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Combined thermo-chemo-sonic disintegration of waste activated sludge for biogas production

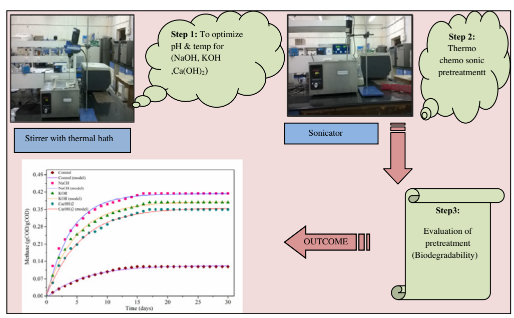
S. Kavitha [a], R. Yukesh Kannah [a], Ick Tae Yeom [b], Khac-Uan Do [c], J. Rajesh Banu [a,*]

[a] Department of Civil Engineering, Regional Centre of Anna University, Tirunelveli, India
[b] Department of Civil and Environmental Engineering, Sungkyunkwan University, South Korea
[c] School of Environmental Science and Technology, Hanoi University of Science and Technology, Viet Nam

HIGHLIGHTS

- Thermo chemo sonic pretreatment enhances disintegration synergistically.
- This novel method aid solubilization at lesser specific energy of 5290.5 kJ/kg TS.
- Kinetic analysis portrays hasty disintegration rate by this synergistic process.
- $Ca(OH)_2$ is also considered to be effective agent based on dewatering properties.
- This process offers profit of about 42.6 USD/per ton of sludge in cost analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present study, there was an investigation about the impact of a new combined thermo-chemo-sonic disintegration of waste activated sludge (WAS) on biodegradability. The outcome of sludge disintegration reveals that maximum Suspended Solids (SS) reduction and Chemical Oxygen Demand (COD) solubilization effectuated at a specific energy input of 5290.5 kJ/kg TS, and was found to be 20%, 16.4%, 15% and 27%, 22%, and 20%, respectively for the three alkalis (NaOH, KOH, and $Ca(OH)_2$). The conversion coefficient of the Volatile Suspended Solids (VSS) to product Soluble COD (SCOD), calculated by nonlinear regression modeling, was found to be 0.5530 g SCOD/g VSS, 0.4587 g SCOD/g VSS, and 0.4195 g SCOD/g VSS for NaOH, KOH, and $Ca(OH)_2$, respectively. In the biodegradability studies, the parameter evaluation provides an estimate of parameter uncertainty and correlation, and elucidates that there is no significant difference in biodegradability (0.413 g COD/g COD, 0.367 g COD/g COD, and 0.342 g COD/g COD) for three alkalis (NaOH, KOH, and $Ca(OH)_2$).

1. Introduction

The excess sludge produced from wastewater treatment plants in India is an undisputed drawback. In those eventualities, the management of sludge has now become a burning issue because of its excess volume and undesired characteristics. Anaerobic digestion (AD) is a burgeoning technology and has lately captivated much attention owing to the need for sustainable energy production (Appels et al., 2013; Kavitha et al., 2015a; Brown et al., 2014). It should be noted that the initial phase of AD, hydrolysis, is considered to be the rate restricting phase (Chen et al., 2013). Hence, sludge disintegration has to be done prior to the AD in order to increase the hydrolysis rate.

* Corresponding author at: Department of Civil Engineering, Regional Centre of Anna University, Tirunelveli 627007, India. Tel.: +91 9444215544.
E-mail address: rajeshces@gmail.com (J.R. Banu).

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To facilitate the sludge liquefaction, various sole and combined disintegration methods (e.g., thermal, thermochemical, ultrasonic, microwave, and biological disintegrations) have been applied to pretreat Waste activated sludge (WAS), as reported in the literature (Uma et al., 2012a; Gayathri et al., 2015; Ebenezer et al., 2015; Kavitha et al., 2013, 2015b). Several researchers have reported affirmative synergistic upshots of the combined pretreatment methods on subsequent anaerobic digestibility (Tyagi and Lo, 2012; Zhen et al., 2014; Sahinkaya and Sevimli, 2013). Among the combinative pretreatment methods, thermochemical was widely applied to disintegrate the sludge (Tyagi and Lo, 2012; Sahinkaya and Sevimli, 2013). The minimum effective sludge disintegration (solubilization) index for anaerobic digestion was reported to be 25% (Gayathri et al., 2015; Zhang et al., 2008). However, achieving solubilization in excess of 18% by thermochemical pretreatment was not cost effective (Jang and Ahn, 2013) but results in the loss of organics (Chiang et al., 2012). Sonication, a cavitational process, was used by legions of researchers to achieve high degree of solubilization (40–50%). However, the practical applicability of sonic pretreatment was constrained because of its high energy cost (Sahinkaya and Sevimli, 2013; Zhang et al., 2008). Thus, in order to overcome the high energy requirement the sonic pretreatment can be combined with other pretreatments to achieve the desirable solubilization with less energy consumption. Based on the above background analysis, the present study intends to develop a new low energy consuming combinative pretreatment method in a cost effective manner by combining thermochemical and sonic pretreatment. So far the combined thermo-chemo-sonic disintegration and energy balance of the study involving cost assessment has hardly been probed in the literature. The core objectives of the present study are to:

(i) optimize the operational parameters for the thermo-chemical and thermo-chemo-sonic disintegration studies; (ii) explore the thermo dynamic modeling for thermo-chemical disintegration; (iii) assess the kinetic study and substrate conversion efficiency of the combined method; (iv) investigate the synergistic effects of this new combined technique; and (v) evaluate the biodegradability potential of this combined technique through nonlinear regression modeling.

