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Research Article

Investigation of the Effect of Process Parameters on the Productivity of Single Slope Solar Still: A Taguchi Approach

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Abstract

The present work focuses on the application of Taguchi technique to investigate the effect of water temperature, inclination angle, salt concentration and water depth on the performance of the single slope solar stills inclined at 25^0, 30^0 and 35^0. An indoor simulation model was developed using constant temperature water bath to maintain water temperatures at steady state for the purpose of experiment. The condensing covers inclined at 25^0, 30^0 and 35^0 were fabricated of commonly used glass sheet to form top inclined cover and GRP sheets to make the side walls of the cover. This research outlines the Taguchi's Parameter Design Approach, which has been applied to optimize the process parameters which affect the productivity of single slope solar still. The factors evaluated are salt concentration, water depth, and inclination angle and water temperature. An orthogonal array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to analyse the effect of these factors. An orthogonal array has been used to plan the experiments. The raw data analysis and signal-to-noise ratio analysis have been employed to analyse the influence of the process parameters on the distillate output of single slope solar still. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This procedure eliminates the need for repeated experiments, saves time and conserves the material as opposed by the conventional procedure.

Keywords: *Distillate output, Solar Desalination, Taguchi method, single slope solar still.*

Abbreviations

SC Salt Concentration (mass %)
IA Inclination Angle (^{0})
WD Water Depth (cm)
WT Water Temperature (^{0}C)
P Productivity (ml)

1. Introduction

Clean potable water is a basic necessity for man along with food and air. Fresh water is also required for agricultural and industrials purposes. Direct use of water from sources like rivers, lakes, sea and underground water reservoirs is not advisable, because of the presence of higher amount of salt and harmful organism. Also the higher growth rate in world population and industries is escalating the demand for fresh water. The natural sources can meet a limited demand and this leads to acute shortage of potable water. Water desalination is an affective technique to meet the demand of portable water for many countries.

Distillation is a well-known thermal process for water purification and water desalination. Most of the conventional water distillation processes consumes high quantity of energy and require fossil fuels as well as electric power for their operation. A solar still, however, makes use of solar energy for desalination and distillation process. It is a greenhouse like structure having a shallow water basin. Water vapor generated inside the still condenses at the inner side of its transparent cover, which is convectively cooled from the outside by natural airflow. The condensed water is than drained out through outlet passage.

The current work focuses on the application of Taguchi technique to investigate the effect of process parameters (salt concentration, inclination angle, water depth and water temperature) on the productivity of single slope solar stills inclined at 25^0, 30^0 and 35^0.

2. Taguchi's definition of quality

The traditional definition of quality states that quality is conformance to specifications. Joseph M. Juran expanded this definition in 1974 and then the American Society for Quality Control (ASQC) in 1983. Juran observed, Quality is fitness for use. The ASQC defined quality as the totality of features and characteristics of a product or service that bear on its

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ability to satisfy given needs. Taguchi presented another definition of quality. His definition stressed the losses associated with a product. Taguchi stated quality is the loss a product causes to society after being shipped, other than losses caused by its intrinsic functions. Taguchi asserted that losses in his definition should be restricted to two categories:

(a) loss caused by variability of function, and (b) loss caused by harmful side effects. Taguchi says that a product or service has good quality if it performs its intended functions without variability, and causes little loss through harmful side effects, including the cost of using it. It must be kept in mind here that society includes both the manufacturer and the customer. Loss associated with function variability includes, for example, energy and time (problem fixing), and money (replacement cost of parts).

Losses associated with harmful side effects could be market shares for the manufacturer and/or the physical effects, such as of the drug thalidomide, for the consumer. Consequently, a company should provide products and services such that possible losses to society are minimized, or, the purpose of quality improvement ... is to discover innovative ways of designing products and processes that will save society more than they cost in the long run. The concept of reliability is appropriate here. The next section will clearly show that Taguchi's loss function yields an operational definition of the term loss to society in his definition of quality.

