Available online at www.sciencedirect.com
ScienceDirect
International Communications in Heat and Mass Transfer 34 (2007) 753 – 761
International Communications in HEAT and MASS TRANSFER
www.elsevier.com/locate/ichmt

Optimal Reynolds number of laminar forced convection in a helical tube subjected to uniform wall temperature ☆

H. Shokouhmand *, M.R. Salimpour

Department of Mechanical Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran

---

Abstract

In this study, fully developed laminar flow and heat transfer in a helically coiled tube with uniform wall temperature have been investigated analytically based on minimal entropy generation principle. The influence of coil curvature ratio and fluid properties, β_1 and β_2 on the optimum Reynolds number have been investigated for two well-known fluids viz. air and water. It was revealed that optimum Reynolds numbers decrease as curvature ratio increases except in the low ranges of curvature ratio where transition to turbulent flow occurs. In the range of the present study, a correlation predicting optimal Reynolds number was proposed for each fluid using least square analysis.

Keywords: Helically coiled tube; Entropy generation; Uniform wall temperature; Optimized Reynolds number

---

1. Introduction

Helically coiled tubes are utilized in compact heat exchangers, power plants, chemical reactors, refrigeration and many other engineering applications. Heat transfer coefficient and friction factor of these tubes are generally greater than their peers in a straight pipe due to the secondary flow motion induced by the curvature. Also, torsion of helically coiled tubes causes more complication in temperature and velocity fields. Because of practical importance, abundant studies have been done on the heat transfer coefficient and friction factor in these pipes [1–5]. Facão and Oliveira [6] investigated laminar flow and convective heat transfer in a curved rectangular channel numerically in a wide range of Dean and Reynolds numbers. The combined turbulent forced convective and radiative heat transfer of a participating medium in the entrance region of a curved pipe subjected to constant wall temperature was investigated numerically by Zheng et al. [7]. Naphon and Wongwises [8] made a quite comprehensive review on the works devoted to the flow and heat transfer in these tubes.

A good design of heat exchangers should include considerations about how to increase the heat transfer performance and reduce the pressure drop simultaneously. However, an inevitable problem challenges all heat exchanger designers, i.e., the methods to enhance heat transfer performance usually cost an increase of pressure loss. Thus, the optimal trade-

---

☆ Communicated by W.J. Minkowycz.

* Corresponding author.

E-mail addresses: hshokoh@ut.ac.ir (H. Shokouhmand), m_salimpour@yahoo.com (M.R. Salimpour).

0735-1933/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2007.02.010

Nomenclature

a	Inner radius of tube, m
b	Coil pitch, m
$C_1,\ldots,C_4$	Constants of Eq. (14)
C_P	Specific heat capacity, J/kg K
De	Dean number, $=Re(a/R_c)^{0.5}$
E	Error function
Ec	Eckert number, $=V^2/C_P T_\mathrm{w}$
f	Friction factor
h	Averaged convective heat transfer, W/m^2 K
He	Helical number, $=De/(1+\gamma^2)$
k	Thermal conductivity, W/m^2 K
L	Passage length of coil, m
m	Exponent in Eq. (13)
$\dot{m}$	Mass flow rate, kg/s
N_S	Entropy generation number
$(N_S)_P$	Entropy generation number due to friction loss
$(N_S)_T$	Entropy generation number due to heat transfer
Nu	Nusselt number, $=2ha/k$
P	Pressure, Pa
Pr	Prandtl number, $=\mu C_P/k$
Q	Total heat transfer, W
R_c	Curvature radius, m
Re	Reynolds number, $=2\rho Va/\mu$
$\dot{\mathrm{S}}_\mathrm{gen}$	Total entropy generation, W/K
St	Stanton number, $=h/\rho VC_P$
T	Fluid bulk temperature, K
V	Fluid average velocity, m/s

Greek letters

δ	Curvature ratio, $=a/R_c$
β_1	Dimensionless parameter, $=4k/\mu C_P$
β_2	Dimensionless parameter, $=\mu^3/32\rho^2 a^2 kT_\mathrm{w}$
γ	Dimensionless pitch, $=b/2\pi R_c$
λ	Dimensionless passage length of the coil, $=L/2a$
μ	Viscosity, kg/m s
ρ	Density, kg/m^3
τ	Dimensionless inlet temperature difference, $=(T_\mathrm{w}-T_\mathrm{i})/T_\mathrm{w}$

Subscripts

i	Inlet condition
cr	Critical value
L	Outlet condition
opt	Optimum value
w	Wall condition

off by selecting the most appropriate configuration and best flow condition has become the primary consideration in design work. From thermodynamic second law viewpoint, the optimal design can be achieved by minimization of total generated entropy due to heat transfer and friction loss. Based on the entropy generation minimization principle,