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Particle transport within water-saturated porous media: Effect of pore size on retention kinetics and size selection

Tahar Ikni [a,c], Ahmed Benamar [a,*], Mohamed Kadri [b], Nasre-Dine Ahfir [a], Hua-Qing Wang [a]

[a] UMR 6294 CNRS–université du Havre, Laboratoire Ondes et Milieux Complexes, 53, rue Prony, 76600 Le Havre, France
[b] Département de génie civil, université de Boumerdès, rue de l'Indépendance, 35000 Boumerdès, Algeria
[c] Département de génie civil, université de Bejaia; université de M'sila, route Targa Ouzemour, 06000 Bejaia, Algeria

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ABSTRACT

The transport and filtration behaviour of fine particles (silt) in columns packed with sand was investigated under saturated conditions by using step-input injections. Three samples of different particle size distributions (coarse medium, fine medium and a mixture of both) were used in order to highlight the influence of the pore size distribution on particle retention and size selection of recovered particles. The main parameters of particle transport and deposition were derived from the adjustment of the experimental breakthrough curves by an analytical model. The higher particle retention occurs in the mixture medium, owing to its large pore size distribution, and the filtration coefficient decreases with increasing flow velocity. Particle size distribution of recovered particles shows a thorough size selection: (i) the first recovered particles are the coarser ones; (ii) the size of the recovered particles increases with increasing flow velocity and enlarger pore distribution of the medium.

1. Introduction

Understanding pollutant transfer in the subsurface systems is of great interest and essential to the protection of groundwater resources, which account for more than 90% of the domestic water supply in North Algeria (Kadri et al., 2011), from contamination by particle-bound contaminants. Particle transport takes place in different types of soil environments: saturated and unsaturated zones, underground aquifers, fissured rocks (Corapcioglu and Jiang, 1993; Masséi et al., 2003; Pang et al., 1998). Solid particles can be detached from the soil matrix under the influence of physicochemical parameters (salinity, organic agents, pH) or mechanical ones (hydrodynamic forces) (Kanti Sen and Khilar, 2006), and can travel far in the subsurface system. Owing to their very important specific surface, fine particles are excellent agents for pollutant adsorption, which are transported over large distances (Kretzschmar et al., 1999; McCarthy and Zachara, 1989; McDowell-Boyer et al., 1986; Ryan and Elimelech, 1996). Many studies are devoted to dissolved elements and colloids transport, while suspended particles are less considered (Ahfir et al., 2007; Benamar et al., 2007; Masséi et al., 2002; Wang et al., 2000).

Several processes (straining, wedging, deposit), other than physicochemical filtration long-time investigated, can affect the transport behaviour of fine particles in saturated porous media. Particle straining represents the main immobilization process that occurs in the groundwater system when a pore space is too small to allow the passage of particles (Bradford and Bettahar, 2006). During the flow of suspended particles through a porous medium,

* Corresponding author.
E-mail address: benamar@univ-lehavre.fr (A. Benamar).

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particle transport and retention derived from several forces and mechanisms depending on particle size, pore distribution, and flow rate (Ahfir et al., 2007; Benamar et al., 2005; Silliman, 1995). The particle retention may reduce the permeability of the porous medium, as observed during the artificial recharge of aquifers or the exploitation of oil wells (Moghadasi et al., 2004). Recent researches indicate that the rate of particle straining within saturated porous media is sensitive to the ratio of particle diameter (d_p) to sand grain diameter (d_g), the shape of surface roughness of the solid matrix, particle size non-uniformity, pore-scale hydrodynamics, and pore water chemistry (Bradford et al., 2007; Keller and Ausset, 2007; Porubcan and Xu, 2011; Xu and Saiers, 2009; Xu et al., 2006). Most studies on particle straining have mainly relied on experiments conducted with uniform sand packs. Natural soil and alluvium, however, are usually characterized with physical heterogeneity, which originates from the mixing of sand grains of various sizes.

