Transport and retention of engineered silver nanoparticles in the presence of phosphorus

Yorck Adrian[1], **Uwe Schneidewind**[2], Scott Bradford[3], Jirka Simunek[4], Erwin Klumpp[5] and Rafig Azzam[1]

[1]RWTH Aachen University, Aachen, Germany
[2]School of Geography, Earth and Environmental Sciences, University of Birmingham, UK
[3]US Salinity Laboratory, USDA, ARS, Riverside, CA 92507, USA
[4]Department of Environmental Sciences, University of California, Riverside, CA 92521, USA
[5]Agrosphere (IBG-3), Institute of Bio- and Geosciences, Forschungszentrum Jülich GmbH, Jülich, Germany

Introduction 1

- Engineered silver nanoparticles have antimicrobial/antifungal properties
- They are used in a variety of sectors such as electronics, textile production, cosmetic and medical industries, agriculture, etc.
- AgNPs are potentially toxic or detrimental to a wide variety of organisms
- AgNPs can enter the subsurface e.g. when WWTP sludge is applied to agricultural fields or in urban areas

Introduction 2

- AgNP fate and transport in porous media is affected by a variety of physico-chemical parameters including
  - Characteristics of the AgNP (e.g., stability, capping agent, size, charge, surface structure, …)
  - Characteristics of the porous medium (e.g., material type and grain characteristics, pH, composition of background solution, organic matter content, surface charge heterogeneities, pore size, …)

Objective

- Study transport and retention of polyvinylpyrrolidone (PVP) coated Ag-NPs in the presence of orthophosphate (NaH_2PO_4) in the background solution
- Compare PVP-AgNP transport behavior
  - at two different orthophosphate concentrations
  - at pH 4.5 and pH 6
  - With and without soil organic matter (SOM)
  - w/o sediments < 63 µm
- Comparison with *myo*-inositol hexakisphosphate (IP6) or $NaNO_3$ in the background solution

Methods 1

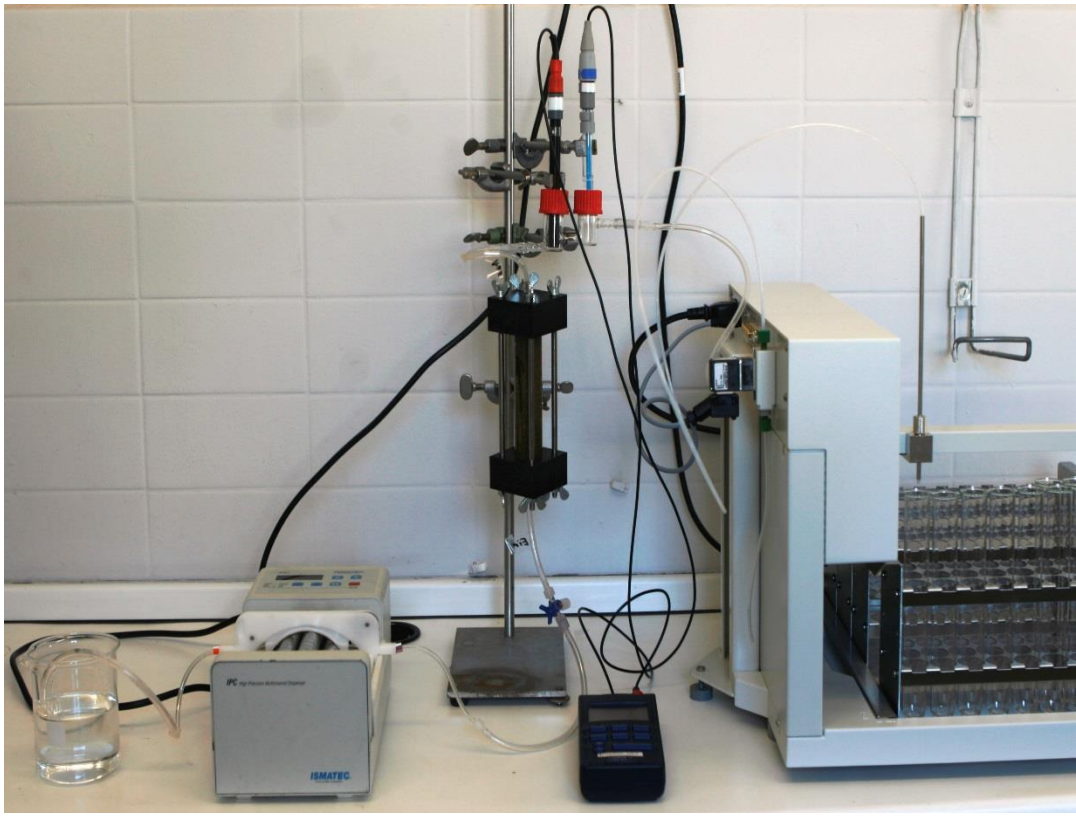
- Column tests containing porous aquifer material comprising mainly quartz (76%) and feldspar (13%) → X-ray powder diffraction
- Total Fe and Al concentrations in sediment determined via aqua regia digestion and ICP-OES
- Aquifer material sieved and wet-packed into columns → known grain-size distribution
- In some experiments material cleaned from soil organic matter
- N_2-BET measurements → average surface area of material
- Camsizer → roundness and sphericity of material
- Carbon los ignition test → SOM content

