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A comparison between the modeling of a reciprocating compressor using artificial neural network and physical model

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ABSTRACT

This article presents the development, validation, and comparison of two methods for modeling a reciprocating compressor. Initially, the physical mode is based on eight internal subprocesses that incorporate infinitesimal displacements according to the piston movement. Next, the analysis and modeling of the compressor through the application of artificial neural networks are presented. The input variables are: suction pressure, suction temperature, discharge pressure, and compressor rotation speed. The output parameters are: refrigerant mass flow rate, discharge temperature, and energy consumption. Both models are validated with experimental data for the refrigerants R1234yf and R134a; computer simulations show that mean relative errors are below ±10% with the physical model, and below ±1% when artificial neural networks are used. Additionally, the performance of the models is evaluated through the computation of the squared absolute error. Finally, these models are used to compute an energy comparison between both refrigerants.

Comparaison entre la modélisation d'un compresseur à pistons grâce à un réseau neuronal et un modèle physique

Mots clés : Réseaux neuronaux artificiels ; Modèle physique ; Froid ; R1234yf ; R134a ; Energie

1. Introduction

A great part of commercial refrigeration and air conditioning equipment are based on the vapor compression cycle. Reciprocating compressors are the most commonly used in systems from low to middle cooling capacity. The compressor is the heart of a refrigeration system, and it is the most complex component of this system. The compressor is the responsible of the greatest energy consumption in these systems. Given that the efficiency of the compressor affects significantly the performance of these systems, it makes that

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Nomenclature

A	area [m^2]
C_p	specific heat [J kg^{-1} K^{-1}]
D	diameter for suction and discharge internal lines [m]
e	internal energy [J kg^{-1}]
f	friction factor
L	length of the suction and discharge internal lines [m]
h	convective heat transfer coefficient [W m^{-2} K^{-1}]
i	enthalpy [J kg^{-1}]
k	thermal conductivity [W m^{-1} K^{-1}]
T	temperature [K]
t	time [s]
V	volume, velocity [m^3], [m s^{-1}]
P	pressure [kPa]
Pr	Prandtl number
Re	Reynolds number

Greek symbols

μ	dynamic viscosity [Pa s]
η	efficiency
ρ	density [kg m^{-3}]

Subscripts

comp	compression
exp	expansion
i	computed
l	actual
p	piston
w	wall

compressor operation be a topic of great interest in the field of refrigeration. Publications related to reciprocating compressors can be found in the literature, they include: experimental studies in transcritical systems (Yuan Ma et al., 2012), a comparative analysis between alternate refrigerants (Navarro et al., 2013), the interactions of the refrigerant with the lubricant oil (Da Riva and Del Col, 2011), some alternatives to adjust design parameters in order to reduce compressor energy consumption (Wang et al., 2013; Yasar and Kocas, 2007), methodologies for the diagnosis of faults and predictive monitoring (Elhaj et al., 2008), among others.

In the field of refrigeration, simulation is very important because it allows predicting the energy behavior of systems used in this field. Thus, a good system simulation depends on the quality of model. Some publications have addressed the modeling of reciprocating compressors for refrigeration systems. For instance, Winandy et al. (2002) proposed a simplified steady-state model. This model needed seven input parameters to compute: mass flow rate, mechanical power, exhaust temperature, and ambient losses. Pérez-Segarra et al. (2005) presented a detailed analysis of thermodynamic efficiencies used to characterize hermetic compressors. This model has been used to generate data in order to illustrate the options for thermodynamic characterization. Navarro et al. (2007) developed a model to predict compressor efficiency and volumetric efficiency in terms of ten parameters. Pereira et al. (2008) displayed a numerical analysis of a reciprocating compressor. The finite volume methodology was adopted to solve the flow field. Ndiaye and Bernier (2010) proposed a dynamic model of a hermetic reciprocating compressor. The model analyzes the phenomena affecting the suction and discharge mass flow rates and the electrical power drawn by the compressor. Castaing-Lasvignottes and Gibout (2010) presented a dynamic simulation based on the volumetric, isentropic or effective efficiencies. Damle et al. (2011) developed a modular unstructured object-oriented methodology, a mathematical formulation and a numerical resolution of the components that integrates the compressor was presented. Negrao et al. (2011) presented a semi-empirical model to predict the transient mass flow rate and the power of a domestic refrigeration compressor. Bin Yang et al. (2013) showed a comprehensive simulation model for a semi-hermetic CO_2 reciprocating compressor. Bin Tang et al. (2013) studied the thermal performance of an L-type air compressor by the use of a theoretical model and experimental work. Jian Hu et al. (2014) developed a new generic network model for the design of reciprocating compressors.

Based on this literature review, it may be said that different topologies of reciprocating compressor models exist with diverse levels of complexity. In some models, the compressor is divided into different elements, and in occasions, it is difficult to obtain input variables from measurements, or by the use of specification datasheets. Models with physical foundations are basic, for instance models based on conservation equations (continuity, momentum, and energy). Other models use correlations but with no physical meaning and cannot be applied outside a specified range. In terms of their applications, these models go beyond design, optimization, or simple prediction of the energy behavior of the compressor. Additionally, the use of Computational Fluid Dynamics, CFD, has been a countless tool in the analysis of these systems. Among the most relevant parameters to consider are: mass refrigerant flow, input power, and discharge temperature of the refrigerant. Therefore, in order to predict the energy behavior of a reciprocating compressor, the area of mechanical engineering is assisted by: basic thermodynamic principles, fluid mechanics, and heat transfer theory. However, there has been a recent influx of modern techniques for modeling and predicting energy behavior. Artificial intelligence is one of these techniques that has been used in recent years for the analysis of vapor compression systems (Belman-Flores et al., 2013; Haslinda et al., 2013).

In the literature there are few publications related to artificial intelligence and reciprocating compressors. Bo-Suk Yanga et al. (2005) developed a practical classification system to select faulty products in a mass production line of reciprocating compressors. Qiang Qin et al. (2012) presented a scheme for fault detection of reciprocating compressor valves based