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Enhancing the productivity of v-type and roof type single basin solar still with internal modification — a Taguchi method

C.K. Sivakumar[a,*], Y. Robinson[b], S. Joe Patrick Gnanaraj[c]

[a]*Department of Mechanical Engineering, RVS Technical Campus, Coimbatore, Tamil Nadu, India, email: kumarabc464@gmail.com*
[b]*Department of Robotics and Automation Engineering, Erode Sengunthar Engineering College, Erode, Tamil Nadu, India, email: yrobin1969@gmail.com*
[c]*Department of Mechanical Engineering, St. Mother Theresa Engineering college, Thoothukudi, Tamil Nadu, India, email: gnanaraj.134@gmail.com*

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ABSTRACT

Solar desalination technologies are an alternative and appealing solution for providing potable water to people in remote and coastal areas. This work presents an experimental and theoretical study of roof-type and v-type solar desalination stills with internal modifications. The Taguchi method reduces the number of experiments conducted physically and gives better results while consuming less time. An experimental investigation of a v-type and roof-type solar still incorporating four internal modification parameters like basin liner design, wick materials, water depth and heat storage materials was carried out to optimize freshwater production. The selected parameter levels to improve the freshwater production in v-type and roof type solar stills have been obtained through an experimental study. Experiments were conducted for nine combinations of parameters suggested by the L_9 orthogonal array. As per the L_9 orthogonal array, nine combinations of parameters were obtained. The maximum SN ratio of parameter levels was selected to redesign the v-type and roof type basins to achieve a robust design. As per the Taguchi method, the redesigned v-type and roof type solar still designs were developed, giving 125% and 172% more freshwater, respectively compared to conventional v-type and roof type solar stills. When compared to v-type solar still, roof-type still produced more freshwater. Theoretical analysis shows that this roof type produces 45% more freshwater yield than a v-type solar still.

Keywords: Solar desalination; Roof type solar still; v-type solar still; Optimum production; Taguchi method; Wick material; Heat storage material

1. Introduction

Life becomes impossible for humankind without potable water. Even though oceans carry more than 70% of the water available on earth, the population most badly affected by the lack of drinking water is in coastal areas. Earlier attempts to produce fresh water from the sea through the solar desalination process date back to the 19th century. Even in the 21st century, there is ample scope for improving the efficiency of the solar desalination process through various design techniques. Smaller-scale conventional single solar stills are less productive and generally produce below 1,000 mL/d [1]. With internal and external modifications that enhance heat transfer, solar still performs better, as in the Cooper experiment, which improved water production by 50% [2]. Many researchers are exploring various means to improve the efficiency of solar stills. Flat plate collectors are coupled with solar stills to improve the efficiency of the still because it will increase the temperature difference inside the system [3]. The daily distillate output

* Corresponding author.

will decrease with increasing water depth and the daily experimental efficiency was found to be around 41.49% and 32.4%, respectively for 10 and 2 cm water depth [4]. Usage of PCM can help store energy during the day, supply energy during the night and produce up to 4,300 mL/m^2·d in single slope desalination still [5,6]. Solar collectors can increase the water temperature up to 87°C and increase the productivity of the still [7]. Using double slope desalination stills, the production can be increased to 7,800 mL/m^2·d without cooling the glass cover and to 8,520 mL/m^2·d with cooling the glass cover [8]. Hybrid solar desalination systems developed by using humidification and dehumidification systems coupled with solar concentrators and two photovoltaic panels (working thermally) will further improve the efficiency of the system [9]. The direct membrane distillation will improve the production up to 8,000 mL/m^2·d by coupling with a flat plate collector [10]. Solar dish concentrators coupled with solar stills can produce 4,950 mL/m^2·d [11]. Different types of wick materials, like sponge sheets, coir mats, cotton cloth, waste cotton pieces, etc., are also used in the water basin to improve efficiency. Out of these, cotton clothes are a more efficient wick material than the other materials [12]. Humidification–dehumidification desalination is one of the new desalination strategies getting popular among research circles and the energy required for it could be suitably obtained from solar energy. A combination of at least two desalination processes is called a hybrid desalination process. It may give a superior pure water yield and improve energy utilization. Using geothermal energy in desalination, pure water production accomplishes the heat source continuously throughout the day (24 h). Similarly, hybrid solar desalination with solar concentrators can increase productivity and could be very useful in coastal areas [13]. Increasing glass cover thickness also reduces the production of freshwater [14]. The use of glass cover shading and evaporative glass cover cooling is also found to enhance desalination performance. Half-shaded covers with glass cover cooling resulted in a productivity enhancement of 8.2% in comparison with ¼th shading and cooling of solar stills [15]. Increasing the wind velocity over the glass cover raises the yield [16]. The design of the bottom absorber plate also affects freshwater yield. The desalination unit with the arched absorber plate produced more water than the still with the level absorber plate. Researchers have also shown that the inclination angle of this still noticeably affects the performance of solar stills [17]. As mentioned earlier, water depth in the solar desalination system is also an essential factor for freshwater production. Decreasing the water depth will increase productivity. For example, the freshwater production at 1, 2 and 3 cm water depths and without cooling was 4,200; 3,540 and 3,090 mL/m^2, respectively [18]. Nowadays, researchers have proven that hybrid solar desalination systems incorporating a water heater powered by a photovoltaic (PV) system increase the total system's yield [19]. While pebbles are one of the heat storage parameters used in the solar desalination process, the diameter of the pebbles is inversely proportional to the productivity of solar water. The use of 2 mm diameter pebbles in the solar still increased the productivity by 134 mL/d and 12 mm diameter pebbles produced 55 mL/d [20]. The airflow structures in the desalination still increase the condensation rate and fresh water yield [21]. In this experiment, optimization is used to minimize the number of experiments. Minitab software was used in this study. Other researchers use optimization algorithms [22], optimization software [23], area optimization [24], multi objective optimization [25], performance optimization [26] and all optimization objectives are intended to find solutions that maximize or minimize some study parameters [27,28]. The internal and external modifications can change the yield of the solar desalination system [29]. The cost of a desalination system varies depending on the design and coupled components [30] and it may rise as the system becomes more complex. Even then, solar desalination is a clean and eco-friendly way of producing fresh water at reasonable costs [31].

From the above literature study, four different sets of parameters were chosen for the present work to do experiments and those parameters are shown in Table 1. The current work aims at obtaining an optimal combination of the four sets of parameters that will maximize freshwater production. The Taguchi method is employed to minimize the number of experiments to be carried out and to find the best set of parameters [32].

2. Objective and methodology adopted

The fundamental goal of this study is to build a robust design of roof type and v-type solar stills and optimize fresh water production, by incorporating the best combination of parameter levels identified by the Taguchi method.

