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Review

Wastewater sludge stabilization using pre-treatment methods

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ABSTRACT

The production and management of sludge in wastewater treatment plants is a significant environmental issue. Sludge is a complex material, treated primarily by biological stabilization methods, i.e., anaerobic and aerobic digestion. However, the presence of complex organics, microbial flocs, extracellular polymeric substances, and various inhibitory compounds, considerably hinders the efficiency of these processes. In order to overcome the effect of these rate-limiting factors, the literature proposes a number of pretreatment technologies, which can be used either as single pretreatment methods, or in combination. The present review describes both the anaerobic and aerobic digestion of sludge, and highlights the issues that limit the efficiency of the process. Emphasis is placed on the potential use of pretreatment methods, including: thermal; ultrasonic; microwave; Fenton; wet oxidation; photocatalysis and some others. These pretreatment approaches demonstrate varying potential for sludge disintegration and solubilization under different circumstances (e.g., operating conditions and sludge composition). However, the ultimate goal is to improve the subsequent biological treatment of sludge. In short durations, thermal, ultrasonic and microwave processes can efficiently solubilize the components of sludge and disrupt the cell walls of microbial flocs. However, issues related to high levels of energy requirements render these processes uneconomical for field application. The Fenton process can be used in combination with either bioleaching or ultrasound. Visible-Photocatalysis pretreatment for sludge can improve the anaerobic treatment of sludge and biogas production, with low energy demand.

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1. Introduction

Sludge production currently results in serious environmental issues in many developed, and developing, nations. Rapid industrialization, in conjunction with the extensive growth of urban zones, has also raised concerns in relation to sludge disposal (Chang et al., 2011b). A wastewater treatment plant is a facility in which a combination of various processes (e.g., physical, chemical and biological) are used to treat industrial wastewater and remove pollutants (Hreiz et al., 2015). The waste residue generated during these treatment processes is known as sludge (Svanstrom et al., 2004; Abelleira et al., 2012). Sludge is potentially hazardous, because it contains adsorbed residual organic pollutants from treated wastewater (Bolobajev et al., 2014). The treatment of the sludge is thus considered one of the most significant issues in wastewater treatment, due to higher energy demands and treatment costs (Huang et al., 2014; Yan et al., 2015). The sludge disposal processes comprise 60% of the total operating (Yan et al., 2015) and40% of total greenhouse gas emissions from wastewater treatment plants (Brown et al., 2010; Pilli et al., 2015). Furthermore, sewage sludge is rich in pathogenic microorganisms and toxic pollutants, with the potential to cause serious risks to health. In order to acquire 'class A' solids, and fulfill the demands of the Environmental Protection Agency, sludge must be stabilized and detoxified prior to its final disposal, or use for land application (Chang et al., 2011b).

A number of techniques have been developed for sludge treatment and minimization. These consist of physical, chemical and biological technologies, or a combination of the three (Xu et al., 2013). Previously, the disposal of excessive sludge has been undertaken through traditional methods, including incineration, land filling or ocean-dumping. However, an increase in related environmental concerns, and stringent environmental laws, has led to these disposal options being replaced by biological methods, i.e., composting, aerobic and anaerobic digestion. These biological processes are now widely accepted and are employed for the following: the removal of toxic compounds and pathogenic organisms; to reduce the total volume of sludge; and to transform sludge into stable biosolids (Semblante et al., 2015; Chang et al., 2011b).

Anaerobic and aerobic digestion systems for sludge are now commonly integrated into wastewater treatment plants, specifically to stabilize the waste activated sludge (Chang et al., 2011a). However, this leads to the efficiency of biological treatments being highly compromised, due to a number of factors, including: complex structural components in sludge; rate-limiting cell lysis (Chang et al., 2011b); the presence of extracellular polymeric substances (Xu et al., 2013) and various inhibitory compounds (i.e., ammonical nitrogen) (Bolzonella et al., 2005; Serrano et al., 2015). Furthermore, Ruffino et al. (2015) and Cho et al. (2014) have reported that that bacterial cells and cell walls/membrane form strong barriers to the penetration of hydrolytic enzymes to degrade the intracellular organic components in waste-activated sludge. The component cell walls are either very hard, or dissolve because they are composed of recalcitrant complex compounds, e.g., lignin, cellulose and hemicellulose (Abelleira-Pereira et al., 2015). In the case of anaerobic digestion, the efficiency of sludge degradation is generally affected by hydrolysis. This is the first stage in anaerobic digestion, which is known as the rate-limiting step, due to the complex structural components present in the sludge (Chang et al., 2011b).

In order to overcome the above-noted issues associated inhibiting the biological treatment of sludge, a number of interventions are required. The efficient stabilization of sludge can be improved through the application of pre-treatment to the sludge prior to biological digestion. Various methods of pretreatment are reported in the literature, e.g., photocatayisi; ozonation; thermal hydrolysis; ultrasound; enzymatic lysis; acidification; alkaline hydrolysis; freezing and thawing; and mechanical disintegration (Zhang et al., 2010: Chang et al., 2011b; Liu et al., 2013a). Moreover, more advanced research has been undertaken over recent years to apply these pre-treatments in a number of combinations, aimed at enhancing the process efficiency at a high level, e.g., alkaline-thermal (Na et al., 2011); thermal-H_2O_2 (Abelleira et al., 2012); microwave-alkaline (Chang et al., 2011a); and Fenton-ultrasonic (Ning et al., 2014). The primary aim of sludge disintegration using the pretreatment option is to rupture the microbial cell wall, leading to the release of both extracellular and intracellular organic compounds. This can accelerate