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Assessment of the Denitrification Rate and Long-Term Performance of an Organic-Based Permeable Reactive Barrier Using Column Experiments

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Nitrate is a major contaminant in groundwater and a key contributor to eutrophication in surface water. To mitigate nitrate in groundwater, organic matter-based permeable reactive barriers (PRBs) that facilitate the denitrification process are widely used. A critical factor in PRBs design is the denitrification rate, as it directly influences barrier thickness, cost, and long-term efficiency. This study evaluated nitrate removal in a newly operated column (New) simulating organic matter-based PRBs and compared its reaction rate with that of an older column (Old), which has been operated for approximately nine years, to assess long-term reactivity and effectiveness. Both columns were filled with a mixture of woodchips and gravel as reactive materials. The influent solution, prepared with sodium nitrate, was injected into the columns at a constant flow rate, with concentrations of 20 mg L^{-1} NO_3-N for the New column and 10 mg L^{-1} NO_3-N for the Old column. Profile sampling was conducted to analyze spatiotemporal changes within the columns, with sampling performed on day 56 (30 pore volume; PV) for the New column and day 2,964 (909 PV) for the Old column. Geochemical parameters (pH, Eh, alkalinity, dissolved oxygen (DO), electrical conductivity (EC)) measured in both columns confirmed the activation of denitrifying bacteria and the transition to a reducing environment, indicating that denitrification was occurring within the columns. To compare denitrification rates, the ratio of nitrate concentration to influent concentration (C/C_o) was analyzed based on column residence time, showing that 60 % of influent nitrate was removed within 0.63 days in the New column, whereas 22 % was removed over 1.85 days in the Old column. The New column exhibited a high initial reaction rate, ensuring stable operation and confirming that woodchips are an effective and suitable material for nitrate removal. The Old column showed a significantly slower denitrification rate, suggesting organic matter depletion within the column. However, considering its extended operational period, nitrate removal was still occurring, demonstrating that woodchip-based PRBs can sustain long-term functionality. Additionally, under field conditions with slower groundwater flow, the PRB's longevity may exceed that of the Old column's operational period, highlighting its substantial economic benefits.