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Implementation of GA-LSSVM modelling approach for estimating the performance of solid desiccant wheels

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ABSTRACT

Substituting conventional air conditioning systems for cooling with solid desiccant cooling systems (SDCSs) appears to be an interesting alternative for both energy saving and better environment and indoor air quality. Because desiccant wheel (DW) is one of the most important components of SDCSs, the precise prediction of its parameters is vital in the overall performance of the systems. The aim of this investigation is to offer an accurate, robust, and fast modelling approach for the prediction of various parameters of DWs. In this work, a novel hybrid model based on least squares support vector machine (LSSVM) and genetic algorithm (GA) is developed to predict accurately process outlet temperature and humidity ($T_{pro,out}$ and $\omega_{pro,out}$), regeneration outlet temperature and humidity ($T_{reg,out}$ and $\omega_{reg,out}$), dehumidification effectiveness (η_{deh}), moisture removal capacity (MRC), and sensible energy ratio (SER) for both Silica Gel (WSG) and Molecular Sieve (LT3) materials considering different supply/regeneration section area ratios. The capability of the model was evaluated through three different statistical error tests. The results revealed that integration of LSSVM and GA is a favorable technique for predicting the DWs with a mean average error (MAE) less than 0.23, determination coefficient (R^2) greater than 0.994, and mean squared error (MSE) less than 0.072.

1. Introduction

Despite the ever-increasing demand for air conditioning systems for a better condition of life, the current conventional vapor-compression has many side effects such as consuming high levels of electricity and emission of hydrofluorocarbon (HFC) in the environment by the usage of conventional refrigerant [1–3]. Thus, during the last decades, heating, ventilation and air conditioning (HVAC) designers have decided to develop and introduce new alternative devices for conventional air conditioning systems due to the increasing concerns for indoor air quality, environment, and energy sources [4,5].

Solid desiccant cooling system (SDCS), which is based upon the integration of both evaporative cooling and dehumidification, can be a high promising system and an interesting alternative for cooling. Among the advantages of SDCS are that it can control sensible and latent loads separately, produce no HFC, and lower energy consumption when using renewable energy [6]. The first idea about SDCS was proposed in 1955 by Penington and, ever since different researchers have tried to modify the cycle to achieve optimum condition [7].

The performance of desiccant wheel (DW), coated with a desiccant material to absorb the moisture of the air, significantly controls the system size, capacity, and cost [8]. The wheel is divided into two parts, namely process and regeneration. In process air side, air goes to the DW to remove the latent load while in regeneration side heat transfers from the heater to air. Consequently, as shown in Fig. 1, hot air takes the humidity of the DW and releases it to ambient air as exhaust air, simultaneously. In this case, different operating variables and design parameters such as rotational speed and proportion of wheel area have a direct influence on the performance parameters, i.e., sensible energy ratio (SER), moisture removal capacity (MRC), and dehumidification effectiveness (η_{deh}), which are among the interests of manufacturers and designers.

Several experimental and numerical research works were conducted to investigate the performance of DWs in different conditions. Nia et al. [9] proposed a model and simulated the combined heat and mass transfer process that occurs in a solid desiccant wheel (SDW). They performed the simulation process using MATLAB Simulink. The solutions of the simulation at different conditions used in air dehumidifiers have also been investigated. The modelling solutions are used to develop simple correlations for the outlet air conditions of humidity and air temperature through the wheel as a function of physical measurable input variables.

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Nomenclature

Acronyms
- ANN — artificial neural network
- DCOP — dehumidification coefficient of performance
- DW — desiccant wheel
- GA — genetic algorithm
- HFC — hydrofluorocarbon
- HVAC — heating, ventilation and air conditioning
- LSSVM — least squares support vector machine
- MAE — mean absolute error
- MRC — moisture removal capacity
- MSE — mean square error
- RBF — radial basis function
- RPH — revolution per hour
- SDCS — solid desiccant cooling system
- SDW — solid desiccant wheel
- SER — sensible energy ratio
- SVM — support vector machine

