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Prediction of the air temperature and humidity at the outlet of a cooling coil using neural networks☆

K. Suleyman Yigit [a,*], H. Metin Ertunc [b]

[a] Mechanical Engineering Department, Kocaeli University, 41040 Veziroglu Campus, Kocaeli, Turkey
[b] Mechatronics Engineering Department, Kocaeli University, 41040 Veziroglu Campus, Kocaeli, Turkey

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Abstract

The main objective of this study is to predict air temperature and humidity at the outlet of a wire-on-tube type heat exchanger using neural networks. For this purpose, initially the heat exchanger was coupled to a refrigeration unit and placed in a wind tunnel. Afterwards, its performance was tested under various experimental conditions. We measured nine input parameters, namely, temperature and humidity of the air entering the coil, air velocity, frost weight, the temperature at the coil surface, mass flow rate of the heat transfer fluid and its temperatures at the inlet and outlet of the coil along with ambient temperature. Additionally, we measured temperature and humidity of the air leaving the coil as the output parameters. Then, a feed-forward neural network based on backpropagation algorithm was developed to model the thermal performance of the coil. The artificial neural network (ANN) was trained using the experimental data to predict the air conditions at the outlet of the coil. The predicted values are found to be in good agreement with the actual values from the experiments with mean relative errors less than 1% for outlet air temperature and 2% for outlet humidity. This demonstrates that the neural network presented can help the manufacturer predict the performance of cooling coils in air-conditioning systems under various operating conditions.

Keywords: Air conditioning; Refrigeration; Heat exchanger; Artificial neural network

1. Introduction

As the moist air comes into contact with a cold surface such as that of a cooling coil having a temperature below the air dew point temperature, the water vapour starts to condense and deposits on the cold surface [1]. Furthermore, when the surface temperature is below the freezing point, frost formation starts to occur on the cold surface. Thus, the water vapour in the air first changes into a liquid phase, and then to solid phase. In these cases, both heat transfer and mass transfer take place concurrently [2]. Therefore, the heat transfer process becomes very complicated during the transition of the water from the gas phase to solid phase.

On the other hand, the heat transfer rate at the cooling coil decreases as a result of the thermal resistance caused by the frost deposition between the tube and air stream [3]. Because the more the time passes the more the frost quantity

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* Corresponding author.
E-mail address: kyigit@kou.edu.tr (K.S. Yigit).

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Nomenclature

a	actual value
b	bias
f	activation function
m_{frost}	deposited frost mass (g)
$\dot{m}$	mass flow rate of coolant (l min^{-1})
MLP	multilayer perception
MRE	mean relative error
n	sum of the weighted inputs
N	number of data points in test set
p	predicted value
P	number of the elements in input vector
T	temperature (°C)
T_{iats}	inlet air temperature of test section (°C)
$T_{\text{cool-1}}$	coolant temperature at the entrance of the coil (°C)
$T_{\text{cool-2}}$	coolant temperature at the outlet of the coil (°C)
w_i	interconnection weights
x_{-i}	input vector

Greek symbols

ϕ	relative humidity (%)

Subscripts

air-in	inlet air of the wind tunnel
air-out	outlet air of the wind tunnel
amb	ambient

increases, the heat transfer through the frost layer to the cold coil surface decreases with time. Furthermore, growth of the frost layer decreases air flow area, which leads to increase the resistance against the air flow over the heat exchanger surface. Consequently, the capacity of the cooling coil will decrease significantly, thus causing a longer operation time of the cooling system and a higher operation cost due to increasing power consumption.

Various engineering techniques have been employed for designing and modelling heat exchangers that are used for industrial and domestic cooling systems. After the production, the refrigeration systems are tested whether they provides the operating conditions adequately or not. It is well recognized that frost grown on the heat exchangers is one of the major problems for refrigeration and air-conditioning systems [3]. Since frost formation depends on several operating conditions, it is very difficult to identify this process using only mathematical functions. Therefore, frost formation on heat exchangers has been attempted to model based on the data obtained by experimental studies.

Since the experimental research studies are very difficult and time consuming, the artificial neural network ANN techniques have been lately preferred for thermal applications such as heating, ventilating and air-conditioning systems, solar water heating, determination of critical heat flux, refrigeration systems and power generation systems. ANN is applied to estimate actual values within a certain error limits when enough experimental data are provided. Therefore, ANN can model physical phenomena in complex systems without needing explicit mathematical representations.

In literature, one can find considerable amount of research about thermal applications of neural networks. Pacheco-Vega et al. [4] applied the ANN for modelling the thermal characteristics of fin-tube refrigerating heat exchanger systems with limited experimental data. They presented a methodology based on the cross-validation technique to find