2.1 Taguchi Philosophy

Taguchi espoused an excellent philosophy for quality control in the manufacturing industries. Indeed, his doctrine is creating an entirely different breed of Engineers who think, breathe and live quality. His philosophy has far 'reaching consequences, yet it is founded on three simple and fundamental concepts.

• Quality should be designed into the product and not inspected in it. No amount of inspection can put quality back into the product.

• Quality is best achieved by minimizing the deviation from a target. The product should be so designed that it is immune to uncontrollable environmental factors.

• The cost of the quality should be measured as a function of deviation from the standard and the losses should be measured system wide.

The above three concepts are becoming the guiding principles of today's quality control activities.

Taguchi builds both his conceptual framework and specific methodology for implementation from these precepts. He recommended the following three-stage process.

Concept Design: It is the primary design stage in which engineering and scientific knowledge is used to produce the basic product or process design. It is very important stage but we cannot afford the research of all the concepts. Therefore, research is limited to few concepts, selected on the basis of past experience or guess.

Parameter Design: It is the secondary design stage in which an investigation is conducted to identify settings that minimize the performance variations.

Tolerance Design: It is the tertiary design stage in which the tolerances of the process conditions and the sources of the variability are set. This is a means of suppressing quality variations by directly removing its cause.

2.2 Factors affecting the Productivity

The factors which affect the productivity of a single slope solar still can be broadly placed in following two categories.

- Uncontrollable Factors: factors such as solar intensity, wind speed, precipitation, humidity, salt concentration, solid impurities are some of the factors which influence the productivity of a single slope solar still and cannot be controlled.
- Controllable Factors: factors such as water depth, inclination angle, basic material, cover material, orientation, geometry etc. are some other factors which influence the productivity of a single slope solar still and can be controlled.

The present investigation is focused on understanding the affect the process parameters (salt concentration, inclination angle, water depth and water temperature) on the productivity of single slope solar still.

3. Experimental Setup

The experimental set-up includes a constant temperature water bath, condensing covers inclined at 25°, 30° & 35°, digital temperature indicators, well calibrated thermocouples (by Zeal Thermometer), two transparent pipes of small diameter and a measuring flask. The output from the still is collected through a channel. Two plastic pipes are connected to this channel to drain the distilled water to an external measuring jar. The total capacity of the constant temperature bath is 40 L, and its effective evaporative surface area is 0.3 m × 0.4 m. The water is heated by bath heating coils. Table 1, shows the detailed dimensions of condensing covers and Fig. 1 shows the picture of fabricated condensing cover.

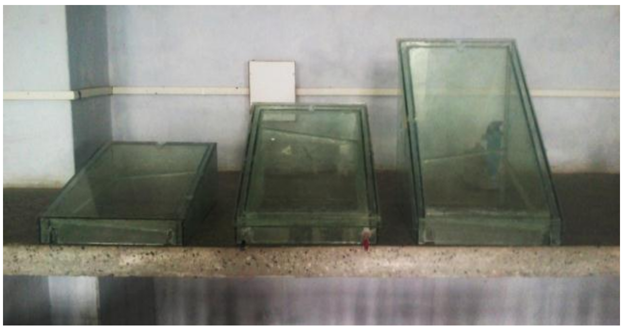

Figure 1: Condensing Covers

Condensing covers at three different inclination angles were fabricated in the lab with the help of common glass to make top inclined covers and 3 mm thick GRP (Glass Reinforced Plastic) sheets to make the side walls of the condensing covers. This glass reinforced plastic is manufactured by sticking many layers of corrugated sheets with special chemicals in such a manner that air is entrapped between its corrugated cavities, which provide a high degree of insulation for heat flow, which is a highly desired quality for the solar still material.

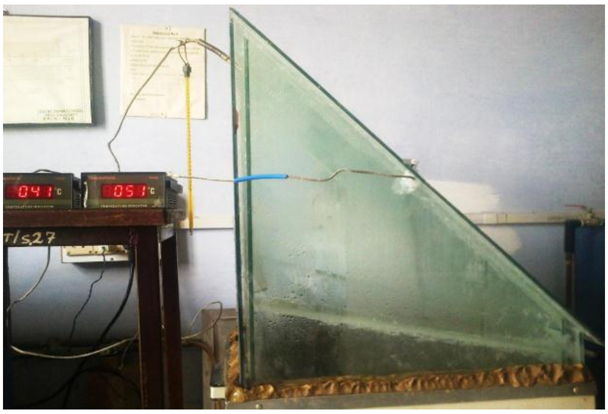

Figure 2: Constant temperature water bath with condensing cover during the experiment

Table 1: Detailed dimensions of condensing covers

S. No	Parameter	Dimension of 25° (mm)	Dimensions of 30° (mm)	Dimensions of 35° (mm)
1	Length	430	430	430
2	Width	330	330	330
3	Higher height	260	308	361
4	Lower height	60	60	60

3.1 Procedure of Experiment

The experiments were conducted in Heat and Mass Transfer Lab of Department of Mechanical Engineering, SHIATS-DU on different days in the month of June, 2015. The inclination angles of fabricated condensing covers are 25°, 30° & 35° and the operational temperatures are 37^{0}C, 55^{0}C and 75^{0}C. The operational salt concentrations on the basis of mass percentage are 0%, 3.5% and 7.0 %. The water depths taken are 8 cm, 12 cm and 16 cm. Constant temperature bath was started at 8:30 am an hour before commencing the experimental work to make sure that steady state has been reached. Continuous readings for every one hour were then observed and recorded under no fan conditions (natural mode).

3.2 Taguchi Method

Taguchi method is being widely used by researchers and industrialists in engineering design, as it reduces the number of experiments to be conducted by using orthogonal arrays and at the same time studies the complete parametric space (Yang WH et al, 1998).

The effect of all the factors on the response can be investigated by doing minimum number of experiments, which are arranged suitably in the orthogonal array.

Analysis of Variance, a statistical technique, it is used for calculation of F value, to find out the significance of each factor on the desired response. The process parameters varied in the experiments were Inclination angle (Degree) and temperature (^{o}C). Table 2 shows the parameters with their levels.

Table 2: Process parameters and their levels

Process Parameters	Level 1	Level 2	Level 3
Inclination angle (^{o})	25	30	35
Water Temperature (^{o}C)	37	55	75
Water Depth (cm)	8	12	16
Salt Concentration (mass %)	0	3.5	7

4. Results and Analysis

Table 3 shows the Design of Experiment table based on Taguchi approach and Table 4 in appendix shows values of the response obtained from the experimental runs, designed by Taguchi method, the corresponding values of S/N Ratio is mentioned for each run. L9 orthogonal array was employed for the experiment.

Table 3: Taguchi L9 orthogonal array

order	Salt concentration	Inclination angel	Depth of water (cm)	Water temp.^{0}C
1	0%	35^0	16	37
2	0%	30^0	12	55
3	0%	25^0	8	75
4	3.5%	35^0	12	75
5	3.5%	30^0	8	37
6	3.5%	25^0	16	55
7	7%	35^0	8	55
8	7%	30^0	16	75
9	7%	25^0	12	37

4.1 Analysis of S/N Ratio

The S/N ratio is calculated using larger the better characteristics for Productivity. Taguchi method studies the response variation using S/N ratio, greater the value of S/N ratio better will be the result. The sample variance is written as formula:

$$S^2 = \sum(y-\bar{y})^2/(n-1) \quad (1)$$

$$S = \sqrt{S^2} \quad (2)$$

S/N Ratio can then be evaluated as

$$\text{S/N Ratio} = -10\log\frac{1}{R}\sum_{n=1}^{P}\left(\frac{1}{y_i^2}\right) \qquad (3)$$

Where n is the number of measurement in a trail/row and Yi is the measured value in the run/row.

Table 5: Response table for S/N ratios larger is better

Level	SC	IA	WD	WT
1.	35.58	22.82	22.70	10.82
2.	21.95	23.47	24.74	31.04
3.	20.55	31.80	30.65	36.23
Delta	15.03	8.97	7.95	25.41
Rank	2	3	4	1

Table 5 shows the Responses table for Signal to Noise ratios of larger the better characteristics for each level of the parameters. The difference of S/N Ratio between level 1 and level 3 indicates the effect of the process parameters on the response, greater the difference, greater will be the effect.

