	Basin solar still	0.3	Distillate yield of about 60.03%.
Negm et al. [5]	Experimental	Al ₂ O ₃	Thermosyphon flat-plate solar collector	-	Increase in efficiency when using nanofluid.
Shoeibi et al. [6]	Experimental	Al ₂ O ₃	Conventional solar still	0.3	49.5% increase in the productivity. Melting point reduced by 1.8 °C at a concentration of 0.1 wt%. Rate of water production increased by 5.7%.
Chaichan and Kazem [7]	Experimental	Al ₂ O ₃	Single-slope solar distillatory	-	Yield of distillate enhanced to 60.53%
Muraleedharan et al. [8]	Experimental	Al ₂ O ₃	Modified active-solar-distillation system (MSDS)	0.1	Hourly yield ranged between 45 and 250.27%. Total yield much higher at 12.190 L/m ² /day.
Rashidi et al. [9]	Experimental	Al ₂ O ₃	Stepped solar still	0–5	22% increase in the hourly productivity.
Choudhary and Subudhi [10]	Numerical	Al ₂ O ₃		0.01 and 0.1	Increase in Ra, suggesting an increase in heat transfer.
Bellila et al. [11]	Experimental	Al ₂ O ₃	Hemispherical solar still	0.1, 0.2, and 0.3	Yield improved between 105.8% and 121%.

2. Effects of CuO Nanofluid on Solar-Still Performance

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Tuly et al. [13] [12]	Experimental	Al ₂ O ₃	Modified DSSS	3	21.5% increase in augmented productivity.

process, Cu (NO₃)₂, NaOH, and acetic acid were used to obtain a fine CuO nanopowder. At 1.5% nanofluid volume concentration, the daily efficiency increased by 54%, 43%, and 36%, compared with that of the conventional solar still at water depths of 10, 20, and 30 mm, respectively.

Arunkumar et al. [\[14\]](#) studied the effect of nano-coated CuO absorbers with polyvinyl alcohol (PVA) sponges within a single-slope solar-still (SSSS) desalination system. Four configurations were used in the experiment, two of which featured an SSSS with CuO-nano-coated absorber plates (NCAPs) and an SSSS with CuO-NCAPs with PVA sponges. The efficiency and productivity of the SSSS with CuO-NCAPs were 53% and 2995 mL/m²/day, respectively, while those of the SSSS with CuO-NCAPs with PVA sponges were 41% and 2318 mL/m²/day, respectively. Thus, the addition of CuO-NCAPs substantially enhanced the productivity of the solar-still system. In a different study, Arunkumar et al. [\[15\]](#) investigated the use of sensible thermal-storage materials in solar-still systems. CuO-NCAPs were assessed within the solar still. The productivity of the SSSS with CuO-NCAPs was 2.9 L/m²/day, while the cost of the water distilled was USD 0.0077/L. Sharma et al. [\[16\]](#) evaluated the effect of copper fins on the freshwater production within a pyramid solar still. The experiment featured two sets of absorber plates—one with copper fins. The study showed that the incorporation of copper tubes which functioned as fins on a black absorber plate resulted in an increase in daily freshwater production, with a maximum value of 1.95 L/m². The distilled water output for the absorber plate with copper tubes was approximately 60% higher than that for the smooth absorber plate. In another study, Sharma et al. [\[17\]](#) investigated the performance analysis of an active solar still in the colder Indian Himalayan region and used CuO-NCAPs in one of the experiments. The productivity of the system with pebbles was 2.80 L/m²/day, while a CuO-NCAP-augmented solar still showed a higher rate of productivity of 2.90 L/m²/day. The minimum productivity levels recorded from the system with the pebbles and from the CuO-NCAP-augmented solar still were 2.60 L/m²/day and 1.90 L/m²/day, respectively. Hence, the productivity with NCAPs was much higher, and the minimum productivity was much lower.

