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Exponential correlations to predict the dependence of effectiveness parameters of a desiccant wheel on the airflow rates and on the rotation speed

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HIGHLIGHTS

► Investigation of a simplified simulation method based on the effectiveness concept.
► Studies involving variable airflow rates and rotation speed.
► New correlations proposed and tested.
► Good accuracy of the results.

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ABSTRACT

The desiccant wheel is a key component in solid-desiccant systems. At present, it is difficult to access a component model that can represent the behaviour of commercialised desiccant wheels with enough accuracy.

In this work, it is investigated the feasibility of a simplified simulation method based on the effectiveness concept. The pair of independent effectiveness parameters based on the changes of enthalpy and of the ratio of the partial to the saturation vapour pressures is adopted instead of the combined potentials.

Extensive parametric studies are conducted using the software of a manufacturer and a detailed numerical model to generate reference data. Exponential-type correlations are investigated to account for the influences of the process and regeneration airflow rates, balanced or unbalanced, and of the rotation speed on the effectiveness parameters. The predicted results provided by the correlations are compared with reference data, separately or combined with the recently developed interpolation approach that accounts for the influence of variable inlet states of both airflows. Cases are identified with an acceptable agreement demonstrating that the correlations can be used with great advantages in the generalised dynamic analysis of systems integrating a desiccant wheel.

1. Introduction

The air-conditioning systems and, particularly, the solid-desiccant dehumidification systems operate at full load only a small fraction of the running time. The simulation of such systems incorporating desiccant wheels is a task that engineers have to manage with increasing frequency nowadays, for sizing purposes and to evaluate the effect of different control strategies on the performance and on the energy efficiency. This is recognised by Griffiths [1], who predicted that annual energy savings can range from less than 10% to over 60% when the desiccant dehumidifier operates under an optimised control strategy instead of the standard control arrangement. However this author did not present the approach used, neither any parametric study demonstrating the effect of the control strategies based on variable airflow rates and rotational speed of the desiccant wheel.

The main design parameters and their effect on the performance of desiccant systems were investigated by Panaras et al. [2], who referred that one of the major constraints to the dissemination of

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Nomenclature

a_ϕ, b_ϕ, c_ϕ	coefficients of the quadratic regression
EIPIS	Effectiveness Interpolation Procedure for the effect of the Inlet States
$F1$, $F2$	characteristic potentials
h	specific enthalpy of moist air (J kg^{-1})
k_ϕ	coefficient used in Ref. [12] ($k_\phi = b_\phi \Omega_H$)
T	temperature (°C)
w_v	water-vapour content of moist air (kg kg^{-1} d.b.)
z_ϕ	auxiliary variable

Greek symbols

β_τ	non dimensional duration of adsorption/desorption cycle
β_Ω	non dimensional specific airflow rate
δT^+	normalised error in predicting the temperature increase of the process air
ΔT	temperature increase of the process air (°C)
ΔT_1^+	normalised temperature increase of the process air predicted by the numerical model or by the manufacturer software
ΔT_1^{*+}	normalised temperature increase of the process air predicted by the effectiveness method
δw_v^+	normalised error in predicting the decrease of the water-vapour content in the process air
Δw_v	water-vapour content decrease of the process air (kg kg^{-1} d.b.)
$\Delta w_{v,1}^+$	normalised decrease of the water-vapour content in the process air predicted by the numerical model or by the manufacturer software
$\Delta w_{v,1}^{*+}$	normalised decrease of the water-vapour content in the process air predicted by the effectiveness method
ϕ	generic variable
Φ	generic variable
η	effectiveness parameter
τ_{cyc}	duration of adsorption/desorption cycle (s)
Ω	specific mass airflow rate (the ratio between the inlet mass velocity and the channel length) (kg s^{-1} m^{-3})
ψ	ratio of the partial vapour pressure to the saturation vapour pressure

Subscripts

1in, 1out	process inlet and outlet states
2in, 2out	regeneration inlet and outlet states
L, M, H	low, medium and high values
ref	reference value

Superscripts

*	variable predicted according to the effectiveness method
+	dimensionless variable

desiccant air-conditioning systems is the lack of knowledge on the design of such systems.

The simulation of a solar-assisted desiccant cooling system was performed by Fong et al. [3] using the simulation platform TRNSYS. Among a variety of component models, the desiccant wheel was treated as a special component. It was simulated by the effectiveness method assuming constant values of the effectiveness parameters. The airflows were assumed to be constant and the rotation speed was not indicated. Another study dealing with the dynamic simulation of a solar hybrid desiccant cooling system was carried out by Fong et al. [4]. The simulation platform TRNSYS and a component library were applied to all the components of the system, except for the desiccant wheel, which was simulated by a physical model. The study was focused on comparing the performances of the desiccant system and of a conventional air-conditioning system, without exploring optimised operating control strategies.

Angrisani et al. [5] presented the analysis of a desiccant wheel performance. Regarding the investigation about the effectiveness parameters, only the dehumidification effectiveness was considered. The results showed that the effectiveness parameter, determined either from the experimental data or from manufacturer data, evidence a significant dependence on the inlet states of both airflows.

Different effectiveness parameters were investigated by using experimental data [6]. The results showed that the dependence of those parameters on the airflows inlet conditions and on the rotation speed is important.

Experimental investigations on desiccant wheels were also developed in two different laboratories to evaluate performance trends [7]. Several effectiveness parameters were defined, however only the dehumidification efficiency dependence on the inlet states and on the rotation speed was investigated. The authors concluded that changes in the volume airflows ratio or in the regeneration/ambient air conditions almost do not influence the optimum rotation speed value. They stated that the best rotation speed of the desiccant wheels can be seen as an independent parameter. The presented results show a strong dependence of the dehumidification efficiency on the inlet state of the process airflow for one of the tested wheels. These authors referred that the rotation speed could be used as a control strategy, but by using variable airflow rate, the control of the system would be much more energy efficient.

A control strategy for the operation of a desiccant air-conditioning system was investigated by Panaras et al. [8]. They referred that: (*i*) the regeneration temperature is a critical operating parameter and can accordingly be controlled and (*ii*) the rotation speed is usually proposed by the manufacturers and can be excluded as a controlled parameter for simplicity reasons.

It comes out obvious the great interest of developing an easy and quick methodology to simulate desiccant wheels, avoiding cumbersome work and excessive time consumption normally required by most numerical models. The component simulation model must provide a good match with the performance of a particular desiccant wheel and must be supported by experimental data or by manufacturers' data [9].

Based on experimental data, Ruivo et al. [10] and Angrisani et al. [11] concluded that the effectiveness parameters do not change significantly when the investigated desiccant wheels operate at constant rotation speed and constant airflow rates. However, a recent work [12] demonstrated that the effectiveness method supported by constant-effectiveness values provides results with unacceptable accuracy in a significant number of cases within the expected range of operation, even in those cases with constant airflow rates and constant rotation speed of the desiccant wheel. A probable reason for the contradictory conclusions of Refs. [10] and [11] can probably be justified by the reduced number of experiments used in both studies. So, the application of the constant-effectiveness method in some published studies [3] is questionable.

A new approach of the effectiveness method was presented in Ref. [12], including: (*i*) a new pair of intuitive effectiveness parameters, (*ii*) a 2D interpolation procedure that accounts for the dependence of the effectiveness parameters on the inlet airflow conditions (EIPIS approach) and (*iii*) a simple correlation of exponential type for predicting the effectiveness parameters in cases of