Research Article

Journal of Environmental Nanotechnology

Enhancing Solar Still Productivity by Leveraging Synergy Between Loofah Sponge and Nanoparticle Coatings using Response Surface Methodology

R. Ashok and T. G. Sakthivel*

Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Science (SIMATS), Chennai, TN, India

Received: 04.04.2025 Accepted: 10.05.2025 Published: 30.06.2025

*sakthitgmanisha@gmail.com

ABSTRACT

The present research proposes a statistical model based on response surface methodology (RSM) to evaluate the efficiency of a batch solar still. The goal is to analyse the impact of variables such as solar-exposed ambient temperature, insulation thickness and water depth on water production. A polynomial regression model based on an energy balance equation is introduced to predict the output of solar still. The adequacy of the quadratic model's fit is evaluated based on the coefficient of determination (R^2) which revealed strong concordance between the outcomes predicted *via* the statistical analysis and numerical simulation executed through the heat balance technique. The performance of solar stills was significantly influenced by the type of nanofluid coating used in combination with loofah. Aluminum nitrate nanofluid coating showed the highest enhancement boosting water productivity by 36.48% due to its superior thermal conductivity and efficient heat transfer. This study presents a straightforward polynomial statistical model developed to forecast and optimize solar still operations based on four significant input parameters.

Keywords: Loofah sponge; Tin oxide; Solar stills; Zinc oxide; Response Surface Methodology.

1. INTRODUCTION

Solar desalination is an effective method for producing freshwater and researchers are continuously working on ways to improve its efficiency. One approach involves using loofah sponges and nanoparticle coatings to enhance heat absorption, evaporation and condensation. Loofah sponges help distribute water more evenly increasing the surface area for evaporation, while nanoparticle coatings improve thermal conductivity. These modifications work together to enhance the efficiency of solar stills. Response surface methodology (RSM) is employed as a statistical tool to ensure the optimal functionality of these enhancements. This study focuses on evaluating the influence of loofah sponges and nanoparticle coatings on the efficiency of solar stills using RSM.

Youssef *et al.* (2019) found that modifying the solar still led to a 16% and 25% improvement in total daily cumulative distilled water yield over the conventional design. Farouk *et al.* (2022) revealed that the average daily productivity of Cu_2O, Al_2O_3 and TiO_2-PSDs increased by 57%, 46% and 36% respectively compared to a conventional Pyramid Solar Distiller (PSD). Abdelgaied *et al.* (2022) showed that the exergy efficiency of the modified stepped still rose by 187.4%. Kumar *et al.* (2023) demonstrated that double effect solar distiller when combined with TiO_2/Jackfruit peel with silver balls led to a 29.95% increase in production at 0.3% validated by Laplacian approach solution analysis.

According to Farouk (2024), the RSM models produced predicted values that closely matched the experimental results indicating high accuracy and reliability. Arun *et al.* (2024) reported that the parabolic trough solar water heater (PTSWH) reached a peak efficiency of 38.25% when utilizing a CuO nanofluid with a 0.3% volume concentration. According to Alawee *et al.* (2024) found that the kNN algorithm delivered remarkable performance in predicting cumulative productivity for both conventional and modified solar distillers. Immanuel *et al.* (2024) demonstrated that thermal efficiency improved by 42%, while water yield increased to 1.8 liters per square meter.

Sathish *et al.* (2024) observed that carbon-based nanofluids are excellent for increasing thermal conductivity, while metal oxide nanoparticles can enhance the thermal efficiency of base fluids by up to 28%. Sakthivel *et al.* (2018) observed that employing a cotton cloth for regeneration increased the solar still's output by 24.1% over a system without heat storage. Abdullah *et al.* (2023) showed that the cords pyramidal solar still had a daily total yield of 8000 mL/m² compared to 3550 mL/m² for the pyramidal solar still (PSS). Sohani

et al. (2022) showed that the exergy and economic parameters annual average exergetic efficiency (AEXEF) and cost per liter (CPL) served as the objective functions in a multi-objective optimization (MOO) framework.

Subramanian *et al.* (2024) applied the Taguchi method to optimize four parameters, achieving a daily efficiency improvement of 57.14%. Essam Banoqitah *et al.* (2023) observed that solar stills with nano composite PCM performed 75.65% better. Dhivagar *et al.* (2024) observed that reducing the water depth to 1 cm enhanced energy efficiency and exergy efficiency significantly in comparison to 2 cm and 3 cm depths. As per the findings of Thirumalai *et al.* (2017), incorporating a 6-mm thick cotton-assisted regenerative system led to a 28% improvement in yield compared to a conventional solar still.

