Transfer of particles in fractured chalk: Experimental study on the Effect of flow velocity

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RESUME

The transport of suspended particles through fractured rocks contributes, for example, to the contamination and therefore to the vulnerability of karst groundwater. Thus, the effect of flow velocity on the transport of suspended particles in an artificial fractured chalk was undertaken. Preliminary results showed that the flow velocity greatly affects the particles'transfer in the fracture. With the increase in flow velocity, the particles recovery rate increases and the residence time decreases. The transport behavior cannot be totally explained with the flow velocity only. Hence, additional investigations should include, for example, the effect fracture aperture, and the physicochemical conditions.

Keywords: Particle transport, Double porosity, Flow velocity, Suspended particles.

I. INTRODUCTION

Fractured rocks have attracted much attention due to the role they play in transporting contaminants (Tran et al 2020, Albrann et al. 2013, Tang 1981). The permeability in fractures is often greater than that in the host rock (Brouyère 2006). Therefore, fractures are considered as preferential routes where contaminants can move quickly. The problem of transport in fractured media arises in the case of safety assessment of the aquitard protecting the freshwater aquifer against contaminations (tang et al. 1981). Therefore, it is crucial to clearly understand the transport of particulate contaminants in fractured rocks.

Contaminants in fractured rocks can originate from many sources, including micro-erosion of the rock matrix (McCarthy et al. 2002), mineral precipitation or leachates from water disposal activities (Lapworth et al. 2005). These particles can travel in fractures mainly by advection and dispersion; they may also sorb on the fracture walls (Reiche et al. 2016). In addition, they can diffuse into the rock matrix, which is beyond the scope of this work.

Fractures are unable to conduct large water flow due to their micron-size opening. However, the insufficient volume can be compensated for in speed. Due to the small aperture of fractures, the transport rates can be surprisingly high. According to Delvin J.A. 2020 (based on personal communication with John Cherry and Tom Aley) the flow velocity can reach 100 meter per day (0.12 cm/s). Moreover, G. Medici et al. 2019 reported that groundwater flow velocities range within two order of magnitude from 13 (0.01 cm/s) up to 242 m/day (0.28 cm/s). Also, Domenico and Schwartz 1998 have found using tracer tests that the linear flow velocity in conduits can reach more than 20 km per day (23.1 cm/s).

Contaminants are transported at high velocities in the saturated parts of fractures (Medici, G. et al 2019). Therefore, the time between the release and the detection of contaminants can be small, leaving no time for precautions.

In the present study, the effect of flow velocity on the transport of kaolinite particles in a single artificial fractured chalk is investigated. Laboratory experiments were carried out to achieve the above aim by using three high flow velocities (0.12, 0.26, and 0.38 cm/s). The mean diameter of the particles injected was 2.5 μm. The tracer tests were performed using the step input injection technique.

II. Materials and Methods

Chalk samples were collected from Saint-Jouin-Bruneval (Normandy, France). The chalk rock was cut into two rectangular segments with the same dimensions 16cm x4.7cm x1cm. Two thin identical metals were placed and glued between the two chalk samples on the edges. The small gap separating the two chalk segments corresponds to the single fracture of aperture 0.81 mm. The whole sample was sealed with epoxy resin, preventing water leakage. The porosity of the chalk is 0.33 (±3%) and its density is 1.7 g/cm^3. Selected kaolinite particles with a mean size d_{50}= 2.5μm were used as suspended particles (Fig.2). In this study, the initial concentration C_0 of the suspension injected was 0.2 g/l. The suspension was prepared in ultra-pure water.

For the transport experiments (fig. 1) the fractured chalk sample was connected to a peristaltic pump (Dinko Instruments) and to a turbidimeter (Kobold Instruments). The chalk sample was saturated with ultra-pure water for several hours. Three pore volumes (NVp) of kaolinite solution were injected, followed by ultra-pure water. Transport tests were always carried out with the fracture oriented horizontally. The detection system consists of a turbidimeter. The kaolinite concentrations in the effluent were determined with the help of correlations made a priori between measured particle concentrations in the water and values in NTU (Nephelometric Turbidity Units) given by the turbidimeter. After each experiment the fracture was cleaned using ultra-pure water, containing 1mM NaOH, at high flow velocity, larger than that used during the transport experiment.

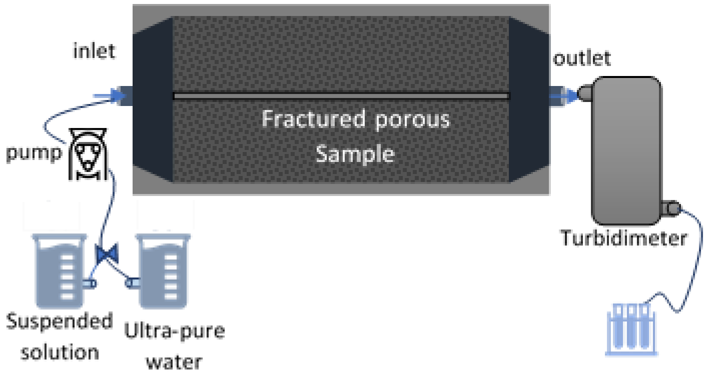

Figure 1: Schematic configuration of the experimental setup for transport experiments.

