Nanotechnology Enabled Remediation Solutions for Persistent Contaminants in Groundwater Environments

Mohan Basnet (PhD Candidate)
Department of Chemical Engineering, McGill University, Montreal, QC H3A 0C5

1. INTRODUCTION

- Accidentally released dense non-aqueous phase liquid (DNAPL) can migrate deep into aquifers causing extensive groundwater contamination
- Palladium-doped nanosized zero valent iron (Pd-NZVI) particles can remediate DNAPL and other redox-sensitive contaminants

A major challenge in implementing this technology is: Bare Pd-NZVI rapidly aggregates and thus exhibits negligible transport while the success of nanotechnology enabled remediation largely depends on the mobility of injected Pd-NZVI to reach the targeted contaminants

2. OBJECTIVES

- To investigate the potential of using environmentally friendly (biodegradable and non-toxic) surface modifiers; carboxymethyl cellulose (CMC), rhamnolipid (RL) biosurfactant and soybean flour (SF); to reduce Pd-NZVI aggregation and improve transport
- To evaluate the influence of groundwater chemistry (e.g. salt concentration) on Pd-NZVI aggregation and transport potential

3. EXPERIMENTAL DESIGN

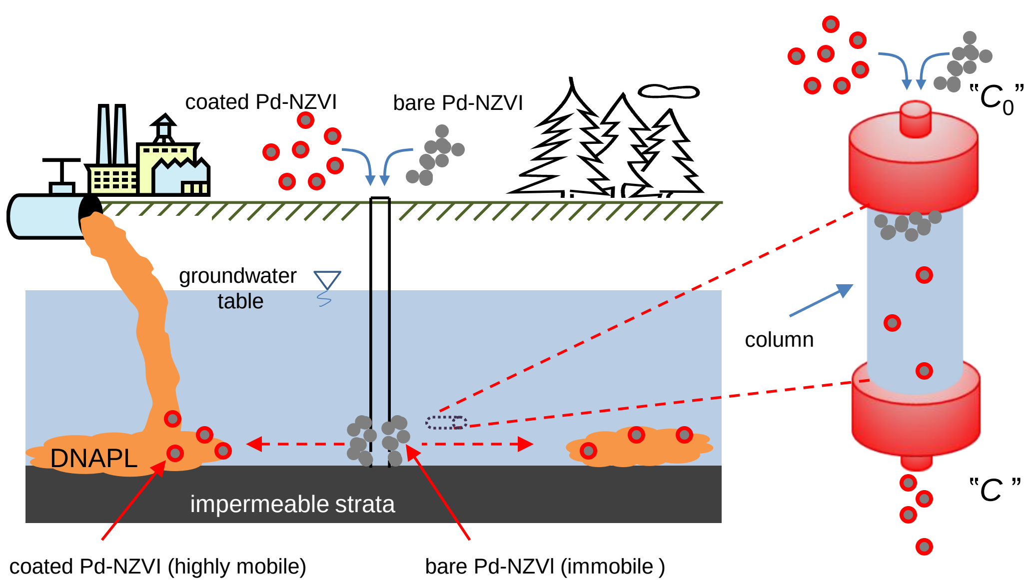


Figure A. Pd-NZVI injection to target persistent contaminants in groundwater environments

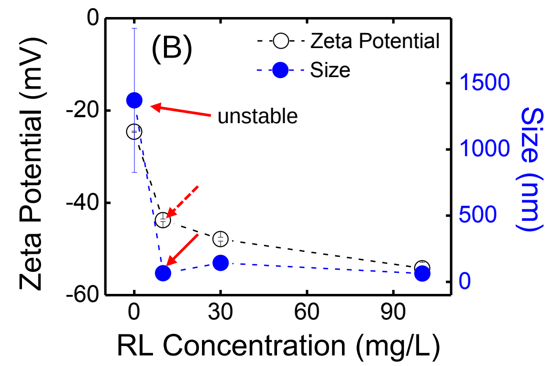
Nanoparticle Aggregation:
- Pd-NZVI hydrodynamic diameter monitored using dynamic light scattering (DLS)
- Aggregation rate determined from the initial slope of the aggregation profile
- The likelihood of particle aggregation is assessed by particle-particle attachment efficiency (α_{pp})

$$\alpha_{pp} = \frac{K \text{ (aggregation rate at a given salt concentration)}}{K_{fav} \text{ (favorable aggregation rate at higher salt concentration)}}$$