Saleque *et al.* (2023) reported that a Ti_3C_2-MnO_2 coating on a loofah sponge improves hydrophilicity and serves as a highly efficient solar absorber achieving an efficiency of 85.28%. This study highlights the potential of Artificial Neural Network (ANN) in forecasting nanofluid thermal conductivity, providing a useful reference for future research and industrial thermal regulation. Babu *et al.* (2024) highlighted the potential of ANN in forecasting nanofluid thermal conductivity, providing a useful reference for future research and industrial thermal regulation. Gunay *et al.* (2024) found that using a 1.97% Cu_2O nanofluid, a corrugated wick absorber, internal reflectors, and an external condenser increased yield by 285.1% compared to a conventional solar still.

The objective of this research is to investigate the combined effects of loofah sponge and nanoparticle coatings on the efficiency of solar stills using response surface methodology. Loofah sponges enhance capillary action, increasing the evaporation rate, while nanoparticle coatings improve heat absorption and thermal conductivity. By optimizing key parameters such as nanoparticle type, coating thickness and loofah placement, the study aims to maximize water productivity. Response surface methodology is employed to analyze interactions between these factors and determine optimal conditions for enhanced performance.

2. EXPERIMENTAL WORK

Nanofluids with high thermal conductivity were used as the working fluid in the solar still experiment to improve heat transfer efficiency. The solar still was constructed as an inclined single-basin model with a side slope, covering an area of 1 m × 0.5 m (0.5 m^2) and made from a 0.001-m thick galvanized iron (GI) sheet. The lower section of the basin was raised to 0.2 m, while the higher section was set at 0.288 m, creating a sloped design to facilitate water flow and evaporation. To enhance solar absorption, the inner surface of the basin was painted black, and a 0.015-m thick thermocol layer was added for insulation. A glass cover with a thickness of 0.003 m was tilted at 10° to improve solar energy absorption. The experimental setup (Fig. 1) was strategically placed to capture the highest possible amount of direct sunlight. To prevent steam from escaping and to maintain a secure seal, a silicone rubber seal was used to fix the glass cover to the structure. Water droplets condensed on the glass cover were efficiently guided into a trough positioned at the end of the solar still for collection.



Fig. 1: (a) Single slope solar still without loofah sponge nanoparticle coating and (b) Single slope solar still with loofah sponge nanoparticle coating

Table 1. Uncertainty in experimental results

Instrument	Technical details	Precision	Range
Thermocouple wires	K type thermocouples	± 0.2 °C	0 – 180 °C
Anemometer	Cup type	± 0.1 ms^{-1}	0-30 ms^{-1}
Solarimeter	Class –A	± 5 Wm^{-2}	0 – 2000 Wm^{-2}
Measuring jar	-	± 5 mL	1-10 L

Sahu *et al.*, (2024) examined formula (1), the amount of fresh water produced per hour expressed in (kg/h) as:

$$Ph = \frac{h\ Ab(Tw-Tg)}{hfg} \times 3600 \qquad \ldots (1)$$

where, Ph is hourly production, h is the heat transfer coefficient for evaporation, Ab is surface area of the basin, Tw is water temperature, Tg is glass cover inner surface temperature, and hfg is latent heat required for water phase change.

The calculation of efficiency of thermal performance (ŋ) per hour of the solar still is done as follows:

$$ŋ = \frac{Ph \times hfg}{Aga \times I \times 3600} \times 100 \qquad \ldots (2)$$

Where, hfg is evaporation latent heat of water, Ph is hourly production, Aga is surface area of the glass cover, and I am solar irradiance.

The efficiency of solar stills can be significantly improved by incorporating loofah with nanofluid coatings that exhibit distinct thermal and optical characteristics. Aluminum nitrate demonstrated the highest performance, increasing water yield by 36.48% due to its excellent thermal conductivity and heat retention, which support rapid and effective evaporation.

3. OPTIMIZATION

3.1 Response Surface Methodology

Response Surface Methodology is a statistical method used to study how input parameters affect the performance of a solar still. The main parameters are solar intensity, wind speed and water depth which play a vital role in evaporation and condensation processes. Solar intensity measured in W/m² supplies heat energy to the water where higher intensity increases evaporation but may also lead to heat losses. Wind speed controls heat transfer, moderate wind speeds promote condensation but high wind speeds produce more heat loss. Water depth influences evaporation, shallow water heats quickly and increases output but may dry up faster while deeper water retains heat longer but reduces evaporation rates. Response Surface Methodology helps to analyze these factors together and find the best combination of parameters using surface and contour plots for maximum water productivity.

