Parameter Optimization of Flat Plate Liquid Desiccant Dehumidification System using Taguchi Method

Rajneesh Kaushal, Akash Sharma

Abstract: *In this research paper, Taguchi method, an influential technique for the optimization of operational parameters, is used to analyse the dehumidification parameters for a flat plate liquid desiccant dehumidification system. An orthogonal array using analysis of variance (ANOVA) and signal to noise ratio (S/N) are applied to find the dehumidification parameters of a liquid desiccant dehumidification system (LDDS). Calcium chloride (CaCl2) is used as a liquid desiccant solution. In this study, desiccant flow rate, air velocity and desiccant solution concentration are kept as operating parameters to find out the optimal relative humidity for room comfort. Experimental findings have shown proficient agreement with this approach.*

Keywords: *Optimization, Taguchi method, liquid desiccant, dehumidification, concentration.*

I. INTRODUCTION

It is quite challenging to work with the latent load in various air conditioning applications such as room air conditioning (RAC), food packaging industries, grains warehouse, multiplexes etc. In RAC, dehumidification is mostly done by conventional vapour compression a system (VCS) in which the process air is kept beneath its dew point temperature and again heated up to a comfortable zone of temperature before it enters to the space to be conditioned. So this whole process of air dehumidification through VCS makes the system very much energy consuming and also leads to a lower coefficient of performance for RAC [1]. Increase in world population raised the requirement of energy for building use is at very fast rate in the recent past due to which there is a continuously depletion of fossil fuels shown in Figure.1 occur which has a great contribution in carbon emission. This scenario creates a critical global environmental issue. Today, most of the buildings cooling needs of the world are fulfilled by traditional vapour compression systems which consumes large amount of conventional energy resources indirectly by using high grade electrical energy[2-4].

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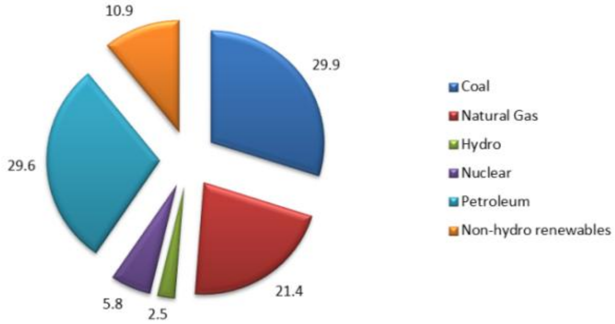

Figure.1. Graphical illustration of energy consumption of world in 2018 [5]

This large amount consumption of conventional energy resources has led to raise greenhouse gases. Heating, Ventilation and Air conditioning systems used in maintaining building comfort level consumes around 50 % of total supplied energy to the buildings which increase the emissions level which results in depletion of ozone layer[6, 7].

1.1Principle of Liquid Desiccant Cooling System:

A desiccant is hygroscopic material which has a strong affinity towards the moisture. It absorbs and holds water vapours from the humid air through the phenomenon of absorption until the vapour pressure of desiccant material comes to equilibrium with humid air [8]. A basic liquid desiccant cooling system includes dehumidifier, regenerator with heat source, evaporative cooling unit and a sensible heat exchanger represented in Figure 2.

To choose the operating parameters accurately, various analytical models depend on statistical regression methods have been generated to build up a correlation among relative humidity and operational parameters. Incoming air velocity, desiccant solution concentration and solution flow rates are set as operational parameters to analyse their effects on relative humidity. Large number of dehumidification investigation test is to be performed to form desired numerical models. Therefore, the desired models formed are so expensive due to high cost of materials and time. In the present research work, an alternate approach is used to determine the essential and required operating parameters based on Taguchi method [9].

Generally, the Taguchi method is a strong and effective operating tool for the optimization for superior grade systems. It delivers quiet simple, effective and standardized path for optimal design to improve quality, cost and performance of the system.

