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Effect of Combined Microwave-Ultrasonic Pretreatment on Anaerobic Biodegradability of Primary, Excess Activated and Mixed Sludge

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ABSTRACT

This work deals with the effect of combined microwave-ultrasonic pretreatment on the anaerobic biodegradability of primary, excess activated and mixed sludge. The characteristics, biodegradability and anaerobic digester performance for untreated primary, excess activated and mixed sludge were compared to combined microwave-ultrasonic pretreated primary, excess activated and mixed sludge. All sludge samples were subjected to Microwave treatment at 2450 MHz, 800 W and 3 min followed by ultrasonic treatment at a density of 0.4 W/mL, amplitude of 90%, Intensity of 150 W, pulse of 55/5 for 6min. Methane production in pretreated primary sludge was significantly greater (11.9 ml/g TCOD) than the methane yield of the untreated primary sludge (7.9 ml/g TCOD). Cumulative methane production of pretreated Excess Activated Sludge (EAS) was higher (66.5 ml/g TCOD) than the methane yield from pretreated mixed sludge (44.1 ml/g TCOD). Furthermore, digested EAS showed significantly higher dewaterability (201 s) than digested primary sludge (305 s) or mixed sludge (522 s). The average Methane: Carbondioxide ratio from EAS (1.85) was higher than that for mixed untreated sludge (1.24). VS reduction was also higher for EAS than the other two sludge types. However, pretreatment of EAS resulted in significant reduction in dewaterability due to higher percentage of fine floc particles in the pretreated EAS.

Keywords: Biodegradability; Combined Microwave-Ultrasonic; Dewaterability; Primary; Excess Activated Sludge; Mixed Sludge

1. Introduction

Anaerobic digestion is a very effective sludge treatment technology applied in municipal and industrial wastewater treatment plants to stabilize organic matter [1]. The process comprises four major microbiological degradation steps of hydrolysis, acidogenesis, acetogenesis and methanogenesis. One of the disadvantages of anaerobic digestion technique is the slow degradation or hydrolysis of microorganisms that accounts for 70% of excess sludge which is the primary degradation step in the anaerobic digestion process. The microorganisms in the excess sludge contain Extracellular Polymeric Substances (EPS) that are resistant to biodegradation which in turn limits the rate of the whole anaerobic digestion process [2,3]. Different pretreatment technologies were found to enhance sludge hydrolysis and anaerobic digestion performance [4]. Pretreatment of sludge through ultrasonic, mechanical, chemical or thermal techniques result in bacterial cell wall disruption, disintegration of EPS and release of enzymes enhance the rate of hydrolysis and biodegradation [5,6]. Ultrasonic, micro- wave, oxidative, and thermal pretreatment techniques are well documented in literature as viable methods to enhance biodegradability, hydrolysis rate and digester peformance [7]. It was reported that ultrasonic pretreatment results in disruption of cells and large sized macromolecules by the hydro-mechanical shear forces produced by ultrasonic cavitation [8]. Sonication density of 0.5 W/mL and sonication intensity of 4.8 W/cm^2 resulted in significant increase in soluble COD and 24.6% increase in VS reduction [9]. Microwave (MW) irradiation is another efficient sludge pre-treatment technology that involves high frequency electromagnetic radiation which interacts with the dipolar molecules in the sludge [6]. Microwave pretreatment helps to enhance rate of anaerobic digestion and dewaterability [10]. Microwave pretreatment increased SCOD up to 4 fold, soluble protein concentration up to 1.8 fold and soluble carbohydrate concentration up to 14 fold [11]. The application of more than one treatment also resulted in improved sludge biodegradation, floc destruction, cell wall disruption and release of organics due to the complementary synergy between the treatment techniques that are combined [12-14]. Microwave enhanced-oxidative pretreatment with H_2O_2 resulted in 11% - 34% TS, TCOD reduction and total biopolymer solubilisation [15]. Combined ultrasonic-alkali pretreatment of waste activated sludge resulted in 60% VS solubilisation. The use of NaOH weakens the cells walls increasing the disintegration effect of ultrasonication or other lysis techniques [5]. Very few researchers have reported that the microwave combined with ultrasonic would be a rapid and economical method of sludge pre-treatment for enhanced biogas production. Combined microwave-ultrasonic pretreatment resulted in significant improvement in gas production, solid removal and dewaterability of municipal sludge compared to the individual ultrasonic or microwave pretreatment approaches [16]. Primary sludge, excess activated sludge and mixed sludge have distinctively different biochemical composition, rheological property, response to pretreatment, biodegradability and methane potential, floc size and dewaterability. Studying effect of pretreatment technologies and biodegradability of each of the sludge types is beneficial for the selection of appropriate pretreatment technology and pretreatment condition, better design and operation of sludge treatment units [17]. This research aims at understanding the effect of combined microwave-ultrasonic pretreatment on biodegradability, methane potential, dewaterability and characteristics of primary, excess activated and mixed sludge systems.

