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Research article

Minimization of diauxic growth lag-phase for high-efficiency biogas production

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ABSTRACT

The objective of this study was to develop a minimization method of a diauxic growth lag-phase for the biogas production from agricultural by-products (ABPs). Specifically, the effects of proximate composition on the biogas production and degradation rates of the ABPs were investigated, and a new method based on proximate composition combinations was developed to minimize the diauxic growth lag-phase. Experiments were performed using biogas potential tests at a substrate loading of 2.5 g VS/L and feed to microorganism ratio (F/M) of 0.5 under the mesophilic condition. The ABPs were classified based on proximate composition (carbohydrate, protein, and fat etc.). The biogas production patterns, lag phase, and times taken for 90% biogas production (T90) were used for the evaluation of the biogas production with biochemical methane potential (BMP) test. The high- or medium-carbohydrate and low-fat ABPs (cheese whey, cabbage, and skim milk) showed a single step digestion process and low-carbohydrate and high-fat ABPs (bean curd and perilla seed) showed a two-step digestion process. The mixture of high-fat ABPs and high-carbohydrate ABPs reduced the lag-phase and increased the biogas yield more than that from single ABP by 35–46%.

1. Introduction

Reckless consumption and exploit of fossil fuels and natural (agricultural and forest) resources due to industrial development and population growth create energy shortage and environmental pollution, and these problems have been emerged as international treats (Choi et al., 2003; Lim et al., 2012). According to the 3rd Basic Plan for Technology Development, Application, and Deployment of New & Renewable Energy in Korea, the share of renewable energy in total energy is expected to reach 11% (Energy Agency Korea, 2014); therefore, various renewable energy policies have been implemented to achieve the goal. Especially treatments of organic wastes have been one of the major issues (Kim, 2014). Methods of the organic waste (food waste and animal manure) disposal are classified into two types: aerobic treatment and anaerobic treatment. (Kim et al., 2012). The anaerobic treatment handles wastewaters with high concentrations of organic material and requires less energy and maintenance costs; moreover, it contributes to the renewable energy policies by using biogas that occurs during the processing (Park, 2015; Kim et al., 2014). Biogas production is influenced by the amount of the added organic materials, pH of the digester, toxic substances, and anaerobic condition C/N ratio. In addition, biogas production is influenced by chemical composition and characteristics of the initial organic materials that give significant effects on the decomposition efficiency of the anaerobic organic materials and methane production (Chynoweth et al., 1993; Walker et al., 2009). Ratio in the components of organic wastes differs depending on seasons and regions, and the performance of the anaerobic digestion differs accordingly. Kafle and Kim (2013) reported that biogas production is not smooth with high-carbohydrate and high-fat by-products, and this is caused by a lag-phase of diauxic growth, one of biogas production patterns. Ashekuzzaman and Poulsen (2011) reported that diauxic (two phase decomposition) was observed for both food waste and leaves/straw during bench-scale, indicating adaptation by the microorganisms and this was evident from the intermediate period of low or no gas production from 2.5 to 12 days for food waste and 4–21 days for leaves/straw. Similarly Zhang et al. (2013) reported that the biogas production for canola plants increased quickly during the first 6 days, following a plateau in the next 15 days, and then it began to increase again after around the 21st day, and

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became stable finally. These biogas production patterns followed the diauxic growth which shows two phases of growth pattern or reaction caused by the involvement of the fast used substrates into the slowly used ones by inhibiting the biosynthesis of the enzymes (VDI 4630, 2006). This inhibiting of the biosynthesis interrupts the microbial growth and increases the digestion period, which has a negative effect on the biogas production. Therefore, it is needed to define the biogas production pattern based on the composition of organic substances treated. In this study the proximate analysis which is a partitioning of compounds in a feed based on the chemical properties of the compounds was introduced to categorize the chemical composition of the organic substances and suggest the method for the high-efficiency biogas production.

The objective of this study was to examine a method to minimize the length of a lag-phase for high-efficiency biogas production depending on the combination of the proximate composition. Specifically, the lag-phase of the agricultural by-products based on the proximate composition was tested and the method to minimize the length of the lag-phase by various combinations of the proximate composition was suggested.

2. Materials and methods

2.1. Experimental materials

Swine manure collected from Gwangil farm in Anseong City, Korea was processed with the anaerobic treatment in a continuous digester at medium temperature (36.5 °C) and used as a digestive inoculum for this study. Agricultural by-products were purchased at a market and cheese whey was collected from the Green Dairy Division in Sunchon National University and was refrigerated. The pH of the digestive inoculum 8.71–8.54, and VS/TS of the agricultural by-products was 0.856–0.927 (Table 1). Each experiment was repeated three times and a mean value was used in the study.

