Experimental study on a liquid desiccant dehumidifier with a solution atomization

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Abstract. The purpose of this study is to improve a dehumidification performance of the liquid desiccant system. The centrifugal atomization technology for spraying the solution was applied to enhance the dehumidification performance by increasing the heat and mass transfer area between the air and solution at low solution flow rate. The experimental study was performed to investigate the effect of the solution atomization for dehumidification performance of the proposed system. The measurement parameters for the test were the inlet air temperature and relative humidity, outlet air temperature and relative humidity, air volume flow rate, inlet solution temperature and density, outlet solution temperature and density, and solution mass flow rate. The dehumidification effectiveness was selected to assess the mass transfer performance of the dehumidifier with the solution atomization using the centrifugal atomizer. To compare the dehumidification performance of the proposed system and conventional packed-bed liquid desiccant system, the simulation was also conducted to estimate the dehumidification effectiveness of the reference system. The thermal load was also estimated of each system to evaluate the energy saving potential of the proposed liquid desiccant system under the conditions that show the same dehumidification performance. The experimental and simulation results indicated that the proposed system required approximately 0.012 liquid-to-gas (L/G) ratio while the reference system needed 0.5 L/G ratio for the same dehumidification effectiveness of 0.58. The most important finding of this result was that the proposed dehumidifier with the solution atomization has improved dehumidification performance at 97.6% lower L/G ratio than the conventional packed-bed type dehumidifier and the proposed system could save 72% cooling load than the reference system.

Keywords. Liquid desiccant, dehumidifier, centrifugal atomization, dehumidification effectiveness, liquid-to-gas ratio.
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1. Introduction

As an importance of the humidity control is increasing, previous studies suggested a liquid desiccant based air conditioning systems [1,2]. A liquid desiccant system has been considered as an effective and economic system because of a high dehumidification performance based on non-vapour compression [3,4]. The desiccant solution is also required the renewable or waste heat for solution regeneration, thus, the liquid desiccant based air conditioning systems have energy saving potential in buildings [5].

The liquid desiccant system was based on a heat and mass transfer between the air and desiccant solution. Therefore, the various contact types of the air and solution were studied and the counter-flow and cross-flow packed-bed type dehumidifier was proposed [6,7]. Fumo and Goswami [6] investigated the packed-bed type liquid desiccant dehumidifier and regenerator performance which has counter-flow under various inlet air and solution conditions. The heat and mass transfer between the air and desiccant solution on the cross-flow packed-bed type dehumidifier was also analysed by Dai and Zhang [7]. However, the packed-bed type liquid desiccant dehumidifier consumed massive desiccant solution to ensure sufficient wetting area of the packing materials and it caused a large thermal load for solution cooling and heating.

In view of this, a new design of liquid desiccant system based on a solution atomization was proposed [8,9]. Yang et al. [8] was suggested the ultrasonic atomization dehumidification system (UADS). The solution is atomized with tiny droplets in UADS with approximately 50μm diameter and the liquid-to-air contact area is dramatically increased.

Yang et al. [9] also analysed sensitivity on the performance of UADS. The experiment and simulation were conducted under various operation conditions and the analysis of variance (ANOVA) was applied to investigate the significant operating conditions in the proposed system. However, UADS consisted of complex and expensive components because of an ultrasonic generator, transducer, and voltage stabilizer and it also has a practical problem because of a corrosion issue by the desiccant solution.

Hence, a state-of-the-art technology for solution atomization should be considered to enhance the dehumidification performance of the liquid desiccant dehumidifier. The objective of this study is to propose the liquid desiccant dehumidifier with centrifugal atomization technology and to evaluate the dehumidification performance experimentally. The energy saving potential was also estimated compared with a conventional packed-bed type liquid desiccant dehumidifier via detailed simulation based on experimental results.

