Supporting Material for Influence of the solid fraction on the clogging by bridging of suspensions in constricted channels

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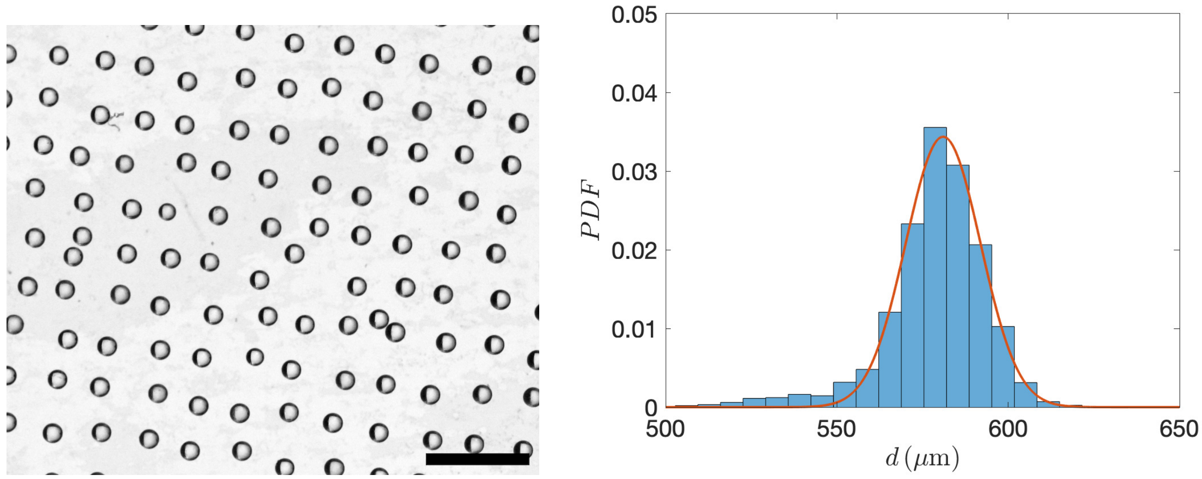
Particle size distribution and fluid properties

The suspensions consist of spherical polystyrene particles (Dynoseeds TS from Microbeads) dispersed in a mixture of water and Poly(ethylene glycol-ran-propylene glycol) monobutyl ether $M_n = 3,900$ (referred to as PEG in the main article, from Sigma-Aldrich).

The particle size is kept constant through the entire study, and only the width of the constriction W is changed. The particles obtained from the manufacturer are already quite monodisperse but are nevertheless sieved between $500\,\mu$m and $600\,\mu$m to remove any outliers. We measure the size distribution by taking pictures of a large number of particles and then using image processing (ImageJ) to obtain their projected area A. The diameter is then obtained from the area, $d = \sqrt{4\,A/\pi}$, since the circularity of the particles is close to 1. The size distribution is then fitted with a Gaussian distribution [figure 1] and matches to a mean diameter $\bar{d} = 581\,\mu$m, and a standard deviation $\delta d = 15\,\mu$m. The density of the particles was measured by suspending them in a mixture of water and salt (NaCl, Sigma Aldrich) until reaching a density match. The density is found to be $\rho_{\rm p} = 1.049 \pm 0.002, {\rm g.cm^{-3}}$.

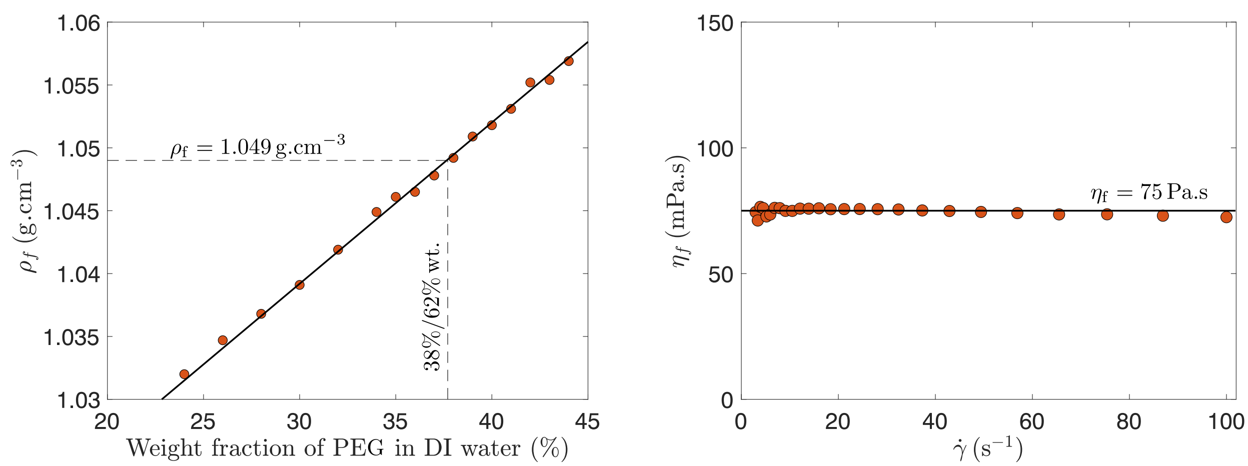
To ensure that the interstitial fluid used leads to neutrally buoyant particles, we measured with a densimeter (Anton Paar DMA 35) the density of the PEG/H_2O mixture when varying the fraction of PEG. The results are reported in figure 2(a) and led to a composition 38%/62% of PEG/H_2O wt for all the experiments reported in the main article. The viscosity of the mixture of PEG/H_2O at this composition has been measured with a MCR302 rheometer (Anton Paar) with a 50 mm plate-plate geometry. The mixture exhibits a Newtonian behavior, as shown in figure 2(b), and a viscosity $\eta_{\rm f} = 75\,{\rm mPa.s}$.



