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Optimization of Moisture condensation rate of Liquid Desiccant Dehumidifier through Genetic Algorithm

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Abstract: Dehumidifier is the most important unit in liquid desiccant air conditioning system. This paper experimentally investigates the performance of an adiabatic dehumidifier using calcium chloride as a liquid desiccant. The dehumidifier inlet parameters namely desiccant flow rate, concentration, temperature, air humidity ratio and liquid to air flow rate ratio, each at four levels have been chosen and sixteen experimental runs based on L16 orthogonal array have been performed. A mathematical model relating the effect of the influencing parameters on the moisture condensation rate has been developed using nonlinear regression analysis with the help of MINITAB software. MATLAB genetic algorithm (GA) has been employed to enhance the performance of the dehumidifier. It has been noted that GA optimum condition would result in the dehumidifier with better performance.
Keywords: Liquid desiccant dehumidifier, Moisture condensation rate, Genetic algorithm.

1. Introduction

The control of indoor temperature and humidity ratio is the main task of air-conditioning systems. Usually, outdoor air will be cooled and dehumidified in summer and heated and humidified in winter before being supplied into occupied spaces. In conventional Heating, Ventilation and Air conditioning (HVAC) systems, the process of dehumidifying air is implemented by condensing dehumidification method, in that the air contacts cold coil surface (lower than the dew point of the air) so that moisture in the air will condense into water. Chilled water with a temperature of about 7°C is usually adopted in conventional HVAC systems, which leads to the low COP of the chiller. Sometimes, the air passing the cooling coil is so cold that it has to be reheated before being supplied into occupied spaces. Furthermore, the condensed surface creates a suitable environment for bacteria, which will impair the indoor air quality. In winter, other electrical humidifier or steam humidifier has to be adopted to meet the humidification requirement. Liquid desiccant air-conditioning systems have developed quickly in recent years. The air is dehumidified by contacting cold and concentrated liquid desiccant directly, and vice versa, it is humidified by contacting warm and diluted liquid desiccant. Compared with conventional HVAC systems, the advantages of liquid desiccant systems [1–4] can be summarized as follows: a) the air can be dehumidified at a temperature higher than its dew point by contacting concentrated liquid desiccant; therefore, reheat is no longer needed b) liquid desiccant system can be driven by low-grade heat, such as solar energy or waste heat c) a number of pollutants will be removed by the system from the processed air and d) the air can be easily humidified in the same handling unit by contacting diluted liquid desiccant.

The concept of using liquid desiccant system to dehumidify the air goes back to the year of 1955, when Löf designed an open-cycle air-conditioning system using tri ethylene glycol as liquid desiccant solution. Since then, the technique has been further developed and studied by more and more investigators [5–10]. The liquid desiccant can be used in air-conditioning systems in two ways one is as a pure liquid desiccant system and hybrid.

Liquid desiccant air conditioning system driven by solar energy or other heat sources was emerged as a potential alternative or as a supplement to conventional vapor compression systems for air conditioning. Dehumidification and regeneration are the key processes of liquid desiccant air conditioning system. Many literatures were dedicated to the investigation of performance of liquid desiccant dehumidifiers and regenerators [11-12].

The performance of a cross-flow liquid-desiccant conditioner that is used structured packing, flooded with a solution of lithium bromide is reported in terms of the moisture removal rate for the conditioner and its dehumidification effectiveness at varying desiccant flow rates, airflow rates, desiccant inlet temperature, desiccant inlet concentration, air inlet temperature, and air inlet humidity ratio (13).

In this study, calcium chloride ($CaCl_2$) is used as a liquid desiccant in dehumidifier. First the process air passes through liquid desiccant dehumidifier, where water vapour from the air partially removed, and then the air sends through indirect evaporative cooler, sensible heat is removed from the air, again the process air passes through second dehumidifier, if further water vapour required to be removed from the air. The process parameters affecting the moisture condensation rate, namely desiccant concentration, flow rate, temperature, air humidity ratio and liquid to air flow rate ratio have been considered in this study. A L_{16} (4^5) orthogonal array is used for the conduct of experiments and Genetic algorithm is employed to obtain the optimum parametric condition in this study.

