Energy 33 (2008) 1807–1815

Contents lists available at ScienceDirect

Energy

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

Experimental investigation on a one-rotor two-stage rotary desiccant cooling system

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

Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, PR China

ARTICLE INFO

Article history:
Received 17 March 2008

Keywords:
One-rotor two stage
Rotary desiccant
Rotation speed
Wheel thickness
Moisture removal
Thermal coefficient of performance

ABSTRACT

A one-rotor two-stage rotary desiccant cooling system (OTSDC), in which two-stage dehumidification process is realized by one desiccant wheel, was investigated experimentally. The system was proposed to reduce the volume of two-stage rotary desiccant cooling system (TSDC) with two desiccant wheels without reduction in system performance by using the novel configuration. An experimental setup was designed and built to evaluate the system performance under various operation conditions. The effects of different wheel thicknesses at various rotation speeds under Air-conditioning and Refrigeration Institute (ARI) summer and humid conditions were investigated. It is observed that there exits an optimal rotation speed where moisture removal of the system D and thermal coefficient of performance COP_{th} are both optimal. Moreover, the unit with wheel thickness of 100 mm performs better for its bigger moisture removal D and higher COP_{th}. Generally speaking, the COP_{th} of this unit is around 1.0 when the regeneration temperature is lower than 80 °C. Compared to TSDC, the OTSDC not only preserves the merits of low regeneration temperature and high COP_{th}, but also has a reduced size by about half.

1. Introduction

The world is facing a large-scale and potentially devastating global energy crisis. People have already realized that traditional resource such as oil and gas cannot meet the rising energy demand. This has led to increasing interest in alternate-energy research such as solar energy, geothermal energy and wind energy. Besides, traditional resource has caused serious environmental problems. In response to these problems, rotary desiccant cooling systems, which adopt water as refrigerant and can be driven by low-grade thermal energy, have been widely recognized as a promising technology for its energy saving and chlorofluorocarbons (CFC)-free characteristics. Researchers have carried out some investigation on one-stage rotary desiccant cooling system such as system simulation [1–3], thermodynamic analysis based on the second law [4] and experimental investigation [5,6]. Recently, many researchers focus on the concepts of staged regeneration and two-stage system. Staged regeneration for solid desiccant dehumidifiers, patented by Glav [7], has been reintroduced [8–11]. Collier and Cohen [8] reported that the best system performance could be obtained by staging the regeneration process while minimizing the amount of inert heat capacity. Worek et al. [9] indicated that high performance for a ventilation cycle could be achieved by using Type 1M material regenerated at 165 °C, with a staged regeneration fraction of 16%. Moreover, there are also some investigations focusing on two-stage solid desiccant cooling system. Meckler [12] proposed an integrated two-stage desiccant dehumidification system with a commercial HVAC system, which would significantly increase thermal coefficient of performance (COP_{th}) and lower initial equipment cost. Gershon Meckler Associates, P.C. (GMAPC) [13] has developed a two-stage desiccant unit for small commercial building such as fast-food restaurants. The results showed that the annual electric energy use by the desiccant unit is 60% less than that of the vapor compression unit; annual energy cost for the gas-energized desiccant cold-air unit is 40% less than that of the conventional unit. Afterwards, a two-stage solid desiccant HVAC system including evaporative cooling was compared with conventional all-air VAV system by Mei et al. [13]. It was demonstrated that the energy consumption in desiccant system is reduced significantly in terms of peak electric demand, electric and gas energy input and annual energy costs.

Lately, researchers in Shanghai Jiao Tong University have developed a novel two-stage rotary desiccant cooling system (TSDC) by using novel configuration and newly developed composite desiccant material. The experimental results showed the system has the merits of lower regeneration temperature and high thermal performance [14]. Hence low-grade thermal energy

* Corresponding author. Fax: +86 21 34204358.
E-mail address: yjdai@sjtu.edu.cn (Y.J. Dai).

0360-5442/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2008.08.006

Nomenclature

COP	overall coefficient of performance taking into account of electric power
COP_{th}	thermal coefficient of performance
D	moisture removal (g/kg)
d	absolute humidity ratio of the air (g water vapor/kg dry air)
h	enthalpy (kJ/kg)
L	wheel thickness (mm)
M	volume rate of the stream (m^3/s, m^3/h)
Q	quantity of heat (kW)
Δd	mass change in desiccant wheel (kg/h)
Δy	absolute error
$\Delta y/y$	relative error (%)
ρ	density of air (kg/m^3)

Subscript

1, 2, …,14, 8-1, 12-1	refers to the positions described in Fig. 2
ads	process air
DW	desiccant wheel
HE	sensible heat exchanger
in	inlet
out	outlet
$reg/reg1/reg2$	regeneration air/regeneration air of the first/second stage

such as solar energy can be efficiently utilized and the operating costs can be significantly reduced. Moreover, if solar energy is utilized, the system can convert more than 40% of solar radiation into the ability for air conditioning. However, the complexity and volume of TSDC increases due to another rotary wheel that is used. This hinders early penetration into the market. Therefore, how to reduce the volume of two-stage system without diminishing system performance becomes a critical issue.