(a)

(b)

Figure 1: (a) Example of images used to measure the particle size distribution and showing that the circularity of the particles is close to 1. Scale bar is 3 mm. (b) Histogram of the size distribution of the particles used in this study: $d = 581 \pm 15\,\mu$m.



(a)

(b)

Figure 2: (a) Evolution of the density ρ_{f} of a PEG/H_2O mixture with the weight fraction of PEG. The dashed line corresponds to the composition used in this study: 38%/62% of PEG/H_2O wt. (b) Shear viscosity of the 38%/62% of PEG/H_2O wt mixture.

Surface fraction of particles in the millifluidic device

The suspension is injected into the quasi-bidimensional millifluidic device via a syringe pump and has to go through various tubing and connectors. We initially control the particle volume fraction $\phi_{\mathrm{V}} = V_{\mathrm{p}}/V_{\mathrm{tot}}$ in the syringe and later used the surface fraction $\phi = A_{\mathrm{p}}/A_{\mathrm{tot}}$ in the quasi-bidimensional channel. These two quantities should be directly related through $\phi = 3\,H/(2\,D)\,\phi_{\mathrm{V}}$. However, the presence of different connectors modifies this value since some self-filtration [1] can be present in some regions prior to the millifluidic channel. We have therefore performed experiments with the same type of millifluidic chip and the same connectors but in a straight channel [figure 3(a)] to measure the experimental evolution of the surface fraction of particles. The evolution reported in figure 3(b) shows that at larger volume fraction the obtained surface fraction is smaller than the theoretical value. As a result, we fit those results with a polynomial curve and the evolution of the surface fraction is given by $\phi = 2.1\,\phi_{\mathrm{V}} - 0.0244\,{\phi_{\mathrm{V}}}^2$ (where ϕ_{V} is the initial volume fraction dispersed in the syringe).

