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Numerical investigation of heat transfer and pressure drop in enhanced tubes ☆

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ABSTRACT

This study investigates passive heat transfer enhancement techniques to determine the distribution of temperature and static pressure in test tubes, the friction factor, the heat flux, the temperature difference between the inlet and outlet fluid temperatures, the pressure drop penalty and the numerical convective heat transfer coefficient, and then compares the results to the experimental data of Zdaniuk et al. It predicts the single-phase friction factors for the smooth and enhanced tubes by means of the empirical correlations of Blasius and Zdaniuk et al. This study performed calculations on a smooth tube and two helically finned tubes with different geometric parameters also used in the analyses of Zdaniuk et al. It also performed calculations on two corrugated tubes in the simulation study. In Zdaniuk et al.'s experimental setup, the horizontal test section was a 2.74 m long countercurrent flow double tube heat exchanger with the fluid of water flowing in the inner copper tube (15.57–15.64 mm i.d.) and cooling water flowing in the annulus (31.75 mm i.d.). Their test runs were performed at a temperature around 20 °C for cold water flowing in the annulus while Reynolds numbers ranged from 12,000 to 57,000 for the water flowing in the inner tube. A single-phase numerical model having three-dimensional equations is employed with either constant or temperature dependent properties to study the hydrodynamics and thermal behaviors of the flow. The temperature contours are presented for inlet, outlet and fully developed regions of the tube. The variations of the fluid temperature and static pressure along tube length are shown in the paper. The results obtained from a numerical analysis for the helically tubes were validated by various friction factor correlations, such as those found by Blasius and Zdaniuk et al. Then, numerical results were obtained for the two corrugated tubes as a simulation study. The present study found that the average deviation is less than 5% for the friction factors obtained by the Fluent CFD program while Blasius's correlation has the average deviation of less than 10%. The corrugated tubes have a higher heat transfer coefficient than smooth tubes but a lower coefficient than helically finned tubes. The paper also investigates the pressure drop penalty for the heat transfer enhancement.

1. Introduction

Experimental studies on passive heat transfer enhancement techniques were conducted to increase the heat transfer rate of heat exchangers. The rough surface technique is a passive method that usually involves surface modification to promote turbulent flow, as it increases the heat transfer surface area. Normally, smooth tubes are replaced by corrugated tubes in many heat exchangers to increase the heat transfer rate by mixing and also limiting the fluid boundary layers close to the heat transfer surfaces. Moreover, they can also promote two-phase heat transfer enhancement. However, studies based on CFD analyses are in limited number. Recent numerical publications that use specific algorithms for the enhanced surfaces related to heat exchangers have come from Zhang and Che [1], Assato and De Lemos [2], Cheng et al. [3], Zhang [4] and Bahaidarah [5]. In this study, five enhanced tubes to which the passive heat transfer technique was applied have been investigated for turbulent flow conditions.

The characteristics of flow inside the helically finned tubes are still not very well understood because of the limited experimental data. Li et al. [6] explained the heat transfer mechanism by visualizing the flow in helically finned tubes. They performed a study on four tubes with rounded ribs. They have used the hydrogen bubble technique to take high speed photographs of the fluid flow. The directions of the flow around the ridges have been determined by investigating the traces of the hydrogen bubbles. Li et al. indicated that bubbles follow a parabolic pattern in laminar flow, and these patterns break down because of random separation of vortices in the turbulent regime. Ravigururajan and Bergles [7] used a Plexiglas tube with a wire coil insert, and the fluid was water. They explained that the flow is dominated by a rotational pattern for helix angles less than 30° and a crossover pattern for helix angles larger than 70°. Jensen and Vlakancic [8] tested fifteen helically finned tubes. They concluded

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