Numerical simulation of Flow Pressure Drop and Friction Factor of Water in 2D channel

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Abstract. The paper presents the results obtained from the numerical study of the dynamic properties of a straight channel 50 mm long and 780 µm wide on a 2D model. Numerical simulations were performed by using Navier-Stokes equation. The results showed a good agreement with experiments and other models. Pressure drop and friction factor of water in the channel in the studied ranges of Reynolds number are due to viscosity effects.

1. Introduction

The development on the manufacture of new devices at a micro and nano scale allows the construction of microchannels of different sizes and shapes that are used in a wide variety of ways, such as heat transfer, biologic material analysis: DNA, cells, embryos, chemical reagents among others. In the present situation, understand the microchannel dynamic characteristics will be followed for a design improvement. Nowadays, device design with integrated electronic microchannels has growth in the industry and research, to be used in medicine, biology and environmental sectors, for instance. Numerical simulation plays an important role study and design of microfluidic devices [1,2,3].

2. Theory

Under the framework of a continuous model, a Newtonian liquid dynamic is represented according the Navier-Stokes incompressible equation [4].

\[
\rho \left( \frac{\partial u}{\partial t} + u \nabla u \right) = -\nabla p + \mu \nabla^2 u + f, \tag{1}
\]

\[
\nabla \cdot u = 0, \tag{2}
\]

where \(u\) and \(\mu\) are the speed and the dynamic viscosity of the liquid, \(p\) is the pressure, \(\rho\) is the fluid density, \(f\) is the volumetric density of external forces acting on the liquid. The characteristic dimensions in systems such as water-filled microchannels or electrolytic aqueous solutions, with a \(D\) diameter, fulfil the conditions for a Reynolds number \(Re = \frac{\rho u D}{\mu} \ll 1\). This means that for most of the stationary problems, in equation (1) can be used the Stokes approximation

\[
-\nabla p + \mu \nabla^2 u + f = 0 \tag{3}
\]
Nevertheless, it is necessary to know the channel behaviour, including values of Reynolds number \( R \geq 1 \). In a laminar flow, the drop of pressure depends linearly on the fluid median velocity. Then, it also depends of the Reynolds number

\[
\Delta p = K \frac{\mu u}{D},
\]

where \( K \) is the dimensionless coefficient of pressure drop. The channel friction factor \( f \) is calculated with the following expression

\[
f = \frac{\Delta p D}{2L \rho u^2}
\]

From equation (5), it is deduced that the friction factor is inversely proportional to the Reynolds number.

3. Numeric model and results

The purpose of the present work is evaluate the pressure drop and the friction factor of a 2D channel 50 mm long and 780 \( \mu m \) wide, where water flows at 18 \( ^\circ \)C. The pressure drop is assessed along the channel for different values of the Reynolds number under no-slip boundary condition. To calculate the pressure drop COMSOL models are used at different mean velocities. In this configuration, the pressure drop is only due to the friction of the bounding walls and no other effect influences in the channel hydraulic performance.

In figure 1, it is shown the flow velocity inside a channel when mean speed is 2 mm/s. As it is observed, no-slip boundary condition is accomplished (\( u=0 \)) in the channel bounding walls. It is calculated the velocity profile along the channel transverse arc length (figure 2).

![Velocity inside the selected channel [mm/s]].

The absolute pressure diminishes along a channel, in which sliding is not present between the fluid and the bounding walls, mainly due to viscosity. Therefore, the loss in pressure depends proportionally to the dynamic viscosity of the fluid. Figure 3 shows the variation in the pressure along the channel for different values of the Reynolds number.
Figure 2. Velocity magnitude along an arch length for a mean velocity of 4.5 mm/s.

Figure 3. Pressure along the channel for Re values of 7.4, 14.8, 22.2, 29.6 and 37.0 (bottom to top).

The pressure drop is evaluated along the channel according to the Reynolds number. Figure 4 shows the percentage of the pressure drop along the channel determined by the Reynolds number.

Figure 4. Pressure drop according to the Reynolds number.

Lastly, the friction factor for the fluid inside the channel is obtained using the equation (5). Figure 5 shows the friction factor diminishing inversely proportional to the Reynolds number value.
4. Conclusions
The data obtained in this study satisfactory agrees with other studied models and theory literature. The development and design of devices at a micro and nano scale is possible with the advancement in the knowledge of the hydraulic characteristics, including how different scale values affect the performance. Recently, new approaches have appeared in this field with a series of novel proposals, technical and experimental developments. For instance, new geometric designs and materials to the improvement of dragging inside of a superhydrophobic channel, new designs of mixers and separators, heat transfer, among others [5,6,7,8]. This project is partially founded by the Engineering Faculty of the Universidad Distrital Francisco José de Caldas de Bogotá, inside the Proyecto Curricular de Ingeniería Electrónica.

5. References
[1] Niklas M, Favre-Marinet M and Asendrich D 2005 Bulletin of Polish Academic of Sciences 53 4 351-359
[2] Mirmanto M 2013 Journal of Mechanics Engineering and Automation 3 641-649
[3] Federspie W J and Valenti I 2012 Open J. Appl. Sci. 2 28-34
[4] Bejan A 1995 Convection Heat Transfer John Wiley & Sons New York USA
[5] Akbari M, Sinton D and Bahrami M 2009 J. Fluids Eng. 131 041202-1-8
[6] Zhao H, Liu Zh, Zhang Ch, Guan N and Zhao H 2016 Exp. Therm. Fluid Sci. 71 57-69
[7] Chai L, Xia G D and Wang H Sh 2016 Int. J. Heat Mass Transfer 97 1081-1090
[8] Chong D T, Liu J P and Yan J J 2011 Energy Convers. Manage 52 2272-2281

Figure 5. Friction factor determined by the Reynolds number.