3.2 Design of Experiment

Design of Experiment (DOE) using RSM is a powerful statistical approach used to optimize processes by examining the relationships between multiple input variables and their corresponding responses (Table 2). It systematically designs experiments to analyze the interactions between variables and their quadratic effects on the output, while RSM integrates central composite design (CCD) and Box-Behnken design (BBD) to support the development of predictive models. This methodology allows researchers to identify optimal conditions by modeling the experimental data using a second-order polynomial equation. One of the major advantages of RSM is its ability to reduce the number of experimental runs while maintaining high accuracy in predictions. It is broadly implemented in engineering, chemistry and industrial processes to boost system performance. The analysis of variance (ANOVA) is commonly used to validate the significance and reliability of the developed model. Visualization tools like contour plots and 3D surface plots provide insights into the interactions between process parameters. Optimization techniques including desirability functions assist in determining the best operating conditions for a given process. Overall RSM plays a crucial role in improving efficiency, reducing costs and maximizing performance across different applications.

Table 2. Lists the variables and their associated levels

Parameters	Units	Code	Levels		
			Low	Medium	High
Solar Intensity	w/m²	A	500	875	1250
Wind Velocity	m/sec	B	0.5	1.75	3
Water Depth	m	C	0.01	0.03	0.05

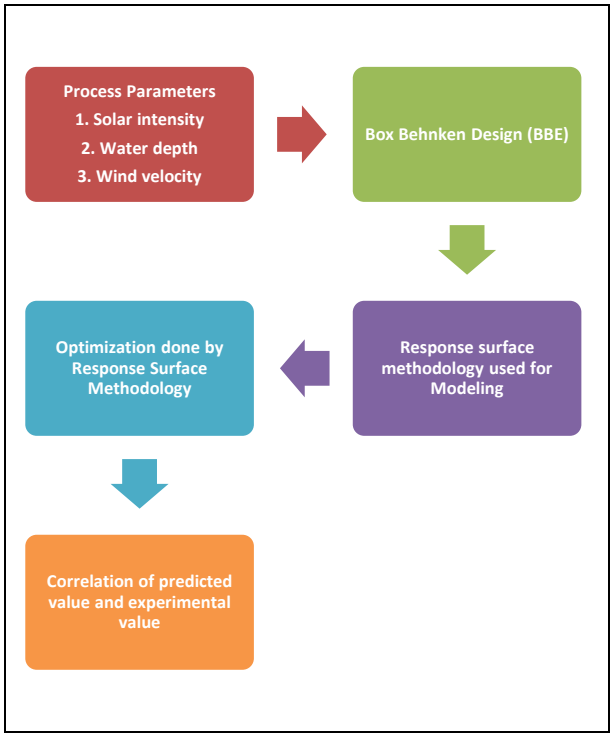


Fig. 2: Optimization of solar desalination using response surface methodology

The second-order polynomial equation serves as a fundamental tool in response surface methodology. The equation for the response 'y' is formulated as:

$$y = \alpha_0 + \Sigma\alpha_i x_i + \Sigma\alpha_{ii} x_i^2 + \Sigma\alpha_{ij} x_i x_j + \varepsilon \quad \ldots (3)$$

In this scenario, y is the response, x_i and x_j are the coded variables, α_i is the coefficient for linear terms, α_{ii} is for quadratic terms, α_{ij} is for interaction terms and ε is for the random error term. To predict the thermal characteristics of the solar still, this study utilized a mathematical model referred to as equation (3) which examines the relationship between the input variables A (solar intensity), B (wind velocity) and C (water depth) and the response y. After conducting the productivity tests on the

solar still 17 response values were identified for each parameter with three repetitions. The Box-Behnken Design matrix was then analyzed for each test trial using the average of the three replicates.

The diagram in Fig. 2 depicts how RSM is used to enhance solar still performance. Key process parameters including solar intensity wind velocity and water depth are considered for analysis. The BBD is used to develop an experimental model. Then, RSM is applied for modeling and optimization of the system. The optimization process helps in improving the efficiency of the solar still. The correlation between predicted and experimental values is assessed to validate the model's accuracy. This approach enhances the understanding of parameter interactions and improves freshwater yield.

4. RESULT AND DISCUSSSION

The study results show that using loofah sponges and nanoparticle coatings can considerably optimize the functionality of solar stills. Loofah sponges help distribute water more evenly, increasing the evaporation rate while nanoparticle coatings enhance heat transfer by improving thermal conductivity. The combination of these techniques led to a noticeable rise in freshwater production compared to traditional solar stills. Response surface methodology analysis identified the best conditions for efficiency such as the appropriate nanoparticle concentration and loofah coverage. The experimental results closely matched the predicted values confirming the model's accuracy. Among the tested materials aluminum nitrate with loofah showed the highest efficiency improvement. The increased productivity was due to better heat retention and enhanced evaporation and condensation processes. The study also found a decrease in energy losses contributing further to improved efficiency. Overall, the findings demonstrate that loofah sponges and nanoparticle coatings are effective in boosting solar still output.

