Applied Thermal Engineering xxx (2013) 1–9

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

The effectiveness method to predict the behaviour of a desiccant wheel: An attempt of experimental validation

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HIGHLIGHTS

- The overall behaviour of a desiccant wheel is investigated.
- Two pairs of effectiveness parameters are considered.
- The study is supported by experimental data measured in an air handling unit.
- An attempt of validation of the effectiveness method is performed.
- A correction of the measured outlet state of the process airflow is required.

ARTICLE INFO

Article history:
Received 3 July 2013
Accepted 15 October 2013
Available online xxx

Keywords:
Desiccant wheel
Experimental data
Effectiveness method
Validation
Empirical correction

ABSTRACT

The desiccant wheel is a key component in solid-desiccant systems. At present, the analysis of the behaviour of air handling units based on desiccant wheels is a complex task. It is difficult to access a simple model that can represent the behaviour of commercialized desiccant wheels with sufficient accuracy.

Experimental data measured in an air handling unit equipped with a desiccant wheel are considered in the present work. The air handling unit belongs to a test facility with a microcogeneration system located at Università degli Studi del Sannio (in Benevento, Southern Italy). Thermal energy from the micro-cogenerator is used to heat up the regeneration airflow. An attempt of investigating the validity of the simplified effectiveness method in predicting the global behaviour of a desiccant wheel is performed. Two approaches are used with different pair of effectiveness parameters.

Only one sensor of temperature and one sensor of relative humidity were used in each measuring section of the air handling unit. This constraint is most crucial at both outlet sections of the desiccant wheel due to the strong dependence of the air state on the angular position.

An empirical correction of the measured state of the process air at the outlet of the desiccant wheel is used. The corrected data are used in the investigation of the validity of the effectiveness method by using constant values in a large set of cases where the rotation speed of the desiccant wheels and the fans are kept constant. Important deviations between the predicted and the experimental results were found in a significant number of cases, therefore there is the need of improving the method by taking into account the effect on the effectiveness parameters of varying the inlet states of both airflows.

1. Introduction

Nowadays the interest in HVAC&R systems based on desiccant wheels is widely increasing due to the possibility of using renewable energy sources with low environmental impact and high potential of fossil fuel consumption and greenhouse gas reduction.

Beccali et al. [1] presented instantaneous, daily and monthly energy performance indicators of a Solar Desiccant Evaporative Cooling system, for the cooling operation mode during five months and heating operation mode during three winter months. The system is composed of an air handling unit coupled with a radiant ceiling that provides most of the energy required to remove the sensible cooling/heating load. Flat plate collectors deliver part of

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http://dx.doi.org/10.1016/j.applthermaleng.2013.10.028

Nomenclature

a_1, b_1, c_1	parameters of Eq. (3)
a_2, b_2, c_2	parameters of Eq. (4)
D_d	diameter of the duct (m)
$F1, F2$	characteristic potentials
h	specific enthalpy (J kg^{-1})
$\dot{m}$	mass airflow rate (kg s^{-1})
p_v	partial pressure of water vapour (Pa)
p_{vs}	saturation pressure of water vapour (Pa)
RMSD	root mean square deviation
T	temperature (°C)
t	time (s)
u	airflow velocity (m s^{-1})
w_v	water vapour content of moist air (d.b.) (kg kg^{-1})

Greek symbols

α	correction factor for the outlet state of process air
χ	percentage of cases evidencing unacceptable agreement (%)
δ	maximum deviation between predicted and measured values
η	effectiveness parameter
ρ	air density (kg m^{-3})
σ	ratio of mass airflow rates
ψ	ratio p_v/p_{vs}
τ_{cyc}	sorption cycle duration (s)

Subscripts

F1, F2	parameter related with characteristic potentials
h	parameter related with enthalpy
id	ideal
max	maximum
T	parameter related with temperature
w	parameter related with water vapour content
ψ	parameter related with the ratio p_v/p_{vs}
1	related with process air
1in	inlet of process air
1out	outlet of process air
2	related with regeneration air
2in	inlet of regeneration air
2out	outlet of regeneration air

