International Journal of Thermal Sciences 121 (2017) 294–304

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Numerical investigation of heat transfer and pressure drop of heat transfer oil in smooth and micro-finned tubes

M. Dastmalchi*, A. Arefmanesh, G.A. Sheikhzadeh

Department of Mechanical Engineering, University of Kashan, 87317-51167, Kashan, Iran

ARTICLE INFO

Article history:
Received 26 October 2016
Received in revised form
17 July 2017
Accepted 25 July 2017

Keywords:
Heat transfer
Pressure drop
Micro-finned tube
Numerical investigation

ABSTRACT

The laminar, non-isothermal flow of the heat transfer oil in horizontal smooth and micro-finned tubes with different fin heights and helical angles are investigated numerically for the constant wall temperature boundary condition. Simulations have been performed for the Reynolds number ranging from 100 to 1000, the fin height varying from 0.2 to 0.5 mm, and the fin helix angle between 5 and 45°. The results are presented in the form of streamlines, temperature contours, relative Nusselt number, and friction factor. The numerical procedure is validated by comparing the simulation results for the flow and heat transfer of the oil through the micro-finned and smooth tubes with the corresponding experimental results from the literature. The comparisons demonstrate good agreements between the simulation and the experimental results for both the smooth and micro-finned tubes. The results indicate maximum heat transfer enhancement of 44 percent and friction factor increase of 69 percent for the flow of heat transfer oil through the micro-finned tubes in comparison with heat transfer and friction factor of the fluid flow through the corresponding smooth tube at the Reynolds number of 10^3.

1. Introduction

Designing highly efficient compact heat exchangers has been an engaging area of heat transfer research in recent years. Extending the heat transfer surface in such devices is a common approach to enhance the heat transfer. Employing helically micro-finned tubes, which increase the heat transfer surface without affecting the overall size of the heat transfer device significantly, is a prevalent approach to accomplish this objective. Commercial applications of internally enhanced tubes to achieve an optimal heat transfer rate have increased substantially in recent years. For example, the refrigeration industry benefits from the tube roughness on the water-side of large refrigeration evaporators and condensers. Considering that, even for the refrigerant condensers and evaporators, a significant length of the heat exchangers is in the single-phase subcooled or superheated vapor regions, the need for accurate single-phase heat transfer and pressure drop correlations seems obvious.

The characteristics of fluid flow inside the helically finned tubes are not thoroughly understood yet due to the experimental and numerical limitations. Li et al. [1] investigated the heat transfer mechanism in helically finned tubes through flow visualizations. They concluded that the flow have parabolic patterns in the laminar regime; however, these patterns broke down because of the random separation of vortices in the turbulent regime. Raviguruajan and Bergles [2] conducted experiments on the flow of water inside a Plexiglas tube with a coiled wire insert. They observed that the fluid flow was dominated by a rotational pattern for the helix angles less than 30° and by a crossover pattern for the helix angles larger than 70°.

A number of recent experimental studies have been conducted on the single-phase fluid flow through micro-finned tubes. Copetti et al. [3] studied the heat transfer and friction characteristics for water flowing in the micro-finned tubes experimentally. As far as comparisons with the corresponding smooth tube were concerned, they observed up to 190% increase of the heat transfer coefficient for the micro-finned tubes in the turbulent flow regime. However, in the laminar flow regime, the heat transfer coefficient increased by about 20% over that of the corresponding smooth tube. In another experimental study, Han and Lee [4] investigated the single-phase heat transfer and fluid flow characteristics of the micro-finned tubes. To evaluate the heat transfer enhancement performance, they introduced an efficiency index. As far as the efficiency index was concerned, they observed that the tubes with a

---

* Corresponding author.
E-mail address: majid.dastmalchi@gmail.com (M. Dastmalchi).

http://dx.doi.org/10.1016/j.ijthermalsci.2017.07.027
1290-0729/

Nomenclature

c_p	specific heat, J/kg.K
d	tube diameter, m
e	fin height, m
f	Darcy's friction factor
g	gravitational acceleration, m/s^2
h	heat transfer coefficient,W/m^2.K
k	thermal conductivity, W/m.K
L	tube length, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number
p	pressure, Pa, and fin pitch, m
Re	Reynolds number
t	fin width, m
r, z	dimensional coordinates, m
T	temperature, K
v	velocity, m/s
U	Uniform inlet velocity, m/s

Greek symbols

α	helix angle
β	apex angle
μ	dynamic viscosity, N.s/m^2
θ	dimensional coordinates
ρ	density, kg/m3

