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Predicting thermal–hydraulic performances in compact heat exchangers by support vector regression

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ABSTRACT

An alternative model using support vector regression (SVR) based on dynamically optimized search technique with *k*-fold cross-validation, was proposed to predict the thermal–hydraulic performance of compact heat exchangers (CHEs). 48 experimental data points from the author's own study were used in the present work. The performance of SVR with different regularization parameter γ and kernel parameter σ^2 had been investigated and the optimal values were obtained. According to predicted accuracy of indicating generalization capability, the model performance was compared and evaluated with the artificial neural network (ANN) model. As a result, it is found that, the SVR provides better prediction performances with the mean squared errors (MSE) of 2.645×10^{-4} for testing *j* factor and 1.231×10^{-3} for testing *f* factor, respectively. Also the computational time of SVR model was shorter than that of the ANN model. Moreover, the versatility of the configured SVR model was demonstrated by presenting the effects of some input variables on the output variables. The result indicated that SVR can offer an alternative and powerful approach to predict the thermal characteristics of new type fins in CHEs under various operating conditions.

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1. Introduction

Due to compact configuration and a good heat transfer performance, compact heat exchangers (CHEs) are being widely employed in heat recovery, heating and air conditioning, power generation and pollution control systems. In CHE, which find diverse applications, a variety of augmented surface are used, plain, wavy, offset-strip, perforated and louvered fins. For these complex geometries, the prediction of the fin's performance (heat transfer and pressure drop) is the primary requirements for the design and efficient operation of CHEs.

Though several studies have been made to predict the thermal–hydraulic characteristics during the last three decades, experimental analyses are the main approaches [1–6]. The most typical study was performed by Kays and London [1], they did systemic experiments and obtained the Colburn factor *j* and friction factor *f* on the various fins which perhaps the most comprehensive design criterion. However, there are a large number of geometrical parameters, only limited experimental data have appeared in the literature. As a consequence, efforts are made to develop empirical correlations for predicting the fin's performance [7–10]. It was observed that though all these correlations represent a major contribution in the understanding and prediction of the fin's performance, but there was ample scope to develop newer and better models due to some shortcomings in them. For all these correlations, only the constants, coefficients, and the maximum deviation are provided. The generalization ability and prediction accuracy of these models is also poor. Moreover, for the same geometry of fins in the same experimental setup, regression constants and coefficients have been reported to be different for different studies.

Thus, with the above observations in mind and given the recent developments in the application of artificial intelligence (AI), it was decided to explore the possibility of using one such technique for developing a new prediction model of the fin's performance in CHEs.

Recently, artificial neural network (ANN), as a typical artificial intelligence (AI) model, has been widely used in the pressure drop and heat transfer predictions in various heat exchangers. Diaz et al. [11–13] and Parcheco-Vega et al. [14–16] did a lot of researches in simulating and controlling heat exchanger performance using ANNs. Akbari [17,18] used a Neural Network for heat transfer data analysis. Islamoglu et al. [19,20] predicted heat transfer rate of a wire-on-tube heat exchanger and made heat transfer analysis for air flowing in corrugated channels. Xie et al. [21,22] developed an ANNs method to analyze the heat transfer of shell-and-tube

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Nomenclature

D_e	hydraulic diameter [m]
F	total heat transfer area [m^2]
G	mass flux [kg/m^2 s]
K	overall heat transfer coefficient [W/m^2 K]
L	effective length [m]
L_f	fin length [m]
MSE	mean squared error
Pr	Prandtl number
ΔP	pressure drop [Pa]
Q	total heat flux [W]
Re	Reynolds number
RE	relative error
R^2	correlation coefficient
St	Stanton number
T	temperature [K]
ΔT_m	logarithmic mean temperature difference [K]
W	weight vector
c_p	specific heat [J/kg K]
f	friction factor
g	gravity [m^2/s]
h_f	fin height [m]
j	Colburn factor
m	mass flow rate [kg/s]
q	heat flux [W/m^2]
r	latent heat [J/kg]
s_f	fin pitch [m]
u	velocity [m/s]
x_i	input variables
x_{ni}	normalized input variables
y_i	output variables
y_{ni}	normalized output variables

