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ABSTRACT

A spray tower in the absorption-dehumidification process was designed to study the separation of water vapor from moist air. The performance of the absorption tower was evaluated under various operating parameters. The role of each operating parameter and the relationship between the parameters are still unknown. A second-order

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polynomial model with a multiple linear regression was used to estimate the model coefficients. The model coefficients of the five selected parameters, including air- and liquid-flow rates, liquid concentration and temperature, and orifice diameter of nozzles were proposed to study the influence of these factors on the response of the mass-transfer coefficient. A factorial design model of the five variables is discussed in a two-level analysis. Only 32 (or 2^5) experimental runs were necessary to assess these variables and the model satisfied the process very well since the coefficient of determination (R^2) was very close to 1. The influence of operating parameters on mass-transfer performance is discussed by the analysis of variance (ANOVA). A statistical methodology was applied to this process to describe the relationship between factors and the response coefficient. The factorial design of experimental design methodology used in this study is able to simulate or elucidate the relationship between the process variables and the mass-transfer coefficient. In addition, the F-ratio was calculated by means of analysis of variance to discuss whether the effect of factors on the mass-transfer coefficient is significant or insignificant.

Key Words: Gas separation; Absorption; Analysis of variance (ANOVA); Experimental design; Response surface methodology (RSM); F-ratio.

INTRODUCTION

The nebulizing degree of the working solution is one of the most important factors that affects the mass-transfer performance in a spray tower. Various types of nozzle were tested in this study to understand the relationship between nebulizing degree and mass-transfer performance of the spray tower. Although the packed, wetted-wall, and spray towers are usually used in liquid–desiccant–dehumidification processes, data on the mass transfer performance in packed or wetted-wall towers are available. However, data for spray towers are limited, and most of the studies of spray towers are focused on computer simulation. Therefore, the study of mass-transfer performance on spray towers and discussion of the interactions between experimental variables were conducted in this study. The experimental design methodology provides a means of building a statistically significant model of a process by performing a minimum set of well-chosen experiments.[1] Chung and colleagues[2] pointed out that analysis of variance (ANOVA) provides a way to understand or discuss the experimental data from a experimental design methodology. The use of the F-ratio to judge or elucidate the influence of experimental variables on the performance of a spray tower is one of the objectives of this study.

Since absorption systems have been applied to industrial processes widely, a lot of investigators were interested in estimating the mass-transfer performance of the system. Based on Fick's law and other mass-transfer theories, the parameters of temperatures and flow rates of air and liquid streams were measured in the process and a dimensionless analysis[3] was used to develop a correlation of the mass-transfer coefficient in the absorber. To reduce the carry-over of the desiccant solution, a U-shaped air tunnel and the co-current contact of air and desiccant solution were designed in this spray tower. Discussing the effects of operating variables on the mass-transfer coefficients and comparing the mass-transfer performance with and without fin coils were addressed in previous studies.[4,5] Gandhidasan[6] conducted an experiment of absorbing water vapor from moist air by an aqueous $CaCl_2$ solution in a packed-bed absorber. The heat-transfer resistance in the gas phase and the mass-transfer resistance in the liquid phase were estimated in this study. However, aqueous triethylene glycol (TEG) solution was selected as the desiccant solution to separate water vapor from moist air in this absorption-stripping system. The combination of the liquid–desiccant–dehumidification system with solar collectors to offer heat for air stripping was also found in published research.[7]

The determination of optimal operating conditions[8] in discussing heat- and mass-transfer performance of a falling-film absorber was investigated recently. Yang and Jou[9] discussed the heat- and mass-transfer phenomenon for a falling-film system and found that the higher heat and mass transfer occurred with a porosity of 0.9 in the liquid film. In general, the gas–liquid contacting area for the falling-film equipment is lower than spray and packed towers. Therefore, the studies of the falling-film systems usually emphasized the absorption mechanism rather than the improvement of their mass-transfer performance.

