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Anaerobic co-digestion of cyanide containing cassava pulp with pig manure

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HIGHLIGHTS

- Cyanide containing CP is a major by product from cassava starch industries.
- Co-digestion of cyanide-containing CP and PM was investigated.
- Digester sludge acclimatized well to cyanide in CP leading to cyanide degradation.
- Digester performance was stable between OLR of 2–6 kgVS/m^3 d.
- Particulate solubilization did not take place efficiently over OLR of 7 kgVS/m^3 d.

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ABSTRACT

Anaerobic co-digestion of cyanide-containing cassava pulp with pig manure was evaluated using laboratory scale mesophilic digester. The digester was operated in a semi-continuous mode with the mixed feedstock having C/N ratio of 35:1. Digester startup was accomplished in 60 days with loading of 0.5–1 kgVS/m^3 d. Subsequently, the loading to digester was increased step-wise from 2 to 9 kgVS/m^3 d. Digester performance was stable at loading between 2 and 6 kgVS/m^3 d with an average volatile solid removal and methane yield of 82% and 0.38 m^3/$kgVS_{added}$, respectively. However, beyond loading of 7 kgVS/m^3 d, solubilization of particulate matter did not take place efficiently. Cyanide present in cassava pulp was successfully degraded indicating that anaerobic sludge in the digester was well acclimatized to cyanide. The results show that cassava pulp can be successfully digested anaerobically with pig manure as co-substrate without any inhibitory effect of cyanide present in the cassava pulp.

1. Introduction

Cassava, *Manihot esculenta Crantz*, is one of the important food crops in the world with an estimated annual world production of about 210 million tons (Ghimire et al., 2015). Over seven million tons of native starch per year is produced in Thailand (Ghimire et al., 2015; Khempaka et al., 2014). About 60% of the total production of cassava is used as food for human consumption in natural form as starch or in fermented form in variety of food products (Pandey et al., 2000). The remaining is used for the animal food production and industrial purposes (Pandey et al., 2000).

Cassava pulp (CP), a solid waste rich in organic carbon, is generated during the cassava starch production process. Approximately 0.33 tons of CP are produced per ton of cassava root processed (Chavalparit and Ongwandee, 2009; Ghimire et al., 2015; Pandey et al., 2000; Sriroth et al., 2000). CP contains about 20–30% starch and 60–70% moisture on wet weight basis. It also contains fiber, protein and cyanide in small proportions (Pandey et al., 2000; Panichnumsin et al., 2010; Sriroth et al., 2000).

Only small portion of CP is used as a low cost animal feed material the remaining large amount is often left untreated, creating serious environmental problems (Panichnumsin et al., 2010). Biodegradation of CP under uncontrolled anaerobic conditions in disposal area results in extensive environmental pollution affecting air, water and soil quality. Besides releasing carbon dioxide and methane into the atmosphere under anaerobic conditions, its degradation also produces leachate that can contaminate soil and groundwater (Ali et al., 2011; Ghimire et al., 2015).

During cassava starch production, although a large amount of cyanide in tuber is extracted together with the starch granules, some cyanide may still remain in CP. The cyanide concentration in CP is reported to be in the range of 0.5–16.6 mg CNeq/kg (Gupta et al., 2010). Cyanide in CP exists in two forms (i) the cyanohydrins (ii) the free hydrocyanic acid (HCN). Only small amount of cyanogenic glucoside (linamarin) is found in CP since

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during process of cassava starch production the cyanogenic glucoside is exposed to extracellular enzyme linamarase and undergoes hydrolysis to cyanohydrin and glucose (Cuzin and Labat, 1992; Fallon et al., 1991).

Cassava tuber is rich in starch, but poor in protein contents. Typically, it contains about 80% starch and less than 2% protein (dry weight basis) (Pandey et al., 2000). The presence of toxic compounds, cyanogenic glucosides (95% linamarin and 5% lotaustralin), is major factor limiting the food value of cassava (Nambisan, 2011). There are a number of varieties of cassava, which differ in cyanide contents e.g. bitter cassava has higher concentration of cyanogenic glucoside, usually in the range of 320–1100 mg CNeq/kg (Nambisan, 2011).

Anaerobic digestion (AD) is an attractive waste treatment option for CP due to its high starch content. AD not only yields energy in the form of methane but also reduces the pollution potential of CP. However, low of nitrogen content as well as the presence of residual cyanide in CP limit its utility in anaerobic digestion process. Carbon content in CP has been reported to be high (about 40% of total solid (TS)) whereas nitrogen content is reported to be low (about 0.2% of TS). Accordingly, typical carbon/nitrogen ratio (C/N) in CP is about 210 (Panichnumsin et al., 2010). However, the optimum C/N ratio for anaerobic digestion is reported to be 20–35 (Panichnumsin et al., 2010, 2012). Thus, low nitrogen content make CP an unsuitable substrate for AD. Moreover, cyanide content in CP also may have inhibitory effect on methanogens (Annachhatre and Amornkaew, 2000; Gijzen et al., 2000; Paixão et al., 2000). These problems can be overcome by the addition of a co-substrate which is rich in nitrogen content. Thus, in co-digestion process, the C/N ratio is adjusted to an optimum values of 20–35. On the other hand, addition of co-substrate also may result in dilution of toxic compounds such as cyanide. Typically, nitrogen rich substrate such as animal manure can be used with CP during AD process (Panichnumsin et al., 2010, 2012).