2. Description Of Experimental Set Up

The schematic diagram of experimental set up is shown in Figure 2.1. It consists of three major components namely dehumidifiers, indirect evaporative cooler (IDEC), regenerator. The dehumidifier (27 cm deep, 10 cm wide and 20 cm long) is made with acrylic sheet (thickness 5 mm) to see inside during operation and inner core of dehumidifier made of corrugated PVC sheets (270 mm x 5 mm x 200mm). In the inner core, the gap 5mm is maintained between corrugated PVC sheets and non woven cloth is wounded over the corrugated sheet surface to promote wetting by air and desiccant. A spray head is used to distribute liquid desiccant over the structured packing. Process air is made to meet with liquid desiccant in crosswise direction. The weak solution is collected at the bottom of the dehumidifier.

The outer casing (50 cm in diameter and 75 cm in height) of regenerator is made of PVC and packed with balls (1 ½" diameter). The weak desiccant solution from dehumidifier is pumped to heater and the hot weak solution is then sprayed over the regenerator through nozzle. The atmospheric air is made to meet with weak solution in counter clockwise direction and the strong desiccant solution is collected at the bottom of the regenerator.

Indirect evaporative cooler (50 cm in length and 20 cm in height, 10 cm in width) outer body made of acrylic sheet is used to cool the process air coming from the dehumidifier. The process air is passed through the channels over which evaporative cooling take place due to the contact of atmospheric air and water, thereby cooling effect is transferred to process air.

The dry bulb temperature of process air is measured at various points using k – type thermocouple. Relative humidity of air, Desiccant flow rate, Concentration of desiccant and Air flow rate is measured with humidity sensors, rotometer, hydrometer and anemometer respectively.

First, the process air is passed through first dehumidifier, where the moisture is removed from the process air. During the dehumidification process, heat is generated, because of condensation of water vapour and heat of absorption. The temperature of air and desiccant solution increased, so this will reduce performance of dehumidification process, hence, the process air passes through indirect evaporative cooler. Where the process air temperature reduce from 2 to 3 at constant humidity ratio, then the process air send through second dehumifier where humidity ratio reduce further from state 3 to state 4. All process are depicted in Figure 2.2. If the humidity ratio of air calculated at inlet and outlet of dehumidifier, the amount of moisture condense during condensation process is

$$(m_c) = m_a (\omega_1 - \omega_4) \qquad (2.1)$$

The above parameter used by many researchers to evaluate the performance of liquid desiccant dehumidifier (14-17)