2. Methods

2.1. Source and characterization of waste activated sludge

The samples were collected from a secondary clarifier of the Municipal waste water treatment plant at Karokonam, India. The initial characteristics of the samples were specified as follows: pH, 8.25; Total Solids (TS), 11500 ± 400 mg/L; Suspended Solids (SS), 7000 ± 300 mg/L; Volatile Suspended Solids (VSS), 5600 ± 200 mg/L; Total Dissolved Solids (TDS), 4800 ± 200 mg/L; Total Chemical Oxygen Demand (TCOD), 10,500 ± 300 mg/L; and Soluble Chemical Oxygen Demand (SCOD), 200 ± 50 mg/L.

2.2. Optimization of thermo-chemical disintegration

The thermo-chemical disintegration of waste activated sludge was carried out with three different alkalis, including NaOH (Sodium hydroxide), KOH (Potassium hydroxide), and $Ca(OH)_2$ (Calcium hydroxide). Later 500 mL of samples were poured into a 1 L glass beaker and the pH of the samples was adjusted to a desired level using 1 N alkalis. A beaker containing the samples were continuously stirred using a slow-speed mechanical stirrer (IKA, RW-20). To reach the desired temperature, a beaker was submerged in a thermostatic water bath (50–90 °C). The samples were collected periodically and analyzed. Based on these above factors, the experimental conditions were optimized for thermo-chemical disintegration.

2.3. Optimization of thermo-chemo-sonic disintegration

The optimized condition of thermo-chemical disintegration was subjected to further combinations with sonic treatment. The combined disintegration (thermo-chemo-sonic disintegration) was carried out by placing a 1 L beaker containing alkalinated 500 mL samples in a thermostatic water bath, and using a 20 kHz frequency ultrasonicator (Make: Bandelin, Model: Sonoplus HD2200). The ultrasonic probe was submerged in the sludge to a depth of 2 cm, which led to the maximum disintegration yield (Sahinkaya et al., 2012; Sowmya et al., 2015). The samples were collected and analyzed at different time intervals in order to study the combined effect of the disintegration process.

2.4. Biodegradability studies

An anaerobic biodegradability assay was done, as per the procedure described by Uma et al. (2012a). The inoculum (bovine rumen fluid) and substrates control (raw-untreated), thermo-chemo-sonically disintegrated for NaOH, KOH, and $Ca(OH)_2$, were taken in the ratio 3:1. The following first order kinetic model was employed to study the methane production (Zhen et al., 2014).

$$Y(t) = Y(f_d) \times (1 - e^{-k_{hyd} \times t}) \quad (1)$$

where $Y(t)$ is the cumulative methane yield at digestion time, t days (g COD/g COD added), $Y(f_d)$ is the methane potential of the substrate (fraction of the degradable substrate that can be converted to methane) (g COD/g COD added), and k_{hyd} is the first order disintegration rate constant (day^{-1}), t is the time (days). The model was executed in a Matlab 2012a Version. The parameter estimation and uncertainty with 95% confidence limit was calculated, based on the work of Batstone et al. (2009). The kinetic parameters are employed to point out the degradation extent of a complex substrate are (f_d), the fraction of the substrate that may be converted to methane, and the apparent first order hydrolysis rate coefficient (k_{hyd}), used to estimate the rate of which conversion occurs.

2.5. Analytical methods

The parameters of sludge were analyzed as per the Standard methods, such as TS, SS, VS, TDS, TCOD, SCOD, Sludge Volume Index (SVI), Time to Filter (TF) Capillary Suction Time (CST), and Supernatant Phosphorus (TP) (APHA, 2005).

2.6. Energy calculations

2.6.1. Thermal energy

Thermal energy is another form of heat energy, which is applied externally to heat the wet sludge to accelerate the pretreatment reaction rate. The definite energy transferred to the sludge was computed using the following Eq. (2).

$$\Delta H_{Consumed} = S \times m \times \Delta T \quad (2)$$

where $\Delta H_{Consumed}$ is the heat energy applied to heat the sludge (kJ)-energy consumed for heating the wet sludge, S is the specific heat of sludge (kJ), m is the mass of sludge (kg), and ΔT is the temperature difference between the initial and final temperatures (K).

2.6.2. Ultrasonication energy

For economic evaluation, the operating cost of ultrasound power can be calculated based on specific energy input. The ultrasonication energy is measured by the evaluation of the biomass