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PARAMETRIC OPTIMIZATION FOR IMPROVING THE PERFORMANCE OF SINGLE SLOPE SOLAR STILL THROUGH EXPERIMENTAL STUDIES

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ABSTRACT

An attempt is made to improve the performance of single slope solar still for the production of fresh water in this study. The prime aim is to experimentally investigate the influence of control factors namely stone quantity, sea water level and double glazing on the yield of the solar still. Nine experiments were conducted based on Taguchi's orthogonal array. It is noted that double glazing effect makes substantial improvement in the yield of solar still. A non-linear regression model is also developed for the process. The optimum parametric conditions are found through the Taguchi method and genetic algorithm. It is confirmed that the optimum conditions exhibit nearly 57% enhancement in the yield than the yield of conventional solar still without stone bed and double glazing effect.

KEYWORDS: solar still, energy storage medium, double glazing effect, yield, Taguchi method, genetic algorithm.

INTRODUCTION

Solar still converts saline water into fresh water using solar energy. In the single slope solar still, the water to be desalinated is kept in a container called basin. The basin is enclosed with an inclined glass to make a closed container. The provisions are made in the basin for filling the water to be desalinated and for collecting the fresh water produced. When the still is placed under sun, the solar radiation enters the glass cover and reaches the bottom of the basin. The heat absorbed by the basin is transferred to the saline water by convection. The saline water gets vapourized and the vapour rises upwards. The vapour gets condensed under the glass, drips downward and reaches the fresh water collector. All contaminates present in the water accumulate in the basin and concentrated saline water is removed every day and fresh saline water is to be filled for making further pure water.

The solar desalination using a solar still is mainly tried in the regions where sea water and solar radiation are available abundant, like in Gulf region where other sources are not able to supply the required quantity of fresh water. The solar stills are not only used to get fresh water for domestic use, but also for the industrial use. In a conventional solar still, large amount of heat is dumped on the glass cover during the condensation process. The heat is also transferred from basin water to glass by convention and radiation. Nearly 25% of solar energy received is lost to the atmosphere through glass cover by both convention and radiation (Tiwari and Tiwari, 2008). The loss of energy from the still can be reduced by placing another layer of glass or plastic sheet over the glass. This arrangement in the solar still is called double glazing. The double glazing allows larger portion of the solar radiation into the solar still and limits the heat loss from glass to the atmosphere by as much as 50% and same is utilized for making more fresh water (Benhammou and Draoui, 2013).

LITERATURE REVIEW

Many authors (Kabeel and El-Agouz, 2011; Gawande et al., 2013) presented an exhaustive review on various developments of the solar stills. They discussed the methods and modifications used in the conventional solar still to improve the productivity. The yield of the conventional solar still was improved by modifying the parameters like water column height, placing energy storage medium in the basin, artificial cooling of condensing glass, glass slope, thickness of glass cover, etc. Few researchers (Kumar et al., 2015; Elango and Murugavel, 2015) modified the conventional still by the addition of multiple or stepped basins and they observed that the modification yielded more fresh water because of higher level of energy utilizations. In the multi basin solar still, the latent heat released in the lower basin was used to heat the upper basin water. Wick-types solar stills were developed by few researchers (Mahdi et al., 2011) to increase the yield to get more fresh water. This arrangement yielded more surface area for the water vaporization and more solar radiation absorption.

Panchal and Shah (2011) studied the effect of glass cover thickness on the fresh water yield. They observed that the reduced glass cover thickness produced more fresh water in a day because the lower glass cover thickness increased heat transfer rate. Tiwari and Tiwari (2005) conducted experiments to study the effect of slope of glass cover on the yield and developed a model representing the relationship between the slope and heat transfer coefficients under indoor conditions. Srivastava and Agrawal (2012) conducted experiments using basins with black and white colour lining and observed that black coated solar still produced more yield. This was due to the absorption of more solar radiation by block colour. Madhav (2011) studied the effect of black granite basin material on fresh water production and noticed a considerable increase of yield in the solar still having black granite basin than the mild steel basin.

