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Batch and semi-continuous anaerobic co-digestion of goose manure with alkali solubilized wheat straw: A case of carbon to nitrogen ratio and organic loading rate regression optimization

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HIGHLIGHTS

- Development of C/N and OLR regression optimization models.
- Methane enhancement up to 96.10% due to C/N optimization.
- 20–30 is the optimum C/N range for AD of goose manure and wheat straw.
- 71.19% lignin removal due to NaOH solubilization of the wheat straw.
- Optimum OLR of 3 g.VS/L.d at C/N of 25 during CSTR experimentations.

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ABSTRACT

The present study focused on carbon to nitrogen ratio (C/N) and organic loading rate (OLR) optimization of goose manure (GM) and wheat straw (WS). Dealing the anaerobic digestion of poultry manure on industrial scale; the question of optimum C/N (mixing ratio) and OLR (daily feeding concentration) have significant importance still lack in literature. Therefore, Batch and CSTR co-digestion experiments of the GM and WS were carried out at mesophilic condition. The alkali (NaOH) solubilization pretreatment for the WS had greatly enhanced its anaerobic digestibility. The highest methane production was evaluated between the C/N of 20–30 during Batch experimentation while for CSTRs; the second applied OLR of (3 g.VS/L.d) was proved as the optimum with maximum methane production capability of 254.65 ml/g.VS for reactor B at C/N of 25. The C/N and OLR regression optimization models were developed for their commercial scale usefulness.

1. Introduction

Due to high rate of industrialization and commercialization in the developing countries, a swift improvement in the rural development was found predominant during the last decade. These developments results in high demand of energy and food requirements that ultimately boosts the poultry sector among rural side. In China especially, goose is considered a favorite protein source and 2.5 million tones of goose production by food and agriculture organization (FAO) were reported in 2010, which contributes about 2.6% of the world poultry meat production (FAO, 2012). Enhanced poultry industry also emerged as a major source of environmental eutrophication that seriously deteriorates the atmosphere, soil structure and groundwater contamination due to direct application of goose manure within the fields (Abouelenien et al., 2010). Likewise, wheat straw is also an abundant biomass resource found in China with 125.6 million tons production and most of it is burnt standing in fields or for direct burning in kitchen that results in addition of green house gas emissions (GHG) (Hassan et al., 2016b; Li et al., 2015b).

Anaerobic digestion (AD) also emerged as a promising treatment option to reduce the risk of environmental pollution by volumetric reduction of the poultry manure. Anaerobic digestion is a biochemical conversion of volatile solids of the substrate into useful gas termed as methane or generally biogas consisting of (50–70)% methane (Zhen et al., 2016). Biogas production through anaerobic digestion process has become Chinese national strategy and goal in order to improve the socio-economic situation

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of the farmers, promotion of rural construction and clean rural environment. (Li et al., 2015b). Anaerobic digestion is well developed for the livestock manures but for the lignocellulosic biomass, still reluctance was observed on industrial scale due to their high lignin content that controls the hydrolysis step of the AD, that's why pretreatment was found prerequisite prior to AD of the lignocellulosic biomasses (Hassan et al., 2016a; Kumar et al., 2013).

The intrinsic property of the lignocellulosic straw reveals its high C/N ratio, floatation in the reactor, high lignin content and cellulosic crystallinity that creates critical situation to the methanogens. Different researches were carried out to reduce the lignin and cellulosic crystallinity to enhance the fermentation stability of the lignocellulosic biomass like pretreatment and co-digestion (Li et al., 2015b). On the other side, livestock manure consisting of high nitrogen content with elevated recalcitrant fiber that limits their anaerobic biodegradability during the AD process (Gronroos et al., 2005). Therefore, C/N optimization was found essential and co-digestion of poultry manure with agricultural biomass has provided a pivotal approach to regulate the nutrient balance during the anaerobic digestion process with enhanced methane production (Comino et al., 2010). Dealing the anaerobic digestion in semi-continuous stirring tank reactor (CSTR), the question of optimum organic loading rate (OLR) has significant importance. Especially, dealing with the livestock manure, those posses high contents of total ammonium nitrogen (TAN), their higher OLR may results with elevated concentrations of TAN within the CSTR that can possibly inhibit the anaerobic digestion process. Therefore, determining the influence of OLR on the anaerobic digestion performance stability of co-digestion has a significant importance in order to optimize the OLR and evaluate the appropriate operational conditions for a commercial scale CSTR.

