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Thermo-Hydraulic Performance of Shell-and-Tube Heat Exchangers with Twisted Oval Tubes

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Abstract

A twisted tube heat exchanger is a type of heat exchanger with an elliptical cross-section. This study aims to evaluate the effects of tube geometry on heat transfer performance and pressure drop. Using computational fluid dynamics (CFD), the thermohydraulic behavior of these heat exchangers was analyzed through three-dimensional modeling. Simulations were carried out for various elliptical aspect ratios and fluid velocities. The analyses were performed in ANSYS Fluent using the k-ε turbulence model.

The simulation results show that wall heat flux increases by approximately 25% at a Reynolds number of 1350 as the aspect ratio increases from 1 (circular) to 2, indicating improved heat transfer with more elongated ellipses up to that point. However, increasing the aspect ratio beyond 2 (up to 4) results in minimal changes in heat flux. At lower velocities, the impact of the aspect ratio on heat transfer becomes more pronounced. Furthermore, the pressure drop increases by about 17% at a Reynolds number of 2000 when the aspect ratio rises from 1 to 2. These findings can be applied to the design of more efficient oval tube heat exchangers.

Keywords: Oval Twisted Tube, Shell and Tube Heat Exchanger, Numerical Heat Transfer, Heat Transfer

1. Introduction

Heat exchangers are among the essential equipment in the field of energy. Among the innovative designs developed to improve performance, the geometry of twisted elliptical tubes has demonstrated good thermal performance [1,2]. A twisted-tube heat exchanger consists of a set of tubes without baffles that are tightened by wrapper around them [3,4].

In recent years, heat exchangers with twisted elliptical tubes have attracted considerable attention due to their high capability in enhancing heat transfer rates [5]. Experimental studies have compared the performance of these tubes with circular tubes and have shown that the use of elliptical geometry in the twisted structure can lead to improved heat transfer rates, although this improvement is usually accompanied by an increase in pressure drop [6-8]. The results have indicated that elliptical tubes have a greater ability to intensify turbulent flow and increase the Nusselt number.

In this study, the performance of a shell-and-tube heat exchanger with seven twisted elliptical tubes inside a hexagonal shell is investigated using numerical simulation. The main focus is on the effect of the elliptical aspect ratio (A/B) and flow velocity on heat transfer and pressure drop. The main difference of this work compared to previous studies, is the large number of elliptical aspect ratios considered and the modeling of all tubes along with the surrounding environment of the exchanger. These results can provide a basis for designing compact and efficient heat exchangers under spatial constraints.

2. Physical Model and Governing Equations

Heat exchanger with elliptical section is shown in Figure 1. The dashed circles represent the twisting region of the tube cross-section. In the elliptical geometry, the major diameter is denoted by A and the minor diameter by B. The ratio A/B is one of the key parameters in the geometry of elliptical tubes. In the present work, in order to enable comparison of the results when changing the cross-sectional dimensions of the tubes, the cross-sectional area of the circular tube is kept constant.

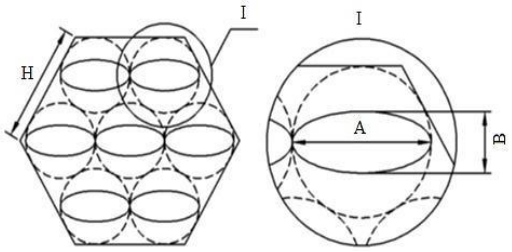


Figure 1. Schematic of the cross-section of twisted tubes

For the numerical simulation, the governing differential equations of incompressible fluid flow and heat transfer are solved. These governing equations include the continuity equation, momentum conservation, and energy conservation [9,10], which are expressed as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial\left(\rho u_j\right)}{\partial x_j}=0 \tag{1}$$

$$\rho\frac{\partial u_i}{\partial t}+\rho u_j\frac{\rho u_i}{\rho x_j}=-\frac{\partial p}{\partial x_i}+\mu\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right) \tag{2}$$

$$\rho\frac{\partial T}{\partial t}+\rho\frac{\partial(u_i T)}{\partial x_i}=-p\frac{\partial u_i}{\partial x_i}+\lambda\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right) \tag{3}$$

For the solution, the *k*–*ε* method with the enhanced wall treatment option in Fluent have been used.

In the numerical analysis, the mesh was refined inside and, on the tubes, to achieve higher accuracy in these regions. Table 1 presents the boundary conditions used in the simulation. The simulation was considered under steady-state conditions.

Table 1. The conditions Numerical Model

PARAMETER	VALUE
Internal inlet temperature	300 K
External inlet temperature	350 K
Diameter ratio	1–4
Fluid velocity	0.2–0.9 m/sec

To examine mesh independence, the geometry was simulated with six different mesh sizes, and a mesh with 2.2 million elements was selected. The residual values in the software were set to 10^{-6}. The Nusselt calculations were carried out based on the parameters available in the Fluent environment.