The objective and methodology adopted in this study is summarized:

Table 1
Roof type and v-type basin parameters

Parameter 1	Basin plate	- Black coated plain basin; - Black coated plain basin with fin; - Black coated corrugated basin; - Black coated corrugated basin fins; - Black coated compartmental basin.
Parameter 2	Basin materials	- Pebbles; - Marble; - Limestone; - Blue metal; - Black limestone; - Granite.
Parameter 3	Wick materials	- Black sponge; - Black cotton cloth; - Jute cloth; - Black jute cloth; - Mixed color cotton.
Parameter 4	Basin water depth	- 10 mm; - 15 mm; - 20 mm; - 25 mm; - 30 mm.

Stage 1: Design and construction of roof type and v-type solar sills

- Construct six roof type and v-type solar stills as per the experimental requirements mentioned in the experimental set-up.

Stage 2: Identification of set of four parameters that can improve desalination process

- Selected parameter sets, such as a set of six basin liner designs, a set of six wick materials, a set of five heat storage materials and a set of five water depths, are shown in Table 1.

Stage 3: Evaluating the performance of each parameter level through experiments

- Experimentally, the fresh water yield of a solar still with various sets of parameters was studied and the best three performing parameter levels were identified.

Stage 4: Finding the best three combinations of parameters of which are used in L_9 orthogonal array

- Three levels in each set of parameters were selected. Using the L_9 orthogonal array, nine different combinations of parameters are obtained and the S/N ratio is calculated.

Stage 5: By applying Taguchi method, identify the best combination of parameters and finding more efficient still among solar still (v-type and roof type) to construct robust design

Choose the parameters from each level with the highest S/N ratio and combine them to create a robust design. Then select the second and third highest S/N ratio parameters and create a robust design. The experiments are done. Each robust design of parameters incorporate with roof type and v-type solar stills and also find the more efficient solar desalination still.

3. Experimental set-up

The experiments were conducted in Kerala at latitude of 11.748050 and a longitude of 77.694626. The wind speed at Thalasseri is 3.5 m/s and six sets of roof-type and v-type solar stills were built out of zinc sheet. Fabricated design details are given in Fig. 1.

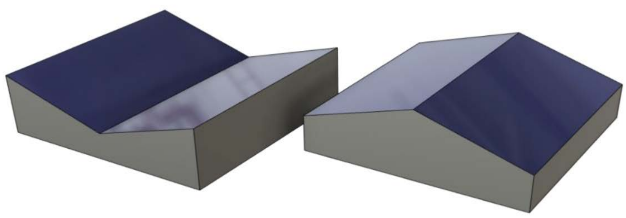


Fig. 1. Roof type and v-type solar desalination still.

3.1. Preparation of roof type solar still

A roof type solar still basin measures 1 m × 1 m. The height of the still was 30 and 14 cm on each side. The basin was constructed from zinc sheet, which has a thermal conductivity of 116 W/mK. The roof-type solar still basin was covered by a 3 mm-thick glass sheet. The water path arrangement was made to feed the basin with saline water and collect distilled fresh water from the basin into a fresh water storage bottle. In this experiment, basin liners have been converted to compartmental basins and corrugated basins. These two basins are made of the same zinc sheet and the corrugated basin has a five-pyramid structure from beginning to end. The compartmental basin size was 10 cm × 10 cm × 10 cm; further basins are converted to finned-type basins. 100 hollow square iron fins of size 2.5 cm × 2.5 cm × 8 cm After that, by using these basin arrangements, six types of basins are created. They are plain basins with fins, corrugated basins with fins and compartmental basins with fins. The schematic diagram of roof-type solar stills is shown in Fig. 1. The roof-type solar desalination still and other experimental components are shown in Fig. 2.

3.2. Preparation of v-type solar stills

The v-type solar still measured 1 m × 1 m at the base, 30 cm on each side wall and 14 cm in the center. The solar still is made by using zinc sheets with 11.6 W/mK thermal conductivity. The roof is covered by 3 mm glass. The feed water was saline water and fresh water was collected in a water bottle. For the v-type solar still, three types of basin trays are available: corrugated basins, compartmental basins and plain basins. The corrugated basin contains five pyramid type structures; the compartmental (15 cm × 20 cm × 8 cm) basin contains 15 compartments and the fins measuring 2.5 cm × 2.5 cm × 8 cm are attached to these three basic basin types. The temperature is measured by using a K-type thermocouple and wind velocity is measured by using an anemometer. A solarimeter is used to measure solar intensity. A measuring jar is used to measure the level of fresh water. From 8 a.m. to 8 p.m., readings were taken every hour. The experiments are conducted in Thalasseri, Kerala, in the month of March 2022. The following parameters are measured every 1 h. Inner and outer glass temperatures,

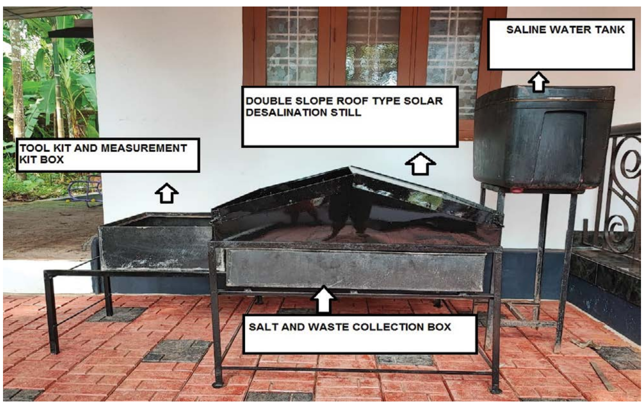


Fig. 2. Roof type solar desalination still with experimental components.

inner and outer basin temperatures, ambient air temperature inside the still and fresh water output. The v-type (double slope inward still) solar desalination still and other experimental components are shown in Fig. 3.

4. Impact of modifications on production

A study of the increasing productivity of roof-type and v-type solar systems is still being conducted as part of this effort. The performance studies of various parameters incorporated into stills are ranked in terms of distilled output, as shown in Table 2. On the performance level, parameters are ranked and the ideal combination of parameters optimizes the freshwater production of both roof type and v-type solar stills.

4.1. Basin liner design and distillate production

Basin liners have a strong influence on the distilled water production in roof type and v-type solar stills. The performance of six different basin conditions was investigated. The variation in the hourly production and cumulative production graphs are shown in Fig. 4.

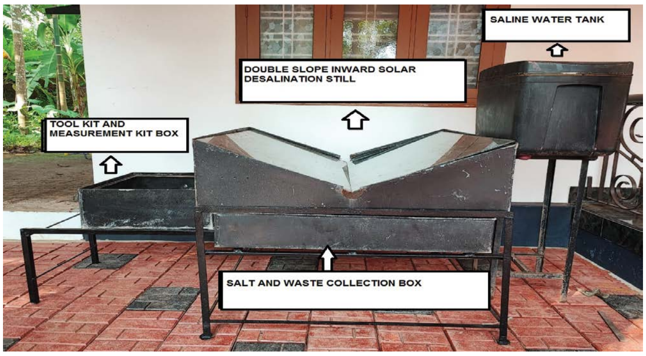


Fig. 3. V-type solar desalination still with experiment components.

