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A Statistical Analysis of Desiccant Dehumidifier for Air Conditioning Application

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Abstract

Due to the direct utilization of thermal energy and possibility of using renewable energy resources, the interest of using desiccant wheels for air-conditioning application is increasing rapidly. The thermally driven desiccant cooling systems are environmental friendly and has a great potential to reduce the peak electricity demand. During the experiments the inlet and outlet parameters in the dehumidifier can be easily measured. However, in theoretical analysis it is difficult to predict the relationship between these parameters because of the complexity of combined heat and mass transfer process. In this paper a statistical analysis using Minitab software is used to predict the functional relationships between the input and output parameters in the dehumidifier. The factorial analysis is first carried out to eliminate the factors which does not affect the response, significantly. Then, the regression analysis is carried out to analyze the effect of significant operating variables (independent) on the moisture absorption rate in the dehumidifier and to develop a relationship between dependent and independent variables. Regression analysis shows that the inlet air humidity ratio, ratio of mass flow rates, and regeneration temperature cause significant variation ($P<0.01$) in the absorption rate.

Keywords: *Desiccant Cooling, Regression, Statistical Analysis, Air Conditioning, Solar Energy*

1. Introduction

The control of indoor air temperature and relative humidity for the human comfort divides the building's cooling load into sensible and latent load, respectively. The conventional compressor based air conditioners can control the sensible load effectively but these systems are less efficient to take the building latent loads. In these systems a lot of energy is wasted to overcool the air below its dew point in order to remove the moisture from the air by the process of condensation and then reheating the air to the required supply temperature. Secondly, this process of overcooling provides the conditions for the growth of molds and bacteria because of surface wetting which can cause health issues by affecting indoor air quality [1].

Some alternative is required to avoid this wastage of energy because of overcooling and reheating [2]. The latent load is more dominant in hot and humid climates and there is a need for alternative air conditioning systems to effectively handle the latent loads [3]. The liquid desiccant cooling units seem to be a feasible and cost effective alternative to provide the human comfort conditions in hot and humid climates. It absorbs and desorbs the moisture from and to the air during absorption and regeneration processes, respectively.

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Liquid desiccant systems consist of two main components: an absorber for dehumidifying the air and a regenerator for regenerating the solution. In the dehumidifier, Kumar et al. [4] said the air comes in direct contact with the desiccant solution and attracts its moisture because of the lower water vapor pressure of the desiccant solution. Liu et al. [5] showed that the process of heat and mass transfer in the dehumidifier and regenerator are the same but the difference is in the heat and mass transfer direction. Regression performance analysis was used by Liu et al. [6] to predict the effect of the air and desiccant inlet parameters on the regenerator performance. Fumo and Goswami [7, 8] assessed the rate of dehumidification and the water evaporation as well as the effectiveness of the dehumidifier and regenerator, respectively, under the effect of different variables.

Yin et al. [9] developed the correlations of the heat and mass transfer coefficients by using regression analysis. Yin et al. [10] correlated the average mass transfer coefficient of a packed tower in terms of liquid desiccant concentration and heating temperature. McDonald et al. [11] predicted a simple functional relationship for the packed tower dehumidifier using statistical analysis software. Wahab et al. [12] studied the effects of several influencing design factors on the performance of the structured liquid desiccant air dehumidifier, where the multiple regression method was used to predict the water condensation rate in terms of these design factors. Additional experimental data provided by Oberg and Goswami [13] to carried out the effect of air and desiccant variables and the area of heat and mass transfer on the performance of the desiccant system. Rafique et al. [14] analyzed the exergy and anergy performance of a desiccant cooling system to estimate the exergy destructed by each individual component of the system. El-Shafei et al. [15] predicted the performance of the regenerator in a solar liquid desiccant dehumidification/regeneration system using artificial neural network (ANN). The results showed that the outputs of ANN investigate good agreement with the experimental results. The scarcity of fresh water is also an issue which need special attention as most of the world population suffers from clean water shortage which results in a lot of diseases and deaths [16, 17]. The liquid desiccant cooling system can also produce pure water by utilizing solar energy.