Nitrogen content in pig manure (PM) has been reported to be high (about 2.5% of TS) as compared to that in CP (about 0.2% of TS). On the other hand, PM has lower carbon content (about 35% of TS) as compared to carbon content in CP (about 40% of TS). Thus, the C/N ratio of PM has lower value of about 6.6 (Panichnumsin et al., 2010). Panichnumsin et al. (2010) reported that co-digestion of CP and PM at C/N 33 achieved 41% higher specific methane yields as compared to mono-digestion.

Although the researchers have studies anaerobic co-digestion of CP and PM in single stage (Panichnumsin et al., 2010) and two-stage (Panichnumsin et al., 2012) process, there is a limited information available on the effect of cyanide content in CP on anaerobic co-digestion, particularly at higher organic loading rate (OLR). Although AD process operated at high OLR may increase biogas production, this also can lead to higher cyanide concentration in the process which could be inhibitory to methanogens. Reduced methanogenic activity due to cyanide inhibition also increases the risk of system failure due to volatile acid accumulation. Therefore, the optimal organic load needs to be evaluated for stable process performance. Thus, the objectives of this research were to: (1) evaluate the efficiency and stability of anaerobic co-digestion of CP and PM under varying OLRs in laboratory scale single stage semi-continuously stirred reactor; (2) investigate the effect of cyanide present in CP on anaerobic co-digestion of CP and PM under various OLRs.

2. Materials and methods

2.1. Substrates and seed sludge

2.1.1. Substrates

CP and PM were used as feed and co-substrates for anaerobic co-digestion. Fresh CP was obtained from cassava starch factory, located in central Thailand, while PM was obtained from a local pig farm in Pathumthani province, Thailand. Both materials were preserved in 1 kg of zip lock bags and were kept below 0 °C in order to curtail any biological activity.

2.1.2. Seed sludge

Seed inoculum was obtained from an up flow anaerobic sludge blanket reactor (UASB) treating brewery wastewater from a brewery factory. The collected sludge was allowed to settle for 24 h and the supernatant was discarded while the settled sludge was used as seed.

2.1.3. Seed sludge and substrates characterization

The seed sludge had moisture content of 98.8%, VS of 9.0 g/L and the VS/TS ratio was 0.71. Table 1 presents the characteristics of individual and mixed feedstock. Carbon content in CP was 52.1 ± 3.2% (dry weight basis) while the nitrogen content was 0.3 ± 0.1% (dry weight basis) yielding C/N ratio of 176.4 ± 3.1. On the other hand, nitrogen content in PM was 4.4 ± 0.6% (dry weight basis) and carbon content was 27.8 ± 0.8% (dry weight basis) with C/N ratio of 6.3 ± 0.6. Recommended C/N ratio in the feedstock for satisfactory anaerobic digestion is reported to be in the range 20–35 (Panichnumsin et al., 2010, 2012). Thus, CP is nitrogen deficient while PM is nitrogen rich feedstock. Accordingly, for satisfactory anaerobic digestion of CP, it is necessary to add a nitrogen rich co-substrate like PM so that the resultant C/N ratio can be adjusted in the recommended range between 20 and 35 for anaerobic digestion. Accordingly, the feedstock ratio of CP:PM was adjusted to 77:23 (wet w/w) so that the resultant C/N ratio 35.0 ± 1.1 was achieved for mixed feedstock.

2.2. Experimental set up

The anaerobic co-digestion experiments were carried out at ambient temperature and in laboratory scale single stage semi-continuously stirred reactor with total volume of 10 L and working volume of 7 L (Fig. 1). The reactor was made of polyvinyl chloride (PVC) with cylindrical body and conical bottom. It had a height and inner diameter of 26.5 and 25.5 cm, respectively and was covered with thermal insulation sheet to avoid the temperature fluctuation. The reactor was equipped with a mixer, a feeding valve, a chemical adding valve for adjusting pH and a gas valve connected to a gas counter for continuous biogas measurement. Sampling valve was located at the side of the reactor. The reactor had one outlet at the bottom for digestate removal. A stainless steel agitator was installed inside the reactor for mixing the contents for 10 min every 2 h at 50 rpm.

Table 1
Characteristics of sole material and mixed feedstock.

Characteristics	Unit	CP	PM	Mixed feedstock*
Moisture content	% wet weight	78.9 ± 0.7	78.5 ± 1.2	78.9 ± 0.9
Total solid (TS)	% wet weight	20.9 ± 0.9	20.6 ± 1.0	20.8 ± 0.8
Volatile solid (VS)	% wet weight	19.6 ± 0.8	13.1 ± 0.9	18.2 ± 0.6
Total organic carbon (TOC)	% dry weight	52.1 ± 3.2	27.8 ± 0.8	47.6 ± 0.3
Total nitrogen (TKN)	% dry weight	0.3 ± 0.1	4.4 ± 0.6	1.3 ± 0.1
C/N	–	176.4 ± 3.1	6.3 ± 0.6	35.0 ± 1.1

* Mixture of CP and PM 77:23 (w/w); CP: cassava pulp; PM: pig manure.