Table 2
Performance levels of parameters incorporated with v-type and roof type

S. No	Parameters		v-type type basin		Roof-type basin	
	Roof type	v-type	Production ml/m²·d	Rank	Production ml/m²·d	Rank
	Basin liner conditions					
1	Black coated plain basin	Black coated plain basin	1,720	6	2,350	6
2	Black coated plain basin with fin	Black coated plain basin with fin	2,560	3	3,150	3
3	Black coated corrugated basin	Black coated corrugated basin	2,290	5	2,870	5
4	Black coated corrugated basin fins	Black coated corrugated basin fins	2,710	2	3,320	2
5	Black coated compartmental basin	Black coated compartmental basin	2,420	4	3,040	4
6	Black coated compartmental basin fin	Black coated compartmental basin fin	2,760	1	3,360	1
	Heat storage materials					
1	Pebbles	Pebbles	2,740	6	3,330	6
2	Granite	Granite	2,750	5	3,340	5
3	Blue metal	Blue metal	2,910	4	3,530	4
4	Marble stone	Marble stone	3,400	3	4,010	3
5	Lime stone	Lime stone	3,460	2	4,060	2
6	Black lime stone	Black lime stone	3,490	1	4,090	1
	Wick materials					
1	Black cotton	Black cotton	2,600	1	3,200	1
2	Black jute	Black jute	2,510	2	3,120	2
3	Black sponge	Black sponge	2,470	3	3,080	3
4	Mixed color cotton	Mixed color cotton	2,050	4	2,660	4
5	Jute cloth	Jute cloth	1,950	5	2,570	5
	Water depth					
1	10 mm	10 mm	1,710	1	2,310	1
2	15 mm	15 mm	1,650	2	2,250	2
3	20 mm	20 mm	1,580	3	2,190	3
4	25 mm	25 mm	1,440	4	2,060	4
5	30 mm	30 mm	1,350	5	1,970	5

Fig. 4. Compartmental basin, corrugated basin and plain basin with fin.

4.1.1. Effect of v-type stills on hourly water productivity with basin liners

In this experiment with a v-type solar still and different basin liner conditions, the maximum fresh water production is achieved by a finned compartmental basin with an output of 485 mL. Other modified basin liner production rates are 475, 445, 420, 400 and 300 mL, respectively for black coated corrugated basins with fins, black coated plain basins with fins, black compartmental basins, black coated corrugated basins and black coated plain basins. Results are shown in Fig. 5.

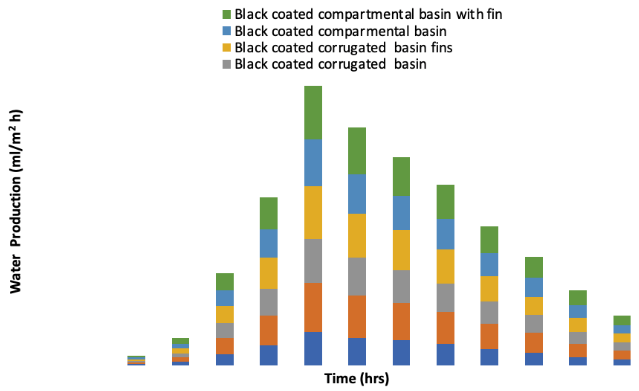


Fig. 5. Hourly performance of v-type incorporated with basin liner.

4.1.2. Effect of v-type stills on cumulative water productivity with basin liners

In the experiments using v-type with different basin liner conditions, the maximum cumulative fresh water production rate was achieved by using a compartmental basin with fin with an output of 2,760 mL and other modified basin liner production rates are 2,710; 2,560; 2,420; 2,290 and 1,720 mL, respectively for black coated corrugated basin with fin, black coated plain basin with fin, black compartmental basin and black coated corrugated basin. Results are shown in Fig. 6.

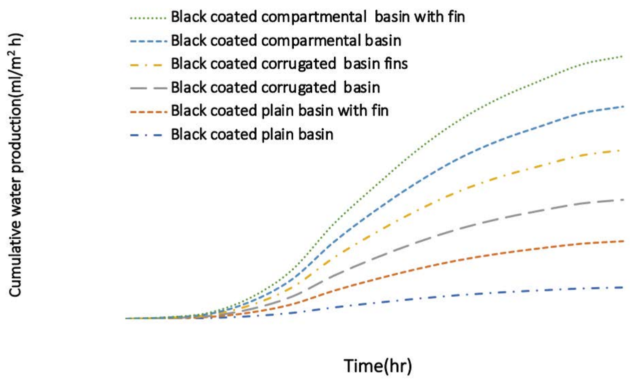


Fig. 6. Cumulative performance of v-type incorporated with basin liner.

4.1.3. Effect of roof-type stills on hourly water productivity with basin liners

For roof-type stills with different basin liner conditions, the maximum freshwater production rate per hour was achieved with a compartmental basin with a fin for an output of 590 mL. The production rates of other modified basin liners are 580, 555, 530, 505 and 405 mL, respectively for black coated corrugated basins with fins, black coated plain basins with fins, black compartmental basins, black coated corrugated basins and black coated plain basins. A result for the case is shown in Fig. 7.

4.1.4. Effect of roof-type stills on cumulative water productivity with basin liners

We used various roof types and basin liner conditions in the experiment. The maximum cumulative fresh water production rate achieved by using a compartmental basin with an output of 3,360 mL and other modified basin liner production rates are 3,310; 3,160; 3,020, 2,890 and 2,320 mL, respectively for black coated corrugated basins with fins, black coated compartmental basins, black coated corrugated basins and black coated plain basins. Results are shown in Fig. 8.

The roof type solar stills had higher hourly production and cumulative production than the v-type. The hourly and cumulative production up to forenoon are average; from 12 p.m. to 3 p.m., the production rate increased; it was at its peak in all stills from 1 p.m. to 2 p.m.

4.2. Heat storage materials in the basin

Heat storage materials (Fig. 9) are used to store heat from solar energy and release energy up to their capacity when the energy of the surroundings decreases, especially during the night.

4.2.1. Effect of roof-type stills on hourly productivity with heat storage materials

The heat storage materials used in both roof-type and v-type solar stills are pebbles, granite, blue metal, marble, limestone and black limestone. Each material measures 15–20 mm in length and weighs 10 kg. The specific heat capacities of each material are 745, 790, 840, 850, 880 and 890 J/kg·K, respectively.