2. Experimental setups

2.1 system overview

The liquid desiccant system consisted of a dehumidification and regeneration part, air controller and solution controller. In this system, the hot and humid outdoor air is blown up into a dehumidification chamber in the dehumidification part by an air fan in the air controller. The air and solution contact into the dehumidification chamber and the air is dehumidified by the mass transfer between the air and solution. The main driving force of the mass transfer is a vapour pressure difference and the solution is cooled by the cooler in the solution controller to increase the vapour pressure difference between the air and solution. After the dehumidification process, the dry air is cooled by a cooling coil in the air controller to meet a target supplying condition (i.e., 26°C and 0.010 kg/kg). The weak solution after the dehumidification process is sent to a regenerator for maintenance of a solution concentration. Because the main purpose of this study is to improve the dehumidification performance using solution atomization with fine droplets, experiments and simulation were focused on dehumidification performance of the dehumidifier.

Fig. 1 indicated a conventional liquid desiccant dehumidifier with a packing material. The packing material consists of many layers of cellulose rigid media pads placed in different orientations such as zigzag path to provide the sufficient specific area. Thus, the solution is sprayed onto this packing material in the conventional liquid desiccant dehumidifier and the heat and mass transfer area to achieve a target dehumidification rate can be obtained.

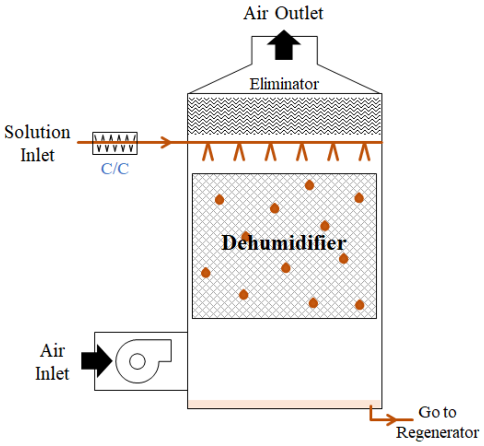
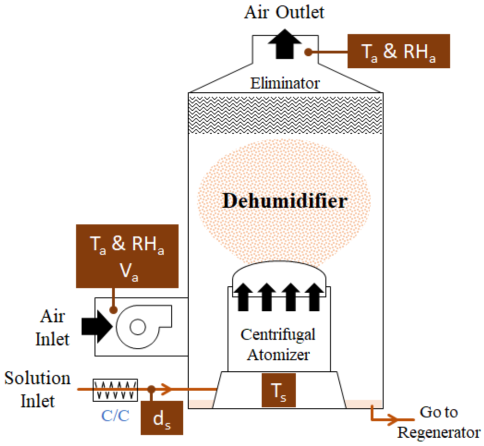


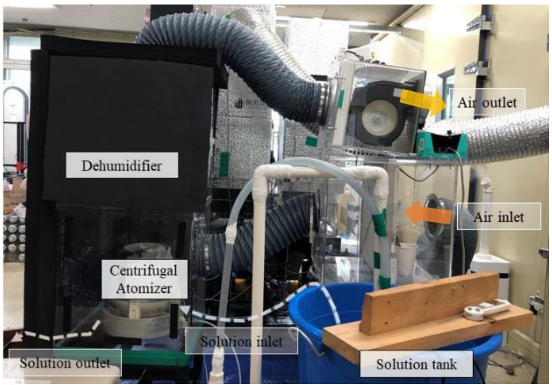
Fig. 1 – Schematic of a conventional liquid desiccant dehumidifier.

As shown in **Fig. 2(a)**, the mainly different part of the proposed system with the conventional system is a contact method of the air and solution in the dehumidification chamber. In the conventional system, the air and solution contact through the packing media, however, the air and solution contact directly in the proposed system. To get an enough contact area for dehumidification rate similar to a packing media, the solution is sprayed as a very tiny droplet by a centrifugal atomization into a dehumidification chamber. **Fig. 2(b)** depicts the test setup.



