Transport of nano-objects in narrow channels: influence of Brownian diffusion, confinement and particle nature

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Transport of confined colloids in nanochannels is a key for many siuations in biology (blood flow, flow cytometry, DNA analysis [9]), and flows in porous media [1] (chemical engineering with polymer processing, clogging [15, 4], separation [14], geophysics i.e. fractured rocks [16]). If the behaviour of advected particles or colloids in microchannels begins to be well understood both theoretically [12] and experimentally [11, 10], this field remains very active. Effect of wall roughness is also very important in natural systems [2, 8]. Furthermore transport of vesicles and soft particles in microfluidic devices is an emerging topic with dramatic implications such as drug vectorization [6] or in the comprehension of the transport of biological objects. Behaviour of soft capsules or vesicles under flow is quite well understood [5, 13]. Nevertheless, the cross effects of Brownian diffusion, particle nature and confinement are still not clear. Yet, in the case of sub-micrometric particles, these effect are crucial to explain transport in porous media. Moreover, the entrance geometry can have substantial effects on particle distribution in the channels and so on their transport in a pore [11].

We study experimentally the transport of solid and casule-like objects in nanoslits. Solid particles are carboxylate-modified polystyrene beads whereas soft objects are polymer auto-assemblies called polymersomes [3]. Channels are etched in silicon with different etching depths between 330 and 3390 nm and covered with glass. The flow is pressure-driven and particles are tracked using fluorescence microscopy. We have access to large statistics. We estimate the expected velocity taking into account Faxén's law and hydrodynamic interactions [7].

Results let appear two regimes for solid beads. In the first one the experimental mean velocity is similar to the theoretical one whereas in the second one the mean velocity of the objects is lower of about 20%. This can be related to cross effects of confinement and Brownian diffusion. The second regime appears at the lower confinement and the lower Brownian diffusion. The transition can be observed in some cases by varying the advection in the pore. The physical mechanism of this regime distinction has for origin the homogeneity or not of the particle distribution in the channels depth, due to the pore entrance geometry. This is demonstrated by deriving the position distributions from the velocity ones.

Concerning the polymersomes, the second regime seems to disappear. Only the transition is visible for similar particles diameter and confinement. This could be due to interactions between mechanical softness of these objects and the flow at the entrance of the channels.

References

[1] Bradford, S. A. & Torkzaban, S. Colloid Transport and Retention in Unsaturated Porous Media: A Review of Interface-, Collector-, and Pore-Scale Processes and Models. *Vadose Zone Journal*, 7(2), 667 (2008).

[2] Charru, F., Larrieu, E., Dupont, J.-B., & Zenit, R. Motion of a particle near a rough wall in a viscous shear flow. *Journal of Fluid Mechanics*, 570, 431 (2007).

[3] Dionzou, M., Mor{\`e}re, A., Roux, C., Lonetti, B., Marty, J.-D., Mingotaud, C., Joseph, P., Goudoun{\`e}che, D., Payr{\'e}, B., L{\'e}onetti, M., & Mingotaud, A.-F. Comparison of methods for the fabrication and the characterization of polymer self-assemblies: what are the important parameters? *Soft Matter*, 12(7), 2166–2176 (2016).

[4] Dressaire, E. & Sauret, A. Clogging of microfluidic systems. *Soft Matter*, 13(1), 37–48 (2017).

[5] Lefebvre, Y. & Barth{\'e}s-Biesel, D. Motion of a capsule in a cylindrical tube: effect of membrane pre-stress. *Journal of Fluid Mechanics*, 589, 157–181 (2007).

[6] Maeda, H. Macromolecular therapeutics in cancer treatment: the EPR effect and beyond. *Journal of Controlled Release: Official Journal of the Controlled Release Society*, 164(2), 138–144 (2012).

[7] Pasol, L., Martin, M., Ekiel-Jezewska, M., Wajnryb, E., Blawzdziewicz, J., & Feuillebois, F. Motion of a sphere parallel to plane walls in a Poiseuille flow. Application to field-flow fractionation and hydrodynamic chromatography. *Chemical Engineering Science*, 66(18), 4078–4089 (2011).

[8] Ranchon, H., Cacheux, J., Reig, B., Liot, O., Terrapanich, P., Leichl{\'e}, T., Joseph, P., & Bancaud, A. Accelerated transport of particles in confined channels with high roughness amplitude. *Langmuir* (2018).

[9] Ranchon, H., Malbec, R., Picot, V., Boutonnet, A., Terrapanich, P., Joseph, P., Leichl{\'e}, T., & Bancaud, A. DNA separation and enrichment using electro-hydrodynamic bidirectional flows in viscoelastic liquids. *Lab on a Chip*, 16(7), 1243–1253 (2016).

[10] Ranchon, H., Picot, V., & Bancaud, A. Metrology of confined flows using wide field nanoparticle velocimetry. *Scientific Reports*, 5(1) (2015).

[11] Staben, M. E. & Davis, R. H. Particle transport in Poiseuille flow in narrow channels. *International Journal of Multiphase Flow*, 31(5), 529–547 (2005).

[12] Staben, M. E., Zinchenko, A. Z., & Davis, R. H. Motion of a particle between two parallel plane walls in low-Reynolds-number Poiseuille flow. *Physics of Fluids*, 15(6), 1711 (2003).

[13] Vlahovska, P. M., Podgorski, T., & Misbah, C. Vesicles and red blood cells in flow: From individual dynamics to rheology. *Comptes Rendus Physique*, 10(8), 775–789 (2009).

[14] Wu, Z. & Hjort, K. Microfluidic Hydrodynamic Cell Separation: A Review. *Micro and Nanosystems*, 1(3), 181–192 (2009).

[15] Wyss, H. M., Blair, D. L., Morris, J. F., Stone, H. A., & Weitz, D. A. Mechanism for clogging of microchannels. *Physical Review E*, 74(6) (2006).

[16] Zhang, W., Tang, X., Weisbrod, N., & Guan, Z. A review of colloid transport in fractured rocks. *Journal of Mountain Science*, 9(6), 770–787 (2012).