

Coupled Effect of Input Concentration and Solution Ionic Strength on Colloid Transport in Saturated Porous Media

Hyunjung Kim ^{1,+}, Minhyuk Lee ¹, Woori Chae ¹, Troy D. Ezeh ², and Sharon L. Walker²

¹ Department of Mineral Resources and Energy Engineering, Chonbuk National University, 664-14 Duckjin-dong 1Ga, Deokjin-gu, Jeonju, Jeonbuk 556-756, Republic of Korea

² Department of Chemical and Environmental Engineering, University of California, Riverside, California 92521

Abstract. The objective of this study is to investigate the coupled role of colloid input concentration and ionic strength on the fate and transport of colloidal particles in saturated porous media. For this purpose, transport experiments were conducted in a well-controlled packed-bed system using 1 μm carboxylate fluorescent latex over a range of ionic strengths (1–200 mM KCl) at a constant Darcy velocity of 0.5 cm/min. Column experiments with two different input colloid concentrations (i.e., 10^7 colloids/ml and 10^8 colloids/ml) were also conducted to examine the coupled role of colloid input concentration and ionic strength. The experimental results showed that colloid deposition was almost identical for very low and high solution ionic strength conditions; however, at an intermediate condition (i.e., 50 mM in this study) colloid deposition was enhanced for low input colloid concentration than for high colloid concentration, suggesting strong coupling influence between solution ionic strength and input colloid concentration. Derjaguin-Landau-Verwey-Overbeek (DLVO) interaction calculation results suggested that colloids may be retained at 50 and 100 mM solution ionic strength conditions via secondary energy minimum. Hence, the above results imply that the balance between the attraction energy for colloids-quartz surfaces and the colliding energy for suspending colloids-retained colloids likely played an important role on colloid deposition in porous media.

Keywords: Colloid transport, Porous media, Input concentration, Ionic strength, Colloid collision

1. Introduction

The presence of colloidal materials in subsurface or groundwater can enhance or retard the transport of biological pollutants (e.g., pathogens (*Escherichia coli* and *Salmonella*)). Hence, in order to effectively prevent drinking water supplies from contamination, understanding fate and transport of bacteria/colloids in soil is important. Although numerous studies which are relevant to this research area have been conducted, the potential influence of colloid concentration (especially, the potential coupled role of colloid input concentration and ionic strength) on the colloid transport in porous media has normally been neglected. Only a limited number of studies have demonstrated that colloid input concentration can play an important role on colloid retention in porous media. Since the concentrations of colloidal materials in subsurface environments widely vary according to the depth of subsurface, source, geological characteristics, the research in this area is required. Therefore, this study was designed to investigate the coupled role of colloid concentration and ionic strength on colloid transport in saturated porous media. For this purpose, packed-bed column experiments were conducted for two different input colloid concentrations (10^7 colloids/ml and 10^8 colloids/ml) over a wide range of solution ionic strength conditions (1–200 mM).

2. Materials and Methods

⁺ Corresponding author. Tel.: +82-63-270-2370, fax: +82-63-270-2366.
E-mail address: kshjkim@jbnu.ac.kr.

The coupled influence of input concentration and ionic strength on colloid transport has been investigated in well-controlled packed-bed column experiments (quartz size distribution: 200-250 μm). All of the experimental conditions were equal (i.e., Darcy velocity=0.5 cm/min, column length=7 cm, pH=5.6-5.8, electrolyte=KCl), but the colloid concentration and ionic strength varied. Specifically, two different colloid concentrations (i.e., 10^7 colloids/ml vs. 10^8 colloids/ml) and five different solution ionic strength conditions (1, 10, 50, 100, and 200 mM) were employed in this study. Fluorescent (excitation 505 nm, emission at 515 nm) carboxyl modified latex (CML) microspheres, which are reported to be 1 μm in size and to be hydrophilic, was used. Following the recovery of the column breakthrough curve (BTC), the deposition profile of colloids in the column was determined. The sand was carefully excavated and poured into tubes containing eluant solution with the same ionic strength and pH that was used in the transport experiment. The solution volume and the weight of sand in the tube were determined from mass balance. The zeta potential of these CML colloids in the various solution chemistries measured, and using the measured zeta potential data the total interaction energy between the 1 μm CML colloids and a quartz surface under various solution chemistries was calculated based on DLVO theory to understand the potential influence of secondary energy minimum on colloid deposition and transport.

