Reduction of the heat capacity in low-temperature adsorption chillers using thermally conductive polymers as heat exchangers material

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ABSTRACT

Aside from the low adsorption capacity of silica gel, often used in commercially available low-temperature adsorption chillers today, the cooling performance of such chillers is limited due to the high heat capacity of the mostly metal-based heat exchangers. As a completely new approach, thermally conductive polymers have been studied and examined as heat exchanger materials for low temperature adsorption chillers in order to decrease the energy consumption during the adsorption cycle. The modification of polyamide 6, which was chosen as a model polymer in this study, with expanded graphite leads to enhanced thermal part properties for adsorption heat exchangers. Compared to aluminum as the commonly used heat exchanger material, the heat capacity of a chiller can be reduced by 30%, if such a thermally conductive polymer is applied. Moreover, the increased thermal conductivity of the polymer based part leads to no significant limitation in the adsorption kinetic of water used as a refrigerant in adsorption chillers.

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1. Introduction

Heat transformation processes based on adsorption have been the focus of research around the world in the last decades [1–4]. Today's cooling production is mainly based on conventional vapor compression chillers revealing the problems of a high consumption of electrical energy and the utilization of environmentally hazardous refrigerants [5]. The increasing demand for renewable energies and environmentally friendly materials has already opened the way for commercially available adsorption chillers [6–8] mainly based on a silica gel-water adsorption pair which allows a wide temperature range in the driving heat [9].

The core of an adsorption chiller is the adsorber itself, which mainly consists out of an adsorbent and a supporting material – the heat exchanger – which has to have very good thermal conductive properties to ensure a good heat transfer from and into the adsorbent during the adsorption and desorption phases. This implies that the adsorbent has to be implemented in a heat exchanger in some way, while the optimal choice of the adsorbent strongly depends on the envisioned application [10–12]. However, by improving the implementation of the adsorbent, the heat transfer, the sorption kinetics and hence the performance of adsorption

and desorption processes can be enhanced. The concepts of implementation can be classified into fixed bed and coated adsorber units. In a fixed bed adsorber, the adsorbent is filled as loose granules in the adsorber unit between heat exchanger fins. This approach distinguishes itself by its easy design but shows only a limited heat transfer between the adsorbent and heat exchanger surface occurring from the point contact of the pellets between each other and the heat exchanger surface [13–16]. The coating approaches aim at an advanced heat transfer between the adsorber and heat exchanger surface to accelerate the adsorption and desorption processes. Coating techniques are commonly subdivided into ex situ and in situ techniques. Both are focused on a reduced heat and mass transport limitation in the adsorbent layer, whereas the in situ techniques further deals with the renouncement of an inert binder system within the adsorbent layer [17–23].

However, as many research groups are trying to enhance the performance and specific cooling power of an adsorber unit by optimizing the adsorbent for a specific application or by improving the heat transfer between adsorbent and heat exchanger, the reduction of the heat exchangers heat capacity seems to exhibit a neglected potential for increasing the coefficient of performance (COP) of an adsorption chiller, which reflects the efficiency of such a system.

The COP for an adsorption chiller can be defined as the quotient of usable energy and the consumed driving energy (Eq. (1)).

Nomenclature

Symbol		*Subscript*	
a	thermal diffusivity [m^2/s]	Ads	adsorption
A	area [m^2]	Des	desorption
c	heat capacity [J/(kg·K)]	Evap	evaporation
h	Enthalpy [J/g]	fluid	thermofluid
k	thermal conductivity [W/(m·K)]	H	high temperature level
m	mass [kg]	hc	heat capacity
Q	heat [J]	hex	heat exchanger
R	resistance [K/W]	M	medium temperature level
s	layer thickness [μm]	s	specimen
T	temperature [°C]	Th-z	thermal in z-direction
x	loading of the adsorbent [g$_{Water}$/g$_{Adsorbent}$]	z	z-direction; perpendicular to the injection direction
ρ	density [kg/m^3]		

$$COP = \frac{Q_{Evap}}{Q_{Des} + \sum Q_{hc}} \qquad (1)$$

Beside the heat needed to desorb the adsorbate (Q_{Des}), the heat capacity of the components in the system ($\sum Q_{hc}$) is an important factor as a lot of energy is consumed during the heating up and cooling down of the system in every sorption cycle. Distinguishing between the single components, the main parts are the adsorbent, whereas the change in water loading is neglected, the thermofluid in the pipes of the heat exchanger and the heat exchanger itself. In a simplified way, the energy consumed by the components heat capacity can be calculated by