The hourly variation and cumulative water collection are given in Figs. 10 and 11. The hourly production rate

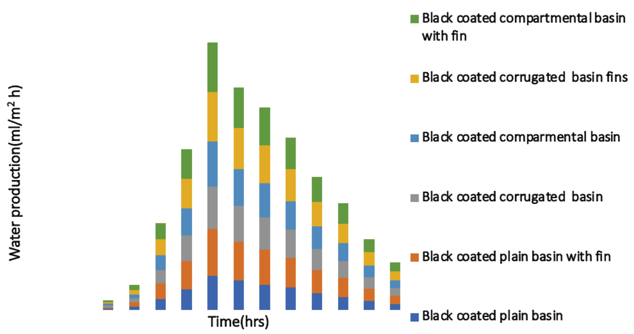


Fig. 7. Hourly performance of roof type incorporated with basin liner.

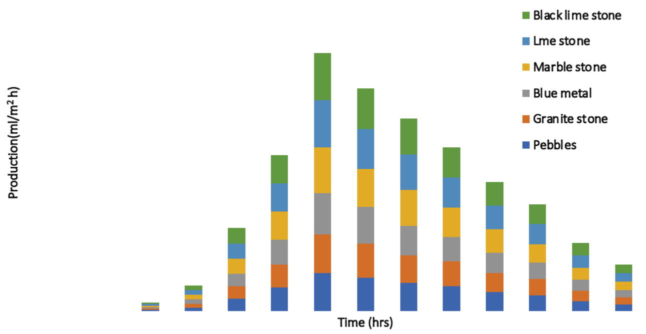


Fig. 10. Hourly performance of roof type incorporated with heat storage materials.

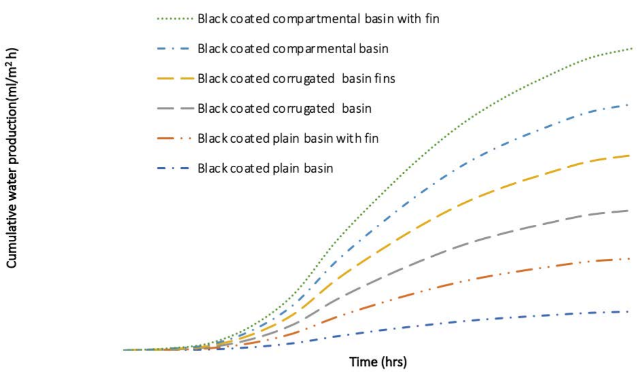


Fig. 8. Cumulative performance of roof type incorporated with basin liner.

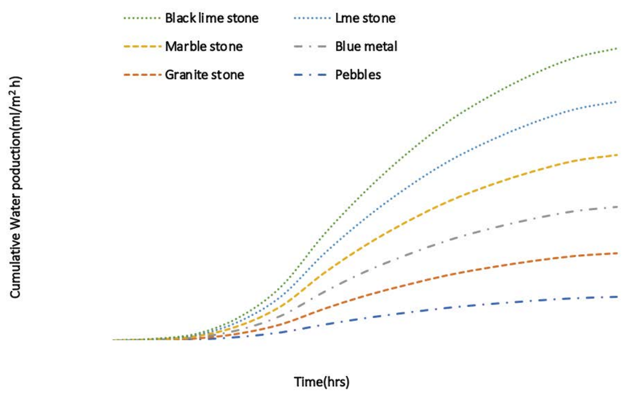


Fig. 11. Cumulative performance of roof type incorporated with heat storage materials.

Fig. 9. Heat storage materials (black limestone, limestone, blue metal, granite, marble, pebbles).

maximum is 715 mL during the period from 1 p.m. to 2 p.m. The highest production was reached at 810 mL when the black limestone storage material was used. 710, 700, 615, 585 and 580 mL are the other maximum production rates achieved with respect to limestone, marble stone, blue metal stone, granite stone and pebbles.

4.2.2. Effect of roof -type stills on cumulative productivity with Heat storage materials

The cumulative water collection in the roof-type still for fresh water production was a maximum of 4,090 mL during the time period from 8 a.m. to 8 p.m. and the maximum production is achieved when the black limestone is used. Other maximum fresh water production readings for limestone, marble stone, blue metal stone, granite stone and pebbles are 4,060; 4,000; 3,510; 3,350 and 3,340 mL, respectively.

4.2.3. Effect of v-type stills on hourly productivity with Heat storage materials

The hourly production of the v-type is still shown in Fig. 12. The hourly production rate reached a maximum of 610 mL during periods 1 and 2 when the black limestone was used. The other highest production rates respected for limestone, marble stone, blue metal stone, granite stone and pebbles are 605, 595, 510, 485 and 480 mL, respectively.

4.2.4. Effect of v-type stills on cumulative productivity with heat storage materials

The cumulative water production is shown in Fig. 13. In the v-type solar still for fresh water production, a maximum of 3,490 mL was produced during the time from 8 a.m. to 8 p.m. when black limestone was used. The other maximum readings of fresh water production are 3,460; 3,400; 2,910; 2,750 and 2,740 mL, respectively for limestone, marble stone, blue metal stone, granite stone and pebbles. Compared to v-type and roof-type solar stills incorporated with heat storage materials, the maximum of hourly and cumulative water production is achieved in the roof-type still with black limestone.

4.3. Wick materials in the basin

Wick materials (Fig. 14) are used to suck the water due to capillary action when the sun's light hits the upper surface of the wick materials. If the water goes to evaporate and condenses, it will get fresh water.

4.3.1. Effect of v-type stills on hourly productivity with wick materials

In this experiment, wick materials were used to cover the sides of the fins from the lower end to the bottom end. The wick materials that were used to improve production are coloured cotton, black cotton cloth, jute cloth, black sponge and black sponge. Results in cumulative and hourly water production are shown in Figs. 15 and 16.

The hourly production in the v-type still measured a maximum of 455 mL during the time period 1–2 and the other production rates were 440, 435, 360 and 340 mL, respectively for black jute, black sponge, mixed colour cotton and jute cloth.

4.3.2. Effect of V -type stills on cumulative productivity with wick material

The cumulative production in v-type still measured a maximum of 2,600 mL during the morning hours of 8 a.m. to 8 p.m. when the black cotton material was used. Other achieved production rates for black jute, black sponge, mixed colour cotton and jute cloth are 2,510; 2,470; 2,050 and 1,950 mL, respectively. Results are shown in Fig. 16.

4.3.3. Effect of roof type stills on hourly productivity with wick materials

The hourly production in roof-type was still 560 mL during time periods 1–2 and the other production rates were 545, 535, 465 and 450 mL for black jute, black sponge, mixed colour cotton and jute cloth, respectively. shown in Fig. 17.

4.3.4. Effect of roof type stills on cumulative productivity with wick material

The cumulative production in the roof-type still measured a maximum of 3,200 mL during the morning hours of 8 a.m. to 8 p.m. when the black cotton material was used. Other achieved production rates for black jute, black sponge, mixed colour cotton and jute cloth are 3,110; 3,070; 2,650 and 2,550 mL, respectively, shown in Fig. 18.