2. Materials and Methods

2.1. Sampling and Characterization

Primary sludge was collected from primary gallery underflow lines particularly from primary sedimentation tank No. 4 of Beenyup Waste Water Treatment Plant (BWWTP), Perth, Western Australia. Mixed sludge was collected from Beenyup anaerobic digesters feed mixed sludge sampling point and the Excess Activated Sludge (EAS) was collected from Module 4 of the secondary treatment section of BWWTP. Primary and Excess activated sludge samples were mixed with 75:25 ratio to prepare the mixed sludge before all the samples were charged to the jacketed digesters. Samples were withdrawn from each anaerobic digester for characterization purpose. The characteristics of sludge fed to the digesters are presented in **Table 1**.

2.2. Analytical Methods

Total solids (TS), Volatile solids (VS), pH, conductivity, chemical oxygen demand and dewaterability were measured and analysed for all sludge samples. Chemical oxygen demand (COD), Total solids (TS) and volatile solids (VS) of the feed and digested sludge were determined according to the standard methods [18]. Methane, carbon dioxide and oxygen content of the biogas was determined by Gas analyser (Thermo Fisher SCIENTIFIC GA 2000 plus). pH and conductivity/total dissolved solids for the feed and digested sludge were measured using WP-90 and WP-81 conductivity/TDS-pH/temperature meter. The dewaterability (filterability) of each of the digested sludge samples was measured using capillary suction timer (Type 304 CST equipment).

Table 1. Characteristics of the sludge fed to the reactors.

Parameter	TS (%)	VS (% TS)	COD (g/l)	pH
Raw primary sludge	2	88.8	30.5	7.2
Primary pretreated sludge	2	88.8	32.8	7.1
Excess activated sludge	1	90	18.9	6.9
Pretreated thickened excess activated sludge	2.7	83	39.6	7
Untreated Mixed Sludge	1.5	87.5	22.9	7.1
Mixed Pretreated Sludge	1.5	87.5	24.9	7.1

2.3. Combined Microwave-Ultrasonic Pretreatment

Primary excess activated and mixed sludge samples were pretreated according to the conditions shown in **Table 2**. Initially each of the sludge samples was homogenized and pretreatment was carried out in the sequence of microwave treatment first followed by ultrasonic pretreatment at the conditions specified in **Table 2**. Pretreatment conditions were selected based on the treatment power and time optimization tests carried out earlier.

2.4. Experimental Setup for Methane Potential and Sludge Biodegradability Tests

The tests for methane potential were conducted in batch continuously stirred 1 L jacketed digesters. All the digesters were kept at a mesophilic temperature of 36.5℃ by means of a water bath heater. 50 ml of digested sludge was introduced to each of the digesters for acclimation. The digesters were inoculated with the digested sludge for a period of 3 days and sludge feeding to the reactors was carried out after adjusting the pH and purging the digesters with nitrogen gas. The effective digester volume was 500 ml for each of the reactors after charging the feed sludge. The pH was maintained between 6.8 - 7.3 using sodium hydroxide and hydrochloric acid. The biogas generated was allowed to pass through buffer tanks to remove any condensate before the gas volume

Table 2. Different conditions of pre-treatment.

