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Effects of pitch and corrugation depth on heat transfer characteristics in six-start spirally corrugated tube

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ABSTRACT

Spirally corrugated tube is one of the most important parts of coaxial heat exchangers. It can greatly improve the heat transfer efficiency of heat exchangers. Here, a novel spirally corrugated tube with six-start is proposed. However, up to now, there is little literature about the heat transfer performance and flow field of this novel six-start spirally corrugated tube. In this paper, the effects of geometric parameters (pitch p, corrugation depth e), Reynolds number Re and fluid properties on the heat transfer performances are investigated based on the validated numerical model. The results show that with the increasing of pitch p, both the heat transfer coefficient h and Nusselt number Nu decrease gradually. Meanwhile, with the increasing of corrugation depth e, both the secondary flow velocity v_{xy} and the vorticity of longitudinal vortex increase gradually. Moreover, under the same working condition, the heat transfer performances of the six-start spirally corrugated tube are affected by both the working medium and Reynolds number. Finally, a criterion correlation for heat transfer calculation in the six-start spirally corrugated tube is proposed and validated to be reliable and suitable. This work can reveal the enhanced heat transfer mechanism of the six-start spirally corrugated tube and benefit the further research on heat transfer characteristics of multi-start spirally corrugated tube or other related devices.

1. Introduction

Nowadays, heat exchangers have been widely used in the petroleum, chemical, energy and other process industries. Spirally corrugated tube is one of the most important parts in coaxial heat exchanger, and it can greatly improve the heat transfer efficiency of coaxial heat exchangers. Meanwhile, the research priority of spirally corrugated tubes has evolved from single-start tubes into multi-start tubes.

Up to now, there have been lots of literatures dealing with the heat transfer characteristics of the single-start spirally corrugated tube. Li et al. [1] conducted numerical study on flow field and heat transfer characteristics of the single-start spirally corrugated tube, and they found that compared to smooth tube, the spirally corrugated tube could further enhance the heat transfer performance. Rainieri et al. [2,3] investigated the heat transfer performance of high viscosity fluid in spirally corrugated tube, and the results showed that the heat transfer characteristic of spirally corrugated tube was better than smooth tube, especially at high Reynolds number. Promthaisong et al. [4] presented a numerical analysis on flow configurations and heat transfer characteristics of turbulent forced convection in spirally corrugated tubes. Then the influences of corrugation depth, pitch ratio and Reynolds number on flow structure and heat transfer characteristics were described. The results showed that spirally corrugated tubes induced vortex flows which helped to increase heat transfer due to enhanced fluid mixing. Liu et al. [5] conducted experiment and numerical simulation on the flow and heat transfer characteristics in helical baffled cooler with spirally corrugated tube. And the results showed that spiral corrugated tube could help improve heat transfer efficiency. Pal and Saha [6] studied the laminar flow of viscous oil in a single-start spirally corrugated tube through experimental method, and the major findings of this experimental investigation were that the twisted tapes with oblique teeth in combination with integral spiral corrugation roughness performed significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain value of fin parameter. Li et al. [7] performed numerical simulation to obtain the turbulent flow and temperature fields in helical tubes cooperating with spiral corrugation. Then the effects of the spiral corrugation parameters

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and Reynolds number on the flow and heat transfer characteristics were studied. They found that the spiral corrugation could further enhance heat transfer of the smooth helical tube due to the additional swirling motion. Seara and Francisco [8] carried out experimental research on evaluating the heat transfer and friction characteristics of spirally corrugated tubes for the outer condensation of ammonia. The results showed that the overall heat transfer performance of the corrugated tubes was around 1.27 times higher than the performance provided by smooth tubes. Kalendar et al. [9] discussed the heat transfer performance and anti-fouling property of single-start spirally corrugated tube and smooth tube. The results showed that spirally corrugated tube had a better heat transfer performance and a smaller fouling resistance than smooth tube. Bhattacharyya and Saha [10] and Saha [11] investigated the thermal hydraulics performance of laminar flow through a smooth tube having integral helical corrugations and fitted with center cleared twisted-tape and helical screw-tape insert respectively. They gave the same conclusion that the spirally corrugated tube fitted with insert had a better heat transfer performance than individual spirally corrugated tube. All of the above studies indicate that spirally corrugated tube has a better heat transfer performance than smooth tube, which provides the basis for further study of multi-start spirally corrugated tube.