Most of the studies carried out for liquid desiccant dehumidifier are packed bed type which has a problem of desiccant carry over with the process air. Rotary wheel are the new configuration for liquid desiccant technology which has advantage of no carry over and good control of supply air conditions. In this paper, a rotary liquid desiccant dehumidifier have been statistically analyzed for its capacity to absorb water vapor from the humid air. After eliminating the factors which are not significantly affecting performance of the system, regression analysis is used to establish a relationship between dependent and independent variables.

2. The Multiple Linear Regression Models

Regression analysis is a statistical technique for modeling and investigating the relationship between two or more variables. A simple linear regression model has only one independent variable. However, there are many applications where there is more than one independent factor that affects the outcome of a process [18]. In this situation, a multiple regression model is required:

$$y = \beta_o + \sum_{j=1}^{k} \beta_j x_i \qquad \textbf{(1)}$$

k represents the independent variables and the βj from j=0 to k are the regression coefficients. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each parameter for:

Total sum of squares:

$$TSS = \sum_{i=1}^{n} \left(y_i - \bar{y} \right)^2 \qquad (2)$$

Sum of squares due to regression:

$$MSS = \sum_{i=1}^{n} \left(\hat{y}_i - \bar{y} \right)^2 \qquad (3)$$

Error sum of squares:

$$MSE = \sum_{i=1}^{n} \left(y_i - \hat{y}_i \right)^2 \qquad (4)$$

Note that the sums squares are independently distributed. The ratio between the mean square for regression and the mean square for error follows the F distribution.

$$F = \frac{\sum_{i=1}^{n} \left(\hat{y}_i - \bar{y} \right)^2}{\sum_{i=1}^{n} \left(y_i - \hat{y}_i \right)^2} \qquad (5)$$

3. Results and Discussion

Firstly, the numerical results in this paper are analyzed using factorial design to eliminate the factors having insignificant effect on response; then the experimental results are analyzed by the method of regression analysis to determine the respective importance of each factor and to establish a relationship between them.

3.1. Factorial Analysis

3.1.1. Screening Analysis of Factors

Before the process of screening, four influence factors are picked out. In order to reduce the number of run only two levels of each of these factors are chosen. The four factors and their levels are shown in Table 1.

Table 1. The Levels of Four Influence Factors

Levels	Factors			
	A	**B**	**C**	**D**
	Regeneration temperature (^oC)	Inlet air temperature (^oC)	Inlet air humidity (kg/kg of dry air)	air mass flow rates ratio
Lower (-1)	40	26.0	0.013	0.84
Higher (1)	50	30.5	0.017	0.33

Table 2. Response for Different Treatment Combinations

Sr. number	Combinations					Water absorption rate (kg/sec)	
	A	B	C	D	Treatment combination	Replicate 1	Replicate 2
1	-1	-1	-1	-1	**(1)**	0.0034	0.0024
2	1	-1	-1	-1	**a**	0.0045	0.0055
3	-1	1	-1	-1	**b**	0.0016	0.0035
4	1	1	-1	-1	**ab**	0.0023	0.0027
5	-1	-1	1	-1	**c**	0.0025	0.0045
6	1	-1	1	-1	**ac**	0.0045	0.0043
7	-1	1	1	-1	**bc**	0.0045	0.0029
8	1	1	1	-1	**abc**	0.0056	0.0032
9	-1	-1	-1	1	**d**	0.0034	0.0019
10	1	-1	-1	1	**ad**	0.0045	0.0037
11	-1	1	-1	1	**bd**	0.0024	0.0047
12	1	1	-1	1	**abd**	0.0056	0.0036
13	-1	-1	1	1	**cd**	0.0053	0.0032
14	1	-1	1	1	**acd**	0.0034	0.0039
15	-1	1	1	1	**bcd**	0.0035	0.0041
16	1	1	1	1	**abcd**	0.0038	0.0023

Through the analysis of data, P value of each factor can be obtained. P value is a probability value, which shows the error probability based on the belief that there exists a significant performance difference among the levels of a factor. A small P value indicates great significance of this factor and vice versa. The detailed relation between P value and the significance of a factor at a significance level of 95% is as follows: when $0 \leq P$ value ≤ 0.01, the factor is highly significant and very important; when $0.01 < P < 0.05$, the factor is significant and important; when $P \geq 0.05$, the factor is insignificant and has no influence on the results. The factorial setup for water absorption rate with two replicates is shown in Table 2.