Numerous studies were reported about the co-digestion of livestock manure and agricultural straw. Wang et al. reported a large number of experiments on co-digestion of wheat straw with dairy manure and chicken manure, corn stover with chicken manure and dairy manure and rice straw with pig manure, chicken manure and dairy manure (Wang et al., 2012a, 2013). Another study conducted on co-digestion of goat manure with rice straw, wheat straw and corn stover (Zhang et al., 2013). Wu et al. conducted co-digestion by using swine manure with corn stover, wheat straw and oat straw (Wu et al., 2010). The significant methane enhancement was reported by all the above stated researches due to co-digestion of the animal manures and agricultural straw. Dong Li et al. have conducted co-digestion of rice straw and pig manure about the organic loading optimization at OLRs of 3.0, 3.6, 4.2, 4.8, 6.0, 8.0, and 12.0 g.VS/(L.d) and specific biogas production of 413 ml/g.VS was achieved at different OLR of (3–8) g.VS/(L.d) (Li et al., 2015b). Another similar study conducted by the same author about the co-digestion and OLR optimization of rice straw and cow manure at the same OLRs reported above with maximum average specific biogas production of 383.5 ml/g.VS at OLR of 6 g.VS/(L.d) (Li et al., 2015a).

The present research focused on the co-digestion of goose manure and pretreated wheat straw to optimize the proper C/N and OLR. The Batch experiment were carried out to evaluate optimum C/N ratio and C/N regression model while semi-continuous experiments were adopted to develop OLR regression optimization model. The effects of pretreatment on the chemical composition of the wheat straw were also determined. The anaerobic digestion process performance parameters like total ammonia (TAN), free ammonia (FA), total volatile fatty acids (TVFAs), ethanol production, soluble chemical oxygen demand (CODs) and pH were strongly monitored during the whole AD process.

2. Material and methods

2.1. Experimental material collection and preparation

Fresh goose manure (GM) was collected from Changzhou Goose Production Farm, Nanjing, Jiangsu Province, China. The goose manure was stored in refrigerator at 2 °C for Batch and downstream CSTR daily feedings. The wheat straw (WS) was collected from Jiangpu agricultural research station. It was first dried in the oven at 105 °C for 24 h. Afterwards it was chopped and grinded to less than 1 mm size. This grinded WS was utilized for pretreatment further and stored in refrigerator. The chemical composition of the GM, untreated and pretreated WS and seed sludge were determined and the results were presented in Table 1. The inoculum was collected from a biogas plant in working condition located at Pukou district, Nanjing, China. That biogas plant was (UASB) upflow anaerobic sludge blanket type working at mesophilic conditions and equipped with horizontal stirrers. As the seed sludge was fully digested from that biogas plant, that's why it was kept in anaerobic conditions for further two weeks for activation purpose. The sludge was feed with 2 g of glucose/L.day to improve the methanogenic consortium within the sludge (Hassan et al., 2016a). Afterwards, it was strained through 1 mm polyester screen to remove all the foreign substance before it was used as sludge in Batch and CSTR experimentation (see Table 2).

2.2. Batch and CSTR experimental setup and pretreatment of wheat straw

In order to reduce the lignin and cellulosic crystallinity and enhance the anaerobic biodegradability of the WS, thermochemical

Table 1
Chemical characterization of the goose manure (GM), pretreated and untreated wheat straw (WS) and seed sludge (mean values ± standard deviation).

Parameters	Units	GM	WS untreated	WS Pre-treated with 7.5% NaOH	Seed sludge
TS	%	29.94 ± 3.1	98.2 ± 0.1	99.2 ± 0.4	2.4 ± 0.9
VS	%	69.1 ± 3.3	95.9 ± 0.5	97.4 ± 0.6	75.8 ± 1.6
TN	%	2.5 ± 0.2	0.85 ± 0.1	0.82 ± 0.3	3.3 ± 0.4
TP	%	1.1 ± 0.2	0.41 ± 0.5	–	2.2 ± 0.3
TAN	mg/L	1835.3 ± 56	–	–	1683 ± 45
FAN	mg/L	92.2 ± 9.8	–	–	65.3 ± 4.2
TOC	%	38.5 ± 1.2	52.1 ± 0.1	43.4 ± 0.1	22.4 ± 1.2
OM	%	66.3 ± 2.1	89.9 ± 0.2	74.9 ± 0.1	38.6 ± 0.7
C/N	–	15.3 ± 0.7	61.4 ± 0.4	53.0 ± 0.8	6.9 ± 0.4
Cellulose	%	–	39.3 ± 0.9	40.4 ± 0.7	–
Hemi-cellulose	%	–	21.3 ± 0.2	16.7 ± 0.5	–
Lignin	%	–	10.1 ± 0.2	5.9 ± 0.3	–
pH	–	7.7 ± 0.0	–	–	7.5 ± 0.1
CODs	mg/L	7564 ± 89	–	–	6304 ± 369
TVFAs	mg/L	–	–	–	283.8 ± 0.0
Protein	%	15.1 ± 0.5	–	–	–