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Research Article

Performance Analysis of Solar Still by Using Octagonal-Pyramid Shape in the Solar Desalination Techniques

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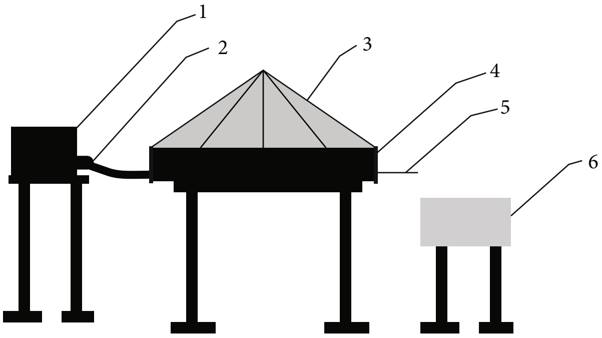
This research work explored and compared the experimental performance of a solar still having novel octagonal-pyramid shape with a single slope solar still. It is found that the novel still provides twice distillation compared with conventional still. The experiments also evaluated the desalination productivity of octagonal-pyramid solar still by varying the depth of saline water inside the basin and angle of inclination of glass cover. It is observed that the optimum condition for high distillation is obtained when depth of water inside the basin is 5 cm with angle of inclination of glass cover which is 30°. Four types of water, i.e., underground borewell water, sea water, leather industry effluent, and plastic industry effluent were also used to see the effect on distillation. Results showed that underground borewell water provides high distillation due to low density. Furthermore, the performance of the octagonal-pyramid solar still is enhanced by adding different latent heat and sensible heat materials in the octagonal-pyramid solar still. Hence, the addition of brick to the octagonal-pyramid still yields the highest productivity compared to incorporation of paraffin wax. Hence, it can be concluded that the octagonal design of the solar still has shown an increased productivity when compared to a single slope solar still (conventional still) under all the conditions.

1. Introduction

The fresh water resources are getting polluted alongside the demand for fresh water which is increasing day by day due to modernization. Water reclamation could bring the complete solution for this problem. There are numerous ways to desalinate sea water and waste water into fresh water [1, 2]. The simplest and cost-effective method is using solar still for distillation. Since the daily productivity of a conventional single slope solar still is very low, hence, in this paper, modification in design is made to improve the productivity. Various research experiments are being performed to increase the distillate productivity of a solar still. Wind velocity, solar radiation, still basin area, water surface area, and water depth and glass cover temperature are some of the influences that affect the daily efficiency of a solar still [3–5].

Single-basin single-slope solar stills are the conventional stills used for desalination of water which works on the basic condensation principle. Though the construction or design of single-basin solar still is simple and constructive cost is cheap and requires low maintenance cost, with the same setup, the productivity cannot be increased [6]. Hence, in order to increase the quality and quantity of the fresh water, the distilled water for drinking and irrigation purpose single-basin solar still is ministering modifications. With the view to overcome the limitations of a single-basin solar still, various modifications to the solar still have been proposed such as double-slope solar still, multistage solar still, stepped solar still, and wick-type solar still. With a flat plate collector enclosed to a single-basin solar still, an improvement of 52% in the productivity was shown. Double glass cover on a single-slope basin also achieved high productivity by running cool water between the double glass cover. A stepped solar still effectively showed an increase in the daily productivity [7–9]. A stepped solar still with a flashing chamber was constructed and investigated by experimenting on a stepped solar still with and without a reflector to illustrate that there was a 20% increase in the daily efficiency of productivity compared to conventional solar still [10].

Later, researchers improved the work efficiency of the solar still by adding wick, fins, and various thermal energy storage materials into the still. Basin-type stepped solar still with wick-type still showed high efficiency in terms of productivity. The wick-type evaporator collector system showed an increase in overall efficiency when compared to the basin-type system [11–13]. Various types of wick materials to innumerable absorber plate designs discovered the most productive as 4.28 L per day while utilising a wire mesh stepped-type absorber plate made up of coral fleece. The research also developed a multibasin solar still added to thermal storage materials in order to increase the performance of the still even in the absence of sunlight [14]. Sensible heat resources such as sand, cement, and glass, as well as latent heat storage materials like wax, were used and found the increased productivity as 73% when compared to traditional solar panels. Experiments with different water nanofluids in basin also showed remarkable improvement in the performances. Incorporated sensible heat storage materials like cement concrete bits, quartzite rock, washed pebbles, iron scraps, and red brick bits into the still found that adding of an inch quartzite rock showed increased productivity than the other materials [15–18].



