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# Heat Transfer Analysis in Microchannel Heat Exchanger: A Review

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**Abstract—***A systematic review on the heat transfer in microchannel heat exchangers with different geometries is presented. The slip and No-slip flow are accounted in this study. The two dimensional, three dimensional studies considered with single phase convective heat transfer microchannel with different geometries. Both theoretical and experimental studies are considered and comparison made between them. From the available experimental literature friction factor, Nusselt number is measured and they compared with the conventional theory and results shows that inequality between experiment and conventional theory results. The compressibility effect, roughness effect, viscous dissipation effect, variation in properties is also considered for find out the pressure drop. The results show that the pressure drop is the function of roughness. By paralleling the experimental data on single-phase convective heat transfer through microchannels, it is manifest that additional methodical studies are essential to generate a sufficient understanding of the conveyance mechanism responsible for the variation in heat transfer in microchannels.*

**Keywords***: Microchannel, Heat Transfer Rate, Friction Factor, Pressure drop.*

## 1. INTRODUCTION

Microfluidic systems are developed by using of micromachining technology. Microchannels also a part of micromachining technology. The electronics cooling system which is based on microchannel retaining single phase liquid heating or boiling has marked its attainment by reaching high heat flux dissipation rate.

Microchannels are described by the hydraulic diameter of channel. The reduction in channel size has different possessions on different processes. The classifications of channels are proposed by Mehendale et al. [14] they distributed the ranges of channel from 1 to 100 µm as microchannels, 100 µm to 1 mm as meso-channels, 1mm to 6 mm as compact passage, and more than 6 mm as conventional passage. Kandilkar and Grade [12] proposed a general scheme based on the smallest channel dimension as shown in table 1

**Table 1: Channel classification**

| | |
|---|---|
| Conventional Channel | $D_h > 3$ mm |
| Minichannels | 3 mm $\geq D_h >$ 200 µm |
| Microchannels | 200 µm $\geq D_h >$ 10 µm |

For the designer of micro fluid device it is important to understand the phenomenon of transport in micro-devices.

Due to high heat transfer rate, microchannel becomes an interested area for researchers in last two decades. Tuckerman and Pease [21] was first announced the conception of microchannel heat exchanger for high heat flux in electronic chip for cooling. This different indication led to a number of inventive schemes and germinated widespread research exertions in the range of micro-channel cooling. Ameel et al. [1], Nguyen [17] gives a complete review on the research and development on the micro-machined flow sensors. The author underlines how, in the last years, the requirement of micro flow sensors able to measure very small flow rates has increased. Bailey et al. [3] concentrated their attention on the single phase forced convection through microchannels and concluded that the literature is inconclusive with respect to the effect of miniaturization on heat transfer and pressure drop. Duncan and Peterson [7] delivered extensive criticism of micro-scale conduction, radiation, and convective heat transfer. Peng and Wang [18] presented a review of their individual broad investigation on the one-phase and two-phase micro-scale convective heat transfer. Morini [15] presented a review of experimental results single phase convective heat transfer in microchannels.

However, microchannels with surfaces patterned or rough surfaces through micro pin fins essentially have nucleation sites. In the manifestation of high heat flux transients, these nucleation sites can trigger commencement of nucleate boiling even throughout single phase heating in microchannel.

## 2. PRESSURE DROP

The pressure drop is the function of friction factor. The investigators usually dignified the pressure drop at the inlet and outlets of the channel. The pressure drop signifies the mutual effect of the losses in the bends, developing region effect, entrance and exit losses, and the core frictional losses. Phillips [19] shows the following equation to measure the pressure drop at 90˚ bends channel as:

$$\Delta p = \frac{\rho u_m^2}{2}\left[\frac{A_c}{A_p}\right]^2 (2K_{90}) + (K_c + K_{e)} + \frac{4lf_{app}}{D_h} \qquad (1)$$

They also considered these victims and mentions that $K_{90}$ to be approximately 1.2.

Judy et al. [10] presented the good agreement (as shown in fig. 1) between conventional theory and experimental results for round and square microchannel with 15 – 150 µm hydraulic diameters which is made of fused silica and stainless steel, methanol, isopropanol, distilled water taken as working fluid.

