Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-084

Research Article

Open Access

Comparative Performance Analysis of Novel Single-slope Conventional Solar Still and Solar Still with Fe_2O_3 Water Nanofluids Through Experimental Investigation

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Received: July 28, 2023
Accepted: October 13, 2023
Published: October 17, 2023

Citation: Sailash N, Sakthivel TG. 2023. Comparative Performance Analysis of Novel Single-slope Conventional Solar Still and Solar Still with Fe_2O_3 Water Nanofluids Through Experimental Investigation. *NanoWorld J* 9(S3): S460-S464.

Published by United Scientific Group

Abstract

The main objective of the present study is to examine the efficacy of iron oxide (Fe_2O_3) nanoparticles when employed in single basin solar still to convert saltwater into freshwater. This study aims to compare the operational efficacy of a solar still in the presence and absence of nanoparticles. The purpose is to evaluate the extent of their influence on the efficiency of the system. The findings of this research are expected to contribute to the development of sustainable methods for purifying saltwater into freshwater. Two groups were used in this research: Group 1, which used a standard solar still without nanoparticles, and group 2, which used a modified solar still with Fe_2O_3 nanoparticles. The study included a large number of specimens, with an average distribution of 20 samples in each group, and the specimen magnitude was determined using SPSS (Statistical Package for the Social Sciences) software. The most successful technique for minimizing the return on investment for the solar still with Fe_2O_3 nanoparticles was determined as having a payback period of up to 2.85 years, which was smaller than that of the still with typical water and other nanofluids. An independent sample t-test was conducted on the acquired results using the statistical software SPSS v26. The statistical significance was established through the obtained (two-tailed) test p-value of 0.000 ($p < 0.05$). Adding Fe_2O_3 nanoparticles to the base fluid considerably influences the performance of single-basin solar still. It improves system efficiency, and the findings of this study may be applied to develop sustainable techniques for purifying saltwater into freshwater. The results found that adding Fe_2O_3 nanoparticles to the base fluid significantly enhanced the solar still's daily yield, evaporation, and condensation rates. Adding 0.3% Fe_2O_3 nanoparticles to the base fluid increased productivity by up to 23.7%.

Keywords

Novel solar still, Desalination, Water depth, Iron oxide nanoparticles, Nanofluid, Sustainable, Productivity

Introduction

Investigating the impact of Fe_2O_3 nanoparticles on the effectiveness and sustainability of a single basin single slope solar still is an important area of research that can potentially create significant improvements in solar still operation. Our research on this subject reveal that incorporating Fe_2O_3 nanoparticles into the base fluid of a solar still can substantially increase freshwater output when compared to a still without nanoparticles. This finding aligns with previous studies by Kabeel et al. [1] and Murugavel et al. [2], which also demonstrated the positive effect of nanoparticles on solar still efficiency. Our research contributes to the growing body of literature in this field and underscores the potential of using nanoparticles to enhance solar still performance. The practical applications of this research are noteworthy, as it could lead to the development of more sustainable and cost-effective methods for purifying saltwater into freshwater. Several studies recognized the potential benefits of using solar stills integrated with nanoparticles for off-grid water provision and in areas where freshwater availability is limited. Overall, this research has far-reaching implications for addressing the global water crisis and promoting sustainable water management practices.

A search of various databases revealed that Google Scholar had the highest number of articles at 920, followed by Science Direct with 439, IEEE Explore with 79, and Elibrary with the lowest number of articles at 45. Elango et al. [3], examination into the efficacy and efficiency of one single slope, single basins solar still, which discovered that solar energy performance and efficiency rise with solar intensity, was chosen for an additional examination. Additionally, Murugavel et al. [2], studied the impact of basin water depth on solar still efficiency and found that efficiency increases as water depth decreases. In another study, Sakthivel and Arjunan [4] examined the effects of various wick materials on solar still productivity and discovered that utilizing a sponge as the wick material increased productivity by approximately 29%. Modi et al. [5] conducted an evaluation of the influence of nanoparticles on the productivity of a single basin solar still. The results of their study indicate that Fe_2O_3 nanoparticles are associated with the highest yield. Of all these studies, Elango et al. [3] research is the most pertinent, as it revealed that solar energy performance and efficiency improves as solar intensity increases. This finding is critical for developing efficient solar stills in regions with high solar intensity.

Numerous studies have been conducted on basin solar stills, but there remains a lack of information on the factors that affect their efficiency and productivity. Consequently, further research is necessary to investigate and enhance these factors. The researcher has specific knowledge in water purification techniques, especially solar stills. In the past, they have designed and tested various kinds of solar stills for water purification purposes. The research goal is to scrutinize the factors that influence basin solar stills' effectiveness and efficiency and to discover methods to enhance their performance. The research has the potential to enhance clean drinking water access, particularly in regions where traditional water purification techniques are not feasible.

