ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

JESTECH

Full Length Article

A numerical study of entrance region in a curved annulus with an inward and outward eccentricity

M.R.H. Nobari *, N. Nekoubin [1]

Department of Mechanical Engineering, Amirkabir University of Technology, 424 Hafez Ave., P.O. Box 15875-4413, Tehran, Iran

ARTICLE INFO

Article history:
Received 15 November 2015
Revised 11 February 2016
Accepted 25 February 2016
Available online xxxx

Keywords:
Curved annulus
Eccentric
Incompressible flow
Finite difference
Projection method

ABSTRACT

In this article, developing incompressible fluid flow in a curved annulus with inward and outward eccentricities is studied numerically. To do so, a second order finite difference method based on the projection algorithm is employed to solve the governing equations written in a general bipolar–toroidal coordinate system using a three-dimensional staggered uniform grid. The effects of the governing dimensionless parameters such as the Dean number, Reynolds number, curvature ratio, aspect ratio, and eccentricity on the flow field pattern and friction factor are studied in the entrance region. The numerical results obtained indicate that the outward eccentricity significantly deforms the secondary flows and axial velocity profiles. Furthermore, as the eccentricity increases, the friction factor decreases due to the reduction of secondary flow intensity.

1. Introduction

Fluid flow in an eccentric curved annulus occurs in many engineering and industrial equipment used in lubrication systems, rheology, heating and cooling systems, and so on. In medical sciences, the blood flow inside the vessels when performing the coronary angiography test is an example which may directly be related to the subject of the current study. Therefore, better understanding of the physics of the problem helps engineers to consider the key points in designing and predicting the performance of equipment. In this regard, the aim of the current study is concentration on the developing flow inside an eccentric curved annulus.

Secondary flow is created in curved pipes due to the centrifugal force resulting from the curvature. This phenomenon increases the complexity of flow field in curved pipes in comparison with the flow field in straight pipes. Yao and Berger [1] describe the physical aspects of this problem. In curved pipes, the centrifugal force generated by the curvature increases the friction factor demanding more pumping power. On the other hand, it provides better mixing of fluid particles, augmenting the heat transfer rate in heat exchangers and the mixing rate in different industrial equipment such as food processing devices. Despite the large pumping power drawback, the increased rates of heat transfer and mixing power in the curved pipe systems have drawn the attention of engineers to take into account these advantages for designing units that are more compact. Therefore, the study of flow field patterns and important physical parameters such as friction factor both in the developing and fully developed regions of the curved pipe systems provides the tools for an optimum design.

The fluid flow and heat transfer in eccentric annuli have been investigated numerically and analytically in many studies considering both fully developed and developing flows with different thermal boundary conditions. Among them, the study by Trombetta [2] investigated forced convection heat transfer in eccentric annuli considering fully developed laminar flow. A similar study has been performed by Suzuki et al. [3]. An exact solution was presented for obtaining the velocity distribution in the fully developed laminar flow in an eccentric annulus by Snyder and Goldstein [4] who calculated the local shear stress on the inner and outer walls to obtain the overall friction factor. They have presented their results for wide ranges of eccentricity and radius ratio. A numerical study by Feldman et al. [5] has investigated the laminar developing flow in eccentric annular ducts using the Navier–Stokes equations in the bipolar coordinate system. He extended his work by solving the energy equation in order to predict the temperature distribution in the thermal entrance region [6]. Natural convection in vertical annuli has been investigated by Arabi et al. [7] using a finite difference method. The same subject in eccentric horizontal cylindrical annuli has been studied by Ho et al. [8] who discovered that the Prandtl number has a weak influence on the heat transfer. Moreover, they

* Corresponding author. Tel.: +98 21 64543412; fax: +98 21 66419736.
E-mail address: mrnobari@aut.ac.ir (M.R.H. Nobari).

Peer review under responsibility of Karabuk University.

[1] Graduate Student.

http://dx.doi.org/10.1016/j.jestch.2016.02.009
2215-0986/© 2016 The Authors. Production and hosting by Elsevier B.V. on behalf of Karabuk University.

