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THE IMPACT OF FLOW CONDITIONS ON THE CLOGGING OF A PORE BY COLLOIDAL PARTICLES

Delouche Nolwenn^{1*}, Tabuteau Hervé ¹

¹Institut de Physique de Rennes, Université de Rennes, France

Summary We use particle tracking to determine the hydrodynamical conditions of the abrupt flux decline during the clogging process of a pore by colloidal particles. We can detect every deposition event during the clogging with the measure of the average particle velocity and volume fraction of the particle accumulation behind the clog. Thanks to the Kozeny-Carman relation, we connect particles velocity and permeability of the clog. This approach helps us to determine the impact of the variation of the hydrodynamic conditions on the clogging process.

INTRODUCTION

The transport of dilute colloidal suspension through a porous medium like a filter or a soil, leads to the formation of clogs. This process is quite complex and results from a coupling between hydrodynamics and physicochemical parameters. Thanks to microfluidics, transparent porous media have been designed and allow monitoring the clogging process at the pore scale. Experimental studies have explored the geometry parameters promoting the fouling, like curvature at the pore entrance, shape and dimensions of the pore or confinement [1,3]. The investigation of the role of particle-wall or particle-particle interactions have also improved the understanding of the partial or total clogging conditions [2,4]. During such experiments there is an abrupt flux decline which corresponds to the clogging transition. Up to now, no quantitative link has been made between those two phenomena. Our experimental work helps to understand the dynamics of clog formation at the particle scale, relating each particle capture event to the corresponding decreases of the average variation of the particle velocity within the pore, using particle tracking. This approach also provides direct measurement of the volume fraction of both the flowing suspension and within the clog. Here we first determine the features of the clog transition and then we investigate the impact of the flow conditions on this transition as well on the subsequent growth of the clog.

MATERIALS AND METHODS

We flow a diluted suspension of polystyrene particles ($\phi = 5.10^{-3}$) under fixed pressure (fig.1a) through a constriction (fig.1b). A camera provides pictures at 100 frames/s that allows us using an algorithm sufficiently sensitive to track particles and get the spatial evolution of their velocity as they flow around the constriction.

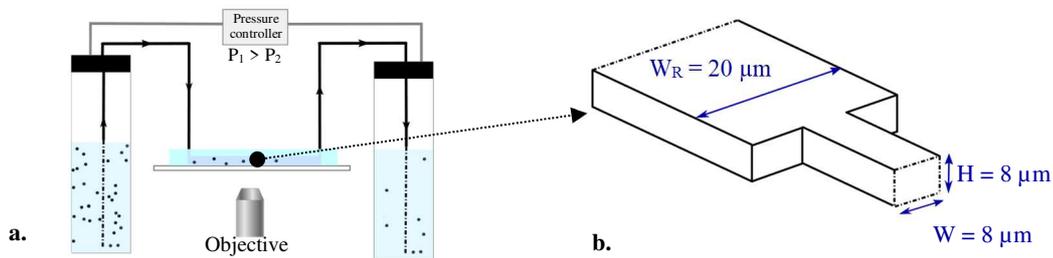


Figure 1: a. Schematic of the setup. b. Zoom in the central part of the channel in the constriction zone

RESULTS

We observe two significant steps during the clogging process. First, a partial clogging where the progressive particle deposition leads to a limited particle velocity decline (fig.2: a-f and plot). These deposits reduce the pore section until its complete clogging. At the very end of this process, an object is responsible of the final clogging which result in the most abrupt increase of the hydraulic resistance (image e to f). Later on, particles just pile up at the clog front leading to a slower increase of the channel resistance (fig.2 from image g up to l). The corresponding decrease of the velocity is also less abrupt since particle accumulation takes place into a wider part of the channel just upstream of the constriction zone, which thus has a lower hydraulic resistance.

We observe that the variation of the flow conditions has a direct consequence on particle deposition, while at high pressure the flow detaches some particles, in the lower range it limits their attachment. One may wonder if these erosion-deposition processes have also an impact of the structure of the clog and thus also on its hydraulic resistance. We investigate this by varying the pressure so that we get a large variation of the average particles velocity at the beginning of the experiment. The temporal evolution of the average particle velocity is reported in figure 3a. All the curves collapsed onto a master curve (insert figure 3b) indicating that the clogs formed for each applied pressure have the same permeability since the flow decline is identical.

