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Pd/Al bimetallic nanoparticles for complete hydrodechlorination of 3-chlorophenol in aqueous solution

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HIGHLIGHTS

- 3-Chlorophenol was effectively dechlorinated with the new Pd/Al nanoparticle.
- The reaction mechanism relied on corrosion effect of Al substrate at different pH.
- Major factors affecting the hydrodechlorination efficiency were investigated.
- The hydrodechlorination rate using Pd/Al NPs was dependent on Pd granule size.

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ABSTRACT

Nanoscale Al particles with average diameter of about 100 nm were employed to prepare Pd/Al nanoparticles (NPs) by chemical displacement deposition. It was proved that Pd^{2+} acidic deposition solution was superior to its alkaline deposition solution in terms of Pd loading rate on Al NPs. The Pd/Al NPs were characterized by ICP–OES, SEM, TEM, XRD, BET and then used to explore hydrodechlorination (HDC) performance of 3-chlorophenol (3-CP) in aqueous solution. Major factors affecting HDC efficiency were investigated including Al substrate sizes, pH, Pd loadings in Pd/Al NPs, dosage of Pd/Al NPs, and temperature. The optimal results indicated that nanoscale Pd/Al bimetallic particles were highly effective for 3-CP HDC. HDC efficiency was only about 30% in 50 min reaction with micron sizes of Pd/Al particles (100–400 mesh), whereas it increased to 99.7% within 30 min using Pd/Al NPs at 25 °C. Aqueous pH presented remarkable effect on HDC and pH 3–4 was the optimum range for HDC as pH varied from 2 to 11. Pd loadings and Pd/Al dosages were optimized for highly effective HDC as 1.16 wt.% and 2 g/L, respectively. In addition, higher HDC performance was obtained while reaction temperature arrived at 45 °C and 0.389 mM of 3-CP could be completely dechlorinated into phenol only within 10 min reaction.

1. Introduction

Chlorinated organic compounds (COCs) have been so widely used that they can be detected in almost all major water environments such as industrial wastewater and groundwater aquifer [1]. For example, chlorophenols (CPs) are often employed as intermediates to synthesize wood preservers, pesticides and biocides. Due to their physico-chemical property, CPs are highly toxic and biorefractory in the natural environment. So CPs are persistent and tend to accumulate in animal tissues. Once released into the environment, they accumulate in the surroundings and cause potential threat to human health and ecosystem safety for a long time. Therefore, it is necessarily to develop the efficient degradation methods to remove COCs from concentrated industrial effluents and contaminated groundwater.

Recently, chemical reduction methods were explored to remove various hazardous compounds such as COCs, which mainly employed zero-valent metals or catalytic hydrogenation to achieve the purification of polluted water [2–5]. Zero-valent iron (ZVI) is the most frequently reported material to dechlorinate COCs due to its reductive reactivity ($E^{\Theta}(Fe^{2+}/Fe) = -0.44$ V) and low cost. Many more active metals also possessed hydrodechlorination (HDC) capability for COCs such as sodium ($E^{\Theta}(Na^{+}/Na) = -2.714$ V), magnesium ($E^{\Theta}(Mg^{2+}/Mg) = -2.356$ V), and zinc ($E^{\Theta}(Zn^{2+}/Zn) = -0.7626$ V) [6–8]; but their applications were

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