(a)

detailed schematic and sensor location



(b) test setup

Fig. 2 – The liquid desiccant dehumidifier with a solution atomization.

Tab. 1 – Specification of the sensors.

parameters	sensor types	accuracy	operating range
air temperature and relative humidity	Negative Temperature Coefficient of Resistance (NTC)	0.3°C 2.0%	-40 – 120°C 0 – 100%
air velocity	Vane probe ϕ150mm	0.1 m/s (+1.5% of mv)	0.1 – 15 m/s
solution temperature	Pt100	0.2°C (at 50 – 300°C)	-50 – 400°C
solution density	glass hydrometer	1kg/m^3	1000 – 1400 kg/m^3

2.2 measuring instruments

Parameters of the liquid desiccant dehumidifier were measured and recorded with the sensors listed in **Tab. 1** during the dehumidification experiment. The air temperature and relative humidity were measured to evaluate the dehumidification performance. The air velocity was also measured to check the air flow rate. The solution temperature and density were collected to verify the heat and mass balance of the experimental setup during the entire dehumidification process.

Two temperature and humidity sensors were located at the inlet and outlet side of the dehumidifier, and one velocity sensor was located at the inlet air-side. The solution temperature sensor was installed in a sump of a centrifugal atomization to measure the temperature of an atomized solution. The temperature and density sensors were also installed at an inlet solution tank and drain tank. The detailed location of the sensors was illustrated in **Fig. 2(a)**.

The air temperature and relative humidity were logged within 1-s intervals using a Testo 400 data logger and the solution temperature and density were measured intermittently.

2.3 experimental conditions

Experiments were conducted with LiCl as a desiccant solution under the hot and humid air conditions as shown in **Tab. 2**. The air temperature and humidity ratio were the outdoor design conditions of air conditioning in Korea. The air flow rate was set to be a minimum ventilation rate in an office building by ASHRAE Standard 62.1.

The solution flow rate was a specification of a centrifugal atomization used in this study. Thus, the liquid-to-gas (L/G) ratio was set to be about 0.012. The temperature and concentration of the solution were assumed to be a 20°C and 37%, respectively, for satisfying the target humidity ratio of a supply air sufficiently [3,10]. The lithium chloride (LiCl) aqueous solution was used for a liquid desiccant solution. The droplet size of solution was affected with provided spec according to the characteristic of the centrifugal atomization.

Tab. 2 – Test conditions.

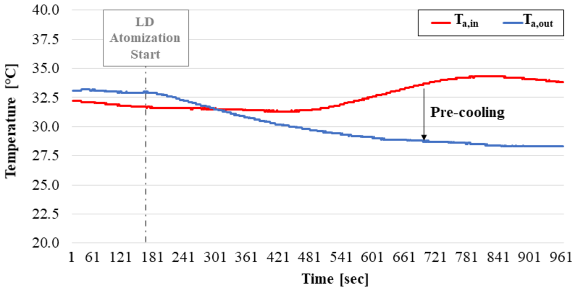
component	parameter	value
Air	flowrate	85 m^3/h
	temperature	32°C
	humidity ratio	0.020 kg/kg (relative humidity: 65%)
solution	flowrate	1L/h (L/G ratio: 0.012)
	temperature	20°C
	concentration	37%

3. Analysis of operating data

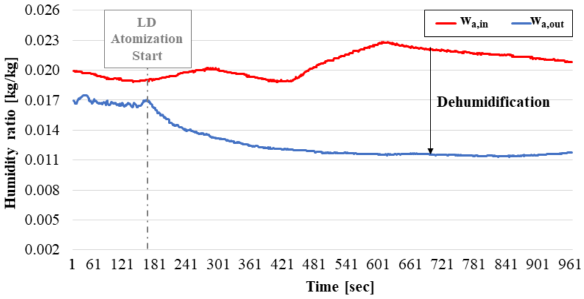
The energy saving potential of the proposed system was evaluated by analysing the experimental data. The simulation of the reference system was also conducted to compare for a thermal load for the same dehumidification performance.

