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Experimental investigations on thin polymer desiccant wheel performance

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ABSTRACT

In this study, the performance of a new polymer desiccant wheel (DW), which can be used for dehumidification in a solid desiccant cooling system, was investigated. In order to investigate the compact design of the DW for compact cooling system, DWs were evaluated at four levels of thickness while varying the inlet air temperature, humidity ratio, regeneration temperature, and rotational speed. It was found that lower inlet air temperature and higher humidity ratio are in favor of better DW performance. Higher regeneration temperature (60 °C) would bring a reduced marginal benefit in terms of latent coefficient of performance (COP_{latent}). Test results also indicate that the optimum rotational speed decreases while DW thickness increases. Three thin DWs (30, 50 and 70 mm) were compared with the typical thick DW (150 mm) and it was found that 50 and 70 mm DWs have the potentials in the compact cooling system with the maximum moisture removal capacity (MRC_{max}) based on specific volume (MRC_{max}/DW Volume) 1.2 and 0.7 times higher than that of 150 mm DW, respectively. In addition, the maximum COP_{latent} of 50 and 70 mm DW can be up to 0.45 and 0.5, respectively.

Investigations expérimentales de la performance de roues déshydratantes minces en polymères

Mots clés : Roue déshydratante ; Etude expérimentale ; Capacité de déshumidification ; Coefficient de performance latent

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Nomenclature

Symbols

T_{p_in}	process air inlet temperature (°C)
T_{p_out}	process air outlet temperature (°C)
w_{p_in}	process air inlet humidity ratio (gw kga^{-1})
w_{p_out}	process air outlet humidity ratio (gw kga^{-1})
w_{r_in}	regeneration air inlet humidity ratio (gw kga^{-1})
V_{face}	face air velocity ($m\ s^{-1}$)
T_{gen}	regeneration temperature (°C)
R_{speed}	rotational speed (RPH)
h_{fg}	enthalpy of evaporation (water) ($kJ\ kg^{-1}$)
$\dot{m}_p$	mass flow rate of process air ($m^3\ s^{-1}$)
$\dot{m}_r$	mass flow rate of regeneration air ($m^3\ s^{-1}$)
W_{in}	power input of the electric heater (kW)
Δu	uncertainty of u
Δx	uncertainty of x
Δy	uncertainty of y
Δz	uncertainty of z

Acronyms

DW	desiccant wheel
MRC	moisture removal capacity ($g\ s^{-1}$)
MRR	moisture removal regeneration ($g\ s^{-1}$)
RTD	resistance temperature detectors
RH	relative humidity (%)
DP	differential pressure (Pa)
DAQ	data acquisition system
COP	coefficient of performance (dimensionless)
COP_{latent}	latent coefficient of performance (dimensionless)
SER	sensible energy ratio (dimensionless)
RPH	revolution per hour (rev hr^{-1})
MRC_{max}	maximum moisture removal capacity ($g\ s^{-1}$)
COP_{latent_max}	maximum latent coefficient of performance (dimensionless)

1. Introduction

In hot and humid regions, removing moisture from the air accounts for a considerable portion of the air conditioning load. Most air conditioning systems have to lower the air temperature below its dew point to accomplish dehumidification. Solid desiccant cooling has been proposed as an alternative to vapor compression refrigeration for space cooling. It is an environmentally beneficial solution since no ozone depleting refrigerants are needed. Instead, low temperature heat sources, like waste heat from engine or solar heat, can be used to operate the system. Desiccant wheels (DW) are used for dehumidification of the humid air. While silica gel is the most commonly used desiccant material, new materials have been developed and tested. Jia et al. (2006) compared two DW materials which were silica gel and a newly developed composite material (mixture of silica gel and lithium chloride). They reported that the newly developed composite desiccant wheel performed better than the conventional one, and can remove 50 percent more moisture. White et al. (2011) studied two materials (zeolite and a superabsorbent polymer), and compared them with silica gel. They found that these two materials were more effective in dehumidification than silica gel at low regeneration temperature (50 °C) and high relative humidity (higher than 60 percent). Lee and Lee (2012) tested a newly developed desiccant material – a superabsorbent polymer and found that it had two to three times higher sorption capacity. Qian et al. (2013) conducted an experimental investigation on the performance of an adsorption chiller with zeolite, which works well at a low regeneration temperature and is also one of commonly used desiccant materials.

Lots of experimental studies have been conducted to investigate the performance of DWs. Ahmed et al. (2005) conducted the evaluation and optimization of a solar DW performance. A numerical model was developed and validated with experimental data. Moreover, parametric studies were conducted to investigate the effects of the design parameters such as rotational speed, regeneration to adsorption area ratio, and the operating parameters such as air flow rate, inlet air humidity ratio, and regeneration air temperature on the wheel performance. Enteria et al. (2010) evaluated the desiccant wheel based on its moisture removal capacity (MRC) and moisture removal regeneration (MRR). Eicker et al. (2012) investigated several commercially available desiccant wheels, and determined the best rotational speeds for different DWs. Angrisani et al. (2012) conducted an experimental analysis of the DW, which focused on the variations of the performance as a function of the process and regeneration air flow rates. The desiccant material was regenerated by low temperature thermal energy from a micro co-generator. Angrisani et al. (2013) also conducted experimental tests on a silica gel DW to highlight the effect of rotational speed on its performance. Narayanan et al. (2013) designed a non-adiabatic DW and examined its performance through mathematical models and experimental testing. The new design could increase the dehumidification level by around 45 to 53 percent.

Mathematical models of DW have been developed to effectively predict DW performance in a reasonable computation time. There are multiple modeling studies on DW in recent years. Wrobel et al. (2013) validated a simplified model based on the results of the physical model for a DW. Yamaguchi and Saito (2013) established mathematical model to predict silica gel DW performances. Their predicted results were similar to their measured results. The recorded differences were 3.3% for humidity ratio and 10.8% for temperature. De Antonellis and Joppolo (2010) developed a one dimensional model to solve heat and mass transfer within a DW. The model supported a wide range of working conditions and sorption wheel configurations. The performance criteria were also introduced and discussed based on simulation results. Ghiaus et al. (2013) proposed a state space model for a DW control with two approaches – black box and gray box. The gray box has fewer requirements for parameter identification than black box approach. Chunga and Lee (2009) optimized the performance of a DW by using an unsteady one-dimensional numerical model. The optimum condition was determined