Proceedings of CHT-17
ICHMT International Symposium on Advances in Computational Heat Transfer

May 28-June 1, 2017, Napoli, Italy

CHT-17-031

NATURAL CONVECTION OF POWER-LAW FLUIDS IN RECTANGULAR CROSS-SECTIONAL CYLINDRICAL ANNULAR ENCLOSURES WITH DIFFERENTIALLY HEATED VERTICAL WALLS

Sahin Yigit[*,§], Osman Turan[**] and Nilanjan Chakraborty[***]
[*]School of Mech. and Systems Eng. Newcastle University, Newcastle upon Tyne, UK
[**] Department of Mech. & Manuf. Eng., Bilecik Seyh Edebali University, Bilecik, TURKEY
[***] School of Mech. and Systems Eng. Newcastle University, Newcastle upon Tyne, UK
[§]Correspondence author. Tel: +44(0)191 208 7532 Email: s.yigit1@ncl.ac.uk

Laminar natural convection of power-law fluids has been numerically investigated in rectangular cross-sectional cylindrical annular enclosures with differentially heated vertical walls subjected to the both constant wall temperature (CWT) and constant wall heat flux (CWHF) boundary conditions. Power-law model of viscosity (i.e. $\mu = K\dot{\gamma}^{n-1}$ where μ is the viscosity, K is the consistency, n is the power-law index and $\dot{\gamma}$ is the shear rate) is used to mimic the strain rate dependence of viscous stress of inelastic non-Newtonian fluids in this study. The viscosity μ decreases (increases) with increasing shear rate for $n < 1$ $(n > 1)$ and thus fluids with $n < 1$ $(n > 1)$ are referred to as shear-thinning (shear-thickening) fluids, whereas $n = 1$ represents Newtonian fluids in the context of power-law model. It has been found that the mean Nusselt number based on the inner periphery of cylinder $\overline{Nu}_i = \bar{h}_i L/k$ (where $\bar{h}_i$ is the mean heat transfer coefficient on the inner periphery of cylinder and k is thermal conductivity) increases with increasing Ra due to the strengthening of buoyancy forces with increasing Ra. By contrast, $\overline{Nu}_i$ increases with decreasing n due to the weakening of viscous resistance. The mean Nusselt number $\overline{Nu}_i$ decreases with increasing r_i/L before approaching the mean Nusselt number for a rectangular enclosure in the limit of $r_i/L \to \infty$. By contrast $\overline{Nu}_i$ normalized by the corresponding Nusselt number for pure conduction (i.e. $\overline{Nu}_i/Nu_{cond}$) increases with increasing r_i/L. The ratio of convection to conduction strength increases with increasing r_i/L, since Nu_{cond} decreases with increasing r_i/L for cylindrical annular enclosures (i.e. $Nu_{cond} = (L/r_i)/(\ln(1 + L/r_i))$. Additionally, it is found that $\overline{Nu}_i/Nu_{cond}$ shows non-monotonic trend with increasing AR for a given set of values of $Ra, Pr, r_i/L$ for shear thinning $(n < 1)$, Newtonian $(n = 1)$ and shear thickening $(n > 1)$ fluids in the CWT configuration, whereas $\overline{Nu}_i/Nu_{cond}$ increase monotonically with increasing AR in CWHF configuration irrespective of the value of n. Competing effects of strengthening of convective and weakening of conductive thermal transport with increasing AR is responsible for the non-monotonic $\overline{Nu}_i/Nu_{cond}$ behavior in response to AR in the CWT configuration. Detailed scaling analysis is utilized to explain the effects of normalized radius, aspect ratio, nominal Rayleigh and Prandtl numbers, power-law index on $\overline{Nu}_i$ for natural convection of power-law fluids within rectangular cross-sectional cylindrical annular enclosures. Finally, new correlations have been proposed for $\overline{Nu}_i$ for both CWT and CWHF boundary conditions, which have been shown to provide satisfactorily predictions of $\overline{Nu}_i$ for the range of the parameters considered in this analysis.