Abstract

There is growing interest in understanding microscale biophysical processes such as the kinematics and dynamics of swimming microorganisms, and their interactions with surrounding fluids. Statistically robust experimental observations on swimming characteristics of bacteria in a wall bounded shear flow are crucial for understanding cell attachment and detachment during the initial formation of a biofilm. In this paper, we combined microfluidics and holography to measure 3-D trajectories of a model bacteria, Escherichia coli (AW403), subjecting to a carefully controlled shear flow. Experiments are conducted in a straight achannel of 40x30x2.2 mm with shear rates up to 200 (1/Ω). Holographic microscopic movies recorded at 40X magnification and 15 fps are streamed real-time to a data acquisition computer for an extended period of time (>5 min) that allows us to examine long term responses of bacteria in the presence of flow shear. Three-dimensional locations and orientations of bacteria are extracted with a resolution of 0.185 μm in lateral directions and 0.5 μm in the wall normal direction. The 3-D trajectories are tracked by an in-house developed particle tracking algorithm. Over three thousand 3-D trajectories over a sample volume of 380x380x200 μm have been obtained for our control (isotropic flow) swimming characteristics, i.e. swimming velocities, Lagrangian spectra, dispersion coefficients, is extracted to quantify the cell-flow and cell-wall interactions. Preliminary results have revealed that near wall hydrodynamic interactions, i.e. swimming in circles and reducing lateral migration, cause the reduction in wall-normal dispersion, subsequently are responsible for wall trapping and prompting attachment. On-going analysis is to understand the effects of shear flow on such a mechanism.

Microscopic holographic digital imaging – 3D Microscopy

Principle of In-line Holographic Recording

Intensity Distribution

Principle of Holographic Reconstruction

In-line Digital Hologram

Numerical Reconstruction

Experimental Setup

collimating lens

pinhole

objective

Nd:YAG laser beam

sample

PDMS channel

glass slide

lens

Nd filter

objective (to camera)

syringe pump

Waste

Near-wall Hydrodynamic Interactions – Swimming in Circles

Concentration of bacteria swimming in circles

Layer in which hydrodynamic interaction dominates is ~ 10 μm

Wall trapping – Consequence of Wall Dependency of Swimming Induced Dispersion

Wall trapping laser (1.15)

Lower wall at x = 7 μm

Upper wall at x = 12 μm

One order of magnitude smaller

Isotopic Dispersion Coefficients

Wall normal diffusion

Assayed by spatial gradient of isotope concentration in wall normal plane