It is difficult to measure the change of mass-transfer coefficients along with the height of the absorber or the contact time of gas and liquid streams. A computer simulation with mass-transfer theory is applied usually. Besides the simulation for the spray tower, commercial 3-D software of flow was applied to the heat-and mass-transfer phenomena while the gas and liquid flowed in a cross-current absorber.[3] Absorption of water vapor in the liquid desiccant solution is an exothermic reaction and the dispersing heat is carried by the air stream. The temperature of air flowing out of the absorber is usually higher than that flowing into the absorber, and the air outlet humidity is lower than air inlet humidity. The changes of temperature and humidity obtained from the simulation agree with experimental results by taking into account the phenomena of heat- and mass-transfer simultaneously.[3] Furthermore, as the spray tower is considered as a cooling tower, the temperature profile of gas and liquid streams inside the tower is important. Based on the ratio of liquid to gas flow rate and the boundary conditions of gas–liquid interface, a mathematical model was developed to estimate the temperatures of liquid and gas streams and the air humidity inside the spray tower.[10] The results showed that the air outlet temperature is dominated by the temperature of liquid flowing into the tower.

EXPERIMENTAL SECTION

The flow diagram of the absorption/stripping (AB/ST) process is shown in Fig. 1. The gas and liquid were allowed to flow countercurrent in the spray tower. The function of nozzle is to nebulize the TEG solution. The smaller the nebulized particle, the larger the gas–liquid contacting area is. The 1.6-mm and 2.0-mm orifice diameters of the full-cone nozzles were used in this study. The average flow rate of the nozzles is about

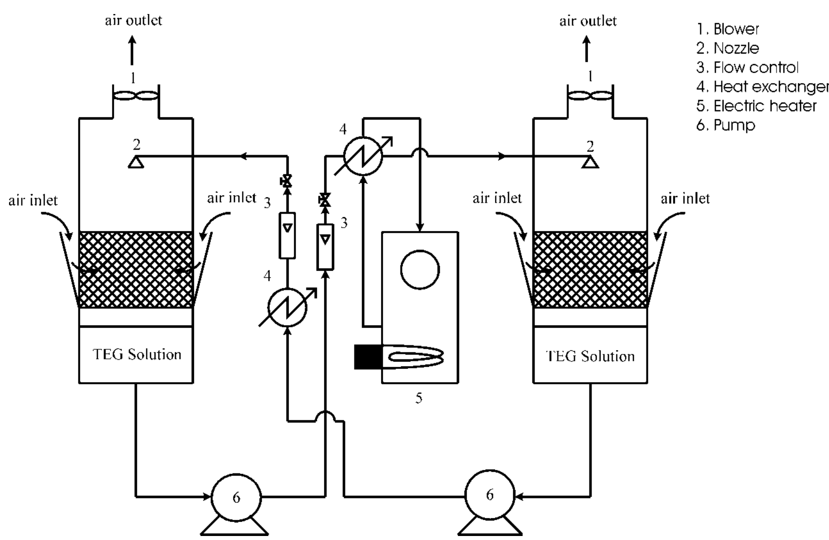


Figure 1. Absorption/stripping system used in this study.

3 L/min at different pressures. This corresponded to a spray angle of 70 degrees. The average diameter of the liquid particles from the nozzles was about 400 μm. Liquid and gas streams contact with each other in the absorber. After absorbing the water vapor, the diluted solution can be regenerated in the stripper. Both of the absorber and stripper are made of stainless steel. The height and diameter of the absorber are 55 cm and 22 cm, respectively. As the TEG solution is mixed with water, its water vapor pressure depression is larger than most of the other desiccant solutions mixed with water. It means that the driving force for absorbing water vapor in the aqueous TEG solution is stronger. Therefore, the aqueous TEG solution was selected as the working solution in this absorption-stripping system for dehumidification. The liquid- and air-flow rates were calibrated by standard method, and the air-flow rates were controlled by transistor inverters on the 0.5 HP blowers. A TESTO-400 hygrometer with two humidity probes, which can measure relative humidity from 0 to 100% RH at −20°C to 70°C, was used in this study. The accuracy of this hygrometer was about ±0.2% RH. The concentration of the solution was measured by a refractometer.

Liquid desiccant flow rates were controlled by the rotameter and sprayed to form fine particles by flowing through the nozzle. Inlet air flowed through a mesh to avoid contaminants and then contacted with aqueous TEG particles. This gas–liquid contact allows the water vapor in air to be absorbed by the liquid particles. Air outlet is on the top of the absorber. The diluted solution was regenerated in the stripper and returned to the absorber. This absorption-stripping process can be operated continuously. The system can handle air-flow rates from 0.73 to 1.30 kg/m^2s and liquid-flow rates from 1.32 to 1.79 kg/m^2s.