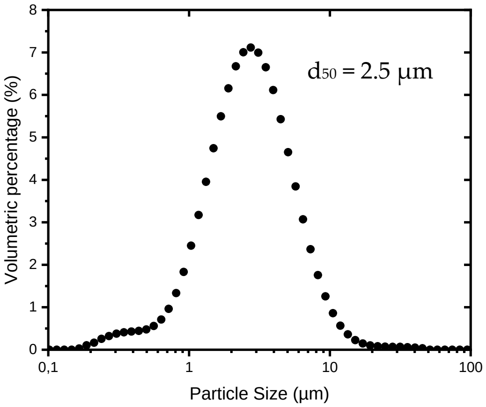

Figure 2: Particle Size Distribution of the selected kaolinite P300

To study the effect of flow velocity on the transport of particles, three experiments were performed with the same conditions but, at different flow velocities: 0.12, 0.26, and 0.38 cm/s. The breakthrough curves are represented by a relative concentration (outlet concentration C divided by the constant inlet concentration C0) as function of the number of pore volumes injected (NVp).

III. Results and Discussion

Figure 3 shows the breakthrough curves of the suspended particles (kaolinite) injected in the fractured chalk. Results indicate that the recovery rate of kaolinite particles increase with flow velocity. Particles retention is more important at low flow velocities (70%, 32% and 17% at 0.38 cm/s, 0.26 cm/s and 0.12 cm/s respectively). This means that hydrodynamic force exerted by the flow has an important effect on the transport of the injected particles. As observed in figure 3, the arrival time of the kaolinite particles at different flow velocities is almost the same (0.6 NVp). However, the breakthrough peak for 0.38 cm/s and 0.26 cm/s are reached at 4.8 NVp approximately preceding that of 0.12 cm/s by around 0.8 NVP. The tailing effect in the three curves is due to the dispersion of kaolinite particles in the fracture and not matrix diffusion. Since in our case there is no diffusion into the matrix, because of the size of the particles with respect to the pore size of the matrix.

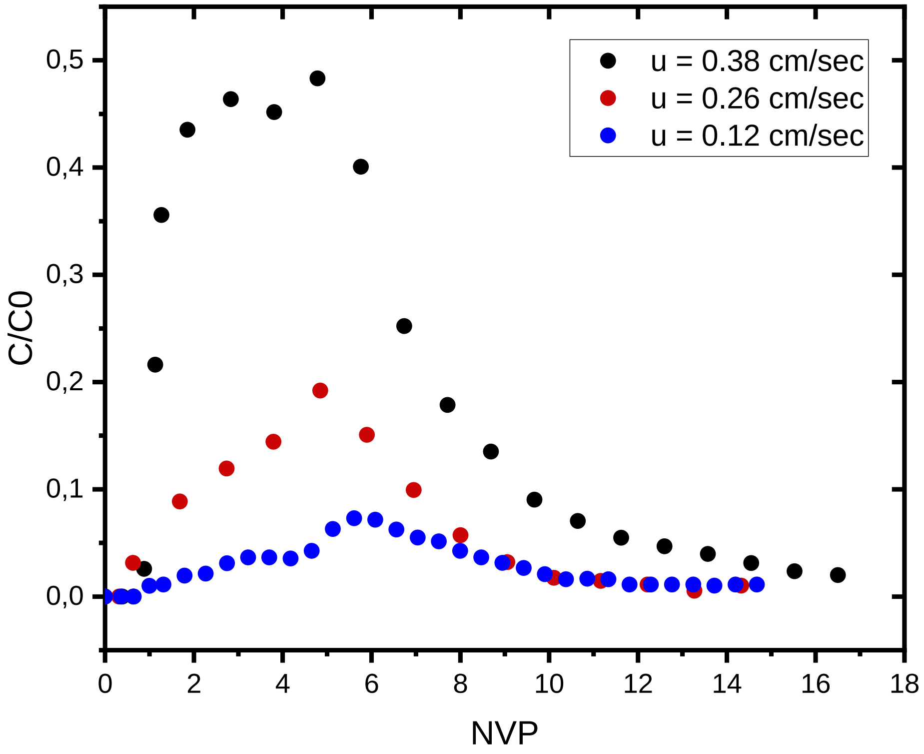

Figure 3: Breakthrough curves of kaolinite at flow velocities of 0.12, 0.26 and 0.38 cm/s

IV. Conclusion

The effect of flow velocity on the transport behavior of kaolinite particles in artificial fractured chalk was experimentally studied. Many studies have been done on the transport of dissolved particles and nanoparticles in fractured porous media, yet very little studies are done on micro-sized particles. The results showed that lower flow velocities, produced an important increase in particle retention. In nature, additional parameters affect the transport process: fracture opening, ionic strength, pH, etc. Therefore, in future the effect of these parameters should be studied.

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