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ScienceDirect

Procedia Engineering 105 (2015) 258 – 263

Procedia Engineering

www.elsevier.com/locate/procedia

6th BSME International Conference on Thermal Engineering (ICTE 2014)

Ultra Compact Heat Exchanger With Geometry Induced Wall Jet

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Abstract

Heat Exchanger (HX) is common but crucial equipment found in almost every engineering application which comes in different types, sizes and shapes. Performance of the HX is directly related with the overall system performance. Compactness of the HX is a good indication of its performance, usually the higher the compactness the higher the effectiveness. Increasing compactness of the HX by reducing the channel dimension is fairly a simple but highly effective technique. Although heat exchanger comprising of very small channel can achieve very high heat flux, its pumping requirement for circulating liquid increases very sharply. The pumping requirement can be reduced by increasing the number of channels either by vertical or horizontal stacking; the flow velocity through each channel is reduced for the same total mass flow rate of the liquid. In this study a novel technique called geometry induced wall jet is proposed to further enhance the performance of this heat exchanger comprising of small channels. The cross-flow from the wall jet disrupts the boundary layer of the channel enhancing its heat removal capacity. A CFD model has been developed using commercially available software package FLUENT to evaluate the overall thermal performance of the proposed design. A parametric study of the flow rates and the effect of the jet locations have been performed. Significant reduction in thermal resistance has been observed for the proposed design.

Peer-review under responsibility of organizing committee of the 6th BSME International Conference on Thermal Engineering (ICTE 2014)

Keywords: Heat Exchanger, Wall Jet, Heat Transfer Enhancement

1. Introduction

Heat transfer in an efficient manner is always demanding and it becomes extremely challenging and complex as the device dimension reduces with the sharp rise of power density. Heat exchangers are the devices that mediates heat transfer between two fluids and a very essential and component used in numerous industrial applications including power generation, transportation, HVAC, electronics cooling, nuclear, manufacturing, food processing industries, just a few of many [1]. Performance of the HX significantly affects the performance of the overall system and thus affects operating cost of different industrial processes. Enhanced heat transfer performance inside the HX reduce its size making it more economic. Demand for the miniaturized, lightweight heat exchangers that can offer

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doi:10.1016/j.proeng.2015.05.105

high heat transfer are increasing due to ever increasing energy density, space constriction for device packaging, energy and material savings, ease of handling, etc. [1-3].

Increasing heat transfer performance of the HX by reducing the channel cross-sectional area is fairly a simple but highly effective technique. Exploiting high surface area to volume ratio, micro size channel offers compact heat exchanger design. Compactness is a good indication of HX performance, generally higher compactness indicates higher effectiveness for a given pressure drop [4]. Compactness ratio for the micro-channel HX can be 14,200 m^2/m^3 and more. Besides micro-channel heat exchanger responses very quickly to the temperature change thus provide a better temperature control for relatively small temperature differences between fluid flows [5]. Micro-channels and micro-channel heat sink have been investigated extensively for the last decade since its early introduction by Tuckerman and Pease [6]. Micro-channel heat sink can transfer large amount of heat from a constrained space; albeit at increased heating loads heat transfer in micro-channel become costly, due to higher pressure drop and larger temperature gradient exists along the flow direction of the channel [7-8]. Single-phase forced convection inside the micro-channel is governed by the laminar flow. The thermal resistance of the micro-channel is mainly governed by the boundary layer thickness that develops on the channel surface. Several research attempts have been made to enhance the heat transfer performance of the micro-channel by changing the geometry, manipulating inlet zone, breaking the boundary layer, introducing synthetic jet, stacking multiple layers of channel, introducing microstructures inside the channel, modifying surface morphology of the channel [9-12].

Recent advancements in precision micro-machining techniques have made it very accessible for the fabrication of micro-channel HX. Micro-channel HX obviously can carry large amount of heat with an increased pressure drop penalty and increased thermal stress due to elevated temperature gradient. Research is going on focusing on micro-channel HX both numerically and experimentally. Effect of channel shape, size and flow path direction has been investigated and enhancement in overall heat transfer performance is reported [3, 13].In this paper, the opportunities of heat transfer enhancement of micro-channel HX by introducing geometry introduced wall jet is investigated numerical. This innovative heat exchanger design takes the advantage of both high surface area to volume ratio of micro-channel and thermal boundary layer re-development and other jet effect due to cross flow from the wall jet. This heat exchanger performance improvement technique is passive and it is very easily implementable in practical HX. Conjugate conduction and convection equations are solved for the heat sink using commercially available CFD code FLUENT. The heat exchanger is compared with the plain micro-channel HX based on thermal resistance and pumping power requirements.

2. Formulation

This study investigates the performance of the heat exchanger comprised of micro sized channel as presented in Fig.1. Each rectangular micro-channel has a width of 50 μm and a depth of 100μm, and between the hot and cold fluid channel a 20μm wall is present. This study is aimed to investigate the effect of the in-plane surface jet introduced by the geometric variations of the channel, which can be implemented between the hot fluid channels or/and cold fluid channels. Performance of this new technique has been compared with that of the conventional micro-channel heat exchanger. To simplify the problem formulation, save computational cost and to focus specifically on the proposed methodology, only two channels of the cold fluid are considered (see Fig.2 for details of the computational domain) and the hot fluid layer is presented with a uniform heat source 20 μm beneath the cold fluid layer (which is justifiable considering copper heat sink). To investigate the effect of induce wall jet; three different geometric configurations were generated as presented in Fig.2. The flow was considered as laminar and steady. Governing equations for conservation of mass, momentum and energy take the following form: