Dynamics of Inertial migration of particles in straight channels

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SUMMARY

We study numerically the entire migration dynamics of spherical and oblate particles in straight rectangular and square cross sectional ducts. The reported results can help in design of straight duct channel based microfluidic systems.

KEYWORDS: Inertial microfluidics, Lateral migration, Oblate particles, Straight particles.

INTRODUCTION

We simulate spherical and oblate rigid particles in straight ducts of different aspect ratios using an Immersed Boundary Method. To the best of our knowledge, this is the first time not only the equilibrium position of particles is described, but also the entire migration dynamics of the particle from the initial to final position, including particle trajectory, velocity, rotation and orientation, are investigated.

EXPERIMENTAL

The fluid is considered incompressible and its motion is governed by the Navier Stokes and Continuity equations. The numerical approach employed is an Immersed Boundary Method (IBM) with two sets of grid points: an equispaced Eulerian mesh for the fluid flow, and Lagrangian grid points uniformly distributed on the surface of the particle. The flow is set up in square and rectangular cross section ducts with no slip and no penetration boundary conditions (Fig.1).

RESULTS AND DISCUSSION

We examine the lateral motion of spherical and oblate particles using the IBM method mentioned above. While simulating three different spheres in a square duct of duct width to sphere diameter ratio H/Ds= [3.5, 5, 10], we find that the particles focus at closest face-cantered equilibrium position from their point of introduction(Fig.2a). We also show the downstream length needed for a sphere to focus, focusing length, as a function of the distance from the vertical duct symmetry line and as a function of Reynolds number(Fig.2b and c respectively). Spherical particles in rectangular duct tend to move laterally toward the longer length wall and then slowly moves towards the equilibrium position at the face-centre along the long wall(fig.3a). We also observe that the focusing length is longer for spherical particles in a rectangular duct, about three times longer than that in square duct (fig. 3b). In case of an oblate particle flowing through a square duct, the lateral motion towards the face centred equilibrium position is similar to that of a sphere (fig.4a), however there is significant tumbling motion of the particle as it tries to reach equilibrium(fig.4b).In a rectangular duct of aspect ratio 2, the oblate particle reaches a steady configuration on the duct symmetry line at the center of the different faces (fig.5a). The focusing length surprisingly is shorter in a rectangular duct for an oblate particle in contrast to its focusing length in a square duct. This is attributed to the higher lateral velocity of the oblate in the second stage of the migration, that with negligible tumbling(fig.5b). The behavior of three oblate particles in a square duct of duct width to longer diameter ratio H/Ds= [3.5, 5, 10] is different compared to a sphere as the largest oblate tend to focus at the duct cross section diagonals compared to the other two which are at face centred equilibrium as in case of a sphere(fig.6a). We attribute this to the rotation rate of the larger particle which is initially increasing and then decreasing(fig.6b).When it comes to focusing lengths, the smaller particles need longer times to reach their final equilibrium(fig.6c). Another interesting behavior we see is the effect of Reynolds number, where it can be seen that the oblate particles show a tilt of 21 degrees when focusing at equilibrium at certain high Reynolds number (fig.7).

CONCLUSION

The results presented employ a highly accurate interface-resolved numerical algorithm, based on the Immersed Boundary Method to study the entire inertial migration of an oblate particle in both square and rectangular ducts and compare it with that of a single sphere. Currently, we apply a volume penalization method and polymeric drag component to the code to solve for viscoelastic effects in circular microcapillaries.

ACKNOWLEDGEMENTS

This work was supported by the European Research Council Grant no. ERC-2013-CoG-616186, TRITOS and by the Swedish Research Council Grant no. VR 2014-5001, COST Action MP1305: Flowing matter, and computation time from SNIC.

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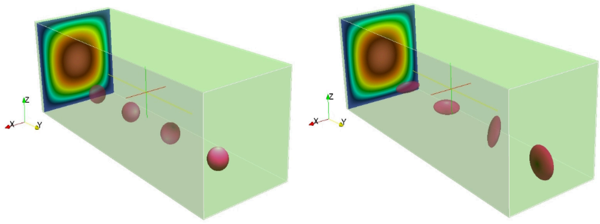

Figure 1. *Flow setup of spherical and oblate particles.*

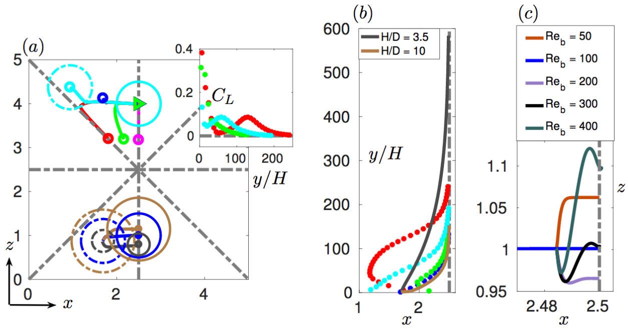

Figure 2. *a) Upper box: Lateral migration of sphere in 1/8th of a square channel at Bulk Reynolds number (Re_b) = 100. Open circles and triangles show the starting and ending points of the lateral trajectories. Dashed/solid lines denote Initial/final position. Right side: Lift coefficient vs traveling length. b) Focussing length of larger and smaller spheres. c) Reynolds number dependence of focusing for H/D_s=5*

