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Exploration of Zero-Valent Iron Stabilized Calcium–Silicate–Alginate Beads' Catalytic Activity and Stability for Perchlorate Degradation

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Abstract: Perchlorate contamination in groundwater poses a serious threat to human health, owing to its interference with thyroid function. The high solubility and poor adsorption of perchlorate ions make perchlorate degradation a necessary technology in groundwater contaminant removal. Here, we demonstrate the perchlorate degradation by employing nano zero-valent iron (nZVI) embedded in biocompatible silica alginate hybrid beads fabricated using calcium chloride (1 wt%) as a crosslinker. The concentration of precursors (sodium alginate, sodium silicate) for bead formation was standardized by evaluating the thermal stability of beads prepared at different sodium silicate and alginate concentrations. Thermal degradation of silica alginate hybrid samples showed a stepwise weight loss during the thermal sweep, indicating different types of reactions that occur during the degradation process. The formation of the silica alginate hybrid structure was confirmed by FT-IR spectroscopy. Scanning electron microscopy (SEM) data revealed the surface morphology of silica alginate hybrid changes by varying sodium silicate and alginate concentrations. nZVI-loaded alginate–silicate polymer bead (nZVI-ASB) exhibited excellent perchlorate degradation efficiency by degrading 20 ppm of perchlorate within 4 h. Our study also showed the perchlorate degradation efficiency of nZVI-ASB is maximum at neutral pH conditions.

Keywords: perchlorate contamination; nZVI; perchlorate degradation; silicate–alginate beads

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1. Introduction

Concerns about perchlorate (ClO_4^-) contamination in groundwater are increasing owing to their serious health effects on human consumption. A major portion of this contamination occurs through anthropogenic activity from the military (used as missile oxidizers) and industrial (e.g., electronic cleaning, automotive airbags, paints, medicines, fertilizer manufacturing) sources. High solubility and stability of perchlorate ions in water lead to effortless contamination in aquifers. A poor water management system could lead to perchlorate intake by humans, which inhibits iodine absorption and thyroid hormone production. Therefore, the development of perchlorate degradation methods has aroused significant interest [1–3].

Recently, nanotechnology has been actively applied to the treatment of environmental pollutants as it shows excellent processing capacity for many pollutants. Nanoscale zero-valent iron (nZVI) has drawn attention due to its high removal efficiency and applicability among nanoparticles used to process pollutants [4,5]. A number of studies have also reported on the application of nZVI to perchloric acid ion decomposition [6]. It is reported that reducing the size of nZVI or increasing the surface area can improve the degradation activity, resulting in enhanced reaction rates [7]. The main challenge here is managing these