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Combined electrical-alkali pretreatment to increase the anaerobic hydrolysis rate of waste activated sludge during anaerobic digestion

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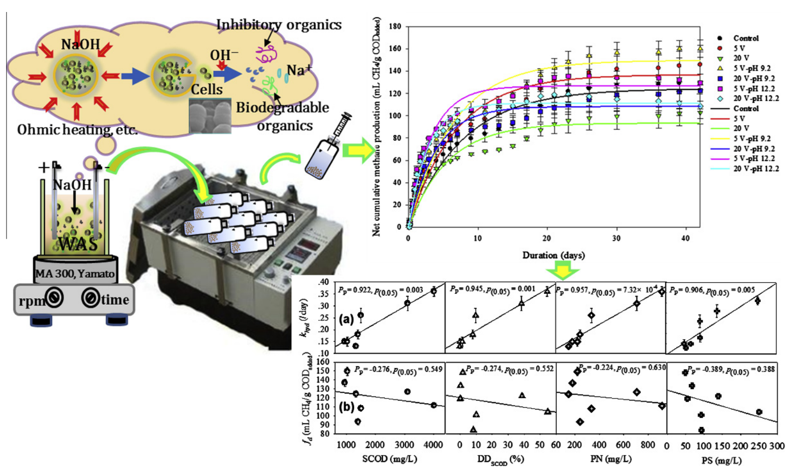
HIGHLIGHTS

- Combined electrical-alkali pretreatment for improving sludge anaerobic digestion was proposed.
- Combined process enhanced the cell lysis, biopolymers releases, and thus sludge disintegration.
- Increased solubilization of sludge increased the anaerobic hydrolysis rate.
- Increased solubilization does not always induce an improved anaerobic digestion efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

Pretreatment can be used prior to anaerobic digestion to improve the efficiency of waste activated sludge (WAS) digestion. In this study, electrolysis and a commonly used pretreatment method of alkaline (NaOH) solubilization were integrated as a pretreatment method for promoting WAS anaerobic digestion. Pretreatment effectiveness of combined process were investigated in terms of disintegration degree (DD_{SCOD}), suspended solids (TSS and VSS) removals, the releases of protein (PN) and polysaccharide (PS), and subsequent anaerobic digestion as well as dewaterability after digestion. Electrolysis was able to crack the microbial cells trapped in sludge gels and release the biopolymers (PN and PS) due to the cooperation of alkaline solubilization, enhancing the sludge floc disintegration/solubilization, which was confirmed by scanning electron microscopy (SEM) analysis. Biochemical methane potential (BMP) assays showed the highest methane yield was achieved with 5 V plus pH 9.2 pretreatment with up to 20.3% improvement over the non-pretreated sludge after 42 days of mesophilic operation. In contrast, no discernible improvements on anaerobic degradability were observed for the rest of pretreated sludges, probably due to the overmuch leakage of refractory soluble organics, partial chemical mineralization of solubilized compounds and sodium inhibition. The statistical analysis further indicated that increased solubilization induced by electrical-alkali pretreatment increased the first-order anaerobic hydrolysis

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rate (k_{hyd}), but had no, or very slight enhancement on WAS ultimate methane yield (f_d), demonstrating that increased solubilization of WAS from a pretreatment does not always induce an improved anaerobic digestion efficiency.

1. Introduction

In China, approximately 9.1 million dry tons of waste activated sludge (WAS) was produced in 2012. This figure is expected to increase continuously in the foreseeable future due to growing cities served by sewers [1], widespread application of the conventional activated sludge (CAS) process [2], and more stringent regulations pertaining to effluent quality [3]. Currently, more than 70% of the sludge has not been disposed of appropriately. Not only does the willful disposal cause health hazard to the public but also brings about significant changes to the ecosystem. Furthermore, the treatment and disposal of sludge accounts for up to 50–60% of the operational costs in a wastewater treatment plant (WWTP) [4]. Sludge management represents a bottleneck in water industries due to increasingly rigorous regulations. The promotion of feasible treatment techniques is thus one of the most imminent challenges facing environmental researchers.