3.1 measurement data

Fig. 3(a) and (b) show the temperature and humidity ratio behaviours of the process air. The red line means the condition profile measured at the absorber inlets and the blue line means the condition profile collected at the absorber outlets. The process air was supplied at a temperature and humidity ratio of approximately 34°C and 0.020kg/kg. The results indicated that the introduced air was cooled by heat transfer with the cold desiccant solution and significantly dehumidified by the atomized desiccant solution. In detail, the introduced air was pre-cooled to a temperature of approximately 28°C by heat transfer with the cold desiccant solution supplied at a temperature of 20°C as described in **Fig. 3(a)**. As shown in **Fig. 3(b)**, the air was dehumidified from a humidity ratio of 0.020 kg/kg to 0.012 kg/kg during contact with a desiccant solution. In summary, the introduced air was cooled to 28°C and dehumidified to 0.012 kg/kg on average.



(a) dry-bulb temperature



(b) humidity ratio

Fig. 3 – The thermal behaviours of the process air.

3.2 dehumidification performance comparison

To analyse the dehumidification performance using measured data by the experiments, the effectiveness of dehumidification was considered as a performance index. The dehumidification effectiveness (ε_{deh}) can be obtained by inlet ($\omega_{a,in}$) and outlet ($\omega_{a,out}$) air humidity ratio and equilibrium humidity ratio (ω_{eq}) as shown in equation (1). The inlet and outlet air humidity ratio were measured data and equilibrium humidity ratio could be estimated by the previous studies [10].

$$\varepsilon_{deh} = \frac{\omega_{a,in} - \omega_{a,out}}{\omega_{a,in} - \omega_{eq}} \qquad (1)$$

The effectiveness of dehumidification was predicted in the reference system for the dehumidification performance comparison with the proposed system. To estimate the dehumidification effectiveness of the reference system, the detailed simulation was performed. It can be estimated by Chung and Luo model for dehumidification effectiveness of a conventional packed-bed type liquid desiccant system [3]. The inlet condition was set a same condition as the experimental setup except L/G ratio.

Fig. 4 illustrates the psychrometric process of the proposed system collected by an experiment and reference system by simulation under the same inlet air and solution condition. In conventional packed-bed type liquid desiccant system, the system has been operated at L/G ratio of 0.8 to meet a target humidity ratio of 0.010 kg/kg. On the other hand, the experimental results indicated that the outlet humidity ratio and effectiveness of dehumidification are 0.012 kg/kg and 0.58, respectively, unsatisfied to a target dehumidification performance. However, the reference system was operated 0.5 L/G ratio while the proposed system required approximately 0.012 L/G ratio to achieve the same performance (i.e., outlet humidity ratio 0.012 kg/kg and 0.58 dehumidification effectiveness). Thus, the proposed system could save about 97.6% desiccant solution consumption.

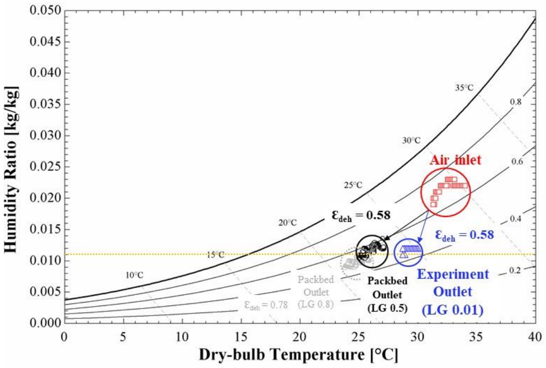


Fig. 4 – Psychrometric process of each system.

