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Analysis on the Significance of Effects from Operational Conditions on the Performances of Ultrasonic Atomization Dehumidifier with Liquid Desiccant

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Abstract

In this work, simulations were carried out based on a L18×L8 cross-product orthogonal array to investigate the significance of the effects from inlet operational conditions on the performances of the ultrasonic atomization liquid desiccant dehumidification system (UADS), where dehumidification effectiveness was adopted as the performance indicator. Taguchi method was employed to analyze the results. It was found that though all of the inlet operational parameters revealed direct effects on the performances of UADS, the significance of their effects was quite different among which, the desiccant flow rate was the most sensible factor in improving DE while air humidity ratio exhibited the least significance. The results presented in this work may help in achieving the optimal running of the liquid desiccant dehumidification system.

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Keywords: Significance analysis; Ultrasonic atomization; Liquid desiccant; Taguchi method.

1. Introduction

Liquid desiccant dehumidification air-conditioning systems (LDAC) have attracted a great deal of attention in recent years for its great potential in energy saving of buildings [1, 2]. Numerous studies have been conducted experimentally to investigate the relationships between the operational conditions and the performances of LDAC. However, due to the complexity of the exhausting dehumidification experiments, most of the existing experimental

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investigations were just performed by means of the incomplete single factor experiment, rather than the comprehensive experiment. In view of this, this study carried out simulations based on a L18×L8 cross-product orthogonal array to investigate the significance of the operational conditions on the performances of UADS. The results presented in this work may help in achieving the optimal running of the liquid desiccant dehumidification system.

2. Methods

2.1. Taguchi Method

The Taguchi method is considered to be one of the best significance analysis methods [3]. It consists of a cross-product orthogonal array, which consists of a set of well-balanced experiments, and is able to figure out the operational conditions that are significant in improving the system's performance and reducing the fluctuation of the output of the system. The overall analysis procedure of the Taguchi method can be demonstrated briefly as Fig.1 shows [4].

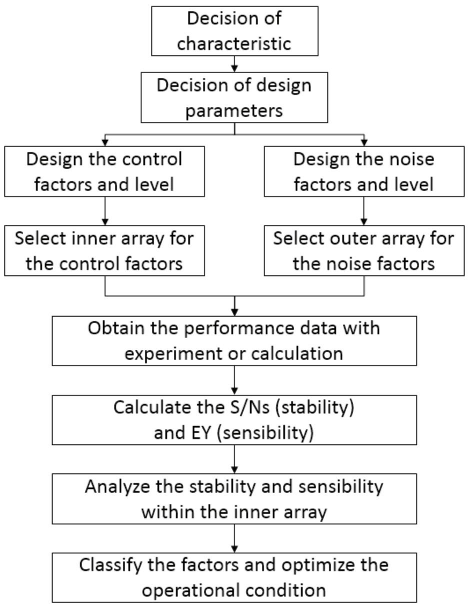

Fig. 1. Analysis procedure of Taguchi method

- Design for the cross-product orthogonal array

In Taguchi method, two kinds of the operational conditions, namely the control factors and the noise factors, are considered to have the decisive effects on the performance of one specific system. It is easy to understand that the control factors refer to the conditions that can be controlled during the running of UADS, while the noise factors stand for the fluctuation of the operational conditions which is inevitable during the dehumidification process. Both of the control factors and the noise factors were arranged into a cross-product orthogonal array as the basis of the performance tests of the system. The array was composed of two data sections, namely the inner array for the control factors and the outer array for the noise factors. In this work, six process control conditions, namely the flow rates of airstream and desiccant solution, the air inlet temperature, the desiccant inlet temperature, the air inlet humidity ratio and the desiccant inlet concentration with three levels were identified as the control factors and set in the inner array. Similarly, the outer array for the noise factors was fulfilled with a L8_2_7 orthogonal array in the current work. The results for each inner array were calculated with the test results of the corresponding outer array with the method introduced briefly as follows.

- Indicator of significance analysis

The aim of significance analysis is to figure out the operational conditions which are significantly sensitive to the performance of UADS and provide the potential ways of approaching to the desired performance. Through adjusting the sensible conditions, it was expected to minimize the gap between the practical performance of the system and the target value.

In Taguchi method, the indicator during the significance analysis was recommended to be represented by the mean value ($\overline{y}_i$) of the corresponding test results of the outer array. It can be calculated as follows:

$$\overline{y}_i = \frac{1}{n}\sum_{j=1}^{n} y_{i,j} \tag{1}$$

, where $y_{i,j}$ and n separately stands for the value and number of the tests in the outer array.

