Applied Thermal Engineering 82 (2015) 8–17

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Statistical analysis of the energy performance of a refrigeration system working with R1234yf using artificial neural networks

J.M. Belman-Flores, Sergio Ledesma*

School of Engineering Campus Irapuato-Salamanca, University of Guanajuato, Carretera Salamanca-Valle de Santiago Km 3.5 + 1.8 Comunidad de Palo Blanco, Salamanca, Gto. 36885, Mexico

HIGHLIGHTS

- An artificial neural network was designed to model a vapor compression system.
- A statistical analysis computing the histograms of input and output parameters in this system was perform.
- 3D color plots were used to display the mean and variance of the COP.
- Histograms were computed to analyze the variability of the COP under different operating conditions.

ARTICLE INFO

Article history:
Received 9 December 2014
Accepted 23 February 2015
Available online 4 March 2015

Keywords:
Random variable
Modeling
Vapor compression system
Histogram
Energy
R1234yf

ABSTRACT

This paper presents the application of an artificial neural network to carry out a statistical analysis of the energy performance for a compression vapor system operating with R1234yf as working fluid. The main contribution of this work is the creation of 3D plots for visualization of energy performance and its variability when changes in the input operating parameters are present. These parameters are: compressor rotation speed, the temperature and volumetric flow of the secondary fluids.

Furthermore, frequency histograms to represent the variability of the energy performance of the refrigeration system were estimated and analyzed. Computer simulations employing neural networks were used to understand the energy performance behavior, and observe the best performance of the installation. In the same way, these simulations were used to statistically analyze the variability of the energy performance.

1. Introduction

The number of refrigeration and air conditioning devices based on compression vapor has considerably increased during the last few years. In this context, the field of refrigeration has been affected, mainly, because of two issues that are currently under study: the reduction of energy consumption, and the decrease of greenhouse gas emission. Thus, different and new alternatives to reduce energy consumption or achieve more efficient systems [1,2], are an important investigation subject in this field. In the same way, the use of environment friendly refrigerants [3–5] has become an area of great research.

In recent years, many engineering techniques have been employed for modeling refrigeration system, through the use of these models is possible to analyze, predict and improve the energy performance of vapor compression systems. Among these techniques, the application of artificial intelligence in the field of refrigeration and air conditioning has notably increased, for instance Adaptive Neuro-Fuzzy Interface Systems (ANFIS) have been applied to model the performance parameters of a refrigeration system employing a cooling tower, [6]. Similarly, Support Vector Machines (SVMs) have also been used to model the performance of a ground-coupled heat pump [7]. Another technique used to model the vapor compression system is by means of a single hidden layer feed-forward neural network (SLFN) which is based on an Extreme Learning Machine (ELM) [8]. In addition, Data Mining (DM) techniques have been employed as analytical tools to predict the performance of a refrigeration system under different refrigerant quantities [9]. In this context, the use of Artificial Neural Networks (ANNs) shows interesting applications in the field of: refrigeration, air conditioning and heat pump systems [10].

In the performance analysis of refrigeration or air conditioning systems, many researches have shown that ANNs offer an acceptable accuracy when predicting the desired output of these systems.

* Corresponding author.
E-mail addresses: jfbelman@ugto.mx (J.M. Belman-Flores), selo@ugto.mx (S. Ledesma).

http://dx.doi.org/10.1016/j.applthermaleng.2015.02.061
1359-4311/

For instance [11], developed an ANN model for experimental air conditioning system using the refrigerant R134a to predict the performance parameters, such as: compressor power, heat rejection in the condenser, refrigerant mass flow rate, compressor discharge and coefficient of performance. Esen et al. [12] described the applicability of an ANN to predict the performance of an experimental ground-coupled heat pump system with minimum input data. Other authors investigated the performance of a single-stage refrigeration system using different refrigerants which do not damage the ozone layer [13], in this case an ANN was used as a complement of their model. Önder [14] developed a new approach based on an ANN to determine the performance of a refrigeration system in terms of its thermodynamics aspects and its energy consumption. Abdulraham et al. [15] investigated the performance of a desiccant regenerator based on an ANN. Haslinda et al. [16] presented a model using steady state input data of an automotive air conditioning system; the model was based on an ANN, and it was used to predict: the cooling capacity, the input power and the coefficient of performance. Belman-Flores et al. [17] developed a new method to model a variable speed vapor compression system using R134a; this method accurately estimates the number of neurons in the hidden layer, and the model can predict the energy performance with good accuracy. Tian et al. [18] predicted the thermal performance of a parallel flow condenser by using an ANN on a system working with R134a. Also, ANNs were used to predict the hourly cooling load of a vehicle during the cooling season [19]. In the previous literature, most studies focused on developing models using ANNs.

