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Enhancement of methane production from co-digestion of chicken manure with agricultural wastes

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HIGHLIGHTS

- Co-digestion of chicken manure and agricultural wastes was used to improve methane production.
- Semisolid material (10% TS) was used at the thermophilic and mesophilic laboratory conditions.
- Co-digestion resulted in increase of the methane production by 93% (e.g. 695 mL g^{-1} VS).
- Ammonia accumulation was reduced by 39%, while 100% of acetate produced was degraded to methane.

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ABSTRACT

The potential for methane production from semi-solid chicken manure (CM) and mixture of agricultural wastes (AWS) in a co-digestion process has been experimentally evaluated at thermophilic and mesophilic temperatures. To the best of author's knowledge, it is the first time that CM is co-digested with mixture of AWS consisting of coconut waste, cassava waste, and coffee grounds. Two types of anaerobic digestion processes (AD process) were used, process 1 (P1) using fresh CM (FCM) and process 2 (P2) using treated CM (TCM), ammonia stripped CM, were conducted. Methane production in P1 was increased by 93% and 50% compared to control (no AWS added) with maximum methane production of 502 and 506 mL g^{-1} VS obtained at 55 °C and 35 °C, respectively. Additionally, 42% increase in methane production was observed with maximum volume of 695 mL g^{-1} VS comparing P2 test with P2 control under 55 °C. Ammonia accumulation was reduced by 39% and 32% in P1 and P2 tests.

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1. Introduction

The fast population growth, the depletion of traditional energy sources, and the increase in their costs prompted many countries to search for new and renewable energy sources (Xie et al., 2011). Biogas through anaerobic digestion offers a promising substitution for fossil fuel and has significant advantages over other forms of bioenergy production.

The growing population also demands for animal protein products, which led to the intensification of the agricultural industry, creating "factory farm" or "CAFO" (concentrated animal feeding operation). These farms allow meat and eggs to be produced at a much lower cost than traditional methods. The animals on these farms are usually confined for most of their life span, under increased stocking densities, leading to large volumes of excreta being accumulated in concentrated areas. For example, the poultry industry in the USA generates more than 10 million tons of poultry litter waste from boiler operations per year (Sharma et al., 2013). In Japan, about 13 million tons of CM was generated annually from broiler and layer farms (MAFF, 2008), mostly treated by composting or incineration.

If improperly managed, poultry wastes can cause serious damage to the environment by polluting water and air, which can harmfully impact human and animal health. On the other hand, CM is a plentiful source of biomass for biogas production via anaerobic digestion (AD), which has not been fully utilized so far, due to the main problems associated with inhibition by accumulation of ammonia and volatile fatty acids (VFA). Since CM has a higher fraction of biodegradable organic matter than other animal wastes, anaerobic decomposition of uric acid and undigested proteins in CM results in the production of high amounts of unionized ammonia and ammonium ions (Abouelenien et al., 2009). AD can be classified as liquid, semi-solid, and solid or dry

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state, when the total solids of substrate are <10%, 10–15%, or >15%, respectively (Li et al., 2011). Based on our previous studies of the mesophilic dry fermentation of CM (TS = 25%), 103.5 mL/g VS methane were produced in 125-mL serum vials, despite the high levels of ammonia varied from 6.4 up to 14 g-N L^{-1} CM (Abouelenien et al., 2009). Furthermore, Niu et al. (2013) reported a feasibility of mesophilic methane fermentation of CM with biogas production yield of 400 mL/g VS in CSTR (TS = 11.2%), when TAN concentration was lower than 5000 mg/L. These authors extended the ammonia inhibition threshold up to 15,000 mg/L, which is generally depending on the adaptation degree of microbial population (Rajagopal et al., 2013). Other relevant factors which may hinder the digestion process, and thus needing special consideration, are organic overloading caused by high concentration of total solids (TS) and inadequate carbon to nitrogen ratio in the digester.

Numerous studies show that the sensitivity of the anaerobic process may be improved by combining several waste streams (Table 1). Co-digestion with various agro-industrial residues was reported with particular interest being shown in the co-digestion of poultry manures with straws (Li et al., 2013; Magbanua et al., 2001; Wang et al., 2012, 2013). As overall, co-digestion of manure with energy crops/crop residues can increase the biogas yield: (i) helping to maintain an optimal pH for methane producing bacteria; (ii) decreasing free ammonia/ammonium inhibition, which may occur in AD of manure alone; and (iii) providing a better C/N ratio in the feedstock (Xie et al., 2011). However, the selection of feedstock for AD is influenced by its accessibility and availability due to the costs associated with their collection and transportation (Li et al., 2011).

