Bacteria deposition mechanisms and interfacial interactions in unsaturated porous media

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Keywords : bacteria deposition, hydrophobicity, DLVO, capillary forces, hydrodynamics

1 Introduction

The investigation of the transport and retention of bacteria in porous media has a great practical importance in environmental applications, such as protection of the surface and groundwater supplies from contamination, risk assessment from microorganisms in groundwater, and soil bioremediation. Considerable research has been devoted to the transport and deposition of bacteria and other colloids in saturated and unsaturated porous media [1]. In comparison to saturated systems, flow and bacteria transport in the unsaturated zone is more complex due to flow discontinuities, interfacial (air/water, solid/water and air/solid/water) process and wetting history [2]. Many mechanisms, such as physico-chemical or physical may be involved in bacteria retention: attachment onto solid-water interfaces or straining occurring at pore constriction of the grains. Both physical straining at grains pore constriction and physico-chemical attachment onto solid-water interfaces govern colloid transport occurring through saturated flow conditions. In addition to these mechanisms, colloids in unsaturated porous media may be retained by attachment at air-water interfaces and by straining in thin water films around the grains (film straining) [3]. The objective of this study was to investigate bacteria deposition mecanisms under unsaturated flow conditions. The DLVO (Dejarguin–Landau–Verwey–Overbeek) interactions and non-DLVO interactions [4] such as hydrophobic, capillary and hydrodynamic forces of bacteria and porous media/air/water interfaces were also evaluated to describe the different interactions between bio-colloidal particles and solid/air/water interfaces.

2 Methods

Laboratory bacteria transport and deposition experiments were performed in two porous sand with distinct grain to investigate and quantify bacteria transport and depositon under unsaturated steady state flow conditions. Two non-motile bacterial strains, *Klebsiella oxytoca* and *Rhodococcus rhodochrous* (DSMZ 11097) were used in this study. Cell size and shape, hydrophobicity, electrophoretic mobility and zeta potential of each bacterium were estimated before column experiments. Hydrophobicity was evaluated through contact angle measurements by using the approach of van Oss and coworkers [5]. Based on contact angles measurements *Klebsiella* sp. is hydrophilic strain while the *R. rhodochrous* is a hydrophobic one.

The breakthrough curves (BTCs) and retention profiles (RPs) of bacteria were simulated using the modified Mobile-IMmobile (MIM) model. Both transport and retention parameters were estimated by fitting the model to experimental BTCs and RPs. DLVO and non-DLVO interactions such as hydrophobic, capillary and hydrodynamic forces of bacteria and porous media/air/water interfaces were considered to estimate the total interaction energy of interaction between bacteria and initerfaces under the current experimental conditions of this study. Hydrophobic forces acting between particles and air-water interfaces, were calculated based on the determination of the degree of hydrophobicity, using water contact angles [6]. In unsaturated porous media capillary and associated friction forces interactions contribute to the retention of bacteria within water films and at air/water/solid interfaces [8]. They were estimated based on the infromation provided by Gao et al. [7]. The magnitudes of all forces described below may be moderated by the hydrodynamic conditions of the system. Colloids adhering to the pore surfaces of the porous media of relatively high porosity and permeability, can be released or detached by the hydrodynamic forces Calculation af hydrodynamics and resisting torques were performed following the procedure described by Bergendahl and Grasso [8].

3 Results

The results obtained showed that bacteria deposition under unsaturated flow conditions is a complex process, involving different interactions between bacteria and solid/water/air interfaces. The most hydrophobic bacteria was the less retained to both fine and coarse sand. The retention decreased in the coarse sand compared to that in the fine one for both bacteria, due to the preferential bacteria flow paths through the larger pores of the coarse sand. The classical DLVO theory predicted reversible attachment of bacteria, in accordance with Hydrus simulations (attachment coefficients values were in the same order of magnitude as bacteria detachment coefficients), but it did not permitted to correctly explain the experimental bacteria retention to both sand. Hydrophobic forces calculations showed that the hydrophobic potential was in the same order of magnitude as the DLVO potential for small separation distances between bacteria-porous media, thus moderating the net repulsive energy predicted by DLVO theory. Based on the hydrophobic potential, the most hydrophobic strain could have a higher potential to be retained, conversely to what has been observed in columns experiments. Capillary potential calculation showed that under unsaturated conditions, capillary forces were much greater than repulsive forces and they can push bacteria close enough to the grain surface where bacteria may be attracted to the porous media through van der Waals forces. This hypothesis was in agreement with high bacteria attachment coefficient values predicted by Hydrus simulations. Hydrodynamics should not be neglected when discussing bacteria-porous media interactions. Hydrodynamics and resisting torques calculations predicted that bacteria detachment in the secondary minimum would always occur under the current experimental conditions, in agreement with Hydrus simulations (detachement coeficients were similar to atachement coeficients values). From the calculations of DLVO and non-DLVO interactions (such as hydrodynamic torque, hydrophobic interaction and capillary potential energy), the deposition of bacteria in unsaturated porous media was governed by the combination of DLVO and non-DLVO interactions.

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