THE ROLE OF IONIC STRENGTH AND GRAIN SIZE ON THE TRANSPORT OF COLLOIDS IN UNSATURATED SAND COLUMNS

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Abstract

The combined effects of ionic strength, and sand grain size on colloid fate and transport in unsaturated porous media was investigated. Spherical fluorescent polymer microspheres with three different sizes and laboratory columns packed with two size fractions of clean quartz sand were used. The saturation level of the packed columns was set to 83-95% with solutions having a wide range of ionic strength (0.1−1000 mM). The experimental collision efficiencies were quantified using the classical colloid filtration theory. The theoretical collision efficiencies were estimated with appropriate DLVO energies using a Maxwell model.

Materials

Porous Media - *Quartz sand of two sizes:*

- Fine:0.150-0.212 mm (sieve No 100)
- Medium: 0.425-0.600 mm (sieve No 40)

Colloids -*Spherical fluorescent polystyrene microspheres (Duke Scientific Corp., Palo Alto, CA) of three sizes:* 0.075 (green) - 0.30 (red) - 2.1 μm (blue)

Influent Colloid Solutions:

1. Effect of colloid and grain size:

- ddH_2O (SC= 7.8 S/cm), mean pH : 7.0±0.2

2. Effect of ionic strength:

- Green colloids: 0.1-10 mM NaCl (C_0=4.31×10^8 N_c/mL)
- Red colloids: 0.1-1000 mM NaCl (C_0=1.35×10^8 N_c/mL)

Table 1. Zeta potentials of quartz sand and microspheres

I_s (mM)	ζ (mV)			
	Microspheres		Quartz Sand	
	Green (d_p=0.075 μm)	Red (d_p=0.3 μm)	Medium	Fine
0.1	-27.3±4.2	-48.9±9.8	-55.47±1.3	-62.55±3.0
1	-30.7±1.2	-43.5±8.1	-54.9±1.8	-62.6±2.3
10	-23.5±3.5	-75.46±3.1	-50.07±3.0	-57.02±1.7
100	-26.97±1.9	-35.45±1.6	-19.8±1.3	-20.47±0.6

Experimental Set Up

- Plexiglass column
  Length 15.2 cm
  Internal diameter 3.8 cm
- Uniformly wet-packed
- Saturation level: 83-95%
- Water potential: constant
- Ionic strength: 0.1−1000 mM
- Tracer / colloid experiments