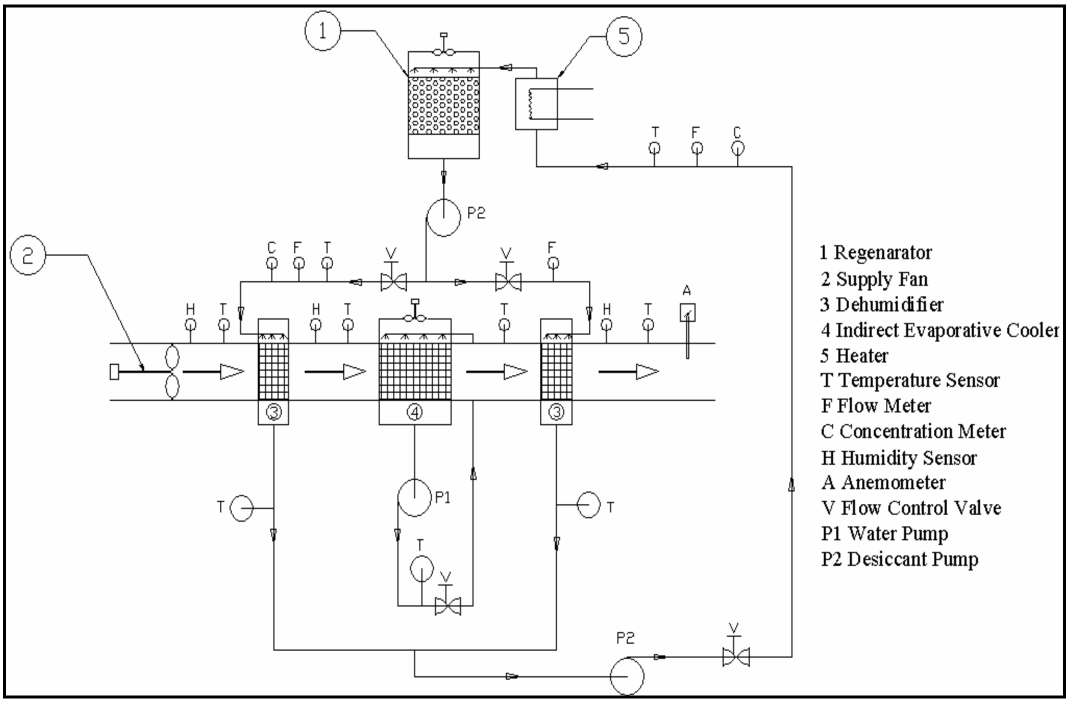
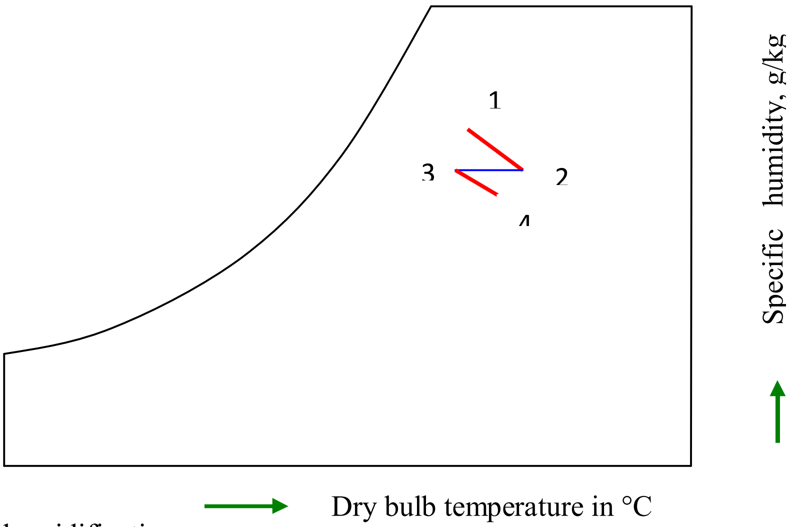


Figure 2.1. Schematic of experimental apparatus



1-2 Adiabatic dehumidification process
2-3 Sensible cooling process
3-4 Adiabatic dehumidification process

Figure 2.2 Psychrometric process

3. Optimization Techniques

It is very difficult to find optimum operating parametric setting for better performance of dehumidifier using conventional methods. Also it takes more time and cost. So optimization techniques are employed to find optimum operating condition. There are many optimization techniques was available to find the optimum conditions. In this study, Genetic algorithm and Microsoft excel solver are chosen to find the optimum parametric setting of dehumidification process.

4. Experimentation and Testing

In this study, five process parameters namely Air humidity ratio (A), Desiccant temperature (B), Desiccant concentration (C), Liquid to air flow rate ratio (D), and Desiccant flow rate (E) were considered for analyzing their influences on the dehumidification process. The four levels of each parameter tabulated in

Table 4.1. The experiments are conducted as per setting given in the Table 4.2. The properties are noted at various points of experimental set up and average moisture condensation rate calculated.

