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Experimental results on adsorption beds for air dehumidification

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ABSTRACT

Desiccant rotors are commonly used in large scale solar cooling open cycle applications. As is well known, adsorption heat sensibly reduces the dehumidification capacity of the desiccant material and results in lower system performance. The aim of this work is to describe an innovative solution that permits simultaneous mass and heat transfer. In particular, two components working with silica gel fixed beds were studied and compared. The first component is a simple packed bed containing silica gel grains. The second component is a fin and tube heat exchanger commonly used in several air conditioning applications wherein the spaces between the fins are filled with silica gel grains. In this case, the adsorption material is cooled through a recooling loop. For both solutions, results are presented in terms of dehumidification performances versus operation time, storage of adsorption capacity and energy required for the regeneration of the desiccant.

Résultats expérimentaux sur les lits à adsorption pour la déshumidification de l'air

Mots clés : Lit tassé ; Gel de silice ; Adsorption ; Déshumidification ; Froid évaporatif à déshydratant (DEC) ; Froid solaire

1. Introduction

Solar DEC (desiccant and evaporative cooling) technology is an interesting and fascinating solution that uses solar energy for applications in air conditioning. DEC is a thermally-driven open cooling cycle based on evaporative cooling and adsorption processes. In this technology, the dehumidification process is commonly carried out using desiccant rotors impregnated or covered by adsorption material (i.e. silica gel or lithium chloride) (Beccali et al., 2003, 2004). The dehumidification component is crossed at the same time by a regeneration and dehumidification stream that guarantees operation continuity in the air conditioning unit (Fig. 1). In a solar desiccant cooling cycle, solar energy is used to regenerate a desiccant material that dehumidifies moist air by vapor adsorption; the resulting dry and warm air is cooled in a sensible heat exchanger (usually rotating) and then in an (direct) evaporative cooler. By associating

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Nomenclature

RH	relative humidity equilibrium air [%]
T	temperature [°C]
w	silica gel water content [$kg_w\ kg_s^{-1}$]
x	absolute air humidity [$kg_w\ kg_s^{-1}$]
S	bed section [m^2]
L	bed thickness [m]
ε	bed porosity [-]
ρ	density [$kg\ m^{-3}$]
M	mass [kg]
Q	air flow rate [$m^3\ h^{-1}$]
t	time [s]
U	global heat exchange coefficient [$W\ m^{-2}\ K^{-1}$]
A	section area [m^2]
v	velocity [$m\ s^{-1}$]
D	average particle diameter [m]
Re	Reynolds number [–]
Δt	sample time [s]
N	number of sample [–]

Subscripts

0	initial
f	final
i	in
o	out
b	bed
s	silica gel
w	water
a	air
*	equilibrium
-	average

different elementary treatments in moist air (dehumidification, sensible cooling and evaporative cooling) in both the process and exhaust air, the technique uses water as a refrigerant and solar energy as the driving heat (Finocchiaro et al., 2012).

Adsorption via desiccant rotors is limited by temperature increases in the desiccant. This phenomenon is due to the release of adsorption heat due to water transfer from air to the desiccant as well as by the carry-over of heat stored in the desiccant material from the regeneration section to the process section. There is a negative impact on the overall system performance because there is an increase in the desiccant material temperatures that is responsible for the lower dehumidification capacity and higher regeneration temperatures. Moreover, desiccant rotor technology cannot be used to store adsorption capacity into the desiccant material because rotors only host low masses of adsorbent. Therefore, the only option for energy storage is related to the driving fluid, i.e. water heated with a solar plant. In addition, the use of hot air as a regeneration fluid is suitable only in systems without storage. Finally, these systems are generally applicable only in medium-large scale solar DEC systems.

Some of these issues can be solved with a liquid DEC system in which the adsorbent is utilized in a liquid solution with water. In such systems, the storage effect is associated with the dehumidification capacity of a dried solution contained in a tank. However, the liquid DEC systems have some problems related to the increase in parasitic electricity consumption, system complexity, as well as the resistance of the hydraulic components to corrosion caused by the water-adsorbent solution.

In the past, fixed packed desiccant beds were also used in systems based on adsorption technology, but these were abandoned over time. The main issues related to pressure drop and system complexity have prompted the use of the desiccant rotor solution. In DEC systems working with fixed beds, two desiccant beds have to be operated in a batch process; this normally requires lots of air dampers.

In this study, fixed desiccant bed technology is considered in a new perspective. In particular, simultaneous heat and mass transfer between air and desiccant as well as the use of the desiccant bed for latent storage has been studied.

Other authors have investigated technical solutions permitting the simultaneous heat and mass transfer or a silica gel- and polymer-coated fin-tube heat exchanger (Ge et al., 2010; Inaba et al., 2008; Rady et al., 2009; Song et al., 2008).

Other authors have studied different configurations of the desiccant fixed bed to improve the performance and increase the utilization of the desiccant material. This has resulted in a radial bed that increases bed thickness without exceeding the pressure drop (Ramzy et al., 2008; Trybal, 1981). Other authors studied configurations aimed to decrease the adsorption heat's negative effect using composite particles in which a portion of the desiccant particle is replaced with an inert

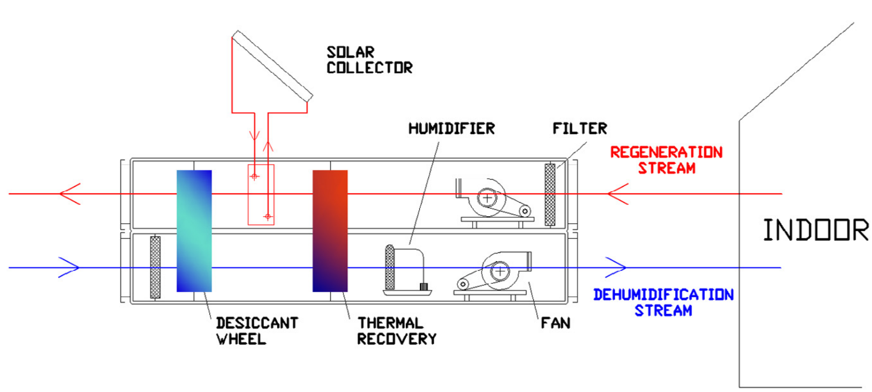

Fig. 1 – Conventional plant scheme of a solar desiccant cooling cycle.