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First and second order simplified models for the performance evaluation of low temperature activated desiccant wheels

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ABSTRACT

Hybrid systems with a desiccant wheel, DW, are an alternative to heating, ventilation and air conditioning, HVAC, commonly used systems for dehumidification and humidity control in rooms with high latent loads.

Currently, the experimental methodology used to study the behaviour of a DW requires a high number of tests. The aim of this study is to obtain a DW empirical model which accurately represents the behaviour of a DW activated at low temperature, values below 60 °C, by conducting a reduced number of experimental tests. For this study, the statistical Design of Experiments technique, DOE, is used.

The proposed models can be used to predict the influence of the inlet process air and inlet regeneration air, on the air process outlet temperature and humidity ratio. The accuracy obtained of the experimental models is more than acceptable, with R^2 values greater than 97.4% for outlet temperature and 95.1% for outlet humidity ratio. The first order model was considered to be a good option due to the balance between accuracy and the low number of experimental tests required. However, the second order model allowed a deeper understanding of the behaviour of the air outlet conditions in the DW.

1. Introduction

The control of the water vapour content in the air is necessary to maintain the required indoor conditions in buildings and certain industrial processes. The external and internal water vapour sources can produce significant latent loads indoors, so it is necessary to use a system to reduce and control the humidity ratio. Restaurants, indoor swimming pools or spas are examples of premises with high latent loads. There are two techniques of removing moisture from air under ambient pressure conditions: cooling-based and desiccant dehumidification. Cooling-based systems reduce the air temperature to condense its moisture. Desiccant dehumidifier systems differ from cooling-based systems in the way of removing moisture from the air. Desiccant dehumidifier systems adsorb water vapour from the air reaching an area of low vapour pressure at the surface of the desiccant [1]. Furthermore, desiccants can adsorb substances other than water vapour removing in this way air contaminants and improving indoor air quality [2].

Desiccant dehumidifiers can be combined with cooling systems, solar systems or waste heat systems. These combined systems are referred to as hybrid systems. Many studies about hybrid systems with desiccant wheels, DW, have been carried out [3,4]. Energy savings were obtained only when the DW was regenerated using waste heat from another process. Some authors studied the behaviour of hybrid systems using waste energy to regenerate the DW, obtaining significant economic savings [5,6]. However, in some cases waste heat energy is not available or the corresponding temperature level is not adequate. In recent years, some studies have analysed the use of solar energy to regenerate a DW [7,8]. However, these systems require an auxiliary source of heat. The solar thermal system also involves a significant increase in the overall economic cost of the system.

A DW integrated into a hybrid system can be operated at low regeneration temperatures. Hybrid systems with air regeneration temperatures of 55 °C and 46 °C [6,9] has been analysed, showing acceptable desiccant capacity. Values below 60 °C were considered low regeneration temperatures in this study, which correspond to the outlet air temperature in an air-cooled condenser of a refrigeration vapour compression system.

Two low temperature activated systems with DW are shown in Fig. 1. The first system is composed of a solar thermal heating system and a low temperature boiler that supplies hot water to the

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Nomenclature

a	estimated parameter
CC	cooling coil
DOE	design of experiments
DW	desiccant wheel
EA	exhaust air
F	centrifugal fan
FC	flow conditioner
EH	electric heater
HC	heating coil
HR	relative humidity [%]
k	number of parameters
MA	mixed air
MB	mixing box
N	number of experimental test
OA	outdoor air
PT	pitot tube
RA	recirculated air
SH	steam humidifier
T	temperature [°C]
X	input variable
$\hat{Y}$	estimated output value

Greek letters

ΔP	pressure difference [Pa]
ω	humidity ratio [g kg^{-1}]
Ω	specific mass airflow rate [kg s^{-1} m^{-3}]

Subscripts

d	dew point
i	inlet
o	outlet
p	process
r	regeneration

heating coil, HC. The HC heats up the regeneration air upstream of the DW, see Fig. 1a. Fig. 1b shows a low regeneration temperature hybrid system composed of a refrigeration vapour compression system and a DW. This hybrid system allows the regeneration of the DW using the heat from the condenser. In addition, the evaporator cooling effect is used to cool and dehumidify the process air.