The above table indicates that for Productivity, the parameter that had the most influence is Water Temperature with a delta value of (25.41), second most influential parameter is Salt Concentration with a delta value of (15.03). Figure 3 shows the main effect plot for S/N ratio for productivity.

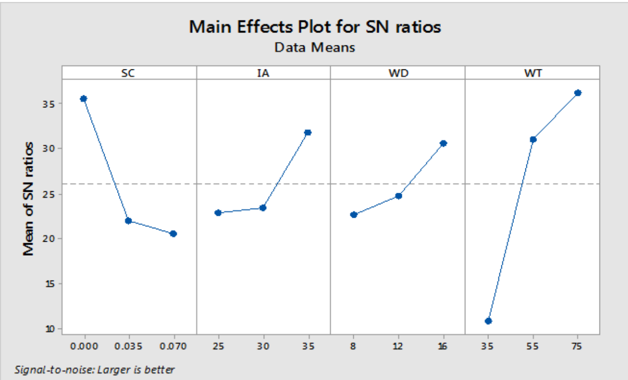

Figure 3: Main Effect Plot for S/N Ratio

4.2 Analysis of Variance (ANOVA)

The response data obtained via experimental runs for distillate output were subjected to ANOVA for finding out the significant parameters, at above 95% confidence level and the results of ANOVA thus obtained for the response parameters are illustrated in Table 6.

Table 6: Analysis of Variance for S/N Ratio for Productivity (ML)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SC	1	2599.17	2599.17	22.17	0.009
IA	1	14.35	14.35	0.12	0.744
WD	1	22.89	22.89	0.20	0.681
WT	1	4668.23	4668.23	39.83	0.003
Error	4	468.85	117.21		
Total	8	7773.50			

On observing the P values of table 4 it is clear that Water Temperature is the most significant factor and Salt concentration is the second most influential factor. The calculated F value for water temperature and salt concentration is greater than the table F value; ($F_{0.05,\,2,\,8}$ = 5.41) at 95% confidence level. Whereas the F value of inclination angle and water depth is less than the table F value.

4.3 Response Optimization

Response	P
Goal	Max
Lower	1.12
Target	
Upper	92
Weight	1
Importance	1

Solution

Solution	1
SC	0
IA	35
WD	8
WT	75
P Fit	92.78
Composite Desirability	1

Conclusion

The study discusses about the application of Taguchi method and ANOVA to investigate the effect of process parameters on Productivity. From the analysis of the results obtained following conclusion can be drawn:

- Statistically designed experiments based on Taguchi method are performed using L9 orthogonal array to analyse Productivity. The results obtained from analysis of S/N Ratio and ANOVA were in close agreement.
- Significant parameters for productivity are Water Temperature and Salt Concentration. Whereas Inclination angle and Water Depth are insignificant parameters.
- Response optimization was conducted and optimal combination of factors and Levels was obtained. The optimal combination of factors and Levels is.

Factors	Levels
SC (mass %)	0
IA (^{0})	35
WD (cm)	8
WT (^{0}C)	75

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Appendix

Table 3: Results for Experimental Trial Runs

Trail No.	A	B	C	D	Response (raw data)/ Productivity (ml)					S/N Ratio	Mean
					P1	P2	P3	P4	P5		
1.	1	1	1	1	30	40	33	42	32	30.7495	35.40
2.	1	2	2	2	65	70	75	70	65	36.7395	69.00
3.	1	3	3	3	86	89	93	97	95	39.2507	92.00
4.	2	1	2	3	60	72	76	65	70	36.6371	68.60
5.	2	2	3	1	1	1.2	1	1.2	1.1	0.8485	1.12
6.	2	3	1	2	20	28	32	25	33	28.3741	27.60
7.	3	1	3	2	20	25	30	25	30	28.0012	26.00
8.	3	2	1	3	40	50	42	40	50	32.8118	44.40
9.	3	3	2	1	1	1.1	1	1.2	1.3	0.8485	1.12