Energy storing medium is placed inside the basin water for improving the yield. The energy storing medium absorbs heat during the solar radiation and gives this energy to the basin water during the non-sun shining period, leads to higher water production. Sakthivel and Shanmugasundaram (2008) used gravel as energy storing medium and observed that solar still basin with black granite gravel was able to improve the yield by 18%. Tabrizi and Sharak (2010) used sand reservoir as energy storing medium in an integrated basin solar still and found that the sand reservoir was able to improve the productivity of the solar still during night and cloudy condition. Abdallah et al. (2009) investigated the effect of coated and uncoated metallic wiry sponges and black volcanic rocks. Their results indicated that the uncoated sponge had the highest water yield followed by the black rocks and then coated metallic wiry sponges.

Tiwari and Tiwari (2006), and Tarawneh (2007) studied the effect of basin water depth and concluded that the water depth significantly influenced the productivity. The increased water depth took more amount of solar radiation for warming up and reduced the energy available for vaporization. Shallow depth water was quickly heated up and vapourized.

Edeoja et al. (2015) studied the effect of multilayer glass cover with and without air gap between the layers. They found that single layer glass produced more yield in day time and two layers separated with an air gap gave more yield in night time. Benhammou and Draoui (2013) investigated the performance of double glazed still having a separate condensing chamber. They concluded that the temperature difference between basin water and inner surface of glass cover decreased because the components of solar still attained higher temperature. Mink et al. (1998) conducted experiments to investigate the effect of double glazing effect on the yield and noted a significant improvement in the yield. Rai et al. (2013) investigated the effect of air cooling of condensing surface of a single basin double slope solar still. They achieved 17% additional fresh water with the increased temperature difference between the water surface and condensing glass cover. Many authors (Verma et al., 2013; Kumar et al., 2009) have employed various optimization tools like Taguchi method, genetic algorithm, response surface methodology, etc for improving the performance of solar still.

The daily production of the fresh water also known as the yield of solar still depends on numerous parameters such as atmospheric temperature, solar intensity, wind velocity, sea water level in the basin, degree of salinity, inlet temperature of the sea water, slope of the glass cover, double glazing effect, presence of heat storage medium, etc. From the literature, it is observed that the performance of solar still depends on the important parameters namely energy storage medium, saline water level in the basin and double glazing area.

EXPERIMENTAL SETUP

A schematic of the solar still fabricated is shown in Figure 1. It consists of a basin made using 3 mm fiber glass material. The basin was covered with 22° sloped glass cover which acted as a solar collector. The basin was made air tight by applying silica gel at the joining surfaces. The provisions were made to supply sea water into the basin, to collect fresh water produced and to flush out salt concentrated sea water from the basin. The basin was placed on a mild steel frame and was insulated with polyurethane foam of 5 mm thickness to avoid heat loss from the sides and bottom of the basin. The inner side of the basin was painted black to absorb more heat during sun radiation. The specification of the solar still components is given in Table 1.

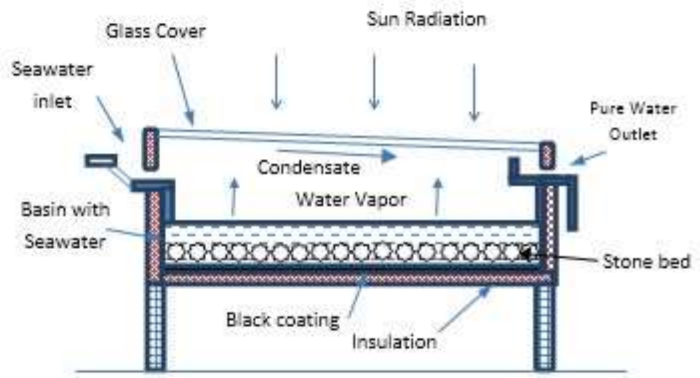

Figure 1 Solar still

Table 1 Specifications of the solar still

S. No.	**Dimension**	**Size**
1	Length of the still	1 m
2	Width of the still	1 m
3	Inclination of glass cover	22°
4	Depth of basin in front side	0.20 m
5	Depth of basin in back side	0.62 m
6	Thickness of glass cover	5 mm

The double glazing arrangement was done by covering glass cover of the solar still with a PVC sheet. The double glazing is able to reduce the heat loss to atmosphere and leads to increase of solar still productivity. The study was carried out by placing Omani rock stone bed as an energy storing medium. The basin of solar still was filled with sea water at certain level. The experiments were conducted by varying the double glazing area from 70 % to 90% for three clear sky days. The experiment was started on 6.00 a.m. on April 1st 2015 and completed on April 30th 2015 at 6.00 a.m. In this research work, the experiments were conducted in Muscat, Oman (Oman Latitude 23.617 / Longitude 58.583).

