Experimental determination of the hydraulic resistance coefficient at the microchannel inlet

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Abstract. The paper presents the results of the hydraulic resistance coefficient measurements at the inlet of microchannel. The Reynolds number ranged from 900 to 2300. The channel with inlet diameter of 3.5 mm is abruptly narrowed to a diameter of 0.9 mm. We measured the pressure drop in the area of sharp change in diameter. Measured hydraulic resistance coefficient was compared with the previously obtained coefficients for microchannels of the same geometry. It is shown that for the studied interconnected channel geometry no differences were found between micro and minichannels.

1. Introduction

The advancement of technology made it possible to produce miniature fluidic devices. When developing and designing microfluidic devices, the question arises about the applicability of known fluid dynamics laws applicable for macrochannels to fluid flow in channels of micron and submicron sizes. Over the past 15-20 years, many research groups presented their results on pressure drop and hydraulic resistance coefficient for laminar and turbulent fluid flow in microchannels as well as studies on heat transfer in microchannels.

The application of microfluidic systems for cooling of microelectronic components is quite attractive and promising due to their large efficiency. Along with cooling systems, microfluidic systems find use in biomedical applications. Optimizing the design of microfluidic systems requires a clear understanding of the fluid transport mechanisms in both laminar and turbulent fluid flow.

When designing microfluidic devices, it is important to correctly account the hydraulic losses in all the areas of the hydrodynamic tract. When dealing with straight microchannels we know how to determine the hydraulic resistance value, the issue of hydraulic losses in coupling areas of different size channels still remains unclear. An additional difficulty in this problem is caused by the lack of information available in handbook on hydraulic resistance relevant to Reynolds numbers or geometric configurations of coupling of different channels that are typically used in practice. The complexity of fabrication of the microchannels with orifices in the wall makes it difficult carrying out experiments to determine the hydraulic resistance coefficients at the microchannel inlet.

Literature reviews dedicated to the hydraulic resistance in the microchannels are given in many papers [1-4], though the number of works on measurement of the pressure inside the microchannels is quite small [5-7].

Considerable interest in the context of design and the overall resistance of the microchannel is focused to the inlet region of the channel, namely the resistance of the inlet section. The study of this
important issue is complicated by the extremely small size of the investigated area, which is responsible for pressure drop.

In our previous works [8, 9] we studied the fluid flow in microchannels with diameters from 70 to 100 microns. The channels were provided with the orifices made in the wall to measure the pressure along the channels. One of the orifices was located near the inlet to the channel at a distance of about one diameter of the channel. This made it possible to determine the hydraulic resistance coefficient at the inlet of the microchannel. The coupling geometry of two channels is shown in figure 1. Here $D=1700 \mu m$, while $d$ is equal to 70 [8] and 100 [9] $\mu m$.

![Figure 1. The coupling geometry of the channels](image)

Hydraulic resistance coefficient of the inlet section of the microchannels in [8, 9] was defined as:

$$ f = \frac{2 \Delta P}{\rho V^2}, $$

where $\rho$ and $V$ – are the density and the average fluid velocity, $\Delta P$ – is the pressure drop at the channel inlet, defined as the difference between the manifold pressure and the pressure in the first orifice of the microchannel.

Unfortunately, the handbook of hydraulic resistance [10] lacks data for a given geometric configuration and experimentally achieved Reynolds numbers. Accordingly, the aim of this work was to obtain information about the hydraulic resistance coefficient of the channel inlet with the same geometry but at larger scale.

2. Experiment
To conduct experiments, we have fabricated experimental setup consisting of two channels with diameters of 3.5 and 0.9 mm. The coupling geometry of the channels corresponded to that shown in figure 1. To measure pressure drop in the channels with a diameter of 3.5 and 0.9 mm we made orifices with a diameter of 300 and 100 $\mu m$, respectively. These orifices were located at a distance of 400 $\mu m$ on either side of coupled channels.

The schematic diagram of experiment is shown in figure 2. Distilled deionized water (1) was used as a working fluid. Through the filter (2) water was fed into the channels (4) by means of Gilson-305 piston pump (3). Fluid flow rate was controlled by weighing system (5). The pressure drop was recorded by Honeywell PC24 differential pressure sensor at 30 psi. The Reynolds numbers ranged from 900 to 2300.
Figure 2. Schematic diagram of the experiment

Figure 3 shows the experimental results compared with the results of [8, 9]. We see good agreement of the data that indicates the absence of differences between hydraulic resistance coefficients obtained in macro and micro scale channels for a given coupling geometry within the studied range of Reynolds numbers.

Figure 3. Hydraulic resistance coefficients at the inlet sections of microchannels

Conclusion
The results of the hydraulic resistance coefficient measurements at the inlet of microchannel is presented. The Reynolds number ranged from 900 to 2300. The channel with inlet diameter of 3.5 mm is abruptly narrowed to a diameter of 0.9 mm. The pressure drop in the area of sharp change in diameter is measured. Measured hydraulic resistance coefficient was compared with the previously
obtained coefficients for microchannels of the same geometry. It is shown that for the studied interconnected channel geometry no differences were found between micro and minichannels.

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References
[1] Obot N 2003 Microscale Thermophys. Engineering 155–173
[2] Morini G L 2004 Int. Journal of Thermal Sciences 631–651
[3] Hetsroni G 2005 Int. Journal of Heat and Mass Transfer 1982–1998
[4] Steinke M E and Kandlikar S G 2006 Int. Journal of Thermal Sciences 1073–1083
[5] Kohl M J, Abdel-Khalik S I, Jeter S M and Sadowski D L 2005 Int. Journal of Heat and Mass Transfer 48 1518–33
[6] Costaschuk D, Elsnab J, Petersen S, Klewicki J C, Ameel T 2007 Experiments in Fluids 43 907–916
[7] Baviere R and Ayela F 2004 Meas. Sci. Technol 15 377–383
[8] Aniskin V M, Adamenko K V and Maslov A A 2012 Nanosystems: Physics, Chemistry, Mathematics, 3 37-46
[9] Aniskin V M, Adamenko K V and Maslov A A 2010 Siberian Journal of Physics 5 63-70
[10] Idelchik I E 1992 The handbook of hydraulic resistance (ed M O Steinberg(M: Mashinostroenie))