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Short Communication

Anaerobic stabilization of waste activated sludge at different temperatures and solid retention times: Evaluation by sludge reduction, soluble chemical oxygen demand release and dehydration capability

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HIGHLIGHTS

- The optimum SRT for the stabilization of WAS should be higher than 10.7 d.
- Effects of temperature on SCOD release were greater at SRT of 32 d and 6.4 d.
- CST was not correlated with soluble proteins/soluble carbohydrates in supernatant.
- CST was observed to be the minimum at SRT of 10.7 d both in MT-AD and RT-AD.

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ABSTRACT

Anaerobic treatment is the most widely used method of waste activated sludge (WAS) stabilization. Using a semi-continuous stirring tank with condensed WAS, we investigated effects of decreasing the solid retention time (SRT) from 32 days to 6.4 days on sludge reduction, soluble chemical oxygen demand (SCOD) release and dehydration capability, along with anaerobic digestion operated at medium temperature (MT-AD) or anaerobic digestion operated at room temperature (RT-AD). Results showed that effects of temperature on SCOD release were greater at SRT of 32 d and 6.4 d. When SRT was less than 8 d, total solids (TS), volatile solids (VS) and capillary suction time (CST) did not change significantly. CST was lowest at SRT of 10.7 days, indicating best condition for sludge dehydration. Principal component analysis (PCA) showed that the most optimum SRT was higher than 10.7 d both in MT-AD or RT-AD.

1. Introduction

A significant increase in the volume of treated domestic wastewater was recorded in most cities in recent years. However, the main method used for the treatment of such wastewater, which involves bio-chemical processes, generates large quantities of sludge annually. If not handled properly, the sludge may result to secondary contamination, thus, more sustainable disposal methods are still being explored such as anaerobic digestion (AD). As a frequently used method for the stabilization of waste activated sludge (WAS), AD had become the more preferred method due to a number of advantages like lower energy consumption, less carbon content but smaller total volume of the digested sludge, and higher methane production (Lee and Rittmann, 2011).

Based on the different types of functional microbes and enzymes involved, the process of anaerobic digestion of sludge can be divided into three main phases (Yuan et al., 2015). The first phase involves the hydrolysis of large organic molecules using various hydrolases such as proteinase, amylase, cellulose, and lipase,

Abbreviations: AD, anaerobic digestion; CST, capillary suction time; CSTR, continuous stirred tank reactor; HRT, hydraulic retention time; MT-AD, anaerobic digestion operated at medium temperature; MT-6.4, anaerobic digestion operated at medium temperature with SRT of 6.4 d; MT-8, anaerobic digestion operated at medium temperature with SRT of 8 d; MT-10.7, anaerobic digestion operated at medium temperature with SRT of 10.7 d; MT-16, anaerobic digestion operated at medium temperature with SRT of 16 d; MT-32, anaerobic digestion operated at medium temperature with SRT of 32 d; PCA, principal component analysis; RT, room temperature; RT-AD, anaerobic digestion operated at room temperature; RT-6.4, anaerobic digestion operated at room temperature with SRT of 6.4 d; RT-8, anaerobic digestion operated at room temperature with SRT of 8 d; RT-10.7, anaerobic digestion operated at room temperature with SRT of 10.7 d; RT-16, anaerobic digestion operated at room temperature with SRT of 16 d; RT-32, anaerobic digestion operated at room temperature with SRT of 32 d; SBR, sequencing batch reactor; SC, soluble carbohydrates; SCFAs, short-chain fatty acids; SCOD, soluble chemical oxygen demand; SP, soluble proteins; SRT, solid retention time; TCOD, total chemical oxygen demand; TS, total solid; VFA, volatile fatty acid; VS, volatile solids; WAS, waste activated sludge.

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among others. The products of this phase, such as amino acids, monosaccharides, and long chain fatty acids, are further converted into smaller molecules via an intercellular acidogenesis, which constitutes the second phase. This next phase generates short-chain fatty acids (SCFAs) such as propionic and butyric acids, which are further reduced to acetic acid mediated by a number of different microbes. The final phase of AD is methane generation, which results to the stabilization of the sludge.

For each one of the three AD phases to work perfectly, it is very important that at each phase be dominated by the right group of microbes. These microbes are in turn influenced by various parameters, the most significant of which are temperature and solid retention time (SRT; (Lee et al., 2011; Yuan et al., 2011). Although hydrolytic acidification can occur at room temperature (RT), the reaction efficiency of hydrolases significantly improves at higher temperatures, resulting to faster SCFAs production (Lee et al., 2014; Yuan et al., 2011). The growth on the other hand of different methanogens is also influenced by temperature (Kundu et al., 2012).