RESULTS AND DISCUSSION

The absorption efficiency and the mass-transfer coefficient are usually used to represent the performance of the AB/ST systems. The main parameters that varied during the experiment including air-flow rate, liquid-flow rate, temperature of the inlet desiccant solution, liquid concentration, and orifice diameter of the nozzle. The performance of the system was evaluated by a series of experimental runs, which are shown in Table 1.

Results obtained from experimental runs were compared with the statistical analysis, such as the method of F-ratio examination, to understand the effects of operating variables on the mass-transfer coefficients. Therefore, discussions about absorption efficiency, mass-transfer coefficient, F-ratio examination, and interaction between factors are discussed as follows.

Table 1. Experimental data of this study.

Air-flow rate (kg/s*m^2)	Liquid-flow rate (kg/s*m^2)	Air inlet temperature (°C)	Air outlet temperature (°C)	Air inlet humidity (kg H_2O/kg dry air)	Air outlet humidity (kg H_2O/kg dry air)	Liquid inlet temp (°C)	TEG concentration (%wt)	Equilibrium humidity (kg H_2O/kg dry air)	Height of the absorber (cm)	Efficiency (%)	Mass-transfer coefficient (kmol/m^3*s)	Height of transfer unit (m)	Orifice diameter of nozzle (mm)
0.731	1.786	31.8	31.0	18.7	10.4	25.8	94	6.42	55	67.59	0.0479	1.309	1.6
0.731	1.630	32.0	32.3	18.9	10.7	26.1	94	6.53	55	66.29	0.0438	1.429	1.6
0.731	1.473	32.1	33.0	19.1	11.6	26.2	94	6.56	55	59.81	0.0374	1.674	1.6
0.731	1.317	32.2	33.4	19.0	13.3	26.1	94	6.53	55	45.71	0.0261	2.400	1.6
1.303	1.786	29.2	32.2	19.3	12.7	25.8	94	6.42	55	51.24	0.0500	2.235	1.6
1.112	1.786	29.3	32.6	19.0	12.3	26.3	94	6.59	55	53.99	0.0434	2.200	1.6
0.921	1.786	29.2	32.2	18.2	11.6	26.6	94	6.68	55	57.29	0.0378	2.089	1.6
0.731	1.786	29.1	31.7	18.5	11.2	26.8	94	6.74	55	62.07	0.0353	1.776	1.6
0.731	1.786	31.3	30.3	18.9	10.3	25.8	94	6.42	55	68.91	0.0512	1.224	1.6
0.731	1.786	31.4	32.3	19.2	11.2	26.7	92	7.56	55	69.26	0.0437	1.434	1.6
0.731	1.786	31.8	32.8	19.1	12.3	27.2	91	8.70	55	65.38	0.0374	1.677	1.6
0.731	1.786	31.9	33.1	19.2	13.5	27.4	89	10.64	55	66.59	0.0324	1.936	1.6
0.731	1.786	30.4	30.9	18.5	9.3	24.9	94	5.27	55	69.54	0.0516	1.215	1.6
0.731	1.786	29.2	30.9	18.1	9.8	29.6	94	6.84	55	73.71	0.0486	1.289	1.6
0.731	1.786	29.3	30.8	18.3	11.1	24.7	94	6.48	55	60.91	0.0363	1.725	2.0
0.731	1.786	30.3	32.9	18.3	11.2	28.9	94	6.92	55	62.39	0.0350	1.788	2.0

Absorption Efficiency

The absorption efficiency of the absorber was defined as the ratio of the actual change in moisture content of the air leaving the absorber to that of the maximum possible change under a given set of operating conditions. Therefore, the absorption efficiency, ε, can be expressed as

$$\varepsilon = \frac{W_{in} - W_{out}}{W_{in} - W_{equ}} \tag{1}$$

where W_{in} and W_{out} are the water contents of the inlet and outlet air streams, respectively. W_{equ} is the water content of the air, which is equilibrated with the TEG solution at a specific concentration and temperature. Since it is difficult to control the air inlet humidity, humidity was selected from 18 to 19.2 g H_2O/kg dry air throughout the study. Figure 2(a) shows that the adsorption efficiency was increased by the liquid-flow rate as the air-flow rate was kept constant. Since the amount of the treated air was fixed and the amount of the liquid desiccant solution (TEG) was increased, the absorption efficiency should increase. On the contrary, Fig. 2(b) also shows that the absorption efficiency was decreased by air-flow rate as the liquid-flow rate was kept constant. Similarly, when the amount of treated air was increased and the amount of TEG solution was fixed, the adsorption efficiency should decrease. Since the capacity of water vapor solving in TEG solution is larger for higher TEG concentration, adsorption efficiency was increased as the concentration of TEG solution increases, as shown in Fig. 2(c). The amount of the nebulized particles is increased for lower liquid temperature and smaller orifice

