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Nanoscale titanium dioxide ($nTiO_2$) transport in water-saturated sand columns: Influence of phosphate, illite colloid, and Fe-oxyhydroxide coating

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Nanoscale titanium dioxide ($nTiO_2$) is an important emerging contaminant due to its mass production in recent years. While extensive research has been performed using simplified laboratory systems to study the stability and transport of $nTiO_2$, much fewer investigations are conducted to examine the behaviour of $nTiO_2$ in complicated systems similar to natural aquifers with heterogeneous transport media and multiple water-borne components. To better understand the fate and transport of $nTiO_2$ in natural environments, we performed laboratory column experiments to measure $nTiO_2$ transport in water-saturated sand columns in the co-presence of multiple components including dissolved phosphate, suspended illite colloid, and Fe-oxyhydroxide coating on sand grains. Results showed that pH plays a crucial role in how phosphate, illite colloid, and Fe-oxyhydroxide coating influence $nTiO_2$ transport. At pH 5 in the absence of phosphate and illite colloid, despite favorable deposition conditions, $nTiO_2$ was found in the effluent of the quartz column after ~4.5 PV (pore volume) due to saturation of deposition sites, after which effluent $nTiO_2$ concentration quickly increased and then levelled off. For the Fe-oxyhydroxide coated sand column under the same conditions, whereas the shape of the BTC (breakthrough curve) was similar to that for the quartz sand column, $nTiO_2$ was detected in the effluent much earlier (~1 PV), owing to the reduction in favorable deposition sites caused by Fe-oxyhydroxide coating. When illite colloid was co-present with $nTiO_2$ in the influent at pH 5, $nTiO_2$ concentration in the effluent gradually increased to C/C0 = ~0.08 and ~0.22 respectively for the quartz sand and Fe-oxyhydroxide coated sand columns. The low transport was attributed to physical straining caused by formation of the $nTiO_2$–illite aggregates during the experiment. For all the experiments with phosphate in the influent at pH 5, $nTiO_2$ was not detected in the effluent regardless of the presence of illite colloid or Fe-oxyhydroxide coating, presumably due to straining of the large $nTiO_2$ aggregates formed via phosphate bridging. At pH 9, for both the quartz sand and Fe-oxyhydroxide coated sand columns with or without phosphate, high $nTiO_2$ transport was observed for all but one experiment. The high transport was due to the repulsive forces between $nTiO_2$ and the transport media. For the Fe-oxyhydroxide coated sand column without phosphate or illite colloid at pH 9, $nTiO_2$ transport was considerably lower (C/C0 ~0.07), as a result of pH buffering by the Fe-oxyhydroxide coating, which made the Fe-oxyhydroxides positively charged, and therefore providing favorable sites for $nTiO_2$ deposition. This study demonstrated that common water-borne components and minerals in transport media could significantly alter $nTiO_2$ transport and the interactions between each component and $nTiO_2$ as well as the synergy effects of these components must be considered in order to predict the behaviour of $nTiO_2$ in natural environments.