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Combined zero valent iron and hydrogen peroxide conditioning significantly enhances the dewaterability of anaerobic digestate

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ABSTRACT

The importance of enhancing sludge dewaterability is increasing due to the considerable impact of excess sludge volume on disposal costs and on overall sludge management. This study presents an innovative approach to enhance dewaterability of anaerobic digestate (AD) harvested from a wastewater treatment plant. The combination of zero valent iron (ZVI, 0–4.0 g/g total solids (TS)) and hydrogen peroxide (HP, 0–90 mg/g TS) under pH 3.0 significantly enhanced the AD dewaterability. The largest enhancement of AD dewaterability was achieved at 18 mg HP/g TS and 2.0 g ZVI/g TS, with the capillary suction time reduced by up to 90%. Economic analysis suggested that the proposed HP and ZVI treatment has more economic benefits in comparison with the classical Fenton reaction process. The destruction of extracellular polymeric substances and cells as well as the decrease of particle size were supposed to contribute to the enhanced AD dewaterability by HP + ZVI conditioning.

Introduction

The most commonly used technology for wastewater treatment is the activated sludge process. However, a huge amount of excess sludge is generated in this process, which causes environmental problem (Foladori et al., 2010; Wang et al., 2013a, 2013b; Zhao et al., 2016). Nowadays, excess sludge management is one of the major challenges in wastewater treatment plants (WWTPs). In fact, treatment and disposal of excess sludge incurs large expenditures, which occupy up to 30%–60% of the total cost of a WWTP (Foladori et al., 2010; Wang et al., 2017).

The sludge treatment and disposal procedure usually encompasses thickening, stabilization, conditioning, dewatering and disposal (Foladori et al., 2010). Dewatering has been proven to be an efficient method to reduce sludge volume, cutting sludge transport and disposal cost. Since sludge has poor dewaterability, conditioning process is commonly used to enhance the sludge

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dewaterability prior to dewatering (Wang et al., 2013c). Sludge comprises free water and bound water. The free water combines with the sludge structure in a loose manner and hence is able to be removed much more easily during the dewatering process. On the contrary, the bound water is combined with the sludge *via* capillary forces or chemical bonds, which is much more difficult to be eliminated compared with the free water. Sludge conditioning could transform the bound water in sludge into the free water to enhance sludge dewaterability (Wang et al., 2014; Li et al., 2016; Liu et al., 2016a, 2016b; Zhang et al., 2016).

Until now, a number of approaches for sludge conditioning have been investigated. They include classical Fenton reaction treatment, alkaline or acid treatment, flocculation agent addition, freezing and heat treatment (Wang et al., 2014; Gong et al., 2015; Li et al., 2016; Liu et al., 2016a, 2016b; Zhang et al., 2016). Amongst them, Fenton reaction is an excellent approach because it is striking in improving sludge dewaterability (Liang et al., 2015; He et al., 2015). The classical Fenton reaction is composed of a series of reactions between Fe^{2+} and hydrogen peroxide (HP) under acid condition (Eqs. (2)–(8)) (Pignatello et al., 2006). In these reactions, huge amount of hydroxyl radical (HO.) is generated (Eq. (2)), which is a much stronger oxidant in comparison to HP (Neyens et al., 2003). When the sludge contacts with hydroxyl radicals, the structure of the sludge is effectively changed and microorganisms would be decomposed by oxidation. This will improve the sludge dewaterability by facilitating the sludge conditioning (Tony et al., 2008; Fontmorin and Sillanpaa, 2015).

