Proceedings of the 18th UK Heat Transfer Conference
9-11 September 2024, Birmingham
UKHTC2024

A MACHINE LEARNING APPROACH FOR THE PREDICTION OF FLOW BOILING HEAT TRANSFER COEFFICIENTS IN SMALL TO MICRO-TUBES

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1. ABSTRACT

Flow boiling in microchannels plays an important role in the future of cooling systems. However, to design efficient devices that exploit the benefits of latent heat cooling, it is necessary to develop a detailed understanding of the several complex phenomena that interact with each other and are extremely challenging to capture mathematically with physics-based models. This study explores the application of machine learning (ML) algorithms to demonstrate their predictive abilities in the absence of detailed deterministic knowledge. The work leverages the extensive Brunel Two-phase Flow Database to extract the explanatory variables needed for predictions and uses various regression models to predict the heat transfer coefficient in single small to micro tubes with diameters ranging from 0.52 to 4.26 mm. The preliminary results demonstrate that the ML algorithm can predict accurately, albeit caution is needed when extrapolating beyond the ranges of the data used for training.

2. INTRODUCTION

The application of micro-evaporators for cooling electronic devices has the potential to reduce the capital cost when manufacturing thermal management systems used in a number of industries and applications including renewable energy systems, electric vehicles and charging stations, refrigeration and components in computers and information technology systems and other high-power semiconductor devices, [1]. However, designing such systems remains a challenge due to the complexity of the phenomena involved at the microscale. Several research studies have focussed on developing mechanistic or statistically derived models to predict the heat transfer coefficient (HTC) in such systems [2–4]. The desired output is a simple yet accurate way to predict the heat transfer coefficient needed for the design. This is currently a developing area and it is now considered that machine learning algorithms could also have a role to play and should be considered as they have the ability to estimate the desired output variables (e.g. the HTC) by learning the underlying complex correlations among the input variables. As a result, while expert knowledge of the system is still needed for an ML model to be applied successfully, detailed information about the system is not, making these algorithms very promising to predict quantities of interest in complex systems such as those in focus here. This study aims to explore the ability of ML algorithms to predict flow boiling heat transfer coefficients in microchannels.

3. METHODOLOGY

The framework for data regression proposed by Loyola-Fuentes *et al.* [5] is used here to analyse and predict the heat transfer coefficients reported in the Brunel Two-phase Flow Database. This extensive database comprises 27,126 data points for flow boiling in single and multi-microchannels of various materials, shapes, dimensions and lengths. The methodology used comprises six steps: 1) Data pre-processing, 2) Features and

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target variable selection, 3) Selection of training and testing data, 4) training and testing stages, 5) Hyperparameter tuning, and 6) Performance assessment [4].

4. RESULTS

First, a preliminary analysis has been carried out on the dataset to provide a statistical summary including the main features of the data and the variables' distribution. Figure 1 illustrates the raw data distribution of the variables that have been measured during the experiments.

