Slip, patterns and other small things in microfluidic systems

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Microfluidics is about flow of liquids and gases, through microdevices fabricated by MEMS (i.e. Micro ElectroMechanical Systems) technology, using hard (silicon or glass) or soft (polymers) materials. The domain is fostered by exciting applications, representing important industrial challenges. It also embraces a number of fundamental issues interesting in their own right. The introductory talk will concentrate on some of them, through a presentation of a number of experiments we have been carrying out at ESPCI, over the last three years.

Let us start with the controversial topics of slip between liquid and solid. In classical textbooks, it is considered that liquids do not slip on solid surfaces ; the so called "no-slip" boundary condition on the tangential velocity u, for ordinary liquids, has the form :

$$u=0$$

on fixed solid surfaces. This provides a fundamental condition in fluid mechanics, allowing for detailed calculations of velocity profiles and flow structures. In contrast with this picture, we now have experimental evidence that simple liquids significantly slip on atomically smooth solid surfaces and, consequently, the no-slip condition is better replaced by the more general relation:

$$u = L_S\left(\frac{\partial u}{\partial n}\right)$$

in which L_s is the extrapolation or slip length, n is the normal (inwards to the fluid). This equation – justified only with perfect gases - is usually called the Navier condition. The estimate of the slip length Ls is controversial at the moment. By using PIV, and working with coated non wetting smooth surfaces, Tretheway and Meinhart(1) measured slip lengths on the order of 1 m. We performed a similar experiment, using glass and a variety of coatings, working with wetting and non wetting surfaces, with different roughnesses(2). We obtained slip lengths below 100 nm in all cases; We don’t know the origin of the discrepancy. In order to account for large slip lengths, one usually speculate on the existence of a thin gas layer confined between the liquid and the solid. This perhaps may reconcile the two sets of experimental observations.

Mixing is difficult in microsystems, and this has been a source of motivation for studying chaotic micro-mixers. I will present an experimental study of chaotic micromixing, which led to observe a novel resonance phenomenon. In this geometry, a pair of fluids flows side by side, in a channel, then pass through an intersection. At the intersection, a time-dependent flow coming from the sides is superimposed with the main stream. This additional flow perturbs the shape of the interface between the two fluids to different extents depending on the amplitude and frequency of the side-flow(3). Typically, when the perturbation amplitude is small, or its frequency large, weak oscillations are generated at the interface between the pair of fluids forming the mean stream. When the amplitude is large, and the frequency moderate, stretching and folding of the interface is produced, leading to chaotic regimes. “Resonance” conditions also exist, for which the interface is strongly distorted in the active region, but returns to a flat shape afterwards. This effect is a novel dynamical phenomenon, involving a particular interaction between space and time(4). From a dynamical system viewpoint, resonant regimes are linked to the existence of KAM trajectories(5). I will present an experiment showing all these phenomena, and, further, exploit the resonance regimes to realize an efficient micromixer/microextractor.

The last topics deals with two-phase flows in microsystems. I first describe a miniaturized version of a tangential filter. The system is composed of a main channel, which drives most of the flow, and a side channel, through which a small fraction of the main stream is sucked. In our case we work with a two phase flows, initially composed of water drops dispersed in hexadecane(6). Depending on the flow-rate conditions, drops may simply move with the main stream, or break up into two parts, each part being entrained in a different channel. The break-up conditions are well accounted for by using a theory based on Rayleigh Plateau instability(7). The second experiment emphasizes on the role of the walls - a direct consequence of miniaturization - : It will appear that wetting characteristics are exceedingly important in miniaturized two-phase flows(8)..

In conclusion, it will appear, through a few examples, that microfluidics offers a context for the development of unfamiliar, sometimes surprising behaviors of fluid systems. Moreover, it is a often a source of inspiration for novel (micro)engineering concepts.

References

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