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Research paper

A novel approach for enhancing the utilization of solid desiccants in packed bed via intercooling

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HIGHLIGHTS

- An intercooled packed bed is proposed to increase the utilization of desiccant material in the trailing layers of the bed.
- Experimental tests are conducted for moisture adsorption processes in conventional and intercooled silica gel beds.
- Numerical model for moisture adsorption in desiccant bed is presented and validated with the experimental data.
- The significance of the intercooling on the bed performance is investigated.
- The effect of air flow velocity on the intercooled bed and the optimum intercooler location are investigated numerically.

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ABSTRACT

Desiccant material in trailing layers of packed beds is not utilized effectively due to the released heat of adsorption. In this study, an intercooled packed bed is proposed to enhance the utilization of desiccant material in the trailing layers of the bed. Experimental and numerical runs are conducted for moisture adsorption processes in conventional and intercooled silica gel beds. The numerical model predicts the exit air condition with an acceptable agreement. Using intercooled bed, 22% increase in total adsorbed mass is achieved for the studied case. The optimum bed length and intercooler location are explored. Also, the effect of air flow velocity on the intercooled bed at the optimum location is presented numerically.

1. Introduction

Dehumidification of air is an important process for many practical applications like, air conditioning [1], solar cooling [2], air drying [3] and water production from the atmospheric air [4,5]. Desiccant dehumidification systems are considered good alternative for the commonly used refrigeration systems. It can be powered using low grade energies like solar energy or waste heat. Desiccants are mainly of two types, namely i) liquid desiccants and ii) solid desiccants. Solid desiccant materials are utilized within the desiccant dehumidification systems in different configurations like the packed [6] and fluidized [7] beds and desiccant wheel [8]. The mathematical models of the heat and moisture transfer in thin packed bed of silica gel were investigated [9–11], where the pressure gradient along the bed is neglected for thin beds. Investigations showed that desiccant material in the trailing layers of the bed is not utilized effectively due to the released heat of adsorption [7,12]. Many investigations are carried out in view to reduce the effect of heat of adsorption on the bed adsorptivity [12–21]. Higher air flow rates [13] and a cooling coil in the core of the fluidized bed [15] were proposed to eliminate the heat of adsorption effect. Increasing desiccant material utilization by continuous particle mixing in a fluidized bed was proposed by Hamed et al. [7]. Also, Awad et al. [14], and Ramzy et al. [19] proposed a radial flow hollow cylindrical packed bed of silica gel instead of the vertical conventional packed bed. Moreover, the same configuration was studied with activated alumina as the desiccant material instead of silica gel [21]. A cross cooled desiccant bed was proposed with pasted silica gel particles on the inner walls

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Nomenclature

A	cross section area [m^2]
a	volumetric surface area [m^{-1}]
c	specific heat capacity [kJ kg^{-1} K^{-1}]
HA	heat of adsorption [J kg$_w^{-1}$]
h	convective heat transfer coefficient [W m^{-2} K^{-2}]
h_m	convective mass transfer coefficient [kg m^{-2} s^{-1}]
L	length [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
P	pressure [Pa]
Re	Reynolds number
RH	relative humidity
T	temperature [°C]
t	time [s]
v	velocity [m s^{-1}]
W	bed water content [kg$_w$ m^{-3}]
w	humidity ratio [kg$_v$ kg$_{da}^{-1}$]
y	axial position in the bed [m]
y_c	axial position of intercooling [m]
Greek	
ρ	density [kg m^{-3}]
ε	porosity
ε_{HE}	effectiveness of heat exchanger
μ	dynamic viscosity [N s m^{-2}]
η_{deh}	dehumidification efficiency
ψ	relative increase in mass adsorbed [%]
Subscripts	
0	initial condition
a	air side property
b	bed side property
i	inlet
o	outlet
s	silica gel
v	water vapor
w	water

of the dehumidifier [16]. The external walls of the bed were cooled/heated by atmospheric/regeneration air, respectively. However, many theoretical and experimental investigations for internally cooled liquid desiccant dehumidification systems were carried out [22–25], at the best of our knowledge; the intercooled packed bed of solid desiccant has not been investigated. It is expected that the effect of adsorption heat can be eliminated and consequently, the utilization of desiccant material in the bed increases.

In this study, an intercooling process of the flowing air is proposed between two sections of the bed, as shown in Fig. 1. Experimental setup for conventional and intercooled silica gel bed is constructed, and the performance of both beds in adsorption mode is investigated. A mathematical model for heat and moisture transfer considering the pressure gradient along the bed is presented and validated. The utilization of the trailing layers of the intercooled desiccant bed is numerically investigated. In addition, the optimum location of the intercooler is numerically explored.

2. Mathematical modeling

The physical models for the conventional and the proposed intercooled silica gel packed beds are illustrated in Fig. 1 a and b, respectively. A mathematical model for the conjugate heat and moisture transfer associated with adsorption in the vertical packed bed is developed.

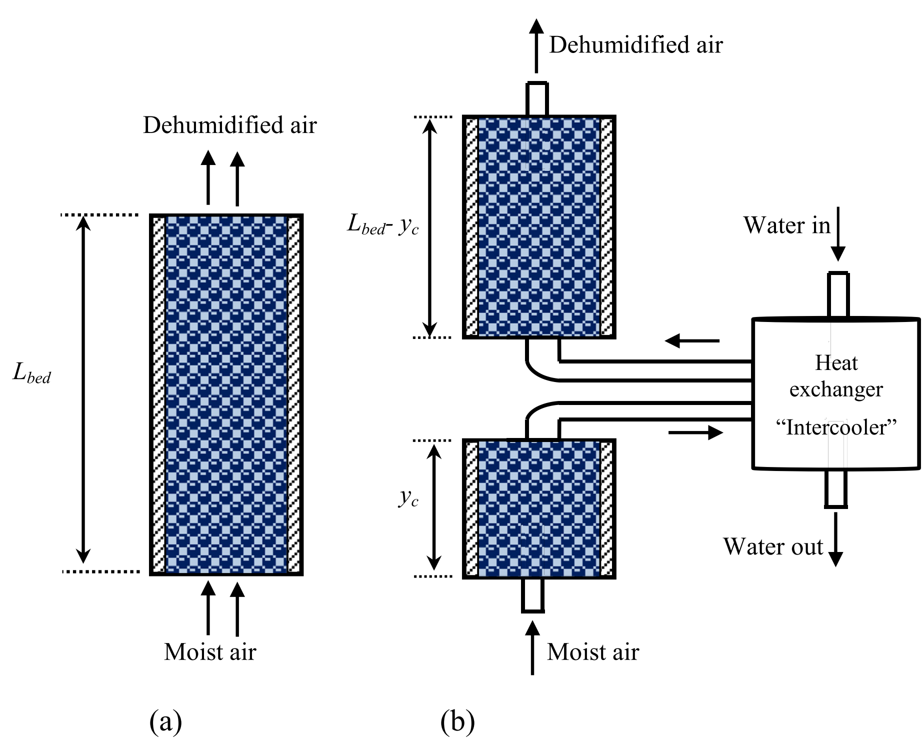

Fig. 1. Physical model of silica gel bed in adsorption mode, (a) conventional and (b) intercooled packed beds.