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Research article

Accelerating settling rates of biosolids lagoons through thermal hydrolysis

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ABSTRACT

Although the improved dewaterability and digestibility of primary biosolids subjected to thermal hydrolysis has been studied for decades, there are a surprisingly small number of studies exploring the use of this thermal treatment for digested biosolids that are typically left to settle in large settling lagoons. This is likely because of the high capital and operating costs associated with thermal hydrolysis, coupled with the limited applications and value of the resulting products. However, due to the anticipated increases in the amount of generated biosolids combined with issues surrounding potential environmental release and the limited availability of land for additional lagoons, other biosolids management strategies are being explored. Here, we show that thermal hydrolysis at 280 °C for 1 h resulted in 78.2 ± 0.8% settling after 2 h. Furthermore, addition of phosphoric acid to lower the pH of the hydrolysate to pH 3 resulted in increased settling rates, but the final volume of unsettled material after 2 h was statistically similar to the thermally hydrolyzed material without pH adjustment (75.7 ± 2.3%). Remarkably, when the pH of the digested biosolids was adjusted to 3 prior to thermal hydrolysis, a settling rate of 87.3 ± 1.1% was observed after just 15 min. Significantly, the dewaterability of thermally hydrolyzed biosolids was measured in our experiments through natural settling, without the use of external mechanics. Taken together, the data presented in this paper demonstrate that high temperature thermal hydrolysis is a promising method for accelerating the settling rates of digested biosolids and may represent a viable alternative to building and maintaining biosolids lagoons.

1. Introduction

Wastewater treatment facilities typically employ an aerobic or anaerobic digestion to breakdown the organic contents within sewage sludge and reduce odor emissions (Harris and McCabe, 2015; Novak et al., 2003). The digested biosolids can then be transferred to biosolids lagoons to facilitate cheap and low-maintenance dewatering through natural settling of solid materials. As the global population continues to increase towards an estimated 9–10 billion by 2050 (UNFPA, 2014), associated increases in the volume of wastewater produced will place pressure on treatment facilities, particularly those that operate in urban areas where space is limiting. In addition, digested biosolids contain heavy metals, organic molecules, and pathogens that can cause adverse effects if released or spilled into the environment in substantial quantities (Lu et al., 2012; Oun et al., 2014). Thus, there is an increasing interest to incorporate novel strategies for biosolids management and disposal that will help mitigate these concerns.

Many pretreatments strategies have been explored that can breakdown complex molecules in the primary sewage sludge into simpler molecules that are more easily metabolized by microorganisms during aerobic or anaerobic digestion. This includes alkaline (Li et al., 2009), ultrasonic (Nickel and Neis, 2007), mechanical (Nah et al., 2000), and thermal (Bougrier et al., 2008; Ross et al., 2016) pretreatments. While all of these pretreatment strategies have been shown to improve digestibility of sewage sludge, thermal hydrolysis has already been incorporated into over 30 wastewater treatment facilities around the world, including the Davyhulme plant in Manchester, England, which can process 121,000 tonnes of dry biosolids per year (Barber et al., 2012).

The operating temperature for thermal hydrolysis that is applied for pretreatment of sewage sludge varies, but is typically in the range of 165–180 °C (Barber, 2016; Neyens and Baeyens, 2003). The main reason for this is likely that Haug et al. (1978) demonstrated that thermally hydrolyzed sludge displayed toxic effects during subsequent digestion when the temperature used for hydrolysis was above 175 °C. Strong et al. (2010) reported that thermal hydrolysis at 165 °C for 2 h resulted in a 22% reduction in volatile suspended solids and a 13% increase in methane production through subsequent anaerobic digestion, relative to the untreated control sample. Furthermore, Pérez-Elvira et al. (2008) demonstrated that anaerobic digestion of thermally hydrolyzed sewage sludge (170 °C, 30 min) led to a 40% increase in biogas generation in only 60% of the time. An advanced thermal

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hydrolysis (ATH) has also been proposed for pretreatment of sewage sludge that combines thermal hydrolysis and oxidation with hydrogen peroxide (Abelleira et al., 2012). This strategy generally improved dewaterability and solubility of organic matter.

Although there are numerous studies exploring the use of thermal hydrolysis to improve digestibility and dewaterability of primary or activated sludge, few have examined the use of this thermal treatment on digested biosolids that are normally left to settle naturally in biosolids lagoons. Neyens et al. (2003) examined the use of thermal hydrolysis for treatment of digested biosolids (5–6% dry solids) and found that at temperatures ranging from 80 to 155 °C, there were significant improvements in dewaterability. To establish dewaterability, they used two different methods of filtration to assess the amount of dry solid remaining after their hot acid hydrolysis procedure. In this manner, they determined that the amount of solids in hot acid hydrolyzed thickened sludge was about 70% lower than the untreated control.

