Discussions on slip length measurements by microPIV/PTV in microchannels

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Fluid transportation in microfluidic system could be benefit from the slip on solid-liquid interface. Slip length on many kinds of hydrophilic/hydrophobic surfaces have been measured recently. The two common-used experimental methods for boundary slip measurement include: (1) surface force measurement, such as surface force apparatus (SFA), atom force microscope (AFM), and (2) velocity measurement, like microPIV/PTV (Particle image velocimetry / Particle tracking velocimetry), total internal reflection velocimetry (TIRV). However, the measured results are rather scattered, larger measured slip lengths were reported by microPIV/PTV experiments. In this paper, we will investigate the deviations of the measured slip length on smooth hydrophilic surface. After measuring detailed velocity profiles very close to hydrophilic glass wall, we give a discussion on the effects influencing the slip measurements.

1. Recent boundary slip measurements

Slip experiments have been made on a lot of surfaces with a wide range of contact angles (CA)[1]. However, the measured results are not in consistence, even for the hydrophilic surfaces (Fig.1). Theoretically, the slip length on a completely wetting surface is very close to zero. AFM/SFA measurements also showed the slip length on this hydrophilic surface is smaller that 1.5nm. But the reported measured slip lengths by microPIV/PTV were surprisingly large, which were in the range of 30nm to 100nm[2],[3]. Thus the microPIV/PTV measurements appeared to be in considerable error.

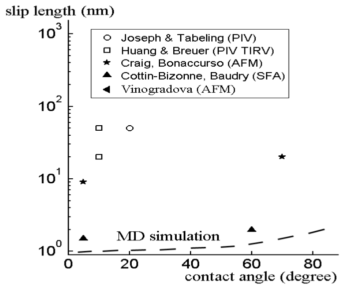

Fig.1 Recent slip measurement results on hydrophilic surfaces

2. Slip length measurements by MicroPIV/PTV

Our measurements were carried out by a microPIV/PTV system at the LNM, Institute of Mechanics, CAS. In a PDMS-glass hybrid microchannel (20μm ×50μm× 1cm), the velocity profiles of the whole flow field were measured. The results showed that the measured data in the main flow region were in good agreement with no-slip theoretical values, but large deviations appeared close to wall (Fig.2)[4]. To investigate the deviations, detailed measurements were carried out focusing on the near wall region[5], from 250nm to 1.5μm away from wall.

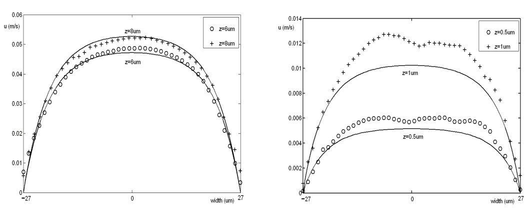

Fig.2 measured velocity profiles in different horizontal planes[4].

The experimental results show that the

deviations between measured data and no-slip theoretical values are from 44.8% to 109.2% (Fig.3). According to the measured velocity profile, we can evaluate the slip length on the smooth hydrophilic glass surface is 70 – 160nm, which is very large.

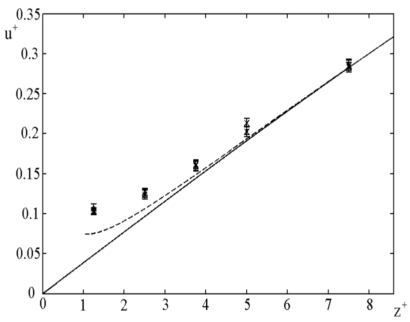

Fig.3 measured velocity close to wall [5].

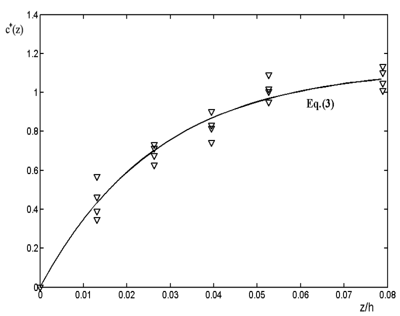

Fig.4 Biased particle concentration distribution close to wall.[5]

During the experiments, we observed and measured the biased particle concentrations distribution near wall region[5]. The measurement results show that the particle concentration distribution can be expressed by a dimensionless exponential formula.

3. Discussions

There are some physical influences on the measurements need to be considered. Based on the biased particle concentrations closed to wall and the effective focal plane thickness of the objective, we proposed an explanation to the large measured velocity near wall. The predicted measured velocity at focal plane $z=z_0$ in one horizontal plane $\bar{u}(z_0)$ is actually a spatial average over the focal plane thickness δz. If the particle concentration is not uniform in this thickness, a deviation of the measured velocity will be introduced. The relative deviation between the measured data and the predicted values $\bar{u}'(z_0)$ for 50 nm particles at z = 0.25μm becomes 10.1% instead of 44.8% (dash lines in Fig.3). As a result, taking the difference of the measured velocities and their predicted values as slip velocities, the slip length on the smooth hydrophilic glass surface can be revised to 10nm. It's close to some previous AFM results. Furthermore, the origin of the biased particle concentration distribution is under investigation now. Since the range of the biased distribution, which is approximately 1μm, is particle size dependent and beyond the Debye length , we suppose that the lateral force due to hydrodynamic shear is the main reasons.

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References:

[1]. Neto et al. Rep. Prog. Phys. 68, 2859-2897, 2005.

[2]. Joseph & Tabeling, Phys. Rev. E, 71, 035303, 2005.

[3]. Huang et al. J. Fluid Mech. 566: 447-464, 2006.

[4]. Zheng & Silber-Li. Exp. Fluids, 44: 951–959, 2008.

[5]. Zheng & Silber-Li. Submitted to Exp. Fluids.