This technique is important when the design parameters are discrete and qualitative. It can enhance the performance attributes of system by improving the framework of process parameters and minimise the reactivity of the execution of the system for sources of deviation. Past few year studies, shows sudden rise in significance of this technique and approached to various utilization techniques in various global industries. In this study, the Taguchi technique is applied to analyse the performance of a flat plate liquid desiccant dehumidification system. The experimental description to use Taguchi technique in order to find and analyse the effective dehumidification parameters are characterized further. Relative humidity is considered as the response (output) for input process parameters to analyse the performance. Finally, the investigation is summarized with conclusion and future scope.

II. TAGUCHI METHODOLOGY

Taguchi method was developed by Taguchi in the year 1986 [10]. It was suggested that parametric optimization of a mechanism or process ought to be conducted in a three mode design process, i.e. system design, tolerance design and parameter design. To obtain high dehumidification performance in terms of low relative humidity in dehumidification process, the design for optimal process parameters mentioned by Taguchi method is utilized in the present work. Design methodology for experimental processes [11, 16] were firstly proposed by Fisher [12]. However, traditional methods for experimental designs are too complicated and difficult to examine. Moreover, an enormous set of experiments are necessary to conducted when there is increase in the number of design parameters. This problem can be resolved through the implementation of Taguchi technique which utilizes a specific of orthogonal arrays design to analyse whole parameter space by conducting some experiments [13] [14]. Then the experimental test results are converted into a signal-to-noise ratio (S/N). It was proposed by Taguchi that, the S/N ratio has to be utilized to calculate the quality attributes diverging from the desired output. In general, to study the quality characteristics of S/N ratio, three prime categories are proposed i.e. lower is desired, higher is desired and the nominal is desired. The S/N ratios for every category of design parameters are calculated according to analysis of S/N ratio. In spite the classification of the quality attributes, a higher S/N ratio approaches to good quality attributes and decided the optimal range for the process parameters for the dehumidification system. Moreover, an arithmetical analysis of variance (ANOVA) is conducted to analyse for the influence of process parameters for the system design. The optimum sets of combination for the process parameters can be analysed with the help of S/N ratio and ANOVA analyses. Furthermore, a verification test run is conducted to confirm the optimization range of process parameters which were obtained through parametric design.

III. EXPERIMENTAL DETAILS

Dehumidifier is a most essential component of the LDDS and has gained most of attention in the various research studies. The process of absorption of water vapour and heat exchange among LiDS and incoming humid air takes place into the dehumidifier. The dehumidifier composed of a flat plate which is further divided into five long channels with one inlet and one outlet port. Ambient air to be processed enters into the absorber through the inlet port of the first channel with the help of an induced draft fan which has varying speed. In this study three sets of velocities are taken 0.5, 0.7, 0.9 m/s. The liquid desiccant solution (LiDS) of calcium chloride ($CaCl2$) with 32 %, 36% and 40% by wt. is used as LiDS. The LiDS solution flows over the entire plate of the dehumidification system in one direction only. The LiDS flows over the entire flat plate in the form of a thin film of 1 mm at very low rates of flow rate. Flow rates of the solution for this study is taken as 0.6, 0.8, 1.0 kg/s. The absorber plate is made flat so that LiDS flows evenly over the entire surface of the plate. There is an interfacial contact between the two films of LiDS and process air to minimise the carryover of desiccant droplets. The details schematic view of experimental test rig used in the present investigation are given below in Figure.2.

