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Effects of titanium dioxide mediated dairy waste activated sludge deflocculation on the efficiency of bacterial disintegration and cost of sludge management

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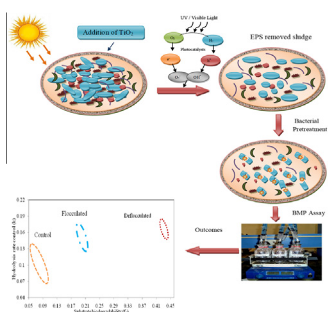
HIGHLIGHTS

- TiO_2 mediated solar photon process disrupt flocs prior to pretreatment.
- 22.9% of solubilization was achieved in bacterial disintegration.
- Kinetic analysis explains the efficiency of sludge disintegration rate.
- Bacterial pretreatment increases biodegradability to 0.43 (gCOD/gVSS).
- Deflocculated sample showed higher net profit than flocculated sample.

GRAPHICAL ABSTRACT



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ABSTRACT

This investigation explores the influence of titanium dioxide (TiO_2) in deflocculating (removal of extracellular polymeric substance – EPS) the sludge and subsequent biomass disintegration by bacterial pretreatment. The EPS removed at an optimized TiO_2 dosage of 0.03 g/g of SS of TiO_2 and a solar radiation exposure time of 15 min to enhance the subsequent bacterial disintegration. The outcomes of the bacterial pretreatment reveal SS reduction and COD solubilization for the deflocculated (EPS removed and bacterially pretreated) sludge was observed to be 22.8% and 22.9% which was comparatively greater than flocculated (raw sludge inoculated with bacteria) and control (raw) sludge. The higher methane production potential of about 0.43 (gCOD/gVSS) was obtained in deflocculated sludge than the flocculated (0.20 gCOD/gVSS) and control (0.073 gCOD/gVSS). Economic assessment of this study provides a net profit of about 131.9 USD/Ton in deflocculated sludge.

1. Introduction

Industries are one of the key sources of producing wastewater that is to be treated in a proper way. Most of the industries adopt conventional treatment methods for treating waste water, in which a huge amount of sludge is produced as the by-product but which are also highly odorous and harmful to health. Proper disposing of this sludge is found to be a foremost problem nowadays. The dairy industry is one of those industries producing great amounts of wastewater containing organic matters, which result in the formation of high stench (Daverey and Pakshirajan, 2011; Lateef et al., 2013; Sowmya et al., 2015). An activated sludge process is carried out for treating that wastewater. During this process, more quantities of sludge are produced; disposing and

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treating the sludge in an efficient manner is found to be expensive, for which financial outlay is about 60% of its total functioning cost of Waste Water Treatment Plant (WWTP), hence it must be treated in an apt way before disposal by reducing its mass (Kavitha et al., 2014). The anaerobic digestion process is one of the most well-established biotechnological methods for stabilization of sludge and for the production of valuable eco-friendly renewable fuel gases, such as methane, from the biogas through an anaerobic process, thereby reducing sludge mass (James et al., 2014). The anaerobic digestion (AD) is a sequential process grouped into four phases namely, hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Among the four stages, hydrolysis is considered as the rate limiting factor (Appels et al., 2008), to overcome this rate limiting factor, pretreatment is adopted, which aids in sludge disintegration. A Biochemical Methane Potential (BMP) assay helps in evaluation of the anaerobic biodegradability potential (Sowmya et al., 2015) and this biodegradability is enhanced by various pretreatment processes, such as acid pretreatment (Neyens et al., 2003a), alkaline thermal pretreatment (Neyens et al., 2003b), microwave pretreatment (Appels et al., 2013; Beszedes et al., 2011;), mechanical homogenization (Appels et al., 2008), peroxidation (Neyens and Baeyens, 2003c; Appels et al., 2011) ultrasonic pretreatment (Shao et al., 2010), thermo-chemical pretreatment (Gonzalez et al., 2013), electrochemical method (Yang et al., 2014), chemo-mechanical pretreatment (Uma et al., 2014) and bacterial (enzymatic or microbial or biosurfactant) pretreatment (Tang et al., 2012). Among the various pretreatment processes, bacterial pretreatment is an ecofriendly method of pretreating the sludge. Because of less toxicity, better environmental compatibility, and high solubilization competency, disintegration with biosurfactant-producing bacteria can be an efficient method of pretreatment to improve a digestion process (Luo et al., 2013).

