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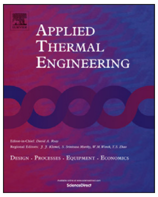

Research paper

Experimental analysis and numerical modelling of an AQSOA zeolite desiccant wheel

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HIGHLIGHTS

- Experimental tests of a recently developed zeolite desiccant wheel.
- Effect of air stream quantities out of experimental testing range conditions.
- Identification of non-dimensional parameters to predict optimal revolution speed.

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ABSTRACT

An AQSOA zeolite based-desiccant wheel is experimentally and numerically investigated in the present work. The synthetic zeolite AQSOA benefits from a favourable S-shape isotherm whose steepest gradient zone is shifted towards higher vapour partial pressure values. An AQSOA-based desiccant wheel is experimentally characterized over a wide range of process and regeneration air inlet conditions. A one-dimensional, time-dependent numerical model is developed and calibrated using the experimental data with root mean square deviation of 0.66 g/kg and 0.99 °C for process outlet humidity ratio and temperature respectively. The model is used to investigate the influence of area ratio, process inlet temperature, humidity and air face velocity on performance. It is found that equal area split is essential to achieve maximum moisture removal capacity, while higher process area ratio leads to higher latent cooling, but only in the high regeneration temperature range, and moisture removal efficiency strongly depends on inlet humidity ratio with a weak dependence on process inlet temperature. Non dimensional analysis is shown to be useful for identifying optimal revolution speed as a function of inlet face velocity.

1. Introduction

Desiccant wheels are key components for desiccant cooling systems with low grade thermal activation energy. This makes them appealing devices for solar thermal applications and cogeneration systems in which low temperature heat can be recovered. The overall design of desiccant cooling systems requires simultaneous optimization of a number of parameters [1] (area ratio, regeneration temperature, surface velocity, revolution speed). Use of simulation tools calibrated with limited experimental measurements is a practical and cost effective approach for energy simulation analysis [2].

Silica gel is one of the best performing and commonly investigated materials in desiccant wheels owing to its good long term stability and minimal hysteresis. Kodama et al. [3,4] investigated performance of rotary adsorbents focussing on fractional residual of water vapour and optimal revolution speed. Silica gel-based adsorbents, both as pure [5] and compound forms [6] have been widely characterized in terms of adsorption equilibrium and diffusivity. Recently interest has risen in alternative desiccant materials with higher moisture uptakes even at low regeneration temperature. Aristov et al. found out that moisture uptake on hygroscopic salts can be significantly higher than pure silica gel [7,8]. Zhang [9] and Ge [10] investigated the increase in performance of desiccant wheels in which silica gel based adsorbent is mixed with calcium and lithium chloride respectively. Zeolites are common alternative to silica gel since they are quite widespread for many chemical uses and can be synthesized according to application requirements. Conventional zeolites, such as Type A and Type Y, show a typical S-shape adsorption isotherm which is ideally suited for dehumidification and drying processes. However, their adsorption isotherm generally has a zone of steepest

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gradient in the low humidity range, i.e., the minimal amount of adsorbed water vapour is achieved only at extremely low relative humidity. It follows that maximum differential uptake is obtained only with very high regeneration temperatures (typically 120–250 °C [11,12]). A new generation of AQSOA™ (Aqua Sorb Adsorbent) zeolites, recently developed by *Mitsubishi Plastics Inc.*, is an interesting solution to exploit low grade heat. AQSOA consists of crystalline silico-alumino-phosphate materials with a CHA structure [13]. With this new generation of zeolites, the steepest gradient zone of the adsorption isotherm can be shifted towards higher relative humidity values [14] compared with conventional zeolites such as Type A or Type Y [15]. Dehumidification performance can be even comparable with common desiccant materials such as silica gel regenerated with low and medium regeneration temperatures.

A preliminary assessment of moisture removal capacity can be based on moisture differential uptake $\Delta W_{\text{ads},\ \text{i.e.}}$, the difference between water vapour uptake evaluated at process inlet and regeneration inlet relative humidity conditions respectively. This would be ideally the maximum amount of water removed per unit mass of desiccant if the adsorbent achieved equilibrium with inlet air flows. As it is shown in Fig. 1 given a pair of reference process and regeneration temperatures with the same humidity ratio (T_{pro} 30 °C, RH_{pro} 50% and T_{reg} 80 °C RH_{reg} 4.5% respectively) the moisture differential uptake may be even larger in AQSOA-based desiccant than a silica gel-based one. Silica gel isotherms [16] have limited dependency on temperature, so that adsorption equilibrium curves can be considered almost overlapping in the RH-W chart (Fig. 1).