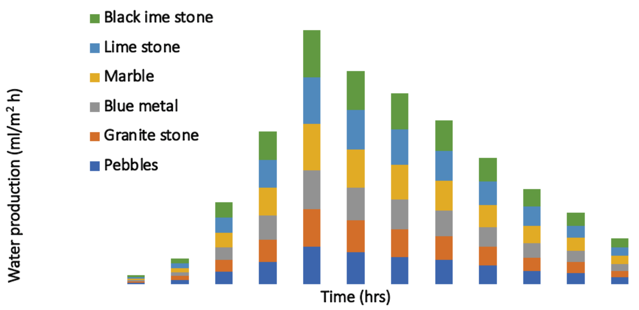


Fig. 12. Hourly performance of v-type incorporated with heat storage materials.

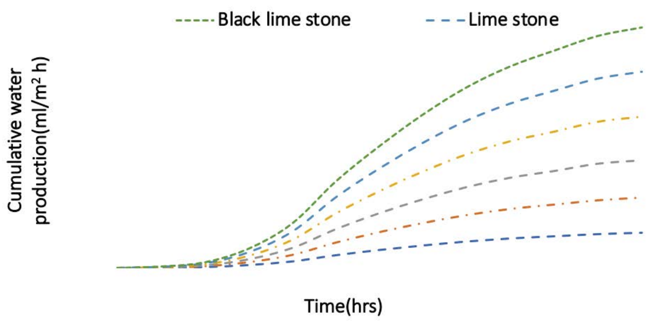


Fig. 13. Cumulative performance of v-type incorporated with heat storage materials.

Fig. 14. Wick materials (black cotton cloth, black jute cloth, black sponge, color cotton cloth, jute cloth).

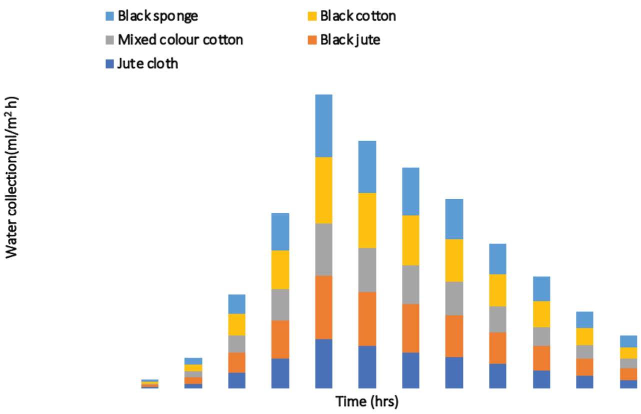


Fig. 15. Hourly performance of v-type incorporated with wick materials.

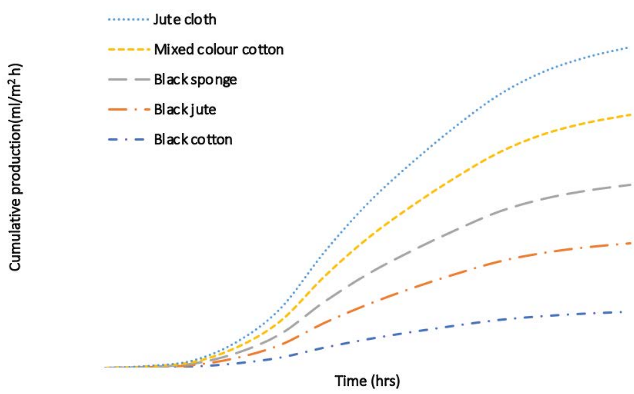


Fig. 16. Cumulative performance of v-type incorporated with wick materials.

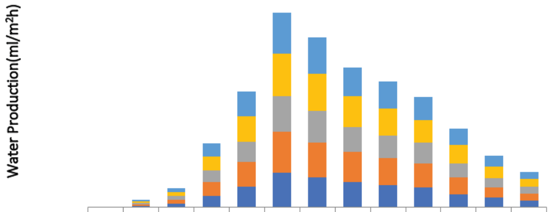
Compared to the roof type and the v-type solar still incorporating wick materials, the roof type with black cotton gives higher productivity than the v-type with black cotton cloth.

4.4. Basin water depth and distillate production

The effect of water depth in the basin has hardly any effect on the evaporation process as well as total fresh water production. In this experiment, five levels of water depth were examined in both stills; those are the 10, 15, 20, 25 and 30 mm results shown in Figs. 19–22, respectively.

4.4.1. Effect of roof type stills on hourly productivity with different water depth

In a roof type basin, 10 mm of water depth gives maximum fresh water production in an hourly variation of 405 mL and other readings respecting 15, 20, 25 and 30 mm are 395, 380, 355 and 340 mL, respectively.



	8	9	10	11	12	1	2	3	4	5	6	7	8
Jute cloth	0	20	50	175	325	535	475	380	350	305	215	145	95
Mixed colour cotton	0	20	55	180	335	560	490	405	360	299	246	150	100
Black sponge	0	15	45	160	270	465	420	320	295	275	180	120	85
Black jute	0	20	50	180	325	545	460	405	355	310	220	140	100
Black cotton	0	15	45	145	265	450	385	325	290	260	170	120	80

Fig. 17. Hourly performance of roof type incorporated with wick materials.

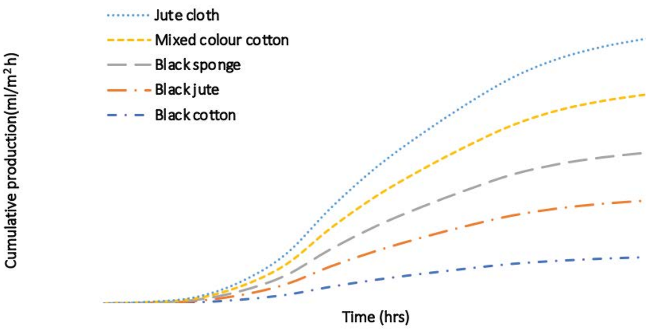


Fig. 18. Cumulative performance of roof type incorporated with wick materials.

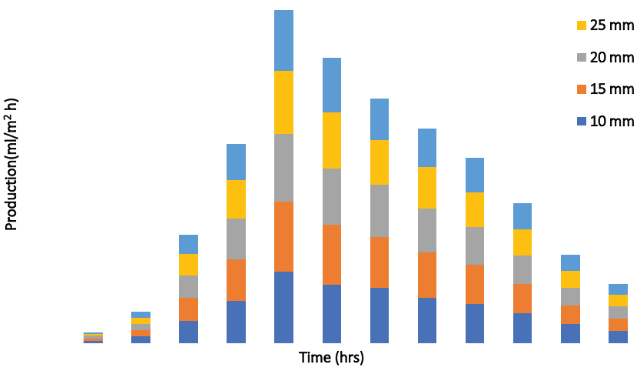


Fig. 19. Hourly performance of roof type incorporated with water depth.

