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Thermal characteristics of electroosmotic flow in a wavy-wall microtube ☆

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ABSTRACT

This study numerically investigates the electroosmotic flow and heat transfer in a wavy surface of the micro-tubes. The solution takes the electrokinetic effect and the amplitude of the wavy surface into consideration. A simple coordinate transformation method is used to transform a complex wavy micro-tube into a regular, circular tube. The governing equations, including the Poisson–Boltzmann equation, the modified Navier–Stokes equations, and the energy equation with their corresponding boundary conditions are also transformed into the computational domain and then solved by the finite difference method. The main objective is to investigate the difference of fluid flow and temperature fields for various wavelength ratio a and the electrokinetic parameter β. Results show that the distributions of the skin-friction coefficient and the local Nusselt number are oscillatory along the stream-wise direction for the wavy micro-tube ($a \neq 0$). The amplitude of the oscillated local Nusselt number increases with an increase in the electrokinetic parameter β and wavelength ratio a, but that of the skin-friction coefficient decreases with an increase in the electrokinetic parameter β. The heat transfer enhancement is significant for the larger electrokinetic parameter β and wavelength ratio a.

1. Introduction

Electroosmotic microflow has been a subject of recent interest. An upsurge in research activities on this field accelerated due to a wide range of application in various disciplines, such as chemical analyses, biomedical diagnoses, drug delivery, DNA genetic engineering etc.

The working principle of electroosmotic flow uses the electroosmotic force to move the charged fluid through the device passages under the application of an external electric field. Electroosmosis was first demonstrated by F.F. Reuss in 1809 from an experimental study on porous clay, and later Helmholtz interpreted the electric double layer theory in electrokinetic transport. From then on, a considerable amount of work has been theoretically and experimentally done. An analysis of mixed electroosmotic and pressure-driven flows in the two-dimensional ultrafine channels with arbitrary zero potentials was presented by Burgreen and Nakache [1]. Lately, some work has been done on electroosmotic flow in a capillary for various configurations such as cylindrical capillary [2,3], elliptical micro-channel [4], and rectangular microchannel [5,6]. Yang and Li [7] evoked the Debye–Hückel approximation and performed a numerical study of electrokinetically driven microflows to identify the streaming potential effects. Yang et al. [8] used the finite difference method to study the electroosmotic entry flow between the parallel plates. The results indicate that the hydrodynamic entrance length is about four times the length for a corresponding pressure-driven flow.

In addition, some studies have also been paid to investigate the thermal behavior of electroosmotic microflows. Yang et al. [9] studied the forced electrokinetic flow and heat transfer in microchannels taking into account the streaming potential effects. Maynes and Webb [10] analytically analyzed the thermal behavior of the fully developed purely electro-osmotically driven flow in circular and parallel plate microchannels. They also accounted for the effect of viscous dissipation on electroosmotic flow in microchannels [11]. Dutta et al. [12] employed the spectral element method to attack the problem of mixed electroosmotic and pressure-driven flows in T-junctions. An analytical study has been carried out by Yang et al. [13] who investigated the fully developed, combined electroosmotically and pressure-driven flows in a narrow parallel channel with imposed constant wall heat flux and constant wall temperature boundary conditions. Dutta et al. [14] explored analytically the heat transfer characteristics of both developing and fully developed mixed electro-osmotically driven microflows in an isothermal channel. Recently, Char and Hsu [15] used the shooting method with a fourth order Runge–Kutta algorithm to examine the Joule heating effects on the heat transfer characteristics of the mixed electroosmotic and pressure-driven flows in microtubes under isothermal boundary conditions.

To enhance the convective heat transfer in heat exchanges, the corrugated walls are frequently encountered. Burns and Parks [16] first used the Fourier series to study the viscous flow in the wavy wall channels under the assumption that the Reynolds number is small

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