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Influence of the rotation speed on the effectiveness parameters of a desiccant wheel: An assessment using experimental data and manufacturer software

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ABSTRACT

The effectiveness parameters of desiccant wheels depend on the variable operating conditions. Experimental data measured in an air handling unit equipped with a desiccant wheel and data provided by the manufacturer software are used in the present work to investigate the dependence of effectiveness parameters on the rotation speed. The air handling unit belongs to a test facility with a micro-cogeneration system. The regeneration airflow is heated up to moderate temperatures in the range 45–70 °C by using thermal energy produced by the microcogenerator and/or a boiler. The analysis of the results shows that i) the manufacturer software tends to underestimate the increase of process air temperature and to overestimate the dehumidification capability of the desiccant rotor compared to experimental data; and ii) the various investigated effectiveness parameters present different dependences on the rotation speed: monotonic dependence, a maximum value for an intermediate rotation speed, and a negligible dependence.

1. Introduction

Dynamic simulation of all equipments of an air conditioning system together with the thermal behaviour of the building spaces is required to find an optimized solution [1,2].

The lack of knowledge on the design and control of desiccant air conditioning systems is one of the barriers in the dissemination of such systems [3]. At present, it is difficult to access a component model that can predict the global behaviour of commercialized desiccant wheels with enough accuracy under variable operating conditions. The use of effectiveness method is suitable, if a proper procedure is available to take into account the dependence of the effectiveness parameters on the variable operating conditions. To this aim, experiments were conducted at the laboratory of "Università degli Studi del Sannio", which were already used in other analyses [4–10], but the considered layout was not investigated in deep by any researcher in similar test facilities.

Regarding the investigation of effectiveness parameters of a desiccant wheel, Angrisani et al. [5] analysed the pair of effectiveness parameters η_{F1} and η_{F2} proposed by Jurinak [11]. It was concluded that the effectiveness parameters do not change significantly when the airflow rates are constant and the rotation speed of desiccant wheel is fixed. This conclusion is corroborated by Ruivo et al. [12]. The use of the effectiveness method with constant effectiveness values was adopted also in other works [2,13,14]. According to more recent works [10,15–17], its validity is questionable. The conclusions of Angrisani et al. [5] and Ruivo et al. [12] can be justified by the relatively low number of adopted experiments.

Both studies of Angrisani et al. [5,7] were restricted to constant rotation speed and constant airflow rates. Some performance indices were also evaluated by Angrisani et al. [4,9]. The results showed that the dehumidification effectiveness evidences a significant dependence on operating conditions.

The investigation on the influence of the rotation speed on the performance of a desiccant wheel has been conducted in some

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Nomenclature

DEC	direct evaporative cooler
DW	desiccant wheel
$F1$, $F2$	characteristic potentials
HE	heat exchanger
MCHP	micro combined heat and power
h	specific enthalpy (J/kg)
$\dot{m}$	mass flow rate (kg/s)
N	rotation speed (rph)
p_v	partial pressure of water vapour (Pa)
p_{vs}	saturation pressure of water vapour (Pa)
t	time (s)
T	temperature (°C)
u	velocity (m s^{-1})
$\dot{V}$	volumetric airflow rate (m^3 h^{-1})
w_v	water vapour content of moist air (kg kg^{-1}d.b. or g kg^{-1} d.b.)
X_ℓ	adsorbed water content in the desiccant porous medium (kg kg^{-1})

Greek symbols

Δ	generic difference
ϕ	generic variable
η	effectiveness parameter
τ_{cyc}	duration of adsorption/desorption cycle (s)
σ	ratio of airflow rates, indicator of mass and sensible energy balance
ψ	ratio of the partial vapour pressure to the saturation vapour pressure

Subscripts

1	process air
2	regeneration air
1in, 1out	inlet and outlet states of process air
2in, 2out	inlet and outlet states of regeneration air
exp	parameter related to experimental data
h	parameter related to specific enthalpy of air
id	ideal
m	parameter related to mass
soft	parameter related to software data
T	parameter related to temperature
w	parameter related to water vapour content
Xℓ	parameter related to adsorbed water content
F1, F2	parameter related to characteristic potentials

studies [9,12,16,18–25], however few works [9,12,16,18,25] analysed the effect on effectiveness parameters and the results were not univocal: so, further research investigation is suitable.

Angrisani et al. [9] performed experimental tests on a silica gel desiccant wheel, to highlight the effect of rotational speed on dehumidification effectiveness. Furthermore, the influence of process air inlet temperature and humidity, regeneration temperature and air flow rates on the optimal rotational velocity is discussed. It was found that the velocity that optimizes the dehumidification performances varies in the range 5–10 rph, depending on operating conditions.

Ruivo et al. [12] used experimental results published in the literature on desiccant wheels for different inlet states of the process and regeneration airflows and for different rotation speeds to investigate a pair of independent effectiveness parameters, based on variations of enthalpy and of the ratio between partial vapour pressure to the saturation vapour pressure. Correlations were derived and applied for predicting purposes. A reasonable agreement with the experimental data was found.

Ruivo et al. [16] investigated the feasibility of a simplified simulation method based on the effectiveness concept. The same pair of independent effectiveness parameters as in Ref. [12] was used. Parametric studies were conducted to investigate the influences of the process and regeneration airflow rates and of the rotation speed on the effectiveness parameters. Results demonstrated that the correlations can be used with great advantages in the dynamic analysis of systems integrating a desiccant wheel.

Mandegari and Pahlavanzadeh [18] experimentally investigated desiccant wheel operation. Experimental conditions included different climates at different operating parameters, namely regeneration temperature and wheel speed. Several effectiveness parameters were used, such as thermal, regeneration, dehumidification and adiabatic effectiveness. Results showed that increasing the desiccant wheel speed, adiabatic efficiency reduced but the other efficiencies followed an ascending trend.

Ge et al. [25] developed a mathematical model for predicting the performance of a novel silica gel haloid compound desiccant wheel. The model was then adopted to analyse the effects of some main parameters on system performance, evaluated with several indicators, among which the relative moisture removal efficiency. It was found that there is an optimal rotation speed of about 12 rph to obtain maximum efficiency.

On the basis of the literature review, the authors have found that:

i) only few authors [9,12,16,18,25] published results about the influence of the rotation speed on the effectiveness parameters;
ii) most research articles use only one effectiveness parameter;
iii) the results of previous researches about the dependence of the desiccant wheel performances on the rotation speed were not univocal;
iv) only few research papers compared experimental or numerical results of a desiccant wheel with those obtained by using the manufacturer software, [4,16,26].

Therefore, further research investigations, such as those of the present work, are justified by these topics.

Moreover, the use of a feasible procedure to predict the dependence of the effectiveness parameters on the rotation speed is crucial even for constant rotation speed operation, as some component models are based on effectiveness parameters, such as the one used by *TRNSYS* software for the dynamic simulation of desiccant wheels. Furthermore, the effectiveness parameters can be used in the design phase of a desiccant-based air handling unit, for example to assess the optimal rotation speed of the desiccant rotor.

Experimental data measured in an air handling unit and data provided by the manufacturer software are considered in this paper to predict the influence of the rotation speed on the performance of a desiccant wheel. Both sources of data are used to analyse the trends of the water vapour content reduction and temperature increase of process air through the wheel, as well as the dependence of effectiveness parameters on the rotation speed. The regeneration airflow is heated up to moderate temperatures in the