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Fenton mediated ultrasonic disintegration of sludge biomass: Biodegradability studies, energetic assessment, and its economic viability

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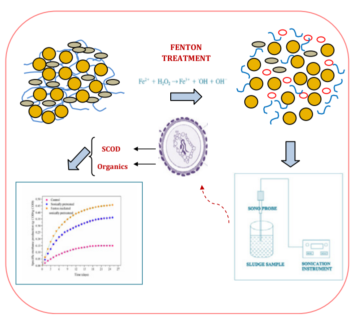
HIGHLIGHTS

- Fenton mediated sonic disintegration of sludge is a novel method.
- Removal of EPS considerably reduces the energy demand of ultrasonication.
- The proposed method shows a higher substrate conversion efficiency (0.7 g SCOD/g VSS).
- Highest solubilization of about 34.4% was achieved by this method.
- A positive net profit of about 44.93 USD/Ton of sludge was achieved by this approach.

GRAPHICAL ABSTRACT



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ABSTRACT

Mechanical disintegration of sludge through ultrasonication demands high energy and cost. Therefore, in the present study, a comprehensive investigation was performed to analyze the potential of a novel method, fenton mediated sonic disintegration (FSD). In FSD process, extracellular polymeric substance (EPS) of sludge was first removed via fenton treatment. It was subsequently disintegrated via ultrasonication. Energetic assessment and economic analysis were then performed using net energy and cost gain (spent) as key factor to evaluate the practical viability of the FSD process. FSD was found to be superior over sonic disintegration based on its higher sludge solubilization (34.4% vs. 23.2%) and methane production potential (0.3 g COD/g COD vs. 0.2 g COD/g COD). Both energy analysis and cost assessment of the present study revealed that FSD could reduce the energy demand of ultrasonication considerably with a positive net profit of about 44.93 USD/Ton of sludge.

1. Introduction

In India, most sewage treatment plants only treat 21.3% of the total sludge generated from class I and class II towns (Agarwal et al., 2015). The cost of sludge management accounts for up to 60% of the entire operational cost (Coma et al., 2013). Anaerobic digestion (AD) is the most widely used technique for sludge stabilization to recover energy in the form of biogas (Le et al., 2015; Kavitha et al., 2015a, 2015b). On the other hand, organics present in the sludge that are difficult to degrade needs hydrolysis process to improve their degradation (Riau et al., 2015; Kavitha et al., 2016a). Therefore, various pretreatment techniques have been developed to increase the slower hydrolysis process. Among them,

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sonication is a very powerful technique due to its efficient disintegration potential (Apul and Sanin, 2010). Although sonication has greater disintegration potential, energy efficiency of this method should be thoroughly investigated.

Sonication, a mechanical disintegration method for sludge, is an energy intensive process (Ning et al., 2014). This limits its application in industrial sectors. Ultrasonication with greater energy utilization (>5000 $kJ\ kg^{-1}\ TS^{-1}$) and more power density/intensity with prolonged treatment time have been found more suitable for sludge disintegration than sonication (Bao et al., 2015). In addition, waste activated sludge (WAS) contains extracellular polymeric substance (EPS) which serves as a network like mesh. It protects the sludge biomass from unfavorable conditions. By removing the EPS, the surface contact area for ultrasonic disintegration of sludge biomass disintegration can be enhanced. Many researchers have attempted to find viable alternatives for energy intensive pretreatment processes. However, there is only meager triumph. Therefore, it is essential to find a solution to this crisis by adopting apt experimentation to balance the result or outcome. The main aim of the present study was to minimize the energy demand of sonic process for sludge disintegration and energy generation. In viewing of the above facts, the present study planned to reduce the high energy requirement of ultrasonic pretreatment through EPS release by fenton treatment in a cost effective manner. Fenton treatment is the most extensively used process for sludge disintegration (Pilli et al., 2016). Fenton reagent generates potent oxidizing radicals that can effectively cleave the cell walls of sludge biomass through oxidation–reduction reaction (Zhen et al., 2014). Even though, Fenton process is considered to be efficient in sludge disintegration, there are some limitations. For instance, in the present study, the dosage of fenton used for deflocculation was found to be lower than that used by other researchers (Hansson et al., 2012) for sludge disintegration. Using higher dosage of Fenton reagent leads to the formation of large amounts of ferrous iron sludge and formation of high concentration of anions in the sludge (Hansson et al., 2012; Babuponnusami and Muthukumar, 2014), a constraint that should be taken into account. In addition, it has been that combining ultrasonication with fenton resulted in higher disintegration of sludge (Bao et al., 2015). However, the effect of fenton treatment on EPS release prior to ultrasonic disintegration of sludge biomass has been barely reported in the literature. Therefore in order to overcome the limitations of fenton and to minimize the energy consumption of ultrasonication, in the present study, it was decided to use lower dosage of fenton for deflocculation followed by ultrasonication for sludge disintegration.

