Optimizing mixing time to lower the energy consumption of an anaerobic digestion waste-to-energy system for food waste management

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Background

One critical parameter that can be optimized to reduce energy consumption in an AD system is the mixing speed and frequency. Generally, the energy consumption for mixing in a full-scale digester is varies from 14 to 54% of the total energy demand of the plant [1, 2]. Mixing results in the formation of a homogeneous substrate, eliminating stratification and ensuring the suspension of solid substrates for degradation [3]. In addition, mixing also facilitates the uniform distribution of heat within the digester and the transfer of gas from the inoculum [4]. There are two main operational modes for mixing: Continuous, and semi-continuous mixing. Continuous mixing enhances the distribution of substrates, heat and microorganisms for the production of methane, but it also consumes a significant amount of energy. Conversely, semi-continuous mixing requires significantly less energy input, but produces comparable quantities of the desired products. The lack of consensus and continued contention regarding this specific AD operational parameter call for deeper investigation into and evaluation of the effects of mixing on the efficiency of AD systems.

Materials and methods

2.1. Inocula and substrates

Seed sludge was collected from a large-scale anaerobic digester from the Ulu Pandan Water Reclamation Plant (UPWRP) in Singapore. The anaerobic digester at UPWRP currently treats waste activated sludge from the secondary wastewater treatment plant for domestic sewage wastes. In this study, each reactor was inoculated with this seed sludge at approximately 80% (v/v). The ratio of volatile suspended sludge (VS) to total suspended sludge was 0.8 with initial TS of 15 g/L. Food Waste (FW) was obtained from a canteen at the National University of Singapore.

2.2. Reactor specifications and operation

Three bench scale reactors with operating capacities of 5 L were used to investigate the effect of mixing conditions on mono-digestion of FW. The bench scale reactors were equipped with temperature control systems and controllable mixing systems. Reactors inoculated with seed sludge were incubated at 35°C. The reactors were labelled R1, R2 and R3. R1 was subjected to semi-continuous mixing, where the reactor mixture was mixed for 2 minutes at 80rpm between 1 hour intervals where no mixing took place. R2 was subjected to continuous mixing at 80rpm for the duration of the experiment. R3 was not subjected to any mixing. Organic loading rate (OLR) was increased from 0.9 g to 2.4-VSFW/L/day.

2.3. Analytical methods

COD and ammonia were detected and quantified using HACH colorimeter (HACH DR900, USA) according to the manufacturer's instructions. The pH was recorded using a pH analyzer (Agilent 3200M, USA). TS and VS were determined based on the weighing method after being dried at 103-105 oC and burnt to ash at 550oC. Methane (CH_4) production was determined using a gas chromatograph (Clarus 580 Arnel, PerkinElmer, USA) equipped with a thermal conductivity detector. Elemental analyses in FW were determined using the vario MICRO cube (Elementar, Germany).

Results and discussion

Mixing in an anaerobic digester creates a homogeneous system enhancing mass transfer, and enables the solid wastes and microorganisms remain in suspension, but continuous mixing strategy is not cost-effective due to the demand of high electric energy. Optimizing mixing time to reduce energy consumption would create a more energy efficient anaerobic digestion (AD) process with higher biogas yield. This study particularly investigates the effect of different mixing strategies on anaerobic digestion of food waste in order to make the AD waste-to-energy process more energy efficient. Results showed that intermittent mixing is an alternative strategy to continuous mixing or unmixing for high efficient biogas production and energy saving. Through computational fluid dynamics modeling of fluid flow in anaerobic digesters (Fig.1), the mixing time was optimized to 2 mins/hr, at which point the reaction mixture is almost entirely homogeneous. The results of the CFD model was validated with the experimental data. At an organic loading rate of 2.4 g VSFW/L/day, the semi-continuously mixed reactor maintains a higher specific methane yield of 437 ml CH_4/g VSFW in comparison with the other controls.

Conclusion

Based on the results of the bench scale experiment, the energy balance of the hybrid AD waste-to-energy system was simulated and evaluated. The energy balance investigated the electricity generated and the net heat output generated, in addition to self-sustaining and meeting the energy requirements of the various AD processes investigated. Based on the analysis, it was found the semi-continuous mixing is more energy efficient and sustainable to generate sufficient biogas output for the energy system to provide a net positive heat and electricity output.

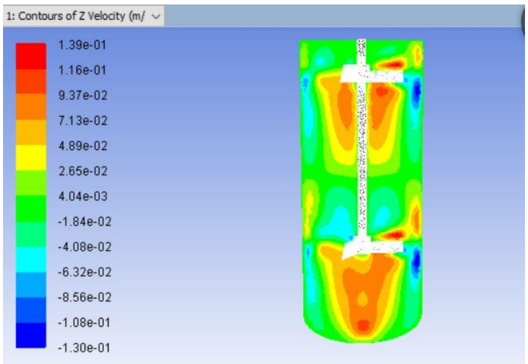

Fig. 1 The contour of axial velocity at mid vertical surface

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