Nanoparticle Transport (Mobility):
- Saturated sand-packed columns were used as a model groundwater environment
- Mobility assessed with the injection of known concentration (C_0) of Pd-NZVI at the column inlet and by monitoring the effluent concentration (C) at the column outlet
- The likelihood of particle deposition (or transport) is assessed by particle-collector (aquifer grain) attachment efficiency (α_{pc})

$$\alpha_{pc} = \frac{\#\text{ of successful collisions leading to attachment}}{\#\text{ of particle – collector collisions}}$$

4. RESULTS - CHARACTERIZATION



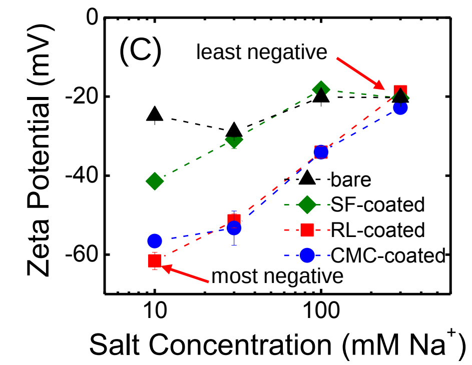
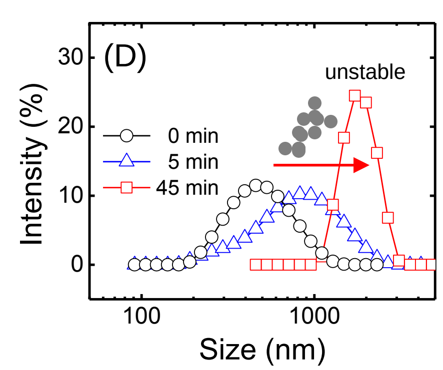


Figure B. A small concentration of RL creates a more stable suspension of Pd-NZVI having a smaller size (solid arrow) and more negative charge (dotted arrow). Note that zeta potential is an indication of surface charge.

Figure C. Increase in salt concentration makes the Pd-NZVI less negatively charged

5. RESULTS - AGGREGATION



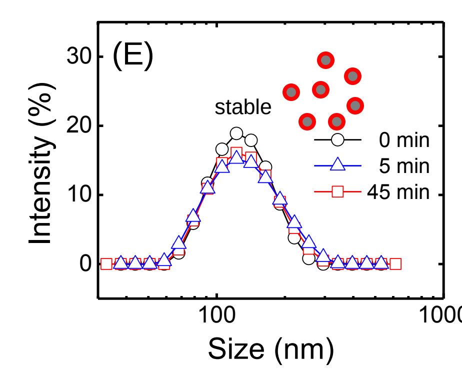
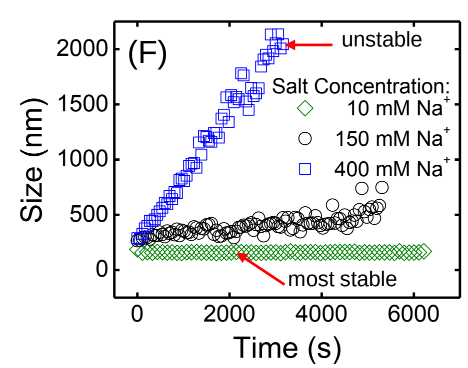


Figure D. Bare Pd-NZVI rapidly aggregates i.e. the particle size distribution rapidly evolves to micron-sized aggregates (unstable)

Figure E. RL-coated Pd-NZVI is much more stable i.e. particle size distribution does not vary with the aggregation time



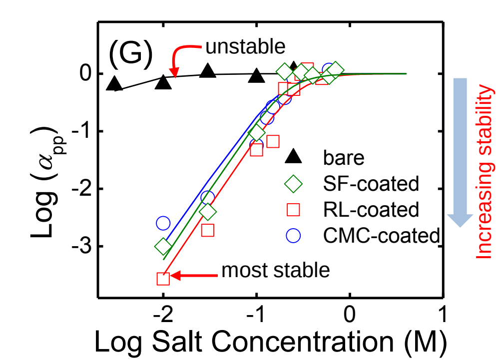


Figure F. An increase in salt concentration induces a marked Pd-NZVI aggregation, representative aggregation profile is presented for RL-coated Pd-NZVI

Figure G. Up to 3 order of magnitude reduction in α_{pp} (and therefore heightened stability) observed for coated Pd-NZVI compared to bare

REFERENCES

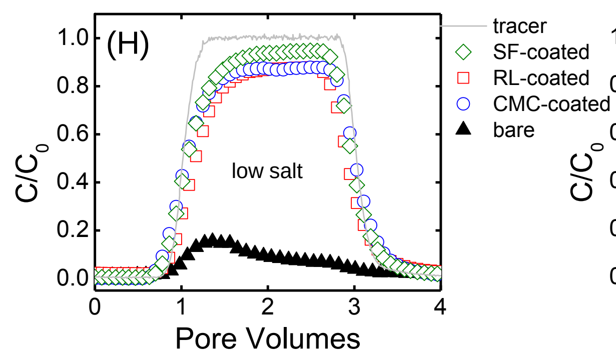
Below are the papers and patent generated from this study:

(1) Basnet, M. et al., *Environ. Sci. Technol.* **2013**, 47 (23), 13355-13364.