Recently, due to its better heat transfer performance than single-start spirally corrugated tubes, many researchers paid attention to multi-start spirally corrugated tubes. Lazim et al. [12] studied the heat transfer performance of a four-start spirally corrugated tube, and then a comparison between the studied four-start spirally corrugated tube and smooth tube was conducted. The results showed that, at low Reynolds number, the heat transfer coefficient of the four-start spirally corrugated tube increased 19.6–71.3% compared to smooth tube. Kareem et al. [13] focused their attention on the heat transfer enhancement in two-start spirally corrugated tube, and they concluded that this creative corrugation could improve the heat transfer significantly with appreciably increasing friction factor. In the same year, Kareem et al. [14] conducted experimental and numerical study on the heat transfer enhancement in three-start spirally corrugated tube. They drew the conclusion that this geometry with a creative spiral corrugation profile could improve the heat transfer significantly with reasonable increase in friction factor. Chen et al. [15] investigated the effect of corrugation angles on hydrodynamic and heat transfer performance of four-start spiral corrugated tube. Then they focused on the non-symmetric nature of the corrugation angles along the longitudinal direction. The results showed that the friction loss was found to become greater as the angle ratio increased. Ahn [16] studied the heat transfer performance of four-start spirally corrugated tube through experimental method. The results showed that the four-start spirally corrugated tube had a better heat transfer performance than smooth tube. Zimparov [17] carried out experimental study on heat transfer performance and isothermal friction pressure drop characteristic of three-start spirally corrugated tube combined with five twisted tape inserts with different relative pitches. The results showed that the isothermal friction coefficients for straight flow and swirl flow in the corrugated tubes increase when the relative pitch H/D_i decreases. Liu et al. [18] conducted numerical simulation on the shell side flow in rod-baffle heat exchangers with spirally corrugated tubes. Then the heat transfer quantities with one-start, two-start, three-start, and four-start spirally corrugated tubes were studied. The numerical results showed that the Nusselt number in RBHXSCT with one-start spirally corrugated tubes could be 1.2 times than that in RBHX, and the heat transfer quantities in the RBHXSCT with one-start, two-start, three-start, and four-start spirally corrugated tubes are 104.6%, 105.4%, 106.7%, and 109.6% respectively, higher than that in RBHX. In addition to spirally corrugated tube, the heat transfer performance of many other related tubes have also become the focus of current research. Aly [19] studied the heat transfer and pressure drop characteristics of water-based Al_2O_3 nanofluid flowing inside coiled tube-in-tube heat exchangers, and the results showed that heat transfer and pressure drop characteristics were mainly affected by coil diameter, curvature ratio and nanoparticles volume concentration. Kittiporn et al. [20] investigated the heat transfer characteristic of micro-fine tube by using the electrohydrodynamic (EHD) technique, which proved to be can help enhance heat transfer performance. Duan et al. [21] and Ahmad et al. [22] investigated the heat transfer characteristic of fixed planar elastic tube bundles and alternating flattened tubes respectively. The results showed that both tubes played an important role in enhancing heat transfer performance. In studying the effect of successive alternating wall deformation on the performance of an annular heat exchanger, Zambaux et al. [23] concluded that the best phase-shifting values could be determined by combining the two secondary flows to increase the heat transfer while limiting the pressure drops. Chidanand et al. [24] and Balaji et al. [25] investigated the heat transfer characteristic of tube bank heat exchangers and absorber tube respectively, and it was shown that the convective heat transfer performance of both tubes was enhanced. All of the above studies show that multi-start spirally corrugated tube can enhance heat transfer performance compared to single-start spirally corrugated tube, which indicates that it is meaningful to carry out research on multi-start spirally corrugated tube.

As is mentioned above, due to the better heat transfer performance than single-start spirally corrugated tubes, the multi-start spirally corrugated tubes are studied by a growing number of researchers. However, up to now, most of the researchers are paid their attention to three-start spirally corrugated tube and four-start spirally corrugated tube, as a novel spirally corrugated tube, there are virtually no literatures about the heat transfer performances and flow field analysis of six-start spirally corrugated tubes. Therefore, in this paper, the effects of geometric parameters (pitch p, corrugation depth e), fluid properties and Reynolds number Re on the heat transfer performances of six-start spirally corrugated tube are investigated. And based on results, a criterion correlation for heat transfer calculation of six-start spirally corrugated tube is obtained. This study can reveal the enhanced heat transfer mechanism and internal flow field of the six-start spirally corrugated tube, which can provide theoretical basis for the industrial application of this novel tube. Moreover, it can also benefit the further research on heat transfer characteristics of multi-start spirally corrugated tubes or other related devices.

2. Numerical model

2.1. Geometrical model

This six-start spirally corrugated tube is made of a copper smooth tube, which has a good machining property. Here, the specific operation of rolling process is that the copper tube passes through six processing mechanisms successively in a rotational stretching way. Fig. 1 shows 3D model of six-start spirally corrugated tube, and the structural diagram of six-start spirally corrugated tube is shown in Fig. 2. It can be seen from Fig. 2 that the main structural parameters of six-start spirally corrugated tube include pitch p, corrugation depth e and inter diameter D_i. The cross section of the six-start spirally corrugated tube is a smooth transitional hexagon. Compared to the commonly used three-start or four-start spirally corrugated tube, the six-start spirally corrugated tube has such advantages as good mechanical properties, enhanced heat transfer performances and high reliability.