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Enhancing heat transfer in vortex generator-type multifunctional heat exchangers

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A B S T R A C T

Global and local analysis of the heat transfer in turbulent vortical flows is studied using three-dimensional numerical simulations. Vorticity is generated by inclined vortex generators in a turbulent circular pipe flow with twelve different configurations that fall into three categories. In the first category are rows of trapezoidal vortex generators in different arrangements; in the second category the vortex generators are fixed at certain distance from the tube wall, and the third category has vortex generator rows between which a row of small protrusions are inserted on the tube wall. First, a global analysis of the thermal performance is performed for all these configurations, which are also compared with other heat exchangers from the literature. New correlations for the friction factor and Nusselt number are then obtained. Local analysis of the effect of the flow structure on the temperature distribution is carried out for the four configurations showing the best performances. The local analysis involves studying the streamwise vorticity flux to characterize the convective transport process, the turbulent kinetic energy characterizing the turbulent mixing, and finally the local Nusselt number.

1. Introduction

Artificially generated vorticity is efficient in fluid mixing and heat transfer since it enhances the exchange of fluid particles between the different flow regions with relatively small increases in pressure loss [1]. Several methods exist for generating vorticity, such as Görtler vortices and Dean cells induced by wall curvature and/or rotation [2,3], embedded vortices generated by jets [4], and turbulence promoters or vorticity generators [5,6]. This last category is the main interest in the present study.

Physical analysis of vorticity effects on heat- and mass-transfer mechanisms is a fundamental issue in optimizing existing heat exchangers and devising new enhanced designs. In fact, two types of vorticity can be distinguished: transverse stagnant vortices that are local recirculations behind the vortex generator and have their axis of rotation perpendicular to the main flow direction, and streamwise vortices advecting in the flow direction with a swirling motion [5]. It was shown that most heat- and mass-transfer enhancement is provided essentially by streamwise vorticity, while the transverse stationary vorticity slightly enhances heat transfer in the region near the vortex generator, generally in the near-wake of the vortex generator [1,5]. This fact is demonstrated by the strong relationship between the streamwise vorticity flux and the span-averaged Nusselt number observed downstream from rectangular [7] and trapezoidal [8] vortex generators.

In the present work, pressure-driven longitudinal vorticities are generated in a turbulent flow by using different configurations of vortex generator rows inserted in a circular tube. These vortex generators are based on the trapezoidal mixing tabs used in the high-efficiency vortex (HEV) static mixer [9] (see Fig. 1a). Flow past trapezoidal vortex generators has been extensively studied due to its ability to enhance turbulent mixing, mass transfer and phase dispersion by the generation of complex coherent structures [10–12]. Mainly, two types of flow structures are observed downstream from a trapezoidal vortex generator: a counter-rotating vortex pair formed by the pressure difference across the vortex generator, and a periodic sequence of horseshoe-like structures shed from the trailing edges of the vortex generator [13]. These structures have been shown to enhance fluid mixing and heat exchange between low-momentum near-wall regions and the high-momentum zone in the flow core.

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