3.3 thermal load comparison

To compare the thermal load of each system, the air and solution cooling were considered, simultaneously. The air cooling load ($Q_{a,cooling}$) means the cooling load required to cool the air passed the absorber ($T_{a,abs,out}$) to the target supply air temperature ($T_{sa,target}$). The air cooling load can be calculated by equation (2). The solution cooling was required to satisfy the target solution temperature of 20°C. The solution cooling load ($Q_{s,cooling}$) can be calculated by mass flow rate of the solution ($\dot{m}_s$), heat capacity ($C_{p,s}$), absorber outlet solution temperature ($T_{s,abs,out}$), and target solution temperature ($T_{s,abs,target}$) according to equation (3). In this study, the target supply air temperature and target solution temperature were set to be 26°C and 20°C, respectively.

$$Q_{a,c} = \dot{m}_a \times C_{p,a} \times (T_{a,abs,out} - T_{sa,target}) \qquad (2)$$

$$Q_{s,c} = \dot{m}_s \times C_{p,s} \times (T_{s,abs,out} - T_{s,abs,target}) \qquad (3)$$

The thermal load of each system was described in **Fig. 5**. The proposed system required the lower solution cooling load than the reference system because of very low flow rate of the solution. However, the heat transfer between the air and solution was also less generated because of the low flow solution in the proposed system. Thus, the proposed system needed an auxiliary cooling for the air to meet a target supply air temperature. On the other hand, the reference system only required a solution cooling because of sufficient cooling of the air by heat transfer with a solution. Finally, the proposed and reference system consumed about 100 Wh and 356 Wh, respectively, during 1 hour and the proposed system could save approximately 72% of cooling load for air and solution.

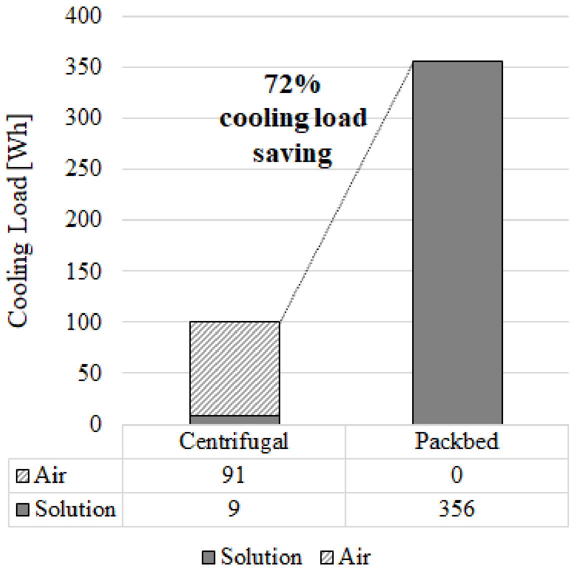


Fig. 5 – Thermal load comparison of each system.

4. Conclusions

The liquid desiccant based air conditioning system is beneficial for hot and humid climate; however, additional cooling and heating load for solution occurred to operate the dehumidifier and regenerator. In this study, the liquid desiccant dehumidifier with a centrifugal atomization technology was proposed to reduce the solution load while maintain the dehumidification performance. The experimental results indicated that the process air was significantly dehumidified from a humidity ratio of 0.020 kg/kg to 0.012 kg/kg under L/G ratio of 0.012. For the same effectiveness of dehumidification, the reference system was operated as 0.5 L/G ratio and the proposed system consumed 97.6% less solution. Finally, the proposed system could save 72% thermal load for air and solution cooling than the reference system.

This study indicated that the feasibility and energy benefits of the liquid desiccant dehumidifier with a centrifugal atomization as a preliminary study. Thus, more comprehensive research is needed for understanding the characteristics of the liquid desiccant dehumidifier with centrifugal atomization technology under various conditions. The consideration about the regeneration process is also required because this study was focused on the dehumidification performance. The whole liquid desiccant system contained regenerator will be manufactured with new atomization technology to control the droplet size in the further study.

5. Acknowledgement

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