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Electron efficiency of zero-valent iron for groundwater remediation and wastewater treatment

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HIGHLIGHTS

- Electron efficiency was firstly proposed to assess the chemical consumption of Fe^0 technology.
- A methodology to quantify the electron efficiency was established.
- A rapid reaction was likely obtained by consuming highly extra Fe^0.

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ABSTRACT

A rapid zero-valent iron (Fe^0) target reduction reaction in groundwater remediation and wastewater treatment is commonly pursued. However, the economic importance of chemical consumption efficiency was ignored. In this study, we introduced a new economy-based factor of electron efficiency (*EE*) defined as the percentage of electrons utilized in a target reduction over an entire consumption at a given time interval. A measurement strategy was established and performed in batch experiments using different types of Fe^0 materials and one substrate (Cr^{VI} or nitrobenzene). Fe^0 materials free of surface oxides were prepared and used for *EE* measurement. We obtained *EE* values within half-life times of initial concentration of substrate, which were affected by pH, Fe^0 dosage, coexisting organic material, and Fe^0 type. Then we compared these values with the associated reaction rate constants (k). The results showed that the organic ligands or nano-sized Fe^0 were able to increase both k and *EE*. Even though lowering the pH or lifting the Fe^0 dosage dramatically accelerated the reactions, no resulting benefits were observed – the *EE* was even reduced around sevenfold. The results implied that accelerated reaction rates were acquired at the expense of chemical consumption. Thus, the *EE* factor must be intelligently balanced against the reaction rate to assess Fe^0-based groundwater remediation and wastewater treatment.

1. Introduction

The treatment of polluted groundwater and wastewater often makes use of zero-valent iron (Fe^0) chemical reduction [1], which reduces numerous contaminants, such as chromium ions [2], nitrobenzene [3,4], nitrate [5,6], chlorinated compounds [7,8], and arsenate [9,10].

Increasing the speed of Fe^0-based reactions, commonly evaluated using the reaction rate constant k, has attracted much research interest [4,11,12]. In the Fe^0-based processes, the directional transfer of electrons from the Fe^0 bulk to the target substrate transforms the latter into a non-toxic or less toxic species. More specifically, one mole of Fe^0 donates two or three moles of electrons to the target substrate, which is thereby transformed into Fe^{II} or Fe^{III}. However, undesired reactions occur simultaneously and divert the direction of electron transfer. As a result, one mole of Fe^0 donates two moles of electrons to O_2 or protons through corrosion instead of the reduction of target substrate [13]. Furthermore, the Fe^{II} formed from the corrosion, or even from the desired reaction, may donate the remaining one mole of electrons to O_2 through oxygenation [14,15]. These undesired reactions result in electron waste and unwanted extra chemical consumption of Fe^0 materials, both of which are considered to be of no value. Hence, excessive Fe^0 materials are used to compensate for electron waste [16–19].

The superfluous dosage of Fe^0 materials unavoidably impedes the economic efficiency of the process. Furthermore, nano-sized Fe^0 particles remaining in the environment raises concerns [20–23]. Therefore, an economic factor that quantifies the extent of electron utilization lays a basis to improve the economic efficiency

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