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Performance investigation on a novel liquid desiccant regeneration system operating in vacuum condition

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HIGHLIGHTS

- A novel liquid desiccant regeneration system operating in vacuum condition is proposed.
- A performance prediction model of the proposed system is developed.
- The regeneration temperature is reduced to 20–35 °C.
- The system has a significant energy saving potential as high as 40.66%.

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ABSTRACT

Liquid Desiccant Dehumidification Systems (LDDS) have been gaining attention due to its great energy saving potential in buildings. The desiccant regeneration system in LDDS plays a vital role in the system as the major energy consumed is due to the heat energy supplied to regain the concentration of the desiccant solution. The high regeneration temperature prohibits the potential use of low-grade or renewable energy as the heat source in the desiccant regeneration system. Therefore, a desiccant regeneration system operating in vacuum condition was proposed in this work. A novel Absorption-based Liquid Desiccant Regeneration (ALDR) system was developed and studied to validate this approach. A performance prediction model was also developed to predict the regeneration performance of the ALDR system. The model predicted values and the experimental values agreed well with each other with average deviation less than 5.90%. The operating parameters in the proposed ALDR system were also compared with the conventional packed-bed desiccant regeneration system available in literature. The regeneration temperature in LDDS was found to be significantly reduced to around 20–35 °C with the operating vacuum pressure between 1000 Pa and 2000 Pa when regenerating Lithium Bromide solution of 36% mass fraction. This study validated the feasibility of the ALDR system in reducing the regeneration temperature of the desiccant regeneration system. The results also showed that the proposed ALDR system was able to reduce the power consumption by 40.66% compared to the conventional packed-type regenerator from literature.

1. Introduction

Nowadays, Heating, Ventilation and Air Conditioning (HVAC) systems consume almost half of the energy consumption in buildings [1]. The large energy consumption in air conditioning system is due to the overcooling and reheating process in the conventional mechanical dehumidification system. Liquid Desiccant Dehumidification Systems (LDDS) have been one of the potential alternatives to replace the conventional mechanical dehumidification systems for greater energy saving. LDDS has the advantages over the conventional systems: (1) consuming relatively less energy in the dehumidification process; (2) giving better humidity control; (3) potential use of renewable or low grade energy as the heat source in the desiccant regeneration system [2–6]. Therefore, LDDS becomes one of the hot research topics recently for the aforementioned advantages.

The desiccant regeneration system plays an important role in the performance of LDDS as the major energy consumption in LDDS is the heat energy supplied for the desiccant regeneration process. The issue of high regeneration temperature around 50–80 °C has caught the attention recently as it prohibits the potential use of the renewable energy as the heat source in the desiccant regeneration system. Therefore, a lot of studies have been focused on investigating the performance of different types of desiccant regeneration systems. Refs. [7–9] investigated the performance of packed-type regeneration systems with counter-

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Nomenclature

Variables

E	power consumption (W)
h	enthalpy (J kg^{-1})
K	ratio of practical to ideal system performance
$\dot{m}$	mass flow rate (kg s^{-1})
MFI	desiccant mass fraction increase (%)
MRR	moisture removal rate (kg s^{-1})
n	desiccant mass fraction (%)
P	pressure (Pa)
$\dot{Q}$	heat flux (W)
T	temperature (K)
$\dot{V}$	volume flow rate (m^3 s^{-1})

Indices

cond	condensed
cw	cooling water
evap	evaporation
gen	generator
hw	hot water
ideal	ideal
in	inlet
out	outlet
Pred	predicted
sol	solution

flow configuration whereas the performance of the cross-flow packed-type regeneration systems was studied in Refs. [10–12]. Internally-heated regenerator was introduced in [13,14] to increase the regeneration efficiency of the system and the regeneration temperature was reported around 55–78 °C.