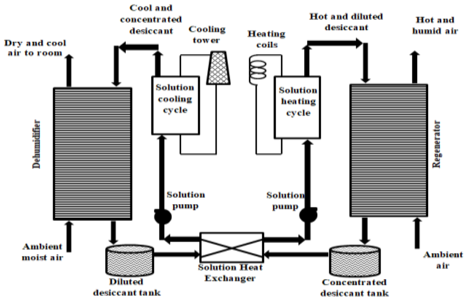

Figure.2. Schematic diagram of the dehumidification system

Table.1. Results from experimental runs for relative humidity and S/N ratio

Experiment No.	Desiccant Flow rate	Air flow rate	Desiccant concentration	Rel. Humidity	S/ N (dB) R.H.
1	0.6	0.5	32	66	-36.3909
2	0.6	0.7	36	66.4	-36.4434
3	0.6	0.9	40	69	-36.777
4	0.8	0.5	36	67	-36.5215
5	0.8	0.7	40	67.2	-36.5474
6	0.8	0.9	32	69.9	-36.8895
7	1	0.5	40	64.1	-36.1372
8	1	0.7	32	66.8	-36.4955
9	1	0.9	36	68.2	-36.6757

3.1 Opting the operating parameters and their levels

The dehumidification investigation was conducted on a five channel flat plate dehumidifier with $CaCl2$ as LiDS. The initial operating parameters for dehumidification process were as follows: desiccant flow rate 0.6 kg/sec, incoming air velocity 0.5 m/sec and desiccant concentration as 32 % by wt. The optimal range for operating parameters was decided by altering the desiccant flow rate from 0.6-1.0 kg/sec, air velocity 0.5-0.9 m/sec and concentration of solution 32-40 % by wt. In the parameter design for the dehumidification process, three sets of operating parameters were taken as mentioned in Table 2.

Table.2. Operating parameters and their levels for dehumidification process

S.no.	Dehumidification parameters	Unit	Level		
			1	2	3
A	Desiccant flow rate	kg/sec	0.6	0.8	1.0
B	Air velocity	m/sec	0.5	0.7	0.9
C	Desiccant concentration	wt.%	32	36	40

IV. OPTIMIZATION OF OPERATING PARAMETERS FOR DEHUMIDIFICATION

To minimise the number of experiments an orthogonal array is used performed for obtaining optimal operating parameters in dehumidification process. Outcomes of the testing are investigated using the analysis of S/N and ANOVA methods. Optimal settings of the dehumidification operating parameters for reducing the relative humidity are calculated and justified which are based on the above mentioned analyses methods.

4.1 Orthogonal array experiment

Total degree of freedom (DOF) is necessary to be calculated to pick an appropriate orthogonal array for the experimental runs. Once the desired DOF are obtained, the appropriate orthogonal array to fits the particular objective is selected. In the present investigation, an L9 orthogonal array with 9 rows and 4 columns was selected. DOF for this array has 8. The layout of the experimental design for three operating parameters using the L9 orthogonal array is described in Table 3.

Table.2. Experimental structure using an L9 orthogonal array

Experiment No.	Operating parameter level		
	A	B	C
	Des. flow rate	Air velocity	Desiccant. concentration
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.2 S/N ratio analysis

Signal and noise represents desired value (mean) and undesirable value (S.D.) respectively, in Taguchi method. Therefore, S/N ratio represents the ratio of mean value to the S.D. value. Taguchi adopted the S/N ratio to calculate the quality attributes diverging from the desired value. The S/N ratio U

$$U = -10\log(M.S.D.) \quad \text{.............................. (1)}$$

M.S.D. stands for mean square deviation for the outcomes.

To procure the desired optimal dehumidification performance, smaller is desirable quality attributes for relative humidity has selected and its quality attributes can be expressed as:

$$M.S.D. = \frac{1}{M}\sum_{i=1}^{m} S_i^2 \quad \text{.............................. (2)}$$

Si shows relative humidity for the ith test.

Table.1. describes the experimental outcomes for the relative humidity with S/N ratio using equations (1) and (2). The table of response for mean and graph for relative humidity exhibits in table 4 and figure 3 which clears that the air flow rate has more significant effect on relative humidity than other two parameters.