$$\sum Q_{hc} = (m_{Ads} \cdot c_{Ads} + m_{hex} \cdot c_{hex} + m_{fluid} \cdot c_{fluid}) \cdot \Delta T_{M-H} \qquad (2)$$

with the masses m of the components, their specific heat capacities c and the temperature rise form the adsorption temperature T_M to the desorption temperature T_H, respectively. From Eq. (2), it becomes clear that a reduction of the heat exchangers heat capacity could directly improve the efficiency of an adsorption chiller.

An appropriate way to reduce the heat capacity of the heat exchanger could be the use of comparatively lighter polymer heat exchangers. To the best of our knowledge, increasing the COP by reducing the heat capacity of the heat exchanger using a polymer has only been done in a theoretical way by Tatlier et al. [24] several years ago. The authors investigated the potential of zeolite coated Polytetrafluoroethylene (PTFE) heat exchanger tubes for adsorption heat pumps based on theoretical models. The authors stated a significant increase of the COP by using a polymeric heat exchanger due to the reduced heat capacity. On the other hand, the authors showed that a wall thickness >1 mm would decrease the performance of an adsorption heat pump due to long sorption cycle durations. This is obvious as polymers have a lower thermal conductivity and thermal diffusivity compared to conventional heat exchanger materials and thus show a slower adsorption kinetic and hence a reduced efficiency of an adsorption chiller.

Until now, no comparative research on polymers and thermally conductive polymers used as supporting specimen for adsorption chillers has been reported. As a heat exchanger material, polymers are only used if the overall thermal resistance is dominated by the inner and outer resistances and when the operating temperatures are low [25]. However, a large number of different types of modified polymers can be found on the market today, showing thermal conductivities from 0.8 to 21 W/mK [26]. An increase in thermal conductivity can generally be achieved by adding metallic, ceramic or carbon-based fillers to the neat polymer. Typical filler contents

are between 5 and 60 vol.-% [27,28]. In addition to the filler content, the intrinsic thermal conductivity, size, aspect ratio and geometry of the filler can significantly influence the compound conductivity. Furthermore, processing non-isometric fillers, i.e. fibers or platelets, by injection molding or extrusion causes a characteristic filler orientation and therefore orientation-related and process-dependent thermal part properties [29]. In addition to low weight, polymers could provide various unique physical properties such as greater flexibility, corrosion resistance and an ease of manufacturing [25,30].

To overcome the high thermal resistance of polymers but keeping the advantage of a reduced heat capacity of the heat exchanger material, the authors prepared thermally conductive polymers based on a semi-crystalline polyamide 6 (PA6) with different filler contents and evaluated their potential for using them as a material for heat exchangers in low temperature adsorption chillers. To emphasize the relevance of the thermal conductivity and the heat capacity of the different heat exchanger materials, plate specimen were conducted by injection molding and investigated in an adsorption test apparatus as supporting materials for different adsorbents. By measuring the adsorption kinetics of shaped silica gel and pelletized TAPSO-34 (titanium containing siliconaluminumphosphate molecular sieve) as a monolayer of loose granules, an easy exchange of the supporting plate specimen can be carried out and ensures a good comparability of the different supporting plate specimen while keeping the adsorbent layer constant.

2. Experimental

2.1. Preparation of compounds and specimens

Thermally conductive polymers (compounds) were prepared on a Leistritz ZSE 27 HP-40 twin-screw extruder. As matrix material, Polyamide 6 (Tarnamid T-27 by Azoty Tarnow™: denoted in the following as PA6) was employed, and 10, 20, 30 and 40 vol.-% of expanded graphite particles were integrated into the compound. Expanded graphite has a platelet-shaped and non-isometric geometry (Fig. 1). The platelets' average diameters D50 were approx. 50 μm. Microscopic analyses revealed that the platelet particles are approximately 1 μm thick. The specific heat capacity of natural expanded graphite has been determined to 0.72 J/g K and the thermal conductivity to approximately 189 W/mK.

To imitate an heat exchanger surface, neat PA6 and the prepared compounds were processed on an Ergotech 25/280-80 standard injection molding machine by DEMAG to plate specimens