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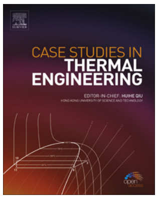

The effect of multi-longitudinal vortex generation on turbulent convective heat transfer within alternating elliptical axis tubes with various alternative angles

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A B S T R A C T

This study strives for a numerical examination of the turbulent flow and the heat transfer of water fluid flow in the alternating elliptical axis tube under various alternative angles. The purpose of this study is to increase the heat transfer by generating multi-longitudinal vortices along the tube flow. By increasing the rotation angle between pitches, the number of the formed multi-longitudinal vortices caused by the secondary flow increase from four to eight. This increase in the number of the multi-longitudinal vortices causes the cold fluid of the tube centre to have interaction in more paths with the hot fluid close to the wall and be mixed as well. This results in an increase of the heat transfer in this type of tubes. In addition, the results show that an improvement in the mean of average Nusselt numbers of alternating elliptical axis tube with the rotation angles of 40°, 60°, 80°, and 90° compared to the circular tube are 7.77%, 14.6%, 16.93%, and 24.42%, respectively. Finally, the correlations of the friction factor and the Nusselt number with the Reynolds number are presented for four AEA tubes with different pitches degree (40°, 60°, 80°, and 90°).

1. Introduction

Heat transfer enhancement in the shell and tube heat exchangers have been an active and important subject for many applications in the engineering fields, including in the petroleum industry, power plant stations, chemical processes, the automotive industry, etc.

Many heat transfer enhancement techniques have been introduced to improve the heat transfer performance of the heat exchangers, such as increasing heat transfer efficiency by reducing energy losses and the operating cost of the involved equipment, particularly in the heat exchangers.

The heat transfer enhancement method can be separated into two major categories: active and passive methods [1]. In an active method, an external energy source, such as magnetic fields [2], is required to enhance the heat transfer rate of the heat exchangers. On the other hand, the passive method does not use any source for increasing heat transfer rate. However, in this method, nanoparticles can be added [3] or the structure of tube geometry can be changed [4]. In the passive method, for increasing the heat transfer, fins [5], twisted tapes [6] and making grooves [7] in the tubes can be considered.

Meng et al. [8] proposed an experimental investigation on the convective heat transfer inside an alternating elliptical axis (AEA) tube. They analysed heat transfer and flow resistance for a range of Reynolds numbers as $500 < Re < 5\times10^4$. Also, they found that heat transfer can be greatly enhanced with less flow resistance increment, compared to the other enhanced elements. Their analysis

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Nomenclature

A	Area, m^2
AEAT	Alternating elliptical axis tube
C_p	Specific heat, J kg^{-1} K^{-1}
C	Perimeter of the tube's wall
D_h	Hydraulic diameter, m
f	Friction factor, $f = (\Delta p\, D_h)/(\frac{1}{2}\rho\, u_{\text{avg}}^2\, L)$
g	Gravitational acceleration, m s^{-2}
h	Convection coefficient, W m^{-2} K^{-1}
K	Thermal conductivity, W m^{-1} K^{-1}
k	Turbulent kinetic energy, m^2 s^{-2}
L	Total length of the tubes, mm
Nu	Nusselt number,
P	Pressure, kg m^{-1} s^{-2}
P_k	Production of turbulent kinetic energy, kg m^{-1} s^{-3}
Pr	Prandtl number, $Pr = \mu C_p/K$
q''	Heat flux, W m^{-2}
Re	Reynolds number, $Re = \rho u D_h/\mu$
T	Temperature, K
u_i	Velocity, m s^{-1}
y	y-direction coordinate, m
y^+	Dimensionless wall distance, $y^+ = (\sqrt{\tau_w/\rho}\; Y)/\upsilon$
Y	Distance of the closest computational node from the wall, m
z	Axial distance from the inlet, m

Greek symbols

δ_{ij}	Kronecker delta
ε	Turbulent dissipation rate, m^2 s^{-3}
μ	Laminar dynamic viscosity, kg m^{-1} s^{-1}
υ	Kinematic viscosity, m^2 s^{-1}
ρ	Density, kg m^{-3}
σ_k	Turbulent Prandtl number of k
σ_ε	Turbulent Prandtl number of ε
τ_{ij}	Stress tensor, kg m^{-1} s^{-2}

Subscripts

avg	Average
eff	Effective
w	Wall

Superscript

–	Time-averaged value

indicated that the mechanism for heat transfer enhancement is substantially due to the impact of the multi-longitudinal vortices induced by the cross-sectional change in the AEA tubes.

Chen et al. [9] presented a numerical study of flow and heat transfer manners in an AEA tube with a low Reynolds number turbulence model. Their results demonstrated that the transition sections had the largest effect on the enhancement of the heat transfer, but those sections would also see an increase in pressure drop per unit length. Zambaux et al. [10] investigated the effect of successive alternating wall deformation on the external and internal walls under a laminar flow of a coaxial annular tube. For a fixed temperature condition on both walls, they represented that the heat transfer performances are increased compared to a smooth annular geometry.

Sajadi et al. [11] studied heat transfer, flow resistance, and compactness of alternating flattened (AF) tubes experimentally and numerically. Their experimental and numerical results illustrate that an AF tube has a better performance enhancement ratio compared to the flattened and circular tubes. Furthermore, they found that increasing flattening and number of sectional units of the AF tube will increase the heat transfer rate.

As mentioned in previous sections, by creating a multi-longitudinal vortex structure of flow with AEA tubes, the heat transfer rate is increased. In this study, a three-dimensional numerical analysis is investigated to study the turbulent convective heat transfer of AEA tubes with different alternative angles. At first, we compare the least squares cell-based (LSCB) and the green gauss node-based (GGNB) approaches for the spatial discretization of gradients of the solution variables in a numerical simulation. Then, by surveying some parameters of the flow, we compare the AEA tubes from various alternative angles. Hence, for comparing the overall thermo-hydraulic performance of the enhanced tube, the friction factor and the average Nusselt number at a same given pump power are studied and investigated. Also, for both the dimensionless parameters, the correlation functions within the range of Reynolds number 10,000–60,000 are presented.

2. Tube geometry and mathematical model

In this section, the tube geometry and mathematical formulations are introduced. The main aim is to introduce four types of tube geometry and the assumptions considered in the governed equations for the numerical simulation based on existing experiments to evaluate the results.

2.1. The physical model

Compared to the circular tube, the AEA tubes can be used to enhance the heat transfer rate [12]. The tube is constructed with a series of alternates pitches with 40°, 60°, 80°, and 90° rotation of the elliptical cross-section tubes which are connected by the transition sections that bridge the cross-section positions. Fig. 1(a) shows the geometrical structure of the AEA tube for all angles used in the present study, and the Fig. 1(b) illustrates the connection procedure between two sections of the transition zones for AEA tube 90°. For modelling the transition zones of the AEA tubes, the multi-sections solid method with four guide lines (red lines) was applied. In addition, the AEA tubes had been created with the constant perimeter of cross-sections.