International Journal of Heat and Mass Transfer 66 (2013) 164–176

Contents lists available at SciVerse ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

The effect of corrugation on heat transfer and pressure drop in channel flow with different Prandtl numbers

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ARTICLE INFO

Article history:
Received 4 November 2012
Received in revised form 18 June 2013
Accepted 19 June 2013

Keywords:
Wavy channel
Plane channel
Turbulent heat transfer
Boundary layer
LES

ABSTRACT

Large Eddy Simulation and Direct Numerical Simulation are applied to study the turbulent flow field in a wavy channel at two Prandtl numbers, $Pr = 0.71$ and $Pr = 3.5$, and Reynolds number $Re_b = 10{,}000$. The characteristics of the separated shear layer and the near wall recirculating zone are discussed in relation to the turbulent heat transfer. Special attention is paid to the behavior of the flow and thermal boundary layers and various turbulent characteristics and their effects on the distribution of the Nusselt number and friction coefficient in the separation and reattachment regions. The results indicate that the thickness of the thermal boundary layer rather than the turbulent fluctuations has a significant effect on the local variation of the averaged Nusselt number. The results are compared with Direct Numerical Simulation results of a plane channel at the same Reynolds number.

1. Introduction

In various heat transfer devices, optimization of wall heat transfer is a key requirement to make the devices more compact or effective. The use of the surface protuberances is a passive heat transfer augmentation method and is based on developing boundary layers or streamwise fluctuations, creating swirl or vortices and flow destabilization or turbulence intensification. One typical technique is to use corrugations (waves) on the wall. Providing considerable heat transfer enhancement with a relatively low pressure drop as well as the simplicity of the manufacture method make these geometries more attractive than other passive enhancement methods such as ribs or vortex generators. The periodic changes of pressure gradient and the streamline curvature effects produce turbulence structures. The corrugated wall enhances heat transfer by destroying or decreasing the thermal boundary layer thickness and increasing the bulk flow mixing. The recirculating bubble in the wavy part of the channel and the separated shear layer formed above the separation point raise the turbulence intensity near the wall. The corrugated channels can be considered to be fully corrugated (fully-wavy or sinusoidal) or half corrugated channels. In a fully corrugated channel, the corrugation is applied to the entire channel length whereas in a half corrugated channel, part of the channel is corrugated and part of it remains smooth (see Fig. 1). The half corrugated channel is chosen as the geometry in the present study (referred to as the wavy channel).

Various studies have been conducted on turbulent flow over the fully corrugated walls [1–5]. Hudson et al. [1], Cherukat et al. [2] and Choi and Suzuki [3] studied the turbulent flow in a fully wavy channel with experimental, Direct Numerical Simulation (*DNS*) and Large Eddy Simulation (*LES*) methods, respectively. They provided an extensive study of different turbulent flow characteristics such as Reynolds shear stress, turbulent intensities and turbulence production over a wave with a wave amplitude to wave length ratio of 0.05. Calhoun and Street [4], Dellil et al. [5] and Yoon et al. [6] carried out numerical investigations of the effect of the wave amplitude in a fully wavy channel. They used different wave amplitude to wave length ratios and compared the turbulent flow patterns, the location of the separation and reattachment points and the mean distributions of heat transfer and pressure drop along the channel. As it has been mentioned in the literature review, most of the previous studies have been concentrated on the flow in a fully wavy channels, whereas in the present study a half corrugated channel is considered as the computational domain (see Fig. 1). Comparing the results of both geometries, some similarities and differences can be identified. For the wavy channels with identical wave amplitudes (fully and half corrugated), a small

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.06.047