Pre-treatment method	Conditions
Microwave-ultrasonic treatment (MU)	Microwave: 2450 MHz, 800 W, 3 min, Ultrasonic: 0.4 W/mL, 48,000 Joules, 90% amplitude, 55/5 pulse , 6 min

was measured in inverted cylinders by water displacement technique. The biogas composition and other parameters were continuously monitored until biogas generation reached SRT of 25 days.

3. Result and Discussion

3.1. Methane Potential of Different Kinds of Sludge

Methane production in pretreated primary sludge (11.9 ml/g TCOD) was 33.6% greater than the methane yield of the untreated primary sludge (7.9 ml/g TCOD) as shown in **Figure 1**. SCOD/TCOD ratio for pretreated primary sludge was 48% less than the ratio for untreated primary sludge as it is consumed due to increased organic disintegration and methanogenic activity in the anaerobic digestion process. In case of untreated primary sludge, the biopolymers and organics are dominantly present in the solid phase than in the soluble liquid phase. Pretreatment enhances destruction of complex floc structure of secondary sludge and biopolymers in primary sludge and promotes the transfer of organics to the solu- ble phase [19]. Specific methane yield of pretreated mixed sludge was 12.6% greater than untreated mixed sludge as shown in **Figure 2**. Excess Activated Sludge (EAS) showed less methane production (20.7 ml/g TCOD) as compared Pretreated Excess Activated Sludge (PEAS) (66.5 ml/g TCOD) as shown in **Figure 3**. The thickening process in the dissolved air floatation tank (DAFT) has significantly increased the solid concentration and the pretreatment further enhanced the methane production and the kinetics of the digestion process.

3.2. Effect of Pretreatment on the Dewaterability of Different Kinds of Sludge

The dewaterability of Excess activated sludge was significantly better than primary or mixed sludge as the total solid in EAS was less than the other two sludge types **Figure 4**. However, combined microwave-ultrasonic pretreatment resulted in the deterioration of the dewaterability of excess activated or slight improvement in case of mixed sludge. Dewaterability is a function of particle size of the flocs and the hydrophilicty of biopolymers released due to the disintegration of microbial cells. Pretreatment decreases average size of flocs and increases release of biopolymers which may trap water and limit the dewaterability. The change in floc structure and col-

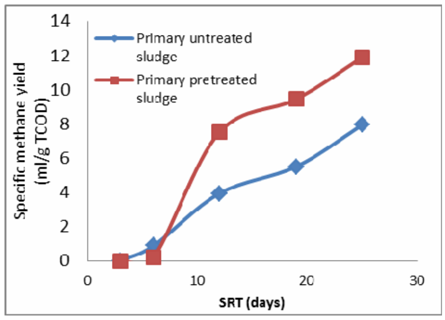

Figure 1. Specific methane yield from pretreated and untreated primary sludge.

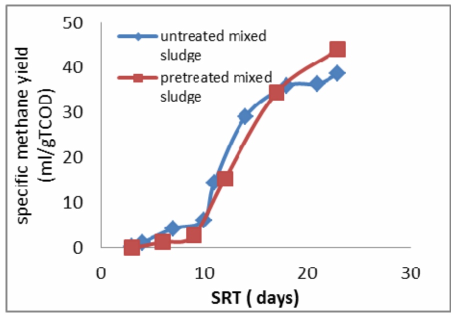

Figure 2. Specific methane yield from untreated and pretreated mixed sludge.

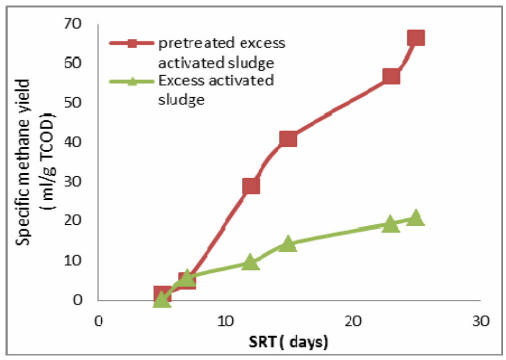

Figure 3. Specific methane yield from untreated and pretreated excess activated sludge.