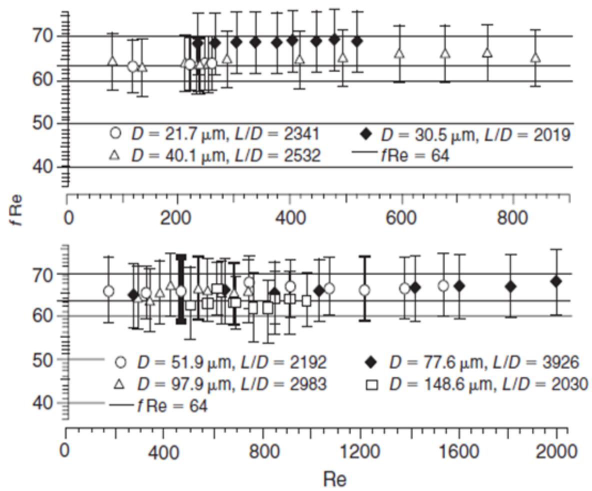


**Fig. 1: Evaluation between theory and investigational data of judy et al. (2002)**

Wu and Little [22] first found the friction factor in silicon microchannels. Different microchannels were tested, having different hydraulic diameter (55.81, 55.92 and 72.38 µm) in trapezoidal cross-section. Gases ($N_2$, $H_2$, Ar) were used as a working fluid the dignified values were greater (10 – 30%) than those expected in conventional theory. They determined that the eccentricities are due to the great relative roughness and to the asymmetric dissemination of the surface roughness on the microchannel walls.

Harley and Bau [9] dignified the friction factor in a trapezoidal silicon microchannel with 45µm hydraulic diameter and for a rectangular microchannel with 67 µm hydraulic diameter. By using isopropanol as working fluid, they originate that the Poiseuille number obtained from experiment is higher than the expected theoretical value.

Choi et al. [5] measured the friction factor for a fully through silica micro-pipes with nitrogen gas as a test fluid having a different hydraulic diameter (3, 7, 10, 53, 81 µm) with Reynolds numbers going from 30 and 20 000. They found that the obtained Poiseuille number *(f Re)* in laminar regime is lower than the conventional value *(f Re* = 16*)*. So no variation of the friction factor with the wall roughness is evidenced.

Lee and Garimella [13] investigated laminar convective heat transfer in the rectangular cross-section microchannels which is subjected to H1 boundary condition. They suggested correlations to predict local and average Nusselt number (for inlet Pr = 5.83). They initiate that their proposed correlations are in very good arrangement with available experimental data.

Bahrami et al. [2] studied pressure drop in smooth arbitrary cross-sections channels to find relationship for $fRe_{\sqrt{A}}$ using existing logical solutions. They establish that square root of cross-sectional area $\sqrt{A}$, as the length scale, is larger to the conventional hydraulic diameter.

Muzychka and Yovanovich [16] had presented that the apparent friction factor is a weak function of the geometrical shape of the channel. Based on these recommendations, Bahrami et al. [2] suggested a compact estimated model as a function of cross-section geometry parameters that could calculate pressure drop in an extensive variety of channel shapes. They authenticated this model for rectangular, trapezoidal, square and circular cross-sections by equating with experimental data and exact analytical results.

## 3. NUSSELT NUMBER

Nusselt number represents the enhancement of heat transfer through a fluid layer as a result of convection relative conduction across the same fluid layer [23].

Celata et al. [4] in experimental setup of circular micro-ducts with different hydraulic diameters investigated single-phase laminar flow. Results displayed that as decrease in diameter of channel the Nusselt number decreasing, an axial dependence that is linked to thermal entrance effects and a dependence of the Nusselt number also on Reynolds number. They also investigated the possible occurrence of scaling effects such as axial conduction in the walls, viscous heating of the fluid and thermal entrance length effects.

Kandlikar et al. [11] showed that the heat transfer rate increased due to advanced relative roughness in 620 µm tube because Nusselt number affected by relative roughness. And also showed the good agreement between their experimental results of Nusselt number to the conventional theory.

Duryodhan et al [8] study the heat transfer in converging diverging microchannel using de-ionized water as a working fluid to obtain Nusselt number. They proposed a pragmatic co-relation for calculate the Nusselt number in converging diverging microchannel heat exchanger.

Rahman and Gui [20] verified the laminar forced convection in rectangular etched silicon microchannels using water as tested fluid. They determined that the obtainable Nusselt numbers were greater than those expected by analytical solutions.

Cuta et al. [6] in rectangular microchannel of 425 μm hydraulic diameter with R124 as a tested fluid measured the Nusselt number. They proposed that in a laminar region the values of Nusselt number are higher than those expected values. Also in turbulent regime the Nusselt number improved with the Reynolds number.

From the study of available literature it can be summarized that the pressure drop, friction factor, heat transfer, and Nusselt number are varies for different geometrical shapes and sometimes the experimental results are matched with the conventional results.

## 4. CONCLUSION

From a chronological analysis of the results mentioned in this paper it is conceivable to generalize how the unconventionalities between the behaviors of fluids decreasing in the microchannels with respect to the large-sized channels. This statement can be clarified by taking into account the development of the techniques of micro-fabrication with the subsequent reduction on the surface roughness of the microchannels and a more suitable control of the channel cross-Sections for this cause the consequences of the older studies may not make available beneficial evaluations. Another possible explanation of the decrease of the observed deviations is related to the increase of the reliability/accuracy of the more recent experimental data. Anyhow, the investigation accompanied in this review recognized that the thoughtful of the fluid flow and the heat transfer mechanisms in microchannels has to be considered, at the moment, a scientific open question.

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