Simulation of the transport of nanofluids in porous media: particle deposition and clogging phenomena

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ABSTRACT

Recently, the use of engineered nanoparticles has been proposed for a variety of environmental applications, such as enhanced oil recovery, subsurface characterization and in situ contaminant remediation. As an example, injection into the subsurface of suspensions of microscale and nanoscale zerovalent iron particles (MZVI and NZVI) have proved to be a promising technology for treatment of aquifers contaminated by recalcitrant compounds. Consequently, such applications require a full understanding of the mechanisms governing the transport of colloidal particles in saturated porous media. Moreover, the development of quantitative predictive models is of pivotal importance for system design and implementation.

Nanoparticles transport in porous media is usually described by a modified advection-dispersion equation that takes into account the mass exchanges between liquid and solid phase due to physical and physico-chemical interactions. The interaction kinetics, resulting in particles deposition onto and release from the solid matrix, have been proven to be strongly influenced by both operative, e.g. injection flow-rate [1, 6], and natural conditions, e.g. pore-water ionic strength [4]. These parameters can substantially vary according to the field of application and the involved subsurface formations (e.g. NZVI injected in contaminated aquifers, nanoparticles released leachate from a landfill, nanoparticles injected in a reservoir for enhanced oil recovery, etc.). Therefore, it is essential that mathematical models take into account the effects of ionic strength and pore water velocity transient conditions on particles mobility.

In this work, two modelling tools, MNMs and MNM3D, are proposed for simulation of colloidal particles, respectively at laboratory and field scale. MNMs is a Matlab based user-friendly graphical interface (www.polito.it/groundwater/software/MNMs.php), which implements numerical solutions to 1D Cartesian colloid transport equations, accounting for both constant and transient ionic strength conditions [4] and porous medium clogging [3]. MNMs can be also employed for pilot scale simulation of particles injection through a single well. To this purpose, transport and flow equations are solved in radial geometry, accounting for the dependency of colloid transport kinetics on pore fluid velocity and viscosity [5].

MNM3D is developed for the simulation of nanoparticles suspensions injection and transport in more complex scenarios. MNM3D is a modified version of the well-known transport model RT3D [2], in which the colloid transport equations and the dependencies of attachment and detachment kinetic coefficients on transients in pore water ionic strength and velocity have been implemented. The approach is validated comparing the simulation results of MNMs and MNM3D run on one-dimensional and 2D (radial symmetry) domains. The tool can be used for multi-dimensional simulations and employed in many practical field-scale applications, such as the preliminary design of in situ aquifer remediation via injection of reactive nanoparticles injection. In particular, it can be useful to estimate important operative parameters, including particles distribution around the injection well, influence radius for a target concentration, number of required injection wells, etc.

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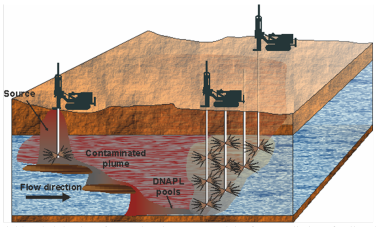
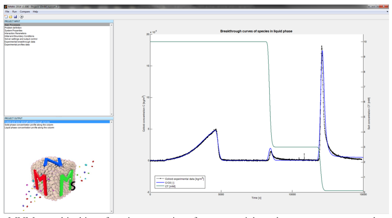
GRAPHICS



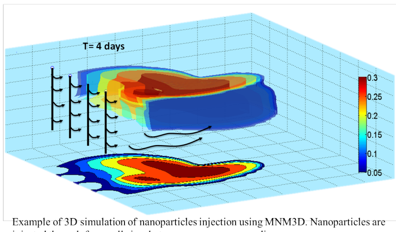
Field scale injection of zerovalent iron nanoparticles for remediation of polluted aquifers.

Graphic1



MNMs graphical interface: interpretation of a nanoparticles column transport test under transient ionic strength conditions.

Graphic2



Example of 3D simulation of nanoparticles injection using MNM3D. Nanoparticles are injected through four wells in a heterogeneous porous medium.

Graphic3