



Correlations for the mass transfer coefficient in desiccant matrices when using linear driving force and pseudo-gas-side-controlled models



Celestino R. Ruivo ^{a, b, *}, António R. Figueiredo ^b, José J. Costa ^b

^a Department of Mechanical Engineering, High Institute of Engineering, University of Algarve, Campus da Penha, 8005-139 Faro, Portugal

^b ADAI-LAETA, Department of Mechanical Engineering, University of Coimbra, Rua Luís Reis Santos, 3030-788 Coimbra, Portugal

ARTICLE INFO

Article history:

Received 24 May 2014

Received in revised form

1 August 2014

Accepted 9 August 2014

Available online 2 September 2014

Keywords:

Adsorption

Mass transfer coefficient

Linear driving force model

Pseudo-gas-side-controlled model

Correlations

ABSTRACT

Following a previous research on the simplified simulation of desiccant matrices with the linear driving force and the pseudo-gas-side-controlled models, correlations for predicting the mass transfer coefficient values are investigated. The study is centred on the behaviour of an element of a cell of a compact desiccant matrix and the reference data are provided by the results of a detailed numerical model. The response of the solid desiccant to a step change in the airflow state is simulated, for both adsorption and desorption processes, until the desiccant achieves equilibrium with the airflow.

The previous research has shown that, when adopting just one of the two simplified models with a constant mass transfer coefficient for the whole range considered of the desiccant wall thicknesses, the accuracy of the results becomes questionable. The linear driving force model is suitable when the mass transfer resistance on the solid side is high, while the pseudo-gas-side-controlled model performs well for cases with low mass transfer resistance.

Useful correlations for estimating the mass transfer coefficient for the processes of both adsorption and desorption as a function of the desiccant wall thickness are now investigated. The correlations are tested and it is found that, when using the linear driving force model in desorption cases, a correction of the correlation accounting for the operating conditions is required in order to obtain acceptably accurate results with the proposed methodology.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The mathematical simulation of sorption processes such as those occurring in desiccant matrices requires models for describing the coupled heat and mass transfer phenomena. The significance of the solid side resistances is a key issue. Two types of models have been usually adopted: GSSCM (gas-and-solid side controlled models) and GSCM (gas-side-controlled models). Numerical models representing in a detailed way the coupled heat and mass transfer phenomena in desiccant wheels [1–3] are GSSCM models. Such numerical approaches present more potentialities, but they are more complex and require more computational time. Most authors have been adopting gas-side-controlled models [4–9] to simulate desiccant wheels, which is an approach strictly valid for

cases with relatively low values of the desiccant wall thickness [10,11]. So, the use of such models without a previous validation over a wide range of operating conditions remains questionable, mainly in cases of significant mass transfer resistance in the solid side. To take this effect into account, PGSCM (pseudo-gas-side-controlled models) have been used in the simulation of sorption processes. The PGSCM can be seen as a modified GSCM (gas-side-controlled model), the main difficulty being the estimation of the pseudo mass transfer coefficient to be used in a particular simulation.

Hougen and Marshall [12] analysed the operation of a bed of particles of silica gel, and by using experimental data of Ahlberg [13], they found correlations for the pseudo-gas-side transfer coefficients as function of the Reynolds number and of the airflow mass velocity. Those correlations were then adopted later by other investigators. Some studies were addressed to the simulation of desiccant matrices [14].

In both the GSCM and PGSCM the potential for mass transfer can be taken as the difference between the mass fractions of water

* Corresponding author. Department of Mechanical Engineering, High Institute of Engineering, University of Algarve, Campus da Penha, 8005-139 Faro, Portugal. Tel.: +351 289 800100; fax: +351 289 888405.

E-mail address: cruivo@ualg.pt (C.R. Ruivo).

