INTERNATIONAL JOURNAL OF REFRIGERATION 67 (2016) 10–21

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Polymer/alumina composite desiccant combined with periodic total heat exchangers for air-conditioning systems

Chih-Hao Chen [a], Po-Chun Huang [a], Tai-Her Yang [b], Yuan-Ching Chiang [c], Sih-Li Chen [a,*]

[a] *Department of Mechanical Engineering, National Taiwan University, Taiwan*
[b] *Giant Lion Know-How Co., Ltd., Taiwan*
[c] *Department of Mechanical Engineering, Chinese Culture University, Taiwan*

ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form 24 July 2015
Accepted 1 January 2016
Available online 7 April 2016

Keywords:
Periodic total heat exchanger
Desiccant material
Dehumidification
Composite desiccant

ABSTRACT

The periodic total heat exchanger system consists of four centrifugal fans and two desiccant beds. During the half-period, one fan drives air through one desiccant bed for adsorption and the other fan operating in the opposite direction induces air through the other desiccant bed for desorption. In the next half-period, both air-flow directions are reversed by the other two fans. In this work, periodic operations are tested under different regeneration temperatures (40°C and 25°C), along with six different desiccant beds: silica gel, polyacrylic acid, activated alumina, a molecular sieve, diatomite and a polymer/alumina composite. A silica gel-packed bed provides an alternative to high-cost honeycomb silica gel in 40°C regeneration temperature systems. Alumina shows comparable performance to honeycomb silica gel and has further cost advantages in low regeneration systems. The power consumption of low pressure drop composite desiccant systems shows an improvement of 33% over packed bed systems.

Déshydratant composite polymère/alumine combiné avec des échangeurs de chaleur totale périodiques pour systèmes de conditionnement d'air

Mots clés : échangeur de chaleur totale périodique ; Matériau déshydratant ; Déshumidification ; Déshydratant composite

1. Introduction

Desiccants are widely used in such applications as paper making, chemicals, cosmetics, pharmaceuticals, food preservation, architectural materials and textiles (Djaeni et al., 2007; Goldsworthy et al., 2015; Nastaj and Ambrożek, 2009). Desiccants have also been applied in evaporative cooling air-conditioning systems (La et al., 2013), total heat exchangers (Yang et al., 2013) and dehumidification systems (Abdel-Salam and Simonson, 2014) for the improvement of indoor air quality. The humidity of indoor environments is related to health

---

[*] *Corresponding author.* No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan. Tel.: +886 2 23631808; Fax: +886 2 23631808.
E-mail address: slchen01@ntu.edu.tw (S.-L. Chen).

http://dx.doi.org/10.1016/j.ijrefrig.2016.01.003

Nomenclature

DCOP	desiccant coefficient of performance [-]
H	enthalpy of moist air [kJ kg^{-1}]
L	latent heat of water vapour [kJ kg^{-1}]
M	mass of water [g]
$\dot{m}$	mass flow rate [kg s^{-1}]
W	humidity ratio [g kg^{-1}]

Greek symbols

τ	period [s]

Subscripts

ad	adsorption
de	desorption
EA	exhaust air
g	air
OA	outdoor air
RA	return air
SA	indoor supply air

problems, construction durability and energy consumption. High moisture levels make houses smell stuffy and create breeding grounds for mould, mildew, dust mites and bacteria. Dry air causes furniture to shrink, warp and crack, and it can be responsible for skin irritation and respiratory problems. Dehumidification technology is very important in subtropical areas like Taiwan. Introducing fresh air from outside increases humidity and excess heat load, but without fresh air, high carbon dioxide (CO_2) concentrations can lead to the development of "sick building" syndrome in building inhabitants. Therefore, it is essential to recover the heat load through the ventilation process. A total heat exchanger is an air-to-air exchanger which deals not only with sensible heat due to temperature differences, but also with latent heat due to humidity differences (Jiang et al., 2015; Zheng et al., 2015). Because of their ability to provide effective energy savings, rotary-type total heat exchangers with desiccant wheels have been used in air dehumidification for several decades (Al-Alili et al., 2015a; Elgendy et al., 2015). However, there are some drawbacks to rotary-type total heat exchangers, such as the need for extra energy to drive the wheel.