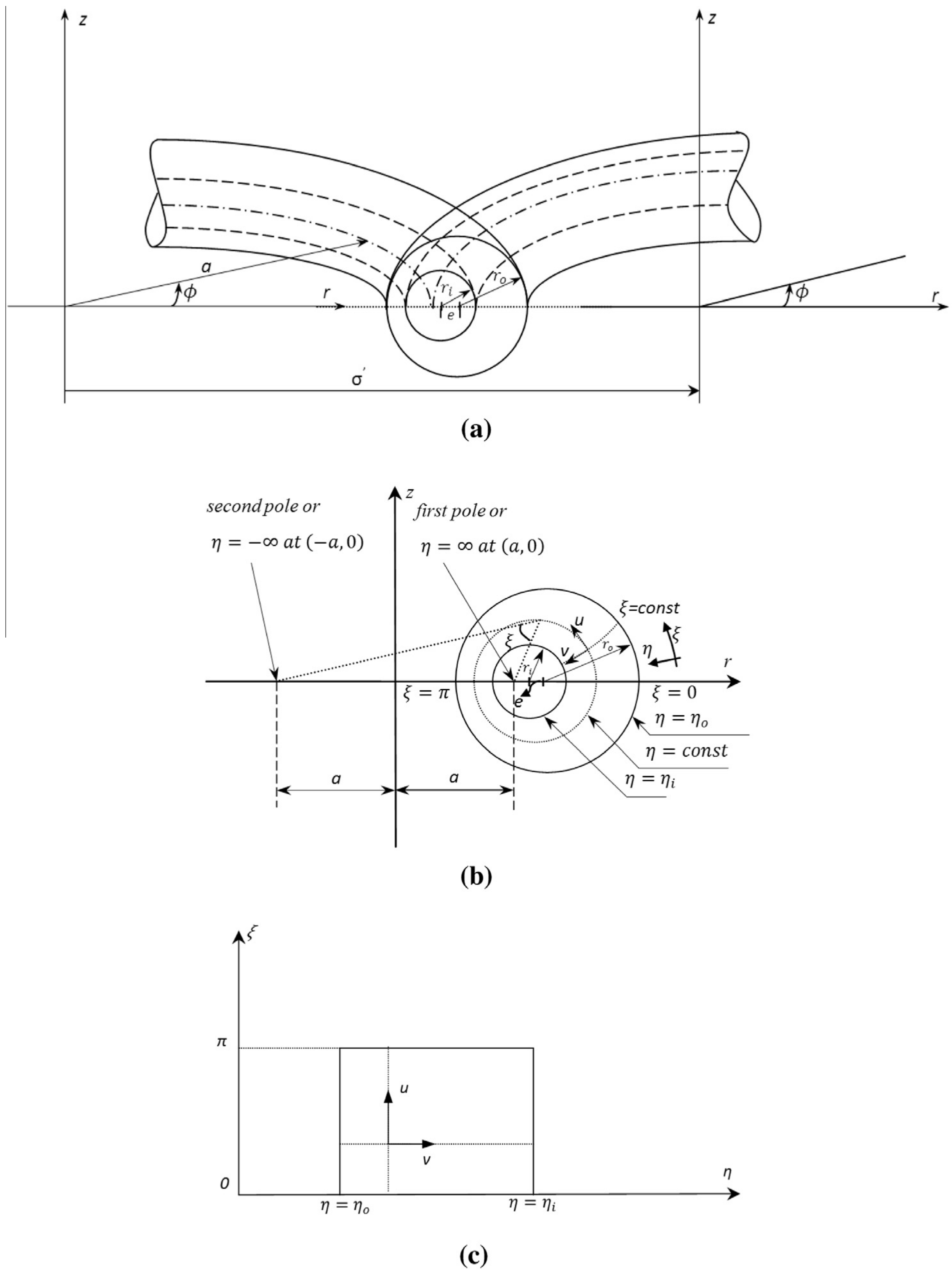
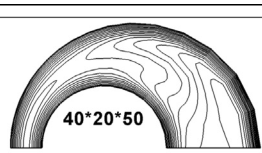
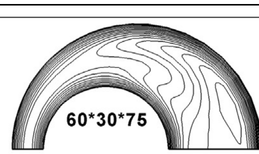
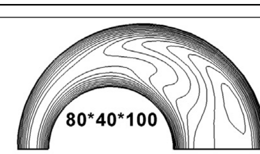


Fig. 1. (a) Geometry of the physical domain, (b) cross-section of physical domain in bipolar–toroidal and displaced bipolar–toroidal coordinates, (c) cross-section of computational domain in bipolar–toroidal and displaced bipolar–toroidal coordinates.

Table 1
Axial velocity contours and its maximum values for three different meshes at $E_i = 0.5$, $N = 0.5$, $\lambda = 0.769$, $Re = 400$.

		
1.661321	1.655169	1.650483

showed that the modified Rayleigh number and eccentricity play an important role in the heat transfer rate. In an experimental study, Naylor et al. [9] investigated the natural convection between two eccentric tubes and compared the experimental results with the numerical ones. Other similar studies on the natural convection have been carried out by Hiroso et al. [10] and Shaarawi et al. [11–14]. Mixed convection in vertical eccentric annuli was investigated by Mokheimer and Shaarawi [15]. They studied the development of hydrodynamic and thermal boundary layers. Nobari and Asgarian [16] have solved full Navier–Stokes equations

Please cite this article in press as: M.R.H. Nobari, N. Nekoubin, A numerical study of entrance region in a curved annulus with an inward and outward eccentricity, Eng. Sci. Tech., Int. J. (2016), http://dx.doi.org/10.1016/j.jestch.2016.02.009