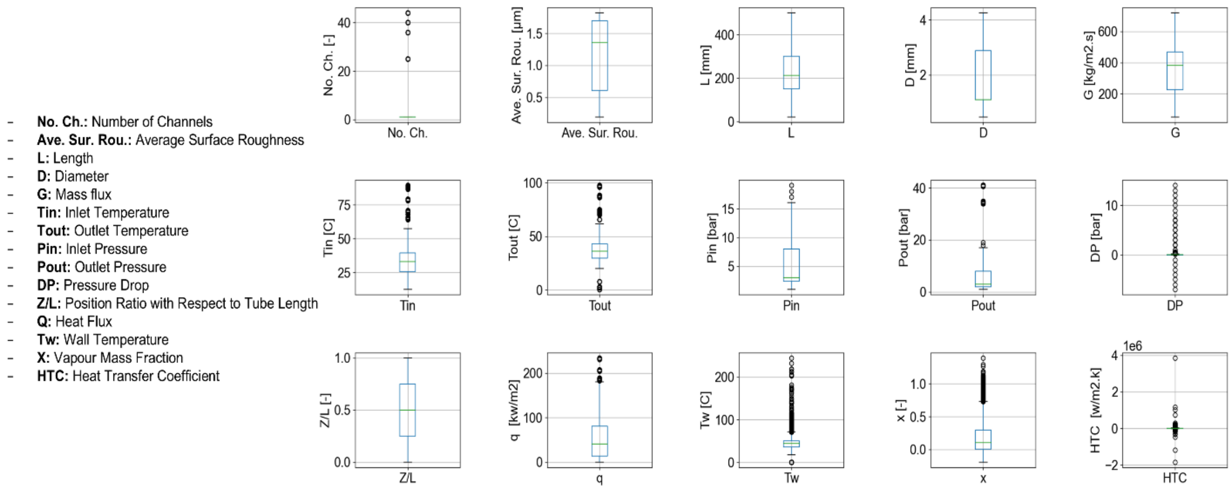

Figure 1: Raw data distribution of input variables and heat transfer coefficient.

Filtering procedures have been applied to remove out-of-scope, i.e. single-phase, multichannel, and rectangular-shape channels. Thereafter, approximately 72% of the dataset was kept for the next steps of the workflow. The remaining data contains only experiments with round small and microchannels of internal diameter 0.52, 1.1, 2.01, 2.88 and 4.26 mm in a two-phase flow. On this remaining data, a correlation analysis and a feature importance analysis have been carried out to reveal correlations between the system's variables and to identify the most relevant features (variables) for the prediction of the HTC. The result of the feature importance analysis is illustrated in Figure 2. The most relevant features in the order of relevance are heat flux (q), inlet pressure (P_{in}), and wall temperature (T_w).

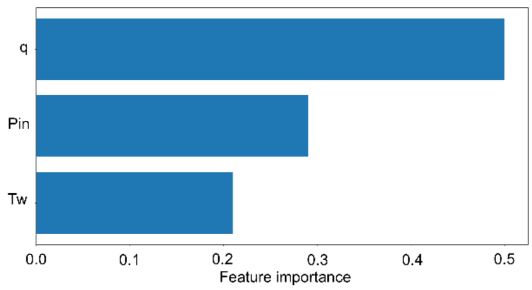

Figure 2: Relevant variables determined with feature importance analysis for the prediction of the flow boiling HTC.

An artificial neural network is applied to the filtered dataset for the prediction of the flow boiling HTC by selecting a set of hyperparameters. The model is trained on 80% of the dataset and tested on the remaining 20% of the data that has not been seen by the model in the training step. Figure 3 shows the parity plots for training and testing of the model together with the residual plots for both stages. The MAPE of the model both on training (8%) and testing (9%) sets show that the employed ML model has been able to learn the underlying correlations among the variables to accurately predict the HTC of this system. The residuals analysis, however, shows that the model tends to underestimate the HTC, both in training and testing sets, for values larger than 25,000 W/m^2K. This potentially can be due to the lower number of experiments for values in this range.

