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GAS FLOW IN A MICRO-CHANNEL WITH AN ELASTIC OBSTACLE

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KEY WORDS

compressible viscous gas, moving wall, obstacle, elastic cantilever beam

ABSTRACT

A two-dimensional slip regime compressible gas flow around an elastic body (cantilever) in shaped in form of beam and fixed to one of the walls in microchannel is considered. The numerical analysis is separated into two parts: obtaining the distribution of normal stress exerted on the elastic body by using a continuum model on the basis of the Navier-Stokes-Fourier (NSF) equations [1] with slip boundary conditions on all solid walls and applying the stress distribution to find the expected small deflections of the elastic body.

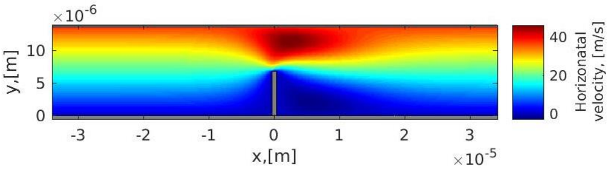
Problem description and results

The problems of gas flow at microscale have a great importance for many high technological devices and they are subjects in studies of many researchers. The essential and intriguing element is that there are fundamental differences in the microfluidic considerations with respect to those of conventional flows at macroscales scales. In many cases in micro channels, where gas flows, there are obstacles with different shapes. In most of the cases they are considered as rigid bodies. In the present work a gas flow in a long microchannel is considered. In the channel there is an obstacle, which deformable properties are considered (see Fig. 1 a) and b)). The upper channel wall is moving with constant velocity 37 [m/s] (M=0.1) while the bottom is at rest. The obstacle – a cantilever beam is vertical and clamped to the bottom channel wall. The Knudsen number is 0.01 and it is based on molecules mean free path in free-stream flow and cantilever's length. The cantilever thickness is 0.1 times its length.

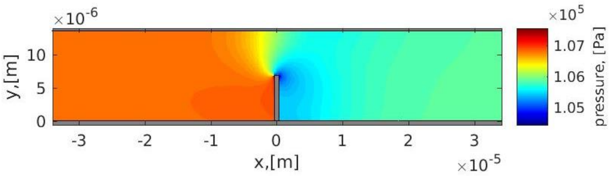
The gas is described by using a continuum model on the basis of the Navier-Stokes-Fourier (NSF) equations [1] for a compressible viscous gas with transport coefficients determined by the first approximation of the Chapman-Enskog theory for low Knudsen numbers. The NSF system of equations was calculated numerically using finite volume algorithm SIMPLE-TS [2]. The cantilever is modeled as an elastic Timoshenko beam and the shear stress and rotary inertia during the beam motion are taken into account.

To determine influence of gas flow over the cantilever we take into account the normal stresses of gas on cantilever's front and back surfaces (see Fig. 1 c)) and neglect shear stresses on all cantilever's surfaces and normal stress on cantilever top surface. The beam was considered to be made of copper. The first 10 natural frequencies of the cantilever were calculated. Due to the small dimensions of the beam the frequencies are very high – the first one is ω_1= 2.644. 10^7 Hz. The obtained pressure on the front and back side of the beam was applied as a step load and the motion of the cantilever was studied. The considered gas flow leads to very small deflections of the beam (see Fig. 2). Small oscillations can be observed at the beginning of the flow (transient vibration) and after that the beam deforms in a shape similar to the one shown in Fig. 2.

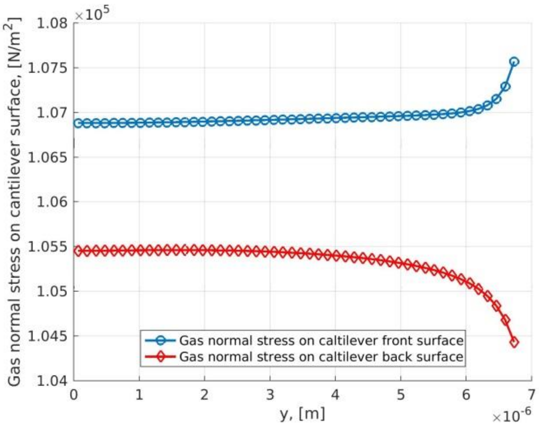
The work is a first attempt to study the interaction of the gas flow with a deformable body during its flow in a microchannel. When the elasticity of the obstacle is considered and the obstacle oscillates disturbing the flow the problem becomes very complicated and could influence essential changes in the flow. We plan to analyze these coupled effects in our further studies. The main conclusion of the present research is that the velocity of the flow could influence essentially the cantilever behavior and this effect could be used to study important phenomena in many high technological devices.



a) Horizontal velocity field



b) Pressure field



c) Gas normal stress on cantilever front and back surfaces.

Figure 1: Horizontal velocity field (a), pressure field (b) and gas normal stress on cantilever front and back surfaces (c).

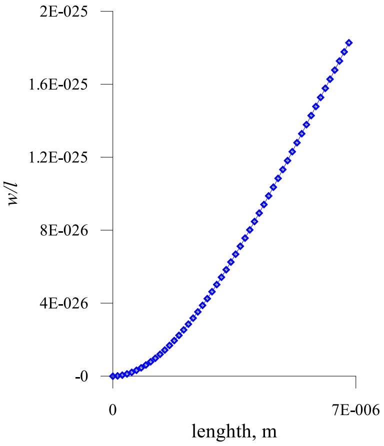


Figure 2. The deflection of the obstacle (cantilever beam) along its length at moment t=2.36. 10^{-8} s.

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