Second law analysis of curved rectangular channels

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\textbf{A B S T R A C T}

The thermodynamic performance of the curved rectangular channels in laminar flow is numerically investigated in terms of entropy generation. The classical Navier–Stokes equations are adopted, and water is selected as the working fluid. The results show that the geometric parameters have important influences on the heat transfer performance of the channel flows. For the channels with the same cross-section, the Nusselt number increases significantly as the curvature ratio increases at the expense of slight increase of pressure drop; the dimensionless total entropy generation generally tends to reduce as Reynolds number grows, and decreases as the curvature ratio increases at the same Reynolds number. The dimensionless total entropy generation lessens with the reduction of cross-sectional area at the same Reynolds number in the channels with the same radius of curvature. Despite the rapid drop of the Bejan number, we have not found the optimal flow regime for curved rectangular channel laminar flows. The local heat transfer and fluid friction entropy generations mainly occur in the narrow region near the walls, especially the outer wall. The field synergy principle provides an alternative way to explain the heat transfer enhancement mechanism for the curved rectangular channel flows.

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1. Introduction

The curved channel as a passive heat transfer enhancement device is widely used in heat transfer equipments. In a curved channel, centrifugal force is generated due to the curvature, which generates a secondary flow field, resulting in the heat transfer enhancement [1]. Dean [2,3] was the first to investigate the hydrodynamics of a curved channel flow, and a single parameter, the Dean number was defined to characterize the flow phenomena of Newtonian fluids in a curved channel. Ito [4] investigated the steady laminar flow in a curved channel with circular cross-section, and derived a formula for the friction factor of the curved channel. Berger et al. [5] comprehensively reviewed the study of the flow of Newtonian fluids in curved pipes. Ligrani et al. [6] investigated the heat transfer in transitional curved channel flow over a range of Dean numbers less than 300, and found that Nusselt number on the concave surface is higher than that on the convex surface for the curved channel. Yang et al. [7] numerically analyzed the laminar flow and heat transfer in a curved pipe with periodically varying finite curvature, and found that a decrease in the wave length of the periodic wavy pipe could enhance the heat transfer rate significantly. Kumar et al. [8] examined the influences of temperature-dependent properties on hydrodynamic and thermal performance of a curved tube in laminar flow regime under cooling and heating conditions, and reported that the Nusselt number markedly depends on the property variation in the curved tube. In [9], the pressure losses of laminar oil-flows in curved rectangular channels with various geometrical aspect ratios and curvatures were investigated, and an empirical equation based on experimental data for Dean numbers between 100 and 800 was developed. Yanase et al. [10] conducted a numerical simulation of the non-isothermal flows through a curved rectangular duct of aspect ratio 2 with the spectral method; the results showed that the Nusselt number on the outer side wall increases as the Dean number increases within the ranges of the Dean number and the Grashof number considered in [10]. Wang and Liu [11] numerically studied the fully developed laminar flow of viscous fluid in a slightly curved square microchannel, and they found that no matter how small the curvature ratio is the channel curvature always generates a secondary flow, which enhances the heat transfer significantly and increases the fluid friction slightly. Che et al. [12] analytically investigated plug flow in curved microchannels, they found that the flow pattern can be controlled by the geometric structure. Chu et al. [13] conducted an experimental investigation of the flow characteristics in curved rectangular microchannels at Reynolds number of 80–876, and found that the