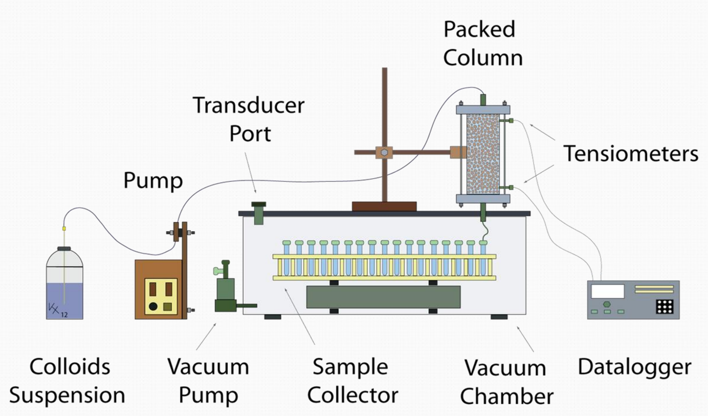

Figure.1. Schematic illustration of the experimental apparatus

Experimental Results

Size Comparison

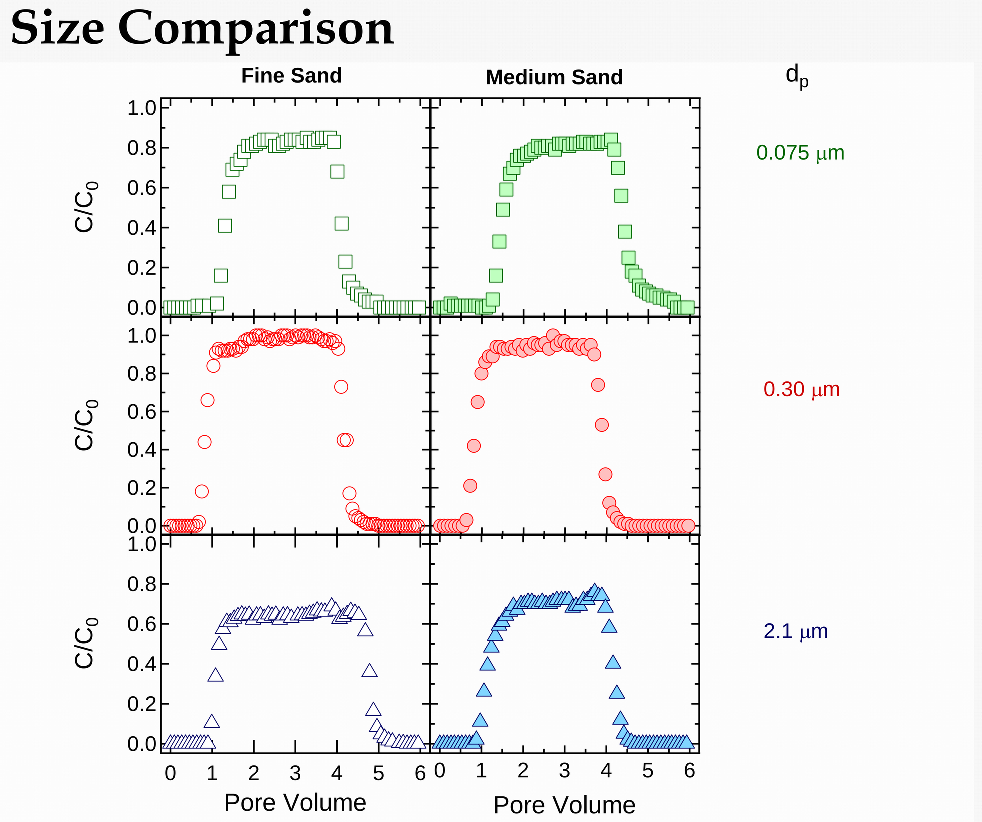

Figure 2. Experimental breakthrough data for green microspheres with d_p=0.075 μm (squares), red microspheres with d_p=0.3 μm (circles), and blue microspheres with d_p=2.1 μm (triangles) in unsaturated columns packed with fine sand (open symbols), and medium sand (filled symbols).

Effect of Ionic Strength

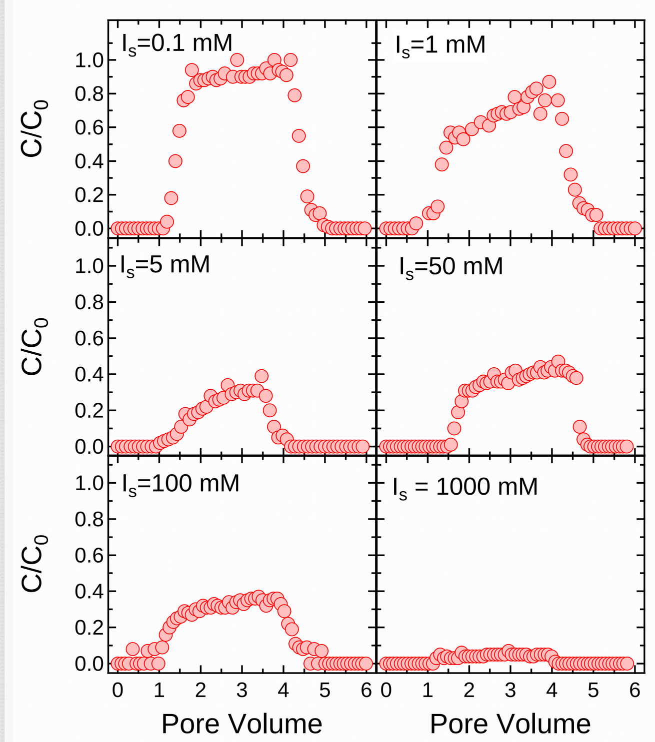

Figure 3. Experimental breakthrough data for red microspheres (d_p=0.3 μm) in unsaturated columns packed with medium sand for influent solutions having different ionic strengths.

