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Parametric studies of silica gel and molecular sieve desiccant wheels: Experimental and modeling approaches

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ABSTRACT

In this paper, six desiccant wheels with diameters of 44 cm, 55 cm, and 77 cm using silica gel and molecular sieve desiccants under different conditions were experimentally evaluated. Process outlet temperature, dehumidification effectiveness, moisture removal capacity, sensible energy ratio, and regeneration specific heat input were examined as functions of regeneration temperature, volume flow rate and, rotation speed at different wheel diameters and materials. The results show that there are optimum operating conditions for each wheel, characterized by a specific diameter and desiccant material. To present a robust, reliable, accurate, and fast model based on the experimental data, a hybrid approach-adaptive neuro fuzzy inference system (Hybrid-ANFIS) is developed to precisely calculate the parameters mentioned above. The outcomes of the developed model are further compared with a genetic algorithm-least square support vector machine approach (GA-LSSVM) to identify the capability of the suggested Hybrid-ANFIS model. It was found that the predictability of the suggested Hybrid-ANFIS model outperforms the GA-LSSVM, confirming that the Hybrid-ANFIS technique represents a simple tool that can be easily implemented in dynamic simulation tools for the optimization and control of desiccant cooling systems.

1. Introduction

1.1. Desiccant cooling systems

Compression air conditioning systems are used in many countries for several months of year to cool buildings. These systems require high grade electric energy for the processing of air sensible and latent energy content [1]. Furthermore, most of them need to lower the air temperature below its dew point to accomplish dehumidification. In recent years, many industries have sought innovative technologies to reduce energy consumption. One of the technologies discussed around the world is the desiccant cooling system (DCS). A DCS is an appropriate replacement for conventional systems [2]. It can be particularly useful in humid climates or when very low dew point temperatures need to be provided. These systems help to reduce the hydrofluorocarbon level in the environment because of their ability to restrict the use of conventional refrigerants. A DCS can be considered as an environmental protection technique for buildings [3,4]. In addition, energy and environmental benefits are maximized when these systems interact with renewable energy sources such as solar energy [5].

Desiccant wheels (DWs) that are coated with a desiccant material are one of the most important components in the type of systems used to remove latent load from room air. Desiccants can take on a liquid or solid form and have long been recognized as components of commercial heating, ventilation and air conditioning (HVAC) systems. The choice of desiccants is based on the following distinctive features: ability to hold considerable amounts of water, reactivation ability, and cost effectiveness.

Different materials have been proposed for use as desiccants in recent years. One is synthetically produced silica gel, which is a fine pored solid silicic acid consisting of 99% silicon dioxide. Silica gel also has its own distinctive features. For example, it can withstand temperatures up to 400 °C and can absorb up to 40% of its dry weight in water. Silica gel does not change physically or chemically during the adsorption process. This is because it is inert, non-toxic, stable, and resistant to most chemicals. Another material suggested for use as a desiccant is a molecular sieve or synthetic zeolite, which is a crystalline material of aluminium silicate and can separate molecules of different sizes by sorption. Therefore, small molecules are adsorbed while large molecules pass through the wheel. Molecular sieve materials are appropriate for special uses that need dehumidification of air to very low levels of humidity and extremely low dew points of about −40 to

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Nomenclature

Act	actual
$\overline{A_i}$	average of the actual data
ANFIS	adaptive neuro fuzzy inference system
ANN	artificial neural network
C_p	specific heat of air (kJ/kg K)
D	diameter (cm)
DCS	desiccant cooling system
DW	desiccant wheel
Exp	experimental
GA	genetic algorithm
HVAC	heating, ventilation and air-conditioning
LSSVM	least square support vector machine
LT3	molecular sieve
$\dot{m}$	mass flow rate (kg/h)
MAE	mean absolute error
MF	membership functions
MRC	moisture removal capacity (kg/h)
MSE	mean square error
Pre	predicted
R^2	determination coefficient
RPH	revolution per hour (rev/h)
RSHI	regeneration specific heat input (kJ/g)
SER	sensible energy ratio (dimensionless)
T	temperature (°C)
$\dot{V}$	volumetric flow rate (m^3/h)
WSG	silica gel
Z	data

Greek symbols

η	effectiveness (dimensionless)
μ	membership function
ρ	air density (kg/m^3)
ω	air humidity ratio (g/kg)
φ	Rotation speed (RPH)
Δh	enthalpy change of process air (kJ/kg)
Δω	moisture removed (g/kg)

Subscripts

a	actual
deh	dehumidification
max	maximum
min	minimum
n	normalized
1	process inlet
1′	outdoor
2	process outlet
3	regeneration

− 60 °C [6].