1 - Saline water storage tank
2 - Saline water outlet
3 - Transparent glass cover
4 - Basin
5 - Desalinated water outlet
6 - Desalinated water storage tank

Figure 1: Schematic diagram of the octagonal-pyramid solar still.

Figure 2: Photograph of experimental setup of the octagonal-pyramid solar still.

In this paper, a novel octagonal-pyramid solar still is developed to improve the desalination productivity of the solar still. The basin of the still is octagonal in shape, and condensing glass covers are slanted over each side of the basin giving it a pyramidal shape. The narrowing effect of the pyramidal glass cover will be an aid in enhancing the laminar flow of water vapour without any disruption [19, 20]. The pyramidal shape of the glass cover circulates the wind around the structure which causes a decrease in glass surface temperature. The difference in temperature between the saline water and the glass cover will enhance the condensation process and thus increase the daily productivity of the still [21]. The hourly desalinate production of the both conventional solar still and the new solar still has been measured. The octagonal-pyramid solar still is erected in the month of May, 2021, in Ramanathapuram, Tamil Nadu, India.

2. Experimental Setup

A conventional single-slope solar still and an octagonal-pyramid solar still were planned and erected to compare the performance of solar desalination. The base and the side walls are built using galvanized steel sheets of 1.6 mm thickness [22, 23]. The base area of the still is 0.36 m^2 (0.6 m length × 0.6 m breadth). The taller side wall has a

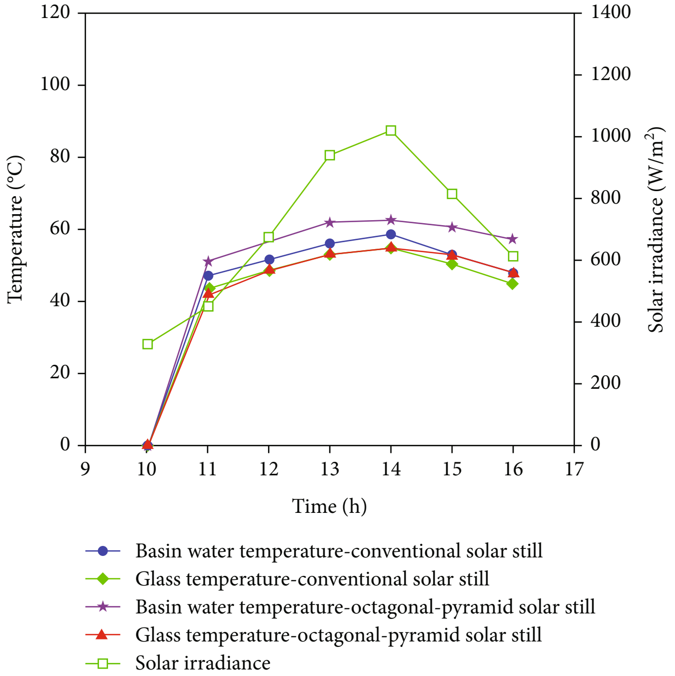


Figure 3: Variation of basin water temperature, glass temperature, and solar radiation of the conventional and octagonal-pyramid solar still.

height of 0.5 m and the shorter side wall has 0.2 m. To increase the absorptive, black paint has been applied to the basin's interior surface [24–26]. The basin is protected with glass which allows the solar radiation to reach the basin plate and also acts as the condensing surface. Tempered glass is used in the experiment as it has a solar transmittance of 91% for the incident solar radiation and has high wet ability. The glass cover is slanted horizontally over the basin at an angle of 30 degrees.