*Corresponding author. E-mail: nolwenn.delouche@univ-rennes1.fr

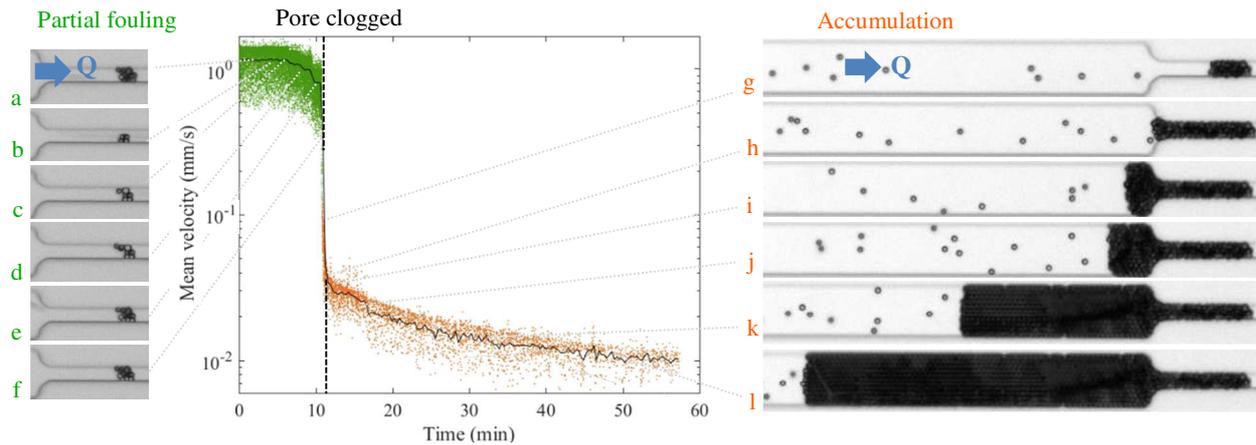


Figure 2: The two steps of the clog formation in a constriction: the partial clogging (a-f) followed by the particle accumulation (g-l). The plot is the temporal evolution of all the particle velocity that flow through the pore during the clogging process, with the continuous and the dotted lines corresponding respectively to the average velocity and the moment when the pore is clogged, i.e. when particle pile up at the clog front.

We use the Kozeny-Carman equation to determine the hydraulic resistance and the permeability of the packing of spherical particle from the constriction. From this equation we deduce that the fluid and also the particle velocity V vary as the inverse of the clog length L_c with a prefactor involving permeability. Based on independent measurement, made from image analysis we obtain a constant volume fraction $\phi_{\text{exp}} = 0.60 \pm 0.025$ for all pressures, which helps us to calculate the hydraulic resistance from the Kozeny-Carman equation. By plotting the average particle velocity against the clog length (fig.3b) we confirm that $V = A/L_c$, A being a constant irrespective of applied pressure. Therefore, we conclude that the hydraulic resistance of a colloidal clog does not depend on its dynamics of formation obtained with various flow conditions.

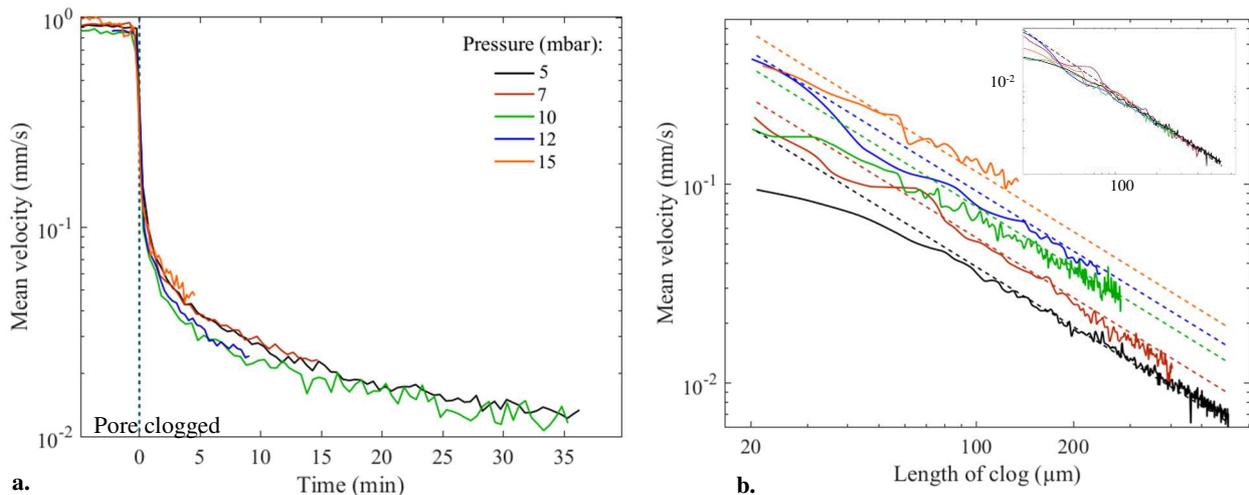


Figure 3: a. Temporal evolution of the average scaled velocity. The time is rescaled such that particle accumulation starts at zero for each applied pressure. b. Hydraulic resistance for a spherical packed bed, for different pressures. The continuous lines correspond to the experimental data while the dotted lines are fit by the Kozeny-Carman equation. Insert: master curve.

CONCLUSION

Coupling image analysis of the forming clog and tracking of flowing particles inside a pore help us to determine the dynamics of the clogging transition and also of the subsequent growth of the clog. We get a good estimate of the volume fraction of the clog which helps us to determine the hydraulic resistance of the clog. We show that this resistance does not change when we form clogs with different applied pressure. This new methodology can be easily implemented in order to study the evolution of hydraulic resistance of interconnected 2D porous media fouled by colloidal particles.

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