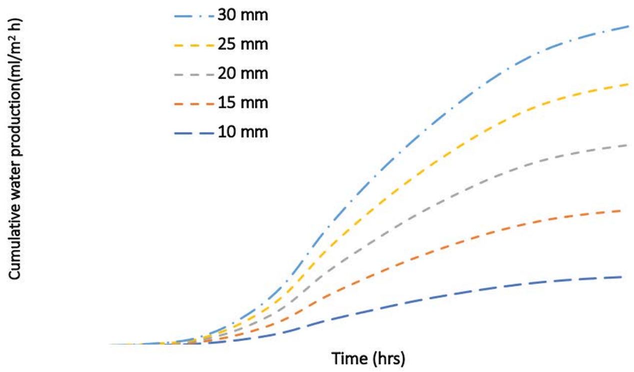


Fig. 20. Cumulative performance of roof type incorporated with water depth.

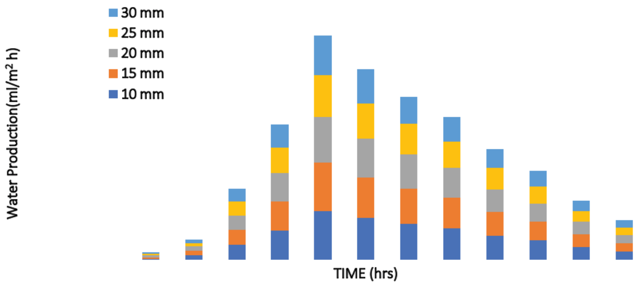


Fig. 21. Hourly performance of v-type incorporated with water depth.

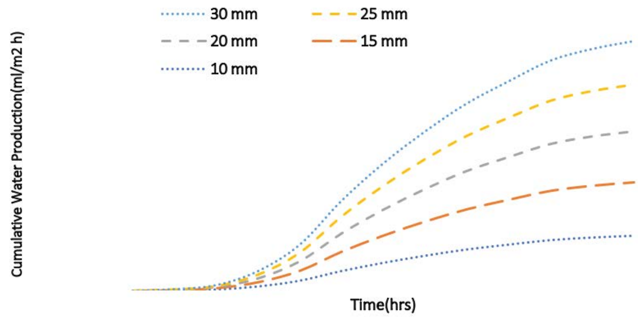


Fig. 22. Cumulative performance of v-type incorporated with water depth.

4.4.2. Effect of roof type stills on cumulative productivity with different water depth

In a roof-type basin, a water depth of 10 mm produces the most fresh water in a total of 2,310 mL, while readings at 15, 20, 25 and 30 mm produce 2,250; 2,180; 2,040 and 1,950 mL, respectively.

4.4.3. Effect of v-type stills on hourly productivity with different water depth

In a v-type basin, 10 mm of water depth produces the most fresh water in an hourly variation of 300 mL, while 15, 20, 25 and 30 mm produce 290, 275, 255 and 240 mL, respectively.

4.4.4. Effect of v-type stills on cumulative productivity with different water depth

In a v-type basin, a water depth of 10 mm produces the freshest water in a cumulative amount of 1,710 mL, while readings at 15, 20, 25 and 30 mm produce 1,650; 1,580; 1,440 and 1,350 mL, respectively. The results of both stills, 10 mm of water depth gives the best production rate. This means that a roof type still with 10 mm gives more yield than a v-type still.

4.5. Hourly variation in temperature with roof type solar still

The useful temperature measured in between the experiments is shown. Figs. 23 and 24 show the maximum water temperature inside the basin at 64.70°C and 640°C for roof type and v-type, respectively. The temperature is measured every hour using a K-type thermocouple. The outside glass roof temperature is always higher than the atmospheric temperature but lower than the bottom glass temperature. Analyzing Fig. 23, the evaporation and condensation processes are carried out properly for this experiment.

5. Thermal energy calculation of v-type and roof type solar still

The theoretical value for v-type and roof type solar still was calculated. The production of the solar still with external modifications was calculated using the technique used by Gnanaraj and Velmurugan [33]

Evaporative heat transfer (water to glass)

$$Q_{e,w-g} = h_{e,w-g}\left(T_w - T_g\right) \tag{1}$$

Evaporative heat transfer coefficient (water to glass)

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g}\left[\frac{\left(P_w - P_g\right)}{\left(T_w - T_g\right)}\right] \tag{2}$$

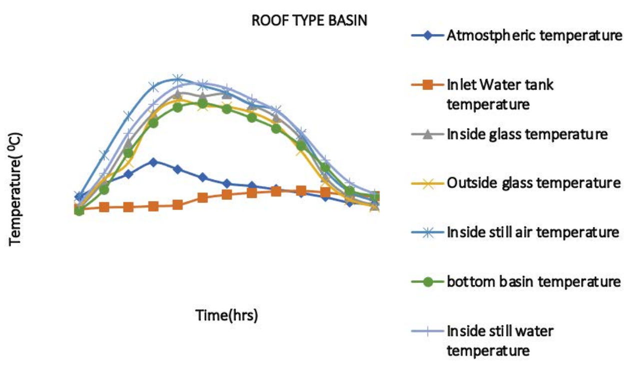


Fig. 23. Hourly performance of roof type incorporated with basin liner.

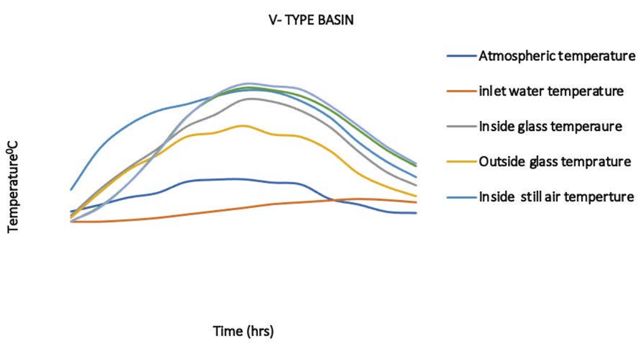


Fig. 24. Hourly performance of v-type incorporated with basin liner.

Saturated pressure for water

$$P_w = \exp\left[25.317 - \frac{5144}{\left(T_w + 273\right)}\right] \tag{3}$$

Saturated pressure for glass

$$P_g = \exp\left[25.317 - \frac{5144}{\left(T_g + 273\right)}\right] \tag{4}$$

Convective heat transfer coefficient (water to glass)

$$h_{c,w-g} = 0.884\left[\left(T_w - T_g\right) + \frac{\left(P_w - P_g\right)\left(T_w + 273\right)}{268.9 \times 10^3 - P_w}\right]^{1/3} \tag{5}$$

Determination of per hour production

$$m_e = \frac{Q_{e,w-g} \times 3,600}{L} \text{ ml/m}^2 \tag{6}$$

L– Latent heat of vapourzation = 2372000 J/kg

Determination of daily production

$$\text{yeild}_{\text{per day}} = \sum_{7\text{ am}}^{6\text{ pm}} m_e \tag{7}$$

Efficiency of the still is as follows

$$\eta_{\text{still}} = \frac{\sum m_e \times L}{\sum H \times A \times 3,600} \tag{8}$$

where m_e = Daily production (mL); H = Hourly solar radiation (W/m²); A = Area of basin (m²).

