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A STATISTICAL ANALYSIS OF A LIQUID DESICCANT DEHUMIDIFIER/REGENERATOR IN AN AIR CONDITIONING SYSTEM

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Abstract

A packed bed is the most common technology employed today as a dehumidifier or a regenerator in a liquid desiccant air conditioning system. During the experiments, the inlet and outlet parameters in the dehumidifier and regenerator can be easily measured, however, in the theoretical analysis it is difficult to predict the relationship between these parameters because of the complexity of the combined heat and mass transfer process in the dehumidifier or regenerator. In this paper statistical analysis using (SPSS) software was used to predict the functional relationships between the input and output parameters in the dehumidifier/regenerator. The analysis of variance (ANOVA) was investigated to analyze the effect of inlet operating variables (independent) on the water condensation rate in the dehumidifier and the water evaporation rate in the regenerator. Statistical analysis shows that the inlet air humidity ratio, inlet air mass flow rate, and inlet solution temperature cause good significant variation ($P < 0.01$) in the water condensation rate. The inlet air mass flow rate, and inlet solution temperature cause also good significant variation ($P < 0.01$) in the water evaporation rate in the regenerator. Experimental results for a counter dehumidifier and regenerator were taken from previous study.

Keywords: Statistical, Dehumidifier, Regenerator, SPSS, ANOV.

1. Introduction

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 [1] 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 [2] 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 [3] to predict the effect of the air and

desiccant inlet parameters on the regenerator performance.

Fumo and Goswami [4,5] assessed the rate of dehumidification and the water evaporation as well as the effectiveness of the dehumidifier and the effectiveness of the regenerator respectively, under the effect of variables such as the air and desiccant flow rate, air and desiccant temperature, air humidity, and desiccant concentration. Yin et al [6] developed the correlations of the heat and mass transfer coefficients by using regression analysis. Yin et al [7] correlated the average mass transfer coefficient of a packed tower in terms of liquid desiccant concentration and heating temperature. McDonald et al [8] predicted a simple functional relationship for the packed tower dehumidifier using statistical analysis software. Abdul-Wahab et al [9] 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 and the dehumidification effectiveness in terms of these design factors. Additional experimental data provided by Oberg and Goswami [10] to carried out the effect of the air and desiccant variables and the area of heat and mass transfer on the performance of the desiccant system. El-Shafei et al [11] 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. In this paper, regression analysis is used to predict the outlet parameters of the dehumidifier and regenerator (outlet air temperature, outlet air humidity ratio, outlet liquid desiccant temperature, outlet liquid desiccant concentration, and water condensation and evaporation rate) as a function of the inlets parameters (air mass flow rate, air temperature, air humidity ratio, solution mass flow rate, solution temperature, and solution concentration). The height of the dehumidifier and the regenerator is a constant according to the experimental facility.

2. Materials and Methods

2.1 Experimental facility

The schematic of the system is shown in Fig. 1. The dimensions of the packed bed absorption tower as constructed by [12] were (25.4 cm diameter and 60 cm height), the packing material used polypropylene Rauschert Hiflow Rings with a diameter of (1 inch); lithium chloride was used as a liquid desiccant and stored in a tank; and cold or hot water was circulated through coils to adjust the temperature of the solution. An air heater or a cooling coil was used to adjust the air temperature and relative humidity before entering the packed tower.

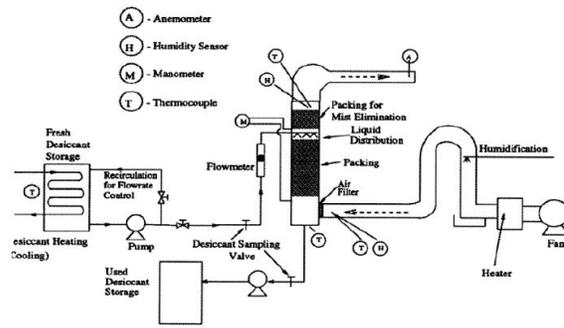


Fig.1. Experimental facility

3. 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 [13]. In this situation, a multiple regression model is required:

