The effect of inertia on the distribution of flow in the microfluidic junctions - numerical simulations and experimental evidence

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1 Introduction

Microfluidic channels are characterised by small diameter (less than 1 mm). Because of small characteristic length and relatively low Reynolds numbers (Re) it is often assumed (without deep consideration) that inertia is negligible.

This assumption allows for radical simplification of the analysis of microfluidic networks. According to the Hagen-Poiseuille's law, stationary, viscous, laminar and incompressible flow satisfies the linear relation between the static pressure drop Δp and volumetric flow rate Q: $\Delta p = RQ$. The coefficient R - so called hydraulic resistance, is analogous to the electric resistance in Ohm's law [1]. Consequently, the pressure drop Δp is equivalent to the voltage drop and the volumetric flow rate Q to the electric current. This analogy provides a simplified description of the flow through regular microfluidic channel, where the channel is treated as a one-dimensional wire characterised by the constant resistance. The fact that the hydraulic resistance is proportional to the length of a channel gives an ability to establish a required resistance of the channels during the process of design and fabrication. If the analogy to electric circuit is satisfied, the analytical solutions prescribing fluid flow in microfluidic networks can be derived from equivalent electric circuit equations, which typically reduce to a system of linear algebraic equations [2].

Beside the straight, regular channels non-trivial microfluidic network consists of branching points. A junction, which connects three channels is very common and standard element of microfluidic devices. It allows for splitting one input flow into two output flows or merging two input flows into one output. In the linear approximation (without inertial effects), a junction is simplified to a point node connection of 1D channels. Such reduced description predicts the constant ratio of output flows with respect to total incoming flow (independent on Re). In the range of Re in which this linear approximation is correct, the design of microfluidic network enables encoding of arbitrary series of dilutions by the ratio of lengths of channels behind each splitting point [3].

However, as we show, the inertial effects, even if negligible in straight, regular channels appear in junctions, due to the sudden change of speed and direction of the flow. Herein we analyse a junction as a source of non-linearity in microfluidic networks for moderate Re.

2 Experimental and numerical results

We developed experimental approach, which allows for precise and effective investigation of the ratio of output flows in microfluidic junctions for moderate Re and for different geometries of junctions (fig.1a). Significant dependence of experimental results on Re clearly prove the non-negligible discrepancy from the linear model (fig.1b). Magnitude of these variations depends strongly on the angles between channels. The experimental data set was used for verification of numerical simulations (fig. 1b) conducted for the same geometry by the use of ANSYS Fluent. The additional numerical simulations allowed for efficient investigations of different geometrical configurations. We propose the mathematical model of the system including dependence of the effect of inertia on angles between channels. The knowledge about the role of a geometry may allow for such design of the microfluidic junction, in which sum of all non-linear elements in equations vanishes and solution recovers its linear character and independence on Re.

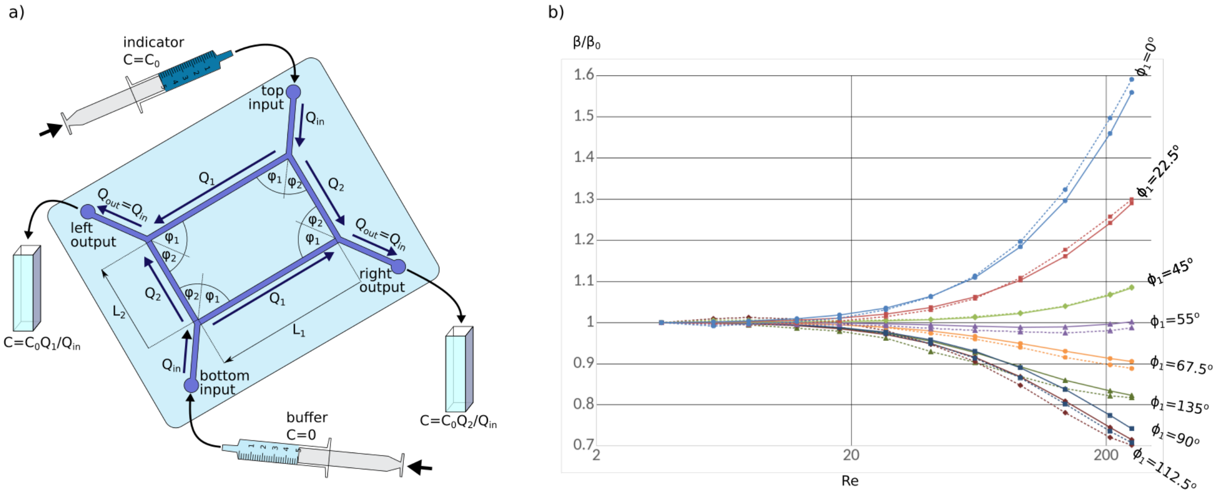

Figure 1: a) - schematic view of the experimental setup. The incoming flow Q_{in} splits into Q_1 and Q_2. The presented approach enables investigations of flow distribbution $\beta = Q_1/Q_2$ as a function of angle ϕ_1 and Reynolds number. b) - normalised distribution of the flows in junction β/β_0, where $\beta_0 = L_2/L_1$ for different angles of the input/output channels as a function of Re. Solid lines - experimental results, dotted lines - numerical simulations.

References

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