International Journal of Heat and Mass Transfer 77 (2014) 124–130

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Experimental and numerical study on heat transfer and flow resistance of oil flow in alternating elliptical axis tubes

A.R. Sajadi [a], S. Yamani Douzi Sorkhabi [b,*], D. Ashtiani [a], F. Kowsari [a]

[a] School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON M5S 3G8, Canada

A R T I C L E I N F O

Article history:
Received 17 December 2013
Received in revised form 3 May 2014
Accepted 9 May 2014
Available online 5 June 2014

Keywords:
Alternating elliptical axis tube
Convection coefficient
Nusselt number
Flow resistance
Heat transfer enhancement ratio

A B S T R A C T

As heat exchangers are used extensively in many engineering fields the increase of their heat transfer rate, while reducing their flow resistance has become one the most challenging aspects in heat transfer. In this study, heat transfer and flow resistance of alternating elliptical axis tubes is investigated both experimentally and numerically. The working fluid is heat transfer oil, and the flow's Reynolds number ranges from 300 to 2000. The grid and numerical models are generated using Gambit 2.4.6 and Fluent 6.3, which are verified by the experimental results. The numerical results show that decreasing the aspect ratio and pitch length, increases heat transfer and flow resistance. However, in order to compare the heat transfer and flow resistance simultaneously, the non-dimensional heat transfer enhancement ratio is defined. The comparison of this ratio shows that alternating elliptical axis tubes perform better than the flattened or circular ones. It is observed that this ratio increases with the increase in Reynolds number.

1. Introduction

Heat exchangers are widely used in many engineering fields, so their design and development are considered as a major field of study in heat transfer knowledge. Several heat transfer enhancement techniques have been introduced to improve the overall thermo-hydraulic performance of heat exchangers resulting in reduction of the heat exchangers' size and operating cost.

In general, there are two main approaches to enhance the heat transfer rate. The first one is called active methods and requires external power source such as surface vibration or electrostatic fields [1–4]. The second approach which is called passive methods performs the task without any direct input of external power. This type of enhancement is achieved by extended surfaces, adding nano-particles to the working fluid, use of tubes with special geometries, and so on [5–9]. The objective of using tubes with special geometries is to boost flow turbulence and to generate secondary flow. However, it should be noted that changing the geometry of tubes would result in more pressure drop. As a result, studying new geometries for tubes should consider both heat transfer enhancement and flow resistance.

Tan et al. [10] investigated convective heat transfer and fluid flow in twisted oval tubes experimentally and numerically. The experimental study showed that heat transfer and pressure drop increase simultaneously using these tubes compared to the smooth circular one. The effects of the geometrical parameters on the performance of the twisted oval tubes have been analyzed numerically. Their results revealed that the convective heat transfer coefficient and friction factor increase with the growth of axis ratio. However, they decrease with the increase in twist pitch length.

Pethkool et al. [11] studied turbulent water flow inside a helically corrugated tube experimentally. Results showed that the heat transfer and thermal performance of a corrugated tube are better than those of a smooth circular tube. Rainieri et al. [12] investigated the forced convective heat transfer in straight and coiled tubes, having smooth and corrugated walls experimentally for Ethylene Glycol where the Reynolds number varied from 150 to 1500. Their main conclusion was that the wall curvature and corrugation enhance heat transfer. They obtained the largest increment in heat transfer using corrugated helical coils. They also suggested that the combined passive technique based on wall corrugation and curvature represents an interesting solution for Reynolds numbers ranging from 150 to 1500.

Meng et al. [13] investigated the alternating elliptical axis tubes with water as the working fluid experimentally. They showed that the heat transfer of the alternating elliptical axis tubes is more than

* Corresponding author. Tel.: +1 (416) 9468216; fax: +1 4169787753.
E-mail address: syamani@mie.utoronto.ca (S. Yamani Douzi Sorkhabi).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.05.014
0017-9310/

Nomenclature

$\dot{m}$	flow's mass flow rate, kg/s
$\dot{W}$	pumping power, W
A	outer minor axis of AEA tube, m
a	inner minor axis of AEA tube, m
A_c	tube's cross sectional area, m^2
A_s	tube's surface area, m^2
B	outer major axis of AEA tube, m
b	inner major axis of AEA tube, m
C_p	isobaric specific heat, kJ/kg K
D	Hydraulic diameter, m
f	friction factor
Gz	Graetz number
h	convection coefficient, W/m^2 K
I	turbulence intensity
k	kinetic energy, J
L	tube's length, m
Nu	Nusselt number
P	tube's pitch length, m
p	tube's section perimeter, m
Pr	Prandtl number
T	temperature, K
t	time, s
U	flow's mean velocity, m/s
u, v, w	physical velocity components, m/s
X	axial position within the tube, m
x, y, z	x, y, and axial direction coordinates
y^+	non-dimensional distance from the wall, $y(\lvert\tau_{wall}\rvert/\rho)/\nu$