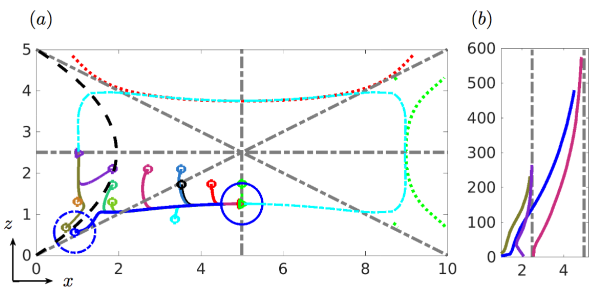

Figure 3. *a)Lateral migration of sphere in rectangular duct at Re_b = 100. Light blue dashed line indicates equilibrium manifold, Black dashed line indicates initial to equilibrium position. Red and green dotted lines indicate iso levels of total shear rate equal to 0.75 and 0.81. b) Focussing length for different particle trajectories with dashed lines representing vertical and horizontal duct symmetry line.*

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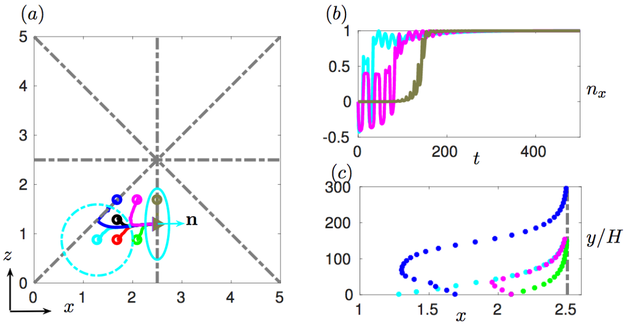

Figure 4.a)Oblate particle trajectory over 1/8th of square duct. b) Orientation of oblate symmetry axis as a function of time. c) Focussing length of oblate particles.

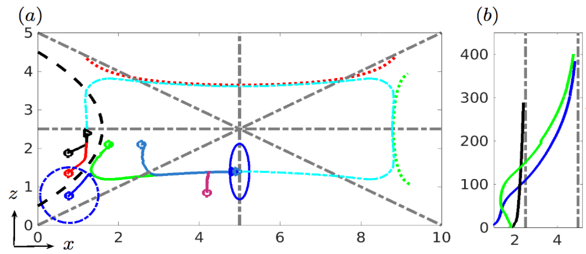

Figure 5.a) Oblate particle trajectory in rectangular over 1/4th of cross section. B) Focussing length for different particle trajectories.

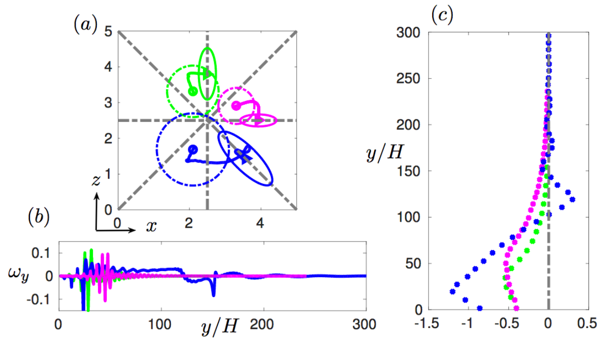

Figure 6.*a) Size based lateral trajectories of oblate particles in square duct b) Size based particle rotation rate vs streamwise particle displacement, c) Particle displacements vs vertical distance.*

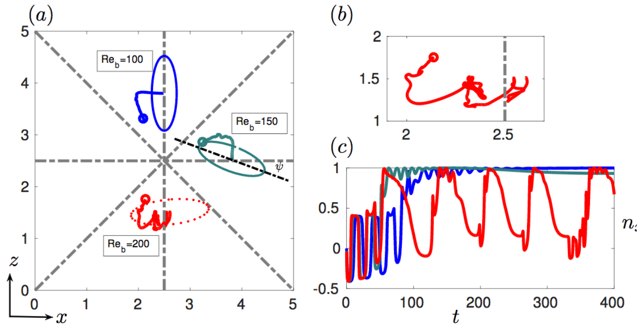

Figure 7. *a) Lateral trajectory vs different Reynolds numbers in a square duct for oblate particle. b)Sample Particle trajectory at Re_b = 200.c) Orientation vector n_x vs Re_b .*