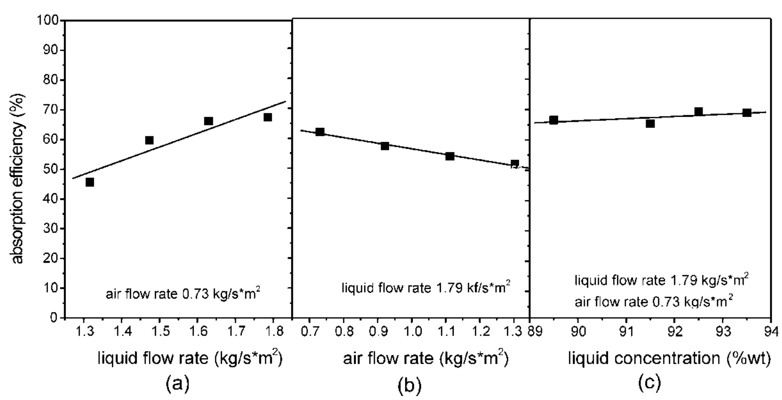


Figure 2. Effect of various operating conditions on the absorption efficiency.

Table 2. Comparison of mass-transfer performance for liquid inlet temperature and orifice diameter of nozzles.

Air-flow rate (kg/s*m^2)	Liquid-flow rate (kg/s*m^2)	Liquid inlet temperature (°C)	Adsorption efficiency (%)	Mass-transfer coefficient (kmol/m^3*s)	Orifice diameter of nozzle (mm)
0.731	1.786	26.3	69.82	0.0360	1.6
0.731	1.786	30.9	62.61	0.0197	1.6
0.731	1.786	26.2	55.95	0.0272	2.0
0.731	1.786	30.1	46.90	0.0162	2.0

diameter. Table 2 shows that the adsorption efficiency for lower liquid inlet temperature and smaller orifice diameter was higher.

Mass-Transfer Coefficient

Based on the heat and mass balance, the overall mass-transfer coefficient for gas phase was derived by Geankoplis[11] for mass transfer in a spray tower. The control volume for heat and mass transfer is shown in Fig. 3. The rate of heat transfer due to latent and sensible heat transferred from the water vapor can be obtained as follows:

$$\begin{aligned} LC_L\,\mathrm{d}T_L = G\,\mathrm{d}H_y = M_B k_y a P \\ \lambda_0(H_i - H_G)\mathrm{d}z + h_G a(T_i - T_G)\mathrm{d}z \end{aligned} \tag{2}$$

Because the ratio of the heat- and mass-transfer coefficients is approximately equal to the humid heat for a water vapor–air mixture, i.e.,

$$\frac{h_G a}{M_B k_y a} \cong C_s \tag{3}$$

Equation (2) becomes

$$G\,\mathrm{d}H_y = M_B k_y a P\,\mathrm{d}z[(C_s T_i + \lambda_0 H_i) - (C_s T_G + \lambda_0 H_G)] \tag{4}$$

From the definition of the total enthalpy of a water vapor–air mixture,

$$H_y = C_s(T - T_0) + \lambda_0 H \tag{5}$$

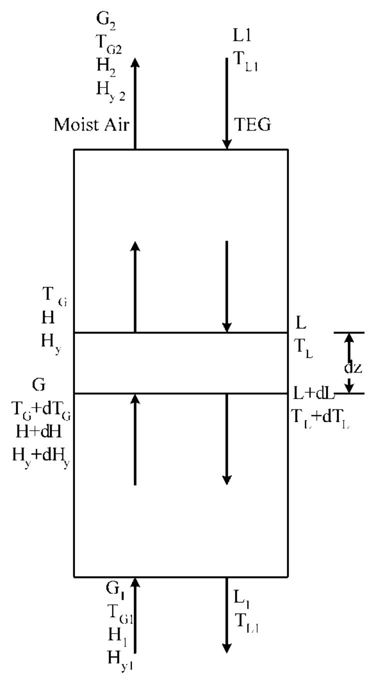


Figure 3. Control volume of heat- and mass-transfer balance for absorber.

