Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 129 (2016) 28–37

SOLAR ENERGY

www.elsevier.com/locate/solener

Neural network and polynomial model to improve the coefficient of performance prediction for solar intermittent refrigeration system ☆

B.A. Escobedo-Trujillo [a], D. Colorado [b,*], W. Rivera [c,*], F.A. Alaffita-Hernández [d]

[a] Facultad de Ingeniería, Universidad Veracruzana, Campus Coatzacoalcos, Av. Universidad km 7.5, Col. Santa Isabel, C.P. 96535, Coatzacoalcos, Veracruz, Mexico

[b] Centro de Investigación en Recursos Energéticos y Sustentables, Universidad Veracruzana, Av. Universidad km 7.5, Col. Santa Isabel, C.P. 96535, Coatzacoalcos, Veracruz, Mexico

[c] Instituto de Energías Renovables, Universidad Nacional Autónoma de México, Privada Xochicalco S/N, Colonia Centro, 62580, Temixco, Mor., Mexico

[d] Posgrado en Matemáticas, Facultad de Matematicas, Universidad Veracruzana, Circuito Gonzalo Aguirre Beltran S/N, Zona Universitaria, C.P. 91090, Xalapa, Veracruz, Mexico

Received 29 January 2015; received in revised form 3 November 2015; accepted 6 January 2016

Communicated by: Associate Editor Ruzhu Wang

Abstract

This study presents a novel hybrid methodology to estimate the coefficient of performance in an absorption intermittent cooling system; the system is for ice production and operates with an ammonia/lithium nitrate mixture. The hybrid model integrates a polynomial fitting method and an artificial neural network model to improve the network performance and the estimation of the COPs. The improvement uses fewer hidden neurons without sacrificing accuracy in the prediction. The proposed hybrid model has two neurons in the input and two in the hidden layers and shows better results than those obtained through polynomial fitting or artificial neural networks separately. The developed model presents an excellent agreement between experimental and simulated values of the coefficient of performance with a determination coefficient $R^2 > 0.9978$.

Keywords: Lithium bromide solution; Multivariable fitting; Residual analysis; Gaussian distribution; Correlation matrix

1. Introduction

In the last two decades, the use of artificial neural networks for the solution of complicated problems in the field of absorption systems has gradually increased. When modeling such a process, the ability of artificial neural networks to integrate complex relationships between process parameters and product quality is of great interest (Hernández et al., 2008). Empirical models based on experimental databases are used as an alternative in the control process, online estimation, and future optimization.

Hernández et al. (2008) presented a predictive model for a water purification process integrated to an absorption heat transformer with an artificial neural network. The model takes into account 16 input variables like temperature, concentration, and pressure levels in order to estimate the coefficient of performance. Colorado et al. (2011) developed a methodology to calculate the optimal input parameters that should be used in order to operate the heat transformer with the lowest irreversibility. The methodology is based on an artificial neural network with seven

☆ This document is a collaborative effort.

* Corresponding authors.
E-mail addresses: dcolorado@uv.mx (D. Colorado), wrgf@ier.unam.mx (W. Rivera).

http://dx.doi.org/10.1016/j.solener.2016.01.041

external operation variables in the input layer. Hernández et al. (2012) reported a study of a direct and inverse artificial neural network approach to predict the coefficient of performance in a solar intermittent refrigeration system for ice production under several experimental conditions. The following operation variables were considered for the input layer: solution concentration, cooling water temperature, generator temperature, ambient temperature, generator pressure, and received heat; to predict the COP six neurons were calculated for the hidden layer. After determining the artificial neural network architecture, a sensitive analysis was conducted in order to find the most important operation variable for an inverse artificial neural network methodology. The works described above, did not present an analysis of the degree of correlation between the experimental operation variables and the coefficient of performance before the learning process of the artificial neural network had taken place. Laidi and Hanini (2013) presented an artificial, neural network model for the prediction of the solar coefficient of performance of a solar intermittent refrigeration system for ice production working with an activated carbon/methanol pair.

On the other hand, polynomial fitting is an attractive technique used for estimating the degree of correlation between independent variables and their prediction. Castilla et al. (2013) proposed the use of approximate models with the aim of reducing the computational cost required to calculate the index. Thus allowing for its use in real-time control of the systems and decreasing the size of the network sensor. The authors compared an artificial neural network to a polynomial model. Although in general, the results obtained with the ANN model were better, the polynomial model was more easily derived. Escobedo-Trujillo et al. (2014) developed a polynomial model to predict the coefficient of performance of a water purification process integrated to an absorption heat transformer. The fit of the polynomial model was expressed by the determination coefficient R^2 which was found to be 0.9919. The polynomial model was compared with an artificial neural network, reported in the literature, with a determination coefficient R^2 of 0.9981.

It can be seen from the literature reviewed, artificial neural networks have been used for the estimation of the coefficient of performance in absorption systems without considering a correlation analysis between experimental operation variables and their prediction. Therefore the objective of this research is to present the use of a polynomial fitting method to improve the artificial neural network model. The improvement involves using fewer hidden neurons without sacrificing accuracy in the prediction, this constitutes a new hybrid methodology. There was also a reduction in time consumption for future control and the size of the network sensor. The experimental database came from the solar intermittent absorption system for ice production operating with an ammonia/lithium nitrate mixture used by Rivera et al. (2011).

2. Description of the system

This section introduces the experimental system of our interest.

The system was designed to operate with an ammonia/lithium nitrate mixture for a maximum capacity of 8 kg of ice/day. It consists of a condenser, an evaporator, a storage tank, a capillary tube, and a compound parabolic collector acting as the generator/absorber, as shown in Fig. 1. Since the lithium nitrate does not evaporate at operating conditions, a rectifier is not necessary in the system. The system operates exclusively with solar energy and no moving parts are required. During the day, the ammonia/lithium nitrate mixture in the generator/absorber is heated by the incidental solar radiation on the CPC until it reaches the saturation temperature. The ammonia then is partially evaporated from the solution and the ammonia vapor moves to the condenser, where it is condensed by water and then stored in the storage tank. At night, the liquid ammonia passes through the expansion valve decreasing its pressure and temperature, producing the refrigerant effect in the evaporator. Also at night the temperature and pressure, in the generator/absorber, decrease due to the decrease in ambient temperature, while the ammonia vapor increases its pressure because of the heat absorbed from the water and stored in the evaporator. In this way, the pressures are naturally inverted in the components and the ammonia vapor produced in the evaporator moves to the generator/absorber where it is absorbed by the strong solution starting the cycle again.

2.1. Experimental procedure

The experimental procedure was carried out in two stages: generation–condensation and evaporation–absorption. The generation–condensation stage began around 8 AM. During the day, the ammonia was evaporated from

Fig. 1. Photograph of the solar intermittent absorption refrigeration system analyzed.