On the other hand, the field of refrigeration is constantly making proposals to reduce the damage to the environment due to the use of some refrigerants. Hence, nowadays there is an increasing pressure to address the problem of global warming caused by the use of this type of gases refrigerants. A promising solution to reduce Global Warming Potential (GWP) is by replacing R134a with R1234yf [20]. Some of the main advantages of using R1234yf are its thermodynamics properties, and its low toxicity. Additionally, its Ozone Depletion Potential (ODP) is zero, and its GWP is four ([21–23]). Several researches in the literature have presented experimental studies to determine the feasibility of substituting R134a with R1234yf in a test bench. Jarall [24] developed a theoretical and experimental study using R1234yf as working fluid in a refrigeration system; this study included a performance comparison with R134a. Honghyun et al. [25] compared the energetic characteristics of the refrigeration cycle with refrigerants R134a and R1234yf; also they used an internal heat exchanger in order to improve the cooling performance of R1234yf. Navarro-Esbrí et al. [26] presented an experimental study of R1234yf as a drop-in replacement for refrigerant R134a in a vapor compression system for a wide range of working conditions. Huashan et al. [27] investigated the performance characteristics of an ejector-expansion refrigeration cycle using R1234yf, and compared these characteristics with those of R134a.

Thus, in the field of refrigeration is necessary to achieve sustainable refrigeration systems that exhibit energy improvements and the use of environmental friendly refrigerants. Consequently, the application of ANNs for the analysis of refrigeration systems leads to the development of models that approximately represent the performance of these systems. In order to provide a more comprehensive analysis in the study of refrigeration systems, in this work the energy performance of a vapor compression refrigeration system with R1234yf as working fluid has been modeled using an ANN approach.

The methods included in this study provide graphic tools to analyze the statistical behavior of the energy performance (COP) to recognize optimal operation conditions. These methods provide new insights to understand the energy performance and its variability in function of the input parameters of the refrigeration system. Specifically, the input parameters of the model are: the compressor rotation speed, the volumetric flow rates, and the temperatures of the secondary fluids (at the evaporator inlet and at the condenser inlet). Note that these input parameters can be easily obtained in this kind of installation when measurement devices are properly setup.

2. Description of the experimental plant

In the present work, tests are carried out in an experimental test facility that consists of a vapor compression system, which diagram is shown in Fig. 1. The experimental facility has a vapor compression circuit and two secondary fluids circuits. The vapor compression circuit is a single-stage vapor compression system using R1234yf as working fluid, its principal components are:

- an open type variable speed compressor,
- a shell-and-tube evaporator in which the refrigerant flows inside the tubes and a brine water-propilenglycol (70/30% by volume) is used as secondary fluid,
- a shell-and-tube condenser with refrigerant flowing along the shell, and water inside the tubes as secondary fluid,
- and a set of expansion valves.

The experimental facility is supplemented with two secondary circuits: a condensing water loop and a heat load simulation system; both loops allow changing the evaporating and condensing conditions. The heat load simulation system consists of a tank with electrical resistances to allow controlling the thermal load of the evaporator with the assistance of a variable speed pump and a temperature control. The condensing system is used to set the water conditions at the condenser using a commercial chiller with a variable speed pump. With these two systems, it is possible to control the secondary fluids conditions at the evaporator and at the condenser.

The experimental setup is fully instrumented with sensors to measure key variables such as: pressures, temperatures, volumetric and mass flow rates, compressor speed, and energy consumptions. The pressure transducers have an uncertainty of $\pm 0.1\%$, while the temperature sensors are calibrated with an uncertainty of $\pm 0.5\ K$. The volumetric fluid rates are measured with an electromagnetic flowmeter with an uncertainty of $\pm 0.33\%$, while the refrigerant mass flow rate is measured using a Coriolis-effect mass flowmeter with a certified accuracy within $\pm 0.22\%$ of the reading. The energy consumption is measured with a digital wattmeter calibrated for a specified uncertainty of $\pm 0.5\%$. Finally, the compressor rotation speed is measured using a capacitive sensor with an uncertainty of $\pm 1\%$. The signals generated by all the sensors, as well as those provided by the measuring devices, are gathered by a National Instruments SCXI 1000 PC-based data acquisition system. Table 1 shows the range of operating conditions in the experimental facility.

In order to select a steady-state test, within the stable behavior of the facility, a time period of 2 min was chosen during which the evaporating and condensing pressures fluctuate by no more than ± 0.005 MPa. Additionally, all data in this work were averaged over the previously specified time period.

3. Background information

This section introduces some basic concepts and definitions to perform the statistical analysis of the refrigeration facility. First, theory about random variables and the histogram is explained.