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Upgrading the temperature-phased anaerobic digestion of waste activated sludge by ultrasonic pretreatment

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HIGHLIGHTS

- BMP assays were performed to assess the effect of US application on the TPAD of WAS.
- Sonication at the beginning and the end of the thermophilic stage was tested.
- Different behaviours were observed between the thermophilic and mesophilic stages.
- Similar CH_4 yields were achieved by the TPAD systems in which US was applied.
- This new treatment, combining TPAD and US, improves the anaerobic digestion of WAS.

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ABSTRACT

Biochemical methane potential assays were performed to assess the influence of ultrasonic pretreatment on the temperature-phased anaerobic digestion (TPAD) of waste-activated sludge (WAS). Ultrasound (specific energy = 3380 kJ kg^{-1} TS) was applied to the WAS before the thermophilic stage or to the effluent after the thermophilic stage. In addition, a control system without pretreatment was also carried out. No significant differences were found in the overall performance of the TPAD process, but different behaviours were observed between the thermophilic and mesophilic stages. Total methane production was enhanced by more than 50% and the volatile solid removal increased by 13% in comparison to the TPAD control process. Finally, a previously defined kinetic model was applied successfully to the experimental data and showed an excellent fit.

1. Introduction

It is well known that nowadays, the activated-sludge process is the most widely used biological wastewater treatment technology. However, this process generates large amounts of waste-activated sludge (WAS): the annual production of sludge in Europe and the United States stands at 10 million and 6 million tonnes dry matter, respectively [1,2]. Moreover, the treatment and disposal of WAS are receiving increasing attention due to its associated high capital and operating costs, which can account for up to 60% of the total plant operation costs [3]. An effective strategy to reduce sludge disposal costs could be to minimise its production within the wastewater treatment plant (WWTP) [4]. Thus, it is important to develop methods of reducing excess sludge produced during wastewater treatment in an economic, environmentally safe and practical manner [3]. For this reason, technologies for reducing sludge generated from both primary and biological treatments are being extensively studied [4,5].

Anaerobic digestion is one of the most widely used processes for the stabilisation of sewage sludge. However, hydrolysis is considered the limiting step of the anaerobic digestion treatment of WAS, since it is an unfavourable substrate for microbial degradation due to its high cellular content (approximately 70% of excess sludge). For this reason, much research has focused on the application of several pretreatments to improve the rate of hydrolysis, thus enhancing solid removal and biogas production [6–8]. Among these pretreatments, ultrasound (US) application has been one of the most-studied technologies in recent years [9].

In terms of the operation regime, a mesophilic temperature (30–40 °C) has been long adopted for anaerobic digestion. However, it has been reported that the removal efficiency of organic matter, as well as methane production and the inactivation

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of pathogens of thermophilic digestion (50–60 °C), at low retention times, were higher than for mesophilic digestion [10]. Despite this, the use of thermophilic anaerobic digestion has been limited due to disadvantages such as poor supernatant quality, sludge dewaterability and process stability related to chronically high propionate concentrations [11].

A leading option is thermophilic (50–70 °C) pretreatment prior to mesophilic anaerobic digestion (temperature-phased anaerobic digestion, TPAD). This technology has gained interest as it possesses the advantages of thermophilic systems in terms of pathogen control, volatile solid reduction and biogas production and is still economical to operate because the bulk of the digestion occurs at the mesophilic stage [12–14]. The good performance of the TPAD process is due to the setting of optimal conditions for the two main microorganism groups: thermophilic hydrolytic/acidogenic and mesophilic methanogens, in terms of pH, temperature and retention time [6].

Very few studies that report the use of pretreatment methods prior to TPAD have been published [6,15] and data concerning US application have not been reported. To further improve the performance of the TPAD process, the objective of this study was to assess its response by determining the methane yield via biochemical methane potential (BMP) assays when US was applied to WAS prior to the thermophilic stage and also when the thermophilically digested sludge was sonicated and fed to the mesophilic digester.

2. Methods

2.1. TPAD biodegradability tests

The TPAD-BMP assays were performed to assess the effect of US pretreatment on WAS biodegradability. All experiments were carried out using amber serum bottles of 240-mL total volume (161 mL working volume) immersed in a thermostatic bath. Manual shaking for the proper contact of seeds and substrate was performed daily.

