Investigating the Effect of Water Temperature and Inclination Angle on the Performance 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 temperature and inclination angle on the performance of the single slope solar stills inclined at 15^{O}, 30^{O} and 45^{O}.

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 15^{O}, 30^{O} and 45^{O} were fabricated of commonly used glass sheet to form top inclined cover and GRP sheets to make the side walls of the cover.

Orthogonal arrays of taguchi, the Signal–to-Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis have been employed to analyze the effect of the factors on the response. Linear regression equation has been developed with an objective to establish a correlation between the selected parameters and the Productivity. The predicted values have been compared with experimental data and are found to be in good agreement. Temperature is found to be the most significant factor contributing towards the productivity.

Keywords: Taguchi method, ANOVA, Regression, Solar Distillation, Inclination angle, Condensing Cover

I. 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 inclination angle and water temperature on the productivity of single slope solar stills inclines at 15^{O}, 30^{O} and 45^{O}.

II. LITERATURE SURVEY

While Hay presented solar still design concepts as far back in 1960s [1], including the use of plastic transparent covers [2], it was Dunkle [3] who derived a widely used as well as analyzed, semi-empirical relation for evaluating the internal heat and mass transfer within solar distillation units. This empirical relation is popularly known as Dunkle's relation. Malik et al. [4] then summarized a historical review on solar distillation systems. Later on, Tiwari and Lawrence [5] attempted to incorporate the effect of inclination of the condensing surface using the same values of *C* and *n* as proposed by Dunkle. Furthermore, Kumar and Tiwari [6] developed a thermal correlation for outdoor conditions based on linear regression analysis to determine convective mass transfer for a varying range of Grashof numbers. They felt a need to develop an empirical relation to calculate convective mass transfer without any limitations. Thus, these values were free from the shortcomings of Dunkle's relation. Tripathi and Tiwari [7] thereafter applied the correlation of Kumar and Tiwari [6] to evaluate the internal heat and mass transfer correlations for active solar distillation for a very small inclination of condensing cover in winter climatic conditions. Though a lot of work has been done on solar desalination in general (Delyannis [8]), and on single-slope passive solar distillation, in particular, the optimization of cover inclination and water depth for maximum daily yield remains outstanding. This technical brief describes an attempt to carry out such an optimization.

III. EXPERIMENTAL SETUP

The experimental set-up includes a constant temperature water bath, condensing covers inclined at 15°, 30° & 45°, 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.

TABLE 1: DETAILED DEMENSIONS OF CONDENSING COVERS

S. No	Parameter	Dimension of 15° (mm)	Dimensions of 30° (mm)	Dimensions of 45° (mm)
1	Length	430	430	**430**
2	Width	330	330	**330**
3	Higher height	300	440	**625**
4	Lower height	64	69	**75**

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, 2012. The inclination angles of fabricated condensing covers are 15°, 30° & 45° and the operational temperature range is from 60^0 to 70^0 at intervals of 5°C. 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 half an hour were then observed and recorded under no fan conditions (natural mode). The same process was applied to all three working temperatures 60°C, 65°C & 70°C at three inclination angles.

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})	15	30	45
Temperature (^{o}C)	60	65	70

IV. RESULTS AND ANALYSIS

Table 3 shows the 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: RESULTS FOR EXPERIMENTAL TRIAL RUNS

Exp. No.	Inclination angle (°)	Temp. (°C)	Productivity (ml)	SNR (Signal to Noise Ratio)
1	15	60	40.4	32.1276
2	15	65	54.4	34.712
3	15	70	67.2	36.5474
4	30	60	44.4	32.9477
5	30	65	65	36.2583
6	30	70	81.8	38.2551
7	45	60	53.6	34.5833
8	45	65	66.8	36.4955
9	45	70	97	39.7354

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.