Methods 2

- Columns were saturated and run in upflow mode
- Columns flushed with ultrapure water before and after tracer tests with NaBr
- Columns conditioned with respective background solutions
- Total Ag concentration in column effluents determined via ICP-MS
- pH recorded in influent and effluent
- Hydrodynamic diameter of PVP-AgNP determined → Zetasizer
- Electrophoretic mobility (at 25° C) of PVP-AgNPs and material < 10 µm determined in the background solutions → Zetasizer

Methods 3

- AgNP breakthrough modeled using HYDRUS 1D.
- Langmuirian blocking with two kinetic retention sites.
- Inverse modeling → maximum PVP-AgNP concentrations on the solid phase.



General experimental setup – Source: Adrian (2015)

Results

- Around 100% of tracer recovered in all column experiments before AgNP breakthrough.
- AgNP mass recovery in effluent 50-75%.
- AgNP in P-background solution show a higher mobility in presence of SOM compared the absence of SOM.
- AgNP exhibit an increased blocking and retention behavior in absence of phosphorous **(Fig. 1)** and SOM.
- For both P species, higher Ag effluent concentrations were detected at pH 6 compared to pH 4.5. → related to varying surface charge of aquifer material

Results

- In columns with 2% amount of grains <63 µm significant reduction of AgNP in effluent observed **(Fig. 2)** → higher for AgNP in IP6 than orthophosphate solution.
- Higher P-concentration in background solution (0.1-1 mM) leads to higher AgNP concentration in effluent.