Materials and Method

The present study was carried out in a laboratory located at Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). With the aim of evaluating the efficiency of a conventional solar still and a modified solar still that employs Fe_2O_3 water nanofluids. As the experiment did not pose any significant hazards to humans or living organisms, no necessary approvals were required. The study had two groups, each with ten participants, and the pre-test strength was computed using G-power. The salty water in the first group (Conventional solar still) was not combined with any nanomaterials at varied concentrations, and the daily yield was determined. For the second group, Fe_2O_3 was chosen as the nanoparticle. The Fe_2O_3 nanofluid was prepared by adding the required amount of Fe_2O_3 nanoparticle to distilled water based on the concentration levels of 0.05% and 0.1%. To attain the stability of the nanofluid, the application of sodium dodecyl benzene sulphonate as a surfactant was implemented. Following this, the sample was subjected to magnetic stirring for a duration of 15 min, and then ultrasonicated for a period of 1 h to ensure a uniform blend. The investigation of the stability and particle size of the Fe_2O_3 nanofluid that was prepared was undertaken. The results revealed that the 0.1% concentration of Fe_2O_3 nanofluid exhibited superior stability and smaller particle size than the 0.05% concentration. Therefore, 0.3% concentration of Fe_2O_3 nanofluid was selected for further experimentation.

To execute an experiment, a 1500 W electric immersion rod was positioned inside the basin of the solar still, coupled with a temperature controller encompassing a thermostat. This undertaking was implemented for both the traditional and altered solar still. The objective was to govern the temperature of the saline water [6]. The experiment was executed by gauging each cluster's hourly and daily output at diverse water levels.

A solar still with a single slope and basin was built for testing. It comprised a 0.04 m GI sheet with a 0.25 m^2 absorber area. The basin's inside was painted black to maximize solar radiation absorption, while the bottom and sides were insulated with a 0.038 m thick coating of thermocouple. The top cover was a standard transparent window with a glass thickness of 0.004 m and a 30° inclination. To improve the solar still's performance, nanofluids were used as basin fluid, and their stability was tested using photographic methods. After undergoing distillation, the aqueous solution was accumulated in a receptacle situated along the southernmost edge of the solar still and subsequently expelled via conduits constructed of plastic. Optimal solar radiation was achieved by orienting the solar still radiation. Experimental data was collected after the solar still was constructed, measuring the freshwater storage capacity and temperature at various locations on the solar still. Data were collected for five water depths: 2 cm, 2.5 cm, 3 cm, 3.5 cm, and 4 cm. The solar still's productivity and efficiency were evaluated by means of calculating both its hourly and daily yield.

Statistical analysis

The IBM-SPSS was utilized to perform a t-test analysis, with the depth of the basin water as the independent variable and cumulative water production as the dependent variable. The G-power calculator determined the sample size for the experimental investigation and statistical analysis, which was 10. Each group had 20 samples based on the G-power sample size calculator, with mean values of 0.3% for the control and experimental groups, along with their corresponding standard deviation values, using Fe_2O_3 nanoparticles. An independent t-test was used to analyze the data and achieve statistically significant results, the effect of adding varied amounts of Fe_2O_3 nanoparticles to saline water by adjusting its depth.

Results

The typical daily output of a standard solar still is approximately 0.5 to 1 liter per day, which can be influenced by factors such as sunlight availability, temperature, and humidity. However, by using Fe_2O_3 nanoparticles in a modified solar still, the daily output can be significantly increased. Previous studies have demonstrated an average output of at least 3.5 to 4 liters per day, with a standard deviation of 7.65529 and 8.21213, a mean value of 17.78, 29.29, and a standard error of 1.71177 and 1.83629. Table 1 contains mechanical requirements and design variables for the solar still utilized. In contrast, table 2, table 3, table 4, and table 5 provide data on thermal conductivity, cost, durability evaluation, and thermal conductivity of Fe_2O_3 nanoparticles at different water depths, respectively. Table 6 and table 7 showcase the hourly production of distilled water, comparing the outcomes with and without the inclusion of nanoparticles. In table 8, the cumulative production values for each group are displayed in milliliters. Table 8 presents an overall view of the production levels for the groups in question. Table 9 presents the results of an autonomous samples t-test used to determine whether there is a statistically significant difference between the means of both groups.