An octagonal-shaped base with each side of length 248.5 mm is cut. The side walls of height 200 mm are fabricated over the base. The base and the side walls are built using galvanized steel sheets of 1.6 mm thickness. Eight sides of the octagonal basin are sealed with a glass cover in the shape of octagonal pyramid as given in Figure 1. The photograph of the complete experimental setup of the octagonal-pyramid solar still is shown in Figure 2.

The water to be desalinated is filled in the basin. On account of incidence of solar radiation, the temperature of the water inside the basin increases and the water evaporates. The water vapour gets condensed on reaching the glass cover. The condensed water was collected in a trough placed at the bottom of the glass cover.

A wired digital thermometer is used to accurately measure the temperature of the water and the glass of ±1°C. Instantaneously, a solarimeter was used to measure the intensity of solar radiation $\pm 1\,\mathrm{W/m^2}$. A digital vane anemometer is used to measure the wind velocity with an accuracy of ±0.1 m/s. A calibrated measuring jar having 2 L capacity with an accuracy of 5 mL is used to measure the hourly distillate yield.

Experiments were conducted at Ramanathapuram, Tamil Nadu, India, during May 2019. For every one hour, solar radiation, wind velocity, basin plate temperature, water to be treated, glass cover, and distilled water were measured. The experiment was conducted on both the conventional and the octagonal-pyramid solar stills, and the hourly yield is measured. The hourly yield of the octagonal-pyramid solar still was measured by the following:

(i) Varying the depth of saline water inside the basin, h

(ii) Varying the angle of inclination of glass cover, ⊠

(iii) Adding latent heat and sensible heat materials, viz., paraffin wax and brick

(iv) Changing the type of liquid to be distilled, viz., underground borewell water, sea water, leather industrial waste liquid, and plastic industrial waste liquid

3. Results and Discussion

Ambient temperature measured at Ramanathapuram, Tamil Nadu, is varied between 38° and 42°. Wind velocity and solar radiation intensity were measured.

3.1. The Effect of Solar Radiation on the Solar Still's Performance. Basin water temperature and glass temperature are measured for both conventional and octagonal-pyramid solar stills after every hour. Figure 3 demonstrates how the temperature of the basin, temperature of glass, and intensity of solar radiation changed over time. It is experiential that the water temperature increases as solar radiation increases. The temperature of the basin rises till it reaches a maximum value around noon and decreases subsequently as the solar

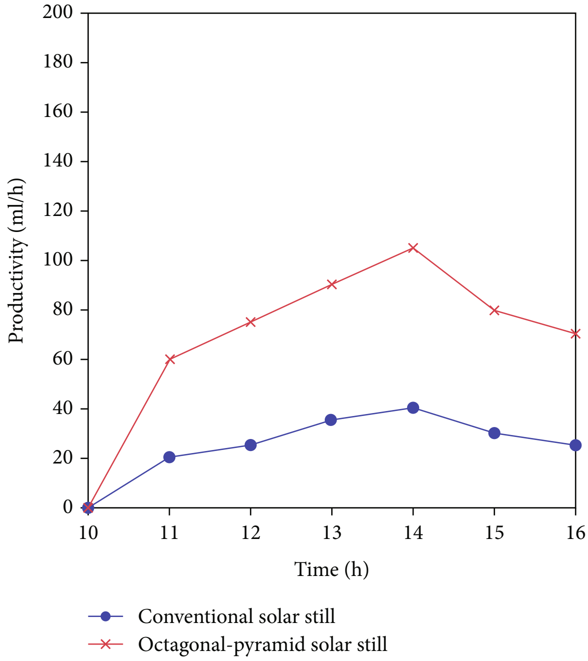


FIGURE 4: Hourly desalination productivity of the conventional and octagonal-pyramid solar still.

radiation decreases. It is also observed that the octagonal-pyramid still shows a lower glass temperature value than a conventional still. It is to be noted that this decrease in the glass temperature is caused due to its conical shape nearly possessed by octagonal-pyramid still.