4. Results and discussion

The multiple linear regression model type for each dependent variable in the dehumidifier and regenerator was analyzed by its R2 value, F ratio, and P value. The value of R2 describes the accuracy of the curve fit, where R2=1 is the optimum fit and R2=0.9 to 0.99 is a very good fit. The F ratio is a measure of the error of the regression, where its values are usually more than 50, while P-value is used to assess the degree of response affected by factors, its values can be divided into five ranges (1) P-value≤0.001, extremely significant (2) 0.001< Pvalue≤

0.01, very significant (3) 0.01< P-value≤0.005, significant (4) 0.05< P-value≤0.1, slightly significant (5) Pvalue>

0.1, insignificant. The results of the ANOVA test indicated that the independent effective factors of inlet air mass flow rate, inlet air temperature, inlet air humidity ratio, inlet desiccant mass flow rate, inlet desiccant temperature, and inlet desiccant concentration on the outlet air temperature, outlet air humidity ratio, outlet desiccant concentration were very 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 and regenerator

Table1. Air dehumidification experimental results by [12]

Inlet Mdot Kg/m ³ sec	Tin C°	Win Kg/Kg dry	Mdot Kg/m ³ sec	Outlet						
				Tout C°	Wout Kg/Kg dry	Tdes C°	Wdes Kg/Kg dry	Wreg Kg/Kg dry	Wreg Kg/Kg dry	
0.890	30.1	0.0180	6.124	30.1	34.6	31.3	0.0104	32.3	34.5	0.32
1.180	30.1	0.0181	6.227	30.3	34.7	32.2	0.0108	32.6	34.6	0.40
1.513	30.2	0.0181	6.113	30.0	34.3	32.2	0.0108	32.7	34.1	0.52
1.109	35.5	0.0188	6.290	30.3	34.5	32.8	0.0112	32.6	33.7	0.42
1.183	40.1	0.0180	6.287	30.5	34.4	33.1	0.0115	32.9	34.3	0.36
1.214	30.3	0.0142	6.273	30.1	33.9	31.1	0.0103	31.5	33.8	0.23
1.187	29.9	0.0215	6.272	30.3	33.9	33.4	0.0120	33.1	33.7	0.53
1.190	30.1	0.0180	5.019	30.2	34.4	32.2	0.0113	32.7	34.2	0.38
1.182	30.2	0.0181	7.420	30.2	34.4	32.0	0.0110	32.5	34.3	0.39
1.198	29.9	0.0177	6.269	25	34.7	28.2	0.0088	28.4	34.5	0.50
1.176	29.9	0.0178	6.309	35.2	34.9	35.7	0.0140	36.2	34.8	0.21
1.182	29.9	0.0179	6.164	30.1	33.1	32.4	0.0114	32.2	33.0	0.36
1.192	29.9	0.0179	6.267	30.2	33.8	32.5	0.0112	32.6	33.7	0.38
1.176	30	0.0181	6.206	30.2	34.8	32.0	0.0107	32.5	34.7	0.41

Table2. Air regeneration experimental results by [12]

Inlet Mdot Kg/m ³ sec	Tin C°	Win Kg/Kg dry	Mdot Kg/m ³ sec	Outlet						
				Tout C°	Wout Kg/Kg dry	Tdes C°	Wdes Kg/Kg dry	Wreg Kg/Kg dry	Wreg Kg/Kg dry	
0.833	30.4	0.0183	6.463	65.0	34.0	58.9	0.0579	58.6	34.5	1.55
1.098	30.1	0.0180	6.206	65.1	34.1	59.3	0.0532	57.8	34.8	1.81
1.438	29.8	0.0177	6.479	65.1	34.5	57.5	0.0488	56.6	35.2	2.10
1.097	35.1	0.0180	6.349	65.1	33.4	58.5	0.0551	57.4	34.1	1.91
1.102	40.0	0.0178	6.354	65.0	33.6	58.9	0.0548	57.6	34.2	1.91
1.132	30.2	0.0143	6.370	65.2	34.0	57.6	0.0513	57.2	34.7	1.97
1.097	29.4	0.0210	6.440	65.5	33.6	58.5	0.0541	58.3	34.2	1.70
1.116	30.3	0.0182	5.185	65.4	34.4	57.6	0.0507	57.0	34.9	1.71
1.101	29.9	0.0180	7.541	65.2	34.3	59.0	0.0556	57.9	34.9	1.95
1.111	30.0	0.0187	6.245	60.3	34.4	55.8	0.0447	54.2	34.8	1.36
1.084	29.7	0.0184	6.315	70.0	34.5	62.6	0.0666	60.0	35.3	2.45
1.099	29.7	0.0177	6.400	64.8	32.8	57.6	0.0542	56.8	33.4	1.89
1.116	30.3	0.0182	6.428	65.0	34.9	57.9	0.0501	57.5	35.4	1.67

