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Abstract

The finite difference method in conjunction with the least-squares scheme and the experimental temperature data is proposed to predict the average heat transfer coefficient and the fin efficiency on the fin inside one-tube plat finned-tube heat exchangers for various air speeds and the temperature difference between the ambient temperature and the tube temperature. Previous works showed that the heat transfer coefficient on this rectangular fin is very non-uniform. Thus the whole plate fin is divided into several sub-fin regions in order to predict the average heat transfer coefficient and the fin efficiency on the fin from the knowledge of the fin temperature recordings at several selected measurement locations. The results show that the surface heat flux and the heat transfer coefficient on the upstream region of the fin can be markedly higher than those on the downstream region. The fin temperature distributions depart from the ideal isothermal situation and the fin temperature decreases more rapidly away from the circular center, when the frontal air speed increases. The average heat transfer coefficient on the fin increases with the air speed and the temperature difference between the ambient temperature and the tube temperature. This implies that the effect of the temperature difference

Introduction

The fins in heat exchangers are always applied to increase the heat flow per unit of basic surface. The analysis of a continuous plate fin pierced by a regularly spaced array of circular tubes in staggered and in-line arrays has many engineering applications. In order to simplify the problem considered, the calculation of the standard in efficiency usually assumes that the heat transfer coefficient is constant over the plate fin. Many investigators also applied various analytical and numerical methods to obtain the fin efficiency under the assumption of the uniform heat transfer coefficient. However, it is well known that there exists a very complex flow pattern within a plate finned-tube heat exchanger due to its three-dimensional nature and flow separations. The flow accelerates around the tube and forms a low-velocity wake region behind the tube. This causes local variations of the heat transfer coefficient, that there exists the great variation of the heat transfer rate on the fin inside a plate finned-tube heat exchanger. On the other hand, the heat transfer coefficient on the fin is very non-uniform. This also implies that the actual steady-state heat transfer coefficient on the fin-

Nomenclature:

A_r	area of the whole plate fin, m^2
A_j	area of *j*th sub-fin region, m^2
$[A]$	global conduction matrix
d_o	outer diameter of a tube, m
$[F]$	force matrix
h	local heat transfer coefficient, W/m^2 K
$\hbar$	unknown average heat transfer coefficient on the whole plate fin, W/m^2 K
$\hbar_j$	unknown average heat transfer coefficient on the *j*th sub-fin region, W/m^2 K
k	thermal conductivity of the fin, W/m K
L	side length of a square plate fin, W/m K
ℓ	distance between two neighboring nodes in the x- and y- directions
m	dimensionless parameter
Re_d	Reynolds number
r_o	outer radius of the circular tube, m
S_1	outer boundary surface of the circular tube temperature
T	temperature
T_j	temperature measurement on the *j*th sub-fin region
T_o	outer surface temperature of the circular tube
T_{oo}	ambient temperature
ΔT	temperature difference, $T_o - T_{oo}$
V_{air}	frontal air speed, m/s
X,Y	spatial coordinates, m

Greek symbols

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defined in Eq. (5)

m_j unknown dimensionless parameter on the *j*th sub-fin region defined in Eq. (10)

N number of temperature measurement on the fin

N_x number of nodes in the *x*-direction

N_y number of nodes in the *y*-direction

Q total heat flux dissipated from the whole plate fin, W

q_j heat flux dissipated from the *j*th sub-fin region, W

δ fin thickness

η_f fin efficiency

v kinematic viscosity of the air, m^2/s

Θ temperature difference, $T - T_{oo}$

$[\Theta]$ global temperature matrix

Superscripts

Call calculated value

mea measured data

inside a plate finned-tube heat exchanger should be the function of position, the measurements of the local heat transfer coefficient on plains fins under steady-state heat transfer conditions are very difficult to perform, since the local fin temperature and local heat flux are required. Thus the estimation of a more accurate heat transfer coefficient on the fin is an important task for the device of the high performance heat exchangers.

Quantitative studies of the heat transfer processes occurring in the industrial applications require accurate knowledge of the surface conditions and the thermal physical quantities of the material. It is well known that these physical quantities and the surface conditions can be predicted using the temperature measurements inside the material. Such problems are called the inverse heat conduction problems and have become an interesting subject recently. To date, various inverse methods in conjunction with the measured temperatures inside the material have been developed for the analysis of the inverse heat conduction problems. However, to the author's knowledge, a few investigators performed the prediction of the local heat transfer coefficients on the fin inside the plate finned-tube heat exchangers.

Maillet applied the analytical and boundary element methods to predict the heat transfer coefficient on a cylinder. Lin used the finite-difference method in conjunction with the linear least-squares scheme to estimate the space-variable heat transfer coefficient on a heated cylinder normal to the laminar and turbulent air streams. Owing to the requirements of the local fin temperature measurements, the estimations of the local heat transfer coefficients on the plate fin under steady-state heat transfer conditions are generally more difficult than that on the boundary surface of a physical geometry. Thus a few researchers predicted the distribution of the local heat transfer coefficients on a plate fin. Jones and Russell applied the transient technique to determine the local heat transfer coefficient on the rectangular fin pierced by an elliptical steel tube and then the finite element method was used to calculate its fin efficiency. Saboya and Sparrow and Rosman cost solid naphthalene plates in the form of a plate-fin-and-tube flow passage and used mass transfer techniques to infer the local heat transfer coefficients from the heat-mass transfer analogy. The local mass transfer coefficients were defined by measuring the thickness of naphthalene lost by sublimation during a timed test run. Recently, Ay performed an experimental study with the infrared thermovision to monitor the temperature distribution on a plate-fin surface inside the plate finned-tube heat exchangers, and then the local heat transfer coefficients on the tested fin can be determined using the obtained experimental temperature measurements. Huang applied the steepest descent method and a general purpose commercial code CFX 4.4 to estimate the local heat transfer coefficients for the plate finned-tube heat exchangers based on the simulated measured temperature distributions on the fin surface by infrared thermography. However, the difference of the local heat transfer coefficients in the wake and frontal regions of the tube and the fin efficiency on the fin inside the plate finned-tube heat exchangers were not shown in the works of Ay and Huang. Sometimes, it is may be difficult to measure the temperature distributions on the fin of plate finned-tube heat exchangers using the infrared thermography and the thermocouples for some practical heat transfer problems. Under the circumstances, the present scheme can be introduced for such problems.

The inverse analysis of the present study is that the whole fin area is divided into several analysis sub-fin regions and then the fin temperatures at these selected measurement locations are measured using K-type thermocouples. Afterwards, the finite difference method in conjunction with these temperature measurements and the least-squares method is applied to predict the average heat transfer coefficients on these sub-fin regions. Furthermore, the average heat transfer coefficient on the whole plate fin $\bar{h}$ and the fin efficiency can be obtained for various frontal air speeds under the given conditions of the ambient temperature and the tube temperature.

The advantage of the present study is that the governing differential equations for the airflow do not need to be solved. In this study, the effect of the temperature difference between the ambient temperature and the tube temperature on the estimation of the $\bar{h}$ value will be investigated. The computational procedure for the estimates of the heat transfer coefficients on each sub-fin regions is performed repeatedly until the sum of the squares of the deviations between the calculated and measured temperatures becomes minimum.