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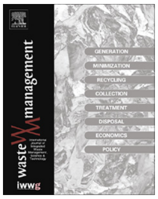

Potential of anaerobic digestion for material recovery and energy production in waste biomass from a poultry slaughterhouse

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ABSTRACT

This study was carried out to assess the material and energy recovery by organic solid wastes generated from a poultry slaughterhouse. In a poultry slaughterhouse involving the slaughtering of 100,000 heads per day, poultry manure & feather from the mooring stage, blood from the bleeding stage, intestine residue from the evisceration stage, and sludge cake from the wastewater treatment plant were discharged at a unit of 0.24, 4.6, 22.8, and 2.2 Mg day^{-1}, consecutively. The amount of nitrogen obtained from the poultry slaughterhouse was 22.36 kg 1000 head^{-1}, phosphate and potash were 0.194 kg 1000 head^{-1} and 0.459 kg 1000 head^{-1}, respectively. As regards nitrogen recovery, the bleeding and evisceration stages accounted for 28.0% and 65.8% of the total amount of recovered nitrogen. Energy recovered from the poultry slaughterhouse was 35.4 N m^3 1000 head^{-1} as CH_4. Moreover, evisceration and wastewater treatment stage occupied 88.1% and 7.2% of the total recovered CH_4 amount, respectively.

1. Introduction

For the past decades, the poultry consumption in South Korea has increased rapidly from 6.9 kg person^{-1} (2000 year) to 10.7 kg person^{-1} (2010 year) (Korean Ministry for Food, Agriculture, Forestry and Fisheries, 2011). As a result of the growth in the poultry industry, the high amounts of organic solid by-products, which are considered to be industrial organic wastes, are generated from poultry slaughterhouses. These organic solid wastes need to be strictly managed by governmental legislation. Varieties of organic solid wastes are generated according to the processing steps of the poultry slaughterhouse. As regards the main solid organic wastes, there are poultry manure & feather of the mooring step, blood of the bleeding process, feathers from the picking and singeing process after scalding, the intestinal residues of the evisceration process, and born by meat trim step. Moreover, sludge cake from the wastewater treatment plant of slaughterhouse is generated (Salminen and Rintala, 2001). These organic solid wastes are characterized by high total solid (TS) contents above 10–15% that are mainly composed of animal proteins and fats (Mata-Alvarez et al., 2000). Until now organic solid wastes from poultry slaughterhouse such as blood, feather, and intestine residues have mainly been recycled as animal feedstock through the rendering process or have used as resources for the production of agricultural compost except for the sludge cake generated from the wastewater treatment plant. Sludge cake should be to be landfilled after incineration because that is considered to be the solid waste of an industrial wastewater treatment plant. However, these organic solid wastes generated from the slaughterhouse were a good substrate for anaerobic digestion producing biogas and anaerobic digestion has been considered to be one of the best alternatives for nutrient and energy recovery from organic solid wastes with high protein and fat content (Hejnfelt and Angelidaki, 2009; Kaparaju et al., 2010).

Literature on the characteristics of organic solid wastes is scarse, including animal protein and fat from poultry slaughterhouses, though lots of studies have been carried out for the characterization and anaerobic digestion of wastewater treatment sludge. Salminen and Rintala (2001) have reviewed the treatment option for organic solid wastes from slaughterhouses. Cooper and Russel (1992), Papinaho (1996), and Papadopoulos (1985) have investigated the discharging unit of specific poultry residues, and have reported that blood, feather, and evisceration products accounted for 5%, 10%, and 11.3% of the live poultry weight. Nowadays, pre-treatment and anaerobic digestion techniques of organic solid wastes from poultry slaughterhouses have been studied by several researchers to improve the efficiency of anaerobic digestion, avoiding the potential risk to human and animal health (Rodríguez-Abalde et al., 2011; Kirchmayr, 2009). However, studies for mass and energy recovery by various organic solid wastes in the context of full-scale slaughterhouse facilities are insufficient, although the

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slaughterhouse, as a point source of large amount of organic solid wastes, needs to be managed and assessed within the framework of environmental management. The objective of this study is to assess levels of material and energy recovery by organic solid wastes within the confines of a full-scale slaughterhouse.

2. Materials and methods

2.1. Slaughterhouse wastes

The selected slaughterhouse wastes were sampled at a poultry slaughterhouse facility with a slaughtering capacity of 120,000 heads per day, located in Eumseong, Korea. Processes of the slaughterhouse facility were composed of mooring, slaughtering, bleeding, scalding, picking and singeing, evisceration, washing, chilling, and further processing for meat cutting and deboning, consecutively. Poultry manure & feathers of the morning step, blood of the bleeding step, intestine residues of the evisceration step, and sludge cake from the wastewater treatment plant were collected for this study, respectively. Furthermore, waste discharging units were investigated and extracted from the waste management data for 2010 year.

