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Review

Heat transfer on topographically structured surfaces for power law fluids



Mohammad-Hossein Javanbakht ^a, Ali Moosavi ^{b,*}

- ^a Department of Engineering and Science, Sharif University of Technology, International Campus, Kish Island 15175311, Iran
- b Center of Excellence in Energy Conversion (CEEC), School of Mechanical Engineering, Sharif University of Technology, Azadi Avenue, P.O. Box 11365-9567, Tehran, Iran

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ABSTRACT

The three-dimensional power law fluid flow through rough microchannels has been studied numerically to determine the effects of the topographic structures on the thermal and hydrodynamic characteristics of the system. Rectangular, triangular and sinusoidal element shapes have been considered in order to investigate the effects of roughness height, width, pitch and channel separation on the pressure drop and heat transfer. Uniform wall heat flux boundary condition has been applied for all the peripheral walls

The results indicate that the global heat transfer performance can be improved or reduced by the roughness elements at the expense of pressure head when compared with the smooth channels. The maximum heat transfer performance has been obtained for triangular roughness shapes with the relative roughness height of 0.333. In most cases heat performance is smaller than unity. It is also revealed that for the sinusoidal and triangular cases by decreasing the relative roughness width, heat transfer performance is improved. Furthermore, the effects of the roughness features and the channel separation are intensified in power-law fluids. For dilatant fluids with a power-law index equal to n = 1.25, channel separation ratio reduction causes a steep rise in normalized friction factor up to 140.8 in the rectangular case. By increasing the relative roughness pitch of the cases with rectangular elements and the power-law index of n = 0.75, a reasonable heat transfer performance enhancement has been observed.

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E-mail address: moosavi@sharif.edu (A. Moosavi).

^{*} Corresponding author.

Nomenclature channel cross-section are (um²) perimeter average wall temperature (K) $T_{w,ave}$ Ā area vector of cross-section along x-direction (µm²) mean wall temperature along (x-direction) (K) $T_{w,ave}$ channel height (µm) $\overline{T}_{f,ave}$ mean fluid temperature along (x-direction) (K) а h channel width (µm) average velocity on x-direction (along the u_m Brinkman number (non-dimensional) Br^* channel)-(m/s) specific heat of the fluid $(I/(kg \cdot K))$ velocity inlet (m/s) C_p ш geometries parameters (non-dimensional) fluid velocity on x, y, z-direction (m/s) c_{1}, c_{2} u, v, whydraulic diameter (µm) D_h 7) velocity vector (m/s) U, V, Wfriction factor (non-dimensional) non-dimensional fluid velocity on x, y, z-direction normalized friction factor (non-dimensional) (dimensionless) *X** h(x)local heat transfer coefficient $(W/(m^2 \cdot K))$ non-dimensional axial distance (non-dimensional) average heat transfer coefficient $(W/(m^2 \cdot K))$ specific axial distance (µm) h_{ave} X_0 counter (dimensionless) fluid thermal conductivity $(W/(m \cdot K))$ k_f Greek letters K consistency index (Pa · s) roughness element width (µm) L channel length (µm) roughness element height (µm) 3 length of the fully developed part (µm) L_{fd} fluid viscosity $(Pa \cdot s)$. effective viscosity μ , μ_{eff} thermal developing length (μm) L_{th} $(Pa \cdot (1/s)^{\wedge}(n-2))$ m mass flow rate (kg/s) index of heat transfer performance (non-dimensional) η power law index (non-dimensional) $\dot{\theta}$ non-dimensional temperature (non-dimensional) average Nusselt number (non-dimensional) Nu_{ave} fluid density (kg/m³) ρ pressure (Pa), Non-dimensional pressure (dimension p_s, P_s α^* channel aspect ratio (non-dimensional) rate of deformation tensor (1/s), magnitude of rate of γ, γ roughness pitch (µm) P deformation (1/s) Pe generalized Peclet number (non-dimensional) shear stress tensor (Pa) τ P_{hw} the perimeter of the heated walls (µm) generalized Peclet number (non-dimensional) Pe^+ Subscripts q''heat flux per unit area (W/m²) hw heated walls generalized Reynolds number (non-dimensional) Re fully developed fd constant parameter Table 1 (non-dimensional) r average ave T_e fluid temperature at inlet (K) $T_{f,ave}$ bulk average temperature (K)

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1. Introduction

In recent years, the advancements in high power microelectronic devices and processors are rapidly increasing. Therefore, a highly effective heat removal system is required to dissipate generated heat in small area. Microchannels due to their features in heat dissipation in small area have attracted much attention. On the other hand, the increasing use of microchannels in biological

sciences such as analyzing DNA, protein and cells provides the second driving force for such investigations.

The fluid transport at the microscale may be affected by the surface roughness. The roughness may be created either intentionally for specific purposes or unintentionally due to the fabrication processes. Even surfaces with high quality polishing have significant roughness features at the microscales. At those scales the channel dimensions are close to the channels roughness and this high

Table 1Test matrix for rectangular channel with two opposite roughened wall.

Case No.	$\frac{L}{D_h}$	<u>a</u> b	$\frac{a}{D_h}$	$\frac{\varepsilon}{D_h}$	$\frac{\lambda}{D_h}$	$\frac{P}{D_h}$	$\frac{P}{\varepsilon}$
1	166.67	1	1.00	0.167	0.50	1.50	9
2	166.67	1	1.00	0.250	0.50	1.50	6
3	166.67	1	1.00	0.333	0.50	1.50	4.5
4	166.67	1	1.00	0.250	0.25	1.50	6
5	166.67	1	1.00	0.250	1.00	1.50	6
6	166.67	1	1.00	0.250	0.50	0.75	3
7	166.67	1	1.00	0.250	0.50	3.00	12
8	250.00	0.5	0.75	0.167	0.50	1.50	9
9	125.00	2	1.50	0.167	0.50	1.50	9

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