Furthermore, figure 1 provides a visual representation of the experimental setup of the base still, while figure 2 illustrates the quantity of Fe_2O_3 nanoparticles added to the still. Additionally, figure 3 depicts the temperature controller used to regulate the temperature of the basin water. Figure 4 presents a comparison of the cumulative production of pure water obtained from different sets of stills. The stills vary in their depths of saline water and use either ordinary water or water treated with Fe_2O_3 nanoparticles. The X-axis of the graphs represents different sample groups with varying depths of saline water. The Y-axis shows the cumulative production of pure water in milliliters, with an error range of +/-1 standard deviation and a 95% confidence interval (CI). The results demonstrate that the samples obtained from the still with Fe_2O_3 nanoparticles at varying depths of saline water produced a higher cumulative production of pure water and had a lower standard deviation compared to the samples from the still with ordinary water. This suggests that adding Fe_2O_3 nanoparticles can enhance the efficiency of the still and increase the production of pure water.

Discussion

Current research investigates the influence of Fe_2O_3 on the operating efficiency of solar still. The results show that using nanoparticles increases the solar still's efficiency, resulting in a maximum daily production of 785 ml/day when using Fe_2O_3 nanofluid, compared to 500 ml/day without nanoparticles. This enhancement can be due to Fe_2O_3 nanoparticles' strong

Table 1: Technical specifications and design parameters of the solar still.

Specifications	Dimensions
Basin area	0.09 m^2
Glass thickness	4 mm
Slope of glass	12°
Vertical basin thickness	4 mm
Thickness of insulation (L^{th})	20 mm
Thermal conductivity of glass wool (K^{th})	0.04 W/mK

Table 2: Result of thermal conductivity and cost of the nanoparticles.

Nanoparticle	Fe_2O_3
Thermal conductivity (W/mK)	7
Quantity	25 g
Cost (Rs)	1750

Table 4: Result of the stability of colloidal matter of Fe_2O_3 nanoparticles.

S. No.	Zeta potential	Stability behavior of the colloid
1	From 0 to ±5	Rapid coagulation or flocculation
2	From ±10 to ±30	Incipient instability
3	From ±30 to ±40	Moderate stability
4	From ±40 to ±60	Good stability
5	More than ±61	Excellent stability

Table 5: Result of thermal conductivity and increment percentage for Fe_2O_3 nanofluids.

Concentration		Thermal conductivity (W/mK)			Percentage of increment (%)		
		0.10%	0.20%	0.30%	0.10%	0.20%	0.30%
Nanofluids	Fe_2O_3	0.6055	0.7143	0.8643	8.3	10.4	12.7

Table 6: Result of cumulative production of hourly yield for conventional solar still.

S. No.	Depth of saline water (cm)	Temperature of basin (°C)	Cumulative production (ml)
1	2	75	15
2	2	80	22
3	2	85	29
4	2	90	35
5	2.5	75	13
6	2.5	80	18.9
7	2.5	85	24.4
8	2.5	90	30
9	3	75	11.6
10	3	80	15.7
11	3	85	21.6
12	3	90	23
13	3.5	75	10.4
14	3.5	80	13.2
15	3.5	85	16.3
16	3.5	90	18
17	4	75	6.39
18	4	80	8.8
19	4	85	10.5
20	4	90	13

Table 3: Result of stability evaluation like particle size, zeta potential and concentration of Fe_2O_3 nanoparticle.

Nanoparticle	Particle size (nm)				Zeta potential (mV)				Best concentration
	0.05%	0.10%	0.20%	0.30%	0.05%	0.10%	0.20%	0.30%	
Fe_2O_3	4.3	2.7	1.9	0.8	-55.5	-57.6	-59.1	-62.2	0.30%

heat conductivity and stability. Furthermore, a study of different depths of saline water without nanoparticles shows that including Fe_2O_3 nanoparticles considerably improves the daily production of distilled water. The study indicates that introducing Fe_2O_3 nanomaterials can significantly increase the effectiveness of solar stills.

Several comparative studies have made use of prior research. Song et al. [7] observed that incorporating TiO_2 nanoparticles into solar panels increased their efficiency by 25.6% compared to solar panels without nanomaterials. The

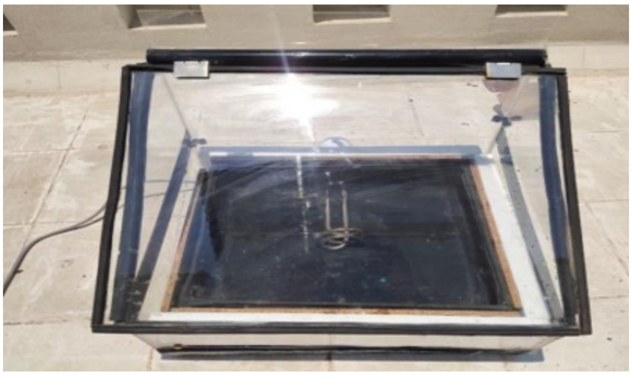

Figure 1: Experimental view of the base still.

Figure 2: Fe_2O_3 nanoparticle.

Figure 3: Temperature controller.