3.2. Hourly Desalination Productivity of the Conventional and Octagonal-Pyramid Solar Still. The hourly variation of desalinated water productivity for conventional and octagonal-pyramid stills is shown in Figure 4. In this experiment, underground borewell water is used as saline water in the solar stills. The depth of saline water is 5 cm, and the angle of glass cover is 30 degrees. It is observed that desalinated productivity increases slowly from zero in the early hours and reaches a maximum value around noon. Both the stills take time to increase from value zero because the water takes time to get heated up to transform into vapour state. The productivity in the afternoon decreases gradually as the solar radiation decreases. The octagonal-pyramid still shows a higher productivity than the conventional still. The hourly productivity obtained on using octagonal-pyramid still is more than twice that of the conventional still.

3.3. Performance of the Octagonal-Pyramid Solar Still on Varying Saline Water Depths. The desalination productivity of the octagonal-pyramid solar still at various saline water depths (*h*) is shown in Figure 5. Borewell water is used as saline water to find the optimum saline water depth in the octagonal-pyramid solar still. The saline water depths are 5 cm, 10 cm, and 15 cm with a fixed glass cover angle of inclination of 30 degrees. It is observed that the increase in water depth decreases the productivity of the still.

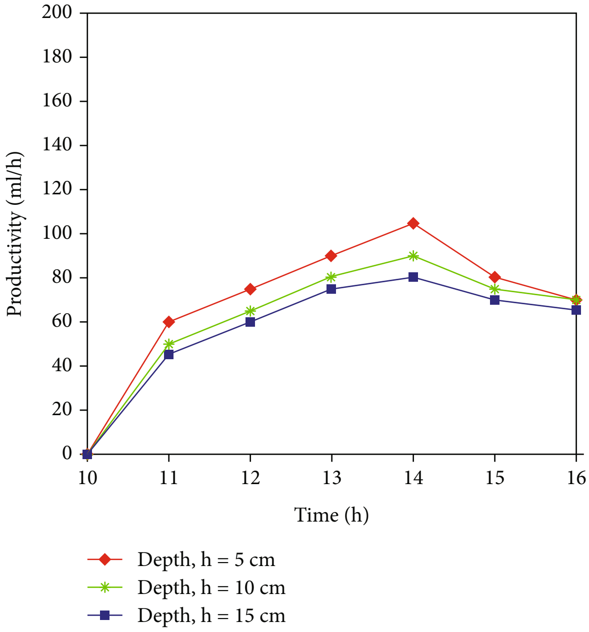


FIGURE 5: Productivity of various water depths of the octagonal-pyramid solar still.

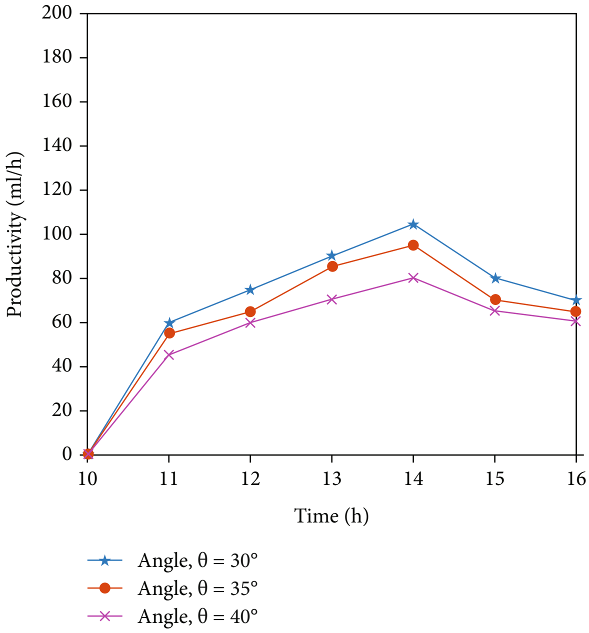


FIGURE 6: Productivity of various glass cover angles of the octagonal-pyramid solar still.

The highest productivity is achieved at the lowest depth of 5 cm. The factors that contributed to achieve increased productivity are the lower depth of water, decreased mass of the water, and the eventual specific increased heat capacity of the water.