Table 4.1 Levels for process and control parameters

Process control Parameters	Notation	Level 1	Level 2	Level 3	Level 4
Air humidity ratio g / kg	A	18	20	22	24
Desiccant temperature($^{\circ}$C)	B	25	30	35	40
Desiccant concentration (kg / kg)	C	0.30	0.35	0.40	0.45
Liquid to Air flow rate ratio	D	1.8	2.0	2.2	2.4
Desiccant flow rate (kg / s)	E	1.6	1.8	2.0	2.2

Table 4.2 Experimental observations and calculation

Sl.No	A	B	C	D	E	Moisture condensation rate (kg /sec)				Average moisture condensation rate (m_{ca}) (kg /sec)
						m_{c1}	m_{c2}	m_{c3}	m_{c4}	
1	18	25	0.30	1.8	1.6	0.0018	0.0017	0.0018	0.0017	0.0017
2	18	30	0.35	2.0	1.8	0.0016	0.0016	0.0016	0.0016	0.0016
3	18	35	0.40	2.2	2.0	0.0016	0.0017	0.0016	0.0017	0.0016
4	18	40	0.45	2.4	2.2	0.0016	0.0016	0.0016	0.0016	0.0016
5	20	25	0.35	2.2	2.2	0.0019	0.0019	0.0019	0.0019	0.0019
6	20	30	0.30	2.4	2.0	0.0017	0.0017	0.0017	0.0017	0.0017
7	20	35	0.45	1.8	1.8	0.0013	0.0014	0.0013	0.0014	0.0013
8	20	40	0.40	2.0	1.6	0.0017	0.0017	0.0017	0.0017	0.0017
9	22	25	0.40	2.4	1.8	0.0019	0.0019	0.0019	0.0019	0.0019
10	22	30	0.45	2.2	1.6	0.0020	0.0020	0.0020	0.0020	0.0020
11	22	35	0.30	2.0	2.2	0.0019	0.0019	0.0019	0.0020	0.0019
12	22	40	0.35	1.8	2.0	0.0020	0.0020	0.0020	0.0020	0.0020
13	24	25	0.45	2.0	2.0	0.0018	0.0018	0.0018	0.0018	0.0018
14	24	30	0.40	1.8	2.2	0.0020	0.0020	0.0020	0.0020	0.0020
15	24	35	0.35	2.4	1.6	0.0016	0.0016	0.0016	0.0016	0.0016
16	24	40	0.30	2.2	1.8	0.0014	0.0013	0.0014	0.0014	0.0013
Mean										0.00174

5. Result and Discussions

5. 1. Optimum Condition via XL solver

By using non-linear regression analysis with the help of MINITAB 14 software, the effect of inlet parameters on average moisture condensation rate (m_{ca}) was modeled as follows.

$$m_{ca} = 0.002206 - 0.000306A + 0.000939B + 0.001027C - 0.000873D - 0.001386E - 0.000075A^2 + 0.000012B^2 - 0.000063C^2 + 0.000212D^2 + 0.000287E^2 + 0.000044AB + 0.000150AC - 0.000056AD - 0.000425BC \quad (5.1)$$