2.2. Classification of the agricultural by-products

In this study carbohydrate, protein, and fat were divided into three levels (high, medium, and low) following the classification of Kafle and Kim (2013). The results of a survey for the proximate composition of the domestic agricultural by-products showed that 50–70% of total carbohydrate (TC), 15–30% of crude protein (CP), and 7.5–15.0% of fat, ether extract (EE) are observed. Thus, basis for the agricultural by-products was determined as shown in Table 2.

Table 2
Basis for ABPs classifications (Kafle and Kim, 2013)

	TC (%)	CP (%)	EE (%)
Low	<50	<15	<7.5
Medium	50–70	15–30	7.5–15.0
High	>70	>30	>15.0

TC, Total Carbohydrate; CP, Crude Protein; EE, Fat and Ether Extract.

2.3. Batch digestion start-up and experimental design

A batch digester was employed to analyze the amount and components of the biogas production (Fig. 1). A vial of 1.3 L was used in the study, and actual volume of 0.8 L was used (El-Mashad and Zhang, 2010). A feed to microorganism ratio of 0.5 was maintained for all experiments (Kafle et al., 2013), and sludge and organic materials were input in the digester after determining the input. And then distilled water was added to match the actual volume. 100% pure Nitrogen was injected for more than 2 min to create the anaerobic conditions, and the digester was sealed with a silicone rubber stopper. The experiments were conducted in an incubator to maintain the batch digester at medium temperature 36.5 °C, and the digester was stirred for two minutes before measuring the amount of biogas produced every 24 h for smooth gas production.

Supplementary material lists the experimental design of this study. Experiment 1 was conducted to examine the lag-phase based on the total carbohydrate, crude protein, and ether extract that were the proximate composition of each agricultural by-product. Skim milk waste (SMW), corn DDGS (DDGS), cabbage waste (CW1), carrot waste (CW2), radish waste (RW), perilla seed waste (PSW), rice straw waste (RSW), bean-curd waste (BCW), and cheese whey (CW3) were used in this study, and BMP experiments were lasted for 70 days.

Experiment 2 was conducted to investigate the method to minimize the length of the lag-phase by mixing the agricultural by-products with organic materials having different decomposition characteristics. High-fat agricultural by-products such as bean-curd waste (BCW) and perilla seed waste (PSW) were mixed with high-carbohydrate one such as cheese whey (CW3) in a ratio of 10:90–97:3, and the BMP experiment was lasted for 60 days.

2.4. Biogas measurement and analytical methods

This study measured methane emissions during the anaerobic incubation period, and the temperature inside the digester and headspace pressure were calibrated by using Eq. (1) to obtain cumulative methane production curves. The daily biogas production of each digester was determined by the volume of biogas produced, which was calculated from the volume and pressure in the headspace of the digester (El-Mashad and Zhang, 2010). A WAL-BMP-Test system (type 3150, Wal, Germany) was used to measure the gas production in the digester (Hansen et al., 2004; Owen et al.,

Table 1
Characteristics of inoculum and agricultural by-products (ABPs).

	TS (%)	VS (%)	VS/TS	pH	VFA (mL/g)	Alkalinity (mL/g)	VFA/Alk
Inoculum 1	1.95	0.86	0.439	8.71	2988	11,066	0.27
Inoculum 2	1.71	0.76	0.442	8.54	3261	14,178	0.23
Skim milk waste, SMW	8.69	7.90	0.909	6.31	–	–	–
Corn DDGS, DDGS	84.57	72.81	0.861	–	–	–	–
Cabbage waste, CW1	10.33	9.10	0.881	6.18	–	–	–
Carrot waste, CW2	10.29	8.97	0.872	6.19	–	–	–
Radish waste, RW	5.76	5.19	0.901	6.11	–	–	–
Perilla seed waste, PSW	97.24	87.62	0.901	6.65	–	–	–
Rice Straw waste, RSW	89.99	76.07	0.845	6.57	–	–	–
Bean-curd waste, BCW	16.91	15.80	0.934	6.29	–	–	–
Molasses waste, MW	69.33	59.35	0.856	5.25	–	–	–
Cheese Whey, CW3	7.09	6.58	0.927	4.50	–	–	–