2.2. Simulation Method

In view of the cross-product orthogonal array employed in this work was kind of complex, it requires not only a large number of experimental runs, (about 144 for each array), but also a prohibitively rigorous accuracy of the operational conditions during the experimental tests. This makes it exceedingly difficult to fulfil the array with experiments. Hence, the Ideal dehumidification model (ab. IDM), proposed in the authors' earlier work [5] was employed to simulate the performance of the UADS in this work. Detailed information of the IDM and the experimental process can be found in the authors' earlier work [6].

3. Results and Discussion

In this work, calculations were conducted for the significance analysis of the operational conditions in UADS. The result displayed in Tab.1 was analyzed with the analysis of variance statistical method (ANOVA). It can be shown and discussed as follows.

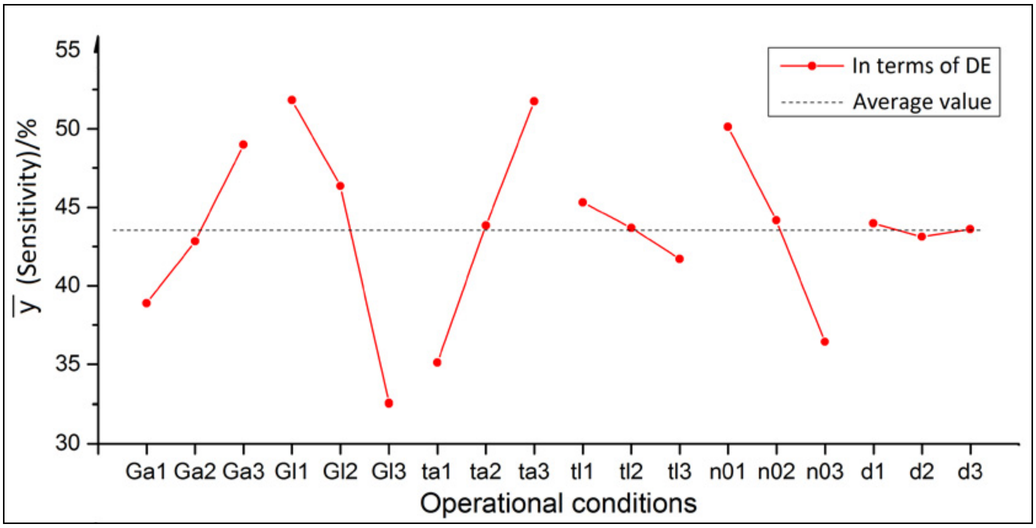

Fig. 2. Factors response curve in terms of significance of DE

The specific response of significance for each operational condition was demonstrated in Fig.2. As shown in Fig.2, the UADS will achieve the better DE when handling a lower amount of the cooler airstream with the desiccant solution of higher mass flow rate and concentration. At the meanwhile, slight decrease of DE was observed when cooler desiccant solution was employed and little change of DE was found when varying the inlet air humidity ratio in UADS, as shown in Fig.2.

Table 1. Data and statistical analysis on the sensitivity of DE in UADS.

Calculation No.	Arrange of orthogonal array for calculation							$\bar{\phi}_i$ /%
	G_a (kg/h) 1	G_l (kg/h) 2	t_a (°C) 3	t_l (°C) 4	n_0 (%) 5	D (g/kg) 6	none 7	
1	1	1	1	1	1	1	1	46.600
2	1	2	2	2	2	2	2	42.141
3	1	3	3	3	3	3	3	30.618
4	2	1	1	2	2	3	3	42.661
5	2	2	2	3	3	1	1	32.218
6	2	3	3	1	1	2	2	43.488
7	3	1	2	1	3	2	3	52.873
8	3	2	3	2	1	3	1	62.106
9	3	3	1	3	2	1	2	24.805
10	1	1	3	3	2	2	1	51.505
11	1	2	1	1	3	3	2	25.043
12	1	3	2	2	1	1	3	37.451
13	2	1	2	3	1	3	2	57.524
14	2	2	3	1	2	1	3	63.030
15	2	3	1	2	3	2	1	18.032
16	3	1	3	2	3	1	2	59.771
17	3	2	1	3	1	2	3	53.586
18	3	3	2	1	2	3	1	40.828
I j	233.4	310.9	210.7	271.9	300.8	263.9	251.3	T=784.28 $T^2/18$= 34171.97
II j	257.0	278.1	263.0	262.2	265.0	261.6	252.8	
IIIj	294.0	195.2	310.5	250.3	218.6	258.8	280.2	
SSj	311.1	1185.5	830.5	39.0	566.2	2.2	196.0	SS_T=3130.48

