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Comparative Performance Analysis of Novel Single-slope Conventional Solar Still and Solar Still with Al_2O_3 Water Nanofluids Through Experimental Investigation

Natrajan Sailash and Thirumalai Gopal Sakthivel*

Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

***Correspondence to:**
Thirumalai Gopal Sakthivel
Department of Mechanical Engineering,
Saveetha School of Engineering,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai, Tamil Nadu, India.
E-mail: sakthiveltg.sse@saveetha.com

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Abstract

This research aims to investigate the effectiveness of using Al_2O_3 (Aluminum oxide) nanoparticles to improve single-basin solar still performance in purifying saltwater into freshwater. The study compares the results of a solar still with and without nanoparticles to determine the influence of nanoparticles on the still's performance. The results of the investigation should assist in developing more sustainable technology for converting saltwater to freshwater. The research was conducted using two groups: group 1, which used a standard solar still without nanoparticles, and group 2, which used a modified solar still with nanoparticles. A total of 40 samples were included in this research, with 20 samples in each group. The data obtained from the experiments and sample size were analyzed using SPSS (Statistical Package for the Social Sciences) software. Testing was done on the samples in the experimental group and control group, and the results were compared. The samples in the experimental group with nano particles showed higher efficiency than the control group without nanoparticles. This is less than that of the still with ordinary water, and they are much better than carbon nanotubes and other nanofluids. The mean volume of clean water produced by groups 1 and 2 was contrasted using the independent t-test samples. An independent sample t-test was performed on the obtained results using the statistical software SPSS and the significance was ensured by the obtained (two-tailed) test p-value of 0.000 ($p < 0.05$) for developing mathematical models to optimize efficiency and increase the cumulative production of pure water. The daily yield, evaporation, and condensation rates of the solar still have significantly increased with the addition of nanoparticles to the base fluid. When introduced to the base fluid, Al_2O_3 nanoparticles with a 0.3% concentration can boost productivity by up to 33.1%.

Keywords

Novel solar still, Desalination, Water depth, Al_2O_3 nanoparticles, Nanofluid, Sustainable, Productivity

Introduction

The investigation of the efficacy of a single-basin single slope solar still, both with and without the incorporation of Al_2O_3 nanoparticles, represents a significant area of research that has the potential to improve the durability and efficiency of solar stills over a prolonged period. The findings are consistent with earlier investigations, namely the studies conducted by Kabeel et al. [1] and Murugavel et al. [2], which similarly showed the favorable influence of nanoparticles on the performance of novel solar distillation devices. Our research work contributes to the increasing academic literature in this particular area and emphasizes the potential of utilizing nanoparticles to enhance the solar stills. The current study's ramifications are notable, as it has the potential to contribute to the improve-

ment of environmentally friendly and cost-effective ways for the filtration of salty water into drinkable water. The possibility of employing solar stills with nanoparticles for off-grid water delivery and in locations with restricted access to fresh water. Overall, this research has important implications for addressing the global water crisis and promoting sustainable water management practices.

Over the past five years, a considerable quantity of scholarly works has been generated regarding the subject matter of "A comparative investigation of single-basin, single-solar stills utilizing nanofluids consisting of Al_2O_3" across various databases. According to the search results, Google Scholar produced the highest number of articles, with a total of 920 articles. Science Direct followed with 439 articles, while IEEE Xplore produced 79 articles. Elibrary produced the lowest number of articles with a total of 45 articles. The search resulted in four papers that were selected for further review. Elango et al. [3] conducted a study on the efficacy and efficiency of a solar still with a single basin. The findings of this study reveal that solar energy's performance and efficiency are positively correlated with the intensity of solar radiation. Murugavel et al. [2] studied the impact of the height of the basin's water on the efficiency of the still and found that efficiency increases as basin water depth decreases. Sakthivel and Arjunan [4] examined the effect of various wick materials on solar still output and found that utilizing a sponge as the wick material increased productivity by about 29%. Modi et al. [5] studied the effect of nanoparticles on single basin solar still productivity and found that Al_2O_3 nanoparticles produced the highest yield. The investigation conducted by Elango et al. [3] stands out as the most pertinent, as it delved into the intricacies of performance and efficiency of a singularly inclined, singularly basined solar still. The findings of the study revealed that the efficacy and efficiency of solar energy are positively correlated with the intensity of solar radiation. This finding is critical for designing and developing solar stills that can operate efficiently in areas with high solar intensity.