Equation (4) can be written as

$$G\,\mathrm{d}H_y = M_B k_y a P\,\mathrm{d}z(H_{yi} - H_y) \tag{6}$$

When eq. (6) is rearranged and integrated, the average mass-transfer coefficient for gas phase becomes

$$(k_y a)_{avg} = \frac{G}{M_B z P}\int_{Hy1}^{Hy2} \frac{dHy}{H_{yi} - H_y} \tag{7}$$

For the overall mass-transfer transfer coefficient, eq. (7) can be written as

$$(K_y a)_{avg} = \frac{G}{M_B z P}\int_{Hy1}^{Hy2} \frac{dH_y}{H_y{*} - H_y} \tag{8}$$

The overall mass-transfer coefficient for gas phase calculated from eq. (8) is shown in Fig. 4 and Table 2 and allows one to observe the effect of experimental variables

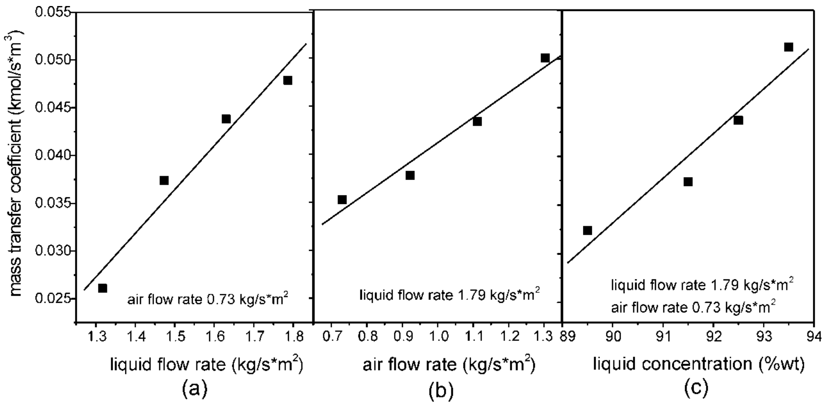


Figure 4. Effect of various operating conditions on the overall mass-transfer coefficient.

on the mass-transfer coefficient. As expected, the effects of various operating variables on the overall mass-transfer coefficients were similar to the effects on the absorption efficiency in Fig. 2 except for the effect of air-flow rate. Since the mass-transfer coefficient is proportional to the molar flux of water vapor in the gas phase, and the molar flux is proportional to air-flow rate of the system, the mass-transfer coefficient is increased by increasing the air-flow rate, as shown in Fig. 4(b).

Experimental Design Methodology

Since the effect of process variables on the response discussed by the statistical method was appreciated gradually in recent years, response surface methodology (RSM)[12] was applied in this study. Compared to the traditional analysis of "one factor at a time" technique, the RSM provides an experimental design to reduce the number of the experimental runs and gives a chance to review the interactive effect between factors. The F-ratio calculated from the RSM was applied to determine the effects of a factor or factors on the response variable of mass-transfer coefficient in this study. Analysis of selected process variables (or factors) affecting mass-transfer coefficients and interaction between these variables can be carried out by F-ratio examination. Performing a minimum set of well-chosen experiments and obtaining more reasonable explanations about interactions between these variables were the advantages of using this method. Using analysis of variance (ANOVA), the value of the F-ratio can be obtained from SAS (statistical analysis systems) software of *JMP* to evaluate the relationship between factors and the response variable. The null, or alternative hypothesis, (H_0 and H_1) is usually assumed to judge whether the effect of selected factors (operating variables) on the overall mass-transfer coefficient is significant or relatively insignificant by the value of F-ratio derived from the analysis of variance. F-ratio means the ratio of mean square for a specific factor to mean square for error. The value of the F-ratio and the related terminologies or notations are represented as follows.[12,13]

$$F = \frac{MSA}{MSE} \tag{9}$$

$$MSA = \frac{SSA}{k - 1} \tag{10}$$

$$SSA = \sum_{i=1}^{k} \sum_{j=1}^{n} (\overline{Y}_i - \overline{\overline{Y}})^2 \tag{11}$$

$$MSE = \frac{SSE}{k(n - 1)} \tag{12}$$

$$SSE = \sum_{i=1}^{k} \sum_{j=1}^{n} (Y_{ij} - \overline{\overline{Y}})^2 \tag{13}$$