5.1. Comparison of freshwater production rate

The production of the roof type and v-type solar stills as per the experimental method is compared with the theoretical work and they are shown in Fig. 25. When the experimental and theoretical production values of roof-type and

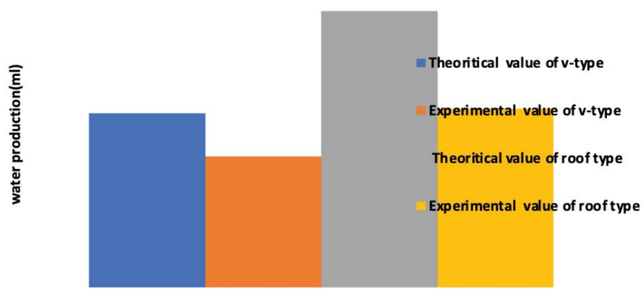


Fig. 25. Comparison of v-type and roof type basin.

v-type solar stills are compared, roof-type stills produce 45% more yield than v-type.

6. Optimizing (maximizing) the performance of v-type basin and roof type basin solar stills

The Taguchi method is used to reduce the number of experiments. As per Taguchi's orthogonal array, the three levels of four parameters are selected with respect to the ranking for optimizing the yield. As per the Taguchi orthogonal array, the three levels of four parameters make nine trails.

6.1. V-type and roof-type solar stills: identification of three levels of the four parameters

The best resulting three parameter levels of v-type and roof type were identified and they are summarized in Tables 3 and 4.

6.2. V-type basin solar still-identification of ideal combination of parameter levels

In terms of ranking, the optimal parameter combinations are combined into an orthogonal array. The nine experiments were conducted, with results shown in Table 5.

6.2.1. S/N ratios-v-type basin still

The results of signal to noise ratio for v-type solar still as per orthogonal array is set as larger is better. As per the S/N ratio results, level 1 of parameters 1, 2 and 3 is the better, which means a black coated compartmental basin, black limestone, black cotton cloth and 10 mm of water depth are the best combinations for v-type solar desalination still. The results are shown in Table 6 and Fig. 26.

The mean response for the S/N ratio of parameters shown in Fig. 27 and Table 7 The results are 4,623; 4,612; 4,620 and 4,617 mL, which are the maximum level results

Table 3
Three levels of the four parameters (roof type basin solar still)

Level \ Parameter	Basin liner	Basin material	Wick material	Basin water depth (mm)
Level I	Black coated compartmental basin with fins	Black limestone	Black cotton	10
Level II	Black coated corrugated basin with fins	Limestone	Black jute	15
Level III	Black coated plain basin with fins	Marble stone	Black sponge	20

Table 4
Three levels of the four parameters (v-type basin still)

Level \ Parameter	Basin liner	Basin material	Wick material	Basin water depth (mm)
Level I	Black coated compartmental basin with fins	Black limestone	Black cotton	10
Level II	Black coated corrugated basin with fins	Limestone	Black jute	15
Level III	Black coated plain basin with fins	Marble stone	Black sponge	20

Table 5
Combination of parameters levels and yield in the v-type still

Trial	Parameter-I	Parameter-II	Parameter-III	Parameter-IV	Output
	Basin liner	Basin material	Wick material	Basin water depth, mm	
1	Compartmental basin with fins	Black limestone	Black cotton	10 mm	4,660
2	Compartmental basin with fins	Limestone	Black jute	15 mm	4,630
3	Compartmental basin with fins	Marble stone	Black sponge	20 mm	4,580
4	Corrugated basin with fins	Black limestone	Black jute	20 mm	4,610
5	Corrugated basin with fins	Limestone	Black sponge	10 mm	4,620
6	Corrugated basin with fins	Marble stone	Black cotton	15 mm	4,625
7	Plain basin with fins	Black limestone	Black sponge	15 mm	4,565
8	Plain basin with fins	Limestone	Black cotton	20 mm	4,575
9	Plain basin with fins	Marble stone	Black jute	10 mm	4,570

Table 6
S/N ratios for different parameter levels (v-type basin still)

Level	Parameter I	Parameter II	Parameter III	Parameter IV
	Basin plate	Basin materials	Wick materials	Basin water depth
1	73.30	73.28	73.29	73.29
2	73.29	73.27	73.26	73.27
3	73.20	73.24	73.23	73.23
Delta	0.10	0.04	0.06	0.05
Rank	1	4	2	3

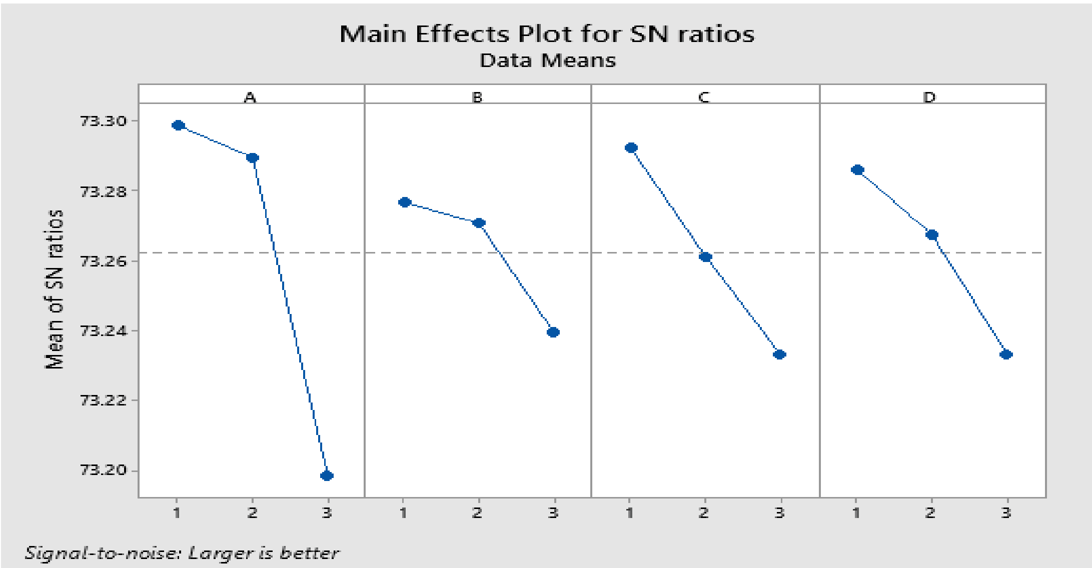


Fig. 26. Main effects plots for S/N ratio.