3.1.2. Confounding

Only 8 treatment combinations can be run at one time instead of 16. In order to divide the treatment combination into two blocks with 8 treatments in each, interaction ABCD can be confounded. The confounding of ABCD by sign table method is shown in Table 3 and two confounded blocks are listed in Table 4.

Table 3. Confounding of ABCD

Combination	A	B	AB	C	AC	BC	ABC	D	AD	BD	ABD	CD	ACD	BCD	ABCD	Block
(1)		-				+	-				-		-		+	1
a		-				+	+				+		+		-	2
b		+				-	+				+		-		-	2
ab		+				-	-				-		+		+	1
c		-				-	+				-		+		-	2
ac		-				-	-				+		-		+	1
bc		+				+	-				+		+		+	1
abc		+				+	+				-		-		-	2
d		-				+	-				+		+		-	2
ad		-				+	+				-		-		+	1
bd		+				-	+				-		+		+	1
abd		+				-	-				+		-		-	2
cd		-				-	+				+		-		+	1
acd		-				-	-				-		+		-	2
bcd		+				+	-				-		-		-	2
abcd		+				+	+				+		+		+	1

Table 4. Blocks With ABCD Confounded

Block 1 (+ABCD)	Block 2 (-ABCD)
(1)	a
ab	b
ac	c
bc	abc
ad	d
bd	abd
cd	acd
abcd	bcd

3.2. Analysis Of Variance Table

Before analyzing the data null and alternative hypothesis needs to be defined for each factor such as:

Null hypothesis: H_o; a factor has insignificant effect on water absorption rate.

Alternative hypothesis: H_1; a factor has significant effect on water absorption rate.

Table 5. Analysis of Variance for Water Absorption Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	0.00000036	0.00000036	0.00000036	0.31	0.587
Main Effects	4	0.00000465	0.00000465	0.00000116	0.99	0.441
A	1	0.00000288	0.00000288	0.00000288	6.45	0.013
B	1	0.00000066	0.00000066	0.00000066	0.56	0.464
C	1	0.00000105	0.00000105	0.00000105	4.90	0.035
D	1	0.00000006	0.00000006	0.00000006	6.05	0.022
2-Way Interactions	6	0.00000659	0.00000659	0.00000110	0.94	0.496
A*B	1	0.00000105	0.00000105	0.00000105	0.90	0.358
A*C	1	0.00000231	0.00000231	0.00000231	1.97	0.180
A*D	1	0.00000078	0.00000078	0.00000078	0.67	0.427

B*C	1	0.00000004	0.00000004	0.00000004	0.04	0.847
B*D	1	0.00000113	0.00000113	0.00000113	0.96	0.342
C*D	1	0.00000128	0.00000128	0.00000128	1.09	0.312
3-Way Interactions	4	0.00000624	0.00000624	0.00000156	1.33	0.302
A*B*C	1	0.00000060	0.00000060	0.00000060	0.52	0.483
A*B*D	1	0.00000040	0.00000040	0.00000040	0.34	0.565
A*C*D	1	0.00000145	0.00000145	0.00000145	1.23	0.284
B*C*D	1	0.00000378	0.00000378	0.00000378	3.22	0.092
Residual Error	16	0.00001879	0.00001879	0.00000117		
Pure Error	16	0.00001879	0.00001879	0.00000117		
Total	31	0.00003663				

When the water absorption rate in the dehumidifier acts as response index, the response is shown in Table 5. From Minitab output, the obtained P value for factor A, B, C, and D, are 0.013, 0.464, 0.035, and 0.022, respectively. By referring to the relation between the P value and the significance of factors at significance level of 95%, it can be concluded:

- Regeneration temperature (A) is evaluated as highly significant for water absorption rate.
- Inlet air temperature (B) is insignificant for water absorption rate.
- The p-value of inlet air humidity (C) and air mass flow rate ratio (D) range from 0.01 to 0.05 which indicates these factors are significant and can be valued as important factors.
- All the interaction terms are not important because of large p-value.

