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Impact of thermo-chemo-sonic pretreatment in solubilizing waste activated sludge for biogas production: Energetic analysis and economic assessment

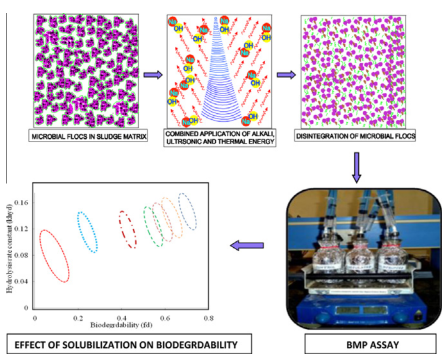
S. Kavitha [a,1], J. Rajesh Banu [a,*], G. Subitha [a,1], U. Ushani [a], Ick Tae Yeom [b]

[a] Department of Civil Engineering, Regional Centre of Anna University, Tirunelveli, India
[b] Graduate School of Water Resource, Sungkyunkwan University, Suwon, South Korea

HIGHLIGHTS

- 20–35% solubilization can be achieved at specific energy of 5500 kJ/kg TS.
- First study to investigate the effect of solubilization on pretreatment cost.
- Cost spent to attain 30–35% solubilization was very lower than to attain 40–50%.
- No major variation in biodegradability for samples with 35–50% solubilization.
- Based on economic analysis, achievement of 30–35% solubilization was beneficial.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this study was to determine the impact of solubilization during thermo-chemo-sonic pretreatment of waste activated sludge (WAS) on anaerobic biodegradability and cost for biogas production. The results revealed that it was possible to achieve 40–50% of solubilization of WAS when ultrasonic energy input was doubled (11,520–27,000 kJ/kg TS). The cost to achieve 30–35% of solubilization of WAS was calculated to be 0.22–0.24 USD/L, which was relatively lower than the cost of 0.53–0.8 USD/L when 40–50% of solubilisation of WAS was achieved. There was no significant difference in biodegradability (0.60–0.64 g COD/g COD) for samples with solubilization efficiency of 35–50%. Comparing energetic balance and economic assessment of samples with different solubilization percentages, the results showed that samples with 30–35% of solubilization had lower net cost (7.98–2.33 USD/Ton of sludge) and negative energy balance compared to samples with other percentages of solubilization.

1. Introduction

Processing (treatment and disposal) of excess sludge generated from biological treatment methods in wastewater treatment plants (WWTPs) entails high expenditure. It accounts for 50% of total operational cost (Yu et al., 2013). Lately, societal and ecological distresses demand extra rigorous policies concerning sludge treatment and clearance that will substantially increase costs. The cost is anticipated to increase more in the future (Chiavola et al., 2013). Therefore, it is crucial to decrease the generation of sludge for cost effective WWTPs. Anaerobic digestion (AD) is the most extensively employed biological process. It generates energy rich methane and minimizes excessive sludge (Cegri et al., 2012;

* Corresponding author at: Department of Civil Engineering, Regional Centre of Anna University, Tirunelveli 627007, India.

E-mail address: rajeshces@gmail.com (J. Rajesh Banu).

[1] These two authors have contributed equally in this work.

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Appels et al., 2013; Montanes et al., 2015; Kavitha et al., 2014a, 2015a). However, the initial phase of AD is a rate restriction step (Chen et al., 2013) that limits its degradation competence. Therefore, pretreatment before AD might be used to improve the efficiency of AD (Saha et al., 2011; Sharmila et al., 2015; Kavitha et al., 2016a). Various disintegration processes (chemical, mechanical, biological, chemo mechanical, and thermochemical) either alone or in combination have been employed for pretreatments (Gonzalez et al., 2013). Based on previous literatures (Kavitha et al., 2015b), thermo-chemo-sonic disintegration is the most powerful method to disintegrate sludge biomass. Its main advantage is its synergistic pretreatment effect with low energy consumption (Kavitha et al., 2015b).

Generally, 'solubilization' is a marker indicating pretreatment competence of sludges (Kim et al., 2013). However, increased solubilization does not always result in enhanced biodegradability although greater disintegration effect can be achieved (Kim et al., 2013). The aim of the present study was to minimize energy input and cost needed for disintegration to achieve desirable solubilization and energy generation. Presently, several researchers have used various combined disintegration processes to minimize ultrasonic energy required for biogas generation. The main disadvantages related to these processes are elevated energy input and cost since the aim is to achieve higher solubilization. Most of these literatures have reported that just escalating solubilization does not enhance consequent energy generation from the sludge (Uma et al., 2012; Park et al., 2012). In addition, higher solubilization requires high energy consumption and cost. Therefore, to investigate the feasibility of combination pretreatment, cost and energy balance need to be considered. In the present study, the effect of specific energy consumption to achieve increased solubilization percentage during combinative pretreatment was investigated. The influence of different sludge solubilisation percentages on pretreatment cost was evaluated. In addition, detailed economic assessment and energetic analysis for different solubilization percentages (20–50%) were performed in this study to assess the economic viability of pretreatment. The objectives of the present study were: 1) to determine specific energy consumption needed to achieve different solubilization percentages, 2) to evaluate the impact of solubilization on cost during thermos-chemo-sonic disintegration, 3) to explore the effect of different solubilization percentages on fermentation and biodegradability, and 4) to perform detailed energetic analysis and cost assessment for different solubilization percentages.