(2) Basnet, M. et al., *Water Res.* **2015**, 68, 354-363.

(3) US provisional patent application: Basnet, M. et al., US 61/886,693, October 4, **2013** (McGill University).

6. RESULTS - TRANSPORT



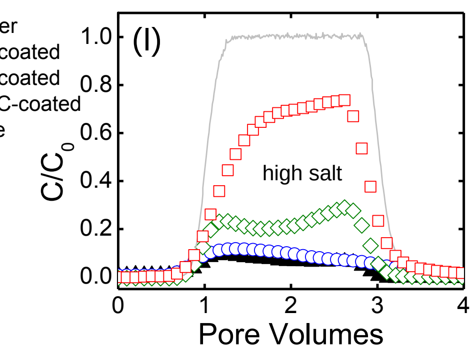
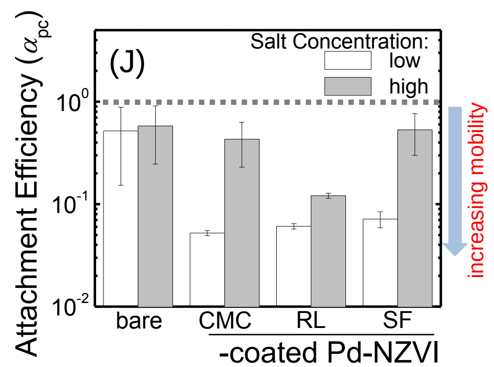


Figure H. Coated Pd-NZVI exhibits dramatically improved transport (C/C_0~90%) than bare (C/C_0<10%) at low salt concentration (pore volume corresponds to an average nanoparticle residence time in the column)

Figure I. RL-coated Pd-NZVI exhibits significantly higher transport than that of Pd-NZVI coated with other surface coatings at high salt concentration



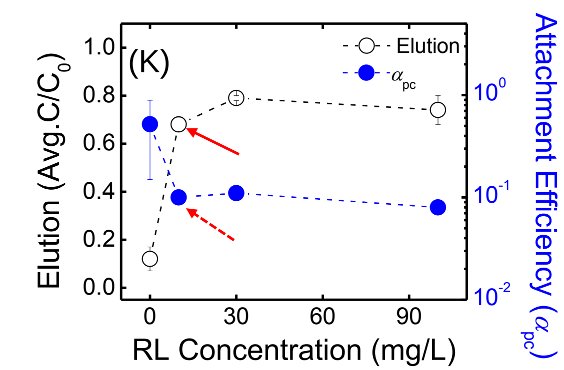


Figure J. Smaller α_{pc} values represent higher transport potential; RL-coated Pd-NZVI exhibits notably higher transport potential at both low and high salt concentration

Figure K. A small concentration of RL appears sufficient to enhance Pd-NZVI transport; note higher elution (solid arrow) and smaller α_{pc} (dotted arrow)

7. CONCLUSIONS AND FIELD IMPLICATIONS

- Bare Pd-NZVI is prone to rapid aggregation and exhibits negligible transport in model groundwater environments
- The selected surface modifiers: carboxymethyl cellulose, soy flour and rhamnolipid dramatically improve Pd-NZVI stability and enhance transport
- Increase in groundwater salt concentration induces significant Pd-NZVI aggregation with a simultaneous decrease in nanoparticle transport potential
- Rhamnolipid is more effective than carboxymethyl cellulose and soy flour at enhancing Pd-NZVI transport at high salt concentrations
- Rhamnolipid significantly improved transport of Pd-NZVI at concentration as low as 10 mg/L, suggesting that rhamnolipid is the most cost effective natural surface modifier in field application (patent filed)
- Our results have the potential to make a major impact in the field of environmental remediation as we greatly improved the properties of reactive nanoparticles using a novel stabilizer (rhamnolipid) which is non-toxic, biodegradable and commercially available - a sustainable solution.

ACKNOWLEDGEMENTS

Supervisors:
Prof. Nathalie Tufenkji
Prof. Subhasis Ghoshal

NSERC CRSNG
Fonds de recherche sur la nature et les technologies Québec
Golder Associates
McGill Engineering Doctoral Award (MEDA)