$$Fe + 2H^+ \rightarrow Fe^{2+} + H_2 \quad (1)$$

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\cdot + OH^- \quad (2)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO\cdot + H^+ \quad (3)$$

$$HO\cdot + H_2O_2 \rightarrow HO_2\cdot + H_2O \quad (4)$$

$$HO\cdot + Fe^{2+} \rightarrow Fe^{3+} + OH^- \quad (5)$$

$$Fe^{3+} + HO_2\cdot \rightarrow Fe^{2+} + O_2H^+ \quad (6)$$

$$Fe^{2+} + HO_2\cdot + H^+ \rightarrow Fe^{3+} + H_2O_2 \quad (7)$$

$$HO_2\cdot + HO_2\cdot \rightarrow H_2O_2 + O_2 \quad (8)$$

Nevertheless, the Fe^{2+} is instable compared with zero valent iron (ZVI). ZVI was able to be oxidized to Fe^{2+} by acid as a result of its highly reductive characteristics (Eq. (1)). Therefore, ZVI was also able to get involved in the Fenton-like reactions at acidic condition (Eqs. (1)–(8)). Recently, the HP-ZVI system has been investigated to enhance the excess sludge dewaterability (Zhou et al., 2014). The capillary suction time (CST) of excess sludge, which is an indicator of sludge dewaterability, was decreased by around 50% using combined HP and ZVI conditioning (Zhou et al., 2014). However, excess sludge usually undergoes anaerobic digestion before dewatering in most WWTPs, to produce biogas and reduce excess sludge (Foladori et al., 2010; Bacenetti et al., 2013). After this, huge quantities of anaerobic digestate (AD) are still produced, which needs to be dewatered before its final disposal. Nevertheless, the dewatering performance of AD is of great difference compared with that of excess sludge because of the different characteristics between AD and excess sludge (Foladori et al., 2010; Zhang et al., 2015). Therefore, the efficient conditioning approach for enhancing AD dewaterability deserves to be explored.

This work aims to systematically evaluate the effectiveness of the HP-ZVI conditioning in the AD dewaterability. To the best of our knowledge, it is the first time that the HP-ZVI treatment is employed as an AD conditioning approach to improve AD dewaterability. The AD dewaterability indicator, that is CST, was measured before and after HP-ZVI conditioning. The concentrations of dissolved iron in AD were determined before ZVI-HP conditioning and after ZVI recovery. Soluble chemical oxygen demand (SCOD) concentration in AD was also measured after HP-ZVI conditioning. The economic potential of the HP-ZVI conditioning approach was determined.

1. Materials and methods

1.1. Sludge and chemicals

The AD was collected from the anaerobic sludge digester of a local biological nutrient removal WWTP. The main characteristics of AD are as following: iron 320 ± 5 mg/L, total solids (TS) 22.3 ± 0.4 g/L, volatile solids (VS) 19.1 ± 0.2 g/L, solid content 2.23% ± 0.04%, moisture content 97.77% ± 0.04%, chemical oxygen demand (COD) 22.1 ± 0.2 g/L, CST 115.6 ± 0.7 sec, and pH 7.72.

ZVI power (size: 80 meshes; Australian Metal Powder Supplies Pty Ltd.) was adopted in this work. The concentration of HP stock solution (Ajax Finechem Co.) was 33%. 30% sulfuric acid was utilized to adjust the AD pH.

1.2. Batch experiments

Two groups of batch experiments were carried out to investigate the effects of HP and ZVI levels on the dewaterability of AD, which is shown in Table 1. The first group was to evaluate the effect of ZVI concentrations (0–4.0 g/g TS) when HP concentration was kept at 90 mg/g TS. The second group aimed to evaluate the effect of HP concentrations (0–90 mg/g TS) while the concentration of ZVI was kept at 2.0 g/g TS. All the experiments were prepared and analyzed in duplicate in this work.

Table 1 – Experimental conditions used in the HP-ZVI enhanced AD dewaterability experiments.

Group	HP concentration (mg/g TS)	ZVI concentration (g/g TS)
I. Effect of ZVI concentration	90	0
	90	0.25
	90	0.5
	90	1.0
	90	2.0
	90	4.0
II. Effect of HP concentration	0	2.0
	18	2.0
	45	2.0
	90	2.0

ZVI: zero valent iron; HP: hydrogen peroxide; TS: total solids.

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