Hence, while conducting the experiments for these four factors only three factors can be used to analyze their effect on water absorption rate i.e. regeneration temperature, inlet air humidity, and mass flow rate.

3.3. Experimental Results

The important factors were figure out by factorial analysis and in this section the effect of these factors is analyzed on water absorption rate. Note, that these are some initial results, more results will be obtained. The response for water absorption rate is shown in Table 6.

Table 6. Experimental Results For Water Absorption

Inlet air humidity (kg/kg of dry air)	Ratio of mass flow rate, (kg/m^{2}sec)	Regeneration temperature (^{o}C)	Water absorption rate (kg/sec)
0.0180	0.9	40.1	0.0032
0.0181	0.8	40.3	0.0040
0.0181	0.7	40.0	0.0052
0.0188	0.7	35.3	0.0042
0.0180	0.6	40.5	0.0036

0.0142	0.5	43.1	0.0023
0.0215	0.4	45.3	0.0053
0.0180	0.3	40.2	0.0038
0.0181	0.3	47.2	0.0039
0.0177	0.2	50.0	0.0050
0.0178	1.176	45.2	0.0021
0.0179	1.182	33.1	0.0036
0.0179	1.192	40.2	0.0038
0.0181	1.176	40.2	0.0041

3.3.1. Regression Output

The F ratio is a measure of error of the regression, while P-value is used to assess the degree of response affected by factors. The p-value for each factor and variance table for regression analysis is presented in Table 7 and 8, respectively. The results of the ANOVA test indicated that the independent effective factors of regeneration temperature (T_{reg}), inlet air humidity ratio (W_{ai}), and mass flow rates ratio (R) on water absorption rate ($M_{absorption}$) are significant in the range of the curve fit between the predicted regression curve and the actual value for each of the dependent variables in the dehumidifier.

The statistical analysis of the results in the dehumidifier shows the main functional relationships of the dependent variable represented by:

$$M_{absorption} = f\,(T_{reg}, W_{ai}, R) \qquad \textbf{(6)}$$

The water absorption rate in the dehumidifier is increased through an increase in the inlet air humidity. Statistically, the P-value was ($P<0.05$). The results demonstrate that the effect of changing the air humidity is significant for the water absorption rate. Comparing this with the mass flow rate ratio, the water absorption rate does not vary much by changing the value of this ratio. An increase in regeneration temperature causes a lower potential for mass transfer in the dehumidifier, this means absorption rate for water will decrease as it can be seen from the regression relation.

3.3.2. Hypothesis For Regression

The general regression expression with one dependent variable (y) and three independent variable (x_1, x_2, and x_3) can be written as:

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad \textbf{(7)}$$

Where,

β_o intercept of the plane

β_1 coefficient of independent variable x_1 which determines how much change in y with unit change in x_1 while x_2 and x_3 are fixed.

β_2 coefficient of independent variable x_2 which determines how much change in y with unit change in x_2 while x_1 and x_3 are fixed.

β_3 coefficient of independent variable x_3 which determines how much change in y with unit change in x_3 while x_1 and x_2 are fixed.

Hypothesis for inlet air humidity ratio

$$H_o: \beta_1 = 0$$

$$H_1: \beta_1 \neq 0$$

Result: Null hypothesis rejected for inlet air humidity ratio.