Rufuss et al. [\[18\]](#) studied the effects of nano-enhanced PCMs in a solar-still system. CuO was among the nanoparticles used to enhance the PCM properties at 0.3 wt% in paraffin to form paraffin–CuO (SSNPCM-2). The findings showed an increase in the thermal conductivity and a decrease in the melting and solidification temperatures with nano-enhanced PCM similar to that of the PCM. The yield of paraffin–CuO was 5.28 L/m²/day, corresponding to a 35% increase in productivity. An economic analysis also revealed that the cost per litre of water for paraffin–CuO was USD 0.026. With the noted advantages in productivity, the authors recommended SSNPCM-2 as the best solar still compared with those using other nanoparticles, as it provides clean water at almost half the cost of bottled water. Thakur et al. [\[19\]](#) conducted a performance analysis of passive solar stills with and without nanoparticles. They included CuO among other nanoparticles in basin water and compared the performance of solar stills. Observations showed that the solar still with CuO nanofluids achieved 41.60% higher productivity than that of the solar still without nanofluids. CuO also showed a higher thermal conductivity than that of ZnO. The solar

still with CuO also generated 2025 mL/day of distilled water, compared with the solar still without nanoparticles, which generated 1430 mL/day. Therefore, the productivity of the solar stills with CuO was found to be much higher.

Abdullah et al. [20] studied the use of reflectors along with nano-enhanced PCM to improve the performance of solar stills. The authors attempted to assess the role of coating solar-still surfaces with black paint and CuO nanoparticles. The nanoparticles were hypothesised to enhance the heat-transfer characteristics between the water and the basin surface. Paraffin wax mixed with CuO nanoparticles was used as a PCM. The results showed an improvement in the freshwater yield by 108% when using the PCM with CuO nanoparticles compared with that of the reference. While conventional solar stills produced 2400 mL/m²/day, those coated with CuO produced approximately 5000 mL/m²/day. The thermal efficiency of the PCM-coated materials was 51.5%. Attia et al. [21] experimentally assessed the methods to improve the yield of hemispherical distillers using CuO nanoparticles. The nanoparticles were used at concentrations of 0.1%, 0.2%, and 0.3%. The results showed that CuO nanoparticles at 0.3% concentration improved the freshwater productivity to 7.9 L/m²/day compared with 3.85 L/m²/day for the normal distiller, suggesting a 105.2% improvement. Essa et al. [22] attempted to improve the thermal performance of stepped solar stills. Among the assessed methods, they applied CuO–paraffin wax on the step liner of the basin and found that the application enhanced the freshwater productivity of the distiller by 127%. The freshwater productivity of the modified stepped solar still was substantially higher at 7000 mL/m²/day compared with that of 2600 mL/m²/day for the conventional still.

Behura and Gupta [23] assessed the effect of PCMs embedded in nanoparticles on solar-still productivity. Paraffin wax was embedded with CuO nanoparticles at 0.1%, 0.2%, and 0.3%, and the productivity was found to be 440 mL/0.25 m²/day, 455 mL/0.25 m²/day, and 510 mL/0.25 m²/day, respectively. Selimefendigil et al. [24] experimentally tested the use of CuO nanoparticles in an SSSS. The results showed that including CuO nanoparticles enhanced the productivity by 26.77% compared with that of conventional solar stills. The energy of the system was enhanced from 15.96% to 19.90%, and the energy efficiency increased from 1.25% to 2.01% when the MSS was used. Sharshir et al. [25] analysed the energy and exergy of solar stills with nanoparticles and found that the exergy of evaporation, energy efficiency, and exergy efficiency of the MSSs were substantially higher than those of traditional solar stills. For CuO, the diurnal productivity of MSSs increased by 32.35%. Gupta et al. [26] studied the performance of a passive MSS with nanoparticles of 0.12 wt% at water depths of 5 cm and 10 cm. The MSS with CuO nanoparticles produced 3445 mL/m²/day and 3058 mL/m²/day at water depths of 5 and 10 cm, respectively, while the conventional solar still in that study produced 2814 mL/m²/day and 2351 mL/m²/day for the two water depths, respectively.