In waste activated sludge, bacterial cells crowd together to form floc because of the formation of the Extracellular Polymeric Substances (EPS) layer. The rupturing of the EPS layer helps in liberation of organic substances and bacterial cell to augment pretreatment (Kavitha et al., 2015). In this present study, floc disruption is carried out by titanium dioxide (TiO_2) in the presence of solar radiation as an energy source (solar photocatalytic process). A solar photocatalytic process, using TiO_2 is an Advanced Oxidation Process (AOP), often highly used for treatment of wastewater (Rajesh Banu et al., 2008) is used for the pretreatment of sludge (Liu et al., 2014). This process is a novel technique in the field of EPS removal in sludge. AOP methods (Photoctlytic process) may be anticipated to progress EPS removal efficiently in WAS. In addition, it is less-energy spending method compared to thermal treatment, sonication, microwave, explosive explosion shockwave, and pressurized electro-osmotic treatment. It is also a cost effective method contrast to other treatment methods as it utilize sunlight.

To the best of our knowledge, a solar photocatalytic process for EPS removal has not been described in any studies so far. The main purpose of the study is: (1) to disrupt the flocs in sludge by a solar photocatalytic process using titanium dioxide; (2) to disintegrate the sludge biomass using biosurfactant bacterial pretreatment in order to explore the hypothesis of deflocculated sludge (EPS removed) by biosurfactant pretreatment using bacteria; (3) to analyze the proficiency of pretreatment by anaerobic biodegradability assay; and (4) to scrutinize the economic assessment.

2. Methods

2.1. Sample collection

The waste activated sludge (WAS) was collected from the Aavin dairy industry, Madurai, India. The collected sample was stored under refrigeration at 4 °C. Prior to the commencement of experimentation, characterization of the waste activated sludge was determined as follows: pH = 6.9, Total solids (TS) = 9000 ± 200 mg/L, Suspended solids (SS) = 4000 ± 200 mg/L, Total oxygen demand (TCOD) = 7000 ± 600 mg/L, and Soluble Chemical oxygen demand = 200 ± 50 mg/L.

2.2. Solar photocatalytic process (using TiO_2) for floc disruption

Seven identical 1 L glass trays were used for the AOP process in which 400 mL of sludge were taken from each. The solar photocatalytic process was carried out by adding titanium dioxide in WAS, which was taken in trays and kept in the solar radiation with an average UV light intensity in the range of about 5.52–6.06 kW h/m^2 day during the months of January to March for 120 min from 11.00 A.M. to 1.00 P.M. which was calculated using the following equation according to work of Zhang et al. (2013).

$$Kt, a\upsilon = Ha\upsilon/Ho, a\upsilon \tag{1}$$

where Haυ is the monthly average irradiation obtained from the monthly registered measurements and Ho, aυ is the monthly average extraterrestrial irradiation, Ho is the extra terrestrial radiation (MJ/m^2 day). The dosage of TiO_2 added to each tray was varied in the range of 0.001–0.1 g/g of SS. At various intervals of time ranges from 5 min to 120 min, the samples were collected from all trays. Each of the collected samples was centrifuged at 7500 rpm for 15 min. The supernatant from sludge were filtered and analyzed for EPS.

2.3. Biosurfactant bacterial pretreatment

After the deflocculation experiment, pretreatment of the deflocculated sludge was carried out by biosurfactant producing bacteria. The bacterium used was *Planococcus jake 01* (GenBank accession number: KJ792465), which had been isolated and identified in a previous work (Kavitha et al., 2015). In a 250 mL conical flask, 100 mL of the deflocculated sludge was taken in which 2 g dry cell weight/L of the inocula (Kavitha et al., 2015) was inoculated and incubated for 42 h at 40 °C, and kept in an orbital shaker under 120 rpm. Similarly, two more conical flasks, one of which was used as control (raw WAS) and another as flocculated (bacterially pretreated), were maintained to study the efficiency of the floc disruption via bacterial pretreatment.

2.4. Biochemical methane potential assay

A biochemical methane potential assay was done, as per the procedure described by Uma et al. (2012). The inoculum and substrates were taken in the ratio 3:1 in 500 mL bottles. The inoculum used was Bovine rumen fluid. The substrates used were control, flocculated, and deflocculated sludge. The methane content in the biogas was analyzed using a Baroda gas chromatograph (GC) equipped with a thermal conductivity detector and porapak Q column with hydrogen as the carrier gas at a flow rate of 40 mL/min. The following first order kinetic model was employed to study the cumulative methane production:

$$Y_{(t)} = Y_{(fd)} \cdot (1 - \exp(-k^{t}_{hyd})) \tag{2}$$

where $Y_{(t)}$ is the cumulative methane yield at digestion time t days (gCOD/gVSS added), $Y_{(fd)}$ is methane potential of the substrate (fraction of the substrate that may be converted to methane) (g COD/g VSS added), k_{hyd} is first order disintegration rate constant (day^{-1}), t is the time (days). The model was implemented in a Matlab 2012a Version. The parameter estimation, and parameter uncertainty evaluation used, was calculated, based on the work of