The solar still was placed with the tilted glass facing the sun (facing south) for all the experiments conducted. When the still was placed under the sun radiation, the incident solar radiation was transmitted through the glass cover. The sea water was thus heated and gave off water vapour. The water vapour was raised upwards and left the salt and other contaminates in the basin. The water vapour condensed on the glass cover and the condensed fresh water was collected in a storage container. The fresh water yield was measured on an hourly basis using a measuring jar. Every day, the salts and other contaminants left behind in the sea water were flushed out and basin was filled with fresh sea water before starting the next experiment. The experiments were repeated on second and third days under the same condition and measurements were recorded.

RESULTS AND DISCUSSION

As mentioned earlier, the same experimental setup was employed for the conduct of experiments. Three important control factors namely Omani rock stone quantity (A), sea water level in the basin (B) and double glazing area (C) were considered in this study.

Stone quantity, A (kg) : $20 \le A \le 30$
Sea water level, B (mm) : $40 \le B \le 60$
Double glazing area, C (%) : $70 \le C \le 90$

All control factors were set at three levels within the above bounds. The control factors and their levels are given in Table 2. Nine experiments were conducted based on the orthogonal array $L_9(3)^4$.

Table 2 Control factors and their levels

Control factor	Notation	Level 1	Level 2	Level 3
Stone quantity (kg)	A	20	25	30
Sea water level (mm)	B	40	50	60
Double glazing area (%)	C	70	80	90

Taguchi Method

S/N Ratio

The yield of solar still has been chosen as the output response with the category of quality characteristic "larger-the-better". The S/N ratio for the yield was calculated using Equation (1) for each parametric condition and their values are given in Table 3.

$$\mathrm{S/N(dB)} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{R_i^2}\right) \tag{1}$$

where i = 1, 2, ..., *n* (here *n* = 3) and *Yi* is the S/N ratio for the j^{th} parametric setting.

Table 3 Design of Experiments

EX. No	Control factor A	B	C	Yield (litre) R_1	R_2	R_3	R_{avg}	S/N ratio (dB)
1	1	1	1	2.83	2.55	2.74	2.71	8.628204333
2	1	2	2	2.53	2.72	2.22	2.49	7.835669145
3	1	3	3	3.13	3.14	3.15	3.14	9.942849983
4	2	1	2	2.36	2.17	2.27	2.27	7.090411247
5	2	2	3	3.15	3.39	3.29	3.28	10.30112768
6	2	3	1	3.4	3.05	2.95	3.13	9.877200264
7	3	1	3	3.02	3.05	3.22	3.10	9.811946768
8	3	2	1	3.25	3.36	3.23	3.28	10.31792382
9	3	3	2	2.5	2.37	2.48	2.45	7.780430614

Optimum Condition

In order to find the optimum level of the control factors, the average S/N ratio response was estimated for every level of each factor. The corresponding details are given in Table 4. Based on the highest value of the S/N ratio, an optimum level for each control factor (A: 3rd level; B: 2nd level; C: 3rd level) and optimum condition $A_3 B_2 C_3$ (stone quantity: 30 kg, sea water level: 50 mm and double glazing area: 90%) were noted. The response graphs shown in Figures 2 - 4 describe the variation of each process parameter towards output response. From the response graphs, it has been observed that the control parameter C has more variation on the output response than the control factors A and B. Percentage contribution for various control factors is shown in Figure 5.