Hypothesis for ratio of mass flow rates

$$H_o: \beta_2 = 0$$

$$H_1: \beta_2 \neq 0$$

Result: Null hypothesis rejected for ratio of mass flow rates.
Hypothesis for regeneration temperature

$$H_o: \beta_3 = 0$$

$$H_1: \beta_3 \neq 0$$

Result: Null hypothesis rejected for regeneration temperature.
Hypothesis for regression

$$H_o: \beta_1 = \beta_2 = \beta_3 = 0$$

H_1: at least one coefficient is non zero.
Result: Null hypothesis rejected.
The regression equation is:

$$\begin{aligned} \text{Water absorption rate} = {} & 0.00602 + 0.381 \times (\text{Inlet air humidity}) \\ & + 0.000622 \times (\text{Ratio of mass flow rate}) - 0.000309 \times (\text{Regeneration temperature}) \end{aligned} \quad \textbf{(8)}$$

Table 7. Experimental Results for Water Absorption

Predictor	Coef	SE Coef	T	P
Constant	0.006021	0.002529	2.38	0.039
Inlet air humidity	0.38133	0.09368	4.07	0.002
Ratio of mass flow rate	0.0006221	0.0005036	3.24	0.024
Regeneration temperature	-0.00030940	0.00006313	-4.90	0.001

S = 0.000443766   R-Sq = 92.8%   R-Sq (adj) = 87.7%

Table 8. Analysis of Variance (ANOVA) table for Regression Analysis

Source	DF	SS	MS	F	P
Regression	3	9.50286E-06	3.16762E-06	16.09	0.000
Residual Error	10	1.96928E-06	1.96928E-07	-	-
Total	13	1.14721E-05	-	-	-

The ANOVA tables illustrate a p value < 0.05 which shows that regression model is highly significant. Also p-value of predictors shows that null hypothesis is rejected for all three factors and these have significant effect on response variable (water absorption rate).

3.3.3. Residual Analysis In Regression

The residuals analysis is necessary for appropriateness of the model because it is always not correct to use a linear regression model for the given data. Residual (e) is difference between the observed value (y) and the predicted value ($\hat{y}$) of the dependent variable and each data point has one residual.

$$e = y - \hat{y} \quad \textbf{(9)}$$

The sum and mean of the residuals are always equal to zero. That is, Σ e = 0 and $\bar{e}$= 0.

If the points are randomly dispersed around the horizontal axis in a residual plot, a linear regression model is appropriate for the data; otherwise, a non-linear model is more appropriate.

The residual plots for the present work are shown in Fig. 1, 2, and 3. There is nothing unusual about the residual plots. One or two points shows unusual behavior. Normality assumptions is satisfied as it can be observed from the normal probability plot shown in Figure 1. From residual versus fitted the variance is not changing as represented in Figure 2 and 3 shows that, data is independent as there is no specific pattern formed on residual versus order plot.

