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Enhancement of aerobic biodegradability potential of municipal waste activated sludge by ultrasonic aided bacterial disintegration

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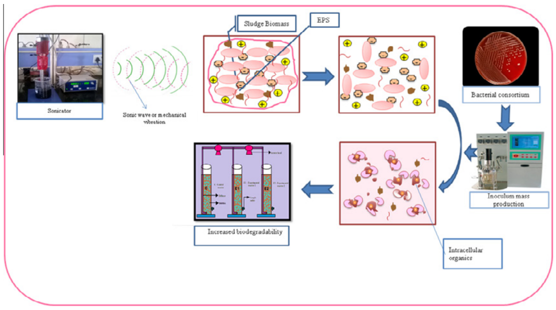
HIGHLIGHTS

- Sonic mediated biological disintegration is an efficient method.
- Floc disruption was effective at 2.45 kJ/kg TS of ultrasonic specific energy.
- 23% Solubilization was achieved by this sonic mediated biological disintegration.
- Kinetic analysis explains that rate was enhanced in deflocculated sludge.
- Biodegradation was higher in floc disrupted sludge with decay constant 0.19 d^{-1}.

GRAPHICAL ABSTRACT



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ABSTRACT

An investigation was performed to study the influence of ultrasonic aided bacterial disintegration on the aerobic degradability of sludge. In first phase of the study, effective floc disruption was achieved at an ultrasonic specific energy input of 2.45 kJ/kg TS with 44.5 mg/L of Extracellular Polymeric Substance (EPS) release including 0.035 U/mL and 0.025 U/mL protease and amylase activity respectively. In second phase, experimental outcomes revealed bacterial disintegration of floc disrupted-sludge showing a maximum solubilization of about 23% and was observed to be superior to bacterially disintegrated (11%) and control (6%), respectively. The result of aerobic biodegradability of ultrasonic aided bacterially pretreated sludge showed volatile solids (VS) degradation of about 40.2%. The kinetic study of aerobic biodegradability through non linear regression modelling reveals that floc disrupted sludge showed better biodegradability with decay constant of about 0.19 d^{-1} relatively higher than the control (0.14 d^{-1}) and bacterially disintegrated (0.17 d^{-1}) sludges.

1. Introduction

The mammoth quantity of waste activated sludge (WAS) generated annually in municipal wastewater treatment plants (MWWTP) pose a major challenge for sludge handling and disposal. Processing of sludge to meet biosolids regulatory specifications is one of the difficult problems in the effective operation of a MWWTP (Jang and Ahn, 2013). Numerous sludge treatment processes (incineration, landfill, aerobic and anaerobic digestion) have loomed out to reduce sludge generation and also beneficial reuse of biosolids. Aerobic and anaerobic digestions are generally employed in sludge treatment with aerobic digestion being primarily used in

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small waste water treatment plants (Garcia et al., 2014; Fall et al., 2014) due to its low capital cost (Lakshmi et al., 2014). Although aerobic degradation of organic matter is more rapid when compared to anaerobic digestion (Kavitha et al., 2013; Merrylin et al., 2014), the hydrolysis of large organic molecules in sludge is the rate-limiting step to achieve rapid degradation (Yu et al., 2008). To improve the rate of hydrolysis, sludge pretreatment for floc disintegration is essential to improve aerobic degradation rates. Sludge disintegration can be achieved by mechanical (Yu et al., 2008), chemo mechanical (Yiying et al., 2009), and biological treatment (Kavitha et al., 2013) processes. Among them, biological disintegration has several advantages including higher yield, minimal energy input, and mild working state (Yu et al., 2013; Merrylin et al., 2014).

Extracellular Polymeric Substances (EPS) are triple faceted, gel-like hydrated compounds secreted by microorganisms that provide structural integrity to aggregate microbes and sludge biomass as flocs (Hii et al., 2014). Soluble EPS is an important factor that reduces the accessibility of substrates (WAS) to bacterial disintegration and by releasing EPS, the surface area of contact for subsequent bacterial action can be enhanced. In addition, soluble EPS imparts a major contribution to bioflocculation (Merrylin et al., 2014). EPS removal can be performed by mechanical and chemical methods. The chemical methods include usage of chemicals such as ethylene diamine tetra acetic acid (EDTA) (Kavitha et al., 2013), sodium dodecyl sulphate (SDS) (Poornima et al., 2014), citric acid (Gayathri et al., 2015), Formaldehyde–NaOH (Merrylin et al., 2014). The mechanical methods include dispersion or ultrasonication (Sowmya et al., 2015). The present investigation aims to release EPS by ultrasonic treatment and improve the effectiveness of bacterial pretreatment so as to increase the surface area for subsequent bacterial disintegration.