The effects of the various operational conditions in terms of DE can be analyzed and ranked as Fig.3 shows. It is evident that the desiccant flow rate, followed by the air inlet temperature, desiccant inlet concentration and air flow rate, was the most sensible factor in approaching the desired values of DE while the desiccant inlet temperature and air inlet humidity ratio exhibited the least significance. Furthermore, when dehumidifying unit mass flow rate of humid air, the DE of UADS was improved substantially via increasing the mass flow rate and the concentration of desiccant solution as well as reducing the air inlet temperature.

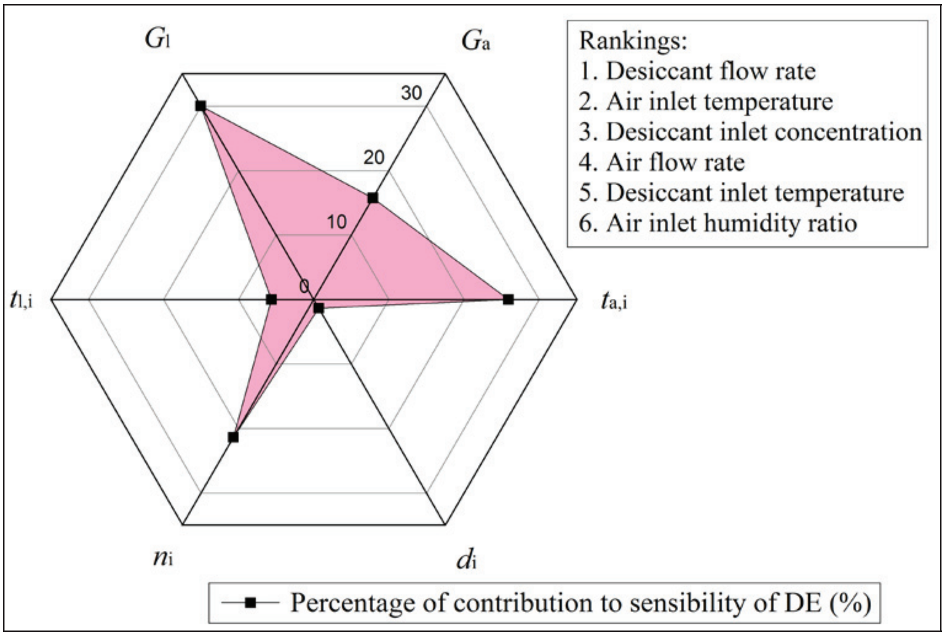

Fig. 3. Percentage of contribution from operational conditions to DE

Table 2. Significance of inlet operational conditions on DE.

Parameters	G_a(kg/h)	G_l(kg/h)	t_a(oC)	t_l(oC)	n_0(%)	d(g/kg)
Significance of effects on DE	*	**	**	--	**	--

** (P<0.05); * (0.05<P<0.1); -- (P>0.1)

Tab.2 illustrates the significance of inlet operational conditions on dehumidification effectiveness (DE) analyzed with the ANOVA method. As shown in Tab.2, analysis of variance showed that the effects on the dehumidification effectiveness of UADS was quite different among the inlet operational conditions discussed in this work. With the P<0.05, the desiccant inlet mass flow rate together with the air inlet temperature and desiccant inlet concentration presented considerable significance on varying the DE of UADS while slight significance was displayed by air inlet mass flow rate in changing the DE. Furthermore, with the P>0.1, the desiccant inlet temperature as well as the air inlet humidity ratio shows least significance in altering the DE of UADS in present work. This results showed in Tab.2 are in line with the results demonstrated in Fig.2 and Fig.3.

4. Conclusions

In this work, simulations were carried out based on the Taguchi method to analyze the sensibility of the operational conditions on the performances of UADS. Through the sensibility analysis, it was found that among the operational conditions discussed in this work, the desiccant flow rate, followed by the air inlet temperature, desiccant inlet concentration and air flow rate, was the most sensible factor in improving DE while air humidity ratio exhibited the least significance.

Acknowledgements

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