Reducing Pressure Drop in Microscale Channel Using Constructal Theory

Authors : K. X. Cheng, A. L. Goh, K. T. Ooi

Abstract : The effectiveness of microchannels in enhancing heat transfer has been demonstrated in the semiconductor industry. In order to tap the microscale heat transfer effects into macro geometries, overcoming the cost and technological constraints, microscale passages were created in macro geometries machined using conventional fabrication methods. A cylindrical insert was placed within a pipe, and geometrical profiles were created on the outer surface of the insert to enhance heat transfer under steady-state single-phase liquid flow conditions. However, while heat transfer coefficient values of above 10 kW/m2·K were achieved, the heat transfer enhancement was accompanied by undesirable pressure drop increment. Therefore, this study aims to address the high pressure drop issue using Constructal theory, a universal design law for both animate and inanimate systems. Two designs based on Constructal theory were developed to study the effectiveness of Constructal features in reducing the pressure drop increment as compared to parallel channels, which are commonly found in microchannel fabrication. The hydrodynamic and heat transfer performance for the Tree insert and Constructal fin (Cfin) insert were studied using experimental methods, and the underlying mechanisms were substantiated by numerical results. In technical terms, the objective is to achieve at least comparable increment in both heat transfer coefficient and pressure drop, if not higher increment in the former parameter. Results show that the Tree insert improved the heat transfer performance by more than 16 percent at low flow rates, as compared to the Tree-parallel insert. However, the heat transfer enhancement reduced to less than 5 percent at high Reynolds numbers. On the other hand, the pressure drop increment stayed almost constant at 20 percent. This suggests that the Tree insert has better heat transfer performance in the low Reynolds number region. More importantly, the Cfin insert displayed improved heat transfer performance along with favourable hydrodynamic performance, as compared to Cfinparallel insert, at all flow rates in this study. At 2 L/min, the enhancement of heat transfer was more than 30 percent, with 20 percent pressure drop increment, as compared to Cfin-parallel insert. Furthermore, comparable increment in both heat transfer coefficient and pressure drop was observed at 8 L/min. In other words, the Cfin insert successfully achieved the objective of this study. Analysis of the results suggests that bifurcation of flows is effective in reducing the increment in pressure drop relative to heat transfer enhancement. Optimising the geometries of the Constructal fins is therefore the potential future study in achieving a bigger stride in energy efficiency at much lower costs.

Keywords : constructal theory, enhanced heat transfer, microchannel, pressure drop
Conference Title : ICHTA 2016 : International Conference on Heat Transfer and Applications
Conference Location : London, United Kingdom
Conference Dates : January 18-19, 2016