The Effect of Particle Size in Large Particle Detachment in a Microchannel

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Introduction

In many microfluidic systems, such as cell sorters or particle-driven microfluidic pumps, it is sometimes necessary to transport biological cells or large particles single-file in a channel nearly the same size as the particle. For the modulation and controlled movement of these individual particles, it is crucial to be able to predict the fluid velocity required to detach a particle in contact with the surface of a microchannel to ensure the fluid velocity is sufficient to entrain the particles into the moving stream and to prevent redeposition along the length of the channel. In addition, particle adhesion to channel walls has been identified as a major problem in two phase microchannel flow[1], so being able to predict the force required to dislodge a particle is critical when designing multiphase microfluidic devices. The velocity required to remove a single particle in small-scale systems is a function of many particle properties, including the ratio of particle diameter to the channel diameter.

In microscale devices the characteristic length scales of flow shrink and we enter a domain of very low Reynolds number where the flow is dominated by viscous forces rather than inertial forces. However, small lift forces have been found to affect particle movement even in this very low Reynolds number regime[2]. Prediction of such lift forces becomes extremely difficult in microscale flows because of surface tension effects and large resistive forces acting in close proximity to the wall, which are direct consequences of large surface to volume ratio in these devices. In addition, van der Waals forces and electrostatic interactions between surfaces may be significant depending on the system chosen. A force balance approach for calculating the critical pickup velocity of a single spherical particle under shear flow as developed by Hayden *et al.*[3] can be applied to estimate the detachment velocity of a single glass sphere from the wall of a cylindrical microchannel. The difference between the theoretical and experimental values indicates the existence and relative dominance of these additional forces as discussed above.

Recently, a two-dimensional model was developed for a single non-deformable cell attached to a microchannel wall where the channel height and the cell size were varied to identify the corresponding stresses, forces, and torques on the cell[4]. It was found that for the ratio of cell height (d) to channel height (D) greater than 0.8, the dimensionless maximum shear stress tends to zero as the particle occupies a major portion of the channel. The major focus of our current research is to experimentally investigate the relationship between d/D (up to a value of 0.9) and the fluid velocity required for incipient motion of the particle, so we anticipate that we will observe interesting phenomena at larger values of d/D, as indicated by the theoretical analysis discussed above.

Microchannel Fabrication

The elastomer gel used for fabrication of the microchannel was produced by combining 30 wt% polystyrene-(polyethylene-polybutylene)-polystyrene (SEBS) with 70

wt% mineral oil. These materials have successfully been used for complex microchannel fabrication and are desirable because of their low cost and their ability to be recycled[5]. The polymer-oil mixture was held in vacuum for approximately 12-14 hours to ensure an even distribution of oil and then transferred to a metal mold (Figure 1). A tungsten rod (100 μm O.D.) was partially inserted into a 304 S.S. needle (110 μm I.D.) and placed in the mold with the polymer. The mixture was heated and deformed in a vacuum oven at 120-170ºC for 2 to 4 hours and then brought to room temperature. The tungsten rod was then removed from the solidified gel, leaving a microchannel embedded in the polymer. Vinyl tubing was used to connect the needle to a micro-infusion pump, and the bottom detachable plate was removed, leaving an opening which served as the viewing window for the inverted microscope.

Figure 1. Mold for Microchannel Fabrication
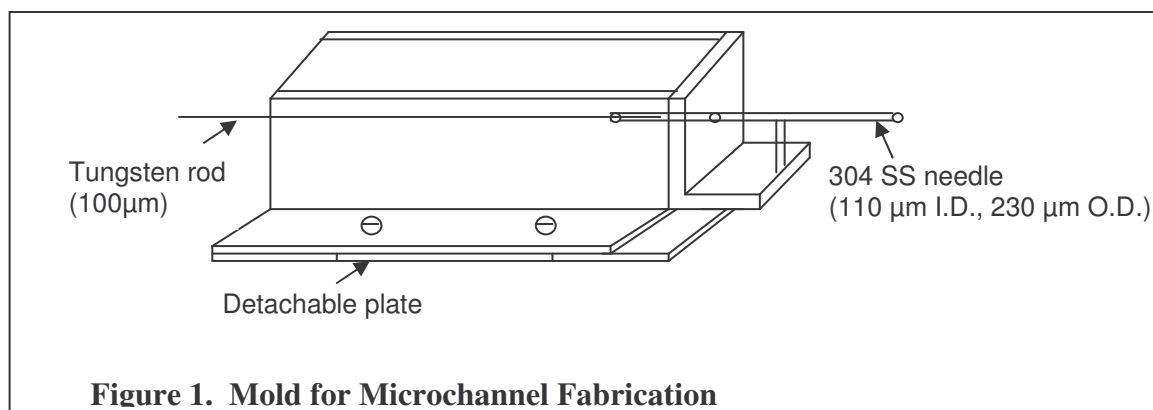
Experimental Procedure