Symbols
- b — bias
- C_p — specific heat of air
- e — desired error
- $K(\chi, \chi_i)$ — kernel function
- ℓ — Lagrangian function
- LT3 — Molecular Sieve
- n — number of data points
- R^2 — coefficient of determination
- T — temperature
- $\dot{V}$ — volumetric flow rate
- w — weight vector
- WSG — Silica Gel
- $\bar{y}$ — average of data

Greek symbols
- η — effectiveness
- φ — feature map
- α — Lagrange multipliers
- Υ — regularization parameter
- χ — input
- y — target
- σ^2 — squared variance of the Gaussian function
- ρ — air density
- ω — humidity ratio

Subscripts
- deh — dehumidification
- i — ith data
- in — inlet
- out — outlet
- pro — process
- reg — regeneration

Superscripts
- act — actual
- pre — predicted
- T — transpose

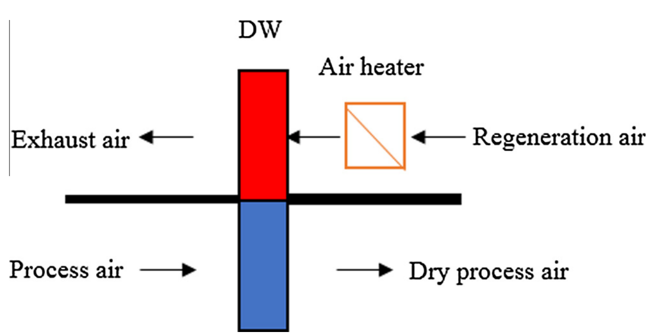

Fig. 1. A schematic of the DW.

A mathematical model for predicting the performance of novel Silica Gel haloid compound DW was proposed by Ge et al. [8]. In this paper, both gas side resistance and solid side resistance were considered; consequently, a better agreement was found compared with experimental data. Additionally, Ruivo et al. [10] used experimental results published in the literature on DWs for different inlet states of the process and regeneration air flows and for different rotational speeds. Then, they investigated a pair of independent effectiveness parameters, based on variations of enthalpy and of the ratio between partial vapor pressure to the saturation vapor pressure. Finally, they derived correlations and applied them for predicting purposes. Angrisani has done various experimental tests in the laboratory of "Università degli Studi del Sannio". In [11], this researcher defined three parameters including dehumidification coefficient of performance (DCOP), SER, and η_{deh} and experimentally evaluated the influence of different operating variables such as rotational speed, process air inlet temperature and humidity, regeneration temperature and air flow rates. The performance of DW in a running HTHP&DW system was described by means of experimental investigation and regression analysis in the work conducted by Sheng et al. [12]. Four regression correlations among the performance parameters, i.e. MRC, η_{deh}, SER, and, DCOP and different variables were presented. The results showed that the coefficient of determination (R^2) was grater than 0.85 for all cases. Further, the highest average and maximum differences were 3.5% and 7.63% for η_{deh} and DCOP, respectively. Antonellis et al. [13] attempted to predict DW outlet conditions based upon experimental data and suggested that the obtained correlations are able to determine process temperature and humidity ratio differences within ±10% in 82.1% and 98.2% of cases, respectively.

Artificial intelligence methods have been implemented in various fields of engineering as a better decision and plan can be obtained for the future by accurate forecasting. These type of models are able to solve nonlinear problems which are fairly tidies to be solved by numerical approaches. A few investigations have been conducted using the artificial neural network (ANN) to predict the performance of DWs. In 2002, physical and neural network models were developed for SDW by Cejudo et al. [14]. The authors used mean absolute error (MAE) and reported its as 1, 0.6, 1.3, 0.7 for process outlet humidity and temperature, regeneration outlet humidity and temperature, respectively, for testing data. The results of this work showed that the ANN models are highly capable of simulating wheel performance. Parmara and Hindoliya [15] also developed another ANN model to forecast the specific humidity and temperature at the outlet of DW. They used experimental data to develop the proposed model and applied mean square error (MSE) to evaluate the model against experimental