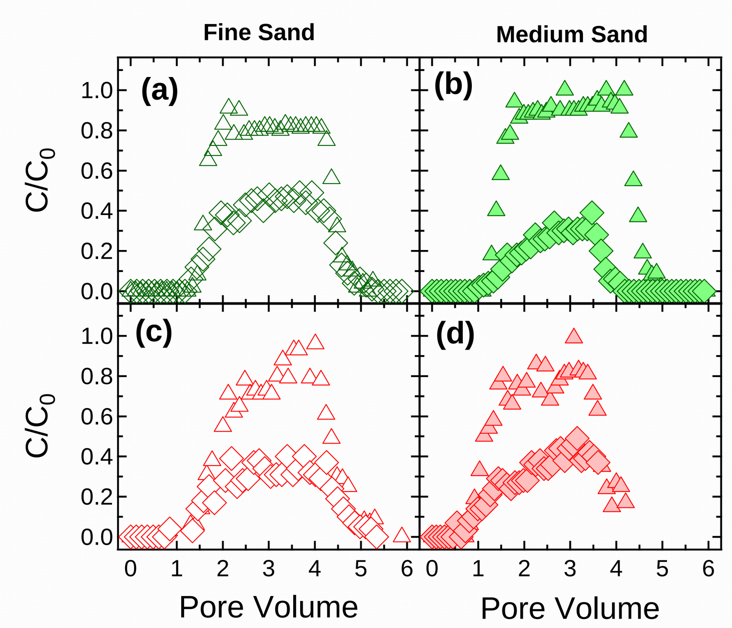

Figure 4. Experimental breakthrough data for: (a)&(b) green (d_p=0.075 μm), and (c)&(d) red microspheres (d_p=0.3 μm) in unsaturated columns packed with fine (open symbols), and medium sand (filled symbols). The data for I_s=1 mM are represented with triangles, and for I_s=5 mM with diamonds.

Collision Efficiencies

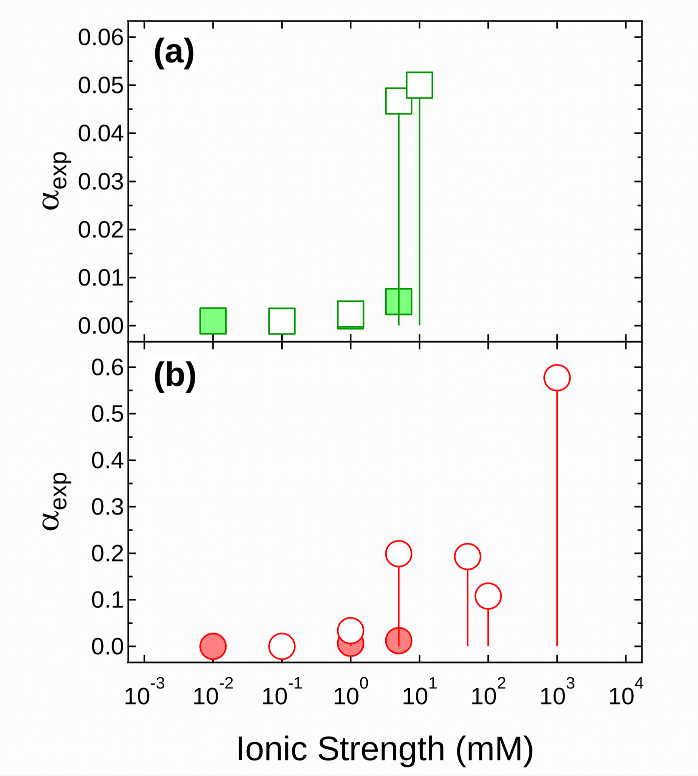

Figure 8. Experimental collision efficiencies in unsaturated columns packed with fine sand (filled symbols) and medium sand (open symbols) as a function of ionic strength for: (a) green microspheres (d_p=0.075 μm), and (b) red microspheres (d_p=0.3 μm).