2.2. Anaerobic batch experiments

Anaerobic methane production was assessed by batch anaerobic reactor in mesophilic conditions (38 °C). Inoculum was collected from a farm scale biogas plant (Anseong, Korea) which digested pig slurry. The characteristics of inoculum were shown in Table 1. The inoculum sample collected from anaerobic digester was sieved in 2 mm size, and prior to initiating the BMP assay, an inoculum sample of 2 L was pre-incubated in 5 L anaerobic batch reactor under mesophilic conditions (38 °C) to deplete the residual biodegradable organic material present in the inoculum samples. Thereafter, pre-incubated digestate was prepared as an inoculum for BMP assay. Subsequently, the fermented digestate was prepared as an inoculum for BMP assay. Substrate to inoculum ratios of all BMP assay cultures were equal to 0.3 $\text{g-VS}_{\text{substrate}}/\text{g-VS}_{\text{inoculum}}$ and BMP assays were carried out in a working volume of 80 mL, using the 160 mL size serum bottle. The head space of serum bottle was filled with N_2 gas, and sealed with a butyl rubber stopper. BMP bottles of triplicate for each sample were incubated up to 48 days for manure & feather, blood, and sludge cake, and 105 days for intestine residues in the convection incubator, mixed manually daily during the incubation period. Methane production was corrected for standard temperature and pressure (STP), and BMP ($\text{N m}^3\ \text{kg}^{-1}\text{-VS}_{\text{added}}$) was determined by unit of VS content of waste added to the vial.

In order to describe the progress of cumulative methane production, the modified Gompertz equation (Eq. (1)), employed to fit the cumulative methane production data, was shown as follows (Costa et al., 2012),

$$M = P \times \exp\left\{-\exp\left[\frac{R_m \times e}{P}(\lambda - t) + 1\right]\right\} \qquad (1)$$

Table 1
Characteristics of inoculum (values in parentheses are standard deviations).

Parameters	Inoculum
pH	8.1 (0.1)
TS (g L^{-1})	14.2 (0.6)
VS (g L^{-1})	7.7 (0.3)
TCOD (g L^{-1})	18.6 (2.3)
TKN (g L^{-1})	5.2 (0.5)
NH_4–N (g L^{-1})	4.0 (0.3)

where M was the cumulative methane production (mL); e was exp (1); R_m is the maximum specific methane production rate (mL d^{-1}); P was methane production potential (mL); λ was lag phase time (days).

2.3. Analytical procedures

Total solid (TS), volatile solid (VS), pH, soluble chemical oxygen demand (SCOD), total chemical oxygen demand (TCOD), total nitrogen (TKN), ammonium nitrogen (NH_4^+—N), total phosphorus (TP), and alkalinity were determined according to standard methods (APHA, 1998). Element compositions (C, H, N, O, S) were determined using the element analyzer (EA1108, Thermo Finnigan, USA). Crude protein was determined by multiplying total nitrogen values by 6.25, and crude fat was extracted with ether using a soxhlet system. Crude fiber was measured as the volatile fraction by ignition after boiling with 1.25% H_2SO_4 solution and 1.25% NaOH solution for 30 min, respectively. Total gas production by BMP assay was measured daily for the first 5 days and every 2–3 days afterwards by displacement of an acidified brine solution in burette and the volume of displaced solution after correcting to atmospheric pressure was recorded (Beuvink et al., 1992; Williams et al., 1996). To investigate the gas composition, the CH_4 and CO_2 concentration in the gas samples were determined using a gas chromatograph (Clarus 680, PerkinElmer, USA) equipped with a thermal conductivity detector with a HayeSepQ packed column (CRS Inc., USA). The column was operated with helium as carrier gas at the constant flow rate of 5 mL min^{-1}. The injector was maintained at 150 °C, the oven was set at 90 °C, and the detector was set at 150 °C.

2.4. Theoretical methane potential

The chemical compositions of substrates were determined from elemental analysis data, and the theoretical methane potential (B_{th}) was estimated based upon the stoichiometry of the degradation reaction using Buswells formula (Boyle, 1976):

$$\begin{aligned} &C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right)H_2O \\ &\rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3d}{8} - \frac{e}{4}\right)CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4} + \frac{3d}{8} + \frac{e}{4}\right)CO_2 \\ &+ dNH_3 + eH_2S \end{aligned} \qquad (2)$$

The B_{th} in terms of normal cubic meter per VS content ($\text{N m}^3\text{-CH}_4\ \text{kg}^{-1}\text{-VS}_{\text{added}}$) under standard conditions (0 °C, 1 atm) was calculated from the following equation:

$$B_{th}(\text{N m}^3\ \text{kg}^{-1}\ \text{VS}_{\text{added}}) = 22.4 \times \left[\frac{\left(\frac{4a + b - 2c - 3d - 2e}{8}\right)}{12a + b + 16c + 14d + 32e}\right] \qquad (3)$$

2.5. Calculation of material and energy recovery

Material and energy recovery obtained from poultry slaughterhouse were calculated by Eq. (4), and herein TMR indicated the amount of total material recovery (kg 1000 head^{-1}) of N, P_2O_5, and K_2O, respectively; TER indicated the amount of total energy recovery ($\text{N m}^3\text{-CH}_4\ \text{1000 head}^{-1}$); i was the processing stage (i_{th}) generating a piggery slaughterhouse waste; D_i was the discharging unit ($\text{kg-waste 1000 head}^{-1}$) of the i_{th} piggery slaughterhouse waste; C_{VSi} was the VS content (w/w, %) of the i_{th} piggery slaughterhouse waste, and C_{MRi} and Y_{URi} were the material and methane yield (w/w, % and $\text{N m}^3\ \text{kg}^{-1}\text{-VS}_{\text{added}}$) of i_{th} piggery slaughterhouse waste, respectively.