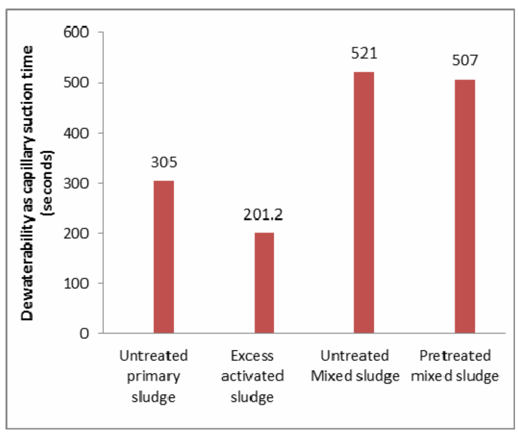

Figure 4. Dewaterability of different sludge samples.

loidal charge may have also contributed to the reduction in dewaterability. Ultrasonication is known to have effects of changing the surface charge.

3.3. Effect of Pretreatment on Biogas Composition and CH_4/CO_2 Ratio

The maximum CH_4/CO_2 ratio for EAS was 1.85 and pretreatment enhanced the quality of the biogas by 7.5%. The CH_4/CO_2 ratio for mixed untreated sludge was 1.24 and the enhancement in gas quality due to combined microwave-ultrasonic pretreatment was 18.9 %. The effect of pretreatment on biogas quality was much greater in mixed sludge system than excess activated sludge. In the initial phase of the digestion process, the CH_4/CO_2 ratio was relatively lower for all sludge types; it progressively increased due to the conversion of CO_2 to CH_4 through hydrogenotrophic methanogenesis reaching the maximum CH_4/CO_2 ratio after 25 days of SRT as shown in **Figure 5**.

4. Conclusions

Combined microwave-ultrasonic pretreatment improved sludge solubilisation, biogas production and anaerobic digester performance and biodegradability of primary, EAS and mixed sludge. This Combined pretreatment technique disintegrates the complex floc structure of EAS and macromolecules in primary sludge. The degree of sludge solubilisation after pretreatment for different sludge types was different. The combined Pretreatment resulted in comparatively greater improvement of methane production and biogas quality (CH_4/CO_2 ratio) and VS destruction in EAS. The increase in digestion efficiency is proportional to the degree of sludge disintegration. Sludge disintegration and increased biodegradability and methane production is due to rapid internal heating of microwave radiation and the floc destruction achieved by ultrasonic treatment. EAS also showed better dewaterability compared to other sludge types. However, dewaterability deteriorated with pretreatment is due to higher percentage of fines and greater availability of biopolymers which increased the amount of bound water. Generally, combined ultrasonic and microwave treatment at the optimum conditions will play great role in reducing sludge treatment handling and disposal expenses and enhances efficiency and profitability.

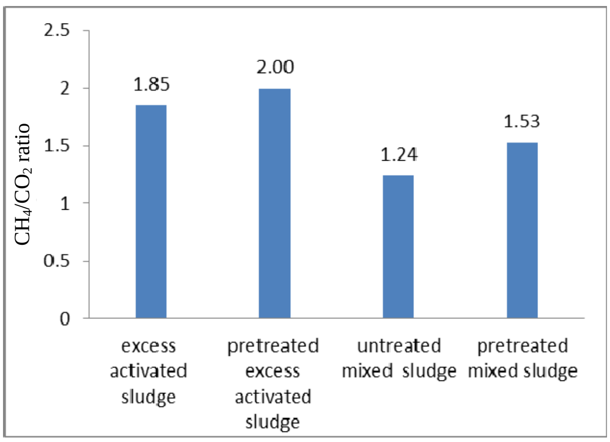

Figure 5. Maximum CH_4/CO_2 ratio in the biogas after 25 days of SRT for untreated and pretreated sludge samples.

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