221i A Rapid Micro-Fluidic Bacteria Trap Based on High-Peclet Momentum and Particle Flux Coupling in Vortex Flows

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A Rapid Microfluidic Bacteria Trap Based on High-Peclet Momentum and Particle Flux Coupling in Vortex FlowsZach GagnonZach Gagnon362005-05-03T21:40:00Z2005-05-03T21:42:00Z16703822318448411.5604While bioparticle trapping applications, such as bacteria or virus concentration, operating under the principle of pure (negative of positive) dielectrophoresis (DEP) are slow, with linear velocities less than 10 microns-sec-1, AC electro-osmotic (ACEO) flows can provide particle convection velocities in excess of 1 mm-sec-1. At high Peclet numbers, the particle trajectories are identical to the fluid streamlines and hence cannot approach a single attracting point or line due to continuity of the flow field. In past designs (Wu, J., Ben, Y., Battigelli, D. and Chang H.-C., Ind. Eng. Chem Res 2005, 44, 2815), a weak DEP force is exercised at a converging stagnation line of the flow field, where the viscous drag on the particle is weakest, to act as a local bioparticle trap. However, such converging stagnation lines can only lie on the electrodes, and capturing particles in the gap between the electrodes, where more sophisticated biosensors or bioparticle manipulations could exist, is not currently possible. In the current strategy, a different trapping scheme is employed using a vortex flow whose rotation velocity is a function of the local particle concentration, and whose particles experience a force that is a strong function of the rotation velocity. The ACEO vortex is designed so that it lies above a planar serpentine wire sustaining a high AC current, with its axis aligned with the long segments of serpentine wire. The AC electric field is strongest on the first and last two segments of the serpentine geometry, and particles on the periphery of the hovering vortex experience a net negative DEP force over these high field segments and in the gap between them. This net negative DEP force attracts the particles to the periphery closed streamline closest to the gap and promotes particle accumulation along the exterior of the vortex, or vortex rim. However, because of the large viscous drag force of the vortex flow, no particle trapping initially takes place. As the particle concentration within the rim increases, the effective viscosity of the suspension increases and the vortex rotation speed is observed to decrease rapidly. The time-average negative DEP force on the particles then increases and when it exceeds a critical value, all the particles within the vortex migrate into the gap precipitously. This vortex bacteria trap hence relies on the high-Peclet ACEO vortex flow to accelerate the concentration of particles at the vortex rim. However, as the negative DEP trap increases in intensity with accumulated particle concentration, a built-in delayed trigger due to coupling with the momentum transfer achieves rapid trapping within the gap only after almost all the particles in the sample are accumulated at the vortex rim. This concentrate-and-trap design is much more effective in both trapping time and trapping efficiency than sequential trapping designs. Experiments with micro-particles and bacteria show that all one the particles within a 70 micro-liter sample with 103 particle per cc concentration can be trapped within the gap in less than 30 seconds. This detection threshold for bacteria represents the lowest reported in the literature without culturing and the trapping time is several orders of magnitude lower than any reported. A time-averaging theory provides an estimate of the net-DEP force on a particle in circuit, which is found to be a strong function of the circuit time and vortex rotation speed. This time-averaged particle force is countered by particle diffusion due to particle-particle interaction and by radial particle migration due to viscosity and shear rate gradients (Leighton, D. and Acrivos, A., J. Fluid Mech 1987, 181, 415), which are dependent on both vortex rotation speed and particle concentration. A critical rotation speed is obtained by balancing the net-DEP force with the opposite migration mechanisms for a generic vortex parameterized by its radius and angular velocity. A perturbation theory is also developed to determine the vortex rotation speed as a function of the particle concentration within the vortex. Combining the two theories, the critical particle concentration at the vortex rim when trapping ensues is determined. The time for the rim-concentration stage and the rapid migration time into the gap during the trapping stage are also estimated for this concentrate-and-trap design with microfluidic ACEO vortex flow and favorably compared to experimental measurements.