Energy 103 (2016) 618–629

Contents lists available at ScienceDirect

Energy

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

Performance prediction of solid desiccant – Vapor compression hybrid air-conditioning system using artificial neural network

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A R T I C L E I N F O

Article history:
Received 18 October 2015
Received in revised form
18 February 2016
Accepted 4 March 2016
Available online 28 March 2016

Keywords:
ANN
COP
Desiccant cooling
Hybrid system
Regeneration

A B S T R A C T

In the present study, ANN (artificial neural network) model for a solid desiccant – vapor compression hybrid air-conditioning system is developed to predict the cooling capacity, power input and COP (coefficient of performance) of the system. This paper also describes the experimental test set up for collecting the required experimental test data. The experimental measurements are taken at steady state conditions while varying the input parameters like air stream flow rates and regeneration temperature. Most of the experimental test data (80%) are used for training the ANN model while remaining (20%) are used for the testing of ANN model. The outputs predicted from the ANN model have a high coefficient of correlation ($R > 0.988$) in predicting the system performance. The results show that the ANN model can be applied successfully and can provide high accuracy and reliability for predicting the performance of the hybrid desiccant cooling systems.

1. Introduction

Integration of the desiccant dehumidification system with traditional VCR (vapor compression refrigeration) air-conditioning system results in hybrid cooling system which efficiently meets both the sensible and latent cooling loads by handling them separately. VCR system operates at higher evaporator temperature requires no post heating, resulting in higher performance of the system. The desiccant cooling systems are very good at providing comfort cooling by reducing the humidity ratio of air. Moreover, hybrid desiccant cooling systems limit the use of chlorofluorocarbons (CFCs) as the size of VCR cooling unit gets reduced by handling the latent heat load separately. Desiccant cooling systems also allow larger flow rates of ventilation air to improve indoor air quality by removing air borne pollutants. The desiccant cooling system can be very cost effective, when used with renewable (solar) or waste heat for regeneration. It also avoids microbial growth in ducting by the use of dry cooling coils. Desiccant cooling are used in several applications such as pharmaceutical plants, supermarkets, theatres, hotels, office buildings, hospitals, health clubs and swimming pools.

Different configurations of desiccant cooling system has been proposed by many investigators so far to attain higher system performance. The earliest form of desiccant cooling cycle was proposed by coupling dehumidifier with heat source and evaporative cooler [1]. Similar cycle was proposed by Dunkle [2] using dehumidifier of molecular sieve with additional heat exchanger to achieve the better performance than the earlier one. Later on, Munter [3] further enhanced the performance of the desiccant cooling cycle by introducing parallel passages in dehumidifier and provided backup of vapour compression system to tackle the cooling load. Since then, number of efforts have been made for the performance evaluation of rotary desiccant dehumidifiers used in the desiccant cooling systems. Important among those were the analogy theory by Banks [4], the pseudo-steady state model by Barlow [5], combined potential technique by Jurinak [6], finite difference method for cross-cooled dehumidifiers [7] and finite difference method by Maclaine-Cross [8] which are now widely used by other researchers in getting better performance of desiccant cooling cycles [9]. Burns et al. [10] evaluated the performance of hybrid desiccant cooling cycle used for supermarket and shows better performance than conventional VCR system. Van den Bulck et al. [11] experimentally investigated the effects of process and regeneration air mass flow rates, temperature, humidity ratio etc. on the performance of solid desiccant cooling system. Higher regeneration temperature was recommended to reduce the required mass flow rates of air streams. Pesaran [12] proposed the

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http://dx.doi.org/10.1016/j.energy.2016.03.014
0360-5442/

use of renewable energy (solar heat) for the regeneration of dehumidifier used in desiccant cooling system to increase the overall cycle efficiency. Comparison between various desiccant cooling cycles for air conditioning in hot and humid climates has been carried out by Jain et al. [13].

From literature review, one can observe that some researchers developed mathematical models for evaluating the performance of desiccant cooling system while the others conducted expensive experimental studies. The mathematical approach requires a large number of geometrical parameters defining the system, which may not be readily available and their predictions may not be sufficiently accurate in many cases. As an alternative, use of artificial neural networks (ANNs) requires less effort, time and cost to model the system. This new modelling technique is used in many engineering applications, where classical approaches are too complex to be used. So, ANNs allow modelling of physical phenomena in complex systems without requiring explicit mathematical representations or without requiring exhaustive experiments. ANNs can predict the desired output of a system when enough experimental data available.

