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Impact of Fe^0 amendment on methylene blue discoloration by sand columns

K. Miyajima [a], C. Noubactep [a,b,*]

[a] Angewandte Geologie, Universität Göttingen, Goldschmidtstraße 3, D-37077 Göttingen, Germany
[b] Kultur und Nachhaltige Entwicklung CDD e.V., Postfach 1502, D-37005 Göttingen, Germany

HIGHLIGHTS

- Reliable methods for designing Fe^0 filtration systems are still lacking.
- Inert admixtures are mostly to account for construction width requirements.
- A recent concept for Fe^0 bed design is verified here for the first time.
- The suitability of sand to sustain Fe^0 reactivity in dynamic systems is corroborated.
- The Fe^0 volumetric proportion should be between 30% and 50%.

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ABSTRACT

The influence of metallic iron (Fe^0) amendment on the efficiency of sand to discolor a 2.0 mg L^{-1} methylene blue (MB) solution was investigated in column studies. MB was used as an indicator to identify the optimum Fe^0/sand ratio for efficient filtration systems. Columns contained 0, 100 or 200 g of a Fe^0 material. The volumetric proportion of Fe^0 in the reactive layer of the columns with 100 g of material varied from 10% to 100%. Results showed that, Fe^0 amendment significantly impaired MB discoloration by sand for experiments lasting for up to 132 days. Early MB breakthrough in Fe^0/sand columns delineated the paramount importance of particle cementation, which has caused preferential flow with a negative impact on discoloration efficiency. The most efficient Fe^0/sand mixtures were the ones with 30–50% Fe^0 (v/v). These volumetric ratios correspond 33–41% weight ratios showing that the commonly used 1:1 weight ratio (50%) may not be optimal. Further research with compounds exhibiting different affinities to both Fe^0 and sand is needed before this observation can be generalized.

1. Introduction

Metallic iron (Fe^0) has been demonstrated in numerous studies to represent one of the best available materials for subsurface permeable reactive barriers [1–6]. Fe^0 is also a very efficient material for above-ground wastewater treatment and safe drinking water provision [7–9]. New applications of Fe^0 for water treatment usually involve extensive pilot-scale studies although several models have been developed for predicting the performance of Fe^0 material [10–13]. Moreover, despite 20 years of intensive research, the question as to whether iron should be used alone or mixed to a cost efficient material is yet to be properly addressed [14–24].

The suitability of Fe^0 for water treatment arises from its aqueous instability (Eqs. (1)–(4)). Immersed Fe^0 is oxidized by water according to Eq. (1):

$$Fe^0 + 2H^+ \Rightarrow Fe^{2+} + H_2 \uparrow \quad (1)$$

$$Fe^0 + 1/2\,O_2 + H_2O \Rightarrow Fe^{2+} + 2HO^- \quad (2)$$

$$2Fe^{2+} + 1/2\,O_2 + H_2O \Rightarrow 2Fe^{3+} + 2HO^- \quad (3)$$

$$Fe^{n+} + n\,HO^- \Rightarrow Fe(OH)_n \Rightarrow FeOOH/Fe_xO_y \quad (4)$$

In the presence of dissolved O_2 the more favorable redox reaction is given by Eq. (2), but reaction following Eq. (1) still significantly occurs due to the abundance of water [25]. Moreover, it has been traceably shown that even under external oxic conditions, Fe^0 is oxidized by water (Eq. (1)) and Fe^{II} by O_2 (Eq. (3)) [26]. In other words, accelerated Fe^0 oxidation under oxic conditions results from Fe^{II} consumption by O_2 (Le Chatelier's principle) and not from any direct interactions between Fe^0 and O_2 [26,27].

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* Corresponding author at: Angewandte Geologie, Universität Göttingen, Goldschmidtstraße 3, D-37077 Göttingen, Germany. Tel.: +49 551 39 3191; fax: +49 551 39 9379.

E-mail address: cnoubac@gwdg.de (C. Noubactep).

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