Table 3. Main statistical values

Dependent	Dehumidifier		
	R ²	F-value	Sig.
T _{ao}	0.877-0.9922	192.052	P<0.01
W _{ao}	0.846-0.941	58.2380	P<0.01
T _{so}	0.966-1.00	339.834	P<0.01
X _o	0.8660	77.6990	P<0.01
m _{con}	0.416-0.967	99.210	P<0.05
Dependent	Regenerator		
	R ²	F-value	Sig.
T _{ao}	0.791	41.653	P<0.01
W _{ao}	0.722-0.872	28.522	P<0.01
T _{so}	0.814-0.914	47.414	P<0.01
X _o	0.961-0.989	274.638	P<0.01
m _{evap}	0.82-0.914	25.225	P<0.01

4.1 Statistical analysis of the dehumidifier

Figure 2 shows the normal P-P plot of regression standardized residual for the dehumidifier. All these plots show a reasonably good fit between the predicted and actual value falling well within the 95% confidence level. Only, the measuring error of the outlet solution concentration in the dehumidifier (Fig.2, curve d) exceeds 5%, which was attributed to the small range of inlet solution concentration, such as the outlet solution concentration as a function of the inlet solution concentration. The 95% confidence interval is a measure of error that provides assurance that the data from repeated experiments would fall within this interval 95% of the time.

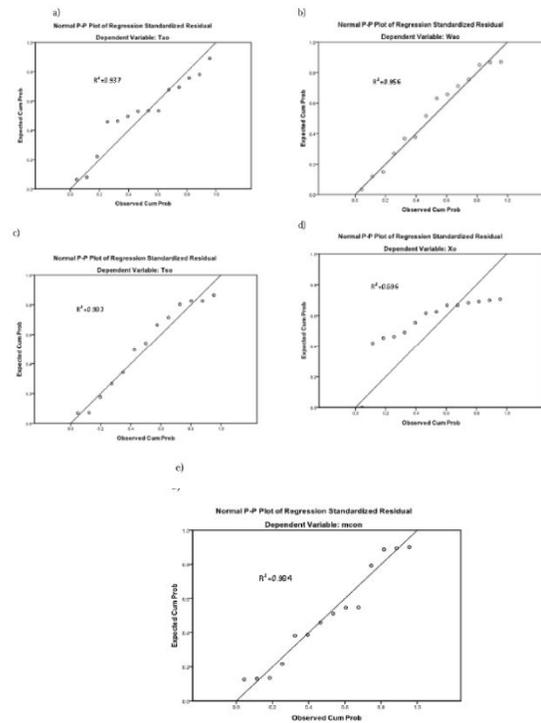


Fig.2. Curves (a, b, c, d, e) the relationships between the actual and the predictor value in dehumidifier

Table4. Final regression functions

Dependent Variables	Dehumidifier	Regenerator
Outlet air temperature	$T_{ao}=11.929+0.743 \cdot T_{si}+0.299 \cdot W_{ai}$ $0.076 \cdot T_{si}+0.333 \cdot X_{si}+1.308 \cdot M_{ai}$	$T_{ao}=13.101+0.696 \cdot T_{si}$
Outlet air humidity ratio	$W_{ao}=-7.873+0.508 \cdot T_{si}+0.201 \cdot W_{ai}$	$W_{ao}=-70.667+2.186 \cdot T_{si}$ $-16.274 \cdot M_{ai}$
Outlet solution temperature	$T_{so}=5.86+0.763 \cdot T_{si}+0.199 \cdot W_{ai}$	$T_{so}=22.69+0.591 \cdot T_{si}+3.364 \cdot M_{ai}$
Outlet solution concentration	$X_{o}=1.309+0.957 \cdot X_{si}$	$X_{o}=-0.651+0.943 \cdot X_{si}$ $+0.043 \cdot T_{si}+0.368 \cdot M_{ai}$
Condensation and evaporation water rate	$m_{con}=0.079+0.044 \cdot W_{ai}$ $-0.028 \cdot T_{si}+0.312 \cdot M_{ai}$	$m_{evap}=6.439+0.112 \cdot T_{si}+0.865 \cdot M_{ai}$