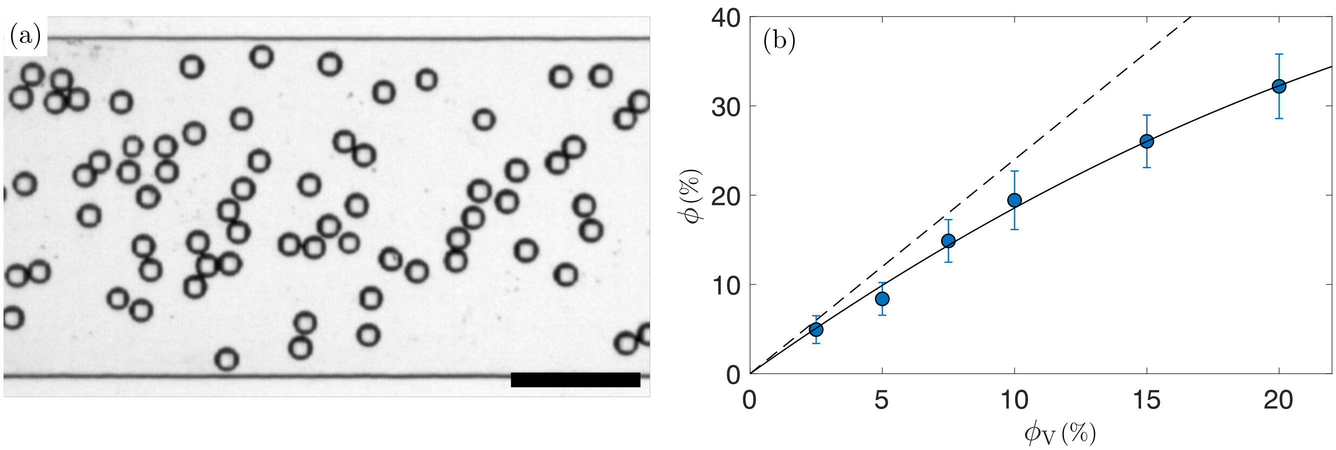
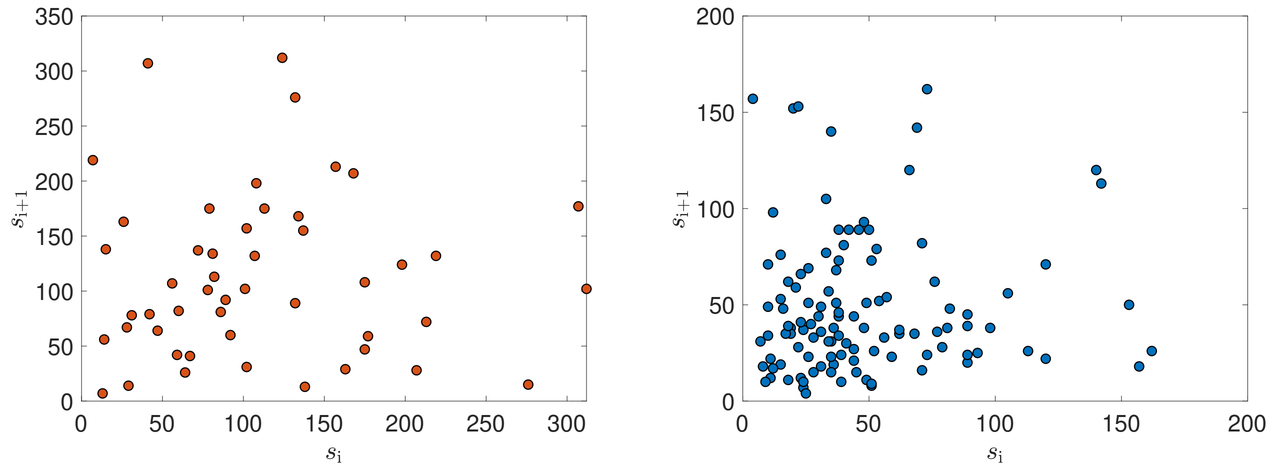


Figure 3: (a) Configuration used to measure the surface fraction ϕ for different volume fraction in the syringe ϕ_{V}. Scale bar is 3mm. (b) Evolution of the surface fraction of particles in the channel ϕ for various volume fraction in the syringe ϕ_{V}. The dashed line shows the theoretical prediction $\phi = 3\,H/(2\,D)\,\phi_{\mathrm{V}}$ and the solid line shows the best polynomial fit $\phi = 2.1\,\phi_{\mathrm{V}} - 0.0244\,{\phi_{\mathrm{V}}}^2$.

Correlation between successive clogging events

In our experiments, after a clog occurs, the flow is reversed and the device completely emptied of particles, as well as the upstream tubing. Then the flow is set back to its initial value, and a new clogging event is recorded. A major assumption in the modeling of clogging by bridging is that the clogging events are uncorrelated. To verify this assumption, we considered the number of escapees for each clogging event as a function of the number of escapees at the previous clogging events. The results are reported in figure 4(a) for $\phi \simeq 0.19$ and $W/d = 1.7$ and in figure 4(b) for $\phi \simeq 0.9$ and $W/d = 2.7$. Our observation confirms that the clogging events are uncorrelated, as observed in the clogging of silos by dry grains [2].



(a) (b)

Figure 4: Number of particles flowing through the constriction before clogging for the event $i + 1$ as a function of the number of particles flowing through the constriction before clogging for the event i for (a) $\phi \simeq 0.19$ with $W/d = 1.7$ and (b) $\phi \simeq 0.9$ with $W/d = 2.7$.

Movies of the experiments

- Movie corresponding to Figure 3(a): "Figure_2a_phi_0_03_WD_1_7.avi".
- Movie corresponding to Figure 3(b): "Figure_2b_phi_0_17_WD_1_7.avi".
- Movie corresponding to Figure 3(c): "Figure_2c_phi_0_95_WD_1_7.avi".

References

[1] M. D. Haw. Jamming, two-fluid behavior, and "self-filtration" in concentrated particulate suspensions. *Physical Review Letters*, 92(18):185506, 2004.

[2] I. Zuriguel, A. Garcimartín, D. Maza, L. A. Pugnaloni, and J. M. Pastor. Jamming during the discharge of granular matter from a silo. *Physical Review E*, 71(5):051303, 2005.