As an extension of the work of Neyens et al. (2003), we examined the thermal hydrolysis of digested biosolids at a temperature regime (280 °C) that was much higher than previous studies, which may promote even faster settling as a result of enhanced hydrolysis of organic material. Furthermore, we chose to assess natural settling rates in order to provide insight into how the biosolids hydrolyzed at high temperatures would settle without additional mechanical intervention that is currently employed, which may help improve the overall process economics. Our results provide proof-of-concept that thermal hydrolysis at 280 °C leads to significant improvements in the natural settling rates of digested biosolids. Thus, thermal hydrolysis of digested biosolids may be a promising treatment strategy for dewatering digested biosolids, particularly if it can be incorporated into high-temperature processes such as hydrothermal treatments or lipid hydrolysis (Asomaning et al., 2014; Espinosa-Gonzalez et al., 2014).

2. Materials and methods

2.1. Biosolids

Digested biosolids (~3.5% dry solids; pH ≈ 9) were obtained from a biosolids lagoon at a wastewater treatment facility in Edmonton, Alberta, Canada. Samples were stored at 4 °C prior to their use in experiments. Biosolids were subjected to thermal treatments as is, or after adjustment to pH 3 using phosphoric acid (Fisher Scientific, Fairlawn, NJ). For some experiments, pH adjustment (to pH 3) was performed after thermal treatments.

2.2. Thermal treatments

In the experiments described below, biosolids were treated in an autoclave (Beta Star Life Science Equipment, Honey Brook, PA) at 121 °C and a minimum of 15 psi for 1 h, or by thermal hydrolysis in a 5.5 L batch reactor (Model 4580, Parr Instrument Company, Moline, Il, USA) at 280 °C for 1 h at an initial pressure of 100 psi. After autoclaving, the pH of the system remained at ≈ 9. For thermal hydrolysis, the reaction start point was considered to be when the reaction reached the desired temperature. At this point, the pressure stabilized at 1200–1300 psi. Following thermal hydrolysis, the reactor was cooled using a refrigerated circulating bath (Model 89202-986) from VWR (Edmonton, Canada) set to −20 °C, which was shut off once the sample reached room temperature (~22 °C). At this point, the pH of the hydrolysate was in the range of 7–8.

2.3. Settling experiments

Following autoclaving or thermal hydrolysis (and pH adjustments when necessary), the sample was homogenized and then 1 L was transferred to a 1 L glass graduated cylinder. The settling of solid material in biosolids was observed over a 2-h period, with measurements of the volume of unsettled material being taken every minute for the first hour, and every 3 min for the following hour. All experiments were performed in triplicate.

2.4. Statistical analysis

Data were subjected to statistical analysis to establish whether or not any differences were statistically significant. Specifically, one or two way-ANOVA with mean comparison by Tukey test (GraphPad Prism 6 software, La Jolla, CA) was performed at a 95% confidence level.

3. Results and discussion

3.1. Biosolids

At wastewater treatment facilities around the world, storage lagoons contain digested biosolids that are concentrated through settling and evaporation over a period of 1–3 years (Farrell et al., 2004). The poor settling rate of biosolids, their rising volumes worldwide, the increasingly limited options for lagoon locations, and the safety concerns surrounding potential release of pathogens and metals into the environment, have collectively led to an increased interest in the development of biosolids management strategies.

The large settling lagoons found at many wastewater treatment facilities around the world contain digested material that is relatively viscous (Fig. 1A). Digested biosolids displayed poor settling after storage at room temperature for 4 months (Fig. 1B). It should be noted that for the experiment shown in Fig. 1 and others described below, autoclaving was used as a necessary precaution to eliminate all pathogens in biosolids thereby removing safety concerns surrounding the handling of biosolids in the laboratory. This mild thermal treatment is commonly employed in the laboratory and is not believed to have a substantial impact on the qualities and characteristic of the material.

3.2. Thermal hydrolysis of biosolids

To explore whether or not a thermal hydrolysis treatment at 280 °C would improve settling rates of biosolids, we monitored natural settling in 1 L graduated cylinders over a period of 2 h. A temperature of 280 °C was chosen for these experiments as this temperature was used in previous studies involving hydrothermal treatment of algal material or lipid hydrolysis, two processes into which biosolids could potentially be applied (Asomaning et al., 2014; Espinosa-Gonzalez et al., 2014). Compared to the autoclaved sample where no settling was observed during the 2-h period, the hydrolyzed sample displayed remarkably better settling, with 48.0 ± 6.2% and 78.2 ± 0.8% settling after 0.5 and 2 h, respectively (Table 1; Figs. 2 and 3). From these data, it is clear that thermal hydrolysis at 280 °C is an effective treatment to promote settling of digested biosolids. The impact of pH adjustment (Systems 2, 4, and 5) will be discussed in Section 3.3.

Feng et al. (2014) studied the rheological behavior of raw municipal sludge and observed that after thermal treatment, the mixture displayed properties more consistent with a Newtonian fluid than the untreated sample. They reasoned that after the 1-h thermal treatment at 170 °C, organic materials contained in the biosolids were denatured, causing them to precipitate. Furthermore, the enhanced degradability of thermally hydrolyzed sludge has been attributed to breakdown of large molecules (Neyens and Baeyens, 2003). It is likely that both of these factors contributed to the increased settling rates observed when digested biosolids were subjected to thermal hydrolysis.

It should be noted that while our studies focused on the settling rate of solid particles in biosolids with or without thermal hydrolysis, there are other indicators that could be used to further define optimal biosolid treatment conditions. For instance, when examining the efficacy of different materials in chemically assisted primary sedimentation