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Trace metals requirements for continuous thermophilic methane fermentation of high-solid food waste

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HIGHLIGHTS

- ▶ The effect of trace metals on methane fermentation of food waste was studied.
- ▶ The most suitable values for Fe/COD, Co/COD, Ni/COD were determined.
- ▶ This is the first report to identify the trace metals requirements theoretically.

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ABSTRACT

The amount of iron, cobalt and nickel required to perform thermophilic methane fermentation using high-solid food waste was examined in this study. To determine this, we devised and applied a theoretical consideration method. Three runs were performed using a completely stirred tank reactor. During the first run, start-up was carried out by decreasing the HRT from 100 to 50 and finally to 30 days, which corresponds to a COD loading rate of 1.9, 3.8 and 6.3 kg m^{-3} day^{-1}, respectively. Four typical operational parameters—the gas production rate, methane content, pH and total volatile fatty acid (VFA) concentration—were stable except a temporary rise in VFA was observed when the HRT was decreased from 50 to 30 days, indicating that the system performed well with COD loading rate of 6.3 kg m^{-3} day^{-1}. After day 57 (HRT: 30 days, COD loading rate: 6.3 kg m^{-3} day^{-1}), the reactor efficiency deteriorated due to the trace metals limitation. A combination of iron, cobalt and nickel (at 10, 1 and 1 mg L^{-1}, respectively) was added to the reactor approximately every 45 days during the second run. The reduced gas production, methane content and pH were all restored to stable levels after regularly adding the trace metals. During the third run, trace metals were added to the substrate, and no limitation was noted at all. Based on the theoretical consideration and the experimental results, the most suitable values for Fe/COD, Co/COD, Ni/COD are 276, 4.96 and 4.43 mg kg^{-1} COD-removed, respectively, for high-solid thermophilic methane fermentation of food waste.

1. Introduction

Most of the research on methane fermentation has focused on the factors that affect stable and efficient production. One important factor is the trace metals that are required by the microorganisms in the reactor. Trace metals have been found to significantly influence reactor performance, more so than even the temperature [1]. The trace metals required for the methane fermentation of various types of waste, such as starch [2], cow dung [3], methanol wastewater [4], food waste [5], and a defined model that uses maize as the substrate [6], have been studied using a mesophilic digester. Although methane fermentation at thermophilic temperatures became of interest in the mid-1990s and has been gaining more recognition ever since [7–10], the trace metals required for efficient continuous thermophilic methane fermentation remain unclear. Previous research has been directed toward ascertaining the optimal concentrations of trace metals required in a pure culture of thermophilic methane fermentation [11,12]. Typically, the trace metal requirements for thermophilic methane fermentation have been studied using a pure culture with a simple substrate. Two of the more noteworthy studies examined cobalt requirements in up-flow anaerobic sludge blanket (UASB) bioreactors that were used to treat methanol wastewater [13] and the minimum concentrations of iron, nickel, cobalt and zinc required for the methane fermentation of glucose [14]. Despite numerous studies

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in the literature, the trace metals required in complex group cultures of methane fermentation of food waste have not yet to be understood. The effects of trace metals in complex group cultures differ considerably in terms of how they behave compared with pure cultures, and under thermophilic compared with mesophilic conditions. In addition, previous results from batch mode cannot provide the real data for requirement of trace metals in practice because the process stability and bioavailability of trace metals is lower than continuous mode.

In previous study [5], we have identified the effects of addition of iron, cobalt and nickel on mesophilic process stability and degradation of accumulated VFA in lab-scale reactor treating high solid food waste. It is very important for practice that the calculation of trace metals requirement per COD removed was obtained experimentally.

In this study, our focus was to investigate whether trace metals (iron, cobalt, nickel) limit the thermophilic methane fermentation of high-solid food waste, and to gain data to long-term process stability. It is also important to determine the appropriate amounts of trace metals required because the chemical addition of trace metals inevitably results in higher operation costs, and the metals in the digester's effluent are potentially toxic and need to be considered before disposal. Still, the amount of trace metals required could be easily added in substrate with different composition and compared with different culture.

In this study, a long-term, continuous digestion process was conducted to ascertain the limitations of trace metals (iron, cobalt, nickel), to gain data to methane fermentation of high solid food waste process stability. The appropriate amounts of trace metals were tested by the regular addition of these trace metals to the continuous digestion process. Then, the amount of trace metals required in terms of the amount of COD removed was determined based on material balance. In addition, we devised a calculation method based on microbiology multiplication models, to compare the amounts of trace metals required with pure culture. Finally, the long-term continuous digestion process was evaluated by adding trace metals to the substrate according to the requirements determined by this study.