In addition to familiar desiccants like silica gel and activated alumina (Gurtas Seyhan and Evranuz, 2000), there are several other materials which can be used as desiccants in heat exchangers. Zhang et al. (2014) tested desiccant wheels made from 10 different types of materials, determining that 3A silica gel exhibited superior performance when the regeneration temperature was 50°C. However, silica gel displays only an average ability to dehumidify air and mediocre total dehumidification ability at various levels of relative humidity. Al-Alili et al. (2015b) used a new zeolite material for the desiccant wheel, and their results showed that zeolite exhibits better adsorption performance than silica gel when the humidity ratio is 20%. Polymers are emerging as desiccant materials (Cao et al., 2014; Lee and Lee, 2012; White et al., 2011); compared with silica gel in high humidity and low regeneration temperature environments, polymer desiccants feature superior total adsorption. However, because polymer desiccants possess a more complex adsorption mechanism, they exhibit a relatively poor transient adsorption rate in low humidity environments. Diatomite is well known as a "humidity control material" (Vu et al., 2013), having the ability to balance indoor humidity throughout the year by adsorbing humidity from ambient air and desorbing it into the air.

Composite desiccants can compensate for the deficiencies observed in single desiccants (Zheng et al., 2014). Huang et al. (2010) improved the dehumidification ability of carbon black at a relative humidity condition of 40% by combining silica gel with activated carbons. Moreover, Zhang and Qiu (2007) produced leak-resistant and high-performance desiccants by placing potassium chloride in the pores of silica gel. Tretiak and Abdallah (2009) fabricated a new clay–calcium chloride composite desiccant which can be used to reduce the regeneration temperature. Furthermore, Knez and Novak (2001) produced a mixed SiO_2/Al_2O_3 aerogel made from silica gel and aluminium oxide; this aerogel remained stable even after 25 repeated adsorption and desorption cycles. These findings show that desiccants made of composite materials yield superior results.

Traditional desiccant wheels are solid packed beds (Kabeel, 2009; Ramzy et al., 2011), but they have the problem of a large pressure drop. Honeycombed desiccant wheels with a low pressure drop are used in industry and pharmaceutical applications (Jia et al., 2006), but they are too expensive and therefore unsuitable for residential buildings. Meanwhile, despite their large pressure drop, packed beds are inexpensive. High pressure drops cause additional power consumption and result in design limitations. Applying desiccant materials directly to the total heat exchanger is one solution for issues associated with a high pressure drop. Zhao et al. (2014) and Enteria et al. (2011) used a soaking method to develop a desiccant-impregnated heat exchanger which not only reduces the pressure drop compared with various desiccant wheel systems, but also uses refrigerant or cooling water, which is pumped into the heat exchanger to remove adsorption heat during the dehumidification process. However, this kind of heat exchanger is very difficult to repair or replace; its high cost makes it unsuitable for use in residential systems.

System design is a critical issue. A two-stage rotary desiccant cooling system was proposed, with a discussion of system performance in terms of moisture removal and the thermal coefficient of performance (Ge et al., 2009). Jeong et al. (2010) investigated a hybrid air-conditioning system, and the performance of a four-partition desiccant wheel was simulated and measured experimentally. A study has also been performed concerning the design of the desiccant wheel, focusing on the impact of the flow direction (Narayanan et al., 2011). However, there is limited previous literature regarding total heat exchangers using periodic flow with a desiccant bed.

In the present study, the desiccant beds of the air-to-air total heat exchanger are stationary, and it uses four centrifugal fans in alternating operations to achieve periodic adsorption and regeneration. Fig. 1 shows that, at the same size as the total heat exchanger, the heat and mass transfer area between the desiccant bed and the air of the device in the periodic type is larger than that in the rotary type. In other words, in the same heat exchange area, the size of the desiccant bed and the total heat exchanger can be reduced because the bed of the periodic type does not have to be divided into adsorption and regeneration parts. In addition, the device using periodic flow