International Communications in Heat and Mass Transfer 46 (2013) 58–66

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

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

Experimental analysis of the single phase pressure drop characteristics of smooth and microfin tubes ☆

Ali Celen [a], Ahmet Selim Dalkilic [a,*], Somchai Wongwises [b]

[a] Heat and Thermodynamics Division, Department of Mechanical Engineering, Yildiz Technical University (YTU), Yildiz, Besiktas, Istanbul 34349, Turkey
[b] Fluid Mechanics, Thermal Engineering and Multiphase Flow Research Lab. (FUTURE), Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangmod, Bangkok 10140, Thailand

ARTICLE INFO

Available online 6 June 2013

Keywords:
Microfin tube
Pressure drop
Friction factor
Single-phase flow

ABSTRACT

In this study, the single phase pressure drop characteristics of smooth and microfin tubes are investigated experimentally. The horizontal test section is a counter flow double tube heat exchanger with water flowing in the inner tube and cooling water flowing in the annulus. By means of experimental setup, required temperature and pressure measurements are recorded and friction factor coefficient and pressure drop of smooth and microfin tubes are determined. Experiments are conducted for mass flow rates in the range between 0.023 kg/s and 0.100 kg/s and effect of Reynolds number on pressure drop is investigated. By using experimental results, Blasius type friction factor equations are developed for both smooth and microfin tubes. Experimental results for both smooth and microfin tubes are compared with correlations given in the literature.

1. Introduction

In today's world, heat transfer enhancement has become a very important issue. Heat transfer enhancement in heat exchangers results in reduced size, low cost and improved heat transfer performance. There are two techniques for heat transfer enhancement: Active and passive techniques. First one is not popular technique because it requires the addition of external power. Passive heat transfer enhancement consists of alteration to the heat transfer surface such as extended surfaces, treated surface etc. Among the passive heat transfer enhancement techniques, the usage of microfin tubes is very popular because of their high heat enhancement and low increase in pressure drop when they are compared with smooth tube. Fuji et al. [1] invented the microfin tube. Geometric parameters which characterize microfin tubes are outside diameter, inside diameter, number of fins (ranges between 50 and 70), helix angle (ranges between 10° and 35°) and fin height (ranges between 0.1 and 0.4 mm). If the ratio of height and inside diameter of a microfin tube is between 0.02 and 0.04, this tube is classified as microfinned tube. If the ratio of height and inside diameter of a microfin tube is higher than 0.04, this tube is classified as finned tube. Microfin tubes are commonly used in HVAC applications (condensers and evaporators for cooling systems). The literature review on this subject is given in the following paragraphs and shown in Table 1.

Wang et al. [2] performed an experimental study related to single phase heat transfer and pressure drop characteristics of micro-fin tubes. In their study, they used double-pipe heat exchanger with water as test fluid and tested a smooth tube and seven micro-fin tubes each having different geometrical parameters. Wilson plot technique [3] is used in order to determine inside and outside heat transfer coefficients of test tubes. Their study showed that critical Reynolds number is an important parameter for enhanced heat transfer. They suggested that heat transfer data can be correlated by using heat-momentum transfer analogy instead of Dittus–Boelter type equation. As a result of their study, they produced heat transfer and pressure drop correlations in the range of $2500 < Re < 4000$ which can predict micro-fin data with high accuracy.

Copetti et al. [4] compared experimentally heat transfer performance of smooth and micro-fin tubes at different flow rates. In the experimental setup, water is used as test fluid and tubes having 9.52 mm diameter is used. They compared measured friction factor data with Blasius [5] and Petukhov [6] equations and heat transfer coefficient data with Dittus–Boelter [7] and Gnielinski [8] equations. They developed correlations for prediction of micro-fin heat transfer data and compared them with experimental results. The experimental study showed that heat transfer coefficient of micro-fin tube was 2.9 times higher than smooth tube in turbulent flow. Although pressure drop of micro-fin tube was 1.7 times higher than smooth tube, heat transfer increase was approximately 80%.

Wei et al. [9] presented an experimental study in order to determine single phase heat transfer and pressure drop in micro-fin tubes by using water and oil as working fluids. In the study, experiments were conducted for Reynolds number ranging between 2500 and 90,000 and Prandtl number varying between 3.2 and 220. Their study showed that critical Reynolds number is an important parameter for heat transfer enhancement. In the case of Reynolds number that is below critical

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: dalkilic@yildiz.edu.tr (A.S. Dalkilic).

0735-1933/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.icheatmasstransfer.2013.05.010

Nomenclature

A	actual flow area of tube [m^2]
A_n	nominal flow area of tube [m^2]
D	inside tube diameter [m]
D_h	hydraulic diameter [m]
D_o	outside tube diameter [m]
D_e	equivalent tube diameter [m]
e	height of fin [m]
f	friction factor
G	mass flux [kg/m^2s]
L	length of test tube [m]
l_c	characteristic length [m]
m	mass flow rate [kg/s]
n	number of fins
N	number of experiments
p	fin pitch [m]
s	average fin thickness [m]
ΔP	pressure drop [mbar]
Re	Reynolds number
t	fin tip thickness [m]
V_m	average fluid velocity [$m\ s^{-1}$]
μ	dynamic viscosity [Pa·s]
α	helix angle (°)
ρ	density of fluid [$kg\ m^{-3}$]

Reynolds number micro-fin tubes behave as smooth tube. For Reynolds numbers higher than critical Reynolds number, heat transfer enhancement can be observed. Their studies showed that heat transfer performance of micro-fin tube for Reynolds number greater than 30,000 with water as working fluid is two times higher than smooth tube. Friction factors of smooth and micro-fin tubes are just about equal for Reynolds number less than 10,000 but friction factor of micro-fin tube is 40–50% higher when it is compared with smooth tube for Reynolds number higher than 30,000.

