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Research Paper

Performance investigation and exergy analysis of enthalpy recovery device using liquid desiccant

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HIGHLIGHTS

- Performance of enthalpy recovery device using liquid desiccant is investigated.
- Unmatched coefficient based on exergy destruction analysis is calculated.
- Efficiencies varying with mass flow ratio and number of transfer unit are analyzed.
- Approach to improve the recovery performance is proposed.
- A multi-stage process helps to lower destruction due to unmatched coefficient.

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ABSTRACT

Enthalpy recovery device using liquid desiccant is regarded as an appropriate approach for energy saving in air-conditioning system. This kind of enthalpy recovery device with a cross-flow pattern is investigated in the present study and its simulation model is built. Exergy analysis is utilized as the theoretical tool for optimizing the handling process. Reasons leading to exergy destruction are clarified. In addition to solution mixing process, limited transfer ability and unmatched coefficient are two main factors accounting for exergy destruction. Recovery efficiencies varying with mass flow ratio between air and solution are analyzed and the optimal flow ratio is obtained. A multi-stage device is proposed as an improvement to reduce the negative influence due to the unmatched coefficient and solution mixing process. Both recovery efficiencies η_h (η_m) and exergy efficiency η_{ex} improve with the increase of stage number, while exergy destruction caused by unmatched coefficient or solution mixing process decreases. The multi-stage process also helps to reduce the required *NTU* for a certain recovery efficiency. Efficiency of a 3-stage or 4-stage device is quite close to that with infinite stages. The present research is beneficial to design an optimized enthalpy recovery device using liquid desiccant.

1. Introduction

With the rapid development of economy and society, energy consumption of buildings accounts for an increasing proportion of the total energy consumption, about 20% in China [1]. About 30–60% of the total building energy is consumed by the air-conditioning system, which is responsible for heating and cooling [1,2]. Then reducing its energy consumption plays an important role in building energy conservation. Meanwhile, outdoor air is required to be supplied indoor for improving indoor air quality and satisfying health demand [3]. Reducing energy consumption for handling outdoor air does good to realize an efficient operation of the total air-conditioning system.

Owe to parameter discrepancy between outdoor air and indoor exhaust air, heat recovery is adopted as an effective way to preprocess the outdoor air [4–6]. It's believed that the recovery process is beneficial to reduce the handling requirement for cooling/heating [7,8]. There are usually two kinds of heat recovery installations: the enthalpy recovery type and the sensible heat recovery type [9,10]. Many researchers have focused on recovery methods or devices for energy saving [11–16]. Fehrm et al. [11] described various means for heat recovery and corresponding energy benefit in Sweden and Germany. Besant and Simonson [12] discussed the performances of various air-to-air energy recovery systems and energy saving potential in a Chicago building was reported. Fernández-Seara et al. [13] tested the recovery performance of a

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Nomenclature

a	outdoor air
c_p	specific heat capacity (kJ/kg °C)
E	exergy (kW)
ex	exergy per mass flow (kJ/kg)
ΔE	exergy destruction or exergy variation (kW)
F	heat or mass transfer area (m^2)
h	enthalpy (kJ/kg)
h_v	latent heat of vaporization (kJ/kg)
m	mass flow rate (kg/s)
NTU	number of transfer unit (dimensionless)
Q	heat exchange rate (kW)
r	indoor exhaust air
s	solution
T	absolute temperature (K)
t	temperature (°C)
V	volume of the heat and mass transfer module (m^3)

Greek symbols

α	convective heat transfer coefficient, W/(K m^2)
ξ	unmatched coefficient (dimensionless)
η_h	enthalpy recovery efficiency (%)
η_m	moisture recovery efficiency (%)
η_{ex}	exergy efficiency (%)
ω	humidity ratio (kg/kg)
χ	solution concentration (mass ratio of desiccant to solution) (%)
λ	slope of the saturation line in a psychrometric chart (dimensionless)

Subscripts

a	outdoor air
de	exergy destruction
e	air in equilibrium with liquid desiccant
h	enthalpy transfer process
in	inlet state
low	lower module (outdoor air handling module)
m	mass transfer process
out	outlet state
r	indoor exhaust air
s	solute
t	sensible heat transfer process
up	upper module (indoor exhaust air handling module)
v	water vapor

sensible polymer plate heat exchanger for air-to-air heat recovery process. Their results showed the sensible heat recovery efficiency could be as high as 60–70%.

