available at www.sciencedirect.com

ScienceDirect

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

Experimental study on a two-stage rotary desiccant cooling system

T.S. Ge, Y. Li, R.Z. Wang[*,1], *Y.J. Dai*

Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, P.R. China

ARTICLE INFO

Article history:
Received 3 January 2008
Received in revised form
28 March 2008
Accepted 1 July 2008
Published online 10 July 2008

Keywords:
Air conditioning
Desiccant system
Desiccant wheel
Two-stage system
Experiment
Performance

ABSTRACT

The objectives of this study were to evaluate the performance of a novel two-stage rotary desiccant cooling (TSRDC) system and to obtain useful data and experiences for practical application. Newly developed compound desiccant (silica gel–haloids) was adopted in the system. An experimental set-up was built and used to test the system performance under three typical environmental conditions. System performances were evaluated in terms of moisture removal *D* and thermal coefficient of performance COP_{th}. It has found that the required regeneration temperature of TSRDC system is low and COP_{th} of the system is high. Regeneration temperatures from 65 °C to 80 °C, 65 °C to 75 °C and 80 °C to 90 °C were recommended for each environmental condition. In addition, the effects of some important operating parameters, such as inlet temperature and humidity ratio of process and regeneration air, on system performance were also investigated in this study.

Etude expérimentale sur un système de refroidissement à roue déshydratante biétagée

Mots clés : Conditionnement d’air ; Système à déshydratant ; Roue déshydratante ; Système biétagé ; Expérimentation ; Performance

1. Introduction

Energy crisis has already become a global issue. Actions should be taken to resolve using clear and renewable energy such as solar energy, geothermal energy and biological energy instead of the traditional one including oil and gas. Besides, traditional vapor compression air conditioning system has caused serious pollutions due to the usage of CFCs or HCFCs. In response to these problems, solid desiccant cooling systems, which adopt water, a natural working fluid, as refrigerant and can be driven by renewable energy, have been widely recognized as a promising technology for their energy saving and CFC-free characteristics. Previous work has been conducted on one-stage rotary desiccant cooling system in which process air is dehumidified once by a rotary wheel. Extensive theoretical investigations have been conducted,

* *Corresponding author*. Tel./fax: +86 21 34206548.
E-mail address: rzwang@sjtu.edu.cn (R.Z. Wang).
[1] IIR-B2 vice president.

0140-7007/$ – see front matter © 2008 Elsevier Ltd and IIR. All rights reserved.
doi:10.1016/j.ijrefrig.2008.07.001

Nomenclature

COP_{th}	thermal coefficient of performance
D	moisture removal ($g\,kg^{-1}$)
d	absolute humidity ratio of the air ($g\,kg^{-1}$)
h	enthalpy ($kJ\,kg^{-1}$)
M	volume rate of the stream ($m^3\,h^{-1}$)
Q	quantity of heat (kW)
T	temperature (°C)
Δy	absolute error
$\Delta y/y$	relative error (%)
ρ	density of air ($kg\,m^{-3}$)

Subscript

1, 2 … 15, 9-1, 9-2	refers to the positions described in Figs. 1 and 2
in/out	inlet/outlet
p	process air
r/r1/r2	regeneration air/regeneration air 1/regeneration air 2

such as system simulation and comparison (Elsayed et al., 2006, in press; Jurinak et al., 1984; Vineyard et al., 2000; Jain and Dhar, 1995; Henning et al., 2001), parameter optimization (Farooq and Ruthven, 1991; Belding et al., 1991), thermo-economic analysis (Camargo et al., 2003) and feasibility studies (Shelpuk and Hooker, 1979; Davanagere et al., 1999). Also, some experimental results have been obtained on one-stage system (Lof George et al., 1988; Vineyard et al., 2000; Jalalzadeh-Azar et al., 2000; Pietruschka et al., 2006).

Recent studies on rotary wheel desiccant cooling system focus on developing isothermal dehumidification which is thought as one of ideal air conditioning processes with the smallest irreversibility (Zhang and Niu, 1999). When the air flows alternately over infinite desiccant wheels and intercoolers, its thermodynamics would be close to isothermal. With other conditions unchanged, the regeneration temperature of an ideal infinite multistage desiccant cooling system is the minimum. Since lower regeneration temperature can be used and thermal energy can be recovered in the intercooler such as sensible heat exchanger, the thermal energy used to drive the system is reduced significantly. Hence, this system has great potential in enhancing the energy performance COP_{th}. Two-stage rotary desiccant cooling system has been proposed because of that (Zhang and Niu, 1999; Ge et al., 2007). It has been demonstrated in theory that the required regeneration temperature of two-stage system is much lower than that of the conventional one-stage sytem. However, to the best knowledge of the authors, there are few experimental works on this subject.

The objective of this work is to build, test and evaluate an actual two-stage desiccant rotary cooling (TSRDC) system under varying conditions and to investigate the influences of some important parameters. In the present work, system performances were evaluated not only under the mild ARI (American Air-conditioning and Refrigeration Institute) summer and humid condition, but also under the extreme weather condition like in Shanghai. Also, sensitivities of system performance to some important inlet parameters were also investigated. The effects of inlet temperature and humidity ratio of process air on dehumidification capacity and thermal coefficient of the system were examined. Similar evaluation was also conducted with regard to different inlet temperature, humidity ratio of regeneration air.

2. Experimental method

2.1. Principle

Fig. 1 shows the schematic diagram and typical psychrometric chart of the present TSRDC system. Three air streams are involved in the present two-stage system: (i) process air; (ii) regeneration air 1; and (iii) regeneration air 2. Process air comes from ambient air, it (state 1) enters the system and flows through the first desiccant wheel (DW1), where the process air is dehumidified and simultaneously heated by the releasing adsorption heat (state 2). The hot dry process air is then cooled by the first sensible heat exchanger (HE1) to become dry cool air (state 3). After that, it flows through the second desiccant wheel (DW2) to state 4 and the second heat exchanger (HE2) to state 5. Simultaneously, in the regeneration side, return air (state 7) is withdrawn from the conditioned space with an equal flow flux of process air. It is mixed with ambient air (state 6) to state 8. Based on the previous results (Ge et al., 2007), the mixing ratio of 1:1 is selected in the experiments. A direct evaporative cooler (DEC) is used to cool the mixture air before it enters sensible heat exchangers (state 9). The cooled regeneration air is divided into two air streams: regeneration air 1 and regeneration air 2, which are preheated by process air in heat exchangers (HE2, HE1) to state 10 and state 13. Afterwards, parts of the preheated regeneration airs are heated up by the heaters to the required regeneration temperature (states 11 and 14). The regeneration air then flows through the regeneration section of the two desiccant wheels (DW2, DW1) to regenerate the adsorbent. The hot and humid regeneration airs at outlet (states 12 and 15) are exhausted to the ambient.

An experimental set-up was built to test the performance of this novel system. Fig. 2 shows the schematic diagram of experimental set-up operating on an open cycle. It mainly consists of four parts: air preconditioning unit which is used to provide air at different conditions, desiccant wheel which is the core