Abdullah et al. [27] used a corrugated absorber with wick and nano-enhanced PCM to augment the performance of a tray solar still. The results revealed that the total freshwater yield of the corrugated-tray solar still increased by 122% when a PCM with CuO nanoparticles was used compared with that of the conventional solar still. The water-production rate improved by 180%. Abdelgaied et al. [28] compared the thermo-economic performance of a hemispherical MSS to that of a traditional hemispherical solar still (THSS). Paraffin wax was used as the PCM, and CuO nanoparticles were used. Based on these findings, the use of CuO–water nanofluid enhanced the productivity by 60.41% compared with that of the THSS. The daily energy efficiency of the system was 56.46% with CuO and

63.61% with paraffin wax and CuO. The use of both paraffin wax and CuO was found to be more effective, and producing fresh water was cheaper by 75% compared with traditional solar stills. Abdelgaied and Kabeel [29] used a novel combination of absorber surfaces coated with CuO. This combination facilitated a higher level of performance, with the cumulative yield improving to 9885–10,015 mL/m²/day, suggesting a 140.1–142% improvement in the performance of the traditional system. The daily thermal and exergy efficiencies also improved by values ranging between 138.1% and 140.1%, and between 243.6% and 252.9%, respectively. Sharshir et al. [30] used evacuated tubes coated with nanofluids to evaluate the performance of pyramid solar stills. The augmentation with CuO improved freshwater production by approximately 27.85%. Nazari et al. [31] tested an SSSS using 0.08% CuO nanofluid—which improved the productivity, energy efficiency, and exergy efficiency by 81%, 80.6%, and 112.5%, respectively. Elsheikh et al. [32] used a copper corrugated absorber plate on a stepped solar still and found that the yield increased by 128% compared with that of the traditional solar stills. Elaziz et al. [33] found a 100% increase in yield using Cu₂O as the nanoparticle compared with that of the conventional solar stills. The effects of the CuO nanofluid on the productivity of the solar stills is shown in **Table 3**.

Table 3. Effects of CuO on the productivity of solar stills.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Dawood et al. [13]	Experimental	CuO	Solar-still system	1.5	Daily efficiency increased by 54%, 43%, and 36% compared with that of the conventional solar still at 10, 20, and 30 mm water depths.
Arunkumar et al. [14]	Experimental	CuO	Single-slope solar still		Efficiency enhanced to 53% and productivity to 2995 mL/m ² /day.
Arunkumar et al. [15]	Numerical	CuO	Solar-still system		Productivity was 2.9 L/m ² /day.
Sharma et al. [16]	Experimental	Copper fins	Pyramid solar still	-	Increase in freshwater production with a maximum value of 1.95 L/m ² /day. Distilled water output was 60% higher.
Sharma et al. [17]	Numerical	CuO	Active solar still	-	Higher rate of productivity of 2.90 L/m ² /day.
Rufuss et al. [18]	Experimental	CuO	Solar-still system	0.3	Daily yield increased by 35%.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Thakur et al. [19]	Experimental	CuO	Passive solar still	-	41.6% higher productivity.
Abdullah et al. [20]	Experimental	CuO	Solar-still system	-	108% increase in freshwater yield.
Attia et al. [21]	Experimental	CuO	Hemispherical distiller	0.1–0.3	105.2% improvement in freshwater production.
Essa et al. [22]	Experimental	CuO	Stepped solar still	-	Enhanced freshwater production by 127%.
Behura and Gupta [23]	Experimental	CuO	Solar-still system	0.1–0.3	Productivity at 0.3% concentration was higher at 510 mL/0.25 m ² /day.
Selimefendigil et al. [24]	Experimental	CuO	Single-slope solar still	-	26.77% increase in productivity. Energy increased from 15.96% to 19.90%; energy efficiency increased from 1.25% to 2.01%.
Sharshir et al. [25]	Experimental	CuO	Modified solar-still system	-	Diurnal productivity increased by 32.35%.
Gupta et al. [26]	Experimental	CuO	Modified passive solar still	0.12	Productivity at 5 cm and 10 cm water depth was higher at 3445 mL/m ² /day and 3058 mL/m ² /day, respectively.
Abdullah et al. [27]	Experimental	CuO	Trays solar still	-	Total freshwater yield improved by 122%. Water production rate improved by 180%.
Abdelgaied et al. [28]	Experimental	CuO	Modified hemispherical solar still	-	Productivity enhanced by 60.41%.
Abdelgaied and Kabeel [29]	Experimental	CuO		-	Cumulative yield improved between 140.1 and 142%.
Sharshir et al. [30]	Experimental	CuO	Pyramid solar still	-	Freshwater production improved by 27.85%.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Nazari et al. [31] [34]	Experimental	CuO ₂	Single-slope solar still	0.08	Productivity, energy, and exergy efficiency improved by 81%, 80.6%, and 112.5%, respectively.
Elsheikh et al. [32]	Experimental	CuO	Stepped solar still	-	Yield increased by 128%.
Elaziz et al. [33]	Experimental	Cu ₂ O	Active solar stills	-	100% increase in yield.

