International Journal of Thermal Sciences 50 (2011) 2132–2140

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Numerical investigation of counter flow microchannel heat exchanger with slip flow heat transfer

Ahmed M. Shakir [a], Ahmed K. Mohammed [a], Mushtaq I. Hasan [b,*]

[a] Mechanical Engineering Department, College of Engineering, Basrah University, Iraq
[b] Mechanical Engineering Department, College of Engineering, Thi-Qar University, Thi-Qar, Iraq

ARTICLE INFO

Article history:
Received 24 February 2011
Received in revised form
29 May 2011
Accepted 30 May 2011
Available online 6 July 2011

Keywords:
Microchannel
Knudsen number
Slip flow
Counter flow heat exchanger

ABSTRACT

The rectangular microchannel heat exchanger performance is numerically investigated in this paper. Hydrodynamic and heat transfer characteristics in a laminar, 3-D, incompressible, slip flow, steady state and counter flow are proposed. The Navier–Stokes equations and energy equation for the hot and cold fluids are solved with the slip velocity and temperature jump conditions. The governing equations are discretized using finite-volume method-upwind differencing scheme, and then these are solved using SIMPLE algorithm method on staggered grid with FORTRAN code. From the obtained results it was found that the factors affecting the effectiveness are: Reynolds number Re, thermal conductivity ratio K_r, Knudsen number Kn and aspect ratio α. Increasing of Re, Kn and α separately lead to decrease the effectiveness. While the effectiveness increases with increasing K_r until it reach a certain optimal value which gives the maximum effectiveness at $K_r = 90$. Also, it is found that Nusselt number decrease with increases Knudsen number. Increasing of Re and Kn separately lead to increase pressure drop.

1. Introduction

In recent years, progress in micro fabrication and assembling various small systems has lead to the development of extremely small scale machines commonly referred to as MEMS (Micro Electro-Mechanical Systems). These systems are generally defined as electro mechanical devices having a characteristic length scale between 1 μm and 1 mm such as microchannel heat exchangers, micro reactors, micro sensors, …etc. Microchannel heat exchanger has found applications in highly specialized areas such as micro-electronics cooling, biomedical processes, metrology and robotics [1]. Miniaturization has provided many benefits including faster response time, high levels of system integration, high heat transfer rates and reduced cost [2]. Knudsen number is a measure of the degree of the rarefaction which is defined as the ratio of mean free path to the characteristic length scale of the system. For small Knudsen numbers, $Kn \leq 0.001$, the fluid is considered to be a continuum, while for large values, $Kn \geq 10$, free molecular flow is assumed. The slip-flow region studied in this paper has Knudsen number in the range of $0.001 \leq Kn \leq 0.1$ rarefaction effects start to influence the flow and the flow can be described by the Navier–Stokes equations with slip flow wall boundary conditions. To understand the flow through microchannels, many researchers have studied experimental, analytical and numerical investigations in last two decades. For example, Yu and Ameel [3] (2001) analytically studied laminar slip-flow forced convection in rectangular microchannels with constant wall temperature by applying a modified generalized integral transform technique to solve the energy equation. Assuming hydro dynamically fully developed and thermally developed flow. They concluded that the normalized fully developed Nusselt number decrease with increasing aspect ratios. The effect of Knudsen number on heat transfer is a result of the reduction of the wall normal velocity and temperature gradients with the increasing velocity and temperature jump that accompany the departure from the continuum regime.

Khan and Yovanovich [4] (2007) analytically investigated the laminar forced convection in 2-D rectangular micro and nano-channel heat sinks under hydro dynamically and thermally fully developed conditions with velocity-slip and temperature jump boundary conditions at the channel walls. They used the air as the coolant fluid. Iso flux thermal boundary condition is applied on heat sink base. They neglected the axial conduction and assumed that the pressure gradient varied linearly in the axial direction. They illustrated that pressure drop decrease with decreasing of Knudsen number and increasing of the channel aspect ratio. Also,

* Corresponding author. Tel.: +964 7801140094.
E-mail address: mushtaq76h@yahoo.com (M.I. Hasan).

1290-0729/$ – see front matter
doi:10.1016/j.ijthermalsci.2011.05.021