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Thermophilic adaptation of a mesophilic anaerobic sludge for food waste treatment

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Abstract

As opposed to mesophilic, thermophilic anaerobic digestion of food waste can increase the biogas output of reactors. To facilitate the transition of anaerobic digesters, this paper investigated the impact of adapting mesophilic sludge to thermophilic conditions. A 5 L bench scale reactor was seeded with mesophilic granular sludge obtained from an up-flow anaerobic sludge blanket digester. After 13 days of operation at 35 °C, the reactor temperature was instantaneously increased to 55 °C and operated at this temperature until day 21. The biomass was then fed food waste on days 21, 42 and 63, each time with an F/M (Food/Microorganism) ratio increasing from 0.12 to 4.43 gVS/gVSS. Sludge samples were collected on days 0, 21, 42 and 63 to conduct substrate activity tests, and reactor biogas production was monitored during the full experimental period. The sludge collected on day 21 demonstrated that the abrupt temperature change had no pasteurization effect, but rather lead to a biomass with a fermentative activity of 3.58 g Glucose/gVSS/d and a methanogenic activity of 0.47 and 0.26 g Substrate/gVSS/d, related respectively, to acetoclastic and hydrogenophilic microorganisms. At 55 °C, an ultimate gas production (Go) and a biodegradation potential (Bo) of 0.2–1.4 L_{STP}/gVS_{fed} and of 0.1–0.84 L_{STP} CH_4/gVS_{fed} were obtained, respectively. For the treatment of food waste, a fully adapted inoculum was developed by eliminating the initial time-consuming acclimatization stage from mesophilic to thermophilic conditions. The feeding stage was initiated within 20 days, but to increase the population of thermophilic methanogenic microorganisms, a substrate supply program must be carefully observed.

Keywords: Anaerobic digestion; Biogas production; Food waste; Mesophilic conditions; Thermophilic adaptation

1. Introduction

In North America and Europe, up to 35% of the total mass of generated municipal solid waste can be made up of organic components (Rhynder et al., 1995). To divert the organic fraction of municipal solid wastes (OFMSW) from landfills while beneficially reusing such waste, more energy-efficient practices are required. For OFMSW, the conventional mesophilic-anaerobic/composting coupled system offers an energy potential of 150 kWh/t_{MSW} which is 21 times higher than that reported for landfill municipal solid waste of 6.9 $kW\text{-}h/t_{MSW}$ recovered from collected biogas (Baldasano and Soriano, 2000). Despite this higher energy yield, there are only a few conventional anaerobic digesters (AD) in North America for the transformation of OFMSW into green-energy carriers (USEPA, 2003). In comparison, Europeans have long accepted to treat the OFMSW using AD, but also know that the choice of technologies depends on the substrate characteristics.

Thermophilic conditions to operate one or two-stage AD systems can further improve the energy efficiency of the technology. According to De Baere (2000) and as opposed to mesophilic plants, the start-up of the first thermophilic plant in 1992 has increased the cumulative capacity (t/year) of treating OFMSW from 56 000 to 280 000 t/year, and this from 1997 through 2000. Under thermophilic conditions, a high level of pathogen kill-off is obtained and more heat and electricity are recovered. Nevertheless, the optimal transition of AD systems from mesophilic to thermophilic conditions is not clearly defined. The transition depends on the microbial adaptation to new operational conditions or

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Nomenclature

Bo	ultimate biodegradation (methane) potential
C/N	carbon to nitrogen ratio
COD	chemical oxygen demand
C0, C1, C2, C3, C4	batch stages
F/M	food to microorganism ratio
Go	ultimate gas production potential
L_{STP}	litre of gas corrected to standard pressure (103.25 kPa) and temperature (273.15 K)
MSW	municipal solid waste
OFMSW	the organic fraction of municipal solid waste
OLR	organic loading rate
SA	substrate consumption rate
SC-OFMSW	selectively collected organic fraction of municipal solid waste
TKN	total Kjeldahl nitrogen
TS	total solids
VFA	volatile fatty acids
VS	volatile solids
VSS	volatile suspended solids

the presence of different groups of microorganisms capable of performing their biological functions at specific temperatures.

When the groups present are not capable of performing under mesophilic and thermophilic conditions, a longer temperature shift period is required. Also, a rapid temperature change from mesophilic to thermophilic may bring about a population shift if the groups are not compatible (Mata-Alvarez, 2002). Nozhevnikova et al. (1999) have assumed that thermophilic and mesophilic methanogenic communities differ in terms of microbial species. This assumption may not be completely true as some mechanisms may permit the microorganisms to evolve from one specific state to another depending on the transition conditions. Nielsen and Petersen (2000) mentioned that the quick and satisfactory start up of full-scale thermophilic anaerobic digesters in Denmark has been achieved with and without a transitional period. The first two days of starting the plant at thermophilic temperatures were associated with a high content of volatile fatty acids and a high biogas CO_2 concentration, requiring the careful monitoring of the loading rate. This period was avoided when the digester was immediately started using thermophilic temperatures. For food waste mechanically sorted from MSW and treated under either a dry or wet anaerobic process, Mata-Alvarez (2002) observed a transition from mesophilic to thermophilic conditions (35–55 °C in 10 d) requiring significant variations in organic loading (from 15% to 40% over 2 d) without permanent effect on the process performance.

The objective of this experiment was therefore to test the development of a thermophilic anaerobic inoculum for the treatment of food waste, by subjecting anaerobic mesophilic sludge to a fast temperature change. The adaptation was conducted using a bench scale reactor seeded with a mesophilic granular sludge obtained from two Upflow Anaerobic Sludge Blanket digester (UASB), one treating apple wastewater while the other treating milk wastewater. Substrate activity tests were conducted to characterize the changes in biomass, and the new thermophilic inoculum was fed selectively collected OFMSW (SC-OFMSW) to test its treatment capacity.

2. Methodology

The project consisted in achieving the adaptation of:

(1) A granular UASB biomass from mesophilic to thermophilic conditions, and;
(2) The resulting thermophilic biomass to a new type of substrate (food waste) at different loading rates, under completely mixed and thermophilically controlled anaerobic conditions using a bench scale reactor.

2.1. Substrate

The SC-OFMSW used in this study was the food waste collected from the solid waste produced by a cafeteria. Immediately after collecting the cafeteria solid waste, the organic fraction was manually sorted and the plastic, glass, metal and wood portions were removed. Despite manual sorting, the substrate was mostly made up of food scraps (meat, egg, fruit and vegetables, bread, pastries), but also contained some paper napkins and packaging, plastic packaging, wood sticks and plastic table-settings.

The resulting substrate was shredded using a 50 mm stainless-steel blade and then chopped into a paste using an 87/Polytron/PTA 36/2 blade connected to a CH-6010 Kiennz-Lu electric rotor (*Kinematica*, Switzerland). All particles larger than 4.75 mm were separated with a No. 4 USA standard testing sieve (*W.S. Tyler*, USA). During the first shredding operation, tap water was added to drop the solid content to 21.8%. The meat and egg fractions were visibly high explaining the high Total Kjeldahl Nitrogen (TKN) of 17% and carbon/nitrogen (C/N) ratio of 3:1 associated with the substrate (Table 1).

2.2. Seed

A large number of sludge types were possible for this study, but two types of anaerobic granular sludge were readily available and were therefore selected. The seed selected consisted of a 50/50% mixture of granular and non-granular sludge taken from two separate-UASB reactors treating dairy process wastewater and apple-juice