thermal conductivity of the working fluid. The findings revealed a thermal efficiency of 20.7% compared with that of the conventional system. Essa et al. [37] also tested this effect using a convex tubular solar still reliant on the nanocomposites. The use of jute cloth increased the daily distillate by 114% with nanocomposites. The highest productivity using jute cloth with nanocomposites was reported to be an output of 9000 mL/m²/day against 4200 mL/m²/day for tubular solar stills. The enhanced design enhanced the performance of solar stills.

Rufuss et al. [38] conducted a numerical study on a solar desalination system using TiO₂. TiO₂ particles were added to paraffin and tested for different thermophysical properties—including thermal conductivity. The use of nanoparticles improved the cumulative yield to 6.6 L/m²/day. Therefore, paraffin enhanced with TiO₂ yielded better productivity compared with that of the unenhanced paraffin. Sahota and Tiwari [39] investigated the effect of TiO₂ particles on the performance of a passive DSSS and observed a higher thermal-energy efficiency of 46.10% compared with that of 37.78% for the base fluid. The thermal exergy was also higher for nanofluids—such as TiO₂(12.38%)—than that for the base fluid (4.92%). Samneang et al. [40] assessed the TiO₂ concentration in a solar-still system. TiO₂ was used in assorted sizes, e.g., 20 nm, 150 nm, and 400 nm. The results showed a highest temperature of 69.69 °C recorded for TiO₂ of 400 nm specimens; the temperature was 15.97% higher than that for the bare plate. Zavour et al. [41] attempted to improve the performance of an SSSS using various metal-oxide nanofluids—including TiO₂ and water. The productivity of the solar-still nanoparticles TiO₂ was 7.1 kg/m²/day.

Kabeel et al. [42] used a novel absorber plate in a solar still and coated it with TiO₂ nano black paint to improve the performance of solar stills. TiO₂ nanoparticles enhanced the water temperature by 1.5 °C compared with that of the absorber plate without the nanoparticle coating. The coating also enhanced the yield during sunshine hours. Overall, there was a 12% improvement in the yield at the maximum water depth when the absorber plate coated with TiO₂ was used. Gandhi et al. [43] developed and assessed the efficiency of a stepped-basin solar still with TiO₂ as a nanomaterial. There was a 49.21% increase in efficiency with 20% and 30% coatings of the nanomaterial. The efficiency of the coated system was substantially higher than that of a solar-still system without nanoparticle coating. Shanmugan et al. [44] experimented with a single-basin SSSS and found that TiO₂ nanoparticles resulted in an average daily efficiency of 57.16% and 36.69% during summer and winter, respectively.

