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Flow restriction by soft particles at a constriction

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1. Introduction

Many microfluidic assays consist in flowing particle suspensions in microchannels, such as cells, liquid cultures, water containing microbes or sediments. Clogging is however a frequent incident that hinders the performance of processes involving flows of suspensions through microfluidic devices (Agbangla et al., 2012, Dressaire & Sauret, 2017). Understanding the underlying mechanisms that lead to clogging is therefore crucial to avoid erroneous analyses. Experimentally, flow of monodisperse suspensions of rigid spheres has been described as intermittent, alternating between periods of clogging, during which arches formed by particles block the constriction, and burst events characterized by collapse of arches and liberation of particles into the downstream flow (Marin et al., 2018). The size of bursts has been shown to depend on the aspect ratio between the sizes of particles and constriction neck, as well as flow properties (Reynolds number, pressure or flow rate-control) (Souzy & Marin, 2022). Recent simulations have demonstrated that the threshold for clogging is modified when particles in the suspension are deformable (Bielinski et al., 2021). The passage of deformable particles is encountered in physiological situations such as splenic red blood cell filtration (Moreau et al., 2023).

2. Methods

2.1 Soft microparticles

Soft microparticles consist of bovine serum albumin liquid-filled microcapsules fabricated by interfacial reticulation (Edwards-Lévy et al., 1993). Briefly, an aqueous albumin solution is emulsified in vegetal oil by stirring, and terephthaloyl chloride is added to the continuous phase to trigger the cross-linking of albumin at the oil/water interface. Capsules are then rinsed, filtered and suspended in water or in glycerol. When capsules are immersed in glycerol, water is transferred from their core towards the continuous phase, which makes initially spherical capsules deflate,

as shown in Figure 1(a) and 1(b), and increases their deformability.

2.2 Micro-constriction fabrication and operation

Rectangular cross-section channels are fabricated in PDMS by standard soft lithography methods. The depth and width of the channel is larger than the particles, and the width decreases locally to form a constriction with 45° angle. As a result of the fabrication process, confinement occurs only in the lateral dimension, like in the works of (Moore et al., 2023), rather than in an axisymmetric configuration as in our earlier work with single capsules (Le Goff et al., 2017). Suspensions are flown through the channels by the means of a syringe pump or a pressure controller, and their behavior in constrictions is monitored using a high-speed camera (Photron AX50). To prevent sedimentation of water-suspended capsules, the reservoir connected to the pressure controller is mechanically agitated during the experiment.

3. Results and discussion

An example of clogging/unclogging of a constriction by a suspension of soft, deflated microcapsules is shown in Figure 1(c). Capsules involved in the clog are strongly deformed and the collapse event of the arch is preceded by visible rearrangements of its structure, with capsules changing both place and shape. We studied the clogging of the same constriction by more spherical, water-suspended microcapsules. Clogs form more easily with rounder, stiffer capsules (not reported here). Figure 1(d) corresponds to the case of a constriction in which a clog formed for an inlet pressure of 38 mbar. The pressure was then increased by steps. Between 38 and 186 mbar, no capsule was able to enter the constriction. During the lifetime of the clog, we track debris of broken capsules to measure the flow velocity in the constriction downstream of the clog by particle tracking technique. This allows us to qualitatively monitor the temporal variations of the flow rate in the constriction, as reported in Figure 1(d). We first observe that the flow rate fluctuates over time, which can result from particle rearrangements within the clog that modulate its permeability. Most intriguing is the non-monotonous dependence of the flow rate on the applied pressure: when the inlet pressure is increased from 51 to 96 mbar, the flow rate decreases, indicating that the clog became denser and more resistive to exerted pressure. A larger pressure increase, to 96 mbar, has this time the effect of increasing the flow rate, while doubling it once more to reach 186 mbar results in the lowest measured flow rate: the constriction is almost completely blocked. The high pressure needed to disrupt this clog will lead to the rapid formation of a new dense clog after the burst.

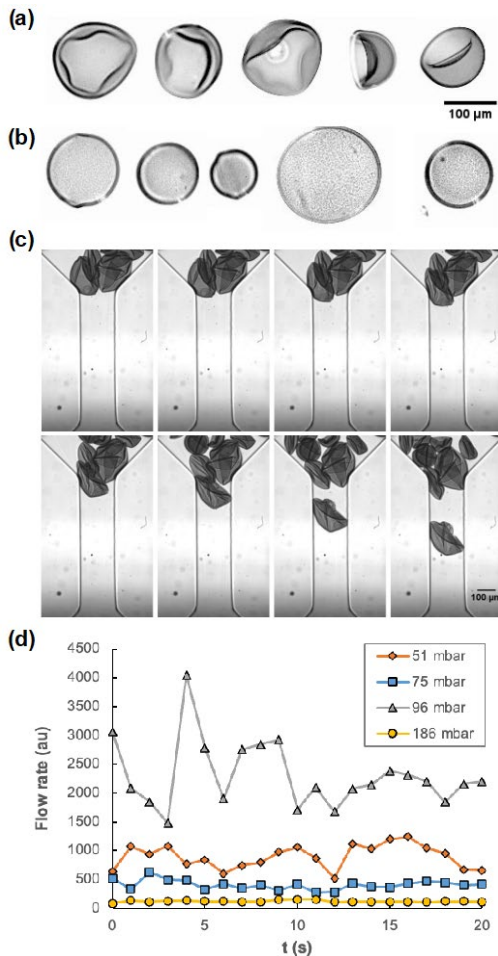


Figure 1. Micrographs of deflated capsules in pure glycerol (a) and round capsules in water (b). Collapse of an arch formed by deflated microcapsules. Time interval 200 ms. (c) Flow rate fluctuations in a blocked constriction.

4. Conclusions

The intermittent behavior of particle flows in microfluidic constrictions has been studied in the literature for rigid particles and predicted by numerical simulations for soft particles in flow-rate driven situations. Here we demonstrate that similar features exist in pressure-driven flow of soft particle suspensions. A better understanding of these phenomena would help prevent the clogging of microfluidic chips with cell suspensions.

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Conflict of Interest Statement The authors have no conflict of interest to disclose.

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