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Performance investigation on the ultrasonic atomization liquid desiccant regeneration system

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HIGHLIGHTS

- We applied ultrasonic atomization technology to boost liquid desiccant regeneration.
- We established a novel UARS and made a thorough study on its performance.
- We developed a performance prediction model for UARS and validated its accuracy.
- The necessary regeneration temperature dropped significantly (4.4 °C) in UARS.
- Energy consumption for regenerating desiccant was reduced greatly (60.4%) in UARS.

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ABSTRACT

Liquid desiccant dehumidification systems have accumulated considerable research interest in recent years for their great energy saving potential in buildings. Within the system, the regenerator recovering liquid desiccant plays a major role in its performance. When the ultrasonic atomization technology is applied to atomize the desiccant solution into numerous tiny droplets with diameters around 50 μm, the regeneration process could be greatly enhanced. To validate this approach, a novel ultrasonic atomization liquid desiccant regeneration system (UARS) was studied in this work. An Ideal Regeneration Model (IRM) was developed to predict the regeneration performance of the UARS. Additionally, thorough experiments were carried out to validate the model under different operating conditions of the desiccant solution and air stream. The model predicted values and the experimental results coincided, with the average deviation less than 7.9%. The performance of UARS was compared with other regeneration systems from the open literature, while a case study was conducted for the power consumption and energy saving potential of UARS. It was found that the ultrasonic atomization technology enabled utilization of lower-grade energy for desiccant regeneration with the regeneration temperature lowered as much as 4.4 °C. In addition, a considerable energy saving potential of up to 23.4% could be achieved by the UARS for regenerating per unit mass flow of desiccant solution, while the power consumption of the ultrasonic atomization system was less than 7.0% of total energy cost. Moreover, when the UARS is integrated with the ultrasonic atomization assisted dehumidifier, energy savings can reach up to 60.4% as compared with the packed-bed system. This study validated the feasibility and energy saving potential of applying ultrasonic atomization technology to liquid desiccant regeneration systems.
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1. Introduction

The electricity cost of the air-conditioning system has been increasing rapidly in recent years. A large portion of the cost is associated with the dehumidification process since the moisture is traditionally removed by the vapor compression refrigeration system as it cools the return air below the dew point temperature. As a consequence, the coefficient of performance (COP) of the refrigeration system is limited to a low level. In addition, the over-cooled air needs to be reheated before being supplied to the conditioned space, which leads to the consumption of extra energy. By contrast, the liquid desiccant dehumidification system removes the moisture in humid air directly and effectively as the liquid desiccant droplets that are sprayed in the air absorb the water vapor. Moreover, the liquid desiccant with high water vapor content can

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Nomenclature

UARS	ultrasonic atomization liquid desiccant regeneration system
UADS	ultrasonic atomization liquid desiccant dehumidification system
G	mass flow rate ($kg\ s^{-1}$)
t	temperature (°C)
n	desiccant mass fraction (%)
d	humidity ratio ($g\ kg^{-1}_{dry\ air}$)
K	regeneration perfectness (%)
MRR	moisture removal rate ($g\ s^{-1}$)
$DMRI$	desiccant mass fraction increase (%)
LGR	liquid–gas ratio (–)
P	pressure (Pa)
PWR	power (W)
M	molar mass ($g\ mol^{-1}$)
h	enthalpy ($kJ\ kg^{-1}$)
DE	Dehumidification effectiveness (%)

Subscripts

l	liquid
a	air
i	inlet
o	outlet
d	dry air
q	moisture
AT	atmospheric condition
equ	equilibrium
v	vapor
deh	dehumidification process
reg	regeneration process

be regenerated with any type of heat, such as the renewable energy and waste heat [1,2]. All of these advantages suggest energy saving potential for air-conditioning applications [3,4] and make the liquid desiccant dehumidification system one of the most appealing research topics in recent years [5–7].

Within the liquid desiccant dehumidification system, the regenerator is considered to be one of the most vital components since it is where the diluted desiccant solution is recovered and the recycling of the desiccant is realized [8]. For this reason, extensive studies have been conducted to research the performance of various types of the liquid desiccant regenerators. For example, Fumo and Goswami [9], Longo and Gasparella [10], Martin and Goswami [11] investigated the performance of regeneration systems configured with counter-flow configured packed towers, while Liu et al. [8], and Kim et al. [12] studied the cross-flow configured regeneration systems. Moreover, the regeneration system equipped with the liquid-to-air membrane exchanger was studied by Ge et al. [13], Abdel-Salam and Simonson [14], and Keniar et al. [15], while a photovoltaic driven liquid desiccant regeneration system was investigated by Li et al. [6]. However, it was found that the necessary regeneration temperature or the grade of energy for desiccant regeneration within these systems is undesirably high. This prohibits the full utilization of either low-grade renewable energy or low grade waste heat and restrains the applicability of the system.

On the other hand, a liquid desiccant dehumidification system equipped with ultrasonic atomization technology, in which the desiccant solution is atomized into tiny droplets with diameters between 30 and 50 μm, was studied by Wang et al. [16], Bian et al. [17] and Yang et al. [18,19]. It was found that with the appliance of the ultrasonic atomization technology, the heat and mass transfer of the dehumidification process is greatly improved [19]. However, these studies focused only on the dehumidification performance of the dehumidifier, while little work has been conducted to investigate the regeneration performance enhancement of the liquid desiccant regeneration system by the ultrasonic atomization technology.

In order to contribute to this under-explored topic, this study aims to answer the following technical questions:

(1) What is the performance of the ultrasonic atomization liquid desiccant regeneration system under different operating conditions?
(2) How to realize the fast and accurate prediction of the regeneration performance in the ultrasonic atomization liquid desiccant regeneration system?
(3) What are the advantages of the UARS over other liquid desiccant regeneration systems, such as the packed bed systems?

To address the above issues, a novel ultrasonic atomization liquid desiccant regeneration system was built in this study. Thorough experimental runs were carried out for the first time to investigate its regeneration performance under various conditions of air and desiccant solution. Besides, a model called the Ideal Regeneration Model (IRM) was developed to predict the regeneration performance of the present UARS system, and good agreement was achieved between the predicted performance and the experimental results. Furthermore, the regeneration performance and the energy consumption of the UARS were compared in detail with other regeneration systems from the open literature [8,9,12,20], and the potential application of the system is also discussed at the end of the paper. This study validates the energy saving potential of applying the ultrasonic atomization technology to the liquid desiccant regeneration system, and confirmed the feasibility of using the IRM model to predict the performance of UARS.

2. Experimental study

As a first step, a novel UARS was built in this work. Extensive experiments were carried out to investigate its regeneration performance under various conditions of air and desiccant solution.

2.1. Test facility

Fig. 1 demonstrates the schematic diagram of the UARS. As detailed in Fig. 1, the system involved five major components: the ultrasonic liquid atomization system, the air handling system, the liquid desiccant supply system, the water heating system, and the regenerator chamber. In this work, LiCl solution was selected to study the performance of the UARS. A weak liquid desiccant flowed from the solution tank A to the ultrasonic atomization system by the pump through the valve, heat exchanger, and the flow meter. The temperature of the desiccant solution was adjusted by the water heating system, which was made of a supply tap water, the valve, the heater B, the heat exchanger, and the flow meter. The ultrasonic atomization system was the core of the UARS, and atomizes the desiccant solution into numerous tiny droplets. In this study, a FYCG, Model YPW 59, 30 kHz ultrasonic atomization system was employed. It was composed of the ultrasonic generator,

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