S/N ratio is calculated by using equation (1)

$$\frac{S}{N}_{(Bigger)} = -10 \log\left(\frac{\Sigma\left(\frac{1}{y_i^2}\right)}{n}\right) \quad (1)$$

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

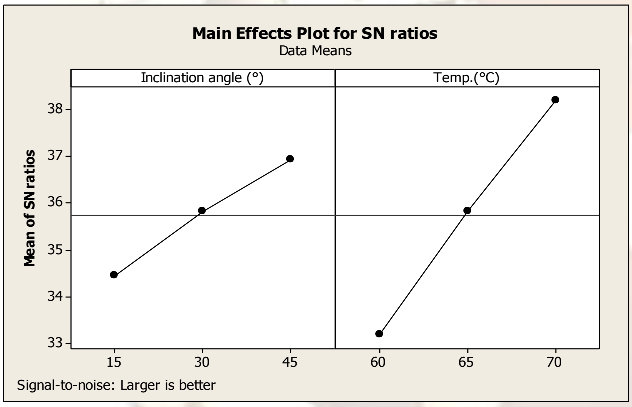
TABLE 4: RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS LARGER IS BETTER

Level	Inclination angle (°)	Temperature (°C)
1	33.46	33.22
2	35.82	35.82
3	**36.94**	**38.18**
Delta	2.48	4.96
Rank	2	1

Table 4 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 Temperature with a delta value of (4.96). Figure1 shows the main effect plot for S/N ratio for productivity.

FIGURE 1: MAIN EFFECT PLOT FOR S/N RATIO



4.2 ANALYSIS OF VARIANCE (ANOVA)

The response data obtained via experimental runs for Tool life 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 5.

TABLE 2: ANALYSIS OF VARIANCE FOR S/N RATIO FOR PRODUCTIVITY (ML)

Source	DF	SS	MS	F	P
Inclination angle (°)	2	9.223	4.611	21.21	0.007
Temperature (°C)	2	36.929	18.464	84.93	0.001
Error	4	0.870	0.217		
Total	8	47.022			

On observing the P values of table 4 it is clear that Temperature is the most significant factor. The calculated F value for both the parameters are more than the table F value; ($F_{0.05,\,2,\,8}$ = 4.46) at 95% confidence level.

4.3 REGRESSION ANALYSIS

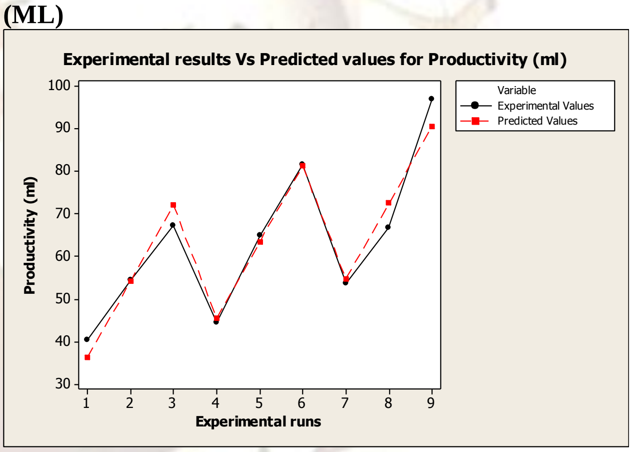
The Inclination angle and Temperature are considered in the development of mathematical model for Productivity. The correlation between the process parameters and Productivity is obtained by linear regression; equation 2 shows the developed model.

Productivity (ml) = - 188 + 0.616 Inclination angle (°) + 3.59 Temp(°C (2)

The predicted and the experimental values of Productivity are shown in figure 2. It is clear from the figure that most of the predicted values are in close agreement with the experimental values for Productivity.

Figure 2 shows the comparison between the experimental values and the predicted values.

FIGURE 2: EXPERIMENTAL RESULTS VS PREDICTED VALUES OF PRODUCTIVITY (ML)



V. 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 analyze Productivity. The results obtained from analysis of S/N Ratio and ANOVA were in close agreement.
- Optimal parameters for Productivity are Inclination angle with 45^0 and 70°C Temperature
- Linear regression equation is developed to predict the values of Productivity, and the predicted values are compared with the measured value.

- Both Inclination Angle and Water Temperature are found to be significant factors but Water Temperature is found to be most significant factor.

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