The Prediction of Productivity of Single Slope Solar Still: A Regression Approach
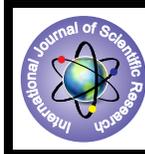
Engineering

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ABSTRACT

The present work focuses on the application of Linear Regression method to predict the productivity of Single Slope Solar Still for the selected range of Salt Concentration, Inclination Angle, Water Depth and Water Temperature. 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 25O, 30O and 35O were fabricated of commonly used glass sheet for the purpose of experiment.
Orthogonal arrays of taguchi, the Signal–to-Noise (S/N) ratio, the analysis of variance (ANOVA) has been used to analyze the effect of the process parameters on the productivity of the Single Slope Solar Still and Linear Regression method has been used to develop an expression to establish a correlation between the selected parameters and productivity. The predicted values have been compared with experimental data and are found to be in good agreement. The experimental value have also been compared with the basic Dunkle Model results and it has been found out that the performance of present model is better than the performance of Dunkle model.

1. INTRODUCTION

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. Extensive research has been going on to make the solar desalination units more efficient.

The factors which influence the productivity of the Solar Still can broadly be classified as:

- Controllable Factors: These are the factors which affect the productivity of Solar Still and can be controlled, eg. Water Depth, Inclination Angle, Geometry, Circulation Type, Orientation etc.
- Uncontrollable Factors: Solar Intensity, Wind Speed, Precipitation, Humidity etc.

The current work focuses on the application of Linear Regression Method to predict the productivity of Single Slope Solar Still for selected range of Salt Concentration, Inclination Angle, Water Depth and Water Temperature.

2. LITERATURE SURVEY

While Hay presented solar still design concepts as far back in 1960s, including the use of plastic transparent covers, it was Dunkle 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.

However, the relation developed by Dunkle has the following limitations:

a) It is valid for a low operating temperature range (45-50^{0}C).
b) It is independent of the cavity volume, i.e. the average spacing between the condensing and evaporative surfaces.
c) It is valid for cavities that have parallel condensing and evaporative surfaces.

Numerous empirical relations were developed later on to predict the hourly and daily distillate output for different designs of solar distillation units. Most of these relations are based on simulation studies. Kumar et. al. has done thermal and computer modelling for determining the constants C and n and consequently heat and mass transfer coefficients for different types of solar still. Lof et. Al have analysed heat and mass transfer of solar still in detail and studied the effect of various design parameters and climatic variables on the performance of a so-

lar still. Numerical solution of the heat balance equations was then obtained with the aid of a digital computer. Sharma et al developed a method for estimation of heat transfer coefficients for upward heat flow and evaporation in still and calculation of hourly output was done with this new approach. It was observed that the performance of solar still has an agreement with the result of an analysis based on Dunkle's relation with a factor of 0.65 to account for instauration. Shukla et al has recently developed a model, based on regression analysis, to determine the values of constants C and n using the experimental data obtained from the stills. Aboul-Enein et al. presented a simple transient mathematical model for a single basin still through an analytical solution of the energy-balance equations for different parts of the still. Akash et al. examined the effect of using a solar still with various cover tilt angles of 15, 25, 35, 45 and 55 ° in outdoor conditions and the optimum tilt angle for water production was found to be 35º.

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.

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).

3.1 THERMAL MODEL

The vapor, which consists of moisture and dry air, is freely convected above the water surface to the condensing cover by the action of pressure difference because of buoyancy force caused

by density variation. This is due to the difference in temperatures between the water surface and condensing cover. This process within the unit always happens in natural mode. However, the external heat transfer from condensing cover to the atmosphere takes place outside the still and can either be under the natural mode, depending on ambient conditions, G.N. Tiwari, et al [11]. A mathematical model was developed by Dunkle to determine the convective heat and mass transfer coefficients and thereby productivity.

$$(h_{ew})_{Duckle} = [(0.01623 \times h_{cw}) \times$$
$$qew_{Duckl} = (h_{ew}) \times (T_w - T_g)$$
$$mew =$$

2.2   LINEAR REGRESSION METHOD

Many researchers and administrators have discovered the usefulness of regression methods in deriving and testing empirical relationships among various observed phenomena. Regression analysis provides an objective and widely accepted routine for fitting mathematical models involving several variables. In addition, there are procedures that can often be used to evaluate the fitted equation, and, with the development of modern electronic computers, much of the computational drudgery has been eliminated.

2.3   TAGUCHI METHOD

Taguchi method has been used to reduce the number of experiments to be conducted by using Orthogonal Arrays and at the same time to study the complete parametric space. The effect of all the factors has been investigated by conducting tests as per the suitably arranged Orthogonal Array. Analysis of Variance, a statistical technique has been 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), Water Temperature (°C), Salt Concentration (mass %), Water Depth (cm). Table 1 shows the parameters with their levels.