In this study, an inclusive energetic investigation was performed on the basis of energy generation and input energy as well as cost to comprehend the economic viability of the proposed method of sludge disintegration. Thus, the main objectives of the present study were: 1) to present new insights to sludge biomass disintegration through fenton mediated ultrasonic disintegration; 2) to reduce the high energy demand of ultrasonic disintegration of sludge through EPS release; 3) to investigate the efficiency of fenton mediated sludge disintegration on solubilization and methane generation; 4) to investigate substrate conversion efficiency of this proposed method; and 5) to analyze the economic feasibility of the anticipated fenton mediated sonic disintegration through detailed energy and cost analysis.

2. Materials and methods

2.1. Sludge collection

Municipal waste activated sludge (WAS) was sampled from sewage treatment plant at Kerala (India). The sludge was then stored at 4 °C for subsequent experimental investigation. The characteristics of the sludge were: total chemical oxygen demand (TCOD), 9000 mg/L; soluble chemical oxygen demand (SCOD), 400 mg/L; pH, 6.91; total solids (TS), 8000 mg/L, suspended solids (SS), 5000 mg/L; volatile solids, 4000 mg/L.

2.2. EPS release by Fenton treatment

For fenton experiment, Fe^{2+} (0.05 g/g SS to 0.25 g/g SS) and H_2O_2 (0.2 –1 g/g SS) mixed in appropriate ratio (1:4) were added to 100 mL of sludge and stirred at 100 rpm to provide uniform mixing. Samples were collected at regular intervals and analyzed. The entire experiment was implemented at room temperature with SS content of approximately 5000 mg/L and pH at 5.

2.3. Ultrasonic disintegration

Sonic disintegration was performed using a Sonopuls ultrasonic homogenizer (Bandelin Sonopuls HD 2200, Berlin, Germany) equipped with a VS 70 T probe with an operating frequency of 20 kHz and a supplied power of 200 W at room temperature. For the disintegration process, 500 mL of fenton treated sludge was taken into a beaker and a probe was sunken into the sludge to a depth of 2 cm above the base of the beaker. Samples were collected at regular time intervals and analyzed. Similarly, another beaker with SD sludge was analyzed to study the efficiency of EPS release prior to sonic pretreatment.

2.4. Biodegradability experiment

Biodegradability experiment was executed using method described in a previous study (Kavitha et al., 2014). Briefly, bovine rumen fluid was used as inoculum. Untreated (control), SD, and FSD sludges were selected as substrates. Methane content in the biogas was analyzed using a Thermo gas chromatograph (GC) equipped with a thermal conductivity detector and a porapack Q column (2 cm in length, 3.25 mm in diameter, 80/100 mesh). In kinetic modelling of methane generation, two non-linear regression models (exponential rise to maximum) were employed to study methane generation. In the control (untreated sludge), methane generation was modelled through first order kinetics with one-phase exponential association model. For disintegrated sludges, methane generation was modelled through first order kinetics with two-phase exponential association model as shown below.

For the control, the one-phase exponential association model was:

$$CH_4(t) = CH_4(max).(1 - exp^{(-kt)}) \tag{1}$$

Where $CH_4(t)$ was methane yield at degradation time of t days (g COD/g COD added), $CH_4(max)$ was maximal methane production potential of the substrate, k was the degradation rate constant (day^{-1}), and t was the time (days).

For disintegrated sludges, the two-phase exponential association model (Risco et al., 2011) was:

$$CH_4(t) = CH_4(max1).(1 - exp^{(-k1t)}) + CH_4(max2).(1 - exp^{(-k2t)}) \tag{2}$$

Where CH_4 (t) was methane yield at degradation time of t days (g COD/g COD added), CH_4 (max1) was maximal methane production potential of the substrate related to rapidly biodegradable organics, CH_4 (max2) was maximal methane production potential of the substrate related to slowly biodegradable organics, k_h was the degradation rate constant (day^{-1}), and t was the time (days).