Siddique and Alhazmy [10] studied heat transfer and pressure drop characteristics inside microfin tube for single phase flow. Double pipe heat exchanger and micro-fin tubes having 7.94 mm outside diameter were used in the experimental setup. They correlated a Dittus–Boelter type correlation for prediction Nusselt number and a Blasius type correlation for prediction of friction factor. These correlations were compared with both experimental results and studies in the literature. Their study showed that friction factor and Nusselt number of micro-finned tube in the range of $3300 < Re < 22{,}500$ can predict by means of developed correlations.

Carvanos [11] investigated heat transfer performance of internal spiral and longitudinal finned tubes in turbulent flow in the range of $10{,}000 < Re < 100{,}000$, $0.7 < Pr < 30$ and $0° <$ helix angle $< 30°$. The author used Wilson plot technique [3] in order to determine heat transfer performance and fin tube efficiency. According to fin tube efficiency results, tubes having higher helix angle and heat transfer surface area have the best heat transfer performance among 11 test tubes. As another result of the study, the pressure drop correlation is proposed which includes the effect of helix angle.

Jensen and Vlakancic [12] proposed new correlations for prediction of Nusselt number and friction factor of both high and microfin tubes. They investigated effect of fin geometry to the performance of finned tubes by means of these correlations and compared friction factor and Nusselt number results with Filonenko [13] and Gnielinski [8] correlations for smooth tube, respectively. The correlations are applied to a smooth and 15 finned tubes having different outside diameter, inside diameter fin height, fin thickness and fin helix angle. Their study showed that friction factor and Nusselt number increased with increasing number of fins. As another result of their study, friction factor and Nusselt number increased with increasing fin height under the same conditions.

Zdaniuk et al. [14] experimentally studied single phase heat transfer characteristic of one smooth tube and eight helically finned tubes having the helix angle of 25°–28°, e/D ratios of 0.0199–0.0327, and number of fin between 10 and 45. They conducted experiments in order to determine fanning friction and Colburn j-factors in the range of between $12{,}000 < Re < 60{,}000$ by using water as test fluid. They evaluated the performance of the correlations with data of other researchers and showed average prediction errors between 30% and 40%.

Al Fahed et al. [15] performed an experimental study in order to determine heat transfer coefficients and friction factors of microfinned tube under turbulent flow conditions. Inside and outside heat transfer coefficients were determined by using Wilson's method [16] in the study. They produced empirical correlations for prediction of heat transfer and friction factor data. They stated that micro-finned tube heat transfer performance enhancement varied from 1.2 to 1.8 times higher than smooth tube and pressure drop increase changed between 1.3 and 1.8.

Han and Lee [17] conducted experiments related to single phase heat transfer and flow characteristics of micro-fin tubes. They tested four different tubes in order to indicate experimental friction factor and heat transfer coefficients in the Reynolds number range between 3000 and 40,000. Heat transfer coefficients and friction factor correlations were produced by means of experimental data in the study. Their performance was evaluated with mean square deviation and root mean square deviation which were lower than 6.4%. Their study revealed that performance of tube having smaller spiral angle and higher relative roughness showed better than tube having larger spiral angle and lower relative roughness among the tested tubes. They also stated that heat transfer area increase was an important parameter for efficiency index.

Table 1
Summary of studies about single-phase flow in micro-fin tube.

Researcher	Year	Fluid	Reynolds number	Number of tested tubes
Wang et al. [2]	1996	Water	$2500 < Re < 40{,}000$	8
Copetti et al. [4]	2004	Water	$2000 < Re < 20{,}000$	2
Wei et al. [9]	2007	Water & oil	$2500 < Re < 90{,}000$	1
Siddique and Alhazmy [10]	2008	Water	$3300 < Re < 22{,}500$	1
Carvanos [11]	1980	Water	$10{,}000 < Re < 100{,}000$	14
Jensen and Vlakancic [12]	1999	Water & EG	$10{,}000 < Re < 100{,}000$	16
Zdaniuk et al. [14]	2008	Water	$12{,}000 < Re < 60{,}000$	9
Al Fahedet al. [15]	1993	Water	$10{,}000 < Re < 30{,}000$	2
Han and Lee [17]	2005	Water	$3000 < Re < 40{,}000$	4
Wang and Rose [18]	2004	Water & R11 & EG	$2000 < Re < 163{,}000$	21
Naphon and Sriromruln [22]	2006	Water	$8000 < Re < 25{,}000$	2
Brognaux et al. [23]	1997	Water	$2500 < Re < 50{,}000$	3