Convective heat transfer in a rotating square channel with oblique cross section

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Abstract A numerical study has been performed to study the fluid flow and convective heat transfer inside a rotating square isothermal channel with the channel cross-section having oblique angles to the rotational axis. The channel is subjected to a radial rotation. Computations are carried out for flows at \( Re = 500, 1000 \) and \( 2000 \) and range from the channel entrance to a flow distance of 300 and 600 times the hydraulic diameter, depending upon the Reynolds number. Results reveal the vortex flow structures, and consequently the heat transfer phenomena, are quite different from that of previous studies with zero oblique angle. The channel with 45 degree oblique angle yields the best overall heat transfer performance.

List of symbols

- \( a \): channel height in the \( y \)-direction, m
- \( b \): channel width in the \( z \)-direction, m
- \( C_p \): specific heat, kJ/kg °C
- \( D_h \): hydraulic diameter, m
- \( Gr \): Rotational Grashof number, \( \Omega^2 L_x \beta (T_w - T_o) D_h^3 / \nu^2 \)
- \( H \): distance from rotational axis to inlet, m
- \( h \): convective heat transfer coefficient, W/m² °K
- \( h^* \): nondimensional distance from rotational axis to inlet, \( H / D_h \)
- \( k \): thermal conductivity of fluid, W/m °K
- \( L_x \): characteristic length in the \( x \)-direction, m
- \( Nu_{av} \): locally-averaged Nusselt number over a wall, \( h D_h / k \)
- \( Nu \): circumferentially-averaged Nusselt number
- \( Nu_{\infty} \): Nusselt number for fully developed flow in stationary and \( \gamma = 0° \) cases
- \( Nu \): average Nusselt number over the computational channel length
- \( P \): pressure, Pa
- \( P^* \): reduced pressure, \( P - \frac{1}{2} \rho \Omega^2 \left[ X^2 + (Y \cos \gamma + Z \sin \gamma)^2 \right] \)
- \( P_c \): characteristic pressure, \( \mu (U_0 / a) \)
- \( p \): dimensionless reduced pressure
- \( Pr \): Prandtl number, \( \nu / \alpha \)
- \( Re \): Reynolds number, \( U_0 D_h / \nu \)
- \( Ro \): Rossby number, \( \Omega D_h / U_0 \)
- \( Ta \): Taylor number, \( Re \cdot Ro \)
- \( T \): temperature, °K
- \( T_b \): local bulk mean temperature, °K
- \( T_i \): characteristic temperature, \( (T_w - T_o) \), °K
- \( T_m \): inlet mean temperature, °K
- \( T_w \): wall temperature, °K
- \( \Delta T \): temperature difference, \( (T_w - T_o) \), °K
- \( U, V, W \): velocity components in the \( x-, y-, z \)-directions, respectively, m/s
- \( U_0 \): inlet mean velocity, m/s
- \( V, W \): characteristic transverse velocity components in \( y \)- and \( z \)-directions, respectively,
- \( u, v, w \): dimensionless velocity components in \( (x, y, z) \) directions, respectively
- \( X \): distance in the axial direction measured from flow inlet, m

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Introduction

Fluid flow and heat transfer in rotating systems, especially in radially rotating channels, have attracted considerable attention in the past several decades due to their important applications in industry. The problems involved in this topic include convective heat transfer, vortex flow evolution and heat transfer enhancement techniques. Under radial rotation, convective heat transfer has been confirmed to enhance with an increase in either the flow rate or the rotational speed, and the vortex flow variation along the channel has been also found to be related to the Reynolds number, Rossby number and heating conditions. However, most of the previous studies focus on the channel cross section with zero oblique angle, $\gamma = 0$ (see Fig. 1). The present study makes an effort toward understanding the effects of inclined channel cross-section on vortex flow and convective heat transfer. Previous studies are briefly introduced in the following.

Hart (1971), Johnston et al. (1972), Smirnov and Yurkin (1983), Kuz'minskii et al. (1983), and Alfredsson and Persson (1989) experimentally studied flow instability phenomena in rotating channels of different aspect ratios, while Hart (1971), Lezis and Johnston (1976), Speziale (1982), Speziale and Thangam (1983), Kheshgi and Scriven (1985), and Finlay (1990, 1992) investigated these phenomena theoretically. Hart (1971) found that in large aspect-ratio channels, there exist: (i) a double-vortex secondary flow at slow rotational speed, (ii) an instability in the form of longitudinal roll cells at intermediate rotational speed, and (iii) a restabilization of flow to a Taylor-Proudman regime at high rotational speed, where the axial velocity profile does not vary along the direction of the rotational axis. Johnston et al. (1972) also disclosed three stability-related phenomena in a channel of large aspect ratio: (i) a reduction (increase) in the rate of wall-layer streak bursting in locally stabilized (destabilized) wall layers; (ii) the