On the influence of ionic strength on colloid transport in porous media in the presence of a rough surface : numerical simulation at the microscopic scale

Nisrine SEFRIOUI-CHAIBAINOU, Azita AHMADI, Henri BERTIN, Aziz OMARI

I2M, UMR CNRS 5295, University of Bordeaux, Arts et Métiers ParisTech, IPB, France

Introduction

The understanding of Colloids transport, deposit or detachment in porous media is of central importance in many practical problems such as filtration, environmental issues and petroleum engineering. In particular, the interaction of colloids with the grain surfaces is a complex problem involving combination of short range physico-chemical forces, acting at the "interface scale" with the hydrodynamics in the pore space. The understating of the processes at these small scales is crucial for the description of colloid transport processes under different physicochemical and hydrodynamic conditions at larger scales.
General experimental features of colloid deposition and their detachment after a flooding with brine of ionic strength and pH different from the resident one have been reported in literature and successfully predicted using DLVO theory (Canseco *et al*., 2009). However and despite various efforts, such prediction remains only qualitative. It is usually believed that the observed discrepancies arise from grain or colloid heterogeneities. Such heterogeneities may concern electrostatic charge or surface topography or both.(Ducker *et al*., 1991; Elimelech & O'Melia, 1990).
The objective of this work is to study the influence of grain surface roughness on the transport, deposit and detachment of a colloidal particle under various physicochemical and hydrodynamic conditions. For this purpose, direct numerical simulations of the transport of a single particle near the fluid/solid interface have been performed.

Methodology

Simulations have been performed with the software Thétis developed in I2M laboratory. Thétis uses a finite volume discretisation of Navier-Stokes equations with staggered grids (velocity/pressure) over the entire domain using a tensorial penalisation method (Caltagirone & Vincent, 2001). The equations are solved with an augmented Lagrangian method. The transport equation for particle displacement is solved explicitly. A special treatment is reserved for the calculation of lubrication forces when particle/surface distance is too small. New routines have been implemented in order to take into account DLVO forces for smooth and rough pore surfaces. A Surface Element Integration (SEI) method (Bhattacharjee & Elimelech, 1997; Hoek & Agarwal, 2006) has allowed us to take into account the DLVO forces between two surfaces of any geometry.

Results and discussion

Test cases considered are chosen on the basis of experimental results presented in the literature. Reynolds number is equal to 1.66 10^{-5}, and ionic strength ranges from 3mM to 18mM. First, transport of a particle near a solid surface is simulated for a given Reynolds number for different values of ionic strength and the influence of various surface roughness types are analysed. Five surface topographies corresponding to two sizes of peaks or valleys (H/a_p = 1 or 2 for peaks and H/a_p = -1 or -2 for valleys, where a_p is the particle radius) and a flat surface (H=0) are considered. The simulations illustrate three different behaviours: (i) the particle is transported by the bulk fluid (ii) the particle is adsorbed and rolls on the solid surface (iii) the particle is adsorbed by the surface and is blocked.

A dimensional analysis leads in particular to a dimensionless number N_2, corresponding to the ratio of electrostatic to hydrodynamic forces. Although the study is restricted to only one particle, an analysis in terms of dimensionless residence time is proposed. This is the time necessary for the particle to travel a given distance on the grain for different surface roughnesses (Fig. 1).

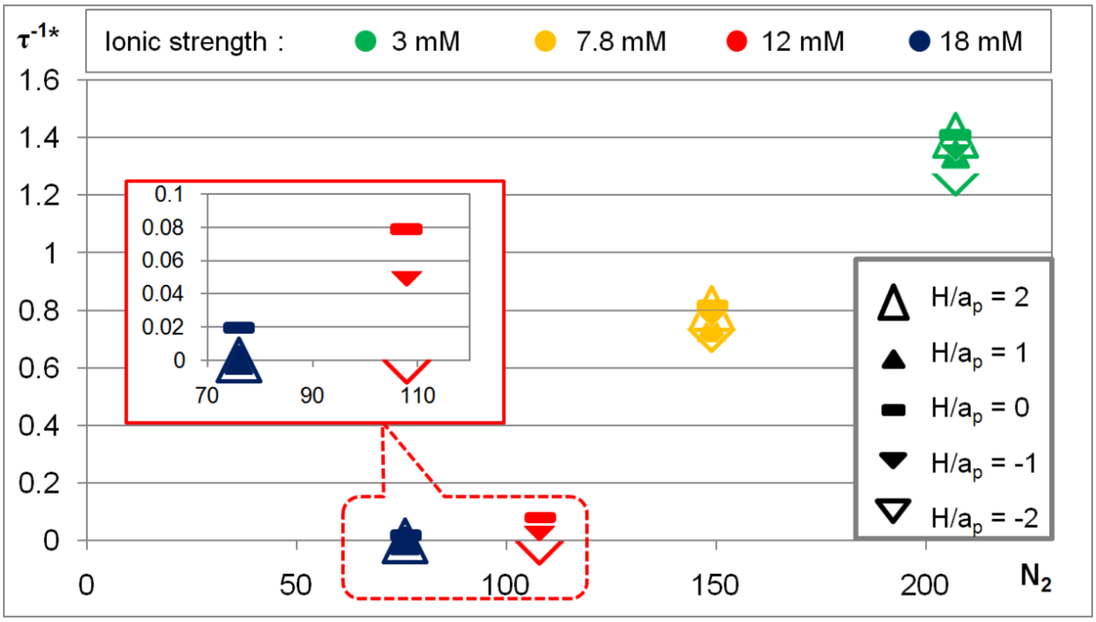

Figure 1 : Inverse of residence time as a function of N_2 for different roughness types

The analysis of Figure 1 leads to the following comments.
For a flat surface we have always a finite value of the residence time meaning that there is no particle retention while the presence of a roughness is a necessary condition for particle retention. The residence time increases with ionic strength due to reduced energy barrier height of the DLVO profile. At a given hydrodynamic conditions, for high ionic strength particle retention is highly dependent on surface roughness (type and size).
Further simulations show that an increase in the Reynolds number leads to the mobilisation of the particle in all cases studied.

References

Bhattacharjee, S. & Elimelech, M., Surface element integration: A novel technique for evaluation of DLVO interaction between a particle and a flat plate, Journal of Colloid and Interface Science, 193(2):273-85,1997.

Caltagirone J-P & Vincent, S., Tensorial penalisation method for solving Navier-Stokes equations, Comptes Rendus de l'Académie de Sciences – Serie IIb : Mécanique, 329(8) :607-613, 2001.

Canseco, V. Djhehiche, A. Bertin, H. and Omari, A., Deposition and re-entrainment of model colloids in saturated consolidated porous media : experimental study, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 352(1-3):5-11, 2009.

Ducker, W.A., Senden, T.J. and Pashley, R.M., Direct measurement of colloidal forces using an atomic force microscope, Nature, 353(6341):239-241, 1991.

Elimelech, M. and O'Melia, C.R., Kinetics of deposition of colloidal particles in porous media, Environmental Science and Technology, 24(10):1528-1536, 1990.

Hoek, E.M.V. & Agarwal G.K., Extended DLVO interactions between spherical particles and rough surfaces. Journal of Colloid and Interface Science, 298(1): 50-58, 2006.

Azita AHMADI, Prof., I2M F33405 TALENCE, (33) 5 56 84 63 94, (33) 5 56 84 54 36, azita.ahmadi@ensam.eu