International Journal of Heat and Fluid Flow 67 (2017) 155–167

Contents lists available at ScienceDirect

International Journal of Heat and Fluid Flow

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

Experimental study of mixed convection heat transfer in a vertical channel with a one-sided semicylindrical constriction with prescribed heat flux

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A R T I C L E I N F O

Article history:
Received 22 March 2017
Revised 25 July 2017
Accepted 23 August 2017

Keywords:
Wall-mounted hemisphere
Convex curvature
Curved step constriction
Flow separation
Bounded flow

A B S T R A C T

An experimental study of mixed convection heat transfer is carried out in a vertical channel with a one-sided semicylindrical constriction with prescribed heat flux while the other bounding walls are insulated and adiabatic. The semicylinder is placed horizontally at the mid-plane with a blockage ratio (*BR*, ratio between the semicylinder diameter and the thickness of the rectangular section) of 0.3 and a semicylinder aspect ratio (*AR*, ratio between the length and diameter of the semicylinder) of 6. The effect of opposing buoyancy on the flow and thermal behavior is analyzed for fixed Prandtl number of $Pr = 7$, Reynolds number based on semicylinder diameter of $20 \leq Re \leq 350$ and buoyancy strength or modified Richardson number, $Ri^* = Gr^*/Re^2$, from 20 to 350. For relatively large values of Ri^*, flow visualization images and thermal analysis confirm the presence of a complex three-dimensional (3D) two-vortex structure with two recirculation bubbles present at the forebody and rear of the semicylinder. Surface temperature distributions and averaged Nusselt number at different Reynolds and modified Richardson numbers have been obtained. The results show that variation of the local temperature distributions with angular position and spanwise location become evident, and their relation to the presence of a complex 3D vortex structure that develops close to the semicylindrical constriction has been studied and discussed in detail. Moreover, empirical correlations for the overall Nusselt number are obtained using both *Re* and Gr^* and *Re* and Ri^* as the controlling parameters.

1. Introduction

Flow in constricted channels with irregular surfaces is often present in many fluidic devices and has wide engineering applications in the cooling of electronic equipment, design of compact heat exchangers, nuclear reactors, solar collection systems, building energy systems, fin-tube baseboard heaters, flat-plate condensers in refrigerators, energy storage systems and electric machinery. Among these, cooling of electronic equipment draws much attention because the production of smaller components with higher power densities has generated an increased interest for dependable and efficient cooling technologies. In most electronic equipment applications, cross-sectional protuberances or heated irregular surfaces in blocked passages are a common occurrence. Because complex geometries generate detachment and reattachment of flows and develop recirculation regions that enhance mixing and significantly improve the thermal performance of heat transfer devices, a good amount of research has been carried out to understand the role of geometrical inhomogeneities and the effect of these obstructions on the modification of the flow and heat transfer characteristics (Viswatmula and Amin, 1995; Roeller et al., 1991; Young and Vafai, 1999; 1998a, 1998b; Habchi and Acharya, 1986; Pirouz et al., 2011; Hamouche and Bessaih, 2009; Boutina and Bessaih, 2011; Chang and Shiau, 2005; Rao and Narasimham, 2007; Du et al., 1998). Examples of these complex geometries can be found in grooved (Adache and Uehara, 2001; Herman and Kang, 2002; Ghaddar et al., 1986; Greiner, 1991; Pereira and Sousa, 1993; Farhanieh et al., 1993) and corrugated channels (Wang and Chen, 2002; Alawadhi and Bourisliy, 2010; Forooghi and Hooman, 2013; Guzmán et al., 2009), channel expansions and chimneys (Thiruvengadam et al., 2009; Wahba, 2011; Auletta et al., 2001;

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http://dx.doi.org/10.1016/j.ijheatfluidflow.2017.08.007
0142-727X/