Many researchers have explored the co-digestion of chicken manure with other organic wastes, as presented in Table 1, however, only a few studies on AD of coconut, cassava, and coffee ground wastes were reported. Because of their high energy potential, coconut and cassava wastes were used as co-substrates for AD of animal manure (Alvarez and Liden, 2008). AD of spent coffee grounds (3 kg m^{-3} day^{-1}) with efficient recycling conversion of 99% solids and gas yields of 0.54 m^3 kg^{-1} (56–63% methane) was achieved by Lane (1983). Nevertheless, gas production declined steadily over the test period and after 80 days had fallen from an initial value of 1.70 L d^{-1} to 0.33 L d^{-1}, due to the inhibition of the digester liquors. Although, co-digestion has been utilized for many years, the conditions used for mixing different feedstock must be evaluated empirically in order to be optimized (Navaneethan et al., 2011). This will allow enhancing the co-digestion process, so that it can fulfill the goal of CM as well as agricultural wastes (AW) nutrients disposal setback.

In the present work, semisolid co-digestion (TS 10%) of agricultural wastes (coconut, cassava wastes, and coffee grounds) with fresh CM or treated CM was studied. Two types of AD processes with repeated batch cultures were applied: process (1) co-digestion of FCM and AWS, and process (2) co-digestion of TCM and AWS. Both mesophilic (35 °C) and thermophilic (55 °C) fermentation conditions were used in each set of experiments. The main goal of the present study was to evaluate the effect of agricultural wastes added as co-substrates on the performance of anaerobic co-digestion of CM. The effects of temperature and types of CM on AD process parameters as biogas yield, ammonia concentration, pH, and VFA degradation were also investigated. Four batches were conducted with the main aim to investigate the stability of the co-digestion processes.

2. Methods

2.1. Substrates and seed sludge used for anaerobic co-digestion processes

Fresh chicken manure (FCM) from Hiroshima University chicken farm (cage layer system) was collected from deposits directly under the chicken cages. Ammonia stripped CM (TCM) was produced by partial removal of ammonia from fresh CM using technique described previously (Abouelenien et al., 2010). The characteristics of FCM and TCM are presented in Table 2. Agricultural wastes, which contained mixture of cassava (root residue wet cake), coconut (wet cake), and coffee grounds, were shipped as frozen from Thailand to the Hitachi Engineering & Services-Japan. Characteristics of each of the AWS are presented in Table 3.

The sludge, collected from Wastewater Treatment Centre in Hiroshima, Japan, was anaerobically incubated at 55 °C for 60 days in the laboratory, in order to achieve complete consumption of the available substrate. The characteristics of seed sludge are shown in Table 2.

2.2. Experimental set up and procedures

2.2.1. AD process 1of semi-solid (10% TS) anaerobic co-digestion of FCM and AWS with repeated batch culture (P1)

The substrates consisted of FCM, mixed with AWS and inoculated with seed sludge. Water was added to adjust TS to 10%, so that the ratio of FCM to AWS was 7:3 (not controlled). Ratio of inoculum (Ozu sludge) to substrate (FCM + AWS) was kept 3:1 (V/V). The substrates were placed in a set of 500 mL capacity anaerobic vials, 240 g of each. As control, vials without AWS supplement were used. The head space in the vials was purged with N2 gas, andsealed with rubber stoppers in crimped aluminum caps. These bottles were incubated anaerobically at 35 ± 2 °C or 55 ± 2 °C. Semi-continuous batch culture was used for this co-digestion. Triplicate vials for each conditions were used. The quantities, composition, and conditions of anaerobic digestion of these substrates and co-substrates are illustrated in Table 4.

2.2.2. AD process 2 (P2) of semi-solid (10% TS) anaerobic co-digestion of TCM and AWS with repeated batch culture

The treatment procedures of TCM and FCM were carried out identically, which was described in Section 2.2.1.

The quantities, compositions, and conditions of anaerobic digestion processes of these substrates and co-substrates are illustrated in Table 5.

2.3. Analytical methods

Volumes of gases and their composition were monitored every day. When gas production stopped, (at the end of each batch) the vials were opened, and samples were taken to measure the ammonia produced, volatile fatty acids (VFAs) and pH. During the next step of the new batch culture, some amounts of the vial contents were removed, and the vials were replenished with the same amounts of substrates. This procedure for batch culture was repeated during the 4 batches and was conducted over a total duration of 176 days. Duration of the first batch was 40 days, second batch – 35 days, the third batch – 39 days, and the fourth batch – 62 days.

Fermentation samples (ca. 0.3 g wet weight) were withdrawn into a 2-mL plastic tube, and suspended with 1.2 mL deionized water. The suspensions were centrifuged at 3000 rpm for 10 min at 4 °C, and the clear supernatants were used to measure pH, ammonia, and volatile fatty acids (VFAs). VFAs were measured using a High Performance Liquid Chromatograph (Shimadzu, Kyoto, Japan) equipped with Aminex HPX-87H Column (300 mm × 7.8 mm, Bio-Rad, Tokyo, Japan). The column temperature was kept at 65 °C. Flow rate of the mobile phase (0.005 M H_2SO_4 solution) was 0.8 mL min^{-1} of. Ammonia was measured using a commercially available ammonia test kit (Wako Ltd. Osaka, Japan). TOC was determined by a TOC analyzer (TOC-5000, Shimadzu). TS, VS, TKN, and pH were measured in accordance with the

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