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Performance analysis of small capacity absorption chillers by using different modeling methods

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HIGHLIGHTS

- Comparison of four empirically based models: GNA, $\Delta\Delta t'$, MPR, ANN.
- Experimental data of 12 kW absorption chiller are used for modeling.
- $\Delta\Delta t'$, MPR, ANN methods are suitable for complex simulation environments.
- The statistical indicators and tests show a slight advantage of the ANN method.

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ABSTRACT

This paper presents a review and comparison of simple, yet accurate steady-state models of small capacity absorption chillers using highly reliable experimental data obtained with an absorption chiller of 12 kW in a state-of-the-art test bench. These models can potentially be used in complete modeling and simulation tools or in supervisory control strategies for air-conditioning systems using absorption chillers.

With respect to that, a comparative evaluation of different modeling methods for predicting the absorption chiller performance is presented. Four empirically based models: the adapted Gordon-Ng model (GNA), the characteristic equation model ($\Delta\Delta t'$), the multivariable polynomial model (MPR) and the artificial neural networks model (ANN) were applied using the experimental data and thoroughly examined. The paper also presents statistical indicators and tests which might assist in selection of the most appropriate model.

The excellent statistical indicators such as coefficient of determination (>0.99) and coefficient of variation (<5%) clearly indicate that it is possible to develop highly accurate empirical models by using only the variables of external water circuits as model input parameters.

1. Introduction

The main aim of this paper is to present a comparative evaluation of different modeling approaches for predicting the performance of small absorption chillers. The comparative evaluation can serve as a reference when there is a need for simple, but accurate models of absorption chillers, for example to integrate these models in complete energy supply and demand models included in simulation software packages. These simple chiller models, characterized by a low number of input parameters, can serve to facilitate the annual simulations of complex building systems providing at the same time an adequate level of performance prediction. Also, this paper aims to provide a statistical approach which may help in selecting the appropriate model.

With respect to absorption chiller modeling, both physical and empirical approaches were many times presented in the literature. Physical or more precise thermodynamic models were reported by many authors. Here just a brief review of the most recent or relevant will be given. Grossman and Zaltash [1] developed a modular simulation tool for absorption systems called ABSIM. With this software is possible to study various absorption cycle configurations using different working fluids. ABSIM calculates the cycle internal state points and thermal loads in each component using a cycle configuration build by the user graphically and for given working fluid specifications and operating conditions. This is enabled through the governing equations for each component of the cycle contained in the software subroutines. However, the calculation convergence is not always easy. Silverio and Figueiredo

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[2] used a thermodynamic approach for steady-state simulation of an ammonia-water absorption system. The thermodynamic state relations, the pressure drop equations and the heat transfer coefficients were solved by using an algorithm based on the Substitution Newton Rapshon method. Kaynakli and Kilic [3] performed a theoretical study on the performance of a H_2O–LiBr absorption system using a thermodynamic analysis of the absorption cycle. These authors investigated the influences of the driving temperature and heat exchanger effectiveness on the thermal loads of the components and COP. Yin et al. [4] developed a detailed thermodynamic model of a 16 kW double-stage H_2O–LiBr absorption chiller. The steady-state model was based on the working fluids property relations, detailed mass and energy balances, and the heat and mass transfer relationships for each chiller component. One of the most recent application of the thermodynamic approach in absorption system modeling can be found in the paper of Wu et al. [5]. The authors developed thermodynamic models of different absorption heat pump cycles to test their applicability with different heat sources, working pairs and in different cold regions. All these thermodynamic models are very demanding since they require comprehensive knowledge of the absorption cycle including some internal state points. These models need lots of input parameters such as heat transfer coefficients (U) and heat transfer areas (A) of heat exchangers, the rich solution flow rate, working fluid properties and water side flows and temperatures as well as some additional assumptions for the convenience of modeling. A more complete explanation on all these degrees of freedom in the modeling of absorption chillers can be found in Dereje et al. [6]. In practice, however, especially with commercial units, the internal parameters are not available. This is the reason why thermodynamic models are more adequate during the design stage of absorption equipment as explained in the paper of Florides et al. [7]. Also, the computation time in simulation software packages using these models is very long since they require a lot of simultaneous iterations. The annual simulation of absorption chillers under different ambient and operating conditions on an hourly time step basis is a clear example of this.

