Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Anaerobic co-digestion of spent coffee grounds with different waste feedstocks for biogas production

Jaai Kim, Hakchan Kim, Gahyun Baek, Changsoo Lee *

School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology (UNIST), 50 UNIST-gil, Eonyang-eup, Ulju-gun, Ulsan 44919, Republic of Korea

ARTICLE INFO

Article history:
Received 1 April 2016
Revised 4 July 2016
Accepted 11 October 2016
Available online xxxx

Keywords:
Anaerobic co-digestion
Biochemical methane potential
Kinetic modeling
Spent coffee grounds

ABSTRACT

Proper management of spent coffee grounds has become a challenging problem as the production of this waste residue has increased rapidly worldwide. This study investigated the feasibility of the anaerobic co-digestion of spent coffee ground with various organic wastes, i.e., food waste, *Ulva*, waste activated sludge, and whey, for biomethanation. The effect of co-digestion was evaluated for each tested co-substrate in batch biochemical methane potential tests by varying the substrate mixing ratio. Co-digestion with waste activated sludge had an apparent negative effect on both the yield and production rate of methane. Meanwhile, the other co-substrates enhanced the reaction rate while maintaining methane production at a comparable or higher level to that of the mono-digestion of spent coffee ground. The reaction rate increased with the proportion of co-substrates without a significant loss in methanation potential. These results suggest the potential to reduce the reaction time and thus the reactor capacity without compromising methane production.

1. Introduction

Global coffee consumption has increased at an average annual growth rate of 2.4% since 2011 to reach approximately 9 million tons in 2014 (http://www.ico.org/trade_statistics.asp). Accordingly, the production of spent coffee grounds (SCG), the solid residue remaining after brewing, has also increased steadily. The worldwide production of SCG is estimated to be approximately 8 million tons per year (Vardon et al., 2013). Most of the SCG is currently discarded as a valueless waste, although some is used as a boiler fuel after drying (Silva et al., 1998) or as a mushroomcultivation medium (Chang, 2008) in some countries. This is largely due to the lack of methods to efficiently address the enormous amount of SCG produced. Improper management of SCG can cause serious pollution because of the high oxygen consumption during decomposition of the easily degradable organic matter and the potential release of residual caffeine, tannin, and polyphenols (Qiao et al., 2013; Vardon et al., 2013). Consequently, the management of SCG has become an increasingly challenging problem.

Given its high organic content (i.e., high calorific value), the potential of using SCG as a feedstock for biofuels is an interesting question in the context of waste-to-energy conversion. Many recent studies have investigated the conversion of SCG into biofuels, such as biodiesel, ethanol, and biogas using physicochemical or biological processes. An increasing amount of attention is being paid to this potential with the ever-increasing production of SCG. Anaerobic digestion (AD), which mineralizes organic compounds to methane and carbon dioxide gases, is considered to be a practical method for recovering energy from a waste feedstock. Methanation of SCG through AD was first reported in the 1980s (Lane, 1983), followed by a number of attempts performed at different operating temperatures and reactor configurations in the 1990s (Fernandez and Forster, 1993; Dinsdale et al., 1996, 1997). However, in the early studies, trace elements and nutrients (e.g., nitrogen and phosphorus) were supplied to the reactors in addition to SCG to stabilize the AD, and it was suggested that the mono-substrate AD of SCG has a limitation in terms of long-term stability. Co-digestion with different substrates, such as sewage sludge, food waste, and agro- and food-processing wastes, has recently been demonstrated as a viable approach to solving this problem with different reactor configurations and operating temperatures (Neves et al., 2006; Ike et al., 2010; Qiao et al., 2013; Li et al., 2015a,b). It has been shown from these studies that co-digestion is advantageous over mono-digestion for efficient and stable performance while the mono-digestion of SCG is prone to failure even when alkalinity and micronutrients were supplied. A co-digestion strategy can be beneficial to enhancing the process feasibility and stability by balancing the C/N ratio of the feedstock, remedying the trace-element deficiency, improving the buffering capacity, and diluting the inhibitory compounds (Khalid et al., 2011; Dai et al., 2013; Fonoll et al., 2015; Usack and Angenent, 2015).

* Corresponding author.
E-mail address: cslee@unist.ac.kr (C. Lee).

http://dx.doi.org/10.1016/j.wasman.2016.10.015
0956-053X/

In anaerobic co-digestion systems, selecting the best co-substrate and mixing ratio is the key to the optimization of AD performance (Fonoll et al., 2015). This is of particular concern in processes operating without supplemental nutrients and additives, which are advantageous for field applications in terms of economic feasibility and operating convenience. The present study examined the various waste feedstocks of food waste (FW), *Ulva* (marine macroalgae), waste activated sludge (WAS), and whey (cheese-processing wastewater), as co-substrates for the AD of SCG. For a more practical approach, in contrast to most previous studies, the biochemical methane potential (BMP) tests for SCG co-digestion were performed without additional supplements but at different mixing ratios. The primary focus is on evaluating the effect of different substrate characteristics and compositions on the co-digestion performance and the feasibility of the waste feedstocks mentioned above as co-substrates. The outcomes of this study will provide a useful reference for selecting a co-substrate and the implementation of co-digestion for effective SCG treatment. For a more comprehensive insight, the methane production kinetics and microbial community structure were also analyzed for co-digestion test runs under different conditions.