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Table 4 Average S/N ratio

	A	B	C
level 1	8.80	8.51	9.61
level 2	9.09	9.48	7.57
level 3	9.30	9.20	10.02
Max-Min	0.50	0.97	2.45
Rank	3	2	1
Optimum level	A3	B2	C3
Contribution (%)	12.77	24.83	62.4

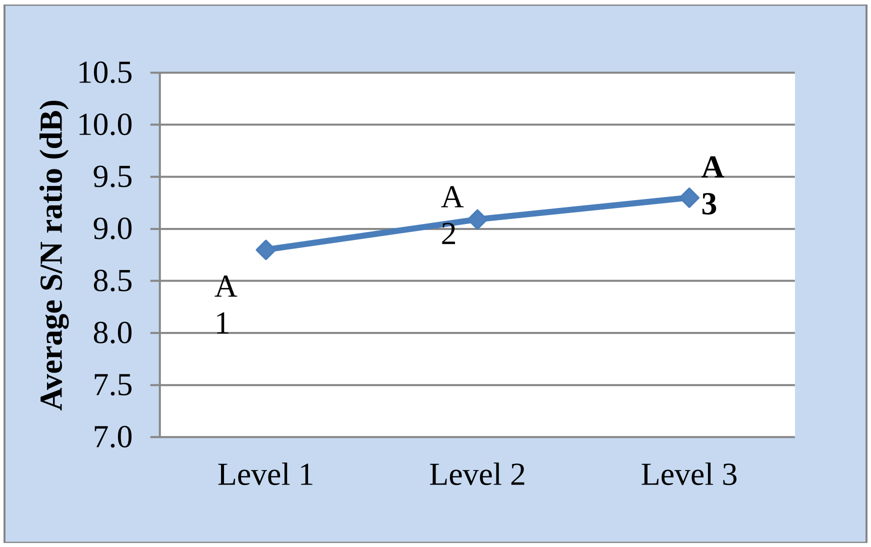

Figure 2 Response graph for control factor A

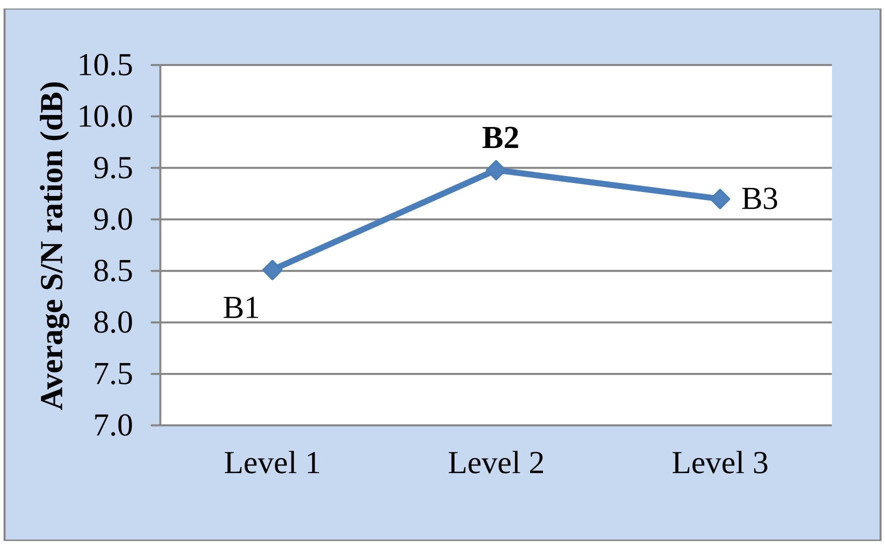

Figure 3 Response graph for control factor B

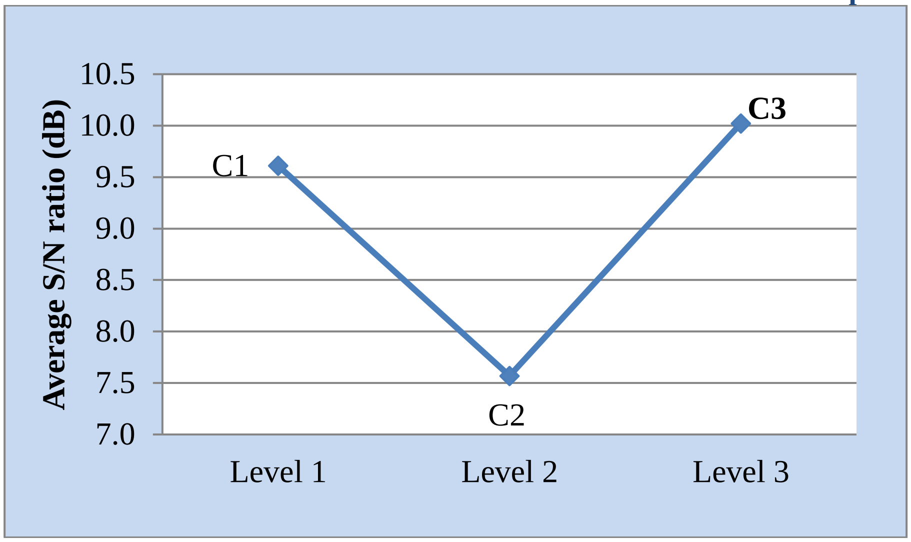

Figure 4 Response graph for control factor C

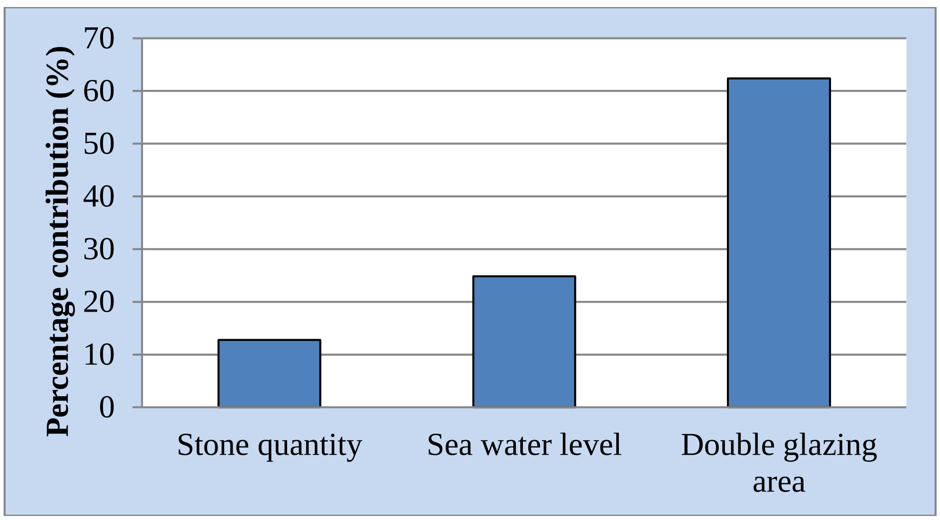

Figure 5 Percentage contributions of control factors

Genetic Algorithm

Regression Model

The relationship between the control factors and their effect on the average yield of the solar still was modeled by using non-linear regression analysis with the help of statistical analysis software MINITAB. The model developed is given in Equation (2).

$$Yield_{avg} = 3.45667 + 0.375A + 1.185B - 2.62667C - 0.03167A^2 - 0.22167B^2 + 0.65667C^2 - 0.09333AB + 0.01\,AC \qquad (2)$$

For this model, it was found that $r^2 = 0.99$ where r is correlation coefficient. The value of r^2 indicates the closeness of the model representing the process. Since r^2 is nearing unity, this model can be taken as an objective function for the application of genetic algorithm.

Optimum Condition

MATLAB genetic algorithm solver was used to find the optimum parametric setting for the maximization of average yield ($Yield_{avg}$) in this study. The mathematical model given in Equation (2) was used as fitness function (objective function). The bound (constraint) for control factors were fixed as per coded option.

	Lower bound	Upper bound
Stone quantity (A)	1	3
Sea water level (B)	1	3
Double glazing area (C)	1	3

Genetic algorithm was run for the evolutionary parameters such as population type (double vector), population size (20), fitness selection function (stochastic), probability of crossover (0.8) and probability of mutation (0.03). It was observed that the fitness value was decreased through generations as shown in Figure 6 and an optimized yield (3.34 litre) was obtained in the 51st generation. The optimum parametric setting in the final generation was noted as follows.