Table 3. Experimental design matrix for daily productivity

Std Order	Run Order	Input parameters			Responses
		A:Solar Intensity	B:Wind Velocity	C:Water Depth	Daily Productivity
		w/m^2	m/s	m	mL
16	1	875	1.75	0.03	103
5	2	500	1.75	0.01	98
14	3	875	1.75	0.03	106
17	4	875	1.75	0.03	105
13	5	875	1.75	0.03	100
12	6	875	3	0.05	97
6	7	1250	1.75	0.01	148
10	8	875	3	0.01	105
7	9	500	1.75	0.05	84
8	10	1250	1.75	0.05	110
3	11	500	3	0.03	92
9	12	875	0.5	0.01	107
2	13	1250	0.5	0.03	116
1	14	500	0.5	0.03	82
4	15	1250	3	0.03	118
15	16	875	1.75	0.03	92
11	17	875	0.5	0.05	74

4.1 Influence of Solar Intensity, Wind Velocity, and Water Depth on the Daily Production of Potable Water

In the ANOVA table, the F-value shows how the data varied from the mean. The mathematical model built is deemed statistically significant since the p-value for each parameter is less than 0.05. The daily productivity ANOVA findings are shown in Table 4. The P-values of the model terms A, B, C, AB, BC, A2, B and C2 in the table demonstrate that they are statistically significant. The R^2 value of 99.79%, being nearly 100%, indicates a highly valid model. Additionally, the high R^2_{adj} value of 99.52% and R^2_{Pred} value of 96.67% confirm the model's exceptional predictive accuracy.

The ANOVA table evaluates the impact of solar intensity (A), wind velocity (B) and water depth (C) on daily potable water production. The model demonstrates statistical significance with a p-value of 0.0005, indicating a strong correlation between the input variables and the response. Among the individual factors, solar intensity (A) has the greatest impact, with a sum of squares of 2312.00 and a p-value of < 0.0001. Water depth (C) also plays a crucial role, with a sum of squares of 1081.13 and a p-value of 0.0004. Wind velocity (B) has a moderate effect, with a sum of squares of 136.13 and a p-value of 0.0570 slightly above the standard significance threshold. Interaction terms vary in significance with wind velocity and water depth (BC) showing a significant effect (p-value = 0.0449) while the interactions between solar intensity and wind velocity (AB) and between solar intensity and water depth (AC)

show lower significance, with p-values of 0.4609 and 0.0518 respectively. Quadratic terms indicate that solar intensity (A^2) and wind velocity (B^2) significantly influence productivity, with p-values of 0.0196 and 0.0310, while water depth (C^2) has little impact (p-value = 0.6256). The residual error is relatively low at 184.05, suggesting a good model fit. The lack-of-fit test is not significant (p-value = 0.6472) indicating that the model effectively represents the data. The analysis confirms that solar intensity and water depth are the most influential factors affecting potable water productivity, with wind velocity playing a moderate role.

Table 4 ANOVA Quadratic model results for daily productivity

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4260.42	9	473.38	18.00	0.0005	significant
A-Solar intensity	2312.00	1	2312.00	87.93	< 0.0001	
B-Wind velocity	136.13	1	136.13	5.18	0.0570	
C-Water depth	1081.13	1	1081.13	41.12	0.0004	
AB	16.00	1	16.00	0.6085	0.4609	
AC	144.00	1	144.00	5.48	0.0518	
BC	156.25	1	156.25	5.94	0.0449	
A^2	238.42	1	238.42	9.07	0.0196	
B^2	190.42	1	190.42	7.24	0.0310	
C^2	6.84	1	6.84	0.2603	0.6256	
Residual	184.05	7	26.29			
Lack of Fit	57.25	3	19.08	0.6020	0.6472	not significant
Pure Error	126.80	4	31.70			
Cor Total	4444.47	16				
(R^2 = 0.9585, R^2_{adj} = 0. 0.9053, R^2_{pred} = 0. 0.7493)						

