Dynamics of *E. coli* suspensions through a microfluidic funnel

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We have forced a fluid suspension of *E. coli* through a funnel-like constriction made on an otherwise straight microfluidic channel. In the case of very active bacteria, symmetry is broken: the bacterial concentration gets higher immediately after passing the funnel. The effect increases with increased input flow, and eventually reaches a maximum. Symmetry is not violated, however, in the case of dead or poorly active bacteria. The phenomena can be explained qualitatively in terms of hydrodynamic interactions of bacteria with the imposed flow and with other bacteria. Our observations suggests a simple way to concentrate very active bacteria in microfluidic channels.

E. coli, an introduction

One of the most studied bacteria in active fluids

- 2μm in length.
- Swims up to 35 body lengths per second.
- *Tumble & run* swimming mechanism [1].
- Extreme importance for sanitary reasons.

A new finding

We report a symmetry breaking in the density of active swimmer suspensions as they are forced to pass through a microfluidic funnel.

Experimental setup

We force a suspension of *E. coli* to flow through a straight microfluidic channel with a constriction at the middle of its length (Figs. 1 and 2).

Channel geometry

- $W = 200\mu$m
- $L_f = 200\mu$m
- $W_f = 40\mu$m
- $h = 20\mu$m

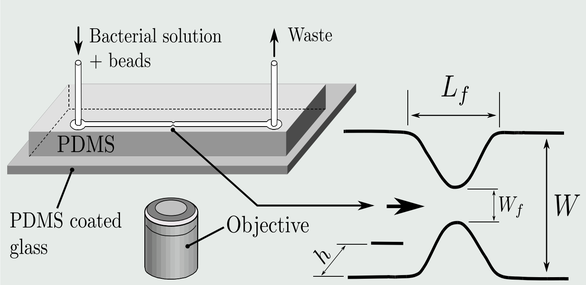


Figure 1: Experimental setup.

Procedure details

- The flux is roughly controlled by varying the height difference between suspension containers connected to the channel.
- Latex beads of 2μm diameter were added as passive tracers to accurately quantify the flux in the channel.
- Images were taken from below with a digital camera through an inverted microscope.
- All the bacteria could be visualized at once due to the small height of the channel.
- Light was shed from above.

Symmetry breaking

Characterizing the symmetry breaking

1. Define the center of the funnel as the point where the tracer beads reach maximum velocity (Fig. 2).
2. Set two regions of interest to the left and right of the center (Fig. 2).

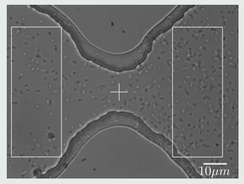


Figure 2: Sample funnel image showing the center of the channel and the regions of interest.

The *symmetry breaking* number is defined

$$n = \frac{N_r - N_l}{N_r + N_l} \quad (1)$$

where N_l and N_r are the number of bacteria in the left and right regions respectively.

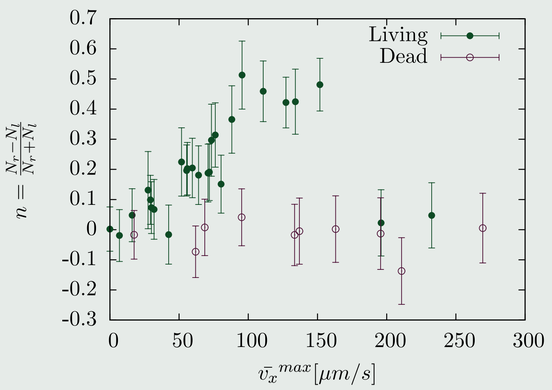


Figure 3: Symmetry breaking in bacterial concentration as a function of flow velocity at the center of the channel.

Several important remarks

- There is a symmetry breaking for living bacteria.
- The effect increases for bigger flows.
- A maximum is eventually reached.
- No symmetry breaking is found for dead bacteria.

Partial summary

The ability to break the concentration symmetry seems to be inherent to very active suspensions of swimmers.

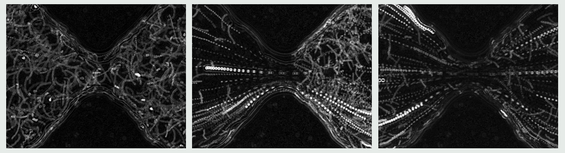
Swimmer trajectories

Trajectories for different flow velocity ranges

Zero flow: Sections of circular trajectories created by bacteria near the surfaces of the channel (Fig. 4a).

Medium flow: Straight trajectories on the left and perpendicular to the flux on the right forming transversal arcs (Fig. 4b).

Large flow: Almost no transversal arcs on any side of the channel (Fig. 4c).



(a) (b) (c)

Figure 4: Trajectories at different flows established from left to right visualized as the standard deviation of the brightness of each pixel over a stack of 20 images taken every 0.05s (a) zero flow (b) medium flow (c) large flow.

Simulation

Simulating the environment inside the channel

- Numerically solve the Navier-Stokes equations.
- Boundary conditions obtained from:
  - Images of the profile of the real channel.
  - The speed of the tracer beads.

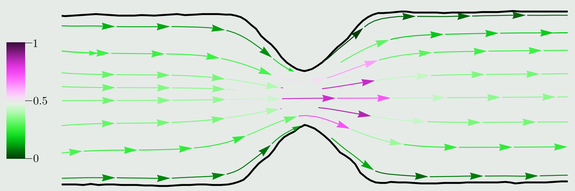


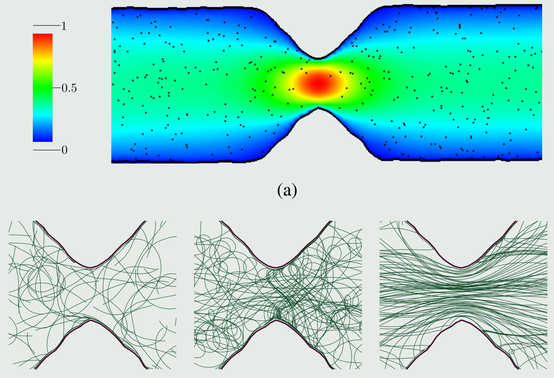
Figure 5: Numerical Navier-Stokes solution obtained using the real channel profile and the velocity of the tracer beads as boundary conditions.

The flow affects bacteria swimming in the channel

1. Circular motion in the absence of flow (Fig 4a) [2].
2. Swimmers are dragged by the flow [3].
3. Some bacteria "stick" to the walls and swim upstream (Fig 4b) [3].
4. A fast perpendicular flow can "detach" swimmers from the walls (Fig 4c).

Simulated trajectories

We have been able to reproduce qualitatively the behavior described in figure 4 using our simulation (Fig. 6).



(a) (b) (c) (d)

Figure 6: (a) Snapshot of the flow profile and bacteria from the simulation (b), (c) and (d) trajectories of simulated bacteria for zero, medium and high flow respectively.

Summary

1. We describe a new phenomenon where the symmetry in the density of swimmer suspensions is broken due to a constriction inside a microfluidic channel.
2. The concentration difference depends on the flux (Fig 3).
3. The phenomenon is inherent to very active swimmers.
4. Simulations show that a combination of interactions among bacteria, the flow and the channel walls might explain the phenomenon (Figs. 4 and 6).

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References

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