Figure 2 is a schematic of the experimental setup used for the detachment experiments, which utilized pressure-driven flow to move a single spherical glass particle. An anti-vibration table provided stability for the experimental setup. An Aladdin micro-infusion pump (Model No. AL-1000) was used to flow water through the channel and to purge air from the system. A single glass sphere (Mo-Sci Corp., Rolla, MO) was injected into the microchannel using a Hamilton syringe and allowed to settle near the middle of the channel to minimize entrance and end effects. A rough estimation of the detachment velocity was made to avoid immediate entrainment of the particle into the fluid. The initial position of the particle was noted and the velocity of the fluid was increased gradually in a stepwise manner until displacement of the particle was observed. Particle movement was monitored using a microscope coupled with a CCD camera, and the minimum velocity that caused the particle displacement was taken to be the detachment velocity for the particle. The experiment was repeated with glass spheres of various sizes to vary the ratio of d/D from 0.5-0.9.

Figure 2. Schematic of the Experimental Setup
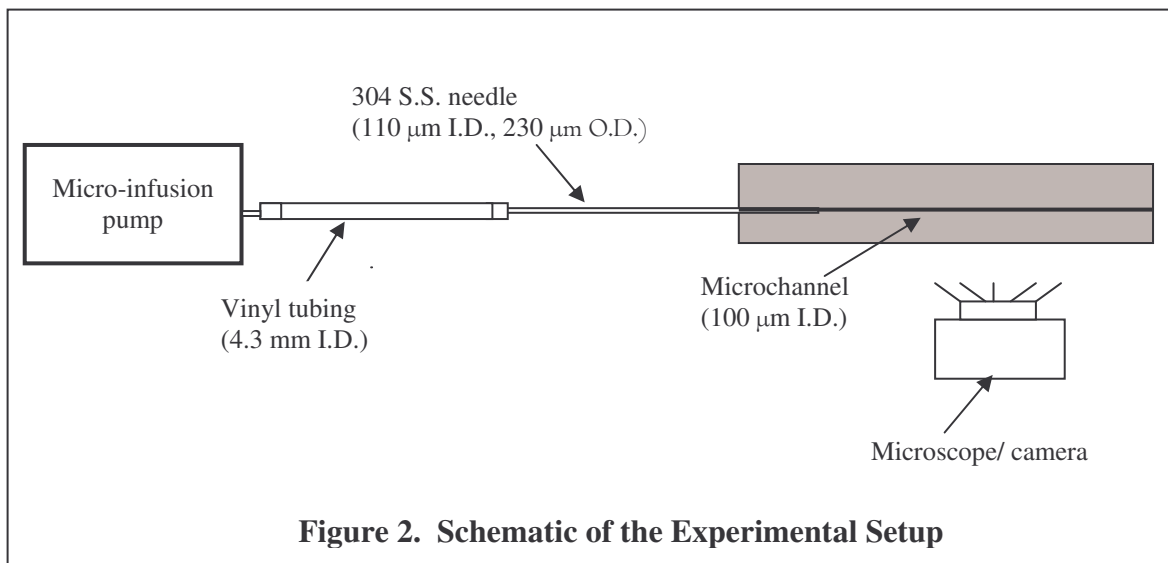
Results

Preliminary results are currently being collected and analyzed and will be discussed in detail during the oral portion of this presentation.

Future Work

Future modifications to the experimental setup include the addition of particle tracking software to measure the velocity of the entrained particles after detachment. In addition, the dimensions of the channel will be varied while holding the relative particle-to-channel size ratio constant. The corresponding changes in the velocity required for detaching the particle will be noted in order to verify scalability. Also, commercial computational fluid dynamics (CFD) packages will be used to investigate the fluid behavior as d/D varies. These results will be compared to experimental micro-PIV and detachment results to gain a better understanding of the interplay of various fluid flow parameters contributing to the process of particle detachment. Finally, based on the experimental data, an empirical correlation relating relative particle size to the detachment velocity will be developed. Since we are experimentally investigating the detachment velocity by varying the ratio of d/D in the range of 0.5 to 0.9, some interesting results could be experimentally obtained for d/D >0.8, and subsequent development of a CFD model for this particular domain could give further insight into fluid mechanical interactions in accordance with Gaver *et al.*[4].

References

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