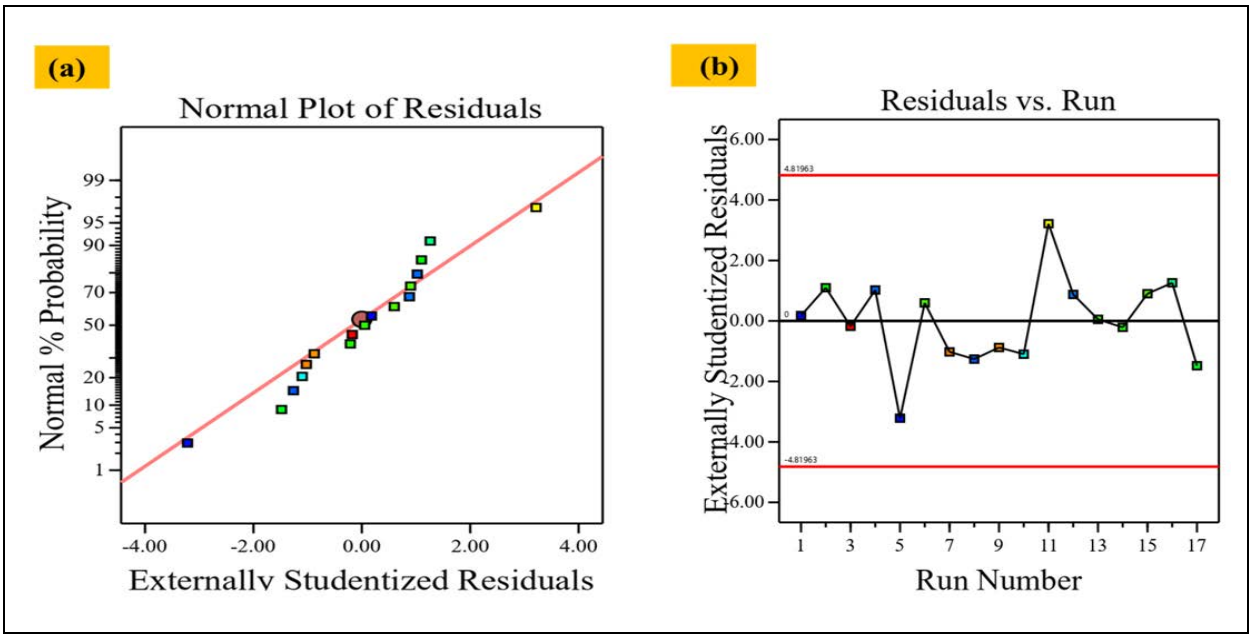


Fig. 3: a) Normal plot of residuals for daily productivity b) Comparison between actual and predicted values

Based on ANOVA results, a multiple regression analysis was executed to compute the coefficients of the second-order polynomial equation. The quadratic mathematical model expressed using coded variables is presented in equation (4) as follows:

$$\text{Daily productivity (mL)} = 262 + 3.75A + 2.875B + 0.625C - 1.75AB - 0.25AC + 1BC - 9.75A^2 + 0.5B^2 + 0.5C^2 \quad \ldots (4)$$

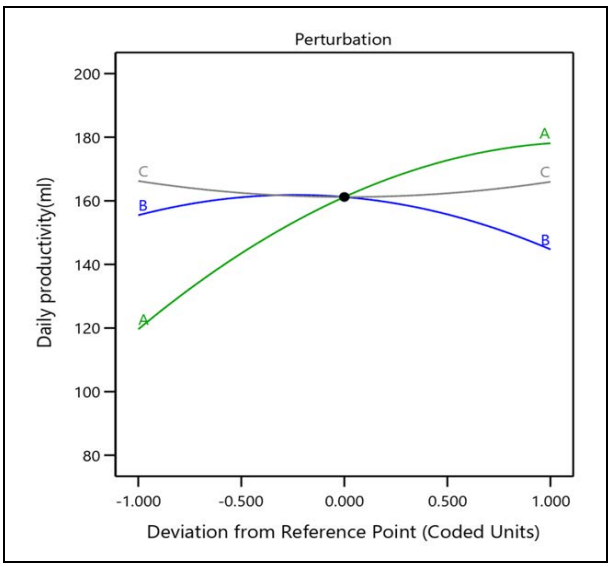


Fig. 4: Perturbation plot depicting the influence of A: Solar intensity, B: Wind velocity and C: Water depth on daily productivity

The coefficients in equation (4) indicate that solar intensity has the greatest effect on daily productivity with wind velocity and water depth duration having a lesser impact.

Fig. 3(b) shows that the predicted *vs* actual plot and assesses the accuracy of a regression model. Points aligning with the diagonal line strongly correlate predicted and actual values. The colour gradient may indicate different data distributions or confidence levels. The model demonstrates high predictive accuracy. The Fig. 3(a) shows normal plot of residuals and checks whether residuals follow a normal distribution. Points near the diagonal line suggest normality supporting the mode's assumptions. Deviations from the line may indicate outliers or non-normality. A good model fit is suggested if residuals align closely with the line.

