CONVERSION OF RAW CASSAVA ROOTS TO BIOGAS

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ABSTRACT Cassava roots, the starch-rich tubers, are one of the cheap and abundant agriculture products in Thailand. The potential conversion of raw cassava roots to biogas, an alternative source of energy, using the single-state digesters was investigated. Dry cassava roots, which contained 18.65% of moisture content and 81.35% of total solids (TS), were used for preparing raw cassava slurry. The total solids 1% (w/v) and the addition of urea (0.4 g/L) were found to be suitable for the bioconversion performed at ambient temperature (29-31°C). When five liters of the raw cassava slurry were fed into the digester, the gas yield of 1.95 L/day containing the maximum methane content of 67.92% was achieved at 10-day retention time. When the fermentation volumes were scaled up to 20 L and 50 L respectively, the gas yields of 5.50 and 24.40 L/day containing 55.70 and 68.65% methane were obtained at 10-day retention time. Whereas the methane contents of 67.57 and 69.79% and the gas yields of 3.88 and 9.95 L/day were achieved at 14-day retention time. These results reveal that biogas containing 67-69% of methane could be potentially produced from raw cassava roots using the simple single-state digesters.

INTRODUCTION

Cassava roots, the starch-rich tubers, have been the staple food in several countries for centuries. In Thailand, raw cassava roots are one of the cheap and abundant agriculture products (Pandey *et. al.*, 2000; Office Agricultural Economics, 2003). The tubers also contain other organic nutrients which could efficiently support growth of microorganisms to produce some biotechnological products (Soccol, 1996; Pandey *et. al.*, 2000). In this study, raw cassava roots are initially investigated to be applied as a raw material for the potential production of biogas, a source of energy. Biogas, the gas generated from organic digestion under anaerobic conditions by mixed population of microorganisms, has been utilized as an alternative source of energy both in rural and industrial areas (Bhumiratana *et al.*, 1984; Stuckey, 1984; Cohen, 2004). The composition of biogas depends on feed materials. The gas generally composes of methane (55-65%), carbon dioxide (35-45%), nitrogen (0-3%), hydrogen (0-1%), and hydrogen sulfide (0-1%) (Milono *et al.*, 1981). Organic waste has been mainly used for the biogas production. Several kinds of waste materials have been reported to be exploited (Cuzin *et al.*,1992; Mackie and Bryant, 1995; Bardiya *et al.*, 1996; Zhang and Zhang, 1999; Carbone *et al.*, 2000; Kalia *et al.*, 2000; Cohen, 2004). In the present study, the maximum production of biogas and methane from raw starch-rich tubers of cassava plant are determined when the simple single-state digesters with scaling up reaction volumes are operated.

MATERIALS AND METHODS

Raw Material For Biogas Production

Fresh cassava roots were obtained from their plantation area in Nakhon Ratchasima Province, Thailand. Dry cassava roots containing the average moisture content of 18% were prepared by chopping the whole root into small pieces (<2.0 cm^3), dried under sun light over a two-day period, then crushed into fine pieces (<0.2 cm^3) using blender (Waring Commercial, U.S.A.) in order to obtain the consistency of the raw material used for biogas production experiments. Total solids (TS), volatile solids (VS), phosphorus, and ash contents of the raw material were determined using standard methods (American Public Health Association,1990; AOAC, 1990). Total carbon and nitrogen contents were also determined using the CNS-2000 Elemental Analyzer (Leco Corporation, U.S.A). Starch concentration was basically detected by spectrophotometry at 580 nm absorbance in the soluble form and presence of iodine (Plummer, 1971; Gales, 1990).

Seed Cultures For Biogas Production

Seed cultures were prepared by mixing chicken manure with liquid waste collected from the cassava starch production factory in Nakhon Ratchasima Province at the concentration of 100 g/L. Then an equal volume of water was added. The total 50-L mixture was prepared, and kept in a closed container at room temperature with adding cassava starch (0.002%, w/v) at regularly 3-day intervals for 3 months before use.