	Coded Condition	Uncoded Condition
Stone quantity	3	30 kg
Sea water level	2.046	51.15 mm
Double glazing area	3	90%

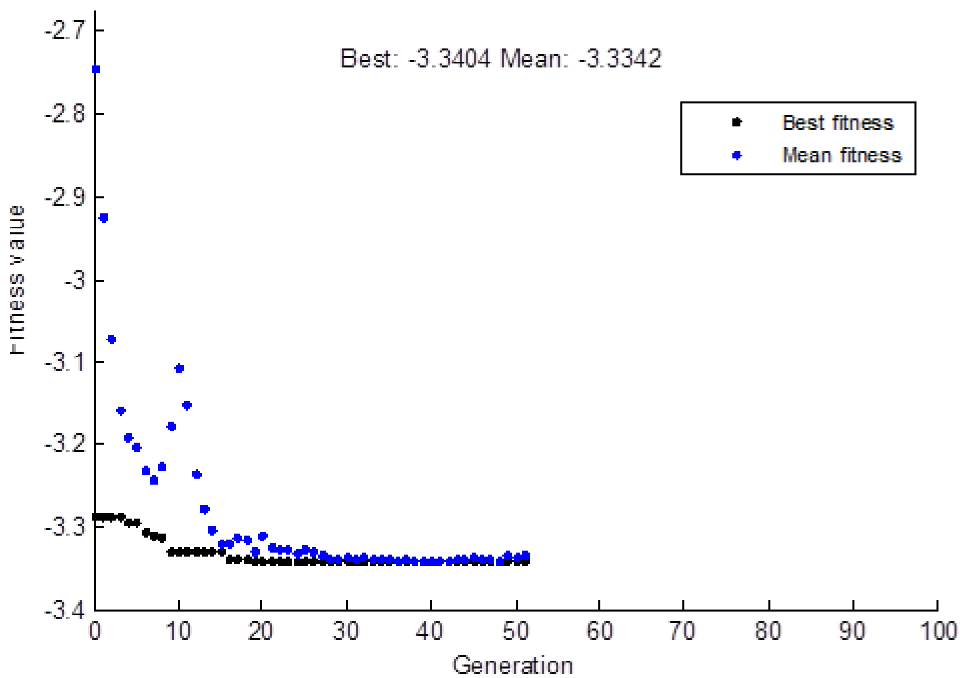

Figure 6 GA generations

Confirmation Experiments

Confirmation experiments were conducted for the optimum parametric conditions suggested by Taguchi Method and genetic algorithm. Average yield (predicted and tested) values are given in Table 5. It is evident that there is a good agreement between the predicted and actual yield since the error is less than 2%. The pH value for the fresh water after solar distillation was measured as 6.75 which was noted to be in the acceptable range of Omani Standard (6.5 – 8.0) for un-bottled drinking water.

Table 5 Optimum parametric conditions

Optimization tool	Optimum parametric condition			Average yield (litre)		% error
	Control factor	Coded	Uncoded	Predicted	Tested	
Taguchi method	Stone quantity	3	30 kg	3.34	3.3	1.2
	Sea water Level	2	50 mm			
	Double glazing area	3	90%			
Genetic algorithm	Stone quantity	3	30 kg	3.34	3.4	1.76
	Sea water level	2.046	51 mm			
	Double glazing area	3	90%			

CONCLUSION

The following are the conclusions drawn based on the performance of the solar still for the production of fresh water from sea water.

i) From percentage contribution, it has been noted that double glazing area has a greater effect on the yield followed by sea water level and stone quantity.
ii) From the results obtained, a regression model has been developed for the yield of solar still. From the model equation, the value of yield can be predicted if the values of quantity of stone, sea water level and double glazing area are known.
iii) From the confirmation experiments, it has been noticed that the error occurred is less than 2% between the predicted model value and tested value.
iv) The optimal settings of control factors for optimal yield can be used wherever solar still is used for the production of fresh water.
v) It has been confirmed that the optimum conditions exhibit nearly 57% enhancement in the yield than the yield of conventional solar still without stone bed and double glazing effect.