To investigate the effect of changing the tube geometry from circular to elliptical, 13 different geometries were considered. For aspect ratios from 1 to 4 with a step of 0.25. A wall thickness of 1 mm is assumed for the inner tubes.

Each geometry is analyzed at 8 different fluid velocities. The inlet temperature of the internal tube fluid is set to 350 K, and the inlet temperature of the external tube fluid is set to 300 K.

3. Results

In this section, the obtained data for different geometries and velocities are presented. The corresponding contours are also shown.

Figure 2 illustrates the variations of the Nusselt number for different geometries and fluid velocities. With increasing velocity and greater elongation of the ellipse, the Nusselt number increases. Due to the twisting of the ellipse, the fluid velocity experiences more swirling motion in different cross-sections. The reduction of fluid velocity near the sides of the ellipse causes a decrease in heat flux. On the other hand, as the ellipse becomes more elongated, the cross-sectional area of the tube increases, and the area involved in heat transfer becomes larger, which leads to an increase in heat flux.

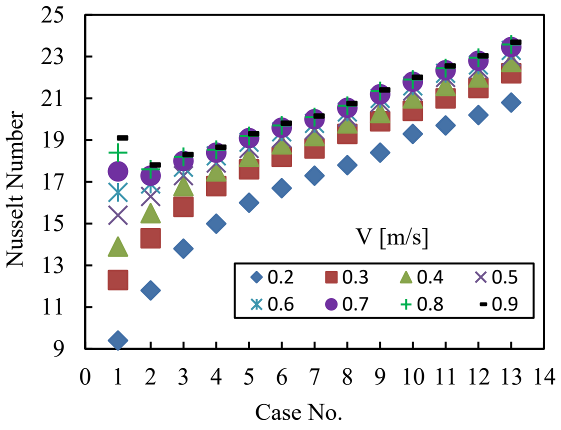
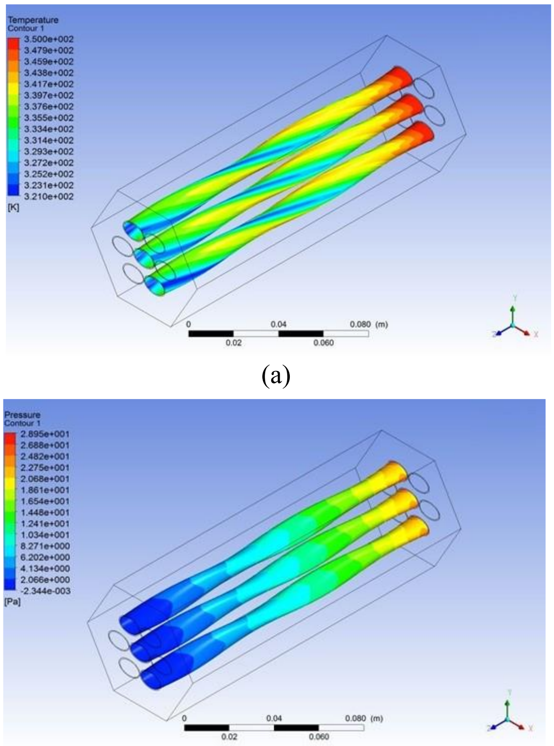


Figure 2. Comparison of the Nusselt number for different aspect ratios and fluid

The pressure difference of the inner and outer fluids at a given aspect ratio increases with increasing velocity, which is completely expected. For higher Reynolds numbers, the difference in pressure drop becomes more noticeable in ellipses with larger ratios. Figure 3 shows the temperature and pressure contours for an aspect ratio of 3.5 and a velocity of 0.9 m/s.

The pressure contour shows that the inlet pressure is higher at the beginning, around 29 Pa for each tube. The temperature contour indicates that the red color corresponds to a higher temperature of around 350 K, which gradually decreases along the flow path until it reaches about 321 K.



(a)

(b)

Figure 3. Temperature contour (a) and pressure contour (b) for aspect ratio of 3.5 and fluid velocity of 0.9 m/s

4. Conclusion

In this study, heat transfer in a multi-tube heat exchanger with elliptical tubes was investigated. The aim of the analysis was to examine the effect of the cross-sectional geometry of elliptical tubes.

The results show that the heat flux passing through the tube walls increases from the ratio 1 (i.e., the circular case) up to the ratio 2. In other words, as the ellipse becomes more elongated up to the ratio of 2, heat transfer improves. At Reynolds number 1350, the heat flux increases by 25%. However, beyond this ratio (up to 4, which was examined), no significant change in heat flux is observed.

As the aspect ratio increases, the ellipse becomes more elongated and its cross-sectional area increases. With the increase in aspect ratio, the pressure drop also increases; at Reynolds number 2000, the pressure drop increases by 17%.

For optimal selection and considering design limitations, a balance between pressure drop and heat transfer can be achieved. Overall, up to an aspect ratio of 2 and at lower velocities, the use of such heat exchangers provides appropriate performance.

5. References

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