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Use of Artificial Neural Networks for Prediction of the Convective Heat Transfer Coefficient in Evaporative Mini-Tubes

Uso de redes neuronales para la predicción del coeficiente de transferencia de calor por convección de la evaporacion en minitubos

Romero-Méndez Ricardo
Universidad Autónoma de San Luis Potosí
Faculty of Engineering
E-mail: rromerom@uaslp.mx

Lara-Vázquez Patricia
Universidad Tecnológica de San Luis Potosí
E-mail: patylarav@gmail.com.

Oviedo-Tolentino Francisco
Universidad Autónoma de San Luis Potosí
Faculty of Engineering
E-mail: francisco.oviedo@uaslp.mx

Durán-García Héctor Martín
Universidad Autónoma de San Luis Potosí
E-mail: hduran@uaslp.mx

Pérez-Gutiérrez Francisco Gerardo
Universidad Autónoma de San Luis Potosí
Faculty of Engineering
E-mail: francisco.perez@uaslp.mx

Pacheco-Vega Arturo
California State University, Los Angeles
Department of Mechanical Engineering
E-mail: apacheco@calstatela.edu

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Abstract

In this work, *artificial neural networks* (ANNs) are used to characterize the convective heat transfer rate that occurs during the evaporation of a refrigerant flowing inside tubes of very small diameter. An experimental setup based on an inverse Rankine refrigeration cycle is used to obtain the heat transfer data in an R-134a refrigerant mini-tube evaporator set operated under constant heat flux conditions. A considerable amount of data was acquired to map the thermal performance of the evaporative process under analysis, 75% of which were used for training the ANN and 25% were reserved for prediction purposes. Several neural network configurations were trained and the most accurate was selected to predict the thermal behavior. The results obtained in this investigation reveal the convenience of using ANNs as an accurate predictive tool for determination of convective heat transfer rates inside mini-tube evaporators.

Keywords:

- artificial neural networks
- thermal systems
- compact evaporators
- mini-tubes
- convective heat transfer

Resumen

En esta investigación se utilizan redes neuronales para determinar la tasa de transferencia de calor convectiva durante la evaporación de un refrigerante en el interior de un minitubo. Se desarrolló un sistema experimental, incluye un ciclo de refrigeración basado en el ciclo de Rankine inverso, instrumentado con equipo de medición y un sistema de adquisición de datos para obtener información del desempeño térmico bajo diferentes condiciones de operación. Con este banco de pruebas experimental fue posible obtener una cantidad considerable de datos que permiten caracterizar el desempeño térmico del proceso de evaporación en consideración. Un 75% de las mediciones se usan para entrenar varias configuraciones de red neuronal y 25% de los datos se emplean para determinar el error de predicción de cada configuración. Los resultados obtenidos en esta investigación demuestran la conveniencia de usar redes neuronales artificiales para la determinación correcta de la transferencia de calor evaporadores de minitubos.

Descriptores:

- *redes neuronales artificiales*
- *sistemas térmicos*
- *evaporadores compactos*
- *minitubos*
- *transferencia de calor por convección*

Introduction

Recent developments of high performance electronic equipment have led to a general reduction of spacing and increase in power. This fact has created a need for efficient heat dissipation. In response to this demand, miniature-size compact heat exchangers with capacity to operate as efficient heat sinks have been recently developed. The reduction of channel size is now a reality and mini-tubes with hydraulic diameters from 200 μm to 3 mm are commonly used. The problem, however, is that the heat transfer and pressure drop in this kind of systems may be significantly different from what has been reported in conventional size evaporators, and there is a lack of reliable information about the thermal performance of these devices.

Much of the progress of heat transfer has been driven by the necessity to predict the performance of a thermal system, which results from applications of fundamental laws (mass, momentum, and energy conservation) for basic problems, supplemented with empirical correlations for more complex cases (complexities stemming from system geometry, flow conditions and appearance of simultaneous heat transfer mechanisms). Unfortunately, there are critical applications related to energy efficiency, environmental impact, optimal system design and control, where traditional techniques fail to provide an adequate prediction and more advanced prediction methods are required. While the thermal sciences must continue to gradually increase knowledge and insight of fundamental phenomena, there are some new technologies, such as artificial neural networks (ANNs) that can be used as application tools to supplement such understanding. This is particularly true in the case of complex flow situations occurring in novel applications, such as the cooling of electronic devices with miniature size evaporators.

Heat transfer prediction of condensation and evaporation processes in refrigeration and air conditioning units is a complex task when compared to the prediction of single phase heat transfer. Traditional power-law correlations have proved to be inaccurate for this kind of processes, even though there is a need of good predictions in these applications. For instance, using their correlation for forced convective boiling, Gungor and Winterton (1986) obtained errors of 21.4% for saturated boiling and 25% for sub-cooled boiling with respect to their own measurements. Years later, it was shown that when experimental data from other authors are used, the errors from this and other correlations can be as large as 50%.The process of phase change in pipes undergoes a series of flow regimes, which go from single phase flow, onset of bubble formation, annular flow boiling, film boiling, mist flow and superheated vapor flow, depending on mass flow rate, degree of superheating, pressure, tube diameter, orientation and vapor quality. All these phenomena occur over a short pipe length. The inability of power-law correlations to catch up with all these phenomena occurring during two phase convection lies as the reason for the inaccuracy of the predictions.

One of the modern technologies that have been successful as an analysis tool is the technique of *artificial neural networks* (ANNs). This technique has been applied for pattern recognition, decision making, control systems, information processing, symbolic mathematics, computer vision and robotics. The use of ANNs has been extended to a wide variety of disciplines, among which are the thermal sciences, because it allows the study of complex thermal systems that otherwise