SSA and *SSE* are the sum of square in deviation and error deviation for A factor. The degrees of freedom for A factor and error are indicated by $k - 1$ and $k(n - 1)$, in which k represents the number of treated level and n represents the number of sampling in the kth group. Similarly, the F-ratio of other factors and interaction between factors can be defined by the same principle, which is offered in Table 3. The factorial design of five factors and the analysis of two levels for mass-transfer performance in a spray tower were designed and are tabulated in Table 4. Only 2^5 experimental runs were enough for this statistical analysis. The five experimental variables (factors) chosen in this study were the air-flow rate (AFR), the liquid-flow rate (LFR), the liquid inlet temperature (LIT), the liquid concentration (LC), and the orifice diameter of nozzle (ODN). The mass-transfer coefficient (MTC) was regarded as a response variable, which is also termed as a dependent variable in statistics.

Table 3. Definitions of statistical terminologies for analysis of variance.

Source of variance	Variance (SS)	Degree of freedom	Mean square (MS)	F-ratios
A Factor	SSA	a − 1	MSA = SSA/(a − 1)	F1 = MAS/MSE
B Factor	SSB	b − 1	MAB = SSB/(b − 1)	F2 = MSB/MSE
Interaction between A and B	SSAB	(a − 1)(b − 1)	MSAB = SSAB/ (a − 1)(b − 1)	F3 = MSAB/MSE
Error	SSE	n_T − ab	MSE = SSE/(n_T − ab)	
Sum	SST	n_T − 1		

To assess the relativity between the experimental results and the statistical model, the determination coefficient (R^2) was estimated by multiple linear regressions with the least squares method. As the value of R^2 is very close to 1, the experimental results are consistent with the statistical model.

Effect of Experimental Variables on the Mass-Transfer Coefficient

The values of F-ratio for the selected factors and interactions between variables were calculated with software and are shown in Table 5. The R^2 resulting from experimental runs was equal to 0.98 in this study. It indicated that the relativity between the experimental results and the statistical model is good. The critical F-ratio (F_c) of this system was obtained from a standard procedure of Bluman.[14] Analysis of variance was conducted by comparing the F-ratio with the critical value of F-ratio (F_c).

In discussions of the effect of single factors, the F_c is equal to 3.84, which was obtained from Bluman.[14] The F-ratio for liquid-flow rate is 39.94, which is larger than 3.84. Among the factors, the F-ratio for liquid-flow rate is the largest, which means that the effect of this factor on the mass-transfer coefficient is the most significant in this process. When the liquid-flow rate was increased, the pressure drop of the liquid flowing through the nozzle was increased as well as the number of nebulized particles. Therefore, the mass-transfer coefficient was changed significantly. In addition, the mass-transfer coefficient is affected by the liquid concentration, orifice diameter of nozzle, and liquid inlet temperature significantly, because the values of F-ratio for

Table 4. Representation of factorial design and variables.