Results

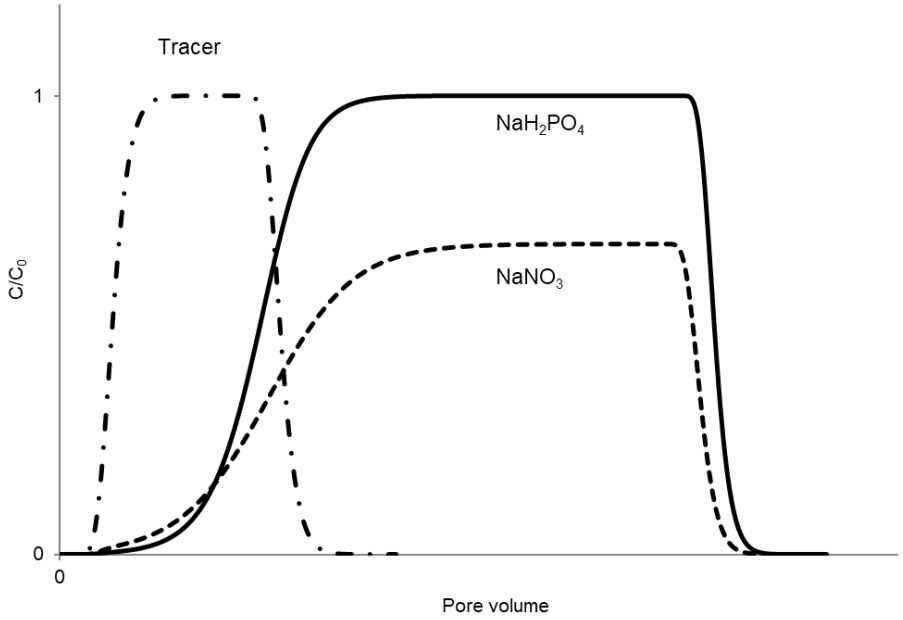


Fig. 1 – PVP AGNP transport in presense and absence of orthophosphate in background solution.

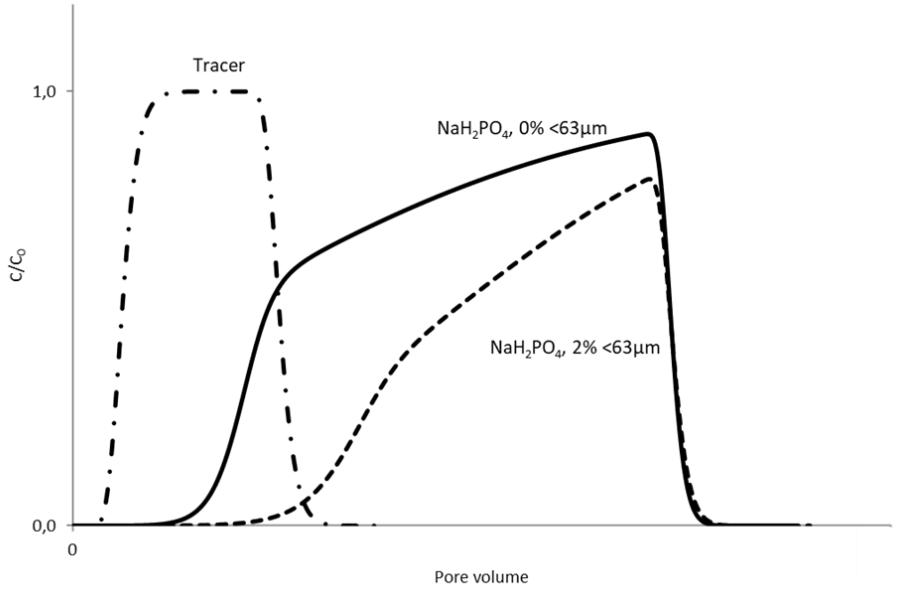


Fig. 2 – PVP AgNP transport in presense of fine grains.

Thank you!

Recent publications:

Adrian, Y.F., Schneidewind, U., Bradford, S.A., Simunek, J., Fernandez-Steeger, T.M., Azzam, R., 2018. Transport and retention of surfactant- and polymer-stabilized engineered silver nanoparticles in silicate-dominated aquifer material. Environ Pollut 236, 195-207, doi: 10.1016/j.envpol.2018.01.011.

Adrian, Y.F., Schneidewind, U., Bradford, S.A., Simunek, J., Klumpp, E., Azzam, R., 2019. Transport and retention of engineered silver nanoparticles in carbonate-rich sediments in the presence and absence of soil organic matter. Environ Pollut 255, 113124, doi: 10.1016/j.envpol.2019.113124.

Liang, Y., Zhou, J., Dong, Y., Klumpp, E., Simunek, J., Bradford, S.A., 2020. Evidence for the critical role of nanoscale surface roughness on the retention and release of silver nanoparticles in porous media. Environ Pollut 258, 113803, doi: 10.1016/j.envpol.2019.113803.