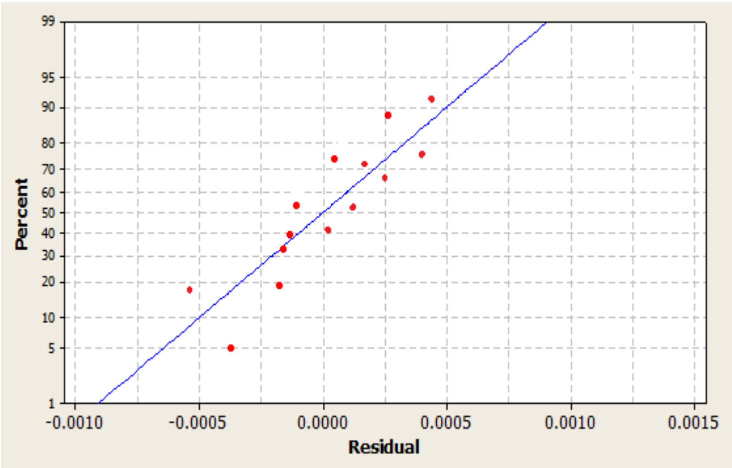

Figure 1. Normality Plot for Residual Analysis

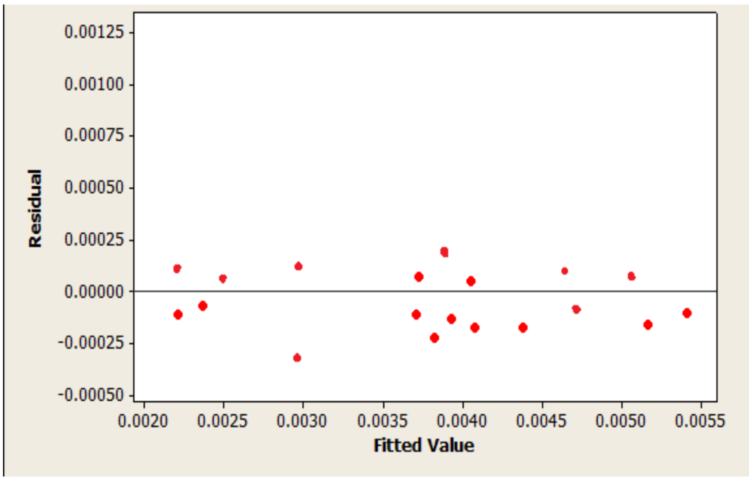

Figure 2. Versus Fit for Residual Analysis

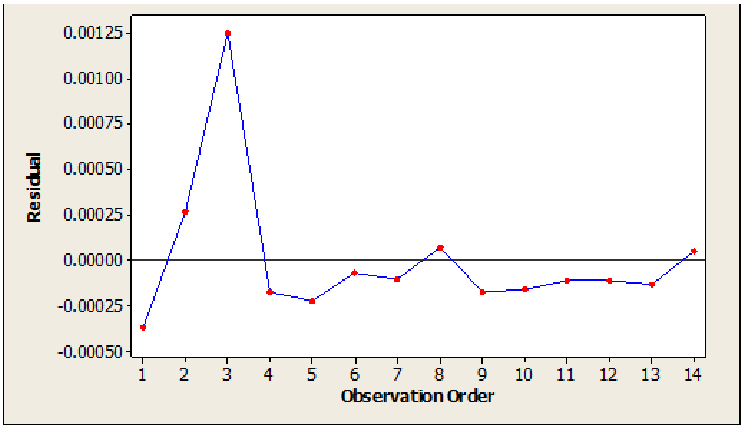

Figure 3. Versus Order for Residual Analysis

4. Conclusions

In this paper a rotary liquid desiccant dehumidifier have been statistically analyzed for its capacity to absorb water from process air. Four factors (inlet temperature, inlet humidity ratio, regeneration temperature, and ratio of mass flow rates) have been taken as influence variables. The theoretical data was first analyzed to eliminate the least significant factors and then experiments were conducted to analyze the effect of these important variables on water absorption rate. A regression relationship have also been developed for significant independent factors. Some conclusions from the factorial analysis can be summarized as follows:

(1) Based on the screening analysis of the factors in liquid desiccant dehumidifier, it is found that, when the water absorption rate acts as response variable regeneration temperature, inlet air humidity, and ratio of mass flow rates appears to be important factors. Hence, in experiment only these three parameters needs to be considered while analyzing water absorption rate.

(2) Based on the further analysis of the interactions between factors, all the interactions have insignificant effect on water absorption rate.

Further, a multiple linear regression model was used to determine the functional relationship between the important parameters and water absorption rate. From the results of this work the main conclusions are:

(1) The effect of inlet air humidity is significant on water absorption rate. An increase in inlet air humidity causes an increase in rate of water absorption.

(2) The effect of mass flow rates ratio is less significant as compared to air humidity but increase in mass flow rate ratio will also increase water absorption rate.

(3) An increase in regeneration temperature will decrease the water absorption rate.

These findings can be utilized to analyze the effect of different factors on dehumidification performance of liquid desiccant wheel.

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References

[1] L. Pérez-Lombard, J. Ortiz J, and C. Pout. A review on buildings energy consumption information. Energy Build. Vol. 40(3), **(2008)**, pp. 394–398.

[2] M.M. Rafique, P. Gandhidasan, S. Rehman, and M. Al-Hadhrami. A review on desiccant based evaporative cooling systems. Renewable and Sustainable Energy Reviews Vol. 45, **(2015)**, pp. 145-159.

