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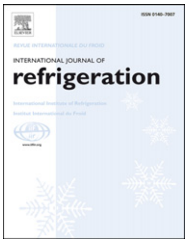

Experimental testing of a lab-scale adsorption chiller using a novel selective water sorbent “silica modified by calcium nitrate”

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ABSTRACT

In this paper, a novel composite water sorbent “silica modified by calcium nitrate” (SWS-8L) has been tested for utilization in adsorption chillers driven by low-temperature heat. The isosteric diagram of the working pair under investigation has been calculated from experimental adsorption data measured at equilibrium. The equivalent specific heat of the sorbent as a function of the water loading was experimentally measured by a calorimetric technique. Thermodynamic cooling COP was estimated to be 0.51–0.71, with desorption temperature lower than 90 °C. Real performance was measured by testing a SWS-8L based sorbent bed in a lab-scale adsorption chiller. With this aim, SWS-8L grains were embedded inside a compact aluminium heat exchanger with high thermal efficiency. Experimental cooling COP, mass specific cooling power SCP and volumetric specific cooling power VSCP obtained are 0.18–0.31 (cycle time 10 min), 190–389 W/kg dry sorbent and 104–212 W/dm^3, respectively.

Essais expérimentaux sur un refroidisseur à adsorption à l’échelle du laboratoire employant un sorbant d’eau à base de gel de silice modifié à l’aide du nitrate de calcium

Mots clés : Refroidisseur à adsorption ; Eau ; Gel de silice ; Additif ; Nitrate ; Calcium ; Évaluation ; Performance

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Nomenclature

c_p	specific heat (J kg^{-1} K^{-1})
COP	coefficient of performance
m	mass (kg)
$\dot{m}$	mass flow (kg s^{-1})
SCP	mass specific cooling power (W kg^{-1})
T	temperature (K)
t_{cycle}	cycle time (s)
VSCP	volumetric specific cooling power (W dm^{-3})

Subscripts

ads	adsorption
bed	adsorbent bed
con	condenser
des	desorption
ev	evaporator
in	inlet
ish	isosteric heating
out	outlet
s	sorbent

Greek symbols

Δt	time variation (s)
Δw	uptake variation (kg kg^{-1})

1. Introduction

Adsorption chillers/heat pumps showed great potential for utilization of low grade waste heat or solar energy (Wang and Oliveira, 2006; Xia et al., 2009). The use of water as a working fluid in adsorption machines offers several significant advantages such as favourable thermodynamic properties and absence of adverse effects on the environment (Cacciola and Restuccia, 1999). However, common water adsorbents like zeolites A, X, Y or microporous silica gel do not guarantee adequate performance when the heat for desorption is available at a temperature lower than 90 °C (Srivastava and Eames, 1998). For this reason, efforts have been addressed towards the research and development of adsorbents which possess large water sorption capacity and low regeneration temperature (Aristov, 2009). New materials like (silico)aluminophosphates and titanosilicates are considered promising in terms of high water adsorption capacity and low regeneration temperature (Ng and Mintova, 2008). Jaenchen et al. (2002) tested different aluminophosphates, showing that the partially hydrophobic framework of such materials allows regeneration temperature significantly lower than that typical of strongly hydrophilic zeolites. van Heyden et al. (2009) proposed the ALPO-18 adsorbent for application in adsorption heat pumps, due to the relatively high water adsorption capacity (up to 25 wt.%) and fast adsorption kinetics. Novel synthetic functionalized materials "AQSOA" have been specifically developed by Mitsubishi (Kakiuchi et al., 2005a,b). Experimental testing of AQSOAs showed that these materials can provide attractive performance when the available temperature of desorption is lower than 90 °C (Sapienza et al., 2007; Kohlenbach et al., 2008). Other authors proposed different solutions such as attapulgite clay sorbents impregnated with inorganic salts (Janchen et al., 2005; Chen et al., 2008), silicalite MCM-41 (Mobile Crystalline Material) (Tokarev et al., 2002) or zeolite/active carbon compounds (Zhenyan et al., 1998), that potentially are attractive for utilization of low grade heat. Recently, BIC-RAS (Novosibirsk, Russia) synthesised and investigated together with CNR-ITAE, a new composite sorbent of water "silica modified by calcium nitrate" (SWS-8L), which belongs to the family of Selective Water Sorbents (SWSs), a family of composite sorbents based on a chemically active salt confined to pores of a host matrix (Aristov et al., 2002). The SWS-8L sorbent is expected to be attractive for utilization in adsorption machines driven by low-temperature heat (Simonova and Aristov, 2008; Simonova et al., 2009). Indeed, the sorbent presents high adsorption capacity and a regeneration temperature which is lower than that of the composite sorbent SWS-1L "silica modified by calcium chloride", previously suggested for application in adsorption chillers driven by heat at 85–100 °C (Restuccia et al., 2004). The aim of this paper is to evaluate the thermodynamic and experimental performance of this novel composite sorbent "silica modified by calcium nitrate" for application in adsorption chillers driven by low-temperature heat. Firstly, the SWS-8L/water isosteric diagram was calculated from sorption isobars, already presented in Simonova et al. (2009). Knowledge of the sorbent heat capacity as a function of temperature and water loading is also necessary for analysis of the cooling cycle. With this aim, the equivalent specific heat of the sorbent was experimentally measured by a calorimetric technique. The obtained data was used for evaluation of thermodynamic performance in cooling cycles. Experimental performance was estimated by testing a SWS-8L based sorbent bed in a lab-scale adsorption chiller. With this aim, sorbent grains were integrated with a compact aluminium heat exchanger. Such type of heat exchangers are light enough and possess very high heat transfer surface, allowing to rapidly provide/remove heat during desorption/adsorption phases of working cycles (Tamainot-Telto et al., 2008; de Boer et al., 2005; Vasta et al., 2008). Such features are important to maximize the adsorption machine performance (Khan et al., 2006). Experimental tests were conducted with the aim of evaluating the cooling COP and the delivered cooling power for different operating conditions.

2. Evaluation of the SWS-8L/water thermodynamic performance

Fig. 1 shows the SWS-8L/water isosteric diagram calculated from sorption isobars, already presented in Simonova et al. (2009). Two typical cooling cycles ($T_{ev} = 12$ °C, $T_{cond} = 35$ °C, $T_{des} = 75$ °C; $T_{ev} = 10$ °C, $T_{cond} = 40$ °C, $T_{des} = 90$ °C) were reported over this diagram, showing that this sorbent can exchange an attractive amount of water during ad/desorption phases ($\Delta w \sim 10$ wt.%), when the maximum desorption temperature is as low as 75 °C and the condensation temperature is 35 °C. An efficient cycle can be obtained even at higher temperature of condensation $T_{cond} = 40$ °C, provided that the desorption temperature is $T_{des} = 90$ °C.