In continuous stirred tank reactor (CSTR) systems, the SRT is equivalent to the hydraulic retention time (HRT). However, longer HRT needs higher reactor volumes, which in turn increases the operating costs. Most studies concluded that shorter SRT increases generation of volatile fatty acid by avoiding methanogens (Lee et al., 2014). With smaller HRT and higher organic loading, it took longer time for methane generation to stabilize (Kim and Lee, 2012). In stable-operating reactors, the dominant group of methanogens also shifted their responses to SRT variations (Kim et al., 2014). As SRT increased from less than 6 days to 8–12.5 days and then to greater than 12.5 days, the dominant methanogenic groups successively dominated by *Methanobacteriales*, *Methanosarcinales*, and *Methanomicrobiales*, respectively. However, since the reactor volume needs to increases with HRT, longer HRT is also associated with higher maintenance costs.

Assessment of the efficiency of sludge stabilization usually involves the monitoring of the decomposition rate of organic matter, reduction of water content, and bio-degradability of digested sludge. To date however, most of the sludge stabilization studies were focused on the primary sludge and mixed sludge.

In this study, we evaluated optimum SRT and temperature conditions for sludge stabilization. We used two 3.2 L semi-CSTR set-ups: one operating at mesophilic temperature (MT; 35 ± 1 °C) and the other at RT, both incubated for a total of over 9 months using WAS as substrate, with SRT ranging from 32 to 6.4 days. Specifically, we aim to: (1) study the capability of sludge reduction through TS and TCOD under different SRT in medium and room temperatures; (2) assess through soluble COD, the impact of temperature and SRT operation parameters on sludge stabilization, and (3) measure the dewaterability of anaerobic digested sludge using CST. Long-term operational data was then used to evaluate the optimum digestion temperature and SRT in the environmentally sustainable process, which could lessen cost and assure a more secure disposal.

2. Materials and methods

2.1. Experimental waste activated sludge

The experimental sludge was collected from a pilot-scale domestic wastewater treatment sequencing batch reactor (SBR) that uses an aerobic-anoxic stepwise process. The treatment facility operates a stable shortcut nitrification-denitrification process with an effective volume of 6 m^3 for at least three years. The condensed sludge from the SBR was added to the anaerobic experimental set-ups. Table 1 lists the main parameters of WAS used for the experiment.

Table 1
Main characteristics of sludge used in this study.

Parameters	Unit	Value
TS	g/L	25.78 ± 1.00
VS	g/L	18.63 ± 0.25
TCOD	mg/L	23286.15 ± 1556.86
SCOD	mg/L	108.76 ± 30.54
CST	s/gTS	6.70 ± 1.87
NH_4^+-N	mg/L	51.70 ± 9.72
PO_4^{3-}-P	mg/L	23.68 ± 9.80
pH	1	6.5–7.5

2.2. Semi-continuous reactors and operation parameters

Here, two experimental semi-CSTR were carried out with a reaction volume of 3.2 L, the first one operated at mesophilic temperature and referred hereafter as MT-AD while the other one incubated at room temperature as RT-AD. Each semi-CSTR was comprised of sub-systems for sealing, sludge dosing, sampling and sludge discharge, temperature control, online monitoring, and pH control. The pH was adjusted by either adding 1 M HCl or NaOH when necessary.

During the experiments, the SRT/HRT was gradually reduced from 32 days to 16, then 10.7, 8 and finally 6.4 days. For this, the MT-AD or RT-AD set-ups coupled to the different SRT/HRT were referred to as MT-32 or RT-32 when HRT was specifically, the same with MT-16, RT-16, MT-10.7, RT-10.7, MT-8, RT-8, MT-6.4, and RT-6.4. Duration of each stage of either MT-AD or RT-AD lasted at least twice of the SRT. Anaerobically digested sludge was discharged every day, and fresh WAS were added into the semi-CSTR.

2.3. Analytical methods

Total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total solids (TS) and volatile solids (VS) were measured using standardized methods for the test of wastewater (APHA, 1998). pH was monitored by multi 340i online system (WTW, Germany), and the Capillary Suction Time (CST) followed the manufacturer‘s protocol using sludge capillary dehydration time measuring instrument (Triton 304 M, Britain).

To measure liquid phase parameters, samples were centrifuged (4000 rpm, 15 min, 4 °C; Hettich MIKRO220R, Germany) and filtered through 0.45 μm filters. Soluble carbohydrate (SC) was measured using the phenol-sulfuric acid method (Guo et al., 2013) and soluble protein (SP) was determined by an improved Bradford kit (SK3041, Shanghai Sangon, China) using bovine serum albumin as the standard solution. Detection of short-chain fatty acids (SCFAs) was carried out in a gas chromatograph (Agilent 6890N, America) with flame ionization detector. These analyses were carried out in triplicate and results were presented as averages. SP, SC and SCFAs were converted to COD using the conversion factor described previously (Yuan et al., 2015).

2.4. Data processing and calculation

Multivariate statistics such as principal component analysis (PCA) and cluster analysis were used to analyze co-dependence of the data relative to temperatures and SRTs. Data were standardized to normalize for the different units of each parameter. The SPSS® statistical software package was used to reduce the variables by forward selection, including TS, VS, CST, etc. Hierarchical clustering method was used to cluster similarities, with between-

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