By contrast with the sensible heat recovery process, the enthalpy recovery type achieves a higher efficiency with a greater energy saving potential as the latent heat accounts for a considerable proportion (more prominent in the humid climate). Enthalpy wheel and plate-fin heat recovery devices are commonly used in the enthalpy recovery process [10]. The enthalpy wheel is the most widely used for enthalpy recovery with a total heat exchange efficiency up to 70%. Zhang and Niu [14] built a two-dimensional model to compare the performance of desiccant wheels used for enthalpy recovery and dehumidification, focusing on key influencing factors including rotary speed, number of transfer units, and specific area. Delfani et al. [15] compared different heat recovery devices for various outdoor climatic conditions in hot and humid regions. It showed the energy saving ratio was about 11–32%. However, there will be a mutual gas leakage between outdoor air and indoor exhaust air in the utilization of rotary wheel. It can hardly avoid the cross-contamination.

Then approaches to avoid the shortage aforementioned are proposed. Using the micro-porous membrane is a solution [17,18]. Liang et al. [17] introduced a membrane-based total heat exchanger, where the coupled heat and mass transfer process proceeded through the membrane. Enthalpy recovery device using liquid desiccant (such as LiBr aqueous solution) is also proposed. Solution's absorbability and dehumidification features are utilized for realizing energy transmission between indoor exhaust air and outdoor air. Owe to the advantages in energy performance and avoiding leakage in operation radically, this kind of enthalpy recovery process has been investigated continually in recent years [19–21]. Mahmud et al. [19] investigated the performance of an enthalpy recovery system using liquid desiccant, consisting of two counter-crossflow liquid-to-air membrane energy exchangers. Recovery efficiency varying with air and solution flow rates was tested with a maximum of about 50–55%.

Although a counter flow type is superior to a cross-flow type in recovery efficiencies, the latter is a popular option in real applications of enthalpy recovery device using liquid desiccant, due to its benefits in air duct layout and occupied area [22]. How to optimize the cross-flow enthalpy recovery device or how to design an optimized structure becomes a key issue to improve its recovery efficiency. In the present study, performance of the cross-flow will be investigated to explore the key issues restricting the recovery efficiency by virtue of exergy analysis. Reasons leading to exergy destruction will be shed light on and approaches to improve the performance will be proposed. It is expected the present analysis will be beneficial to the optimization of the enthalpy recovery device using liquid desiccant.

2. Operating principle of enthalpy recovery device using liquid desiccant

2.1. Operating principle

Fig. 1 shows a typical cross-flow single-stage enthalpy recovery device using liquid desiccant, where the packing module is utilized. The packing in the module could increase the contact area between solution and air, thereby enhancing the effectiveness of the heat or moisture exchange. The device consists of two packed modules and one circulating pump for solution. The upper module is the exhaust air handling module and the lower is for handling the outdoor air. Outdoor air and indoor exhaust air are represented by a and r respectively, with solution state by s shown in Fig. 1. L refers to the width of the module in the air flow direction and H indicates the height of the module.

In summer, solution is transported from the bottom of solution tank in the lower module to the top of the upper module. Then it sprays from the top to wet the packing. Coupled heat and mass transfer process proceeds between indoor exhaust air and solution. The exhaust air is heated and humidified by the solution and then flows out of the module. The cooled and dehumidified solution flows out of the upper module directly and then sprays from the top of the lower module by gravity without mixing. The outdoor air flows into the lower module. It is cooled and dehumidified as the solution temperature or vapor pressure is lower. The solution is diluted and flows back to the bottom of the lower module, accomplishing the circulation.