Biogas Production From Raw Cassava Roots

The production of biogas from raw cassava root was performed using the simple single-state digesters with working volumes of 5, 20, and 50 L (Table 1). The digesters were fed on a batch basis with the slurry of dry cassava root containing the average moisture content of 18% and 10% (v/v) of seed cultures. The biogas fermentation was operated in triplicate at ambient temperature for 30 days.

Table 1: Physical characteristics of 5-L, 20-L, and 50-L working volume digesters

Parameter	5 L	20 L	50 L
Digester height (cm)	25.00	35.00	80.00
Liquid height (cm)	13.50	41.30	71.00
Empty volume (L)	7.50	26.00	56.50
Filled volume (L)	5.00	20.00	50.00

The amount of main nutrients (carbon and nitrogen sources) has been reported to affect the growth of microorganisms and the production of biogas. The optimum ratios of carbon-to-nitrogen for the maximum biogas generation have been suggested to be 20:1 to 30:1 (Polprasert, 1989; Viswanath *et al.*, 1992). The high carbon-to-nitrogen ratio of approximately 80:1 of cassava root (dry weight) has also been reported (Soccol, 1996). In this study, the optimal concentrations of TS and nitrogen source supplement were determined using the 5-L reaction volume. Urea (46% of nitrogen) was selected to be used as a nitrogen source. The optimal concentrations of both TS and nitrogen source were applied to produce biogas in the scaled-up digesters of 20-L and 50-L working volumes. All bioreactors were operated at ambient temperature for 30 days.

The volume of biogas produced in each digester was measured by the displacement of water in the gas collector chamber. The pH of water in the gas collector was adjusted to 2 to avoid carbon dioxide dissolution (American Public Health Association, 1990). Gas production was monitored daily. The composition of biogas, which collected over water, was analyzed using the Gas Analyser (Shimadzu, Class-GC14B, Japan) equipped with a thermal conductivity detector (TCD) and 1-M Porapak Q (80-100 mesh) column. Helium was used as a carrier gas at a flow rate of 25 mL/min. The oven, injector, and detector temperatures were 80, 120, and 120°C, respectively.

Volatile acids (acetic, propionic, and butyric acids) were analyzed using the Gas Analyser (Shimadzu, Class-GC14B, Japan) equipped with a flame ionization detector (FID) and DB-FFAP column. Helium was used as a carrier gas at a flow rate of 40 cm/sec whereas nitrogen was used as a makeup gas at a flow rate of 30 mL/min. The oven, injector, and detector temperatures were 100, 250, and 300°C, respectively. Peak areas were used to calculate concentrations by comparing to calibration curves prepared from standard solutions of acetic, propionic, and butyric acids.

Starch content, alkalinity, and volatile fatty acids (VFA) of cassava slurry during bioconversion were monitored daily. Alkalinity and VFA were determined by the direct titration with sulfuric acid (American Public Health Association, 1990). The VS content in the slurry was detected. And the reduction of VS was calculated as described by Zhang and Zhang (1999). The measurement of pH value and temperature of the fermenting slurry was also performed using the pH meter (CONSORT, Belgium) and thermometer, respectively.

RESULTS AND DISCUSSION

Compositions of the fresh starch-rich roots of cassava plant collected from their plantation area in Nakhon Ratchasima Province, were 17.96% of starch, 61.66% of moisture, 38.34% of TS, 99.12% of VS, 18.64% total carbon, 0.22% of total nitrogen, 0.08% of phosphorus, and 0.88% of ash. The dry starchy material contained 18.65% of moisture, 81.35% of TS, 98.05% of VS, 39.56% of total carbon, 38.10% of starch, 0.46% of total nitrogen, 0.18% of phosphorus, and 1.95% of ash. Soccol (1996) stated that fresh cassava roots had 20-30% of starch, 65% of moisture, 0.9% of ash, and 0.03% of phosphorus, which were higher than results from this study in the case of starch and moisture contents. But the phosphorus content was less than this experiment.

