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Turbulent heat transfer enhancement in a heat exchanger using helically corrugated tube ☆

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ABSTRACT

The augmentation of convective heat transfer in a single-phase turbulent flow by using helically corrugated tubes has been experimentally investigated. Effects of pitch-to-diameter ratio ($P/D_H = 0.18$, 0.22 and 0.27) and rib-height to diameter ratio ($e/D_H = 0.02$, 0.04 and 0.06) of helically corrugated tubes on the heat transfer enhancement, isothermal friction and thermal performance factor in a concentric tube heat exchanger are examined. The experiments were conducted over a wide range of turbulent fluid flow of Reynolds number from 5500 to 60,000 by employing water as the test fluid. Experimental results show that the heat transfer and thermal performance of the corrugated tube are considerably increased compared to those of the smooth tube. The mean increase in heat transfer rate is between 123% and 232% at the test range, depending on the rib height/pitch ratios and Reynolds number while the maximum thermal performance is found to be about 2.3 for using the corrugated tube with $P/D_H = 0.27$ and $e/D_H = 0.06$ at low Reynolds number. Also, the pressure loss result reveals that the average friction factor of the corrugated tube is in a range between 1.46 and 1.93 times over the smooth tube. In addition, correlations of the Nusselt number, friction factor and thermal performance factor in terms of pitch ratio (P/D_H), rib-height ratio (e/D_H), Reynolds number (Re), and Prandtl number (Pr) for the corrugated tube are determined, based on the curve fitting of the experimental data.

1. Introduction

Several heat transfer enhancement techniques (HTEs) have been introduced to improve the overall thermal-hydraulic performance of heat exchangers resulting in the reduction of the heat exchanger size and the cost of operation. In general, the HTE can basically be classified into two methods including active method (requires external power source) and passive method (not requires external power source). The mechanism for improvement of heat transfer performance in the passive method is promoting the turbulence near the tube wall surface to reduce the thermal boundary layer thickness and introducing a chaotic fluid mixing which acted by several enhancing modified tubes [1–18] such as a finned tube, tube with rib, tube with spirally roughened wall, corrugated tube, fluted tube, helical tube, elliptical axis tube and microfin tube, etc, as can be seen in Fig. 1. Among the modified tubes, the corrugated tube and the fluted tube become important for the heat transfer enhancement in a turbulent single phase flow as the pressure drop increment is fairly reasonable.

The studies on the heat transfer and pressure drop characteristics in fluted tubes for different conditions such as flow region, type of fluid, and shape of the fluted tube, etc. have been reported extensively. Rousseau et al. [1] described the development of a simulation model for the design of fluted tube in the water heating condensers. Qi et al. [2] applied cationic and zwitterionic/anionic surfactant solutions as drag reducing additives in a fluted tube. Kang et al. [3] determined the flooding mechanism in a fluted tube fitted with a twisted insert by visual observation and also developed the experimental correlations for flooding in both vertical and nearly horizontal tubes. Dengliang et al. [4] presented a practical procedure for calculating the heat transfer of laminar film condensation on a vertical fluted tube. Wanga et al. [5] studied the heat transfer in a carbon–steel/copper spirally fluted tube. They found that the carbon steel spirally fluted tube yields higher heat transfer coefficient than the carbon steel smooth tube up to 17%, while the spirally fluted copper tube provided higher heat transfer coefficient than the copper smooth tube up to 52%.

Corrugated tube is one of the important enhanced tube in many engineering applications, for example, heat exchangers, food industry, paint production, naval and pharmaceuticals. Rainieri and Pagliarini [6] studied the convective heat transfer and thermal performance behaviors in corrugated tubes at different pitch ratios. Their results showed that the helical corrugation significantly induced swirl components. Vicente et al. [7] reported the heat transfer and

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