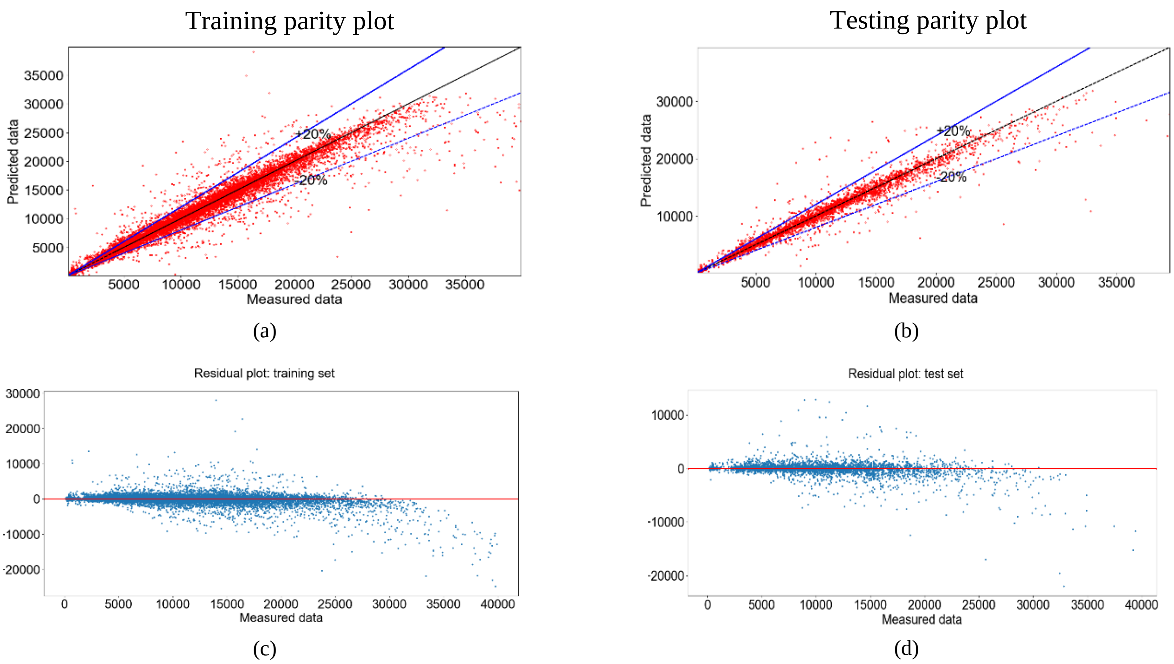

Figure 3: (a) Training and (b) Testing parity plots; (c) Training and (d) Testing residual plots of the applied ANN model

5. CONCLUSIONS

In this study, the application of a machine learning modelling framework has been extended and assessed against the Brunel Two-Phase flow Database of flow boiling in microchannels. First, the data has been pre-processed to develop a better understanding of the variables and their correlation for the estimation of the heat transfer coefficient. An artificial neural network has been trained to predict the flow boiling heat transfer coefficient and the results show that the model accurately predicted the HTC of an unseen dataset by the model but care needs to be taken when extrapolating the results beyond the conditions present in the training dataset. Additional work is needed to better determine the explanatory variables used for predictions and assess the extrapolation capabilities of the model.

ACKNOWLEDGMENTS

The support of EPSRC (EP/T033045/1) for the work at Brunel University London and the help of Dr A. Al-Zaidi in collating the data are acknowledged.

REFERENCES

1. T.G. Karayiannis, M. M. Mahmoud, Flow boiling in microchannels: fundamentals and applications, Applied Thermal Engineering, 115 (2017),1372-1397.
2. M.M. Mahmoud, T.G. Karayiannis, Heat transfer correlation for flow boiling in small to micro tubes, Int J Heat Mass Transf 66 (2013) 553–574. https://doi.org/10.1016/j.ijheatmasstransfer.2013.07.042.
3. Y. Wang, K. Sefiane, S. Harmand, Flow boiling in high-aspect ratio mini- and micro-channels with FC-72 and ethanol: Experimental results and heat transfer correlation assessments, Exp Therm Fluid Sci 36 (2012) 93–106.
4. J.R. Thome, V. Dupont, A.M. Jacobi, Heat transfer model for evaporation in microchannels. Part I: presentation of the model, Int J Heat Mass Transfer 47 (2004) 3375–3385. https://doi.org/10.1016/j.ijheatmasstransfer.2004.01.006.
5. J. Loyola-Fuentes, N. Nazemzadeh, E. Diaz-Bejarano, S. Mancin, F. Coletti, A framework for data regression of heat transfer data using machine learning, Appl Therm Eng 248 (2024) 123043. https://doi.org/10.1016/j.applthermaleng.2024.123043