Greek symbols

δ_f	fin thickness [m]
δ_w	wall thickness [m]
μ	dynamic viscosity [Pa s]
ρ	density [kg/m^3]
γ	regularization constant
σ^2	width parameters of Gaussian function
α	heat transfer coefficient [W/m^2 K]
λ	heat conductivity [W/m K]

Subscripts

as	air side
i	inlet
m	mean value
max	maximum
min	minimum
o	outlet
ss	steam side
w	wall

Upper scripts

e	experimental
p	predicted

heat exchangers. Wijayasekara [23], Tan et al. [24] and Peng et al. [25] applied ANNs approach to analysis the thermal characteristics of compact heat exchangers with limited experimental data. It was found that a good prediction performance was achieved by ANNs models.

With the interdisciplinary development of modern computational technologies and statistical learning theory, support vector machine (SVM), as new artificial intelligence (AI) model which developed by Vapnik [26], has become a more attractive approach for modeling highly complicated and nonlinear system. SVM is a supervised learning theory from the field of machine learning and is applicable for both nonlinear classification (SVC) and regression (SVR). It has been successfully applied to many filed of pattern recognition, phase diagram assessment, solar energy, mechanical industry, chemical engineering and technology, etc [27].The applicability of SVR-based models in the field of chemical engineering and mechanical industry has been well demonstrated [28–31]. Very few works has been reported in literature on the application of SVR to heat transfer in general. Li [32,33] used the SVR model to predict the hourly cooling in the buildings. The estimation of heat transfer coefficient in bubble column reactors using SVR algorithm was presented by Gandhi [34]. Cai [35] applied SVR to predict the critical heat flux in concentric-tube open thermosiphon. Besides, to the best of the author's knowledge, no published literature is there on the application of SVR for modeling of the thermal–hydraulic performances in compact heat exchangers.

In the present study, it is for the first time that SVR-based modeling has been used for predicting the Colburn factor j and friction factor f in CHEs. The experimental data from author's own studies was first preprocessed. Next to that, the k-fold cross-validation procedure was developed to obtain the key parameters of the SVR model. Thereafter, the configured SVR model was applied to the experimental data to show its capability in the prediction accuracy. Furthermore, the estimation performance of SVR model was compared and evaluated with the conventional ANN model. Finally, the effects of each input variable on the output variable were investigated by the present model.

2. Experimental and data reduction

2.1. Experimental system

The experimental facility used to obtain the data is shown in Fig. 1. It consisted of testing samples, a wind tunnel, a steam-condensation water loop and a measuring subsystem.

The wind tunnel system has a rectangular cross section throughout the test section which is 300 mm in height and 200 mm in width. The blower sucks the required cooling air through the test section via a centrifugal fan. The air flow rate can be regulated by a butterfly valve. The steam-condensation water loop has a boiler and the saturated steam is generated and moves to the test section (CHEs), where it condenses by the cold air. The air inlet temperature is measured by Pt100 thermal resistance. The air outlet matrix temperatures and the steam inlet temperature are obtained by 17 pieces of T type thermocouples. These thermocouples are pre-calibrated and have an accuracy of 0.1 K. The Pitot tube combined with a differential pressure transducer is inserted to measure the air velocity, which has the uncertainty of 1%. The condensed water flow rate and the pressure drop at the air side are read by two differential pressure transducers, whose accuracy is 0.5%. All the measured data are obtained using a data acquisition system for further analysis.

The relative uncertainty analysis is studied using the estimation method. By using this method, the relative errors for the Colburn factor j and friction factor f are 3.12% and 3.87% respectively.

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