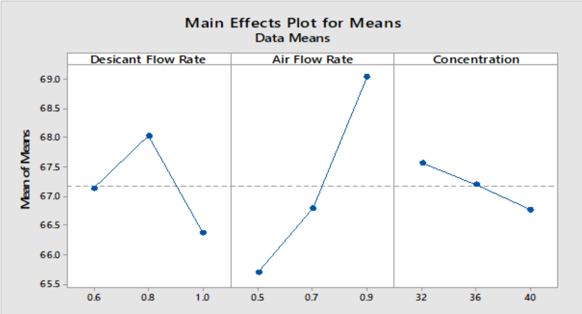

Figure.3. Mean graph for relative humidity

Table.4. Response Table for Means (smaller is better)

Level	Desiccant Flow Rate	Air Flow Rate	Concentration
1	67.13	65.70	67.57
2	68.03	66.80	67.20
3	66.37	69.03	66.77
Delta	1.67	3.33	0.80
Rank	2	1	3

4.3 Analysis of Variance (ANOVA)

The main function of ANOVA is to analyse the operating parameters which significantly affects the output of the experimental runs. This can be achieved by dividing the total divergence of the S/N ratios, and that would be measured by the sum of the squared deviations from the mean S/N ratio [15]. Firstly, the total number of squared deviations (SST) from the total mean S/N ratio (Um) is to be calculated as:

.... (3)

where, number of experiments is denoted by n in the orthogonal array and mean S/N ratio for the ith experiment is denoted by Ui as mentioned in Table.5. shows the results of ANOVA for relative humidity and Figure.3 showing the variation in the experimental and the predicted value of relative humidity.

Table.5. ANOVA (analysis of variance)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Remarks
Desiccant Flow Rate	2	4.1756	2.0878	4.31	0.188	--
Air Flow Rate	2	17.3089	8.6544	17.86	0.053	significant
Concentration	2	0.9622	0.4811	0.99	0.502	--
Error	2	0.9689	0.4844	--	--	--
Total	8	23.4156	--	--	--	--

4.4 Regression Equation

Regression model was built to make predictions about the value of the relative humidity based on different values of the independent variable (des. flow rate, air velocity and des. concentration) as shown in equation 4.

$$R.H. = 66.48 - (1.92 * A) + (8.33 * B) - (0.10 * C) \quad ...(4)$$

In this work, statistical analysis done by regression equation by the help of Minitab software and find out the value of R-sq is equal to 79.04 %.

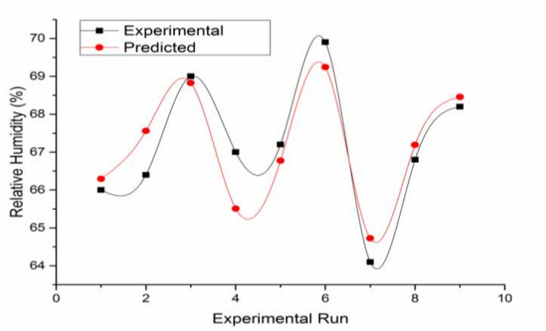

Figure.4. variation between experimental and the predicted value of relative humidity.

V. CONCLUSION

In the current study, Taguchi L9 orthogonal array has been used for the optimization of relative humidity of dehumidification process in a LDDS. The LiDS flow rate, concentration and air velocity were taken as input parameters. The following conclusions are drawn from above discussions of results:

- The air flow rate was found to be the most significant factor affecting the relative humidity of flat plate dehumidification system followed by desiccant flow rate and its concentration.
- The optimum setting proposed by Taguchi's L9 is desiccant flow rate at 1 kg/sec, air flow rate at 0.5 m/s and 40 % by wt. desiccant concentration.
- The relative humidity of the flat plate dehumidification system first increased with raising the flow rate of the LiDS from 0.6 to 0.8 kg/sec than decrease with increase in desiccant flow rate because of short time span of interfacial contact between incoming moist air and concentrated desiccant films from 0.8 to 1.0 kg/sec.

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