Number	Pattern	AFR	LFR	LIT	CON	ODN	MTC
1	−++−−	0.731	1.786	30	89	0.5	0.0220
2	++−++	1.303	1.786	25	94	0.625	0.0593
3	+−++−	1.303	1.317	30	94	0.5	0.0240
4	+−−−+	1.303	1.317	25	89	0.625	0.0298
5	−−−−−	0.731	1.317	25	89	0.5	0.0168
6	−−+−−	0.731	1.317	30	89	0.5	0.0111
7	−+−+−	0.731	1.786	25	94	0.5	0.0363
8	−+−−+	0.731	1.786	25	89	0.625	0.0317
9	−−++−	0.731	1.317	30	94	0.5	0.0168
10	−−−+−	0.731	1.317	25	94	0.5	0.0210
11	−+−++	0.731	1.786	25	94	0.625	0.0516
12	+−+−−	1.303	1.317	30	89	0.5	0.0121
13	+−−−−	1.303	1.317	25	89	0.5	0.0268
14	++++−	1.303	1.786	30	94	0.5	0.0466
15	−−+−+	0.731	1.317	30	89	0.625	0.0129
16	−++−+	0.731	1.786	30	89	0.625	0.0252
17	++−−+	1.303	1.786	25	89	0.625	0.0358
18	+++++	1.303	1.786	30	94	0.625	0.0561
19	−+−−−	0.731	1.786	25	89	0.5	0.0272
20	+++−−	1.303	1.786	30	89	0.5	0.0332
21	−++++	0.731	1.786	30	94	0.625	0.0486
22	−−−−+	0.731	1.317	25	89	0.625	0.0227
23	++−−−	1.303	1.786	25	89	0.5	0.0349
24	+−−++	1.303	1.317	25	94	0.625	0.0361
25	++−+−	1.303	1.786	25	94	0.5	0.0506
26	−+++−	0.731	1.786	30	94	0.5	0.0350
27	+++−+	1.303	1.786	30	89	0.625	0.0283
28	+−−+−	1.303	1.317	25	94	0.5	0.0277
29	+−+−+	1.303	1.317	30	89	0.625	0.0176
30	−−+++	0.731	1.317	30	94	0.625	0.0243
31	+−+++	1.303	1.317	30	94	0.625	0.0302
32	−−−++	0.731	1.317	25	94	0.625	0.0254

these factors are all larger that 3.84. However, the F-ratio for air-flow rate is smaller than 3.84. This implies that the effect of this factor on the mass-transfer coefficient is relatively insignificant. Since the change of humidity from inlet to outlet is smaller or insignificant for changing air-flow rate, the experimental

Table 5. Representation of factor design and variables.

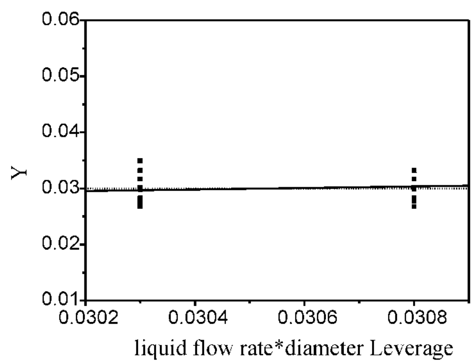
Factor	Sum of squares	F-ratio	Prob > F
AFR	0.00000407	0.6760	0.4230
LFR	0.00023600	39.1991	<0.0001
LIT	0.00004561	7.5761	0.0142
CON	0.00022413	37.2265	<0.0001
ODN	0.00006398	10.6267	0.0049
AFR*LFR	0.00000603	1.0014	0.3319
AFR*LIT	0.00000809	1.3438	0.2634
AFR*CON	0.00001609	2.6723	0.1216
AFR*ODN	0.00001117	1.8561	0.1920
LFR*LIT	0.00001936	3.2156	0.0919
LFR*CON	0.00025374	42.1458	<0.0001
LFR*ODN	0.00000206	0.3414	0.5672
LIT*CON	0.00004253	7.0636	0.0172
LIT*ODN	0.00000237	0.3938	0.5392
CON*ODN	0.00009015	14.9734	0.0014

or calculated error is larger than other factors among the smaller humidity interval. Therefore, the relativity between mass-transfer coefficient and air-flow rate is insignificant.

Interaction Between Two Factors

Interaction between two selected factors can also be assessed by F-ratio examination. In discussions of the interactive effect of the two factors, F_c is equal to 4.20, which was obtained from Bluman.[14] Select two operating variables and compare the effect of both variables on the mass-transfer coefficient. While the change between the deviations of mass-transfer coefficient for the selected factors were close to each other, the acquired F-ratio is lower. As shown in Fig. 5, the deviations of mass-transfer coefficient change from 0.026 to 0.034 and from 0.026 to 0.033 kmol/m^{3}s for the factors of liquid-flow rate and orifice diameter of nozzle. Both of these two intervals are close to each other. On the contrary, while the change between the deviations of mass-transfer coefficient for the selected two factors does not approach well, the acquired F-ratio is larger. As shown in Fig. 6, mass-transfer coefficients change from 0.026 to 0.034 and from 0.028 to 0.036 kmol/m^{3}s for the factors of liquid flow rate and liquid

Liquid flow rate*diameter

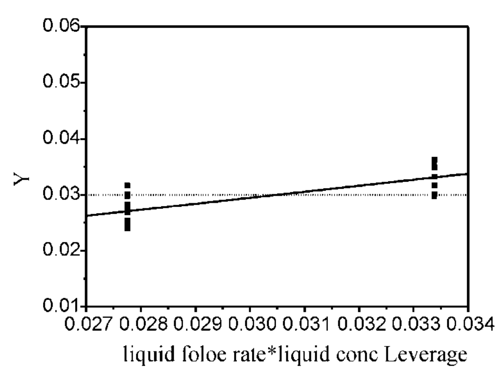


Effect Test

Sum of Squares	F Ratio	DF
0.00000206	0.3414	1

Figure 5. Interaction between liquid-flow rate and orifice diameter of nozzle.