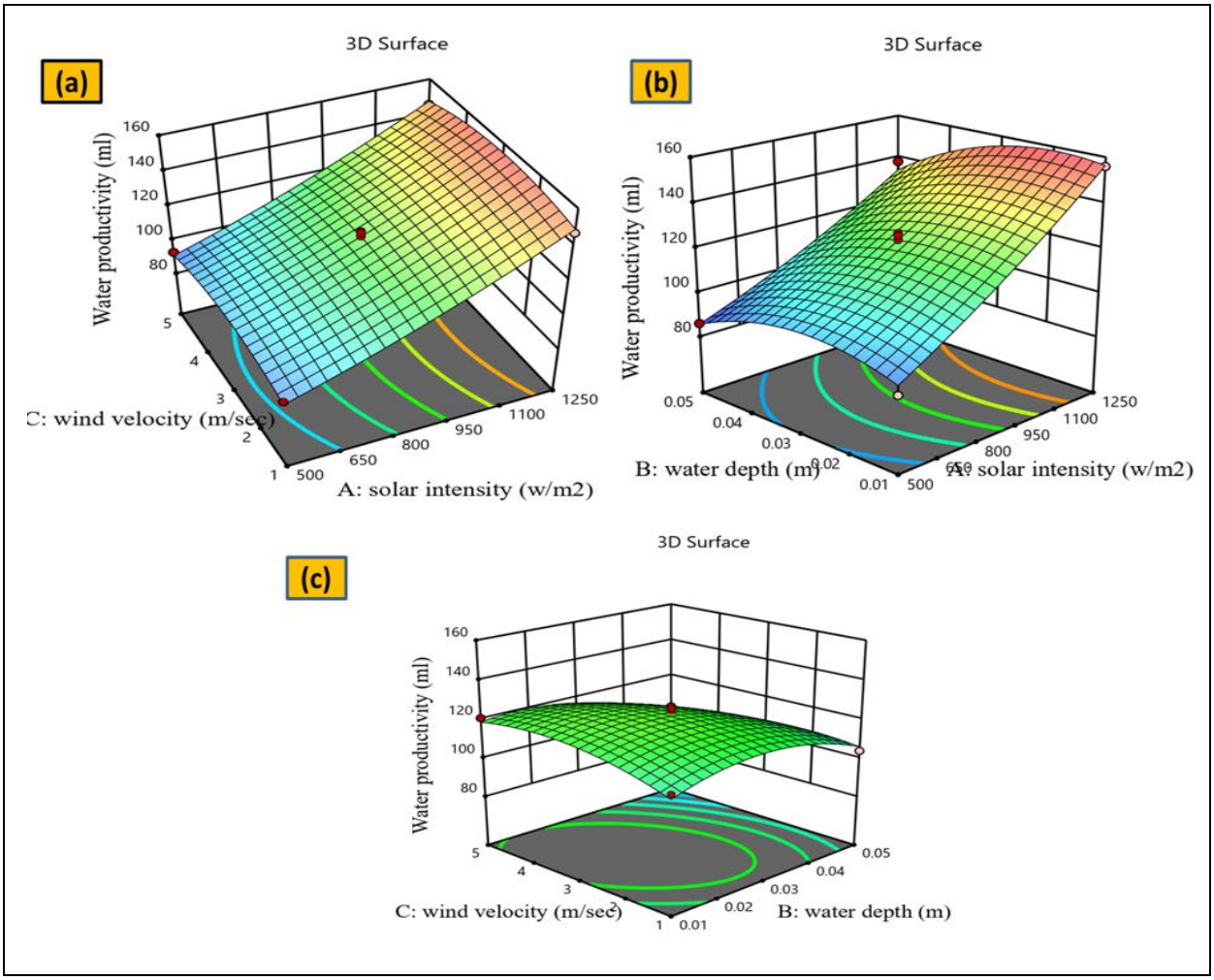


Fig. 5: Three-dimensional plots showing Daily productivity as a function of (a) solar intensity and wind velocity (b) solar intensity and water depth and (c) wind velocity and water depth

The perturbation plot in Fig. 4 shows how different independent variables affect daily productivity (m) by illustrating their deviations from a reference point in coded units. The X-axis represents these deviations while the Y-axis shows changes in productivity. A central black dot marks the reference point where all variables are balanced. Three factors A, B and C influence productivity in different ways. Fig. 4 shows the effect of multiple independent variables on daily productivity (m) through a perturbation plot. The Factor A has a strong positive effect meaning productivity increases as its value rises. Factor C has a negative effect indicating that increasing this factor reduces productivity. Factor B has a nearly flat slope suggesting it has little to no impact. This plot helps in understanding key factors that influence productivity for better optimization.

A comprehensive evaluation of the 3D plots for all interactions was performed. Fig. 5(a-c) presents the 3D surface plots of tensile strength as a function of (solar intensity and wind velocity), (solar intensity and water depth) and (wind velocity and water depth).

In accordance with the data, Fig. 5(a) shows that 3D surface plot represents the relationship between daily productivity (m^2) and two key variables: solar intensity (W/m^2) and wind velocity (m/s). The X-axis denotes solar intensity, ranging from approximately 500 W/m^2 to 1250 W/m^2, while the Y-axis represents wind velocity, varying between 0.5 m/s and 3 m/s. The Z-axis indicates daily productivity, which shows an increasing trend as solar intensity rises. The surface plot exhibits a gradual incline, indicating that higher solar intensity enhances daily productivity. However, wind velocity appears to have a relatively smaller impact, as changes along the Y-axis do not lead to significant variations in productivity. The colour gradient, transitioning from blue to yellow-green, visually reinforces the positive correlation between solar intensity and productivity.

