Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 104 (2014) 103–114

SOLAR ENERGY

www.elsevier.com/locate/solener

Advanced performance of an open desiccant cycle with internal evaporative cooling

Constanze Bongs [a,*], Alexander Morgenstern [a], Yudhi Lukito [b], Hans-Martin Henning [a]

[a] Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstr. 2, 79110 Freiburg, Germany

[b] LuK GmbH Co. KG, Industriestr. 3, 77815 Bühl, Germany

Available online 21 October 2013

Communicated by: Associate Editor Jane Davidson

Abstract

An enhanced evaporatively cooled open sorption cycle which can be driven by solar thermal heat is presented as an environmentally benign alternative to conventional air conditioning cycles. Experimental data of the core component – the desiccant coated heat exchanger – cooled by water evaporation are given. This evaporation of water in the heat exchanger leads to an increase in adsorbed water mass by 46% and an enhancement of the cooling capacity by factor 4.1 when compared to a solely air cooled process. By simulation analysis, the recently designed heat exchanger is then compared to data of an air cooled open sorption process published in earlier research. Measurement data of this earlier research are analysed with a dynamic model. It is demonstrated that only a fraction of the dry desiccant mass was actively cycled in the earlier prototype. Simulation of the evaporatively cooled current prototype underlines the enhanced performance that can be achieved with the new concept and prototype design.

Keywords: Desiccant; Adsorption; Cooled sorption; Sorptive coated heat exchanger

1. Introduction

The demand for domestic air conditioning is expected to rise significantly (Riviere et al., 2008). Reasons for this are an increasing desire for comfort, rising temperatures and the phenomenon of heat islands in urban areas (Grignon-Masse et al., 2011). Applying conventional, electrically driven compression chillers to satisfy the cooling and dehumidification loads may therefore lead to a higher electricity consumption and an augmented risk of grid failures in summer peak hours.

Thermally activated desiccant air-conditioning technologies may use renewable solar heat to drive the air dehumidification and cooling process. Therefore, they can be considered a promising alternative to conventional compression cooling. Desiccant evaporative cooling technology combines the thermally driven sorptive air dehumidification with indirect (Finocchiaro et al., 2012) or direct evaporative cooling to reduce the temperature of the supply air (White et al., 2009; Henning et al., 2001).

Commercially available systems generally use desiccant rotors which have also been subject of extensive modelling efforts (see references in Ge et al. (2008a)). Commercial implementation has so far been dominated by systems designed for higher airflow rates. Desiccant wheels for small-scale residential applications were recently comparatively studied by experimental analysis (Eicker et al., 2012), analysed with respect to the influence of different sorption materials on the expected performance (Goldsworthy and White, 2012) and with respect to complete system setup and design (Goldsworthy and White, 2011).

However, the working principle of desiccant wheels implies the following disadvantage which is not easy to overcome: the release of adsorption heat during the dehumidification process leads to a temperature increase

* Corresponding author. Tel.: +49 76145885487.
E-mail address: constanze.bongs@ise.fraunhofer.de (C. Bongs).

0038-092X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.solener.2013.07.022

Nomenclature

A	mass transfer area (m^2)
c_p	specific isobaric heat capacity (kJ/(kg K))
d_h	hydraulic diameter (m^2)
dp	pressure difference (Pa)
h	specific enthalpy (J/kg)
i	index of logged time interval
l	length (m)
Le	Lewis factor
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
Meas	measured
n	number (–)
Nu	Nusselt number
t	time (sec)
T	temperature (°C)
p	pressure (Pa)
Pr	Prandtl number
Q	heat, energy (J)
$\dot{Q}$	heat flow rate (W)
Re	Reynolds number
Sim	simulated
x	humidity ratio (kg_W/kg_{Air})
X	desiccant water loading (kg_W/kg_{Ads})

Greek

α	convective heat transfer coefficient (W/m^2 K)
β, beta	mass transfer coefficient (m/s)
φ	relative humidity (%)
ρ	density (kg/m^3)
Δ	difference

Subscripts

Ads	adsorbent/desiccant
Adt	adsorbate/adsorbed water
Air	dry air
Cyc	cycle
Des	desorption
eff	effective
in	inlet
out	outlet
S	sorption side
V	cooling side
W	water
0	reference value

Abbreviations

AC	air cooled
ADS	adsorption stage
DES	desorption stage
EC	evaporatively cooled
ECOS	evaporatively cooled sorptive heat exchanger
F	flap
HX	heat exchanger
ISE	Fraunhofer Institute for Solar Energy Systems
P	purging stage
PC	pre-cooling stage
PT	prototype

in the sorption material. As the ability of the desiccant to adsorb moisture significantly decreases with higher desiccant temperature, cooling of the desiccant should lead to an increase in moisture adsorbed. Therefore, cooled desiccant cycles promise to achieve higher dehumidification rates than adiabatic desiccant cycles. Recently, the concept of staged desiccant air-conditioning has been studied in order to approximate an isothermal adsorption process (Ge et al., 2008b; Ge et al., 2009). In staged regeneration, the air is dehumidified and subsequently sensibly cooled before passing a second sorptive dehumidification step.

The basic approach of the research presented in this paper is the removal of the adsorption heat directly at the location of its release in the sorptive component. In order to achieve such internal cooling of the desiccant, a different component design has to be implemented. A sorptive coated air-to-air heat exchanger is applied instead of a rotary desiccant wheel. The novel desiccant evaporative cooling cycle presented in the following is designed for small-scale applications (airflow rates 200–400 m^3/h). It shall provide simultaneous dehumidification and cooling of the supply air and promises to more effectively use the desiccant than usual in desiccant wheels.

2. Process description and objectives

2.1. ECOS process description

The main component of the novel desiccant evaporative cooling system is the evaporatively cooled sorptive-coated cross-flow heat exchanger (ECOS). The working principle of air-conditioning performed by this novel component is shown in Fig. 1a–c. Fig. 1a shows the operation of the sorptive coated air-to-air heat exchanger during the adsorption stage, in which fresh ambient air is dehumidified and cooled. In the paper, the following nomenclature is used for the different airflows. The airflow passing the sorption channels during adsorption is called sorption air (index S) while the airflow passing the sorption channels during desorption is called regeneration air (index Des).