Fluids in Small Confined Spaces Stirred with Self-Assembled Chains of Iron Beads

Mixing in microfluidic channels is difficult because confined spaces inhibit viscosity-induced turbulence. Diffusive mixing can occur in these situations, but some devices utilizing submillimeter channels require faster mixing than this achieves. Pursuing stirring methods at the micrometer-scale is therefore a priority for lab-on-a-chip applications, and the most useful methods utilize the strong, long-range interaction between a magnet and a magnetic field. As reported in the July issue of *Physical Review* E (DOI: 10.1103/PhysRevE.80.016312; #016312), J.E. Martin, L. Shea-Rohwer, and K.J. Solis of Sandia National Laboratories have introduced a method of mixing fluids with self-assembled chains of 4–7 µm carbonyl iron beads driven by a magnetic vortex field.

A vortex field is a combination of three fields, two perpendicular sinusoidal fields oscillating 90° out of phase (a rotating field) and a third normal to their plane. By measuring the angular deflection due to the vortex magnetic field of 150 mg of Fe particles in 2 ml solution, the researchers measured the torque imparted to several fluids with viscosities varying by an order of magnitude. They found that the mixing is optimized when the ac field and dc field magnitudes are equal. A sample of the magnetic powder was suspended in resin to test if the deflection measured was due to the magnetic torque of the beads or the torque imparted to the fluid. The resin did not move, from which the researchers inferred that the frequency-dependent susceptibility of the iron plays a negligible role.

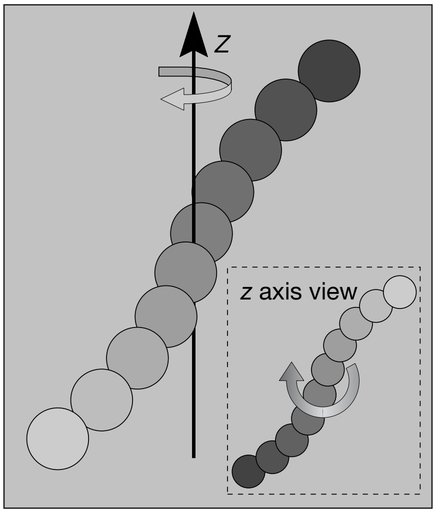

Figure 1. Magnetic beads rotate in response to a vortex field. Inset: The view along the mixing axis. Reprinted with permission from *Physical Review E* **80** (2009), #016312. ©2009 by the American Physical Society.

The researchers found that the iron beads did not rotate independently; rather they stirred the liquids by forming magnetically linked chains (see Figure 1). Because chains fragment as they whirl around faster, the chain imparts a constant torque to the fluid as the frequency of the vortex field increases. This is not what happens with a magnetic stir-bar. The research team found that this action also keeps the mixing torque independent of the viscosity of the fluid and the diameter of the beads. It can be controlled only by changing the magnitude of the applied field. These effects ultimately cease at sufficiently high field frequencies or low field strengths that the chains fragment into solitary magnetic particles, but otherwise this method of imparting torque to a fluid allows for mixing fluids on any scale.

Jim Rantschler

Piezomagnetoelastic Device Harvests Vibrational Energy

In the current era of energy awareness, the ability to recover energy wasted as heat or vibration is an important component of conservation. Commonly called "energy harvesting," it requires a way to gather and store minute amounts of energy, a complex problem that is leading researchers to novel materials solutions. As reported recently in *Applied Physics Letters* (DOI: 10.1063/1.3159815; #254102), researchers A. Erturk, J. Hoffmann, and D.J. Inman, from Virginia Polytechnic Institute and State University, have devised a system for harvesting vibrational energy based on a magnetoelastic structure originally studied for the type of behavior known in chaos theory as strange attractor motion.

The device, a simple cantilevered construction with magnetic and piezoelectric components, achieves power generation over a broad spectrum of vibrational frequencies, which has been difficult to achieve but is important for effective energy harvesting. The design consists of a small cantilevered beam of a ferromagnetic material (tempered steel), the tip of which vibrates between two permanent rare earth magnets. Piezoceramic layers are used at the base of the beam to convert the vibration to electricity and the entire device is about 15 cm tall.

Erturk and colleagues present time domain simulations as well as experimental data, both demonstrating broadband response achieved from a variety of starting conditions. They show that the presence and position of the permanent magnets near the beam tip is crucial. Without the magnets, the only significant output voltage occurs at the beam's resonant frequency whereas the full piezomagnetoelastic system delivers roughly 20 V across the investigated spectrum (4.5–8 Hz). According to the researchers, their measured 200% increase in the open-circuit voltage translates into an 800% increase in the power amplitude, and they are optimistic that this design could be extended to other transduction mechanisms, such as electrostatic or magnetostrictive energy conversion.

Alison Hatt

Soot Aggregates from Pre-Mixed Flame Observed to Have Low Fractal Dimension

Fractal-like soot particles are among the combustion-generated carbonaceous aerosols that influence Earth's radiation balance, climate, atmospheric chemistry, and therefore the welfare of all its living inhabitants. In addition, fractal-like aggregates (FAs) are relevant to interstellar dust and to large-scale nanomaterial production with flame synthesis. Flame-formation of aerosols and colloids in the cluster-dilute regime, where the average distance between clusters is much larger than the cluster size, occurs by a three-dimensional, diffusion-limited, cluster-aggregation growth mechanism. For FAs formed by this mechanism, the mass is a function of linear size (i.e., the radius of gyration, R_g) raised by an exponent, D_f, which is the fractal dimension. Heretofore, FAs in the cluster-dilute regime have exhibited D_f values in the range of 1.7–1.8.