DLVO Energy Profiles

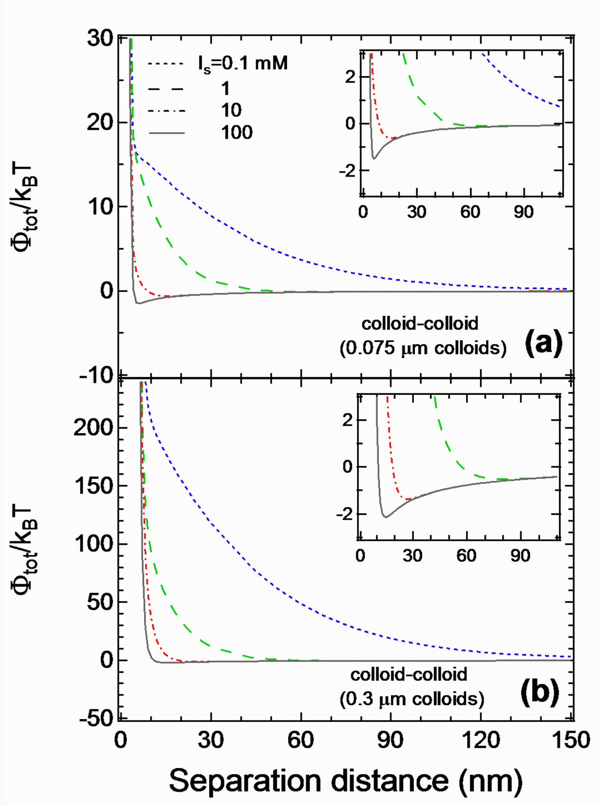

Figure 5. Predicted colloid-colloid (sphere-sphere) Φ_{DLVO} energy interactions for I_s=0.1, 1, 10, 100 mM with: (a) green microspheres (d_p=0.075 μm), and (b) red microspheres (d_p=0.3 μm), as a function of separation distance.