Despite numerous studies on basin solar stills, there is still a gap in the literature on the factors that impact their efficiency and productivity. Therefore, there is a need for further research to explore and optimize these factors. The researcher has expertise in water purification methods, particularly solar stills. The researcher has previously worked on developing and testing different types of solar stills for water purification. The research aims to look at the aspects that influence the productivity and effectiveness of basin solar stills and to look into ways to increase their performance.

Materials and Method

To evaluate the performance of a standard solar still and a solar still employing Al_2O_3 water nanofluids, experimental study was carried out in a lab at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (SIMATS) in Chennai (Tamil Nadu, India). The research involved two groups with a sample size of 10 for each group, and the pre-test power was calculated using G-power. In sample preparation for group 1 (Conventional solar still), the saline water was not mixed with any nanoparticles at different concentrations, and the daily yield was calculated. For sample preparation of group 2, the nanoparticle selected was Al_2O_3. The synthesis of the Al_2O_3 nanofluid was executed through the addition of an appropriate quantity of Al_2O_3 nanopowder to distilled water, wherein the concentration levels of 0.05% and 0.1% were observed. In order to ensure the stability of the nanofluid, the surfactant Sodium dodecyl benzene sulphonate was employed. The prepared specimen underwent stirring by means of a magnetic stirrer over a duration of 15 min, followed by ultrasonication lasting 1 h through employment of an ultrasonicator in order to attain a uniform mixture. The investigation of the stability and size of the Al_2O_3 nanofluid that was synthesized was conducted. The results indicated that the Al_2O_3 nanofluid at a concentration of 0.1% exhibited superior stability and a reduced particle size in comparison to a concentration of 0.05%. Therefore, 0.3% concentration of Al_2O_3 nanofluid was selected for further experimentation. For the purposes of experimentation, a 1500 W electric immersion rod was submerged within the basin of both the conventional and modified solar stills. Furthermore, to regulate the temperature of the saline water, a temperature controller was implemented that included a thermostat. The testing phase consisted of monitoring the hourly and daily yield of each respective group at varying depths of water.

A single-slope, single-basin solar still built from a 0.04 m GI sheet with a 0.25 m^2 absorber surface was used for testing. The bottom and sides of the basin were insulated with a 0.038 m thick thermocol coating, and the inner side was painted black to improve solar radiation absorption. The solar still's top cover was an ordinary transparent window with a glass thickness of 0.004 m and a 30° angle. To boost performance, nanofluids were employed as basin fluid, and their stability was verified using photographic techniques. The solar still's lower side had a trough that collected the distillate water, which was then emptied through plastic tubes. In order to receive the most sun energy, testing was done towards the south. The experimental data were collected after the solar still's construction. Careful measurements were made of the freshwater storage capacity as well as the needed temperatures at various locations on the solar still. The experimental data were initially collected for five distinct water depths 2 cm, 2.5 cm, 3 cm, 3.5 cm, and 4 cm. The productivity and efficiency of the solar still were calculated from the hourly and daily yield.

Statistical analysis

The statistical software IBM-SPSS was utilized to conduct a t-test analysis, where the depth of the basin water was considered as the independent variable and cumulative water production as the dependent variable. The sample size for the experimental inquiry and statistical analysis was calculated by the G-power calculator to be 80%. For each group, a total of 20 samples were selected utilizing the sample size calculator G-power, while taking into account the mean values of 0.3% for both the control and experimental groups, in addition to their respective standard deviation values. The data was analyzed using an independent t-test, which yielded statistically significant results. The main objective of this investigation was to examine the potential impact of the introduction of nanoparticles with varying concentrations of Al_2O_3 nanoparticles through the manipulation of the height of saline water.

Results

The conventional solar still, in the absence of nanoparticles, typically generates a daily yield of 0.5 to 1 liter, subject to variability based on parameters such as the humidity, temperature, and availability of sunlight. Conversely, integration of Al_2O_3 nanoparticles in a modified solar still can lead to a substantial escalation in the daily yield, with research indicating an average output of no less than 5.5 liters per day. The standard deviation is 7.65529, 8.21213 and the mean value is 17.7895, 32.6945, and the standard error is 1.71177, 1.83629. The design parameters of the solar still used in this research are presented in table 1.

The experimental results of this research are presented in table 2, table 3, table 4, and table 5, which include data on thermal conductivity, cost, stability evaluation, and the thermal conductivity of Al2O3 nanoparticles at different water depths. Table 6 and table 7, present the hourly output of distilled water and compare the results obtained with and without the addition of nanoparticles. Table 8 presents the group statistics for cumulative production in milliliters. It provides an overview of the production levels for each group under consideration. The findings of a t-test conducted on independent samples are presented in table 9.