Greek symbols

ΔP	pressure drop, kPa
ΔT_b	bulk temperature difference, K
ΔT_m	logarithmic mean temperature difference, K
$\dot{\forall}$	flow's volume flow rate, m^3/s
ϵ	dissipation rate, J
κ	thermal conductivity, W/m K
μ	dynamic viscosity, Pa s
ν	kinematic viscosity, m^2/s
ρ	density, kg/m^3
ε	effectiveness

Subscripts

b	bulk
c	cross sectional
D	hydraulic diameter
in	inlet
max	maximum
out	outlet
s	surface
t	turbulent
$wall$	wall

that of the twisted elliptical and the corrugated tubes for equal pumping power within a wide range of Reynolds numbers (500 to 5×10^5). Chen et al. [14] investigated flow in an alternating horizontal or vertical oval cross-section pipe with computational fluid dynamics. They showed that it is difficult to find an optimized geometry that can perform well for a wide range of Reynolds numbers. However, their results indicated that the pipe, if well designed, can perform better than a circular pipe for the flow conditions specified in their paper.

Despite the above mentioned studies, there is not sufficient work done about heat transfer and flow resistance of high Prandtl number fluids in noncircular tubes. The present work investigates both experimental and numerical results for heat transfer and flow resistance of heat transfer oil in alternating elliptical axis tubes. The effects of changing the geometry on these two main parameters are studied for the Reynolds numbers ranging from 300 to 2000.

2. Experimental setup

As the first step towards explaining the experimental setup, Alternating Elliptical Axis (AEA) tube is shown in Fig. 1. AEA tubes are developed based on boundary layer breakage principle. Regrading this principle, a circular tube is flattened alternately with 90° rotation of its cross-section in each segment. AEA tubes are put into practice with five different geometrical characteristics presented in Table 1. It should be noted that all the investigated tubes are made of copper, their outer diameter in the circular section is $\frac{5}{8}''$, and their thickness is 0.63 mm.

The experimental apparatus is shown schematically in Fig. 2. It mainly consists of a reservoir tank, a pump, a flow loop, a test section, a cooler, and a steam supplier tank. The transparent plastic reservoir tank with the capacity of 4 l is utilized to reserve the working fluid and monitor its height. In order to measure the tube's wall temperature, six K-type thermocouples are mounted on it with equal distances from each other. The bulk temperature of the working fluid is measured by two other K-type thermocouples at the entrance and exit of the test section. Two adjusting valves control the flow rate, one at the end of the test section and the other at the by-pass line. A shell and tube heat exchanger is used as a cooler to reduce the temperature of the working fluid. The 50-l steam supplier tank is fitted with an 8 kW element heater to generate fully saturated vapor. In order to maintain the constant temperature boundary condition at tube's wall, 120 cm of the test section is surrounded by the saturated vapor. The entire steam supplier is totally insulated by fiberglass cover with the purpose of minimizing the heat loss. The flow resistance along the test section is measured by an Endress Hauser differential pressure transducer with an uncertainty of ±1 Pa. A 1-l glass vessel with a drain valve and a stop watch with ±0.01 accuracy are utilized to calculate the flow rate.

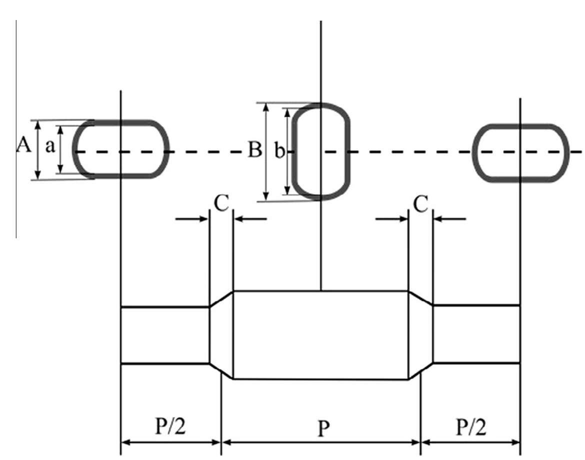

Fig. 1. Alternating Elliptical Axis (AEA) tube.