Anaerobic digestion is considered as an interesting option for WAS treatment as it can allows the sludge stabilization to reduce odors and pathogens, the sludge decrement, and also the recovery of renewable energy in the form of methane [4,5]. Usually, anaerobic digestion occurs in several steps, i.e., hydrolysis, acidogenesis, acetogenesis and methanogenesis. Hydrolysis, however, is the rate-limiting step [6] in the anaerobic digestion process because of the complex and rigid floc structure of WAS, giving rise to long retention time and low degradation efficiencies [7]. In this sense, numerous strategies such as mechanical [8], ultrasonic irradiation [9], microwave [7], thermal [10], acid [11], and alkaline solubilization [12,13] have been previously studied on laboratory and pilot level to enhance the hydrolytic limiting stage and to improve the performance of the global process. Among these alternate methods, alkaline pretreatment, often achieved by adding NaOH, presents the obvious advantages over others: a simple device, ease of operation, and high methane conversion efficiency. For example, Zhang et al. [14] compared different pretreatment methods used to favor the degradability of WAS, and found that the sludge pretreated at pH 10 for 8 days gave the highest accumulative methane yield of 398 mL/VSS, which was 3.5- and 3.1-fold of the ultrasonic and thermal pretreated sludge, respectively. Alkaline pretreatment breaks the flocs apart and induces the swelling of particulate organics [15], rendering the biopolymer substances more susceptible to the extracellular enzymes produced by anaerobic microflora [8]. Of late, this pretreatment has been combined with other sludge disintegration methods such as ultrasound [16,17], microwave [18], thermal [19], and high pressure homogenization (HPH) [20] to maximize the sludge biodegradability and/or methane production. Several research works have indeed confirmed the positive synergistic effect of the combined pretreatment on sludge anaerobic digestion [3,4,21,22].

Very recently, electrolysis has shown to be an efficient alternative for sludge modification prior to aerobic digestion [23], membrane treatment process [24], as well as dewatering [25]. The principle of electrolysis pretreatment relies on the ohmic heating, electrophoresis, and electro-osmosis [24,26], resulting in particle disintegration and microbial cell lysis. The pretreatment, especially if assisted by chemical methods [27], will become more energy-efficient for sludge treatment as they solubilize sludge and obviate the need for high voltages. Furthermore, the combined treatment can not only reduce the required quantity of chemicals and energy, but also greatly enhance the efficiency of WAS anaerobic digestion by the synergistic functions, and thus is more economically attractive. Yet, to the best of our knowledge, no studies have been carried out in the literature to evaluate the effectiveness of combined electrical-alkali pretreatment on sludge disintegration/solubilization and subsequent anaerobic digestion.

In this study, the combined electrical-alkali process was first applied to pretreat WAS, aiming to enhance sludge disintegration and subsequent anaerobic digestion. Firstly, pretreatment effectiveness was analyzed by comparing the soluble chemical oxygen demand (COD), disintegration degree (DD_{SCOD}) of sludge, total suspended solids (TSS), volatile suspended solids (VSS), protein (PN), and polysaccharide (PS) in pretreated and non-pretreated sludges in order to propose the best conditions to achieve the effective sludge solubilization, and also to explore the responsible reasons for enhancing the anaerobic biodegradability of WAS. Secondly, the performances of anaerobic digestion of different pretreated sludges were assessed in terms of methane yields via biochemical methane production (BMP) tests in batch mesophilic anaerobic digesters. Finally, preliminary testing of dewatering effectiveness before and after anaerobic digestion was also performed to clarify the exact role of anaerobic digestion on sludge dewaterability. The outcome of this study will establish some fundamentals that permit on the further exploration of novel electrical-alkali technique for the potential improvement of WAS anaerobic digestion.

2. Materials and methods

2.1. Test materials

The WAS used for this experiment was withdrawn from the secondary sedimentation tank of a municipal WWTP in Sendai, Japan. The samples, pre-screened through a 4.0 mm sieve to remove any large debris present, were transferred immediately to the laboratory and stored at 4 °C in order to maintain sample freshness. From the same WWTP, the digested sludge was sourced from a methophilic anaerobic digester (35 ± 1 °C), for use as inoculum. Anaerobic digester is fed continuously with the sludge collected from primary and final clarifiers. The inoculum was degassed and incubated under anaerobic conditions at 35 ± 1 °C prior to commencing the experiments. Within 48 h of sampling, the WAS was prepared for experimentation. The main characteristics (average date plus standard deviations of triplicate tests) of WAS and inoculum were given in Table 1.

2.2. Electrical-alkali modification

A series of batch-scale experiments were conducted under constant electrical voltage electrolysis conditions in a 500 mL undivided single-compartment glass cell by using a pair of Ti/RuO_2 meshes as the anode and cathode [27]. The porous electrodes ensured an adequate mixing of WAS sample in the whole reactor. Electrodes were 7 cm × 10 cm in dimension and the distance between two electrodes was 4 cm in all experiments. The electrodes were connected by copper wires to a regulated digital DC power supply (AD-8735, A&D Co., Japan) with galvanostatic operational options for controlling the electrical voltage. The effect of