3. Results and Discussion

Figs. 1a and b show the BTCs obtained from the column experiments conducted with high and low colloid injection concentrations, respectively. Overall, the colloid deposition increases with increasing ionic strength and decreasing input concentration. The trend is likely due to the reduced interaction energy barrier for colloid deposition by the decrease in zeta potential of CML colloids with ionic strength (Fig. 2). The BTC results are consistent with deposition profiles (Fig. 3) and mass balance results (Table 1). Specifically, at high ionic strength, more colloids deposited in the quartz media and the deposition profiles exponentially decreases with the column depth (Fig. 3). Negligible effect of colloid input concentration on colloid deposition was observed for very high and low solution ionic strength conditions (i.e., ionic strength=1, 10, 100, 200 mM). However, the effect of input concentration was pronounced at intermediate solution ionic strength condition (i.e., 50 mM), indicating that strong coupled effect of colloid input concentration and solution ionic strength on colloid transport in porous media. In order to further gain insight on this phenomenon, the interaction energy profiles between colloids and quartz surfaces were obtained based on classic DLVO theory and presented in Fig. 2. The DLVO interaction profiles indicate that significant secondary energy minimum exists at the solution ionic strength of 50 and 100 mM, indicating that potential colloid retention occurred at both conditions via weak attractive interaction. However, the effect of colloid input concentration on colloid retention was only observed for 50 mM condition where weaker attractive interaction is expected as compared to 100 mM condition). These results suggest that the balance between attraction energy for colloids-quartz surfaces and colliding energy for suspending colloids-retained colloids likely played an important role on colloid deposition in porous media.

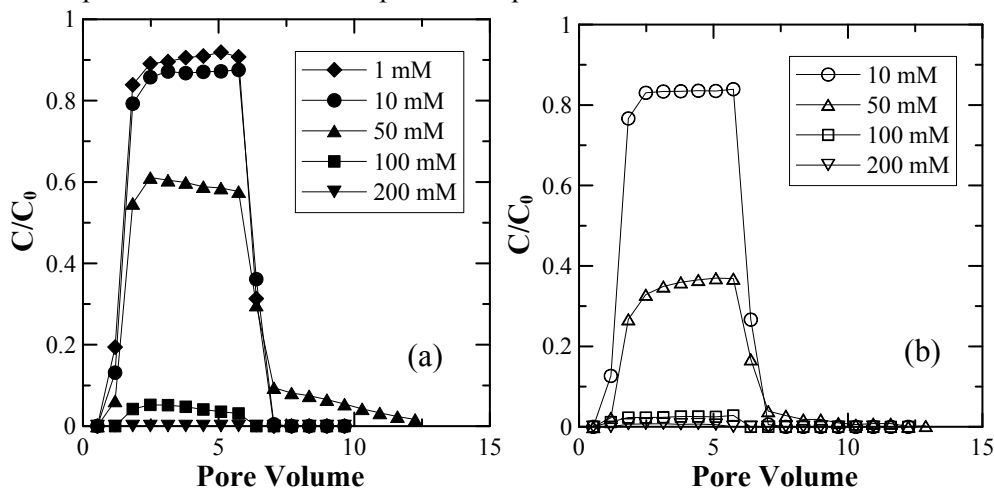


Fig. 1. Column BTC results with different solution ionic strength conditions: (a) 10^8 colloids/ml and (b) 10^7 colloids/ml. Other experimental conditions such as pH, fluid velocity, electrolyte type are same for both cases.

Table 1. Mass balance results for the column studies with different input colloid concentrations (10^7 vs. 10^8 colloids/ml).