2. Materials and methods

2.1. Collection and characterization of waste activated sludge

Waste activated sludge (WAS) samples used in this study were collected from secondary settling tank of a municipal waste water treatment plant in Trivandrum, India. Their pH values were 6.8 ± 0.2. Total suspended solids (TSS) were 12,000 mg/L. Total chemical oxygen demand (COD) and soluble chemical oxygen demand (SCOD) were 10,000 mg/L and 200 mg/L, respectively.

2.2. Thermo-chemo-sonic disintegration

Thermo-chemo-sonic pretreatment was carried out under the following conditions: 70 °C, 80 °C, 90 °C, or 100 °C at pH of 9, 10, or 11 using alkali (1 N NaOH) exposed to a 20 kHz ultrasonic homogenizer (Sonoplus HD2200, Bandelin, Berlin, Germany). Experiment was performed in 1 L glass beaker containing alkalinized sample (500 mL) in a thermal water bath followed by ultrasonication. These samples were collected and analyzed at equal time period (0 min to 3 h) to determine their proficiency in solubilization, suspended solids reduction, and economic feasibility.

2.3. Fermentation experiment

Fermentation experiment was carried out in 300 mL bottles. Substrate and inoculum were employed in a ratio of 9:1. The inoculum used in this experiment was anaerobically digested sludge. Pretreated samples resulting in soluble organic release at lower cost with 20–50% of COD solubilization were selected as substrates. The experiment was carried out using published methods (Kavitha et al., 2014b).

2.4. Biodegradability studies

Anaerobic biodegradability assay was performed using published method of Kavitha et al. (2014b). The inoculum used in this study was bovine rumen fluid. Pretreated samples resulting in soluble organic release at lower cost with 20–50% of COD solubilization were selected as substrates. Methane content in the biogas was analyzed using a Thermo gas chromatograph (GC) equipped with a thermal conductivity detector and porapack Q column (2 cm in length, 3.25 mm in diameter, 80/100 mesh). The methane content was analyzed using nitrogen as carrier gas with thermal conductivity detector. The following kinetic model was used to determine biodegradability and methane generation (Cegri et al., 2012)

$$M(t) = M_{(fd)}(1 - e^{-kt}) \tag{1}$$

where M(t) was methane yield at digestion time of t days (g COD/g COD added), $M(f_d)$ was methane production potential of the substrate (conversion of biodegradable substrate fraction to methane) (g COD/g COD added), k_h was hydrolysis rate constant (day^{-1}), and t was time (days). The model was executed in Matlab (2012a Version). Parameters with 95% confidence interval were estimated using calculation methods executed by Batstone et al. (2009).

2.5. Energy consideration and economic analysis

In this study, theoretical computation of energy balance was performed based on experimental data. Heat and electricity consumption during the combined thermos-chemo-sonic disintegration process and the anaerobic degradation process were taken into consideration. For thermos-chemo-sonic disintegration, input heat energy needed for thermal treatment was assumed to be the heat required to raise the temperature of WAS under all pretreatment conditions. Definite energy needed to increase the temperature of WAS was computed using the following equation (Passos and Ferrer, 2014):

$$Energy_{(input,heat)}Q = \rho * V * C * (t_f - t_i) \tag{2}$$

where Q was the heat energy needed to heat the sludge (kJ), ρ was the density of sludge (kg/m^3), V was the volume of sludge treated (m^3), C was the specific heat of sludge (kJ/kg °C) (4.2 kJ/kg C), t_i and t_f were the initial and final temperatures (°C) of the sludge, respectively. Electrical energy (EE) required for ultrasonic pretreatment was calculated based on ultrasonic power input and time using the following equation (Kavitha et al., 2016b):

$$Energy_{(input,electricity\ for\ sonication)}EE = P * t \tag{3}$$

where EE was electrical energy (KWs), P was ultrasonic power (KW/m^3), and t was sonication time (s). The input electricity for anaerobic degradation was computed as energy needed for sludge