Thus, there is a need for simple models which can provide sufficiently good representation of the absorption machine behavior based only on available external parameters (experimental measurements or manufacturer catalog data). Simple models can be more easily incorporated in simulation programs or used for fault detection and control. Contrary to the physical models, the empirical and semi-empirical models require less time and effort to develop and computation time is much shorter when they are built into complete energy management simulation programs. The parameters and fitting coefficients in these models are determined by using a regression method or a minimization algorithm applied to a dataset obtained performing experimental measurements or using a manufacturer catalog.

The studies about development of empirically based models for absorption chillers have been reported by several authors. Gordon and Ng [8] developed a general model for predicting the absorption chillers performance. The model lays both on physical and empirical principles. The physical principles that govern the performance of the absorption chiller are fitted to the experimental or manufacturer data by using a regression method. Ziegler et al. [9,10] developed a model (Characteristic equation method) which predicts the performance of the absorption chiller by using two simple algebraic equations: one to calculate the cooling capacity and another for the driving heat input. These two previous models belong to semi-empirical (gray-box) category of models, in which the fitted parameters can be interpreted under the actual physical principles which govern the absorption chiller performance. Labus et al. [11] used a completely empirical approach to model absorption chillers based on manufacturers curves in order to investigate the energy savings when different absorption chiller configurations were considered for their integration in a complete chiller plant.

The Artificial neural networks approach has been also used for absorption chiller modeling. ANN models belong to the black-box model category, that unlike gray-box models, the estimated parameters of the model have no physical interpretation. Sözen [12] used the ANN to determine thermodynamic properties of an alternative working pair for absorption systems. The study also demonstrated that ANN can replace mathematical models in the simulation of absorption systems. In the paper of Sözen and Akçayol [13] the ANN approach was proposed for performance analysis of an absorption chiller. The ANN model used only the working temperatures in the four main components as input parameters in order to predict the performance of the chiller. Manohar et al. [14] applied ANN for the modeling of steam fired double effect absorption chiller. Later, a similar work was carried out by Rosiek and Batlles [15], who used ANN to model solar-assisted air conditioning system with hot water driven double effect absorption chiller. The last approach considered in this paper is the simple multivariable polynomial regression which also belongs to the black-box category of models.

Regardless the numerous studies on the modeling of absorption equipment, literature review shows that there is a lack of information with respect to comprehensive comparative studies on different modeling techniques for predicting absorption equipment performance in a similar way as Swider [16] or Lee et al. [17] did for the case of vapor-compression chillers.

The main aim of this paper is to present a comparative evaluation of different modeling approaches for predicting the performance of absorption systems. In the next section are presented the experimental data and a brief description of the evaluated types of models. Later the application of these models to the experimental data is evaluated with the help of statistical indicators and statistical tests to select the best modeling approach.

2. Experimental data and absorption chiller models

Four different types of absorption chiller models were developed and examined:

- Adapted Gordon–Ng model,
- Adapted characteristic equation model,
- Multivariate polynomial regression model and
- Artificial neural networks model.

The experimental data required for the models' development were obtained in the state-of-the-art test bench of the Rovira i Virgili University in Tarragona (Spain). The test bench is fully equipped to test under controlled operation conditions a variety of units commonly used in HVAC systems. A more detailed explanation about the functionality of the test bench can be found in Labus et al. [18] and Labus [19]. For the models described in this research the data were collected in a series of experiments with a 12 kW absorption chiller Pink Chilli PSC12. The measured variables in the experiments were inlet and outlet temperatures of hot, chilled, and cooling water circuit; volumetric flow rates and pressure drop in each circuit; and electric consumption of the chiller. The raw data were processed using a comprehensive test procedure which includes several techniques: data reduction, development of steady-state detector with additional filtering and uncertainty estimation. Based on external measurable parameters only, this procedure allows the creation of the complete performance map for absorption machines based on highly accurate data. In data reduction, the