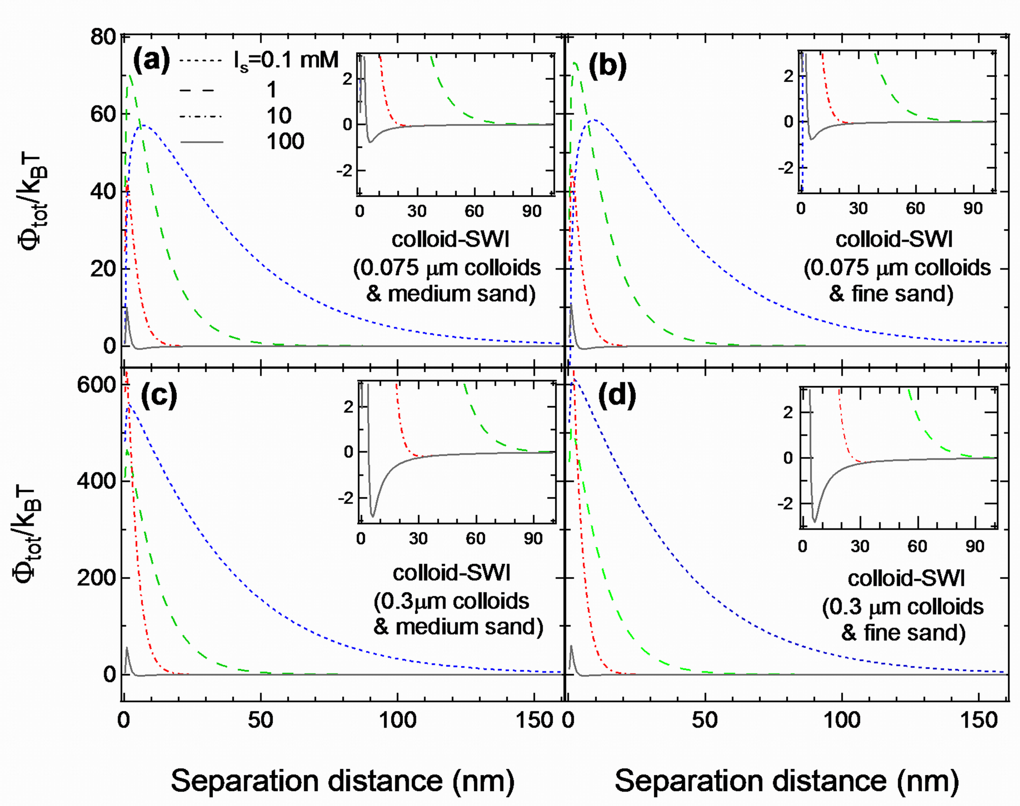

Figure 6. Predicted colloid-SWI (sphere-plate) Φ_{DLVO} energy interactions for I_s= 0.1, 1, 10, 100 mM with: (a) green microspheres (d_p=0.075 μm) and medium sand, (b) green microspheres (d_p=0.075 μm) and fine sand, (c) red microspheres (d_p=0.3 μm) and medium sand, and (d) red microspheres (d_p=0.3 μm) and fine sand, as a function of separation distance.

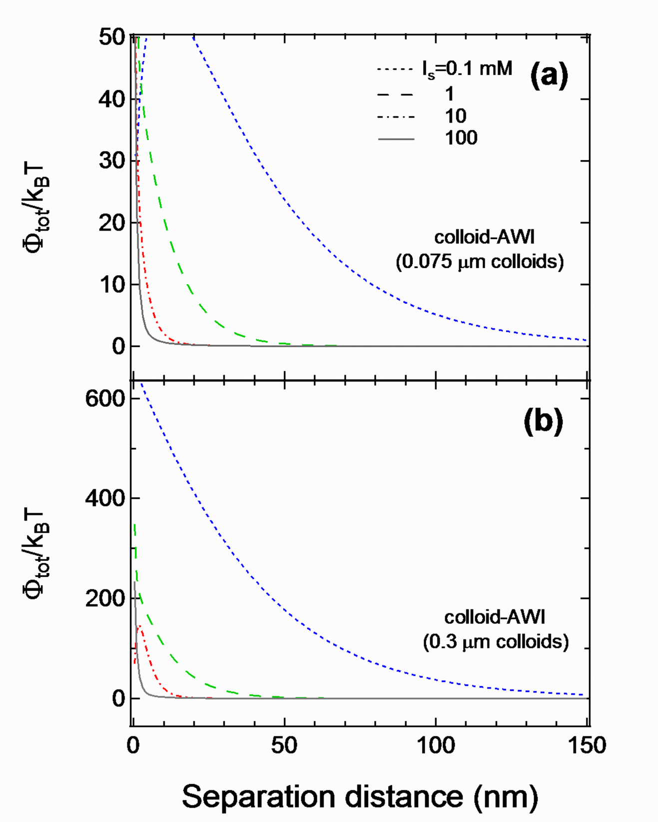

Figure 7. Predicted colloid-AWI (sphere-plate) Φ_{DLVO} energy interactions for I_s=0.1, 1, 10, 100 mM with: (a) green microspheres (d_p=0.075 μm), and (b) red microspheres (d_p=0.3 μm), as a function of separation distance.

