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The potential of silica encapsulated DNA magnetite microparticles (SiDNAMag) for multi-tracer studies in subsurface hydrology

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With tracer experiments, knowledge on solute transport, travel times, flow pathways, source areas, and linkages between infiltration and exfiltration zones in subsurface hydrological studies can be obtained. To overcome the well-known limitations of artificial tracers, we report here the development and application of an inexpensive method to produce large quantities of environmentally friendly 150-200 nm microparticles composed of a magnetite core to which small fragments of synthetic 80 nt ssDNA were adsorbed, which were then covered by a layer of inert silica (acronym: SiDNAMag). The main advantages of using DNA are the theoretically unlimited amount of different DNA tracers and the low DNA detection limit using the quantitative polymerase chain reaction (qPCR); the main advantage of the silica layer is to prevent DNA decay, while the magnetite core facilitates magnetic separation, recovery and up-concentration. In 10 cm columns of saturated quartz sand, we first injected NaCl, a conservative salt tracer, and measured the breakthrough. Then, we injected SiDNAMag suspended in water of known composition, harvested the SiDNAMag in column effluent samples, and measured the DNA concentration via qPCR after dissolving the SiDNAMag. The results indicated that the timing of the rising limb of the DNA breakthrough curve, the plateau phase and the falling limb were identical to the NaCl breakthrough curve. However, the relative maximum DNA concentration reached during the plateau phase was around 0.3, indicating that around 70% of the SiDNAMag mass was retained in the column. From these results we inferred that SiDNAMag was not retarded and therefore not subject to equilibrium sorption. Instead, first order irreversible kinetic attachment appeared to be the dominant retention mechanism. Based on our results, we speculate that, despite significant retention, due to the low DNA detection limit and the possibility of magnetic up-concentration, the use of SiDNAMag is a very promising technique to determine complex flow patterns, travel times, and flow pathways in many different subsurface hydrological applications.