The contour plot at the base provides an additional perspective on productivity trends, showing different levels through contour lines. The red points on the surface likely represent experimental or optimized data values. The curvature of the plot suggests a nonlinear relationship, with solar intensity playing a more dominant role compared to wind velocity. Overall, this visualization is useful for optimizing productivity conditions, highlighting solar intensity as the primary influencing factor.

As stated in the study this 3D surface plot represents the relationship between daily productivity (m^2), solar intensity (W/m^2) and water depth (m). The X-axis shows solar intensity ranging from about 500 W/m^2 to 1250 W/m^2 while the Y-axis represents water depth varying between 0.01 m and 0.05 m. The Z-axis indicates daily productivity which increases with higher solar intensity and decreases as water depth increases. The surface plot shows an upward trend meaning that higher solar intensity leads to greater productivity whereas deeper water reduces it. The color gradient shifting from blue to yellow-green visually represents this trend. The contour plot at the base provides additional insight into the variations in productivity levels with contour lines depicting different output values. The red points on the surface likely indicate experimental or optimized data used for comparison.

The curved nature of the surface suggests a nonlinear relationship where solar intensity has a stronger effect on productivity compared to water depth. This plot helps in understanding how solar intensity and water depth interact showing that lower water depth is more favorable for maximizing productivity. The X-axis indicates wind velocity, ranging from about 0.5 m/s to 3 m/s, while the Y-axis represents water depth, varying between 0.01 m and 0.05 m. The Z-axis shows daily productivity which tends to increase when water depth is lower and wind velocity is at an optimal level. The surface plot has a curved shape, suggesting that the highest productivity occurs with a specific combination of wind velocity and water depth. The color gradient shifts from blue to green visually indicating changes in productivity levels.

The contour plot at the base provides a projected view with contour lines illustrating variations in output. The red points on the surface likely represent experimental or optimized data. The shape of the surface suggests a nonlinear relationship between the variables, where both wind velocity and water depth influence productivity. This plot helps identify conditions that maximize productivity showing that lower water depth and appropriate wind velocity contribute to better performance.

5. CONCLUSION

The research explored the impact of adding loofah sponges and nanoparticle coatings on the thermal efficiency and the water yield of a solar still. Response surface methodology was employed to evaluate the effectiveness of these modifications under various operating conditions. The results showed that these enhancements played a crucial role in improving the distillation process by optimizing heat transfer, evaporation, and condensation. These nanoparticles enhanced solar energy absorption and heat distribution, thereby promoting more efficient water evaporation and overall system performance. The response surface analysis identified the optimal conditions for maximizing distillate output by adjusting key parameters such as nanoparticle concentration, water depth, and solar intensity. Additionally, the statistical model showed a strong analysis of the consistency between predicted and measured results confirming its accuracy and reliability.

The use of aluminum nitrate ($Al(NO_3)_3$) nanofluid coating combined with loofah, resulted in the highest increase in water output achieving a 36.48% improvement compared to a conventional solar still.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

COPYRIGHT

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

REFERENCES

Abdelgaied, M., Abdulla, A. S., Abdelaziz, G. B. and Kabeel, A. E., Performance improvement of modified stepped solar distillers using three effective hybrid optimization modifications, *Sustain. Energy Technol. Assessments*, 51, 101936(2022). https://doi.org/10.1016/j.seta.2021.101936

Abdullah, A. S., Alawee, W. H., Mohammed, S. A., Majdi, A., Omara, Z. M. and Essa, F. A., Increasing the productivity of modified cords pyramid solar still using electric heater and various wick materials, *PSEP*., 169, 169–176(2023). https://doi.org/10.1016/j.psep.2022.11.016

Alawee, W. H., Al-Haddad, L. A., Dhahad, H. A. and Al-Haddad, S. A., Predicting the cumulative productivity of a solar distillation system augmented with a tilted absorber panel using machine learning models, *J. Eng. Res.*, S2307187724000075 (2024). https://doi.org/10.1016/j.jer.2024.01.007

Arun, M., Barik, D., Naik, C. K., Bora, B. J., Dasarathy, A. K., Singh, S., Alqarni, S. A., Islam, S., Kumar, S., Pathani, A. and Wodajo, A. W., Advancements in parabolic trough water heaters with dimpled tube–CuO deionized nanofluid: experimental and numerical investigation, *Int. J. Low-Carbon Technol*., 19, 2477–2492 (2024). https://doi.org/10.1093/ijlct/ctae169

Babu, M. D., Babu, M. N. and Devarajan, Y., Study on the prediction of thermal conductivity for Al-CuO/water nanofluids using artificial neural networks. Multiscale and Multidisciplinary Modeling, *Exp. & Des.* , 8(1) (2024). https://doi.org/10.1007/s41939-024-00677-z