Ultrasonication is an emerging and promising mechanical disruption technique for sludge pretreatment due to several inherent advantages that include efficient sludge disintegration (>95%), improvement in biodegradability, improved biosolids quality, no chemical addition and lower retention time (Pilli et al., 2011). Ultrasonication is a budding method for destabilising sludge flocs and cleaving sludge biomass, as it brings about organic matter disintegration and decrease in particle size. Sonic disintegration causes the formation of cavitation bubbles in the liquid phase (Kavitha et al., 2015a; Sowmya et al., 2015). As acoustic cavitation continues, high hydrodynamic shear forces are formed which reacts with organics; this is mostly accountable for the pretreatment of organics (Zhang et al., 2007). The objective of the present work is to (1) optimise the specific energy for sonication in floc disruption (2) study the efficiency of sonic mediated bacterial disintegration (3) investigate the kinetics of bacterial disintegration (4) assess the effect of aerobic biodegradability on WAS and (5) estimate the parameters for VS degradation profile through non linear regression modelling (exponential decay analysis).

2. Methods

To achieve the objectives of the study, the experiments were conducted in three steps. Firstly, the sludge was deflocculated (floc disrupted) using an ultrasonicator. Secondly, it was disintegrated through bacterial pretreatment. Finally, the efficiency of the study was assessed in an aerobic digester.

2.1. Collection of sludge

The municipal waste activated sludge (WAS) was collected from a secondary clarifier of a MWWTP located in Karokonam, Kerala. The primary characteristics of WAS are tabulated in Table 1.

2.2. Optimization of ultrasonic specific energy for floc disruption

EPS release was achieved by using an ultrasonic homogenizer (Bandelin, Model: HD 2200). The sonication was carried out at room temperature without any temperature regulation using 500 mL of sludge and the pH was maintained at 6.9 with SS content of 7000 mg/L. The equipment was fitted with a VS 70 T probe with a fixed operating frequency of 20 kHz, which is considered to be the most effective ultrasonic frequency for sludge pretreatment (Pilli et al., 2011) and a power supply of 200 W to get active floc disruption. Highest yield was observed when the probe was immersed to a depth of 2 cm into the sludge (Sahinkaya et al., 2012). To evaluate the floc disruption performance, specific energy (SE) is the primary parameter (Sahinkaya et al., 2012) and is determined by Eq. (1), where (P) is the ultrasonic power, (t) sonication time, (V) sample volume and (TS) the initial total solids concentration.

$$\mathrm{SE}\ (\mathrm{kJ/kg\ TS}) = (P * t)/(V * \mathrm{TS}) \tag{1}$$

2.3. Biomass disintegration by bacterial pretreatment

In sonic mediated biological disintegration, three conical flasks (F1, F2 and F3) of working volume 250 mL were taken. In F1, 100 mL of untreated sludge was taken and maintained as control. In the F2, 100 mL of sludge was added with 2 g drycell weight/L of bacteria to evaluate the effectiveness of bacterial disintegration. The bacterial consortium used in this work was isolated and recognised in the previous study (Lakshmi et al., 2014) and named as *Bacillus jerish 03* (Accession number: KC597266) and *Bacillus jerish 04* (Accession number: KC597267). They were gram positive rods and the colonies were white in colour, fibrous in shape with an uneven margin, increased elevation, crumpled surface and were translucent in appearance. In F3, 100 mL of ultrasonically treated sludge was inoculated with 2 g drycell weight/L of bacteria to evaluate the effectiveness of floc disrupted bacterial disintegration. The three conical flasks were placed on an orbital shaker set to 150 rpm and incubated at 40 °C with pH maintained at 6.5. Samples were collected at regular time intervals and analysed for protein, carbohydrates, EPS, DNA extracellular enzymes periodically to compare the effectiveness of floc disruption.

2.4. Analysis of growth change of inoculated bacteria

Growth dynamics analysis of inoculated bacteria was done as per the procedure described by Kavitha et al. (2015b).

2.5. Aerobic digestion

Aerobic digestion was conducted in three identical poly vinyl chloride (PVC) tubular reactors with a working volume of 7 L. The three reactors were designated as C, E1 and E2. Diffused aerators fitted with flow regulators were used to aerate the sludge

Table 1
Primary characteristics of sludge.

S. No	Parameter	Quantity
1	pH	6.9
2	Total solids	12000 ± 300 (mg/L)
3	Suspended solids	7000 ± 120 (mg/L)
6	Volatile suspended solids	5600 ± 100 (mg/L)
7	Total chemical oxygen demand	10000 ± 200 (mg/L)
8	Soluble chemical oxygen demand	100 ± 5 (mg/L)
9	Total protein	6047 ± 100 (mg/L)
10	Total carbohydrate	760 ± 60 (mg/L)
11	Soluble protein	5 ± 0.2 (mg/L)
12	Soluble carbohydrate	3 ± 0.2 (mg/L)