The Sebaou River in northern Algeria supplies an alluvial groundwater submitted to a hydrological and environmental stress. Excessive pumping causes a dramatic lowering of the groundwater level, and the extraction of aggregates significantly reduces the thickness of the filtering layer. Both processes make the groundwater vulnerable towards the surface pollution. This study is devoted to the influence of the grain size variability of the alluvial layers on the transport and the deposition kinetics during particle transfer.

2. Materials and methods

2.1. Column transport experiments

Transport experiments were performed in a horizontal column under constant flow conditions using the step-input injection method. In this investigation, a Plexiglas column with an inner diameter of 6.4 cm and a length of 33 cm is used. The column was equipped with four equally spaced (9 cm) piezometers, allowing one to measure pressure variations during the suspended particles' injection in the porous medium. The column was packed in 5 cm increments by pouring the sand into the column, mixed with deionised water (saturated conditions) to avoid trapping air bubbles. Using a Master-Flex peristaltic pump (Cole-Parmer Instruments), the column is fed by two reservoirs (Fig. 1); the first one contains deionised water (pH of 6.8 ± 0.1) and the other one contains suspended particles subjected to a permanent agitation with the help of a motorised stirrer. When the steady-state flow conditions are reached with deionised water, the valve is switched to the second reservoir and the flow of suspended particles is directed toward the column. So, a perfect step-input injection was assumed to be achieved, even if Taylor dispersion occurs at the boundary of the system (Mainhagu et al., 2012). However, the distance between the reservoir and the cell was kept as short as possible in order to minimize the Taylor dispersion effect.

The detection system consists of a Kobold Instrument turbidimeter (calibrated with respect to the suspended particles concentrations) and a Turner Designs 10-AU fluorometer (calibrated with respect to the fluorescein concentrations).

The used material as porous medium is alluvial sand (collected from Sebaou River, Algeria), whose grains present a smooth angular and elongated shape. Two size distributions were selected from this material (Fig. 2): fine medium, and coarse medium. A third medium (noted mixture) was obtained by mixing the fine and the coarse

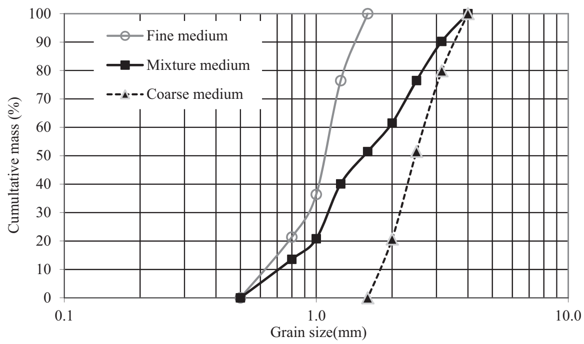

Fig. 2. Particle size distribution of the three porous media.

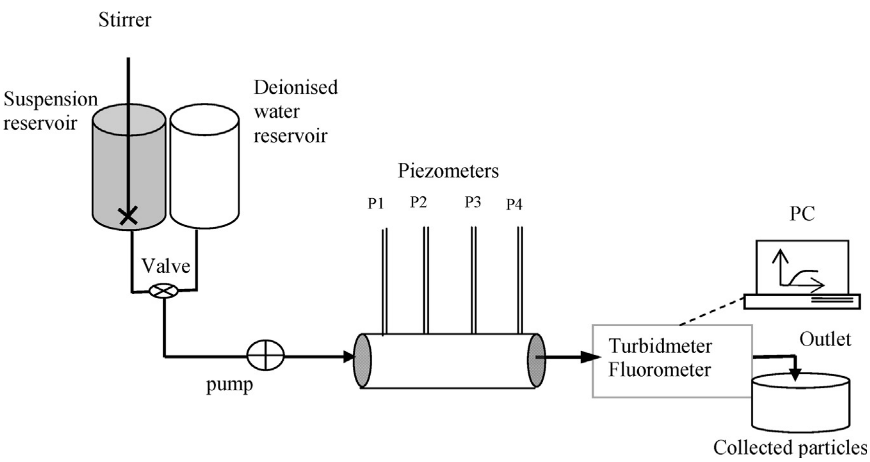

Fig. 1. Experimental set-up.