[3] G. Ge, F. Xiao, and X. Niu. Control strategies for a liquid desiccant air-conditioning system. Energy Build. Vol. 43(6), **(2011)**, pp. 1499–1507.
[4] N. Kumar, G. Srivastava, and B. Gangil. Heat and mass transfer study of liquid desiccant with heat exchange by solar cooling technology. Int. J. Eng. Studies Vol. 2, **(2010)**, pp. 105-118.
[5] X. H. Liu, Y. Jiang, X. M. Chang, and X. Q. Yi. Experimental investigation of the heat and mass transfer between air and liquid desiccant in a cross flow regenerator. Renewable Energy Vol. 32, **(2007)**, pp. 1623-1636.
[6] X. H. Liu, Y. Jiang, and K. Y. Qu. Heat and mass transfer model of cross flow liquid desiccant air dehumidifier /regenerator. Energy Convers. Manage. Vol. 48, **(2005)**, pp. 546-554.
[7] N. Fumo and Y. Goswami. Study of the aqueous lithium chloride desiccant system, Part II: desiccant regeneration. Proc. of Millennium Solar Forum 2000, C. A. Estrada, ed., Asociacion Nacional de Energia Solar **(2000)**, pp. 313-318.
[8] N. Fumo and Y. Goswami. Study of the aqueous lithium chloride desiccant system, Part I: air dehumidification. Proc. of Millennium Solar Forum 2000, C. A. Estrada, ed., Asociacion Nacional de Energia Solar **(2000)**; pp. 307-312.
[9] Y. Yin and X. Zhang. A new method for determing coupled heat and mass transfer coefficient between air and liquid desiccant. Int. J. Heat Mass Transfe Vol. 51, **(2008)**, pp. 3287- 3297.
[10] Y. Yin, X. Zhang, Z. Chen. Experimental study on dehumidifier and regenerator of liquid desiccant cooling air conditioning system. Build. Environ. Vol. 42, **(2007)**, pp. 2505-2511.
[11] B. McDonald, D. G. Wagaman, and C. F. Kettleborough. A statistical analysis of a packed tower dehumidifier. Drying Technol. Vol. 10, **(1992)**, pp. 223-237.
[12] S. A. Abdul-Wahab, Y. H. Zurigat, and M. K. Abu- Arabi. Predictions of moisture removalrate and dehumidification effectiveness for structured liquid desiccant air dehumidifier. Energy Vol. 29, **(2004)**, pp. 19 34.
[13] V. Oberg and D. Y. Goswami. Experimental study of the heat and mass transfer in a packed bed liquid desiccant air dehumidifier. J. Sol. Energy Eng. Vol. 120, **(1998)**, pp. 289-297.
[14] M.M. Rafique, P. Gandhidasan, M. Al-Hadhrami, and S. Rehman. Energy, exergy and anergy analysis of a solar desiccant cooling system. Journal of Clean Energy Technologies Vol. 4(1), **(2016)**, pp. 78 – 83.
[15] B. El-Shafei, A. Ayman. and M. H. Ahmed. Investigation on the effect of operating parameters of solar desiccant cooling system using artificial neural networks. International Journal of Thermal & Environmental Engineering Vol. 1, **(2010)**, pp. 91- 98.
[16] M. M. Rafique, M. K. Anwar, and M. Abd-ur-Rehman. Experimental investigation of a solar Still with and without phase change material (PCM) under climatic conditions of Dhahran, Saudi Arabia. International Journal of Advanced Scientific and Technical Research (IJAST) Vol. 5(2), **(2015)**, pp. 681-698.
[17] M. M. Rafique, M. Abd-ur-Rehman, and M. K. Anwar. Fluid mechanics in membrane filtration: A simplified analytical approach. International Journal of Scientific Research Engineering & Technology, Vol. 4 (5) **(2015)** pp. 490-502.
[18] E. B. Magrab, S. Azarm, B. Balachandran, J Duncan, K. Herold and G. Walsh. An Engineers Guide to MATLAB. Prentic Hall, New Jersey; **(2000)**.

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