Subscripts

b	bulk
f	fluid
i	inlet
o	outlet
p	particles
w	wall

higher relative roughness and a smaller spiral angle demonstrated better heat transfer performance compared to the tubes with a larger spiral angle and a smaller relative roughness. Naphon and Sriromruln [5] investigated the heat transfer and the pressure drop characteristics of horizontal double-pipes with and without a coiled wire insert. They observed that the coiled wire insert had a significant effect on the enhancement of heat transfer. However, the friction factor of the tube with the coiled wire insert increased simultaneously. Li et al. [6] measured the pressure drop and the heat transfer of oil and water flowing through a micro-finned tube experimentally. Their results showed that there was a critical Reynolds number, Re_{cr}, for the heat transfer enhancement. For $Re < Re_{cr}$, the heat transfer in the micro-finned tube was the same as that of the corresponding smooth tube; however, for the Reynolds numbers larger than Re_{cr}, the heat transfer in the micro-finned tube was gradually enhanced over that of the corresponding smooth tube with increasing the Reynolds number. Afroz and Miyara [7] measured the pressure drop of a single-phase turbulent fluid flow inside the herringbone micro-finned tubes for different fin dimensions experimentally in order to develop a general correlation for the single-phase fluid flow friction factor for such tubes. Their results indicated that larger helix angle and fin height resulted in a greater pressure drop inside the herringbone micro-finned tubes. Furthermore, the pressure drop of the herringbone tube was significantly higher than those of the helical micro-finned and smooth tubes depending on the fin geometric parameters and the mass velocity of the working fluid. Zdaniuk et al. [8] determined the heat transfer coefficient and the friction factor for eight different micro-finned tubes as well as for one smooth tube experimentally. Their results indicated that a micro-finned tube with a helix angles of 48°, the ratio fin height to tube diameter of 0.0244, and a number of fins equal to 48 could be recommended for the heat exchanger applications due to its high j-factors and moderate f-factors for all of the considered Reynolds numbers. Siddique and Alhazmy [9] investigated the single-phase heat transfer and pressure drop characteristics for the turbulent fluid flow inside a double-pipe heat exchanger with micro-finned tubes experimentally. They correlated the heat transfer and the pressure drop data with Dittus–Boelter and Blasius type relations, respectively. They concluded that the microfins had a significant effect on both the heat transfer rate and the pressure drop in such tubes. Bharadwaj et al. [10] studied the pressure drop and the heat transfer characteristics of water flowing in a micro-finned tube with a twisted tape insert experimentally. They considered a wide range of fluid flow regimes from Laminar to fully turbulent. For a constant pumping power, their results demonstrated that the grooved tube without a twisted tape yielded maximum heat transfer enhancements of 400% in the laminar range and 140% in the turbulent range compared to the heat transfers of the corresponding smooth tube. Similar comparisons for the spirally grooved tube with a twisted tape showed maximum enhancement of 600% in the laminar range and 140% in the turbulent range compared to the values for the corresponding smooth tube. Celen et al. [11] investigated the single phase pressure drop characteristics of smooth and micro-finned tubes experimentally. They employed a horizontal counter-flow, double-tube heat exchanger as their test section. Their measurements showed that the friction factor and the pressure drop for the micro-finned tube were generally higher than the corresponding value for the smooth tube; implying that the micro-finned tube generated more flow disturbances as a result of the swirl and the recirculation caused by the fins which led to larger pressure drops. Very recently, Akhavan-Behabadi et al. [12] investigated the laminar convective heat transfer of the heat transfer oil-copper oxide nanofluid flowing through horizontal smooth and micro-finned tubes with constant wall temperature experimentally. Based on these experiments, they concluded that the Nusselt number of the base fluid flowing in the micro-finned tube increased by 56% compared to that of base fluid flowing through the smooth tube. Derakhshan et al. [13] and Hekmatipour et al. [14] investigated the mixed convection heat transfer characteristics of MWCNT and copper oxide-heat transfer oil nanofluids flowing inside smooth and micro-finned tubes experimentally. Their results indicated that employing the nanofluid instead of the pure fluid was a more effective way to enhance the convective heat transfer coefficient compared to utilizing the micro-finned tube.

There are only a few numerical studies devoted to the non-isothermal fluid flow through micro-finned tubes. Kim et al. [15] employed a stabilized finite element solver to simulate the turbulent fluid flow and heat transfer in a micro-finned tube numerically. They assumed that, for the fully developed regime, the velocity components became periodic in a helical coordinate system. They concluded that, among the considered turbulence models, the Goldberg model performed the best. Recently, Ağra et al. [16] investigated the pressure drop and heat transfer characteristics of five different micro-finned tubes for the turbulent flow regime