Table 4 provides a summary of the effects of TiO₂ on the performance of distinct solar-still systems, as discussed above.

Table 4. Summary of the effects of TiO₂ on the performance of several types of solar-still systems.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Parikh et al. [34]	Experimental	TiO ₂	Solar-still system	20 and 40	At 20% and 40% concentrations, the productivity increased by 11–18% and 20–23%, respectively.
Ibrahim et al. [35]	Experimental	TiO ₂	Wick-type solar still	-	Thermal conductivity improved by 9.6%.
Parsa et al. [36]	Experimental	TiO ₂	Double-slope solar still	0.1	Thermal efficiency improved by 20.7% compared to conventional system.
Essa et al. [37]	Experimental	TiO ₂	Convex tubular solar still	-	Daily distillate enhanced by 114%.
Rufuss et al. [38]	Experimental	TiO ₂	Solar desalination system	-	Cumulative yield improved to 6.6 L/m ² /day.
Sahota and Tiwari [39]	Experimental	TiO ₂	Passive double-slope solar still	-	Higher thermal energy efficiency of 46.10% compared with that of 37.78% for the base fluid.
Samneang et al. [40]	Experimental	TiO ₂	Solar-still system	-	400 nm TiO ₂ generated the highest temperature of 69.69 °C.
Zabour et al. [41]	Experimental	TiO ₂	Single-slope solar still	-	Productivity was higher at 7.1 kg/m ² /day.
Kabeel et al. [42]	Experimental	TiO ₂	Solar-still system	-	Enhanced water temperature by 1.5 °C. Overall, 12% increase in yield at maximum water depth.
Gandhi et al. [43]	Experimental	TiO ₂	Stepped-basin solar still	20 and 30	49.21% increase in efficiency.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Shanmugan et al. [44]	Experimental	TiO ₂	Single-slope-basin solar still	-	Average daily efficiency was higher at 57.16% during summer and 36.69% during winter. [45]

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studied a solar-still system incorporating a nano disbanded PCM. ZnO nanoparticles were used on the crude wax. The results indicated that the addition of ZnO enhanced the output of clean water by 65.17%. Saleh et al. [46] used ZnO nanoparticles to enhance the distillation capacity of a solar-still system. The use of these nanoparticles increased the productivity and efficiency of the solar still by 30% and 38%, respectively, compared with that of the system without nanomaterials. Attia et al. [47] experimented with a hemispherical solar still using a series of nanomaterials including zinc trays. The modification resulted in a major increase in the rate of evaporation of the saltwater owing to better heat-transfer characteristics. The cumulative yield resulting from the use of zinc trays was 6.3 kg/m²/day. The use of Zn also caused a 31.25% increase in productivity compared with that of the conventional solar stills. Panchal and Sadasivuni [48] conducted an experiment on a modified solar still using ZnO nanoparticles and reported a 52.5% overall efficiency.

SiO₂ is another material that has been extensively considered by researchers. Arani et al. [49] used SiO₂ nanoparticles on an absorber plate of a tubular solar still and showed that the basin and water temperatures increased by 10.49% and 10.88%, respectively, when using SiO₂ nanoparticles at 20% concentration along with black paint. Water production was enhanced by 55.18%. Sathyamurthy et al. [50] used fumed-silica nanoparticles to boost the yield of stepped solar stills. The fumed silicon oxide concentration ranged from 10% to 40%. The total yield improved by 27.2%, 34.2%, 18.3%, and 18.4% at 10%, 20%, 30%, and 40% concentrations, respectively. Kumar et al. [51] also used silica nanoparticles along with paraffin and noted a 67.07% increase in freshwater production. Thakur et al. [52] used a nanosilicon-coated cover to augment the performance of a solar desalination unit. Augmenting the system with a silicon coating increased the water yield by 15.6% compared with that of the conventional solar stills.