This new generation of zeolites has been raising interest both in adsorbent characterization and cooling applications. Goldsworthy [17] has recently compared different kind of AQSOA zeolites for modelling of adsorption chillers and desiccant wheels. Frazzica [18] adopted a new experimental protocol to evaluate thermodynamic performance of AQSOA-Z02 as a desiccant for advanced working pair in adsorptive heat transformers. Dawoud [19] provided an insight into water vapour adsorption kinetics on small AQSOA-Z02-coated aluminium substrates for adsorption heat exchangers. Plenty of experimental results are available on alternative desiccant materials [20], however only few authors dealt with new generation of zeolites [21,22] and neither a comprehensive nor a model driven numerical analysis has been carried out on AQSOA zeolite-based desiccant wheels.

In the present work, an AQSOA-Z02 desiccant wheel is investigated both numerically and experimentally. First, a brief introduction to the desiccant wheel test facility is provided, including details on the measuring process and uncertainty analysis. Then, a time dependent numerical model is described and calibrated on experimental data. The model is adopted to investigate wheel performance on out of testing range conditions.

2. Experimental setup

Tests on an AQSOA desiccant wheel have been performed using the Controlled Climate Test Facility at the CSIRO Energy Centre in Newcastle. A schematic is provided in Fig. 2. The facility is designed to provide two air streams at accurate controlled conditions of temperature and humidity. The former stream simulates the fresh supply air, mainly referred as the *process flow*, which is to be dehumidified by the test desiccant wheel. The latter stream is a relatively high temperature air flow that regenerates the desiccant and is referred to as the *regeneration flow*.

Process and regeneration air streams are then ducted to the desiccant wheel test bench in counter flow arrangement. The supply and regeneration air streams leaving the desiccant wheel are ducted from the wheel and exhausted outside. Data acquisition and system control is programmed via LabVIEW 7.1. Measurement sensors in the test facility are described below;

- Temperature is measured with class B RTD sensors, with accuracy a function of temperature as follows $\delta T = 0.005T + 0.3$ (T and δT in °C).
- Relative humidity is measured with capacitive sensors with accuracy ±1.3%RH and with two high accuracy Optica chilled mirror hygrometers. The four air flows are each sampled by sampling tree located in each of the wheel inlet and outlet ducts. The resulting dew point temperature can be measured with an accuracy of 0.2 °C.
- Volume flow rate is measured downstream with Pitot tube anemometer. Pressure drop across the nozzles is measured by

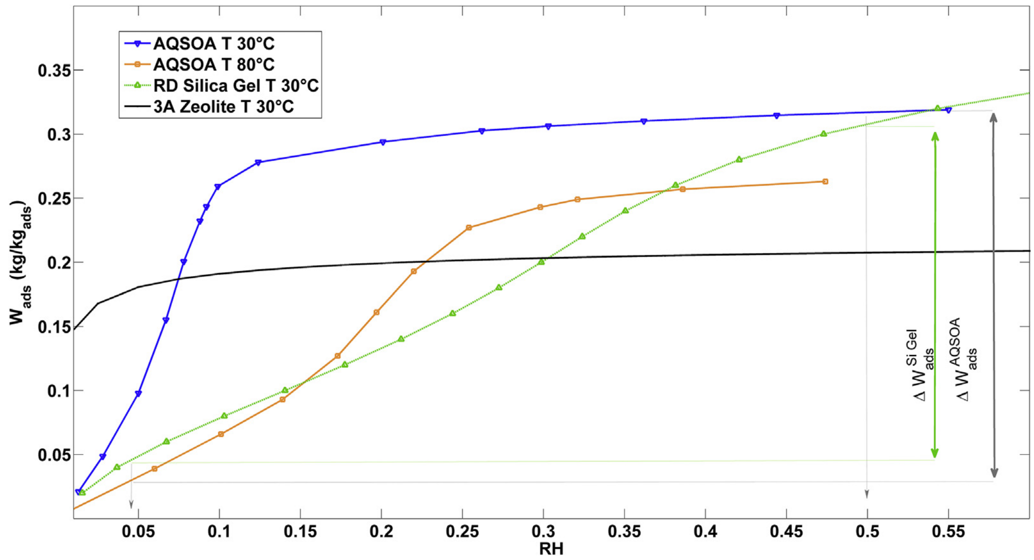

Fig. 1. Comparison of Novel AQSOA Zeolite Isotherms (data extrapolated from Kakiuchi [14]) with regular density silica gel [16] and 3A Zeolite isotherms [15].