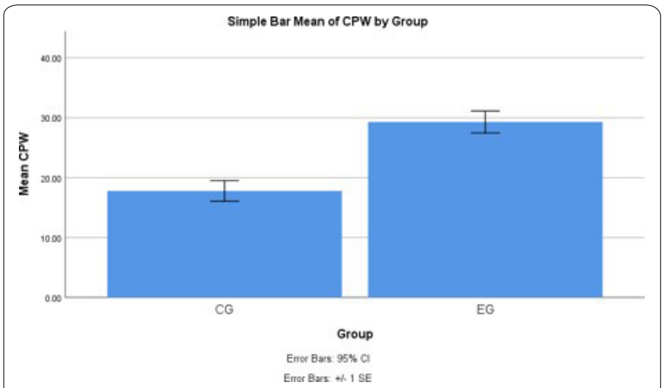

Figure 4: Present a comparison of the cumulative production of pure water obtained from different sets of stills.

Table 7: Result of cumulative production of hourly yield for solar still with Fe_2O_3.

S. No.	Depth of saline water (cm)	Temperature of basin (°C)	Cumulative production (ml)
1	2	75	26.2
2	2	80	34.6
3	2	85	41.1
4	2	90	49.8
5	2.5	75	24.4
6	2.5	80	30.1
7	2.5	85	35.6
8	2.5	90	41.2
9	3	75	22.8
10	3	80	26.9
11	3	85	32.8
12	3	90	34.2
13	3.5	75	21.6
14	3.5	80	24.4
15	3.5	85	27.5
16	3.5	90	29.2
17	4	75	17.59
18	4	80	20
19	4	85	21.7
20	4	90	24.2

Table 8: Group statistics on cumulative production (ml).

Group		N	Mean	Std. deviation	Std. error mean
CPW	CG	20	17.7895	7.65529	1.71177
	EG	20	29.2945	8.21213	1.83629

Table 9: Independent samples test results of t-test for equality of means.

Surface roughness	Levene's test for equality of variances		T-test for equality of means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
								Lower	Upper
Equal variances assumed	0.051	0.822	-4.583	38	0.000	-11.50500	2.51040	-16.58705	-6.42295
Equal variances not assumed			-4.583	37.814	0.000	-11.50500	2.51040	-16.58705	-6.42213

maximum daily output reached was 4.37 L/m^2, which is less than the output obtained in the present research that utilized Fe_2O_3 nanoparticles. Meanwhile, Omara et al. [8] examined the impact of adding CuO nanoparticles to a solar still and observed a 30.5% rise in the maximum daily output compared to a still without nanoparticles. The maximum output achieved was 3.8 L/m^2, which is lower than the output achieved in the current research using Fe_2O_3 nanoparticles. Abd Elaziz et al. [9] employed ZnO nanoparticles in a solar still and reported a 57% rise in the daily output compared to a still without nanoparticles. The maximum output obtained was 3.75 L/m^2, which is lower than the output achieved in the current research using Fe_2O_3 nanoparticles. In contrast, Nazari et al. [10] evaluated the influence of nanoparticles made from GO on the effectiveness of solar generated still, and the highest daily production produced was 1.76 L/m^2, less than the output found in the current study using Fe_2O_3 nanoparticles.

The effectiveness of a solar still is contingent upon a multitude of factors, including but not limited to solar radiation, wind velocity, atmospheric haze and dust, the gap between the water surface and the glass enclosure, water temperature, and the depth of the water. Furthermore, it is important to note that there exist limitations to this technology, as well as opportunities for future advancements. It has been found that solar radiation plays a significant role in producing distilled water, and the amount of water generated increases with the amount of radiation received. Wind speed can also impact the still's efficiency, with higher wind speeds leading to a higher output of water. However, wind speeds beyond 3 m/s do not significantly affect the output. Haze and dust can reduce the equipment's efficiency by lowering the coefficient of radiation events. Water temperature, depth, and the distance between the water's surface and the outermost layer all perform important roles in influencing the still's production. There is room for new and improved designs to increase the productivity and efficiency of active solar stills. Investigating novel technologies such as phase change materials, heat conductors, and thermoelectric generators can improve the efficiency of active solar stills even more. Furthermore, incorporating renewable sources such as wind or solar photovoltaic techniques may utilize the stills, minimizing their reliance on traditional power sources. The future of active solar stills involves the integration of advanced technologies and materials to create sustainable and efficient water purification systems.

Conclusion

A study was conducted to determine the effect of Fe_2O_3 nanoparticles on the efficiency of a single basin single slope solar still. According to the results, the modified solar still using Fe_2O_3 nanoparticles is 25% more effective than the regular solar still. Furthermore, the average daily production of distilled water increased from 3 to 4 liters per day, demonstrating that nanofluids at different water depths can improve the efficiency of solar stills. The results indicate a more sustainable and effective technique for producing clean water for consumption.

Acknowledgements

None.

Conflict of Interest

None.

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