THE ROLE OF GAS AS A LUBRICANT IN MICROFLUIDIC WALL SLIP

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Microfluidics is the science of manipulating and controlling fluids, usually in the range of microlitres to picolitres, in networks of channels with dimensions ranging from tens to hundreds of micrometres. In the study of fluid flow on a microscale the general approach is to use the classical fluid mechanics formulation which is essentially based on the well-known Navier-Stokes equations. Notably, the small dimensions bring other physical phenomena to prominence such as the possible violation of the generally applied no-Slip boundary condition at the walls[1]. Therefore, a fluid could eventually show a certain degree of slippage, assuming different velocity with respect to the one of the solid surface. In these cases a different condition at the boundaries should be applied. This condition is known as Slip boundary condition or Velocity-Offset boundary condition and it assumes a discontinuity in the velocity function meaning a relative motion between the fluid and the wall. The velocity distribution does not hold a Poiseuille profile anymore, as one can appreciate from the following figure.

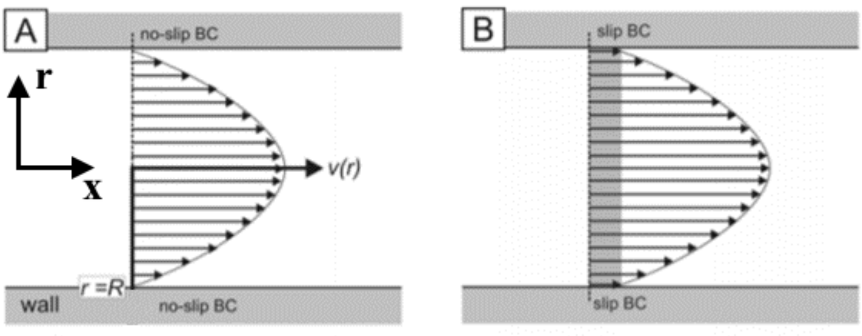

Figure 1 - A) Classical parabolic velocity profile in cylindrical geometry.
B) Modified Poiseuille velocity profile when Slip occurs at the walls.

Tuning the hydrodynamic boundary condition is essential for both applied and fundamental aspects of drag reduction. The phenomenon of Slip refers to all the situations in which the value of the tangential component of the fluid velocity is not equal to the one of the solid wall in direct contact with it. The physics involved in this scenario is that of a complex behaviour at a liquid/solid interface, involving an interplay of many physicochemical parameters such as wetting, surface roughness and dissolved gas. Many experts in fluid dynamics have, in the previous centuries, pronounced about this topic and in particular, in 1823 Navier introduced the linear boundary condition which remains the standard characterization of Slip used today[2].

Three main types of Slip could occur at the solid wall: molecular Slip, apparent Slip, and effective Slip. Molecular Slip refers to the possibility to use hydrodynamics to push fluid molecules to Slip on solid molecules which will occur when intermolecular forces are balanced by the viscous one. Apparent Slip refers to the situation when there is a certain portion of the channel in which no-Slip occurs and another in which Slip occurs and when the latter is higher than the former. Effective Slip is instead a more macroscopic phenomenon which refers to the case when molecular or apparent Slip is estimated by averaging an appropriate measurement over the length scale of an experimental apparatus[3].

To achieve high slippage of liquids at walls, the use of gas as a lubricant, such as microbubbles trapped in superhydrophobic surfaces, has been suggested[4-5]. Hydrodynamic friction on superhydrophobic substrates characterized by a gas–liquid interface can potentially be optimized by recreating a gas bubble mattress at the interior walls of a capillary such that the fluid is not in direct contact with the solid surface but with a gas phase, inducing a certain degree of slippage. The amount of Slip generated at the walls can be quantified by deriving the slip parameter or slip length (λ_w) which is defined as the distance below the liquid\solid interface where the liquid velocity extrapolates to zero, as schematically represented in Figure 2.

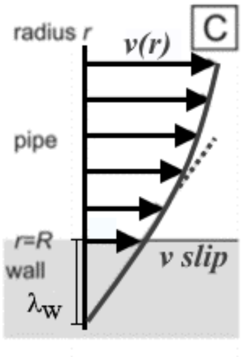

Figure 2 - Slip length.

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[3] L. E., "Microfluidics: The No-Slip Boundary Condition," in *Handbook of Experimental Fluid Mechanics*. New York: Springer, 2007, ch. 19, pp. 1219-1240.
[4] T. P., P. A.M., P. C., W. M., L. R.G.H., and L. D., "Quantifying effective slip length over micropatterned hydrophobic surfaces," *Physics of Fluids,* vol. 21, no. 11, 2009.
[5] K. E. *et al.*, "Control of slippage with tunable bubble mattresses," *PNAS,* vol. 110, no. 21, pp. 8422-8426, 2013.

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