Available online at www.sciencedirect.com

ScienceDirect

Applied Thermal Engineering 27 (2007) 1096–1104

APPLIED THERMAL ENGINEERING

www.elsevier.com/locate/apthermeng

Heat transfer analysis for shell-and-tube heat exchangers with experimental data by artificial neural networks approach

G.N. Xie, Q.W. Wang *, M. Zeng, L.Q. Luo

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Shaanxi, Xi'an 710049, China

Received 21 March 2006; accepted 11 July 2006
Available online 24 October 2006

Abstract

This work applied Artificial Neural Network (ANN) for heat transfer analysis of shell-and-tube heat exchangers with segmental baffles or continuous helical baffles. Three heat exchangers were experimentally investigated. Limited experimental data was obtained for training and testing neural network configurations. The commonly used Back Propagation (BP) algorithm was used to train and test networks. Prediction of the outlet temperature differences in each side and overall heat transfer rates were performed. Different network configurations were also studied by the aid of searching a relatively better network for prediction. The maximum deviation between the predicted results and experimental data was less than 2%. Comparison with correlation for prediction shows superiority of ANN. It is recommended that ANN can be used to predict the performances of thermal systems in engineering applications, such as modeling heat exchangers for heat transfer analysis.

Keywords: Heat transfer rate; Outlet temperature difference; Artificial neural network; Shell-and-tube heat exchanger; Segmental baffles; Continuous helical baffles

1. Introduction

The Computational Intelligence (CI) techniques, such as Artificial Neural Networks (ANNs), Genetic Algorithms (GAs), Fuzzy Logic (FL), have been successfully applied in many scientific researches and engineering practices. ANNs have been developed for about two decades and now widely used in various application areas such as pattern recognition, system identification, dynamic control and so on. ANN offers a new way to simulate nonlinear, or uncertain, or unknown complex system without requiring any explicit knowledge about input/output relationship. ANN has more attractive advantages. It can approximate any continuous or nonlinear function by using certain network configuration. It can be used to learn complex nonlinear relationship from a set of associated input/output vectors. It can be implemented to dynamically simulate and control unknown or uncertain process. In recent years, ANNs have been used in thermal systems for heat transfer analysis, performance prediction and dynamic control. For example, Thibault and Grandjean [1] earlier used a Neural Network (NN) for heat transfer data analysis, Jambunathan et al. [2] evaluated heat transfer coefficients from experimental data by using a NN, Bittanti and Piroddi [3] used a NN to identify and control heat exchangers, Yang and Sen [4,5] reviewed works in dynamic modeling and controlling of heat exchangers using ANNs and GAs, Diaz et al. [6–10] did lots of works in steady/dynamic simulation and control heat exchangers using ANNs, Parcheco-Vega et al. [11–14] also did many works in analysis for fin-and-tube heat exchangers with limited experimental data using soft computing and global regression, Islamoglu et al. [15,16] predicted heat transfer rate for a wire-on-tube heat exchanger and made heat transfer analysis for air flowing in corrugated channels. Other researches about heat exchangers control by means of ANNs were reported in references [17–19]. From

---

* Corresponding author. Tel./fax: +86 29 82663502.
E-mail address: wangqw@mail.xjtu.edu.cn (Q.W. Wang).

1359-4311/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2006.07.036

Nomenclature

D_c	diameter of center blocked tube (mm)
D_o	outside diameter of tube (mm)
Er	relative error
M	number of sets of data for training network
N	number of sets of data for testing network
N_b	number of baffle
N_t	number of tube
Pr	Prandtl number
Φ	heat transfer rate (W)
R	evaluation factor for average accuracy, Eq. (3)
Re_w, Re_o	Reynolds number in water-side, oil-side
rms	Root-mean-squares error
S_b	baffle pitch (mm)
C	coefficient of heat transfer correlation
m	exponent of heat transfer correlation
Nu	Nusselt number
Pr	Prandtl number
$T_{w,in}$, $T_{o,in}$	inlet temperature in water-side, oil-side (K)
u_{max}	velocity at minimum cross-section (m/s)
$\Delta T_{o,out}$	temperature difference in oil-side (K)
$\Delta T_{w,out}$	temperature difference in water-side (K)
σ	evaluation factor for scatter accuracy, Eq. (4)
ν	kinematic viscosity
Superscripts	
e, p	experimental, predicted
Subscripts	
o, w	oil, water
in, out	Inlet, outlet

aforementioned successful applications, it is shown that ANNs are well suitable to thermal analysis in engineering systems, especially in heat exchangers.

In many experimental studies and engineering applications of thermal science, researchers and engineers expect to reduce experimental data into one or more simple and compact dimensionless heat transfer correlations. The disadvantages of the correlation methods are that heat transfer coefficients strongly depend on their definitions and temperature differences, and inevitably need iterative method to obtain correlations when fluid properties are dependent on fluid temperatures [20]. However, ANN does not need definition of correlations and iterative method, only needs input/output samples for training a special neural network, in turn, obtaining output results as test samples fed into trained network. In the above-mentioned literature, most works were done in thermal analysis for fin-tube heat exchangers, while for shell-and-tube heat exchangers only few works were done in open literature. For this reason, the objective of this paper is that, setting up experimental system for investigation on three shell-and-tube heat exchangers, and applying ANN for heat transfer analysis of heat exchangers with experimental data based on back propagation algorithm to train the network. The predicted outputs of ANN are temperature differences of two sides and heat transfer rate. Different network configurations were studied for searching an optimal network. In addition, the predicted results by ANN were compared with those by correlations from references.

2. Physical model and experimental data

2.1. Experimental system

The experimental loop is shown in Fig. 1, which was designed by our research group and built at school of Energy and Power Engineering, Xi'an JiaoTong University. There are three sub-loops (an oil loop, a cold water loop and a cooling water loop) for achieving the heat exchange of the experimental loop in the present study.

In Fig. 1, 41 is the tested heat exchanger. We can carry out oil–water (by oil loop and cold water loop) or water–water (by hot water loop and cold water loop) heat exchanger on the experimental loop. The cooling water loop is used to cool the heated water of the cold water loop.

More detailed description of the experimental system and tested heat exchangers can be found in Ref. [21].

2.2. Data acquisition

Three main parameters, mass flow rate, temperature and pressure drop are obtained, for both hot and cold working medium of the tested heat exchangers. The heat balances between water and oil are less than 8% by on-line calculations for all studied cases. If the heat balance were well satisfied, all the corresponding experimental data were saved and averaged on a computer for data reduction. The uncertainties of obtained temperature difference, flow rate, heat transfer rate and heat transfer coefficient are less than 2%, 0.15%, 2.5% and 4%, respectively.

The three tested heat exchangers are shown in Fig. 2. Fig. 2(a) is a heat exchanger with segmental baffles (hereafter, the heat exchanger is called HX1), the other two are heat exchangers with continuous helical baffles, as shown in Fig. 2(b) and Fig. 2(c). The only difference between the latter two helical heat exchangers is the inlet–outlet flow manner of shell-side fluid. One is middle-in-middle-out (so called HX2, Fig. 2(b)) and the other one is side-in-side-out (so called HX3, Fig. 2(c)). The cores of HX2 and HX3 are same (i.e., the layouts of tubes and baffles are identical), and the only difference between the HX2 and HX3 is the position/location of inlets and outlets of shell-side flows. The positions of inlet and outlet of HX2 are on the middle of the shell side, which is normal to shell,