A numerical model of a DW is very convenient for parametric optimization analysis of hybrid systems. Different experimental and numerical research works have been carried out in order to study the operational parameters that influence the overall performance of the DW. Some researchers developed detailed mathematical models, considering the heat and mass transfer in the DW [10–14]. These models are not easy to implement and require long computation time. Moreover, some physical characteristics and specific materials of the DW are not normally available.

Another mathematical modelling approach is based on simplified models of the DW which requires less computation time. A widely used simplified method to study the behaviour of the DW is one that is based on the effectiveness concept. It is also referred to as the linear analogy method [15] and takes into account two independent potential variables [16]. The effectiveness method based on constant values has been used previously in several studies [17,18]. These simplified mathematical models are easy to implement, but many experimental tests are required to fit the effectiveness parameters. Important errors can be introduced when constant values of the effectiveness parameters are assumed in the effectiveness method [19]. Simplified mathematical models can be improved by using variable parameters of effectiveness. However, the accuracy of simplified models is reduced when variable effectiveness parameters are obtained by means of interpolation [19].

Other authors have developed simplified models based on correlations to study the behaviour of the DW [20–22]. The advantage of this approach is that the model fits any physical characteristics and specific materials of one specific DW. However, the obtained simplified model is not valid for any other DW.

A methodology widely used in engineering to obtain a regression model is the design of experiments, DOE [23,24]. DOE is a technique used for exploring new processes, gaining knowledge of the existing processes and optimizing these processes to achieve high performance [25].

The objective of this work is to obtain a DW empirical model which accurately represents the behaviour of a DW activated at low temperature by conducting a reduced number of experimental tests. The methodology used is based on the statistical technique of DOE. The secondary aim of this work is to identify the most influential factors in the behaviour of a DW activated at low regeneration temperatures.

2. Methodology

2.1. Experimental setup

In order to analyse DW performance under different working conditions, a test facility has been designed. A schematic diagram of the DW experimental setup is shown in Fig. 2. Process and regeneration air streams flow across the DW in counter-current arrangement. Inlet process air and regeneration air temperature and humidity are carefully controlled by means of a cooling coil (CC), heating coil (HC), electric heater (EH), and a steam humidifier (SH), located, for each air stream, upstream of the DW [26,27].

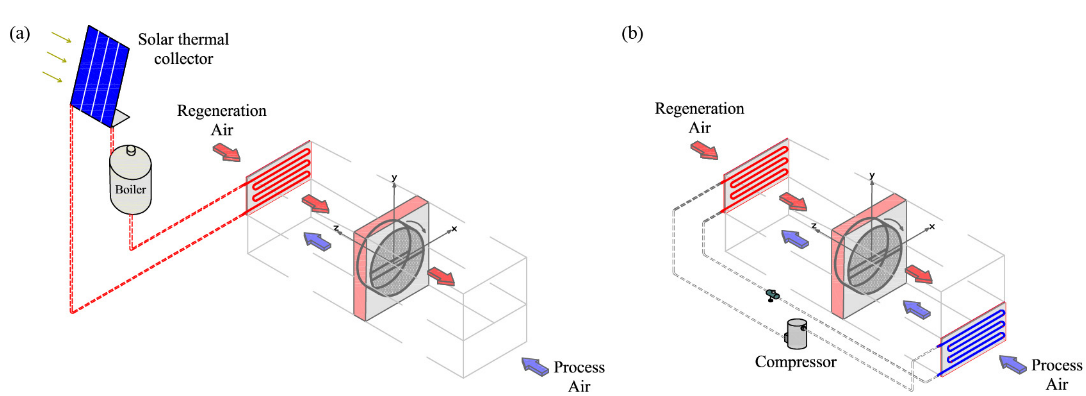

Fig. 1. Schematic of hybrid low temperature activated systems (a) solar thermal system with desiccant wheel; (b) refrigeration system with desiccant wheel.