$R^2 = 99.9\%$ $R^2(adj) = 99.0\%$

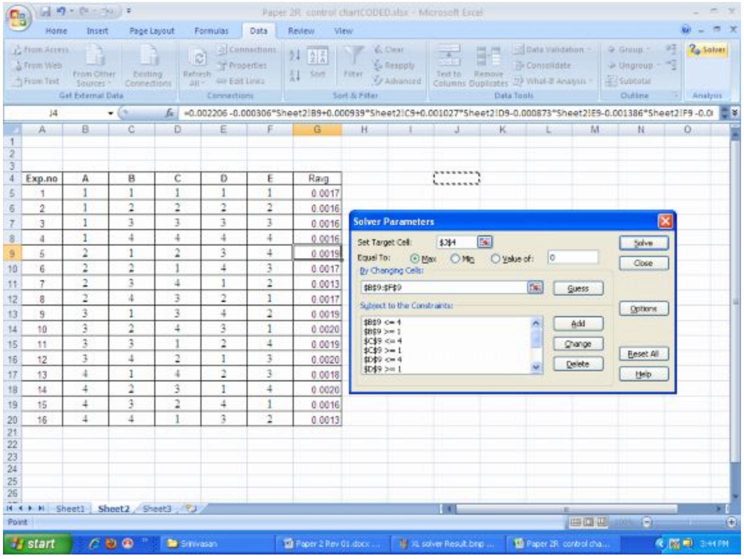


Figure 5.1 Input settings in XL solver

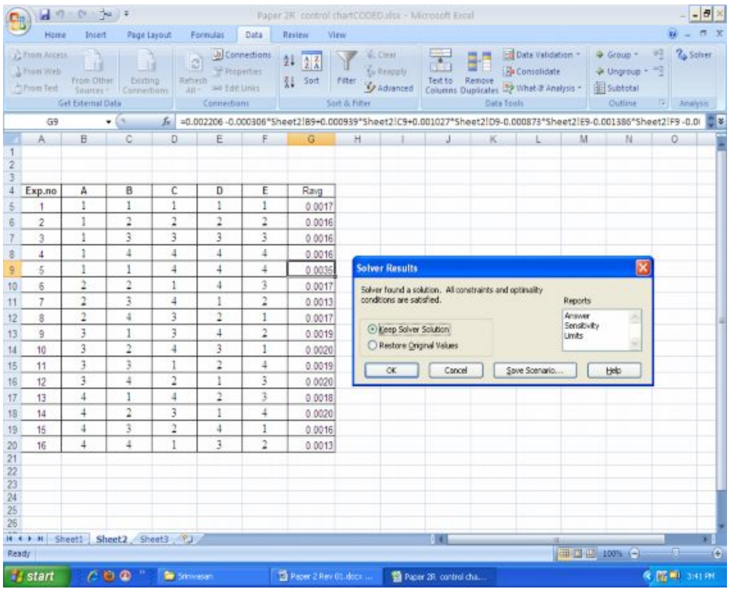


Figure 5.2. Optimum condition using XL solver

For this model, it was found that R^2 = 0.99 where R is correlation coefficient. The value of R^2 indicates the closeness of the model representing the process. Since R^2 is nearing unity, this model can be taken as an objective function for the application of optimization algorithms through which better parameter settings can be found. Windows XL solver tool was used in order to find the optimum parametric setting for maximizing moisture condensation rate. The mathematical model given in the equation (5.1) was given as a target function with a condition of maximization. The constraints were set for all significant control parameters. An optimized moisture condensation rate was found at optimum parametric condition as in Table 5.1. The input settings and optimum condition using XL solver are shown in Figures 5.1 and Figure 5.2.

Table 5.1 Inlet parameters and Optimum moisture condensation rate using XL Solver

Sl No	Input parameters	Optimum values	Optimized Moisture condensation rate kg / sec
1	Air humidity ratio g / kg (A)	24	0.0035 kg / sec
2	Desiccant temperature(°C) (B)	25	
3	Desiccant concentration(kg/kg) (C)	0.40	
4	Liquid to Air flow rate ratio (D)	2.4	
5	Desiccant flow rate (kg / s) (E)	2.2	

5. 2. Optimum Condition via Genetic algorithm

MATLAB genetic algorithm tool was used to find the optimum parametric condition for the maximization of moisture condensation rate in this study. The mathematical model given in Equation (5.1) was used as fitness function. The bound for all significant control parameters (A, C and E) were inputted. Genetic algorithm was run with setting values for the evolutionary parameters such as number of iterations (100), population type (double vector), population size (20), crossover probability (0.8), fitness selection function (stochastic) and mutation probability (0.03). It was observed that the fitness value decreased through generations as shown in Figure 5.3 and an optimized moisture condensation rate was obtained in the final generation. The optimum parametric condition in the final generation was noted as shown in Table 5.2

Table 5.2 Inlet parameters and Optimum moisture condensation rate using GA Solver

Sl No	Input parameters	Optimum values	Optimized Moisture condensation rate kg / sec
1	Air humidity ratio g / kg (A)	24	0.0035 kg / sec
2	Desiccant temperature(°C) (B)	25	
3	Desiccant concentration (kg / kg) (C)	0.40	
4	Liquid to Air flow rate ratio (D)	2.4	
5	Desiccant flow rate (kg / s) (E)	2.2	