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REFERENCES

[1] Abdallah, S., Abu-Khader, M.M. and Badran, O., 2009. Effect of various absorbing materials on the thermal performance of solar stills, Desalination, 242(1), pp.128-137.
[2] Benhammou Mohammed, Draoui Belkacem, 2013, Effect of Double Glazing on the Thermal Performances of a Solar Still Coupled to a Condenser, ISESCO Journal of Science and Technology, Vol. 9 (15), pp. 2-8.
[3] Edeoja A.O., Unom Fadoo and Edeoja J.A., 2015, Investigation of the Effect of Cover Thickness on the Yield of a Single Basin Solar Still under Makurdi Climate, International Journal of Engineering Science Invention,Volume 4, Issue 1, pp.1-8.
[4] Elango T. and Murugavel K.K, 2015,The effect of the water depth on the productivity for single and double basin double slope glass solar stills, Desalination, Vol.359, 2 pp. 82–91.
[5] Gawande, J.S., Bhuyar, L.B. and Deshmukh, S.J., 2013, Effect of depth of water on the performance of stepped type solar still. International Journal of Energy Engineering, Vol.3(4), pp.137-143.
[6] Kabeel A.E. and El-Agouz S.A., 2011, Review of researches and developments on solar stills, Desalination, Vol. 276, pp.1-12.
[7] Kumar, P.V., Kumar, A., Prakash, O. and Kaviti, A.K., 2015, Solar stills system design: A review. Renewable and Sustainable Energy Reviews, Vol51, pp.153-181.
[8] Kumar, G.S., Mahendra, A.K., Sanyal, A. and Gouthaman, G., 2009, Genetic algorithm-based optimization of a multi-stage flash desalination plant. Desalination and Water Treatment, Vol.1(1-3), pp.88-106.

[9] Madhav J., 2011, Performance of Black Granite Basin Solar Still, International Journal of Tech Science, Vol. 2, No. 2, pp. 161-168.

[10] Mahdi J.T, Smith B.E. and Sharif A.O., 2011, An experimental wick-type solar still system: Design and construction, Desalination, Vol. 267, 233-238.

[11] Mink G., Horvath L., Evseev E. G. and Kudish A. I., 1998, Design parameters, performance testing and analysis of a double-glazed, air-blown solar still with thermal energy recycle, Solar Energy Vol. 64 (4-6), pp. 265-277.

[12] Panchal H.N. and Shah P.K., 2011, Effect of Varying Glass cover thickness on Performance of Solar still: in a Winter Climate Conditions, International Journal Of Renewable Energy Research, Vol.1 (4), pp.212-223.

[13] Rai, A.K., Singh, N. and Sachan, V., 2013, Experimental study of a single basin solar still with water cooling of the glass cover. International Journal of Mechanical Engineering & Technology, Vol.4(6), pp.1-7.

[14] Sakthivel, M. and Shanmugasundaram, S., 2008, Effect of energy storage medium (black granite gravel) on the performance of a solar still. International Journal of Energy Research, Vol. 32, pp. 68-82.

[15] Srivastava P.K. and Agrawal S.K, 2012, Experimental Investigation of Some Design and Operating Parameters of Basin Type Solar Still, International Journal of Emerging Technology and Advanced Engineering , Vol. 2 (5), pp.225-230.

[16] Tabrizi, F.F. and Sharak, A.Z., 2010. Experimental study of an integrated basin solar still with a sandy heat reservoir. Desalination, 253(1), pp.195-199.

[17] Tarawneh, M.S.K., 2007, Effect of Water Depth on the Performance Evaluation of Solar Still, Jordan Journal of Mechanical and Industrial Engineering. Vol. 1 (1), pp. 23-29.

[18] Tiwari A.K and Tiwari G.N., 2005, Effect of condensing cover's slope on internal heat and mass transfer in distillation: an indoor simulation, Desalination, Vol. 180, pp 73-88.

[19] Tiwari A.K and Tiwari G.N., 2006, Effect of Water Depths on Heat and Mass Transfer in a Passive Solar Still: In Summer Climatic Condition", Desalination, Vol. 195, pp. 78-94

[20] Tiwari G.N. and Tiwari A.K., 2008. Solar Distillation Practice for Water Desalination Systems, Anshan Ltd, New Delhi, India.

[21] Verma, V.K., Rout, I.S., Rai, A.K. and Gaikwad, A., 2013, Optimization of parameters affecting the performance of passive solar distillation system by using Taguchi method. IOSR Journal of Mechanical and Civil Engineering, Vol.7(2), pp.37-42.