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Performance prediction for a parallel flow condenser based on artificial neural network

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HIGHLIGHTS

- Experiments have been done for a PF condenser used in electric vehicle.
- Distributed parameter model for PF condenser gives MRE = 3.89%.
- ANN model is determined with 9 hidden neurons.
- ANN shows the RMSE in the range of 0.00149–0.00605, R^2 between 0.99989 and 0.99999 and MRE in the range of 0.24143–1.31947%.

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ABSTRACT

This paper reports the use of artificial neural network (ANN) to predict the thermal performance of a parallel flow (PF) condenser with R134a as working fluid. The ANN predictions were compared with the distributed parameter model (DPM) calculation data, which had been validated by experiments at steady-state conditions while varying the air inlet temperature and velocity, refrigerant inlet temperature, pressure and mass flow rate. Based on the data deduced from DPM, ANN was built to predict heat exchange capacity, outlet refrigerant temperature and pressure drop for both air side and refrigerant side. The ANN was optimized for 6-9-5 configuration with Lavenberg–Marquardt (L–M) algorithm, which showed good performance with the root mean square error (RMSE) in the range of 0.00149–0.00605, correlation coefficient (R^2) in the range of 0.99989–0.99999 and mean relative error (MRE) in the range of 0.24143–1.31947%.

1. Introduction

Parallel flow (PF) heat exchangers with mini channels or micro channels are becoming well accepted as condenser to condense the refrigerant vapor [1,2]. Mini channel or micro channel tubes offer substantial refrigerant charge reductions over conventional round tube heat exchangers [3]. Because of its merits in thermal performance, structural robustness, compactness and weight reduction, PF condenser is extensively utilized in the automobile air conditioning system [4,5].

The performance of PF condenser such as heat exchange capacity, outlet refrigerant temperature and pressure drop are of great significance in refrigeration system design and optimization [6]. Numerous experimental studies have been done to measure the condenser thermal performance. Wang et al. [7] investigated flow distribution for U-type and Z-type PF heat exchangers by experiments and numerical simulations subject to various operating conditions. Chen et al. [8] done the experimental verification in cooling capacity and energy efficiency ratio (EER) of a condenser with liquid–vapor separation. Mathew and Hegab [9] conducted experimental investigation of the theoretical model for predicting the thermal performance of PF micro channel heat exchangers subjected to external heat flux. Fernando et al. [10] obtained heat transfer results during condensation of R290 inside a mini channel aluminum heat exchanger. Al-Hajri et al. [11] provided a comparison of heat transfer coefficients and pressure drops in a single micro channel by condensing R134a and R245fa.

Utilizing the samples from the experiments, ANNs can be applied to the problems with no algorithmic solutions or complex algorithmic solutions to be found. ANN is an easy modeling tool to obtain a quick preliminary assessment in response to the

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Nomenclature

A	area (m^2)
c_p	specific heat at constant pressure (kJ kg^{-1} K^{-1})
d	data points
D	diameter (m)
f	friction coefficient
h	enthalpy (kJ kg^{-1})
F	fin
j	j factor
L	louver
$\dot{m}$	mass flow rate (kg s^{-1})
n	number of data points
Nu	Nusselt number
p	pressure (kPa)
Δp	pressure drop (kPa)
Pr	Prandtl number
Q	heat exchange capacity (W)
R	radiating fin
Re	Reynolds number
T	temperature (K)
u	air velocity (m s^{-1})
x	vapor quality
z	weighted sum of the input

Greek letters

α	heat transfer coefficient (w m^{-2} K^{-1})
δ	thickness (m)
λ	thermal conductivity (w m^{-1} K^{-1})
μ	dynamic viscosity (Pa s)
ρ	density (kg m^{-3})
χ	wetted perimeter (m)
θ	angle of inclination (°)

Subscripts

a	air side
c	condenser
ac	actual data
d	long axis
eq	equivalent
f	fin
h	height
i	in
l	length
liq	liquid
min	minimum value
o	out
p	gap spacing
pre	predicted data
r/Ref.	refrigeration side
t	tube side
vap	vapor
w	wet bubble

engineering modifications to the condenser. Ertunc and Hosoz [12] applied ANN to predict the performance of a refrigeration system with an evaporative condenser, which showed that even complex system involving concurrent heat and mass transfer can be modeled within a high degree of accuracy. Xie et al. [13] and Arturo et al. [14] applied the ANN approach to accurately model the thermal characteristics of refrigerating heat exchangers based on limited experimental data. They found that ANNs could predict given experimental data with errors of the same order as the uncertainty of the measurements. Tan et al. [15] reported the use of ANN to simulate the thermal performance of a compact, fin-tube heat exchanger with air and water/ethylene glycol anti-freeze mixtures as the working fluids, which showed that ANNs were able to predict the overall rate of heat transfer in the exchanger with a high degree of accuracy.

Although there are many examples of ANN applications in heat exchangers, quite a few studies have been done on PF condenser. In this study, ANN method to predict the performance of a PF condenser with R134a as refrigerant was presented based on the data deduced from the distributed parameter model (DPM). In order to confirm the validity of the DPM, experiments have been done to study the thermal performance of PF condenser. Then, the Scaled Conjugate Gradient (SCG) algorithm and Levenberg–Marquardt (L–M) algorithm were utilized for training ANN model, respectively. Finally, the least error-yielding ANN was determined by L–M algorithm with 9 hidden layer neurons by trial and error. The results suggested that the ANN approach can reliably be used for forecasting performance of PF condenser.

2. Distributed parameter model for PF condenser

2.1. Distributed parameter model

The distributed parameter method was applied to establish a steady-state model for PF condenser. The condenser was divided into three parts: refrigerant side, tube side and air side. To simplify the research, the following assumptions were made.

(1) Parameters for all sides are not time-varying and under a stable condition.
(2) Both refrigerant flow and air flow are one-dimensional.
(3) The distribution of refrigerant is uniform and the pressure drop influence is neglected.
(4) The heat conduction along axial direction and radiation heat transfer are ignored.

2.1.1. Heat transfer coefficient

The structure of louver fin has a great influence on air side heat transfer and flow performance, thus traditional Nusselt number is not suitable to calculate the air side heat transfer coefficient. The j factor empirical correlation compiled from the experimental data for 91 kinds of louver fin showed that the average relative error between predicted data and experimental data was 8.21% [16]. Therefore the j factor empirical correlation was utilized to predict the air side heat transfer coefficient.

$$\alpha_a = j \cdot c_{pa} \cdot u_a \cdot \rho_a \cdot \mathrm{Pr}_a^{-2/3} \tag{1}$$

$$j = \mathrm{Re}_a^{-0.49} \cdot \left(\frac{\theta}{90}\right)^{0.27} \cdot \left(\frac{F_P}{L_P}\right)^{-0.14} \cdot \left(\frac{F_l}{L_P}\right)^{-0.29} \cdot \left(\frac{R_d}{L_P}\right)^{-0.23} \times \left(\frac{L_l}{L_P}\right)^{0.68} \cdot \left(\frac{R_P}{L_P}\right)^{-0.28} \cdot \left(\frac{\delta_f}{L_P}\right)^{-0.05} \quad (100 < \mathrm{Re}_a < 3000) \tag{2}$$

where $\mathrm{Re}_a = D_a \cdot M_a / \mu_a$, $D_a = 2 \cdot F_P \cdot F_h / F_P + 2\sqrt{F_P^2/4 + F_h^2}$, $\mathrm{Pr}_a = \mu_a \cdot c_{pa} / \lambda_a$.

As for the refrigerant side, the heat transfer section can be divided into superheated region, two-phase region and sub-cooled