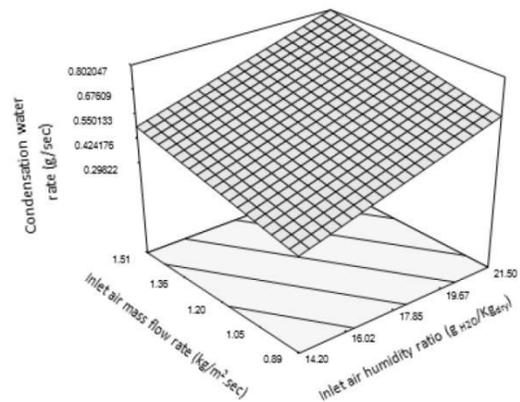


Fig.3. Effect of the inlet air mass flow rate and humidity ratio on the condensation rate in dehumidifier

5. Conclusions

A multiple linear regression model was used to determine the functional relationship between the inlet and outlet parameters for the counter flow dehumidifier and regenerator. This model was performed on a counter flow

dehumidifier and regenerator in an air conditioning system tested by [12] in a solar energy and energy conversion laboratory, in the USA, 2002. From the results of this work, the main conclusions can be summarized by: (1) The effect of inlet air and desiccant variables were very significant in the range of $P < 0.01$; (2) The values of R^2 are considered to be between 0.416 and 1.00 for the dehumidifier and between 0.722 and 0.989 for the regenerator; (3) Very good accuracy of the curve fit between the predicted regression curve and the actual value for each dependent variables in the dehumidifier and the regenerator; (4) Higher air flow rate would result in increasing of the water condensation rate from the air and evaporation rate from the desiccant. (5) Higher desiccant temperature can provide more regeneration rate in the regenerator and provide less condensation rate in the dehumidifier.

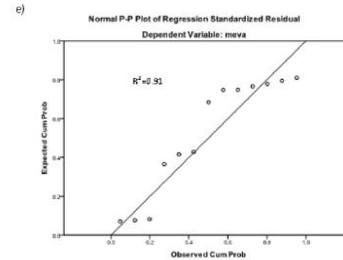
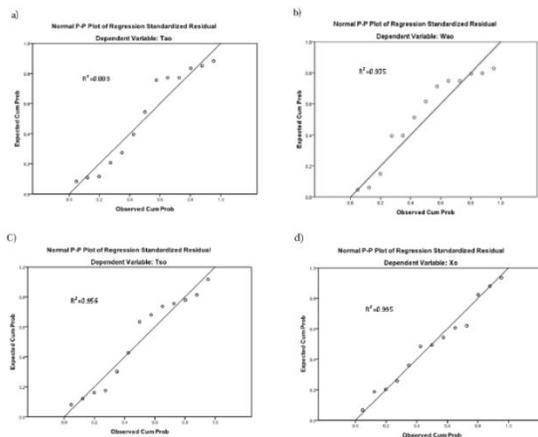


Fig.4. Curves (a, b, c, d, e) the relationships between the actual and the predictor value in regenerator

Nomenclature

F	ratio of mean square model to the mean square error	W_{in}	inlet air humidity ratio, $kg_{H_2O}/kg_{dry\ air}$
M_{in}	air inlet mass flow rate, kg/m^2sec	W_{out}	outlet air humidity ratio, $kg_{H_2O}/kg_{dry\ air}$
m_{con}	condensation water rate, g/sec	X_{in}	inlet solution concentration, %
m_{evap}	evaporation water rate, g/sec	X_{out}	outlet solution concentration, %
M_s	solution inlet mass flow rate, kg/m^2sec		
P	significant coefficient	Subscripts	
R	accuracy of the curve fit	ANOVA	analysis of variance
T_{in}	inlet air temperature, $^{\circ}C$	SPSS	statistical Package for the Social Sciences
T_{out}	outlet air temperature, $^{\circ}C$		
T_{in}	Inlet solution temperature, $^{\circ}C$		
T_{out}	Outlet solution temperature, $^{\circ}C$		

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