Sharshir et al. [53] used carbon black nanoparticles to enhance the thermal performances of a solar-still system in an economical and environmental-friendly approach. The accumulated yield in the system improved by 59.33%, while the average energy efficiency and exergy efficiency improved by 75.12% and 142.7%, respectively. In another study, Sharshir et al. [54] used carbon black nanoparticles on a stepped DSSS. The addition of nanoparticles increased freshwater productivity by 80.57% and energy efficiency by 110.5% compared with those of the traditional solar stills.

Rasachak et al. [55] evaluated the capability of SnO₂ in enhancing solar-still productivity. SnO₂ concentrations of 15 wt% resulted in the highest surface temperature of 101.61 °C—which was 53.67% higher than that of the conventional solar still. Kabeel et al. [56] added graphite nanoparticles to paraffin wax in a solar-still system. The distillate production of the system ranged between 7.123 and 8.52 L/m²/day across different concentrations. The percentage improvement in the water production ranged between 62.62% and 94.52% across different graphite-nanoparticle mass concentrations. Alqsair et al. [57] used a PCM–Ag mixture to experimentally test a solar

desalination system. The nanoparticles improved the production of the system by approximately 320%, with an efficiency of 72%. Gupta et al. [58] tested the effectiveness of Cu_2O on an MSS and noted an efficiency of 34% compared with that of 22% recorded for the conventional still. Lawrence et al. [59] used NiO on a wick-type SSSS and reported an increased yield of $5.8 \text{ L/m}^2/\text{day}$.

Table 5 provides a summary of the reviewed studies on different nanofluids and their effects on the performance of solar stills.

Table 5. Summary of the effects of other nanomaterials on solar-still productivity.

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
Kumar et al. [45]	Experimental	ZnO	Solar-still system	-	Output of clean water enhanced by 65.17%.
Saleh et al. [46]	Experimental	ZnO	Solar-still system	-	Productivity and efficiency increased by 30% and 38%, respectively.
Attia et al. [47]	Experimental	Zinc trays	Hemispherical solar still	-	31.25% increase in productivity.
Panchal and Sadasivuni [48]	Experimental	ZnO	Modified solar still	-	52.5% increase in overall efficiency.
Arani et al. [49]	Experimental	SiO_2	Tubular solar still	20	Basin and water temperatures increased by 10.49% and 10.88%, respectively. Water production enhanced by 55.18%.
Sathyamurthy et al. [50]	Experimental	Fumed silica	Stepped solar still	10–40	Total yield improved by 27.2%, 34.2%, 18.3%, and 18.4% for 10%, 20%, 30%, and 40% concentrations, respectively.
Kumar et al. [51]	Experimental	Silica	Solar-still system	-	67.07% increase in freshwater production.
Thakur et al. [52]	Experimental	SiO_2	Solar desalination unit	-	Water yield increased by 15.6%.
Sharshir et al. [53]	Experimental	Carbon	Solar-still system	-	Accumulated yield in the system improved by

Author	Type of Study	Type of Nanofluids	Type of Solar Device	Concentration (%)	Results
					59.33%. Average energy efficiency and the exergy efficiency improved by 75.12% and 142.7%, respectively.
Sharshir et al. [54]	Experimental	Carbon	Stepped DSSS	-	Freshwater productivity and energy efficiency increased by 80.57% and 110.5%, respectively.
Rasachak et al. [55]	Experimental	SnO ₂	Solar-still system	15	Surface temperature was 53.67% higher than that of conventional system.
Kabeel et al. [56]	Analytical	Graphite	Solar-still system	-	The percentage improvement in water production ranged between 62.62% and 94.52%.
Alqsair et al. [57]	Experimental	Ag	Solar desalination system	-	Production and efficiency improved by 320% and 72%, respectively.
Gupta et al. [58]	Experimental	Cu ₂ O	Modified solar still	-	Efficiency was higher at 34% compared with that of 22% for the conventional still.
Lawrence et al. [59]	Experimental	NiO	Single-slope wick-type solar still	-	Increase in the yield of 5.8 L/m ² /day.

single slope

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