Superscripts

*	predicted parameter
**	predicted parameter after correction of the outlet state of the process air

Abbreviations

Eff-A	approach using (η_h, η_ψ)
Eff-B	approach using (η_{F1}, η_{F2})

the heat required to regenerate the desiccant wheel during the cooling mode and space heating during heating mode. Monthly results are elaborated and seasonal performance indicators such as electric and thermal COP and primary energy savings for cooling and heating operation are presented. Primary energy savings in cooling mode operation, in comparison to a conventional air handling unit, came up to nearly 50%.

Aprile et al. [2] investigated the control optimization of a solar assisted air-conditioning concept combining a desiccant and evaporative cooling system with an electrical reversible water/water heat pump. In summer, the heat pump cools the supply air stream and pre-heats the regeneration air when dehumidification is needed; in winter, the heat pump provides auxiliary heat if a minimum temperature is available in the heat storage, otherwise a backup boiler is used. The depicted system has been modelled and an extensive simulation work has been carried out to identify an optimal control strategy. According to the simulation results, the system can deliver primary air at the requested temperature and humidity while holding the overall primary energy consumption at significant low levels compared to reference system solutions, using a gas boiler and an air-condensed chiller.

Primary energy and emissions savings can also be achieved when regeneration of the desiccant wheel is performed by means of thermal wastes from cogeneration systems.

Henning et al. [3] showed the results of a simulation model, carried out to design a hybrid desiccant-based HVAC system. A microcogenerator (MCHP, Micro Combined Heat and Power) supplies electric energy to an electric heat pump and other electric devices. Waste heat recovered from the MCHP is used in summer to regenerate the desiccant wheel. Surplus of thermal energy is used to produce domestic hot water. During winter, waste heat is directly used for heating using fan-coils as well as an air handling unit. Regarding energy performance, results indicate an electricity saving greater than 30% in comparison to state-of-the-art solutions based on conventional technology.

Angrisani et al. [4] performed laboratory tests to experimentally evaluate a small scale polygeneration system based on a natural gas-fired MCHP and a desiccant-based HVAC system. Cogenerated thermal energy is used for the desiccant wheel regeneration, while electric energy for auxiliaries, chiller and external units. The main results state the increase of the COP of the chiller in desiccant-based HVAC systems. The paper identifies the operating conditions (outdoor and supply air thermal-hygrometric conditions, electric grid efficiency and partial load operation of the MCHP) which guarantee significant primary energy savings (up to around 30%) and CO_2 equivalent emission reductions (up to around 40%) of the polygeneration system compared to a conventional HVAC system.

However, the dynamic energy analysis of air handling units based on desiccant wheels remains difficult. The use of simple methods to describe the global behaviour of a desiccant wheel, such as the effectiveness method, is an interesting approach, but it requires the previous knowledge of the dependence of the effectiveness parameters on the operating conditions.

Several test facilities integrating a desiccant wheel are operated in Germany [5], Italy [1–4,6–11] and Turkey [12]. Some attempts regarding the validation of simulation models of desiccant wheels have been done by comparing experimental data with the predicted results. This kind of studies is not easy to be carried out with high accuracy in real systems, mainly due to the difficulties in measuring each outlet state of the airflow exiting the desiccant wheel with only one sensor of temperature and one sensor of humidity. Moreover, very few works indicate mass and energy imbalance errors or the whole set of data that would enable their calculation. The exhaustive experimental research in lab conditions [13] showed significant mass and energy imbalances between the regeneration and the process air streams crossing a desiccant wheel.

In most experimental researches the process airflow rate, the inlet state of process air, the inlet state of regeneration air and the outlet state of process air are measured only in one point of each air stream.

Please cite this article in press as: C.R. Ruivo, G. Angrisani, The effectiveness method to predict the behaviour of a desiccant wheel: An attempt of experimental validation, Applied Thermal Engineering (2013), http://dx.doi.org/10.1016/j.applthermaleng.2013.10.028