Nomenclature		Greek symbols	
a_s	specific transfer area of the matrix, $m^2 m^{-3}$	χ_{des}	correction of the mass transfer coefficient γ_{des} predicted by the correlation, taking into account the influence of the operating conditions
a_0, b_0, c_0	y-intercepts of linear regressions: Eqs. (17)–(19), respectively	Δt	time step, s
a_1, b_1, c_1	slopes of linear regressions: Eqs. (17)–(19), respectively	δX_ℓ	error indicator
H_p	half-thickness of the desiccant layer, m	ϵ_m	matrix porosity
K_m	mass transfer coefficient in the LDFM (linear driving force model), s^{-1}	$\varphi_{v,f}$	water vapour mass fraction in the airflow, $kg kg^{-1}$
\bar{K}_m	average mass transfer coefficient in the LDFM, s^{-1}	$\varphi_{v,p}$	average water vapour mass fraction in the wall, $kg kg^{-1}$
\hat{K}_m	mass transfer coefficient in the LDFM that minimizes the error indicator, s^{-1}	γ_{des}	correlation for estimating the mass transfer coefficient in the desorption cases D2 as a function of H_p , s^{-1}
j_m	convective mass flux, $kg s^{-1} m^{-2}$	$\rho_{d,p}^*$	apparent density of the dry desiccant, $kg m^{-3}$
T_f	airflow temperature, $^\circ C$	ρ_f	density of the airflow, $kg m^{-3}$
T_p	average temperature of the wall, $^\circ C$	$\rho_{d,p}^*$	average apparent density of the dry desiccant, $kg m^{-3}$
T_0	initial temperature in the porous medium, $^\circ C$	k_m	mass transfer coefficient in the PGSCM (pseudo-gas-side-controlled-model) s^{-1}
t	time, s	\bar{k}_m	average mass transfer coefficient in the PGSCM, s^{-1}
t_f	(final) instant of the sorption processes when the variation of the adsorbed water content achieves 99% of the maximum, s^{-1}	\hat{k}_m	mass transfer coefficient in the PGSCM that minimizes the error indicator, s^{-1}
U_m	pseudo mass transfer coefficient, $m s^{-1}$	Superscripts	
$w_{v,f}$	water vapour content of the airflow (d.b.), $kg kg^{-1}$	*	apparent density; adsorption-desorption averaged value of the mass transfer coefficient
X_ℓ	adsorbed water content (d.b.), $kg kg^{-1}$	Subscripts	
$X_{\ell,p}$	average adsorbed water content (d.b.), $kg kg^{-1}$	0	initial condition
$X_{\ell,eq}$	average adsorbed water content at equilibrium (d.b.), $kg kg^{-1}$	ads	relative to the adsorption phenomenon
$X_{\ell,f}$	final adsorbed water content in the porous medium (at instant t_f), $kg kg^{-1}$	corr	value predicted by a correlation
$X_{\ell,0}$	initial adsorbed water content in the porous medium, $kg kg^{-1}$	d	dry desiccant
y	spatial coordinate, m	des	relative to the desorption phenomenon or process
		eq	equilibrium conditions
		f	airflow; final
		m	mass
		p	porous medium

vapour at the solid side and at the gas side domains. Another simplified approach, known as the LDFM (linear driving force model), takes as transfer potential the difference between the adsorbed water content at solid side domain and the equilibrium adsorbed water content dictated by the air state on the gas side domain. This approach is simple and physically consistent [15,16], but also requires the knowledge of a mass transfer coefficient. Despite the great advantage of its simplicity, the LDFM has been used in just few works for modelling desiccant matrices [17–19].

The range of validity for the application of such simplified models can be investigated by using calibrated GSSCM or experimental techniques. A single-blow test procedure to evaluate those overall transfer coefficients in compact heat and mass transfer exchangers, aimed at being used with the PGSCM, is presented in Ref. [20]. Ruivo et al. [21] investigated numerically the validity of this simple approach with constant transfer coefficients, and concluded that it is feasible only for half-thickness of silica layer below 0.1 mm, approximately.

Like the pseudo-gas-side-controlled model, the use of the simple LDFM approach avoids the need of solving the governing differential equation in the solid side domain. However, the use of a constant mass transfer coefficient seems to be questionable when simulating the coupled heat and mass transfer in desiccant matrices.

Chauveau et al. [22] derived values of the mass transfer coefficient of the LDFM for simulating the adsorption of volatile organic compounds on activated carbons. The comparison between

experimental and predicted breakthrough fronts by the LDFM for methyl acetate and vinyl chloride was considered globally good.

Sheng and Costa [16] investigated the LDF (linear driving force) approximations to square-wave, sinusoidal and triangular cyclic steady perturbations on a spherical particle and the mass transfer coefficients thus obtained depend on the type of perturbation and on the cycle time. Choong and Scott [23] investigated also the stepwise cyclic mass transfer problem and calculated the time evolutions of the mass transfer coefficient during each half-cycle as a function of mass transfer Biot number. The mass transfer coefficient evolution is almost constant only when the internal mass resistance is relatively low. Rodrigues and Dias [24] refer that the mass transfer coefficient for the LDFM depends on the cycle period and show that the linear driving force approximation used in the analysis of cyclic adsorptive processes can be easily understood on the basis of results from frequency response system dynamics.

A new closed-form relationship, based on the LDFM, for predicting the adsorbate uptake rate during the adsorption/desorption processes in ACS (adsorption cooling systems) was developed [25]. The proposed relationship is applicable to the entire range of mass transfer Biot numbers and is as convenient-to-use as the linear driving force model.

Following a previous research on the simplified simulation of desiccant matrices by the linear driving force and the pseudo gas side-controlled models [26], empirical correlations for predicting the values of the constant mass transfer coefficient are determined and tested in the present work. The investigation is centred on the

Download English Version:

<https://daneshyari.com/en/article/8076891>

Download Persian Version:

<https://daneshyari.com/article/8076891>

[Daneshyari.com](https://daneshyari.com)