3.4. Performance of the Octagonal-Pyramid Solar Still on Varying the Angle of Inclination of Glass Cover. The variation in desalination productivity is observed by changing

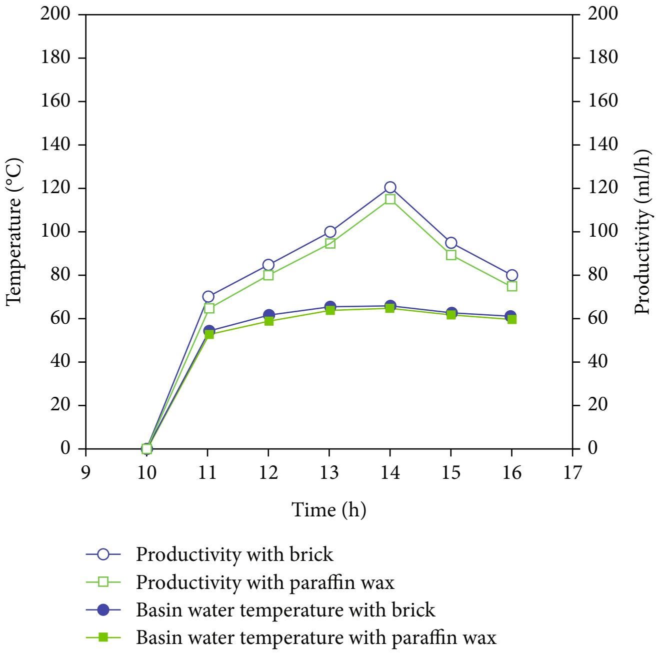


Figure 7: Effect of latent heat and sensible heat materials in the octagonal-pyramid solar still.

the angle of glass cover (θ). The angle of glass cover is varied from 30°, 35° to 40°. Borewell water is used as a saline water, and a uniform saline water depth of 5 cm is used in this experiment. The hourly desalination productivity at various angles of glass cover in the octagonal-pyramid solar still is shown in Figure 6. The experimental results show that the change in angle of inclination affects the desalination productivity of the still. It is seen that the octagonal-pyramid solar still yields the highest cumulative distillate for $\theta = 30°$.

3.5. Performance of the Octagonal-Pyramid Solar Still on Adding Latent Heat and Sensible Heat Materials. Latent heat and sensible heat materials are the thermal storage materials added separately inside the still so that the high heat is maintained inside the basin. The latent heat and sensible heat materials used in the experiment are paraffin wax and brick, respectively. Initially, paraffin wax is stored in a small stainless-steel container which is half-filled and placed in a basin area of the still. As the basin water temperature increases, the paraffin wax absorbs the heat and melts inside the small container and supply heat to the saline water.

After experimenting with paraffin wax, a brick is added in the basin area of saline water. The brick absorbs heat from the saline water and releases additional heat to the saline water inside the still. Underground borewell water is the saline water used in this experiment. The octagonal pyramid maintains an angle of glass cover at 30° and the saline water depth of 5 cm throughout the experiment. The increased desalination productivity due to the addition of latent heat and sensible heat materials is shown in Figure 7. Following the addition of the thermal heat storage materials, the basin water temperature rises in the late afternoon. The addition of brick to the octagonal-pyramid still yields the highest productivity compared to incorporation of paraffin wax.

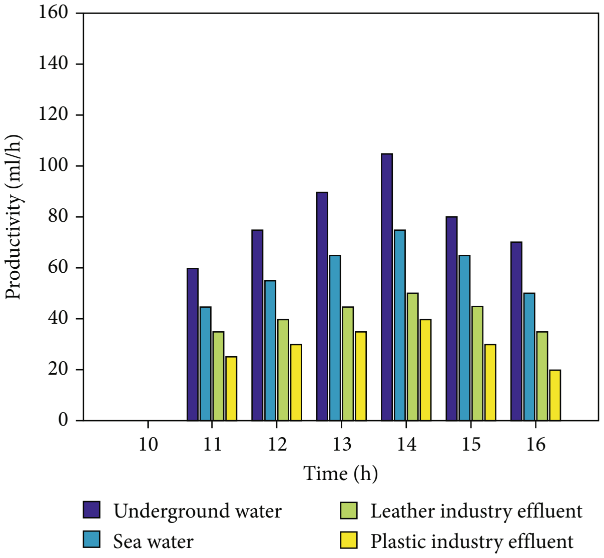


Figure 8: Productivity of underground water, sea water, leather industry waste, and plastic industry waste in the octagonal-pyramid solar still.