Three batch TPAD systems; STM (sonication–thermophilic–mesophilic), TSM (thermophilic–sonication–mesophilic) and TM (thermophilic–mesophilic), were operated in duplicate: STM1/STM2, TSM1/TSM2 and TM1/TM2 (Fig. 1). The TM system, which was initiated as a process control, was a temperature-phased two-stage system, which consisted of a thermophilic digester (55 °C) and a mesophilic digester (35 °C) in series; the STM system was a temperature-phased two-stage process in which the thermophilic stage was fed with sonicated WAS; and finally, TSM corresponded to a temperature-phased two-stage system with intermediate sonication, in which the mesophilic digester was fed with the previously sonicated thermophilic effluent.

Firstly, all digesters were filled with a mixture of thermophilic sludge (inoculum) and WAS (substrate). The TSM1, TSM2 and TPAD control reactors (TM1 and TM2) were fed with non-pretreated WAS (2.7 g CODs/L), whereas STM1 and STM2 were fed with sonicated WAS (19.0 g CODs/L). In addition, two reactors (duplicates) were inoculated in each stage, as process blanks, without substrate: thermophilic blank (TB1/TB2) and mesophilic blank (MB1/MB2). These blanks allowed the activity of the inoculum to be confirmed. The BMP test with starch as a substrate was also carried out as a positive control. A 10% (v/v) basal medium with macro- and micronutrients was used. The reactors were filled and nitrogen gas was used and sparged, to maintain anaerobic conditions before the experiments began.

The initial inoculum substrate ratio (ISR) of the first thermophilic stage, in terms of volatile solids (VS), corresponded to a value of 0.6, which was a high initial organic loading rate. Based on previous results [13], all reactors were operated under thermophilic conditions for 6 days. Subsequently, the digesters were re-started and inoculated with digested mesophilic sludge and the thermostatic bath temperature was altered to 35 °C. The substrate in this case was the product of the thermophilic stage, which was sonicated prior to feeding to TSM1/TSM2 reactors. The VS ratio between the inoculum and the substrate was two. The system remained under mesophilic conditions until the biodegradation process was completed, i.e., until no further methane production could be detected.

2.2. Substrate and inocula used

Mesophilic inoculum and WAS samples were collected from San Fernando-Cádiz WWTP (Southern Spain). The treatment in this plant consisted of a preliminary and primary treatment as well as a secondary treatment in the activated sludge unit; afterwards the WAS was thickened at the flotation unit. Sludge stabilisation was carried out by anaerobic digestion operating at 35 °C with 20 days of solid retention time (SRT).

WAS samples were taken from the flotation thickener, whereas the digested sludge used as the inoculum in the second-stage, operating at mesophilic conditions, was collected directly from

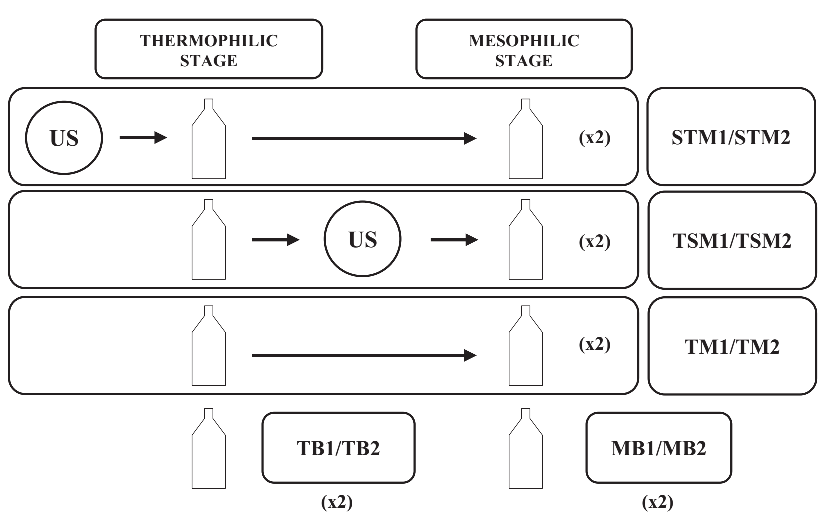

Fig. 1. Experimental set-up of TPAD-BMP tests.