Antifouling surfaces

Citation for published version (APA):

Document status and date:
Published: 08/11/2018

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the author's version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain.
• You may freely distribute the URL identifying the publication in the public portal.

Take down policy
If you believe that this document breaches copyright please contact us:
openaccess@tue.nl
providing details. We will immediately remove access to the work pending the investigation of your claim.
Antifouling Surfaces: Removal of Micro-Particles by Magnetic Artificial Cilia

Shuaizhong Zhang,*,† Ye Wang,† Patrick R. Onck and Jaap M.J. den Toonder†
* s.zhang1@tue.nl
† Eindhoven University of Technology, Eindhoven, The Netherlands
‡University of Groningen, Groningen, The Netherlands

MOTIVATION

The fouling of surfaces submerged in a liquid is an important problem for many applications. One biologically inspired strategy to tackle this problem is given by cilia-induced particle transportation and cleaning. Biological cilia are micro-hairs, which have been reported to have such functions as fluid propulsion, feeding, mucus removal out of the human airway, transport of microscopic particles, etc. Here, for the first time, we experimentally prove that magnetic artificial cilia (MAC) are able to remove micro-particles from the ciliated area.

EXPERIMENTS

I Micro-Molding Process of MAC

Step 1: Standard photolithography to make a SU-8 mold
Step 2: Fill the mold with a PDMS-Iron mixture
Step 3: Remove the top layer
Step 4: Pour pure PDMS
Step 5: Put a permanent magnet under the mold, and leave the sample in an oven at 80 °C for 2 hours
Step 6: Peel off MAC Transparent PDMS substrate

Figure 1. Schematics of the process to fabricate MAC which have a strong magnetic response. [1]

II Actuation scheme

Figure 2. Actuation scheme of the MAC. (a) Schematics of the actuation setup with MAC integrated in an open-top circular chip with a rectangular cross section with a width of 5 mm and height of 4 mm. The fouling representative particles (blue polylactic acid (PLA) particles) are loaded in the ciliated area before actuation. The rotation axis of the magnet is offset by a distance d=6 mm with respect to the center of the ciliated area, and the magnet is placed at a distance r=6.5 mm from the rotation axis. The vertical distance h between the top surface of the magnet and the MAC was set to 2 mm. (b) Schematic drawing of a rotating cilium performing a tilted conical motion in perspective view. Illustrations are not to scale. (c) A top-view SEM image of the MAC with a diameter, length and pitch of 50, 350, and 250 μm, respectively. (d) A top-view image of the motion of the rotating MAC at 40 Hz in water. The image is composed of 25 overlapping frames in one actuation cycle. The red dashed line indicates the cilium tip trajectory. (e) Cross sectional view of the MAC. [1]

RESULTS

Figure 3. (a) Snapshots from one recorded experiment after the MAC operate for (i) 0 seconds, and (ii) 1 minute, showing that PLA particles (blue) are gradually removed from the ciliated area. In this experiment, the actuation frequency was 40 Hz; the MAC had a pitch of 250 μm, and the micro-particles had an average diameter of 100 μm. (b) Calculated cleanliness as a function of the operating time at different actuation frequencies. The cleanliness is defined as \( C = \frac{N_p - N_a}{N_p} \), where \( N_p \) is the number of particles within the ciliated area at time 0, and \( N_a \) is the number of particles left after the MAC operating for \( t \) seconds. In these experiments, the MAC had a pitch of 250 μm, the particles used were 100 μm PLA particles. (c) Calculated cleanliness as a function of the ratio between the particle diameter and the cilia pitch when the actuation frequency is 40 Hz. The cleanliness is \( C = \frac{N_p - N_a}{N_p} \). The insets are snapshots from the recorded experiments for particle size to cilia pitch ratio of (i) 2.7, (ii) 1 and (iii) 2. The scale bars in (i) are 700 μm, and the scales bars in (ii) and (iii) are 500 μm.

CONCLUSION

Micro-molded magnetic artificial cilia are able to remove the vast majority of a large size range (30 to 500 μm) of micro-particles from their vicinity within a minute, creating a clean area. This finding offers a new method to manipulate micro-particles and to create a novel type of self-cleaning/antifouling surface, which can find applications in, for example, marine antifouling and lab-on-a-chip devices.