3.6. Performance of the Octagonal-Pyramid Solar Still for Different Types of Liquid. In this experiment, four types of saline liquids are used for desalination in the octagonal-pyramid solar still. The four liquids are underground borewell water, sea water, leather industry effluent, and plastic industry effluent. The desalination productivity of four liquids is given in Figure 8. The still shows higher desalination productivity for underground borewell water than other liquids. It is because of low density and low salinity in underground borewell water.

Table 1: Chemical examination of saline water and desalinated water.

Sl. No.	Chemical examination	Permissible limit	Bore water	Desalinated bore water	Sea water	Desalinated sea water	Leather industrial waste	Desalinated leather industrial waste	Plastic industrial waste	Desalinated plastic industrial waste
1	Turbidity (NT units)	5	1	1	2	1	160	3	240	1
2	Total dissolved solids (mg/L)	2000	320	675	33250	1680	5530	1960	23100	1820
3	pH	6.5-8.5	8.1	6.6	7.8	7.4	7.6	7.1	6.8	7.4
4	Total alkalinity as $CaCo_3$ (mg/L)	600	335	100	280	125	800	190	1200	410
5	Total hardness as $CaCo_3$ (mg/L)	600	460	150	8600	320	1300	320	5200	580
6	Calcium as Ca (mg/L)	200	96	32	480	72	420	72	400	120
7	Magnesium as Mg (mg/L)	100	53	16	1776	34	144	34	1008	67
8	Sodium as Na (mg/L)	—	220	130	6500	380	890	520	4600	320
9	Potassium as K (mg/L)	—	16	8	430	24	16	8	240	24
10	Iron as Fe (mg/L)	0.3	0	0	0.2	0	14.0	0.2	22	0
11	Free ammonia as NH_3 (mg/L)	0.5	0	0	0	0	6.8	0	11.9	0.16
12	Nitrite as $NO_{3\,(}$mg/L)	45	5	0	15	0	30	6	25	12
13	Chloride as CL (mg/L)	1000	380	230	15500	680	2300	820	9400	580
14	Fluoride as F (mg/L)	1.5	0.8	0.2	1.6	0.4	1.6	0.8	1.8	1.0
15	Sulphate as SO_4 (mg/L)	400	40	25	1450	35	145	85	685	60
16	Phosphate as PO_4 (mg/L)	—	0	0	0	0	2.0	0.8	4.0	0.6
17	Tidy's test 4 hrs. as O_2 (mg/L)	—	0.64	0.52	1.12	0.60	1.04	0.51	1.64	0.72

Table 2: Economic analysis and payback period of the still.

Sl. No.	Fabrication cost	Maintenance cost/day	Cost of distilled water	Cost of water produced/day	Net profit/day = cost of water produced – maintenance cost	Payback period
Octagonal-pyramid solar still (cost in rupees)	4,000	0.5	15	15	14.5	40000/14.5 = 276 days

3.7. Chemical Examination. The four types of saline water are tested in the laboratory of Tamil Nadu Water Supply and Drainage board Sivagangai, Tamil Nadu, India. The laboratory results of four types of saline water and their desalinated types are shown in Table 1. The chemical examination of desalinated water shows that it can be used for domestic purpose.

3.8. Economic Analysis. The octagonal-pyramid solar still's economic analysis is calculated and tabulated in Table 2. The payback period of the octagonal-pyramid solar still can be calculated using the fabrication and maintenance cost of the still. The payback period of the octagonal-pyramid solar still has 276 days [27–29].

4. Conclusion

Successful functioning of the octagonal-pyramid solar still has been demonstrated by subjecting it to a series of experimental tests. The performance of the octagonal-pyramid solar still is experimentally compared with a conventional single-slope solar still. The results of experiments showed that the productivity in case of the octagonal-pyramid solar still has increased more than twice than that of the conventional still. The optimum values for maximum productivity are obtained when

(i) the depth of water inside the basin $h = 5\,\text{cm}$

(ii) angle of inclination of glass cover $\theta = 30^\circ$

The novel developed solar still also showed better efficiency when coupled with latent heat and sensible heat material, viz., paraffin wax and brick. The comparative analysis showed an increased the productivity of 9.18% by adding a brick. The experimental results also showed that the still is suitable for the desalination of different types of liquid, viz., underground borewell water, sea water, leather industry waste liquid, and plastic industry waste liquid. Among these liquids, the best efficiency is obtained for underground borewell water due to low density.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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References

[1] M. Abu-Arabi, Y. Zurigat, H. Al-Hinaib, and S. Al-Hiddabib, "Modeling and performance analysis of a solar desalination unit with double- glass cover cooling," *Desalination*, vol. 143, no. 2, pp. 173–182, 2002.

[2] T. Elango, A. Kannan, and K. KalidasaMurugavel, "Performance study on single basin single slope solar still with different water nanofluids," *Desalination*, vol. 360, pp. 45–51, 2015.

[3] A. M. El-Zahaby, A. E. Kabeel, A. I. Bakry, S. A. El-agouz, and O. M. Hawam, "Augmentation of solar still performance using flash evaporation," *Desalination*, vol. 257, no. 1-3, pp. 58–65, 2010.

[4] R. S. Hansen, C. S. Narayanan, and K. K. Murugavel, "Performance analysis on inclined solar still with different new wick materials and wire mesh," *Desalination*, vol. 358, pp. 1–8, 2015.

[5] M. Balu, K. Lingadurai, P. Shanmugam, K. Raja, N. Bhanu Teja, and V. Vijayan, "Biodiesel production from Caulerpa racemosa (macroalgae) oil," *IJMS*, vol. 49, no. 4, pp. 616–621, 2020.

[6] A. Hanson, W. Zachritz, K. Stevens, L. Mimbela, R. Polka, and L. Cisneros, "Distillate water quality of a single-basin solar still: laboratory and field studies," *Solar Energy*, vol. 76, no. 5, pp. 635–645, 2004.

[7] J. Ganeshkumar, D. Kathirkaman, K. Raja, V. Kumaresan, and R. Velraj, "Experimental study on density, thermal conductivity, specific heat, and viscosity of water-ethylene glycol mixture dispersed with carbon nanotubes," *Thermal Science*, vol. 21, no. 1 Part A, pp. 255–265, 2017.

[8] T. Balasundaram and K. Raja, "Development and morphology of titanium nanotubes anode for new generation solar cell by electrochemical anodizing method," *Journal of Scientific and Industrial Research*, vol. 75, pp. 315–319, 2016.

[9] A. E. Kabeel, Z. M. Omara, and F. A. Essa, "Enhancement of modified solar still integrated with external condenser using nanofluids: an experimental approach," *Energy Conversion and Management*, vol. 78, pp. 493–498, 2014.

[10] K. Raja, V. Srinivasa Raman, R. Parthasarathi, K. Ranjitkumar, and V. Mohanavel, "Performance analysis of DEE-biodiesel blends in diesel engine," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 1016–1020, 2019.

[11] C. Tiris, M. Tiris, Y. Erdalli, and M. Sohmen, "Experimental studies on a solar still coupled with a flat-plate collector and a single basin still," *Energy Conversion and Management*, vol. 39, pp. 853–856, 1998.

[12] T. Balasundaram and K. Raja, "Growth and characterization of titanium nanotubes anode for solar cell application by electrochemical anodization method," *International Journal of Advanced Engineering Technology*, vol. 7, no. 2, pp. 359–363, 2016.

[13] A. Senthil Rajan, K. Raja, and P. Mari Muthu, "Augmentation of single basin and pyramid still desalination using common biomass heat source and analytical validation using RSM," *Australian Journal of Basic and Applied Sciences*, vol. 8, no. 10, pp. 212–218, 2014.