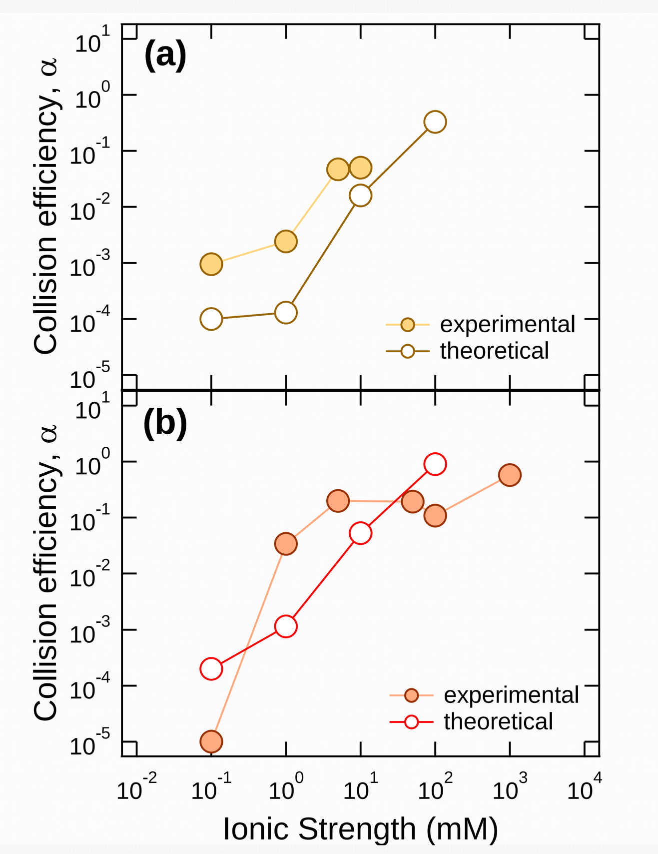

Figure 9. Experimental (filled symbols) and theoretical (open symbols) collision efficiencies in unsaturated columns packed with medium sand as a function of ionic strength for: (α) green microspheres (d_p=0.075 μm), and (b) red microspheres (d_p=0.3 μm).

Theoretical Calculations

A. Moment Analysis *(James and Chrysikopoulos, 2011)*

$$M_n(x) = \frac{\int_0^\infty t^n C_i(x,t)dt}{\int_0^\infty C_i(x,t)dt}$$

B. Colloid Filtration Theory

Experimental attachment efficiency, α_{exp}:

$$\alpha_{exp} = -\frac{2}{3}\frac{d_c}{L(1-\theta_m)\eta_0}\ln\left[\frac{C_{SS}}{C_0}\right]$$

C. DLVO Interaction Energy *(Loveland et al. 1996)*

$$\Phi_{DLVO}(h) = \Phi_{vdW}(h) + \Phi_{dl}(h) + \Phi_{Born}(h)$$

Theoretical collision efficiency, α_{th} (Shen et al.2007):

$$\alpha_{th} = 1 - \int_{-\Phi_{min2}}^{\Phi_{max1-min2}} f(E_k)dE_k$$

$$E_k = \frac{1}{2}m_p v_p^2$$

D. Water film thickness *(Wan and Tokunaga, 1997)*

$$w_f = \left(\frac{\varepsilon_r\varepsilon_0}{2}\right)^{1/2}\left(\frac{\pi k_B T}{Ze}\right)\left(\frac{4\sigma_{aw}}{d_c} - \psi\right)^{-1/2}$$

Conclusions

- Larger microspheres were retained slightly more than the conservative tracer and smaller microspheres (in ddH_2O, possibly due to straining).
- Microsphere attachment was higher onto medium than fine sand, and for most of the cases examined, early breakthrough (velocity enhancement) of the microspheres was observed.
- The mass recovery of the microspheres was shown to significantly decrease with increasing I_s.
- The α_{exp} values calculated in this study indicate that more favorable attachment conditions existed for the red microspheres (d_p=0.3 μm) than the green microspheres (d_p=0.075 μm). Both α_{exp} and α_{th} increased with increasing I_s.

References

1. James, S.C., and C.V. Chrysikopoulos, Adv. Water Resour., 34, 1249-1255, doi:10.1016/j.advwatres.2011.06.001, 2011.
2. Loveland, J.P., J.N. Ryan, G.L. Amy, and R.W. Harvey, Colloids Surf. A: Physicochem. Eng. Aspects, 107, 205-221, 1996.
3. Shen, C., B. Li, Y. Huang, and Y. Jin, Environ. Sci. Technol., 41, 6976-6982, 2007.
4. Wan, J.M., and T.K. Tokunaga, Environ. Sci. Technol., 31, 2413-2420, 1997.

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