Mode Switching and Collective Behavior in Chemical Oil Droplets

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Extended Abstract

We have designed a series of chemical experiments to investigate the emergence of spontaneous self-movement in a simple chemical system. More specifically we have followed the dynamic motile behavior of oil droplets consisting of oleic anhydride in an aqueous environment. The droplets can move by creating an internal convection flow, which enforces a break in symmetry and organizes droplet movement. The droplets can exhibit several different styles of motion depending on their age, size and the pH condition. The dynamics of single droplets on a glass plate show a transition from the anomalous diffusion to a directional motion then to a more complex vibrating motion by radically modulating its boundary shape. When many droplets are present, they aggregate and physically contact each other. We often observe that the internal convection flow of those droplets synchronize, i.e. the directions of flow become parallel to each other like magnetic spin systems. These discoveries illustrate that coupling a chemical reaction (hydrolysis of the anhydride) to a physical body (the oil droplet) can result in an instability that affects both convective flow patterns and overall shape, and therefore the agents and their collective behavior.

In order to clarify how droplet 'behavior' changes with controlled parameters of the system, we analyzed the system for micro scale flow patterns using microscopy and for macro scale behavior using image analysis and droplet tracking tools. First, the shape of the droplet changes at a certain point as we increase the size from a few micrometers to a few centimeters, and accordingly the motion pattern changes from the quasi Brownian to directional movement to a vibrating mode. We have characterized those tendencies by measuring the stop/go intervals and the auto correlation functions. A shape change in such a system has great importance since deformations will create new interfacial surfaces where dynamic phenomena may occur. Second, when droplets come together, their internal convection flow is re-configured resulting in a collective motion. When the droplets use up their chemical energy (reaction on their surfaces), the collective behavior will disappear. Therefore the collapse and genesis of collective behavior is the evidence of the active moving droplets.

We tried to replicate those phenomena with the numerical procedure (coupling the Navier-Stokes equation with a chemical reaction). When the initial size exceeds a certain limit, the numerical procedure fails to produce physically correct values. The droplet breaks up into pieces. Thus the breakup of the numerical procedure may correspond to the shape transition. Therefore the system is challenging for both experimental and numerical studies and at the conference we will focus on how single droplet mode switching may reflect the important parameters that will allow different behaviors to emerge from such a simple chemical system. Also when multiple droplets are present, the same signals that organize the movement of a single droplet may be used to organize and coordinate the behavior of several droplets. Collective behavior can begin to be understood following the simple physico-chemical processes described here.

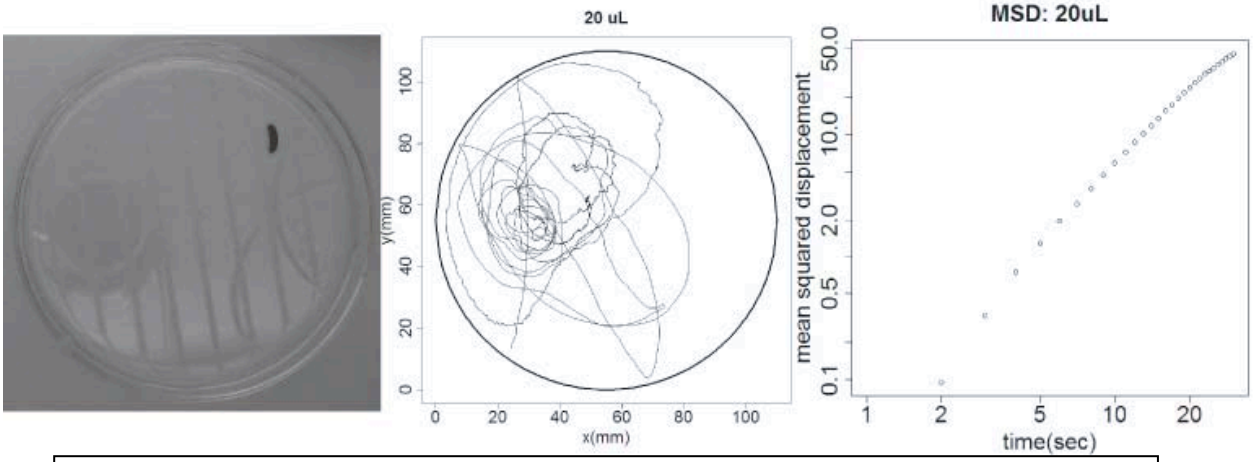

Fig. Droplet in a glass plate, trajectory of a droplet and autocorrelation function of a trajectory.