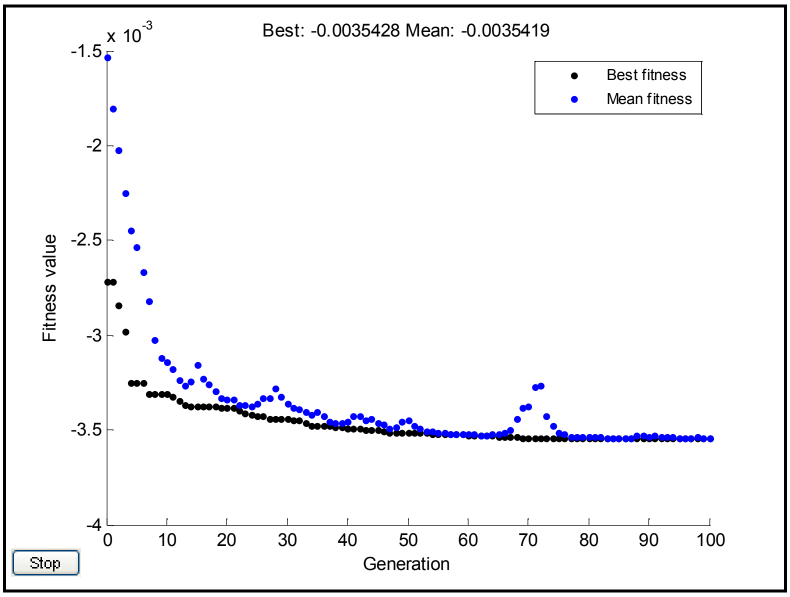


Figure 5.3 Fitness function values through generations

5.3. Confirmation Experiments

The optimum condition from XL solver and GA was noted to be same and confirmation experiment was conducted for the optimum condition. The results are summarized in Table 5.3

Table 5.3 Confirmation test results

Sl. No	Optimization tool	Description of parametric condition	Numerical value	Average Moisture condensation rate, m_{ca} (kg/s)		% error
				Model value	Tested value	
1	XL Solver	Air humidity ratio g / kg	24	0.0035	0.00335	4.28
		Desiccant temperature(°C)	25			
		Desiccant concentration(kg/kg)	0.40			
		Liquid to Air flow rate ratio	2.4			

		Desiccant flow rate (kg/m^2 s)	2.2			
2	Genetic Algorithm	Air humidity ratio g / kg	24	0.0035	0.00335	4.28
		Desiccant temperature(°C)	25			
		Desiccant concentration(kg/kg)	0.40			
		Liquid to Air flow rate ratio	2.4			
		Desiccant flow rate (kg/m^2 s)	2.2			

6. Conclusion

Dehumidification process is plays an important role in conditioning hot humid air. From the literature survey significant parameters affecting moisture condensation rate were predicated. Among all significant parameters such as air humidity ratio, desiccant temperature, concentration, flow rate and liquid to air flow rate ratio were noted to be a prime parameter in controlling moisture condensation rate. A mathematical model was developed for the process. XL solver and GA were applied to determine the optimum parametric conditions which maximize the moisture condensation rate of dehumidification process in liquid desiccant dehumidifier. The optimum conditions were determined and confirmed by experiments. It was confirmed that GA and XL solver were produced same optimum condition.

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Nomenclature

ω_i – Specific humidity of inlet air – g / kg
ω_o – Specific humidity of outlet air – g / kg
ω_e – Equilibrium specific humidity of air with solution at interface - g / kg
P_{vs} – Saturated vapour pressure – N / m^2
P_a – Ambient Pressure – N / m^2
T – Temperature of liquid desiccant solution – °C
S/N – Signal to noise ratio
ε – Effectiveness
X – Concentration of liquid desiccant solution kg / kg of solution

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