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Review of micro- and mini-channel heat sinks and heat exchangers for single phase fluids

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ABSTRACT

Depleting energy resources have become the driving force for their conservation. Increasing the system efficiencies is one method by which sustainability of energy may be ensured, for which miniaturization has successfully provided solutions. Miniature heat exchangers, owing to their high thermal performance, have the potential to provide energy efficient systems. In addition, their characteristics of compactness, small size and lesser weight have attracted widespread applications. Various works on micro- and minichannel heat exchangers as heat sinks and heat exchangers have been reviewed in this paper. Currently employed fabrication techniques and different applications have been summarized. An overview of the single-phase thermo-hydraulic studies in micro- and minichannel heat sinks has been presented. Literatures related co-current, counter-current and cross-current micro- and minichannel heat exchangers have been discussed. Finally, the persisting lacunae of this technology drawn from the review have been pointed out.

Contents

1. Introduction

One of the major concerns of the twenty-first century is the energy conservation and the quest for development of alternative sources of energy. Conventional energy resources, being continuously exploited, are expected to get exhausted in the coming few decades [1]. Scientists, researchers and industrial organizations are endlessly thriving to address this vital issue so that mankind continues to enjoy the fruits of technological feats that it has achieved.

Solutions for energy management issues are twofold – either dependency on traditional energy resources is to be totally discarded and renewable sources of energy be searched for; or, innovative methodologies to increase the efficiency of energy systems are to be determined thereby saving conventional energy resources and increasing their sustainability. Research on development of energy-efficient systems has led to the evolvement of

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various subset fields, one of it being miniaturization. Studies reveal that miniaturization in manufacturing and electromechanical systems have the potential of becoming the "economic drivers" in near future [2].

Miniaturization has captured the heat exchanger technology as well. Heat exchangers are inherently a crucial part of the systems involving heat and mass transfer. The efficiency of a heat exchanger contributes immensely to the overall system efficiency. In case of cryogenic heat exchangers, systems may even cease to work if the exchangers do not work above the critical efficiency values [3]. Micro- and minichannel compact heat exchangers have become widely popular owing to their benefits of reduced dimensions without bringing a compromise in the thermal performance [4,5]. A report by Roth et al. [6] show that these exchangers can be effectively used as energy efficient systems. The growing potential of this technology is evidently visible from the numerous research works available [7].

Micro- and minichannels are different from the conventional channels in terms of channel hydraulic diameters. Classifications proposed by Mehendale et al. [8] and Kandlikar and Grande [9] are generally followed, the latter being more popular. The nomenclatures adopted by both these authors have been presented in Table 1. Kandlikar and Grande [9] have distinguished the channels based on manufacturing constraints and the Knudson number, while Mehendale et al. [8] have classified the channels somewhat arbitrarily. Nevertheless, deviations from either of the nomenclatures are quite common and the terms 'microchannels' and 'minichannels' are frequently used interchangeably.

The concept of micro- and minichannels was at first proposed by Tuckerman and Pease [10] in heat sinks about three decades ago. They postulated that an increase in heat transfer coefficient could be achieved with the reduction in channel hydraulic diameter. This development gave a boom in the electronic industry which was then dealing with problems of high heat dissipation in limited space. Subsequently, researchers have found different possible prospective of this revolutionary technology.

The initial hurdle was of fabricating the micro- and minichannels since the conventional techniques were found incapable of machining such small sized channels. As a result, non-conventional techniques were steadily developed to provide in-par solutions to manufacturing problems of these channels. In spite of high heat removal rates, micro- and minichannels are currently being used for high-end applications only. They are yet to replace the conventional channels commercially, primarily because of the high cost associated with specialized fabrication techniques required to manufacture micro- and minichannels.

Thermo-hydraulic characteristics of micro- or minichannels are the pre-requisites for using them in any thermal applications. An obvious question accompanying the reduction of size is regarding the aptness of the scaling laws [11]. Consequently, researchers are incessantly trying to determine whether the conventional channel theory can be used to predict the thermo-hydraulic performance

Table 1
Channel classification by Mehendale et al. [8] and Kandlikar and Grande [9].

Mehendale et al. [8]		**Kandlikar and Grande** [9]	
Conventional channels	$D_h > 6$ mm	Conventional channels	$D_h > 3$ mm
Compact Passages	$1 \text{ mm} < D_h \le 6$ mm	Minichannels	$200\ \mu m < D_h \le 3$ mm
Meso-channels	$100\ \mu m < D_h \le 1$ mm	Microchannels	$10\ \mu m < D_h \le 200\ \mu m$
Micro-channels	$1\ \mu m < D_h \le 100\ \mu m$	Transitional channels	$0.1\ \mu m < D_h \le 10\ \mu m$
		Molecular nanochannels	$D_h \le 0.1\ \mu m$

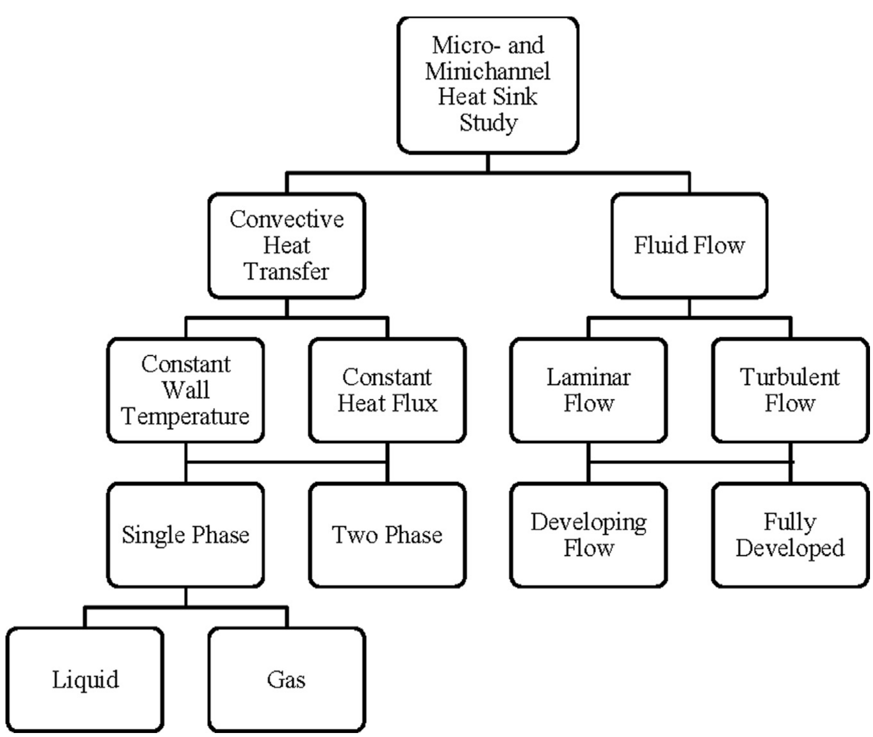

Fig. 1. Schematic of the general studies on micro- and minichannels.