Fig. 27. Main effects plots for S/N ratio.

Table 7
S/N ratios for different parameter levels (v-type basin still)

Level	Parameter I	Parameter II	Parameter III	Parameter IV
	Basin plate	Basin materials	Wick materials	Basin water depth
1	4,623	4,612	4,620	4,617
2	4,618	4,608	4,603	4,607
3	4,570	4,592	4,588	4,588
Delta	53	20	32	28
Rank	1	4	2	3

6.2.2. Roof type basin solar still-identification of ideal combination of parameter levels

Table 8
Combination of different parameters levels and production in the roof type basin

Trial	Parameter-I	Parameter-II	Parameter-III	Parameter-IV	Output
	Basin liner design	Basin material	Wick material	Basin water depth, mm	
1	Compartmental basin with fins	Black limestone	Black cotton	10 mm	5,280
2	Compartmental basin with fins	limestoNE	Black jute	15 mm	5,240
3	Compartmental basin with fins	Marble stone	Black sponge	20 mm	5,210
4	Corrugated basin with fins	Black limestone	Black jute	20 mm	5,220
5	Corrugated basin with fins	Limestone	Black sponge	10 mm	5,250
6	Corrugated basin with fins	Marble stone	Black cotton	15 mm	5,230
7	Plain basin with fins	Black limestone	Black sponge	15 mm	5,180
8	Plain basin with fins	Limestone	Black cotton	20 mm	5,190
9	Plain basin with fins	Marble stone	Black jute	10 mm	5,200

Table 9
S/N ratios for different parameter levels (v-type basin still)

Level	Parameter I	Parameter II	Parameter III	Parameter IV
	Basin plate	Basin materials	Wick materials	Basin water depth
1	74.39	74.36	74.38	74.39
2	74.38	74.36	74.35	74.35
3	74.30	74.34	74.34	74.33
Delta	0.09	0.02	0.03	0.06
Rank	1	4	3	2

for black coated compartmental basins, black limestone, black cotton cloth and 10 mm water depth, respectively.

6.2.3. S/N ratios-roof basin still

The results of signal to noise ratio for v-type solar still as per orthogonal array is set as larger is better. As per the S/N ratio results, level 1 of parameters 1, 2 and 3 is the better, which means a black coated compartmental basin, black limestone, black cotton cloth and 10 mm of water depth are the best combinations for v-type solar desalination still. The results are shown in Tables 8 and 9 and Fig. 28.

The mean responses for the S/N ratio of parameters are shown in Fig. 29 and Table 10. The results are 4,623; 4,612; 4,620 and 4,617 mL, which are the maximum level results for black coated compartmental basins, black limestone, black cotton cloth and 10 mm water depth, respectively.

6.3. Robust design v-type basin and roof type basin solar stills

For optimizing the fresh water productivity of the roof type and v-type solar stills, they are designed as per Taguchi technique and the robust designs for roof type and v-type solar stills are fabricated. The robust design for both roof types, still and v-type, was a compartmental basin as the basin plate, lime black limestone as heat storage material, black cotton as wick material and 10 mm as water depth. Compare both still experimental result roof type basin with parameters gives more result.

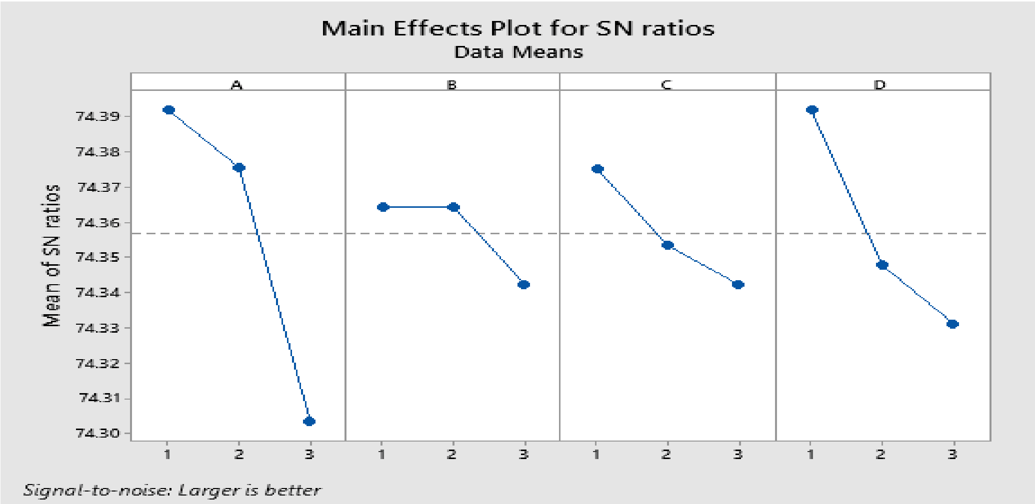


Fig. 28. Mean response for S N ratio of parameter.

Fig. 29. Main effects plots for S/N ratio.

Table 10
Mean response values for parameter levels (v-type basin still)

Level	Parameter I	Parameter II	Parameter III	Parameter IV
	Basin plate	Basin materials	Wick materials	Basin water depth
1	5,243	5,227	5,233	5,243
2	5,233	5,227	5,220	5,217
3	5,190	5,213	5,213	5,207
Delta	53	13	20	37
Rank	1	4	3	2

7. Conclusion

Six sets of roof-type and v-type solar stills are fabricated. Experimentally, the best three parameters are selected from a set of parameters. Using the L_9 orthogonal array and the best three parameters from each set, nine different combinations of parameters are obtained. Each set of parameters' signal-to-noise ratio has been determined and the robust design was chosen from those with the highest S/N ratio among the parameters.

The main findings of the study are listed:

- Out of two types of desalination stills (roof type and v-type), the roof type basin is 36% more efficient than the v-type solar desalination still.
- Comparing the theoretical water production rates of conventional roof type and v-type solar desalination stills, conventional roof type is 45% more efficient than v-type solar stills.
- Among the four sets of operational parameters taken for the study, a black coated compartmental basin, a black limestone, a black cotton cloth and a 10 mm water depth were identified as the best combinations for both still and fresh water production.
- Among the four sets of operational parameters considered for optimizing the fresh water production, the basin plate design is given first priority, the basin water depth is given second priority, the wick materials are given third priority and the heat storage is given fourth priority.
- The theoretical estimation for the maximum production of the robust design roof type was still 5,423 mL and the experimental result was 5,280 mL. The experimental and theoretical results are found to be in good agreement.
- The estimated optimum distillate from the robust design v-type solar still was 4,623 mL and experimental production was 4,660 mL. Here also, agreement between the two was seen.

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