In this study, a one-rotor two-stage rotary desiccant cooling system (OTSDC), in which two-stage dehumidification process is realized by only one wheel, is proposed and investigated. The newly developed compound desiccant wheel as used in TSDC is also adopted in this study. It is expected that the structure as well as volume of two-stage system can be significantly reduced. The objective is to validate the feasibility of OTSDC by an experimental prototype and evaluate system performance under standard Air-conditioning and Refrigeration Institute (ARI) summer and humid conditions. Also the effects of the main operation parameters, including rotation speed, wheel thickness and regeneration temperature on system performance are analyzed and summarized.

2. Description of one-rotor two-stage rotary desiccant cooling system (OTSDC)

The key technology to realize OTSDC is how to build the two-stage dehumidification process with one desiccant wheel. Fig. 1(a) shows the conventional desiccant wheel with one-stage dehumidification process. Cross-section of the wheel is divided into two parts: one for process air and another for regeneration air. If the cross-section was divided into four parts: two for process air and the others for regeneration air, it is possible that two-stage dehumidification process can be achieved in one rotary wheel as shown in Fig. 1(b). Jia [15] reported that the optimal area ratio of process air to regeneration air in one composite desiccant wheel is 3. This value is also adopted in OTSDC, therefore the central angle for process air is 135° and for regeneration air is 45°.

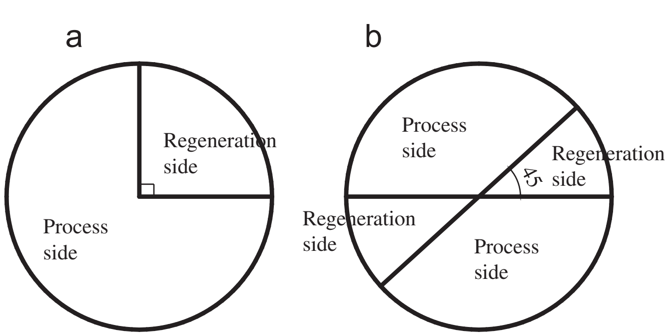

Fig. 1. Cross-section of one-stage and two-stage system.

In order to keep the merits of TSDC, similar circulation mode as TSDC was applied in OTSDC. Fig. 2 shows the schematic drawing of OTSDC. Process air (state 1) enters the system and flows through the first section for process air within desiccant wheel, where the process air is dehumidified and simultaneously heated by released adsorption heat (state 2). Then the hot dry process air is cooled in a sensible heat exchanger (state 3). Afterwards process air flows into the same desiccant wheel once again but through the second part for process air to state 4. Similarly, it then passes through the second heat exchanger and is cooled to state 5. At the same time, in the regeneration side, return air coming from the conditioned space is mixed with outdoor air to constitute regeneration air (state 6). Two groups of regeneration air work in parallel (state 6-7-8-9-10; state 6-11-12-13-14). They are at first cooled in the evaporative coolers to state 7/11. Then both are preheated by process air in sensible heat exchangers to states 8 and 12. Afterwards, the preheated regeneration air is heated up in the heaters to the required regeneration temperature (states 9 and 13). Regeneration air then flows through the two regeneration sections within desiccant wheel to their respective regenerate desiccant material. The hot humid outlet regeneration air (states 10 and 14) is exhausted to the ambient.

Two points should be noted here: (1) since the humidity ratio of process air at state 5 is very low, its temperature could be further reduced by an adiabatic humidification process in an evaporative cooler. However, in order to analyze the dehumidification capacity of OTSDC and reduce the initial cost of experimental setup, no evaporative cooler is installed here; (2) study focusing on composite silica gel-haloid desiccant wheel [15] pointed out that reducing the mass flow rate of regeneration airstream to one third of the process flow can lead to significant COP_{th} improvement without substantial influence on dehumidification capacity. Therefore at states 8 and 12 before regeneration air entering into the heaters, parts of the regeneration air are exhausted to the ambient to obtain high performance.

3. Experimental setup and test sensors

3.1. Experimental setup

Fig. 3 gives a photographic view of the experimental setup. An air-preconditioning unit (Fig. 3(a)) was adopted to provide various process air inlet conditions (state 1) under different environmental conditions. The unit was equipped with a hot water coil for