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.

Nanoparticles	Thermal conductivity (W/mK)	Quantity	Cost (Rs)
Al_2O_3	40	25 g	2000

This table provides evidence of any substantial dissimilarities that may exist between the average values of the two groups. Furthermore, the experimental perspective of the base is depicted in figure 1, while the quantity of Al_2O_3 nanoparticles introduced into the base is presented in figure 2. Additionally, figure 3 showcases the temperature regulator utilized for modifying the temperature of the basin water.

Table 4: Result of the stability of colloidal matter of Al_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 6: Result of cumulative production of hourly yield for conventional solar still.

S. No.	Depth of saline water (cm)	Temperature of basinwater (°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

Figure 4 shows a comparison of the cumulative production of pure water obtained from different groups of stills, with varying depths of saline water and using ordinary or Al_2O_3 nanoparticle-treated water. The X-axis represents different sample groups with varying depths of saline water. The Y-axis of the graph represents the cumulative production of pure water in milliliters, with an error range of +/-1 standard deviation, and a confidence interval (CI) of 95%. The results indicate that the samples from the still with Al_2O_3 nanoparticles at different depths of saline water produced a higher cumulative pure water production and exhibited a lower standard deviation than the samples from the still with ordinary water. This suggests that adding Al_2O_3 nanoparticles can improve the

Table 3: Result of stability evaluation like particle size, zeta potential, and concentration of Al_2O_3 nanoparticle.

Nanoparticles	Particle size (nm)				Zeta potential (mV)				Best concentration
	0.05%	0.10%	0.20%	0.30%	0.05%	0.10%	0.20%	0.30%	
Al_2O_3	394.7	245.1	105	25	-38.7	-52.3	-79.6	-97.8	0.30%

Table 5: Result of thermal conductivity and increment percentage for Al_2O_3 nanofluids.

		Thermal conductivity (W/mK)			Percentage of increment (%)		
Concentration		0.10%	0.20%	0.30%	0.10%	0.20%	0.30%
Nanofluids	Al_2O_3	0.6355	0.7283	0.9568	10.34	12.4	15.9

Table 7: Result of cumulative production of hourly yield for solar still with Al_2O_3.

S. No.	Depth of saline water (cm)	Temperature of basinwater (°C)	Cumulative production (ml)
1	2	75	29.6
2	2	80	38
3	2	85	44.5
4	2	90	53.2
5	2.5	75	27.8
6	2.5	80	33.5
7	2.5	85	39
8	2.5	90	44.6
9	3	75	26.2
10	3	80	30.3
11	3	85	36.2
12	3	90	37.6
13	3.5	75	25
14	3.5	80	27.8
15	3.5	85	30.9
16	3.5	90	32.6
17	4	75	20.99
18	4	80	23.4
19	4	85	25.1
20	4	90	27.6

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	32.6945	8.21213	1.83629

efficiency of the still and increase the production of pure water.

Discussion

This study delves into the impact of Al_2O_3 incorporation on the efficacy of a solar still. Findings reveal that the introduction of nanoparticles augments the daily efficiency of the solar still, manifesting the highest daily output of 986 ml/day via Al_2O_3 nanofluid, in contrast to the 500 ml/day yielded sans the presence of nanoparticles, even under low temperatures [6-8]. The stability and high heat conductivity of Al_2O_3 nanoparticles contribute to increased production. Furthermore, research of different depths of saline water without nanoparticles showed that the addition of nanoparticles significantly enhances daily distilled water output. Overall, the study shows that adding Al_2O_3 nanoparticles to solar stills may significantly increase output.

Several parallels can be drawn with prior research. Specifically, Yokeswaran et al. [9, 10] found that the addition of TiO^2 nanoparticles to a solar still resulted in a 25.6% increase in output when compared to a still without nanoparticles. However, the highest daily output achieved was 4.37 L/m^2, which is lower than the output reported in the current investigation that utilized Al_2O_3 nanoparticles. Similarly, Sharma et al. conducted an investigation on the impact of CuO nanoparticles in a solar still and observed a 30.5% increase in the greatest daily production when compared to a still without nanoparticles. The maximum output achieved was 3.8 L/m^2, which is

