USING MICROFLUIDICS TO INVESTIGATE REACTION-DIFFUSION PHENOMENA IN SIMPLE FLOWS

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Summary We report new experimental and theoretical results on the problem of reaction-diffusion in a microfluidic chip. The chemical reactor under study is a T-shaped microchannel (about 200 μm wide and 10–20 μm deep) in which the two analytes are bring into contact at a constant flow rate. In the interdiffusion zone, the local concentration of the reaction product is measured using optical epi-fluorescence. To extract useful informations about the reaction kinetics, one needs to model the reaction-diffusion zone and compare the simulations with the experiments. We show that such a microfluidic device is a well-suited method to access fast chemical kinetic rates.

INTRODUCTION

In the macroworld, chemical reactors usually operate in three dimensional turbulent regimes. Investigating such systems requires measuring, locally, the concentration field of the reactants, along with the velocity fluctuations, which is an extremely difficult task. More generally, the coupling between flow and chemical reactions lacks of experimental input at the moment, and this is unfortunate, owing to the considerable importance that such an interaction has, in industrial and natural contexts.

We show here that microfluidics allows to improve the situation, by offering the possibility to analyze, on an experimental basis, fundamental chemical diffusion phenomena, under an unprecedented control level. The physical reason is that, by miniaturizing, the laminar nature of the flow is fully guaranteed, whatever the liquid of interest we may use in the experiment. The paper focuses on the particular case of the spread of a reaction zone along a channel flow.

REACTION-DIFFUSION DYNAMICS IN A MICROCHANNEL: COMPARISON BETWEEN THEORY AND EXPERIMENTS

The microchannel we use here is in form of a T, similar to the one proposed in Refs. [1, 2] (see Fig. 1). The channels are etched in glass, and covered by a silicon wafer, anodically bonded to the glass [3]. Reactants are driven along the T arms and are further collected in the main channel, forming a diffusion reaction front, which grows downstream. In this work, we use thin channels, 10 μm deep, so as to put three-dimensionnal effects under control. Figure 2 shows the reaction zone, formed by a Ca^{2+}/ CaGreen reaction, in such a system. We show here that the system is amenable to full theoretical understanding, provided we assume the chemical reaction to be of second order. To show this result, we compared the observed fluorescent field with the numerical solutions of the two-dimensional reaction diffusion equations, which govern the system evolution. In this comparison, the diffusion constants are measured independantly, or are known from existing tables. Only one parameter is left free – the kinetic factor k – and we adjust this parameter so as to optimize agreement between the numerics and the experiment (this in turn may provides a method of determination of k). Figure 3 indicates that agreement obtained under these conditions is good.

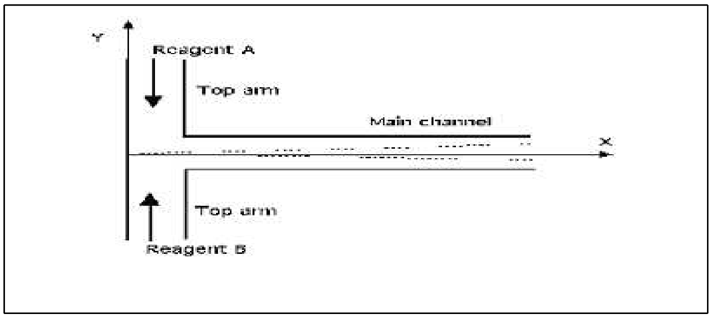

Figure 1. Sketch of the experimental system used, in form of a T-sensor, to measure fast chemical kinetics.

The method was used for a set of different flow rates and concentrations. At the largest concentrations we considered, the kinetic factor k we used was $k = 10^6$ L.(mol s)$^{-1}$, corresponding to a half-time reaction of 1 ms. This illustrates the idea that microfluidics may improve the measurements of the kinetics of fast chemical reactions, compared to the traditional stopped-flow techniques. In conclusion, we have investigated a fundamental situation of chemical diffusion (the spread of a reaction zone in a channel flow), and we have shown that the system is fully amenable to theoretical understanding.

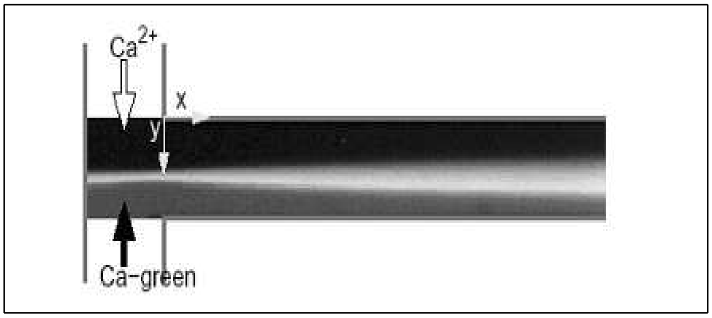

Figure 2. Experimental micrograph of the diffusion reaction zone for a Ca^{2+}/ CaGreen reaction, for 40 nL.min^{-1}

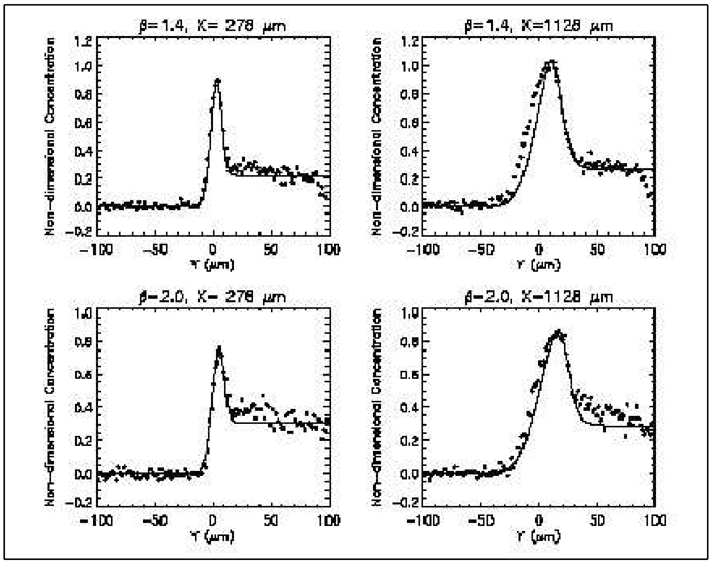

Figure 3. Comparison between the numerical concentration profiles of the product obtained by solving the two-dimensional reaction diffusion equations (full lines) and the experimental measurements (points), at various locations, for two values of the reactant concentration ratio; X and Y are the same as in Fig. 2.

Microfluidics systems may indeed allow to investigate other situations, under well controlled situation, and we hope this will be done, so as to elaborate an experimental basis for the important problem of handling reaction-diffusion phenomena in hydrodynamic systems.

References

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