INTERNATIONAL JOURNAL OF REFRIGERATION 39 (2014) 152–159

Available online at www.sciencedirect.com

ScienceDirect

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

Design and performance of an internal heat exchange desiccant wheel

M.J. Goldsworthy [a,*], S. White [b]

[a] Commonwealth Scientific and Industrial Research Organisation, 10 Murray Dwyer Cr., Mayfield West 2304, Australia

[b] Commonwealth Scientific and Industrial Research Organisation, Newcastle 2304, Australia

ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form
24 October 2013
Accepted 27 October 2013
Available online 2 November 2013

Keywords:
Desiccant wheel
Internal cooling
Non-adiabatic
Air-conditioning

ABSTRACT

A fundamental limitation in the dehumidification performance of adiabatic desiccant wheels occurs due to heating of the air stream to be dried. This results from both the carry-over of heat stored in the wheel and the release of the adsorption heat. Previous authors have identified an isothermal dehumidification process as theoretically superior, though the practicalities of constructing such a wheel have meant that demonstrating the benefit is difficult. Recently experimental data from testing of an internally cooled wheel was published. Here we use this data to calibrate a mathematical heat and mass transfer model of the internally cooled heat exchange desiccant wheel. The model is then used to estimate the performance for selected modifications to the design and materials. The results show that more than a 40% improvement is possible relative to the previously tested cooled wheel. The results have application to the development of desiccant air-conditioners.

Conception et performance d'une roue déshydratante à échange de chaleur interne

Mots clés : Roue déshydratante ; Conditionnement d'air ; Non-adiabatic ; Refroidissement interne

1. Introduction

Desiccant wheel based air-conditioning is an alternative building air-conditioning technology that has the potential to reduce reliance on grid-connected electricity for comfort space conditioning. The key component in these systems is the desiccant wheel that uses a hot regeneration air-stream to remove moisture from a process air stream which, after subsequent processes, is transferred to the conditioned space.

A fundamental performance limitation of desiccant wheel based systems occurs due to the heating of the process air-stream being dried by the wheel. This results from two main processes; i) the carryover of heat from the regeneration side of the wheel due to the heat capacity of the wheel matrix and, ii) the exothermic adsorption process (Goldsworthy and White, 2012). Process air heating is undesirable not only due

* *Corresponding author*. Tel.: +61 2 49606112.
E-mail address: mark.goldsworthy@csiro.au (M.J. Goldsworthy).

0140-7007/$ – see front matter © 2014 Elsevier Ltd and IIR. All rights reserved.
http://dx.doi.org/10.1016/j.ijrefrig.2013.10.009

Nomenclature

a	*m* Tube thickness
β	$Wm^{-2}K^{-1}$ Heat transfer coefficient
β_m	$kgm^{-2}s^{-1}$ Mass transfer coefficient
ρ_a	kgm^{-3} Dry air density
c	*m* Channel wall half thickness
c_p	$Jkg^{-1}K^{-1}$ Specific heat capacity at constant pressure
D_{eff}	m^2s^{-1} Effective moisture diffusivity
D_h	*m* Channel hydraulic diameter
D_t	*m* Diameter of tubes
f	- Fraction of active desiccant
H	Jkg^{-1} Heat of adsorption
h	Jkg^{-1} Enthalpy
k	$Wm^{-1}K^{-1}$ Thermal conductivity
L	*m* Channel length
Le	- Lewis number
N_t	- Number of tubes in wheel
Nu	- Nusselt number
t	s Time
T	K Temperature
u	ms^{-1} Velocity
$\dot{V}_w$	m^3 Volume flow-rate of water
W	$kgkg^{-1}$ Desiccant moisture loading
x	*m* Cross-channel co-ordinate
Y	$kgkg^{-1}$ Absolute humidity
z	*m* Axial co-ordinate
τ	s Rotation time for process or regeneration
ϕ	- Relative humidity (fraction)

Subscript

a	air
d	desiccant matrix
eq	equilibrium
p	process
r	regeneration
surf	desiccant-air surface
t	tube
v	vapour
w	water

to the sensible heat added to the process air-stream, but also because it limits the amount of moisture that can be removed from the process air-stream.

While both of these processes can be minimised through judicious wheel design (Goldsworthy and White, 2013), in an adiabatic wheel they cannot be eliminated. Hence, a number of researchers (see for example (La et al., 2010)) have suggested an isothermal dehumidification process where heat is transferred to a third stream so that the process air is cooled and dried at the same time.

For liquid desiccant packed bed dehumidifier devices, realisation of a practical design incorporating internal cooling during dehumidification, and measurement of an improvement in dehumidification performance, have been documented. For example Bansal et al. (2011) have performed experimental testing of an internally cooled packed bed dehumidifier and measured an increase in dehumidification of 30–40% over the same system without internal cooling.

However, in the case of solid desiccant wheels, incorporating process air cooling in the rotating desiccant matrix naturally leads to a more complicated design than when a batch process is used, and demonstration of improved performance is yet to be achieved. Kodama et al. (2005) have developed a multi-pass cross-flow desiccant wheel design incorporating process air cooling via a cooling air flow in separate channels as well as regeneration side heating with additional hot water channels. In their design, cooling air flows along the axial direction while process and regeneration air streams enter the wheel in a direction perpendicular to the wheel axis before turning 90° and travelling counter-current to the cooling flow. However, they found that the performance of the wheel was less than expected due to the high heat capacity of the structure.

An internally cooled wheel design based on a parallel plate arrangement has been proposed by Narayanan et al. (2013). In their design, cooling air enters in the axial direction through the wheel hub and exits the wheel in alternate channels perpendicular to the axis. Although this wheel was not constructed, testing results in a single channel suggest a significant increase in dehumidification performance when cooling was activated.

While previous works have suggested that an internally cooled desiccant wheel should provide better dehumidification performance than an adiabatic wheel, this has only recently been demonstrated in a functioning desiccant wheel (Goldsworthy et al., 2013). Here we use this experimental data to validate a numerical model of the internally cooled wheel. The model is then used to predict the theoretical performance with selected changes to the design and materials.

2. Wheel design

The internally cooled desiccant wheel is based on a shell and tube heat exchanger housed between two circular plates as shown in Fig. 1. Process air flows through the desiccant coated channels inside the aluminium tubes in the lower half of the wheel, and regeneration air flows through the channels in the upper half of the wheel. Cooling water enters through the stationary central shaft about which the wheel rotates and then travels around the outside of the tubes in the lower half of the wheel before exiting through holes in the shell at the other end of the wheel. The tubes are held in place by three separate face plates at each end of the wheel, each with two rubber sealant gaskets to prevent water leaking into the air streams. The entire assembly is held together with fasteners to allow replacement of the tubes.

The outer plates have a diameter of 0.4 m and house 788 0.2 m long aluminium tubes with 9.6 mm outer diameter and 8.7 mm inner diameter and centre-to-centre spacing of 11.7 mm. These tubes are packed with a super-adsorbent polymer desiccant material (Shim et al., 2008) that forms