Hosoz et al. [14] applied ANN (artificial neural network) to predict the performance of AAC (automotive air conditioning). The model was used to predict various performance parameters of the system, namely the compressor power, heat rejection rate, refrigerant mass flow rate, compressor discharge temperature and coefficient of performance. Power consumption, thermal efficiency and COP (coefficient of performance) of the mechanical cooling system were predicted by using artificial neural network [15]. The results showed that the ANN can be used in performance prediction of heating and cooling devices with appropriate network architecture and training set. Modeling of a MAC (mobile air conditioning system) was carried out by Atik et al. [16] using ANN (artificial neural network). COP (Coefficient of performance), cooling capacity and compressor power were predicted by using ANNs of different architecture having inputs like refrigerant flow rates and compressor speeds. An ANN (artificial neural network) approach was applied to predict the COP (coefficient of performance) of a solar refrigeration system [17]. Koronaki et al. [18] applied an artificial neural network approach to predict the performance of an open cycle desiccant air conditioning system. An ANN model was developed to predict the cooling capacity, compressor power input and the COP (coefficient of performance) of the AAC (automotive air conditioning) system [19]. The performance of the ANN model was assessed using the mean square error, rootmean square error, error index and the correlation coefficient. Tian et al. [20] applied ANN (artificial neural network) to predict the performance of EVACS (electric vehicle air conditioning system). It also shows that the proposed model can work well as a predictive tool to complement the experiments [21].

To the best of authors' knowledge none of the previous investigators predicted the performance of solid desiccant – vapor compression hybrid air-conditioning system in terms of system coefficient of performance using ANN (artificial neural network). Most of the previous studies have considered the ANN prediction of outlet air stream parameters for rotary desiccant dehumidifier based on experimental measurements. In the current study, a neural network model has been developed using a neural network toolbox of MATLAB© [22] with feed forward back propagation method based on the experimental results for a solid desiccant-vapor compression hybrid air-conditioning system. Experiments have been performed to evaluate the performance of the system in terms of cooling capacity, power input and COP (coefficient of performance) at varying air stream flow rates, regeneration temperature and different ambient conditions. These experimental data are used for training and prediction of ANN model and for validation against the experimental results. The proposed ANN model can efficiently predict the system performance within the range of experimental test data.

2. System description

A test room having dimensions 3 m × 3 m × 3 m, has been selected for the study. The sensible and the latent cooling loads [23] are taken as 1.371 kW and 0.391 kW, respectively. SHR (Sensible heat ratio) has been obtained as 0.78 [24]. Flow rates of the process air stream and the regeneration air stream are measured as 322.7 m^3/hr and 196.8 m^3/hr respectively. The comfort conditions are taken as 50% relative humidity and 26°C dry bulb temperature [25].

The schematic diagram and the photographic view of solid desiccant and vapor compression hybrid air-conditioning system have been shown in Figs. 1 and 2 respectively. The return room air at state 1 passes through the rotary desiccant dehumidifier. Its moisture is adsorbed significantly by the desiccant material and the heat of adsorption raises its temperature up to state 2. The hot and dry air is first sensibly cooled in an air-to-air heat exchanger (2–3) and then in cooling coil of VCR system up to state 4. In the regeneration air line, ambient air at state 6 enters the air-to-air sensible heat exchanger and cools the supply process air. Consequently, its temperature rises when exiting from sensible heat exchanger at state 7. At this point, it is heated to reach temperature at the state point 8 which is high enough to regenerate the desiccant material. Moist air at the outlet of dehumidifier is exhausted to atmosphere at state 9.

The rotary desiccant dehumidifier used is 360 mm diameter and 100 mm width. Rotational speed of the dehumidifier is kept constant as 20 rph. Synthesized metal silicate is the desiccant material used in desiccant wheel.

3. Measurements

Experiments are carried out by simultaneous measurement of temperature, relative humidity, pressure drop and flow rate with the help of multifunctional temperature, humidity and velocity digital transmitters connected via Masibus- 85XX micro-controller based scanner with control panel, to control and operate the system. All the sensors are connected to a central computer via data acquisition unit. The inaccuracies in measurement of temperature, relative humidity and flow rate are found ±0.3 K @ 296 K, ± 2.0%, ±3.0% respectively. Energy meter is also used to measure the electrical power consumption of the system. The measurements were carried out once the temperature and humidity of the system attain steady state condition. Humidistat is fitted inside the test room to control the dehumidifier operation according to the room humidity. Temperature controller is also fitted inside the test room to control the compressor operation through relay, so as to maintain the room temperature constant.

4. Performance parameters

The performance of solid desiccant – vapor compression hybrid air-conditioning system is evaluated by calculating the cooling capacity, power input and COP (coefficient of performance).

The COP of system [26] based on electrical energy input is defined as the ratio of the cooling capacity to the total electrical energy input (E_{total}) to the system. It is given by