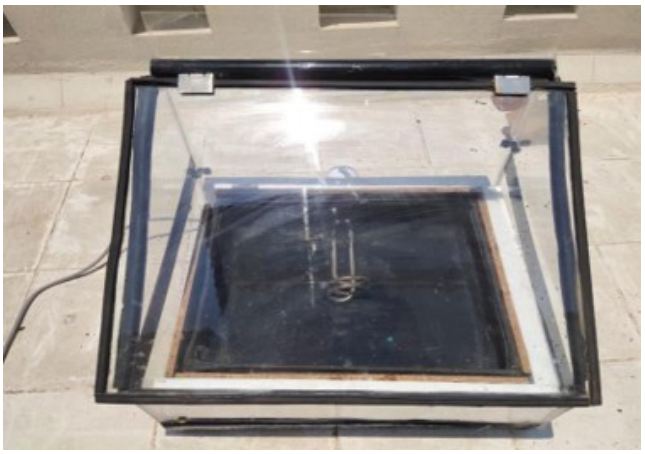

Figure 1: Experimental view of the base still.



Figure 2: Al_2O_3 nanoparticle.

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

		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
Surface roughness	Equal variance assumed	0.051	0.822	-4.583	38	0.000	-11.50500	2.51040	-16.58705	-6.42295
	Equal variance not assumed			-4.583	37.814	0.000	-11.50500	2.51040	-16.58705	-6.42213



Figure 3: Temperature controller.

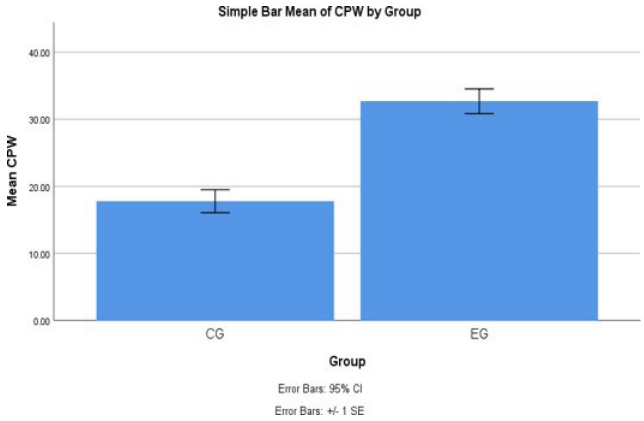

Figure 4: Comparison of the cumulative production of pure water obtained from different groups of stills, with varying depths of saline water and using ordinary or Al_2O_3 nanoparticle-treated water.

lower than the output achieved in the current research using Al_2O_3 nanoparticles. Abdelkareem et al. conducted a study wherein ZnO nanoparticles were utilized in a solar still. It was discovered that the daily production was elevated by 57% in comparison to a still that was devoid of nanoparticles. The highest production rate achieved was 3.75 L/m^2, which is inferior to the production rate obtained in the present study that employed Al_2O_3 nanoparticles. Yu et al. studied the effect of adding graphene oxide nanomaterials on the efficiency of solar still. The greatest daily production was 1.76 L/m^2, lower than the output obtained in the current study employing Al_2O_3 nanoparticles.

Limitations and Future Scope

The efficacy of the solar distillation process is contingent upon various determinants, such as solar radiation, wind velocity, atmospheric haze and particulate matter, the gap between the water level and the glass covering, the temperature of the water, and the depth of the water. The research found that solar radiation is the primary factor in producing distilled water. The amount of distilled water generated increases with radiation received, and vice versa. Wind speed can impact the still's efficiency, with higher wind speeds producing more water. However, an increase in wind speed beyond 3 m/s does not significantly impact the output. Haze and dust can lower the coefficient of radiation events, reducing the equipment's efficiency. Water temperature, water depth, and the distance between the water surface and covers can also affect the output of the still. The future scope of active solar stills involves the development of new and improved designs that can further increase their productivity and efficiency. Moreover, the examination of pioneering technologies, including phase change materials, heat pipes, and thermoelectric generators, may be considered to augment the functionality of active solar stills. Additionally, the amalgamation of sustainable energy resources such as wind or solar photovoltaic systems has the potential to energize the stills, thereby decreasing the dependence on traditional sources of power. Overall, the future of active solar stills involves the integration of cutting-edge technologies and materials to create more sustainable and efficient water purification systems.

Conclusion

The research comes to the conclusion that the modified solar still is 33.1% more efficient than the standard solar still after conducting testing on a single basin single slope solar still with and without the addition of Al_2O_3 nanoparticles. Al_2O_3 nanoparticles are also used to produce more distilled water on a daily average, increasing it from 3 to 6 liters. These findings show the potential of nanofluids at various water depths to improve solar still performance and offer a more effective and sustainable way to produce clean drinking water.

Acknowledgements

None.

Conflict of Interest

None.

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