2. Materials and methods

2.1. Feedstock and sludge

The feedstock comprised simulated food waste, as described in a previous study [5], which included the following (w/w): potato, 31%; vegetable patty ("koroke" in Japanese), 41%; bread powder, 19%; onion, 8%. This composition was based on a case study on food waste processing. This food waste was freshly prepared for every 15 days. It was chopped into 2-cm cubes, shredded to <3.0 mm in diameter using a high-speed shredder, and diluted by adding tap water to obtain approximately 140 g L^{-1} total solids (TS). The substrate was fed into the reactor using a time-controlled pump from a feed tank that was maintained at 4 °C. In order to maintain process stability, the feed had to be added to lower than 1% of the working volume. The characteristics of the substrate are shown in Table 1. Thermophilic anaerobic digester sludge that was obtained from a municipal sewage treatment plant (Sendai, Japan) was used as the seed sludge. The sludge was filtered to eliminate particles >3 mm. The seed sludge was not subjected to any pretreatment.

Table 1
Characteristics of the substrate [5].

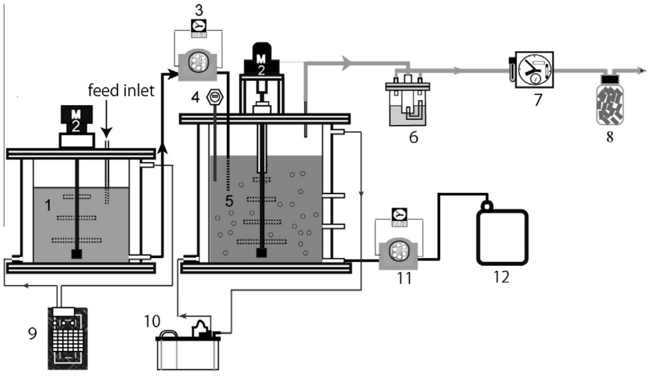
	Constituent	Value (*n* = 3)	SD (±)
Composition of the substrate	TS (%)	14.3	1.75
	VS (%)	13.1	1.71
	SS (g L^{-1})	122	24.0
	VSS (g L^{-1})	120	24.0
	T-COD (g L^{-1})	188	6.53
Organic elemental composition of waste	C (%)	47.4	0.01
	O (%)	43.7	0.28
	H (%)	6.65	0.28
	N (%)	1.90	0.09
	S (%)	0.41	0.06
Inorganic elemental composition of waste	Na (mg L^{-1})	5880	206
	K (mg L^{-1})	5480	134
	P (mg L^{-1})	4260	928
	Mg (mg L^{-1})	1410	26.6
	Ca (mg L^{-1})	482	12.0
	Zn (mg L^{-1})	14.0	3.00
	Fe (mg L^{-1})	34.9	4.58
	Co (mg L^{-1})	0.08	0.01
	Ni (mg L^{-1})	ND	ND

ND: not detected.

2.2. Reactor setup and process operation

In order to investigate the effects of iron, cobalt and nickel on thermophilic methane fermentation with complex group cultures, a CSTR with a working volume of 12 L was used. Fig. 1 illustrates the schematics of the equipment used in this study. The temperature of the reactor was maintained at thermophilic conditions (55 °C) by circulating the water in the water jacket surrounding the reactor. The reactor was agitated continuously using a motor mixer (1400 rpm).

At the beginning of the experiment, the seed sludge was added to the CSTR without adding the substrate. After 1–2 days, stable gas production was confirmed in the reactor, then, the reactor received regular additions of the substrate. In order to prevent the accumulation of volatile fatty acids (VFAs), the feedstock was added to the reactor eight times per day and the hydraulic retention time (HRT) of the substrate was gradually shortened from 100 to 50 to 30 days. Gas production was measured using a wet gas meter. Start-up was successful when the HRT was 100 days. Then, the HRT was decreased stepwise from 100 to 30 days. Performance stability was evaluated in terms of the gas production rate, pH, VFA content, TS content and other analytical indices. Three analyses were carried out in order to determine the most accurate



1-feedstock tank, 2-Mixer, 3-Sampling pump, 4-Thermometer, 5- Methane reactor,
6 - Gas-water separation chamber, 7 -Gas meter, 8-Desulfiration bottle, 9-Recirculation cooler,
10-Hot water recirculation, 11-Effluent pump, 12-Digestation sludge tank

Fig. 1. Schematics of the continuously stirred tank reactor (CSTR) [5].