2. Materials and methods

2.1. Seed sludge and waste feedstocks

The main substrate of interest, SCG, was collected from a coffee shop on the campus of UNIST, Ulsan, Korea. Simulated FW was prepared based on the composition of actual FW generated in Korea: 16% boiled rice, 8% napa cabbage, 20% potato, 20% onion, 2% white radish, 7% apple, 7% orange, 5% pork, and 15% mackerel on a wet-weight basis. Fresh *Ulva* biomass was freshly collected from a local beach and rinsed gently with a small amount of tap water to remove sand and other detritus. WAS thickened by gravity was obtained from a local municipal wastewater treatment plant. Whey was obtained from a local cheese manufacturer (Samik Dairy & Food Co., Korea). FW and *Ulva* biomass were used after being finely ground with a household blender. The physicochemical characteristics of the substrates used in this study are summarized in Table 1. Anaerobic sludge used as the inoculum for the methanation tests was collected from a full-scale anaerobic digester co-digesting sewage sludge and FW. The total solids (TS) content of the seed sludge was 23.7 g/L, with 65% of it being volatile solids (VS), and the chemical oxygen demand (COD) concentration of the seed sludge was 20.4 g/L (data not shown).

2.2. Biochemical methane potential test

BMP tests were conducted in 120-mL serum bottles with a 100-mL working volume that contained 80 ml of seed sludge and 20 ml of substrate mixture. For each co-substrate, a set of runs at four different mixing ratios with SCG (25, 50, 75, and 100% of the mixture, v/v) were tested in parallel with the no-inoculation control. The mono-digestion of SCG (100% SCG) was conducted with and without inoculation for comparison, and the no-substrate blank was also examined to correct for background biogas production from the inoculum itself. All runs were tested in triplicate, and consequently, a total of 69 BMP trials were conducted under 23 different conditions. Prior to inoculation, the seed sludge was degassed by starvation for several days and sieved (860-μm mesh) to remove coarse particles. Each bottle was flushed with nitrogen to remove oxygen in the headspace and was tightly sealed with a rubber stopper. The bottles were incubated at 35 °C with intermittent manual shaking for 28 days with periodic monitoring of biogas production. The biogas volume was corrected to standard temperature and pressure (STP; 0 °C and 1 atm) conditions.

The observed methanation profiles were modeled using a modified Gompertz equation (Eq. (1)).

$$CMP_t = P_M \cdot \exp\left[-\exp\left\{\frac{MPR_m \cdot e}{P_M}(\lambda - t) + 1\right\}\right] \quad (1)$$

where CMP_t is the cumulative methane production (L CH_4/g VS_{in}) at time t (days), P_M is the methane production potential (L CH_4/g VS_{in}), MPR_m is the maximum methane production rate (L CH_4/d), λ is the lag phase length (days), and t is the incubation time (days).

Table 1
Physicochemical characteristics of the substrates tested in this study.

	SCG	FW	*Ulva*	WAS	Whey
C (%)	51.4 (0.2)	48.4 (0.7)	37.8 (0.5)	37.1 (0.4)	35.3 (0.3)
H (%)	7.0 (0.1)	7.1 (0.1)	7.2 (0.3)	5.7 (0)	7.3 (0.1)
O (%)	38.4 (0.1)	40.4 (0.5)	35.7 (0.3)	27.2 (0.1)	45.8 (0.5)
N (%)	2.2 (0)	4.4 (0.1)	5.4 (0)	6.6 (0.1)	1.5 (0)
S (%)	–[a]	0.2 (0)	1.9 (0.2)	0.5 (0.1)	0.2 (0)
C/N	23.3	11.0	7.0	5.6	23.7
CHONS (%)	99.0	100.5	88.0	77.1	90.1
Al (mg/L)	1.60 (0.10)	0.09 (0)	21.85 (2.75)	114.77 (2.07)	0.10 (0)
Ca (mg/L)	33.87 (1.29)	25.43 (0.38)	93.63 (4.77)	149.51 (5.09)	72.76 (0.30)
Co (mg/L)	–	–	–	–	–
Cr (mg/L)	0.10 (0.02)	–	0.03 (0)	0.3 (0.01)	–
Cu (mg/L)	0.68 (0.07)	0.03 (0)	0.15 (0)	4.73 (0.02)	0.03 (0)
Fe (mg/L)	23.10 (0.37)	0.93 (0)	15.27 (0.80)	123.54 (1.43)	0.09 (0)
K (mg/L)	51.25 (0.69)	50.05 (0.57)	109.85 (1.74)	75.43 (1.75)	226.44 (0.48)
Mg (mg/L)	21.50 (0.42)	5.15 (0.05)	215.12 (8.17)	91.06 (1.27)	17.00 (0.03)
Mn (mg/L)	0.96 (0.02)	0.06 (0)	0.58 (0.03)	1.88 (0.03)	0.03 (0)
Mo (mg/L)	0.01 (0)	–	0.06 (0)	0.12 (0)	0.14 (0)
Na (mg/L)	19.28 (0.69)	9.62 (0.13)	208.08 (1.74)	51.71 (1.59)	79.73 (2.65)
Ni (mg/L)	–	–	0.03 (0)	1.07 (0.04)	–
W (mg/L)	0.05 (0)	–	0.09 (0.06)	0.11 (0)	0.09 (0)
Zn (mg/L)	3.63 (0.09)	0.33 (0)	0.31 (0.03)	12.70 (0.03)	0.03 (0)
TCOD (g/L)	19.2 (0.53)	15.6 (0.41)	15.3 (0.46)	16.1 (0.48)	17.0 (0.08)
TS (g/L)	14.5 (0.14)	12.1 (0.42)	16.5 (0.50)	16.3 (0.07)	15.5 (0.07)
TVS (g/L)	14.3 (0.07)	11.4 (0.42)	12.6 (0.92)	12.3 (0.00)	14.6 (0.07)
TVS/TS (%)	98.0	94.2	76.3	75.7	94.2

[a] Not detected.

Please cite this article in press as: Kim, J., et al. Anaerobic co-digestion of spent coffee grounds with different waste feedstocks for biogas production. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.10.015