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RESEARCH PAPER

Numerical simulation of flow and heat transfer in radially rotating microchannels

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Abstract Investigation of fluid flow and heat transfer in rotating microchannels is important for centrifugal microfluidics, which has emerged as an advanced technique in biomedical applications and chemical separations. The centrifugal force and Coriolis force, arising as a consequence of the microchannel rotation, change the flow pattern significantly from the symmetric profile of a non-rotating channel. Successful design of microfluidic devices in centrifugal microfluidics depends on effectively regulating these forces in rotating microchannels. In this work, we have numerically investigated the flow and heat transfer in rotating rectangular microchannel with continuum assumption. A pressure-based finite-volume technique with a staggered grid was applied to solve the steady incompressible Navier–Stokes and energy equations. It was observed that the effect of Coriolis force was determined by the value of the non-dimensional rotational Reynolds number (Re_ω). By comparing the root mean square deviation of the axial velocity profiles with the approximate analytical results of purely centrifugal flow for different aspect ratios (AR = width/height), a critical rotational Reynolds number ($Re_{\omega,\mathrm{cr}}$) was computed. Above this value of ($Re_{\omega,\mathrm{cr}}$), the effect of secondary flow becomes dominant. For aspect ratios of 0.25, 0.5, 1.0, 2.0, 4.0 and 9.09, this critical rotational Reynolds number ($Re_{\omega,\mathrm{cr}}$) was found to be 14.0, 5.5, 3.8, 4.7, 6.5 and 10.0, respectively.

Keywords Centrifugal microfluidics · Lab-on-a-CD · Convection in rotating microchannel · Finite-volume method · Secondary flow

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List of symbols

a	Width of the microchannel (m)
AR	Channel aspect ratio $\left(=\frac{a}{b}\right)$
b	Height of the microchannel (m)
C_p	Specific heat at constant pressure (J/kg K)
D_h	Hydraulic diameter of microchannel (m)
d_r	Radial distance of inlet from the disk center (m)
f_app	Apparent friction factor (m/s)
f_c	Coriolis force (=$2\omega w$)
f_ω	Centrifugal force (=$\omega^2 d_\mathrm{r}$)
G	Modified axial pressure gradient
G^*	Reduced axial pressure gradient
h	Convective heat transfer coefficient (W/m^2 K)
k	Thermal conductivity (W/m K)
Kn	Knudsen number
L	Length of the microchannel (m)
Nu	Nusselt number $\left(=\frac{hD_\mathrm{h}}{k}\right)$
p	Pressure (Pa)
Ra	Rayleigh number
Re_ω	Rotational Reynolds number $\left(=\frac{\omega D_\mathrm{h}^2 \rho}{\mu}\right)$
$Re_{\omega,\mathrm{cr}}$	Critical rotational Reynolds number
Re	Reynolds number $\left(=\frac{\rho W_\mathrm{avg} D_\mathrm{h}}{\mu}\right)$
Ro	Rossby number $\left(=\frac{Re_\omega}{Re}\right)$
RPM	Revolution per minute
S_j	Source term in j-direction
T	Temperature (°C)
u, v, w	Velocities in x, y and z directions (m/s)
x_i	Co-ordinates in i-direction (x, y, z for i = 1, 2, 3)

Greek symbols

β	Ratio of the Coriolis force to the centrifugal force
λ, Γ	Eigen values
ω	Angular velocity (rad/s)