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RESEARCH PAPER

Effect of patchwise slip on fluid flow

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Abstract In this paper, we show that large *connected slip patches* (hydrophobic patches) are a necessity to induce macroscopic slip effects of water flow in microchannels. For this purpose, the 2D fluid flow between a planar stationary surface with alternating stick and slip patches and a parallel planar surface moving with a constant relative velocity has been studied by computer simulations based on Navier–Stokes equations. A *slip patch* is defined as the slipping length in a 2D system or a slip area of the surface in a 3D system. The simulations reveal that the ratio (size of each slip patch)/(distance between the two parallel interfaces) has profound effect on the viscous stress on the moving surface when this ratio is around and above one. However, when the ratio is much below one, the effect of the slip patches are minor, even if the area fraction of slip patches are higher than 50 %. Obviously, the stick patches adjacent to the slip patches act as effective barriers, preventing the fluid velocity to increase near the surface with alternating stick and slip patches. The obtained results are scalable and applicable on all length scales, with an exception for narrow channels in the subnano regime, i.e. <1 nm where specific effects as the atomistic composition and the nanostructure of the wall as well as the interactions between the wall and the water molecules have an effect.

Keywords Slip patch · Stick · COMSOL Multiphysics · Navier–Stokes equations

1 Introduction

There is an increasing interest in fluid flow in small, confined systems, i.e. microfluidics. This is partly due to new available methods of producing flow systems in the nano- and micrometre length scales, the importance of small volume handling in biology and biotechnology research, and the potential use of microfluidics in fundamental studies in biology and chemistry (Whitesides 2006). The microfluidic systems require the same components as a large-scale fluid system such as pumps, valves, and mixers, but since laminar flow dominates, driving and mixing of the fluids are difficult (Whitesides and Stroock 2001). However, there are different possible parameters to use for manipulating the fluid, for example, pressure, capillary effects, electric fields, magnetic fields, centrifugal forces, and acoustics, in addition to geometrical parameters (Stone et al. 2004).

Another interesting parameter for fluid flow manipulation in systems on these length scales is slip. Slip is the presence of a tangential slip velocity (u_s) at a solid surface, proportional to the shear stress normal to the surface and may depend on several factors such as surface roughness, the presence of nanobubbles on the surface, wettability, and the solvent used (Tretheway and Meinhart 2004; Pit et al. 2000; Tyrrell and Attard 2001). By combination of surface chemistry and micropattering, superhydrophobic surfaces can be engineered. The surface structure alters the drops ability to stick and allow them to move very fast, one part of which is due to slip (David 2005). In water systems, hydrophilic surfaces show almost no slip whereas slip

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