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Recently, however, R. Chakrabarty at the Desert Research Institute in Reno and the University of Nevada, M.A. Garro of the Desert Research Institute in Reno and Harvard University, J.G. Slowik of the University of Toronto, E.S. Cross of Boston College, T.B. Onasch of Aerodyne Research, Inc. in Billerica, Mass., and their colleagues have observed ensembles of cluster-dilute soot FAs with much lower D_f values, in the range of 1.2–1.5.

As reported in the June 12 issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.102.235504; #235504), Chakrabarty and co-researchers used a pre-mixed ethene-oxygen flame set-up that allowed them to vary the fuel-to-air equivalence ratio, ϕ, from 2.3 to 5.0. After removing soot particles larger than 5 μm from the sample with an impactor, the particles were bipolarly charged with a neutralizer, and then directed to two in-series electrostatic classifiers (ECs), which are widely used for particle sizing and operate with a combination of viscous and electrostatic force to select particles with a combination of charge and electrical mobility diameter, D_m. The researchers said that this morphology segregation technique is based on the higher likelihood for more elongated particles becoming doubly charged than compact particles because less energy is required to add a second charge at a larger distance than at a short one. Constituting about 3% of the total submicron particle sample and following a Gaussian distribution with a peak D_m of about 460 nm, elongated FAs were impacted onto clear polycarbonate filters for scanning electron microscopy (SEM) analysis.

Samples were coated with 1 nm Pt to prevent aerosol charging during SEM. The researchers imaged about 150 doubly-charged FAs for each ϕ and corrected for the screening effect of 3D particles projected onto two dimensions. Image analysis showed a monotonic decrease in D_f from 1.51 to 1.20 as ϕ increases from 2.3 to 3.5, which the researchers explained by suggesting that the electric field inside the flame causes a partial alignment of aggregates with a dipole moment and non-Brownian diffusion of charged monomers during the aggregation process. D_f should approach unity in the limit of vanishing Brownian motion.

The researchers said, "If the electrostatic force hypothesis can be verified, it may be possible to control the fractal dimension and associated properties of soot through application of a static electric field."

STEVEN TROHALAKI

Surface-Modified Mesoporous Silica Nanoparticles Serve as Drug Carrier System

The future of cancer therapies will draw from nanotechnology, cell biology, and organic chemistry. Drug delivery will play a vital role in realizing the potential success of newly discovered therapeutic agents, at least 40% of which are poorly soluble in water. Drug delivery matrices, targeting systems, and drug discovery can combine to create the ideal cancer therapy. By utilizing an interdisciplinary approach to address these requirements, J.M. Rosenholm of Åbo Akademi University, Finland, E. Peuhu of the University of Turku and Åbo Akademi University, Finland, and their colleagues have recently described their study using poly(ethylene imine) (PEI)-functionalized mesoporous silica nanoparticles as a cancer therapy delivery system.

As reported on July 2 in the online issue of *Nano Letters* (DOI: 10.1021/nl901589y), the research team created mesoporous silica nanoparticles with hyperbranched PEI conjugated to the surface. In order to design a cancer-targeting system, folic acid moieties, a ligand for a cell surface receptor that is over-expressed in cancer cells, were covalently attached to the PEI layer. By incubating nanoparticles with fluorescent dyes, delivery to cells could easily be monitored by confocal microscopy. Two different fluorescent dyes were used as models of poorly water-soluble compounds. Both molecules could be delivered into HeLa cells, a commonly studied cervical cancer cell line, without any leakage prior to endocytotic uptake. Furthermore, both fluorescent dyes could be co-delivered, suggesting the ability to administer multiple therapeutic agents simultaneously. As a final control, nanoparticles were incubated with both HeLa cells and a noncancerous cell line, epithelial HEK 293 (human embryonic kidney) cells. Minimal fluorescence was observed in HEK 293 cells, while HeLa cells were easily detected by fluorescence microscopy, demonstrating specificity of delivery between healthy and cancerous cell populations.

By combining aspects of materials chemistry, polymer chemistry, cell biology, and biotechnology, a very complex and innovative delivery matrix was designed. The researchers said that future research will be aimed at evaluating targetability, pharmacokinetics, toxicity, and particle degradation in animal tumor models *in vivo*.

DEVIN G. BARRETT

Optical Transistor Developed with Single Molecule

In order to reduce heat and increase the rate of data transfer in computers, scientists are searching for ways to produce integrated circuits that operate on the basis of photons instead of electrons. While optical transistor-like action has been previously reported in molecular systems involving many molecules as well as in single emitter configurations such as high-finesse micro-cavities or waveguides, these approaches are not generally suitable for photonic integrated circuits. Now V. Sandoghdar and colleagues at the Swiss Federal Institute of Technology have created an optical transistor using a single emitter configuration consisting of single molecules of dibenzanthanthrene doped in an *n*-tetradecane matrix.

As reported in the July 2 issue of *Nature* (DOI: 10.1038/nature08134; p. 76), the researchers discuss using one laser beam to prepare the quantum state of a single molecule of dibenzanthanthrene in a controlled fashion, such that they could significantly attenuate or amplify a second laser beam incident upon the molecule. This mode of operation is similar to that of a conventional transistor, in which electrical potential can be used to modulate a second signal. In order to enable this mode of operation, the researchers found that it was necessary to focus both laser beams to spot sizes approximately equal to the interaction cross-section of the single molecule. However, laser beams cannot generally be focused to spot sizes below the optical diffraction limit. On the other hand, at low temperatures, the cross-section for interaction of light with the dibenzanthanthrene molecule increases. The researchers found that by cooling the molecule down to –272°C, they could achieve a regime in which the enlarged interaction cross-section of the molecule corresponded approximately to the diameters of the tightly focused laser

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