Liquid flow rate*liquid conc



Effect Test

Sum of Squares	F Ratio	DF
0.00025374	42.1458	1

Figure 6. Interaction between liquid-flow rate and liquid concentration.

concentration. The calculated values of F-ratio for the interaction of liquid inlet temperature and liquid concentration and the interaction of liquid concentration and orifice diameter of nozzle were larger than 4.20 (F_c). The results demonstrate that the effects on mass-transfer coefficient are significant. However, the F-ratio for air-flow rate and liquid-flow rate, air flow rate and liquid inlet temperature, air-flow rate and liquid concentration, air-flow rate and orifice diameter of nozzle, liquid-flow rate and liquid inlet temperature, liquid-flow rate and orifice diameter of nozzle, and liquid inlet temperature and orifice diameter of nozzle were smaller than F_c. This means that the effects of these selected two-factors are not significant on the mass transfer coefficient.

CONCLUSION

The variables, including air-flow rate, liquid-flow rate, orifice diameter of nozzle, liquid inlet temperature, and liquid concentration were discussed as to their influence on the mass-transfer coefficient in a spray tower. A countercurrent spray tower in an absorption-stripping system was designed and tested successfully for dehumidification of air. The results show that the mass-transfer coefficient increases as the air- or liquid-flow rate increases. The mass-transfer coefficient increases along with decreasing the orifice diameter of the nozzle as the air- and liquid-flow rates are kept constant. Not only the effect of the selected factors on the mass-transfer coefficient but also the interaction between factors can be obtained by analysis of variance in the experimental design methodology. The results show that the effects of liquid-flow rate and liquid concentration on the mass-transfer coefficient are more significant, which are consistent with the experimental data. Besides, by means of evaluating the interaction between the two factors, the results demonstrated that the deviations of mass-transfer coefficient for the factors of liquid-flow rate and liquid concentration would be larger than a single factor. However, as the values of F-ratio smaller than F_c, the effects of the selected factors are not significant on the mass transfer coefficient. The experimental design methodology for factorial design of two levels and five factors was applied to the analysis of the mass-transfer performance in this study. It is useful to apply the experimental design methodology for modeling or understanding the chemical processes to reduce the complexity of the experimental systems.

NOMENCLATURE

C_L = heat capacity of the liquid, J/kg·K
C_S = heat capacity of solution, J/kg·K
G = air-flow rate, m/sec
H_G = the humidity of the gas in the bulk gas phase, kg water/kg dry air
h_Ga = volumetric heat-transfer coefficient for gas, $W/m^3 \cdot K$
H_y = enthalpy of air–water vapor mixture, J/kg dry air
H_y* = the enthalpy of air–water vapor mixture in equilibrium with
TEG at specific temperature and concentration, J/kg dry air
k_ya = volumetric mass-transfer coefficient, $kgmol/m^3 \cdot s \cdot Pa$
K_ya = volumetric overall mass-transfer coefficient in the gas, $kgmol/m^3 \cdot s \cdot Pa$
L = liquid flow rate, kg/esc
M_B = molecular weight of air, kg/kg mole
P = atm pressure, Pa
T = temperature of the liquid desiccant solution, °C
T_G = gas temperature, °C
T_i = interfacial temperature, °C
T_L = liquid temperature, °C
T_o = base temperature, 0°C
W_{in} = inlet air humidity
W_{eq} = the humidity of air in equilibrium with triethylene glycol solution at specific temperature and concentration
W_{ou} = outlet air humidity
Z = height of the absorber, m
λ_0 = the latent heat of water, J/kg water
Y_{ij} = value for the i and j factors under the defined level
$\overline{Y}_i$ = average value of I factor
$\overline{\overline{Y}}$ = average value of all experimental factors

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