Liquid-to-air membrane exchanger was also introduced in the desiccant regeneration system and the regeneration temperature was around 45–60 °C [15–18]. Besides that, desiccant regeneration system equipped with the ultrasonic atomization technology was also discussed in Refs. [19,20] where the desiccant solution was atomized into tiny droplets with diameter around 50 μm. The application of this technology in the desiccant regeneration system was able to reduce the regeneration temperature to around 45–64 °C. In addition, a novel compression-assistant regeneration method was proposed in [21] where the diluted desiccant solution entered into the low-pressure regenerator and the water vapor in the solution was inhaled into the vacuum compressor. The regeneration temperature obtained was around 40–55 °C. The regeneration temperatures of all these regeneration systems were still undesirably high that would prohibit the potential use of renewable or low-grade energy as the heat source in the desiccant regeneration system.

Ref. [22] introduced another way of regenerating desiccant solution which was by using the vacuum flash evaporation approach. The water component in the desiccant solution would be evaporated dramatically when the diluted desiccant solution was released into the vacuum. The temperature distribution in the solution droplets was analyzed theoretically in the study and the results showed that the regeneration temperature could be reduced and the regeneration rate could be increased at the same time. However, the study focused only on the theoretical analysis on the temperature distribution and there was no study conducted on investigating the regeneration performance of the desiccant regeneration system. Therefore, a novel liquid desiccant regeneration system operating at vacuum condition was developed in the study here to investigate its regeneration performance.

Since the proposed way of regenerating desiccant solution under vacuum condition is still a new topic to explore, an accurate and reliable regeneration performance prediction of the newly developed system is important here. This study will focus on exploring the following questions to clarify the originality of this work and contribute to this new topic: (1) How is the feasibility of the proposed desiccant regeneration system operating at vacuum condition? (2) How to realize the performance prediction of the proposed desiccant regeneration system? (3) What is the regeneration performance of the proposed desiccant regeneration system under different operating conditions? (4) What are the advantages and energy saving potential of the proposed desiccant regeneration system over other regeneration systems?

The performance prediction model will be exploited to predict the regeneration performance of the proposed liquid desiccant regeneration system under different operating conditions. The performance prediction models for other desiccant regeneration systems discussed in references [19,23] would be applied and modified to this newly proposed desiccant regeneration system by introducing the mass and energy balance equations in the system. In addition, the regeneration performance indices are vital when investigating the performance of a desiccant regeneration system. The performance indices namely the moisture removal rate and desiccant solution mass fraction increase used for other desiccant regeneration systems in several literatures [10,11,19,24,25] were referred here. The advantages and energy saving potential of the current studied desiccant regeneration system over the other regeneration system available in literature were also discussed to highlight the contribution of developing this novel desiccant regeneration system.

Therefore, a novel Absorption-based Liquid Desiccant Regeneration (ALDR) system was first built in this study. Several experimental testing was done to investigate the regeneration performance of the system under various operating conditions. A performance prediction model was also developed to predict the regeneration performance of the newly developed regeneration system. The predicted regeneration performance was then validated with the experimental results. Furthermore, the system parameters and operating conditions of the proposed desiccant regeneration system were compared with those of the conventional packed-bed regenerator in LDDS. The regeneration temperature was also taken as one of the compared parameters to highlight the contribution of this paper. This study validated the potential of reducing the regeneration temperature of the desiccant solution and reducing the power consumption by operating the regeneration process in vacuum condition and confirmed the feasibility of the prediction model to predict the regeneration performance of the newly proposed ALDR system.

2. Experimental study of ALDR system

An experimental platform of ALDR system was first set up in the laboratory. The possible range of regeneration temperature is one of our main concerns in the proposed system. Fig. 1 shows the possible range of regeneration temperature when the desiccant regeneration system operates under vacuum condition. The desiccant solution is regenerated through the boiling process of the desiccant solution. During the boiling process, the surrounding pressure acts as an important parameter in the proposed desiccant regeneration system. From the figure, the regeneration temperature of the desiccant solution is theoretically expected to be around 20–35 °C if the desiccant solution is regenerated from 35% concentration to 45% concentration when the operating vacuum pressure is set between 1400 Pa and 2000 Pa. Therefore, experiments should be carried out to investigate the feasibility of proposed system in reducing the regeneration temperature.