Concentration	Ionic strength (mM)	M_{eff} (%)	M_{sand} (%)	M_{total} (%)
10^8 colloids/mL	1	90.3	1.2	91.5
	10	86.7	2.7	89.4
	50	66.0	23.6	89.6
	100	4.0	76.9	80.9
	200	0	69.7	69.7
10^7 colloids/mL	10	82.3	7.5	89.8
	50	36.5	41.0	77.5
	100	2.5	73.5	76.0
	200	0.5	49.9	50.4

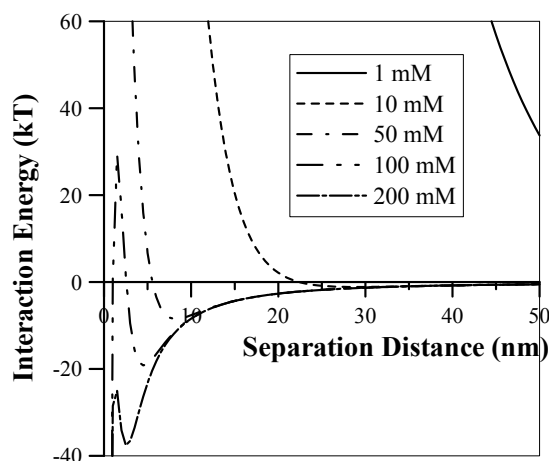


Fig. 2. DLVO interaction energy profiles for $1 \mu\text{m}$ CML colloids at different solution ionic strength conditions.

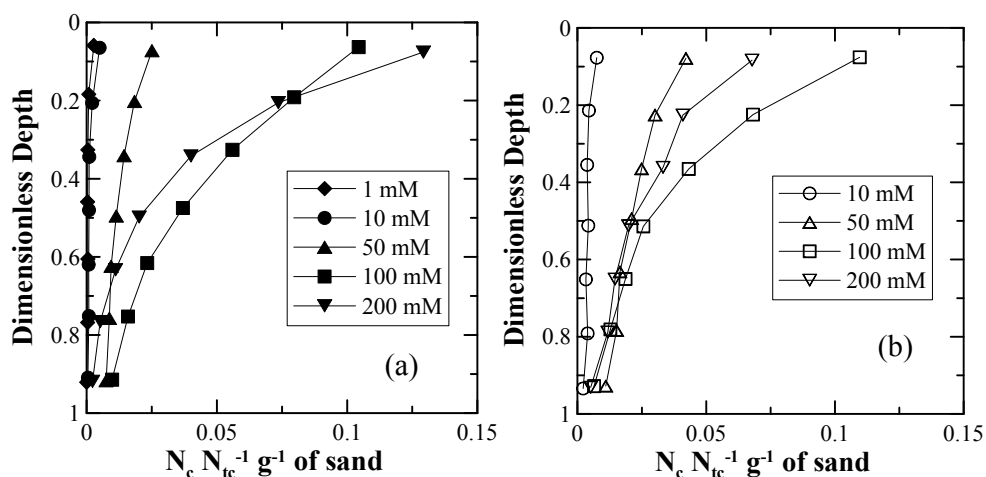


Fig. 3. Deposition profiles at different solution ionic strength conditions: (a) 10^8 colloids/ml and (b) 10^7 colloids/ml.

Other experimental conditions such as pH, fluid velocity, electrolyte type are same for both cases. (10^7 vs. 10^8 colloids/ml). The X-axis represents the normalized concentration of the cells (the number of colloids in each section of column, N_c , divided by the total number injected into the column, N_{tc}) per gram of dry sand.

4. Conclusions

In this study, two major parameters (ionic strength and colloid concentration), which possess an influence on colloid transport in porous media, were investigated in a well controlled packed bed column.

Additionally, the interrelation of the colloid input concentration with ionic strength was also examined and the key observations are as follows: first, deposition of colloids on quartz media substantially increases with increasing ionic strength. The deposition trend can be explained by the fact that the electrostatic repulsive interaction between colloids and quartz media decreases with increasing ionic strength. Second, colloid deposition increases with decreasing colloid concentration injected into the column. Interestingly, the effect of colloid concentration was pronounced at intermediate ionic strength where secondary energy minima exist between colloids and quartz media. The results indirectly suggest that the interaction between the colloids suspended in bulk fluid and attached onto quartz media may be important in colloid deposition especially at high concentration.

5. Acknowledgements

This research was supported by two Basic Science Research Programs through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2010-0023782 and NRF-2011-0014627). We thank to Dr. Scott A. Bradford (United States Department of Agriculture-ARS, U.S. Salinity Lab.) for his helpful advice and comments.

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