1.2. Literature review

A great deal of research has focused on DWs. Jia et al. [7] evaluated experimentally the performance of two honeycombed desiccant wheels, a conventional one treated with silica gel and a new one fabricated with a new kind of composite desiccant material. Enteria et al. [8] assessed a 30 cm diameter silica gel DW at regeneration temperatures in the range 60, 70, and 80 °C. In Panaras et al. [9], the validation of a silica gel 63 cm diameter DW model was obtained using experimental data taken in a test facility, and a satisfactory comparison between experimental results and manufacturer data was performed. White et al. [10] studied two materials, zeolite and a superabsorbent polymer, and compared them with silica gel. Eicker et al. [6] investigated several commercially available DWs, and determined the best rotational speeds for each of them. Angrisani et al. [11] evaluated different performance parameters as a function of the regeneration temperature, the inlet process air humidity ratio and temperature, and the ratio between the regeneration and process air flow rates. This was done for both the fixed regeneration temperature case and the fixed regeneration thermal power case. Angrisani et al. [12] performed other experimental tests on a silica gel DW with a 70 cm diameter at low regeneration temperature to highlight the effect of rotational speed on performance parameters. Yamaguchi and Saito [13] developed and validated a mathematical model of a silica gel DW by comparison to experimental results. Sheng et al. [14] evaluated the performance of a DW and obtained useful data for practical application. The combined influences of multiple variables including regeneration temperature, outdoor air temperature and humidity ratio, and the ratio between regeneration and process air flow rates, on the performance of DW were investigated based on several indices. An experimental investigation on thin polymer DW performance was carried out by Cao et al. [15]. They explained how operating variables like process air inlet temperature and humidity, regeneration temperature, and DW thickness could affect the performance of a polymer DW. Zendehboudi and Esmaeili [3] experimentally evaluated the effect of supply and regeneration section area ratio on the performance of DWs in hot and humid climates for both silica gel and a molecular sieve considering 1:1, 1:2, and 1:3 splits.

The DW performance determines the size and cost of the whole system. A good DW model is crucial for optimizing the design and operation of the device. Researchers primarily use empirical correlations and theoretical analysis models for evaluating DW performance. Because of the high number of influential parameters on DWs and the complex interrelations among them, the theoretical and empirical models may not be the best choices for such problems as accurate estimation is critical. Empirical correlations have low performance and require experimental data to identify the parameters used in the models because of the use of algebraic equations, which need to be updated if new available data differs from the original data. Furthermore, literature review confirms that theoretical analysis models are very complex and require long computation times. Additionally, assumptions are made which can further complicate the problem and result in estimations errors.

Nowadays, scholars pay more attention to the application of modern computational techniques for problem solving and determining optimal values. Introduction of artificial intelligence techniques for intelligent control and performance prediction of different systems is a good option that can be regarded as a superior alternative to conventional models. In particular, intelligent models provide the capability to model complex and difficult problems, such as high precision DWs. Computational time and cost for designing the required equipment can also be reduced. Different attempts have been made in the literature to describe the applicability of artificial neural algorithms to DW performance prediction. Cejudo et al. [16] studied the performance of an artificial neural network (ANN) and physical models for DW to predict the process outlet humidity and temperature, and regeneration outlet humidity and temperature. Their results indicated that the ANN approach, by generating good predictions, showed better performance than the physical model and was therefore introduced as a useful technique. Parmar and Hindoliya [17] employed another ANN approach to estimate the specific humidity and temperature at the outlet of a DW. In this investigation, the authors used experimental data to develop the proposed model and applied mean square error (MSE) to