Banoqitah, E., Sathyamurthy, R., Moustafa, E. B., Fujii, M., Sudalaimuthu, P., Djouider, F. and H. Elsheikh, A., Enhancement and prediction of a stepped solar still productivity integrated with paraffin wax enriched with nano-additives, *Case Stud. Therm. Eng.*, 49, 103215(2023). https://doi.org/10.1016/j.csite.2023.103215

Dhivagar, R., Shoeibi, S., Kargarsharifabad, H., Sadi, M., Arabkoohsar, A. and Khiadani, M., Performance analysis of solar desalination using crushed granite stone as an energy storage material and the integration of solar district heating, *Energy Sources A: Recovery Util. Environ. Eff.,* 46(1), 1370–1388(2024). https://doi.org/10.1080/15567036.2023.2299693

Farouk, W. M., Abdullah, A. S., Mohammed, S. A., Alawee, W. H., Omara, Z. M. and Essa, F. A., Modeling and optimization of working conditions of pyramid solar still with different nanoparticles using response surface methodology, *Case Stud. Therm. Eng.*, 33, 101984(2022). https://doi.org/10.1016/j.csite.2022.101984

Farouk, W. M., Hamisa, G., Omara, Z. M. and Essa, F. A., Mathematical modeling and optimization of pyramidal still performance using response surface method and Ag-nanoparticle enhanced phase change material, *J. Energy Storage.*, 75, 109569(2024). https://doi.org/10.1016/j.est.2023.109569

Gunay, T., Gumus, C. and Sahin, A. Z., The impact of using nanofluid on the performance of solar stills: A comprehensive review, *PSEP*., 189, 1464–1516(2024). https://doi.org/10.1016/j.psep.2024.06.104

Immanuel, G., Isaac, S., Kaur, A., E, P., Bohidar, S. K. and Manikandan, R., Optimizing pyramid solar still performance using response surface methodology and artificial neural networks, *J. Environ. Stud.*, 36(1), 40–50(2024). https://doi.org/10.21608/jesj.2024.296455.1079

Kumar, R., Tripathi, P., Ongar, B., Khidolda, Y., Omara, Z. M., Abdullah, A. S. and Shanmugan, S., Experimental study on double effect solar distiller using bioactivity nanoparticles with analysis of thermo-economic and enviro-economical, *Case Stud. Therm. Eng.*, 47, 103045(2023). https://doi.org/10.1016/j.csite.2023.103045

Sahu, R. and Tiwari, A. C., Performance enhancement of single slope solar still using nanofluids at different water depth, Desalin. Water Treat., 317, 100046(2024). https://doi.org/10.1016/j.dwt.2024.100046

Sakthivel, T. G. and Arjunan, T. V., Thermodynamic performance comparison of single slope solar stills with and without cotton cloth energy storage medium, *J. Therm. Anal. Calorim*., 137(1), 351–360 (2018). https://doi.org/10.1007/s10973-018-7909-0

Saleque, A. M., Ma, S., Thakur, A. K., Saidur, R., Han, T. K., Hossain, M. I., Qarony, W., Ma, Y., Sathyamurthy, R. and Tsang, Y. H., MXene/MnO_2 nanocomposite coated superior salt-rejecting biodegradable luffa sponge for efficient solar steam generation, *Desalination*, 554, 116488(2023). https://doi.org/10.1016/j.desal.2023.116488

Sathish, T., Prabhu, K. A. V. R. and Yokeswaran, R., Influence of nanoparticles on thermal performance augmentation in solar collectors: a review, *Interactions*, 245(1) (2024). https://doi.org/10.1007/s10751-024-02209-0

Sohani, A., Delfani, F., Fassadi Chimeh, A., Hoseinzadeh, S. and Panchal, H., A conceptual optimum design for a high-efficiency solar-assisted desalination system based on economic, exergy, energy, and environmental (4E) criteria, *Sustain. Energy Technol. Assess.*, 52, 102053(2022). https://doi.org/10.1016/j.seta.2022.102053

Subramanian, K., Meenakshisundaram, N. and Barmavatu, P., Experimental and theoretical investigation to optimize the performance of solar still, Desalin. Water Treat., 318, 100343(2024). https://doi.org/10.1016/j.dwt.2024.100343

Thirumalai, G. and Thottipalayam, V., Performance enhancement of a solar still using cotton regenerative medium, *Therm. Sci*., 21(2), 427–434(2017). https://doi.org/10.2298/tsci17s2427t

Yousef, M. S., Hassan, H. and Sekiguchi, H., Energy, exergy, economic and environeconomic (4E) analyses of solar distillation system using different absorbing materials, *Appl. Therm. Eng.*, 150, 30-41(2019). https://doi.org/10.1016/j.applthermaleng.2019.01.005