[14] A. E. Kabeel, Z. M. Omara, and F. A. Essa, "Improving the performance of solar still by using nanofluids and providing vacuum," *Energy Conversion and Management*, vol. 86, pp. 268–274, 2014.

[15] K. Kalidasa Murugavel and K. Srithar, "Performance study on basin type double slope solar still with different wick materials and minimum mass of water," *Renewable Energy*, vol. 36, no. 2, pp. 612–620, 2011.

[16] K. Vikas, “Evaluation of machining performance and multi criteria optimization of novel metal-Nimonic 80A using EDM,” *SN Applied Sciences*, vol. 3, no. 3, pp. 1–10, 2021.

[17] A. Pratap, B. K. Singh, and N. Sardana, “Fracture in self-lubricating inserts: a case study,” *Materials Today: Proceedings*, vol. 66, pp. 3738–3742, 2022.

[18] A. Pratap, P. Kumar, N. Mandal, and B. K. Singh, “Effect of indentation load on mechanical properties and evaluation of tribological properties for zirconia toughened alumina,” *Materials Today: Proceedings*, vol. 26, pp. 2442–2446, 2020.

[19] M. A. S. Malik, G. N. Tiwari, A. Kumar, and M. S. Sodha, *Solar Distillation*, Pergamon Press, Oxford, 1982.

[20] S. M. A. Moustafa, G. H. Brusewitz, and D. M. Farmer, “Direct use of solar energy for water desalination,” *Solar Energy*, vol. 22, no. 2, pp. 141–148, 1979.

[21] A. Senthil Rajan, K. Raja, and P. Marimuthu, “Increasing the productivity of pyramid solar still augmented with biomass heat source and analytical validation using RSM,” *Desalination and Water Treatment*, vol. 57, no. 10, pp. 4406–4419, 2014.

[22] Z. M. Omara, A. E. Kabeel, and M. M. Younes, “Enhancing the stepped solar still performance using internal and external reflectors,” *Energy Conversion Management*, vol. 78, pp. 876–881, 2014.

[23] A. Senthil Rajan, K. Raja, and P. Marimuthu, “Multi basin desalination using biomass heat source and analytical validation using RSM,” *Energy Conversion and Management*, vol. 87, pp. 359–366, 2014.

[24] M. Lokeshwari, P. V. Sagar, K. D. Kumar et al., “Optimization and tribological properties of hybridized palm kernel shell ash and nano boron nitride reinforced aluminium matrix composites,” *Journal of Nanomaterials*, vol. 2022, Article ID 8479012, 9 pages, 2022.

[25] N. Bhanu Teja, P. Ganeshan, V. Mohanavel et al., “Performance and emission analysis of watermelon seed oil methyl ester and n-butanol blends fueled diesel engine,” *Mathematical Problems in Engineering*, vol. 2022, Article ID 2456338, 12 pages, 2022.

[26] N. Mohanraj, N. Mathan Kumar, P. Prathap et al., “Mechanical properties and electrical resistivity of the friction stir spot-welded dissimilar Al–Cu joints,” *International Journal of Polymer Science*, vol. 2022, Article ID 4130440, 7 pages, 2022.

[27] V. Velmurugan, S. SenthilKumaran, V. NiranjanPrabhu, and K. Srithar, “Productivity enhancement of stepped solar still – performance analysis,” *Thermal Science*, vol. 12, no. 3, pp. 153–163, 2008.

[28] M. K. Patan, K. Raja, M. Azaharahmed, C. D. Prasad, and P. Ganeshan, “Influence of primary regulation on frequency control of an isolated microgrid equipped with crow search algorithm tuned classical controllers,” *Journal of Electrical Engineering & Technology*, vol. 16, no. 2, pp. 681–695, 2021.

[29] M. Azaharahmed, K. Raja, M. K. Patan, C. D. Prasad, and P. Ganeshan, “Invasive weed optimized area centralized 2 degree of freedom combined PID controller scheme for automatic generation control,” *Journal of Electrical Engineering & Technology*, vol. 16, no. 1, pp. 31–42, 2021.