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Theoretical investigation of entropy generation and heat transfer by forced convection of copper-water nanofluid in a porous channel - Local thermal non-equilibrium and partial filling effects

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Abstract

Forced convection of copper-water nanofluid through a channel partially filled by a centrally located, porous insert is considered. Constant heat flux boundary conditions are imposed on the channel walls and the nanofluid flow is assumed to be hydrodynamically and thermally fully developed. The investigated system is under the local thermal non-equilibrium and two well-established interface models are employed to specify the thermal boundary conditions at the interface of the porous insert and nanofluid flow. Analytical expressions are derived for the temperature fields, Nusselt number and, total and local entropy generations. A parametric study reveals that variations in nanoparticles volumetric concentration only affect the temperature of the nanofluid flow within the clear region. It also shows that regardless of the choice of the porous-nanofluid interface model, addition of nanoparticles can improve the Nusselt number by up to around 15%. However, the local and total entropy generations are found to be strongly depended upon the employed interface model and increase considerably by increasing the concentration of the nanoparticles. It is shown that at high Biot numbers the effects of the interface model upon the thermal and entropic behaviours of the system diminish. This is argued to be related to the approach of the system towards local thermal equilibrium at larger values of Biot number.

Keywords: Nanofluid; forced convection; entropy generation; local thermal non-equilibrium; porous media.

Nomenclature

a_{sf}	Interfacial area per unit volume of porous media (m^{-1})	*Greek Symbols*	
Bi	Biot number, $\frac{a_{sf} h_{sf} h_0^2}{(1-\varepsilon)k_s}$	γ	Ratio of the wall heat flux to the heat flux at the interface, $q_w/q_{\text{interface}}$
$C_{nf,p}$	Specific heat of the nanofluid, (J $kg^{-1}K^{-1}$)	ε	Porosity of the porous medium
Da	Darcy number, K/h_o^2	θ	Dimensionless temperature
D_h	Hydraulic diameter of the channel ($4h_0$)	μ	Viscosity (kg $m^{-1}s^{1}$)
h_{sf}	Fluid to solid heat transfer coefficient (W $m^{-2}K^{-1}$)	μ_{eff}	Viscosity of the fluid in porous media (kg $m^{-1}s^{1}$)
h_0	Height of the channel (m)	μ_{nf}	Viscosity of nanofluid (kg $m^{-1}s^{1}$)
h_p	Porous substrate thickness (m)	ρ	Density, (kg/m^3)
K	Permeability of the porous medium (m^2)	ξ	Constant parameter used in Eq. (43)
k	Ratio of solid effective thermal conductivity	φ_1	Constant parameter defined by Eq. (54a)

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