TABLE 1: SELECTED PARAMETERS AND THEIR LEVELS
TABLE 1: PROCESS PARAMETERS AND THEIR LEVELS

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

4. RESULTS AND ANALYSIS

Table 2 in Appendix 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.

4.1 REGRESSION ANALYSIS

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

PM = -23.6 - 595 SC + 0.309 IA - 0.49 WD + 1.466 WT

The predicted and the experimental values of Productivity are shown in figure 1. It is clear from the figure that most of the predicted values are in close agreement with the experimental values for Productivity.

FIGURE 1: EXPERIMENTAL RESULTS VS PREDICTED VALUES OF PRODUCTIVITY (ML)
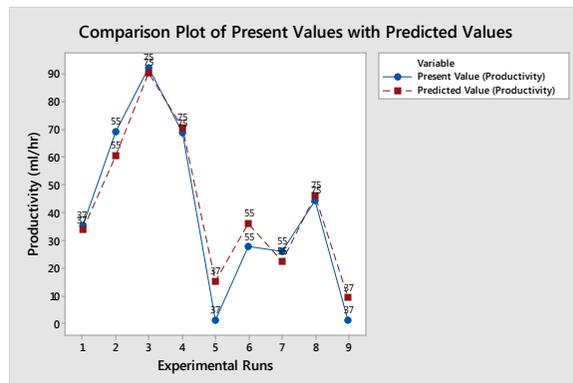
Figure 2 shows the comparison between the experimental values of productivity and Dunkle model values of productivity.

FIGURE 2: COMPARISON PLOT OF PRESENT VALUE AND DUNKLE VALUE
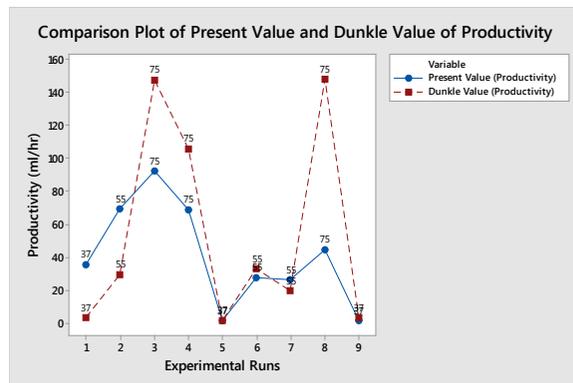
It can be concluded from the graph that the performance of present model is better than Dunkle model at 37°C and 55 °C and is lower than Dunkle model at 75°C. This can be explained by the fact that (I) Dunkle relation is valid for low temperatures only; (II) Dunkle value is independent of water depth, and salt concentration. So it can be concluded that the performance of present model is better than Dunkle model.

Table 3 in Appendix shows the Dunkle value, Predicted value and Present value of productivity (ml/hr) and Figure 3, shows comparison between Dunkle value, Predicted value and Present value of productivity.

FIGURE 3: COMPARISON PLOT OF PRESENT VALUE, PREDICTED VALUE AND DUNKLE VALUE
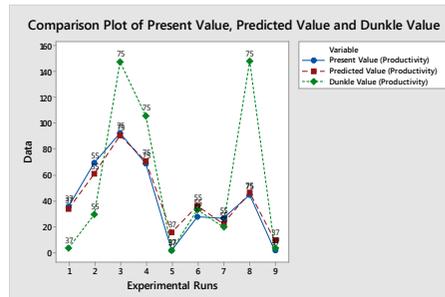
5. Conclusion

The study discusses about the application of Linear Regression Method to predict the productivity of Single Slope Solar Still for selected range of parameters. 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.
- Based on the results obtained from experiments a linear regression equation was developed to predict the productivity of the Single Slope Solar Still.
- The predicted values are in close agreement with the experimental values of Productivity.
- Values of productivity were also calculated using Dunkle model and the calculated values were compared to the present model values.
- The performance of present model was found out to be better than the Dunkle model.

TABLE 2: 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

TABLE 3: PRESENT VALUE, PREDICTED VALUE AND DUNKLE VALUE OF PRODUCTIVITY

Experimental Runs	SC	IA	WD	WT	Present Value (Productivity) (ml/hr)	Predicted Value (Productivity) (ml/hr)	Dunkle Value (Productivity) (ml/hr)
1	0.000	35	16	37	35.40	33.617	3.07
2	0.000	30	12	55	69.00	60.420	29.23
3	0.000	25	8	75	92.00	90.155	147.41
4	0.035	35	12	75	68.60	70.460	105.45
5	0.035	30	8	37	1.12	15.167	1.48
6	0.035	25	16	55	27.60	36.090	32.57
7	0.070	35	8	55	26.00	22.275	19.49
8	0.070	30	16	75	44.40	46.130	147.62
9	0.070	25	12	37	1.12	9.160	3.07

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