The dry cassava material was used to prepare slurry to feed the simple single-state digesters. The average carbon-to-nitrogen ratio of the dry material was 86:1, which was very high ratio compared to the optimum ratios of 20-30:1 recommended for the maximum biogas generation (Polprasert, 1989; Viswanath *et al.*, 1992). In this study, various TS concentrations (0.25, 0.50, 1.00, 2.00, 4.00, and 8.00%, w/v) were, therefore, applied to the 5-L reaction volume to obtain the optimum TS content. Then the addition of urea (46% of nitrogen) as a nitrogen source at various concentrations (0, 0.2, 0.3, 0.4, 1.0, and 2.0 g/L) was investigated. The supplement of urea (0.4 g/L) to the cassava slurry (1%, w/v, TS) corresponding with the carbon-to-nitrogen ratio of 20:1, was found to stimulate the maximum biogas production. The maximum yield of total biogas was 569.29 L/kg TS fed (Table 2). The gas yield of 1.95 L/day containing the maximum methane content of 67.92% was achieved at 10-day retention time (Figure 1A). The utilization of volatile solids was 56.83%. The fermentation reactions were ceased after 16-day operation (Figure 1A).

Table 2: Biogas production from cassava roots

Parameter	Reaction volume (L)		
	5	20	50
Total biogas yield (L/kg TS fed)	569.29	611.32	611.54
Total biogas yield (L/kg VS fed)	474.67	509.71	509.89
Total methane yield (L/kg TS fed)	263.90	339.53	337.69
Volatile solids (VS) reduction (%)	56.83	61.51	61.98

When the optimal concentrations of TS (1%, w/v) and urea (0.4 g/L) were applied to the scaled-up experiments, 20-L and 50-L reaction volumes respectively, the maximum yield of total biogas was 611.32 and 611.54 L/kg TS fed (Table 2).The gas yields of 5.50 and 24.40 L/day containing 55.70 and 68.65% methane were obtained at 10-day retention time (Figures 1B and 1C). Whereas the methane contents of 67.57 and 69.79% and the gas yields of 3.88 and 9.95 L/day were achieved at 14-day retention time. The fermentation reactions were ceased after operating for 24 and 21 days (Figures 1B and 1C), respectively.

For the total gas yield during the bioconversion of raw cassava root, the maximum yields were achieved at the first week of operation for all reaction volumes (Figure 1). These high yields did not reveal the high methane contents. When the composition of the gas was analyzed, the high proportion of carbon dioxide was found (Figure 2A). The high proportion of carbon dioxide corresponded to the dramatic decrease in starch concentration (Figure 1) which implied the activity of hydrolytic microorganisms in the digestion vessel. The total biogas yields, which obtained from 5-L, 20-L, and 50-L cassava slurry after the bioconversion process completion, were 569.29, 611.32, and 611.54 L/kg TS fed, and 474.67, 509.71, and 509.89 L/kg VS fed, respectively. The biogas yields from 20 L and 50 L was approximately 7% higher than 5 L. The total methane yields and VS reductions from 20 L and 50 L were also higher than 5 L (Table 2). The total methane yields were 263.90, 339.53, and 337.69 L/kg TS fed. And the average methane contents would be 46.22, 55.54, and 55.22% for the complete bioconversion of 5-L, 20-L, and 50-L digestion mixtures, respectively.

When the digesters were initially fed, acid forming-bacteria quickly produced acid resulting in declining pH below the neutral pH and diminishing growth of methanogenic bacteria and methanogenesis. The pH could be maintained by adding sodium carbonate to increase digester alkalinity (Cuzin *et al.*, 1992). In this study, sodium carbonate (0.25%, w/v) was added four times during the first week of fermentation for all bioreactor sizes. Afterwards the digesters could maintain themselves (Figure 1). At the daily methane yield of more than 50% of biogas composition,

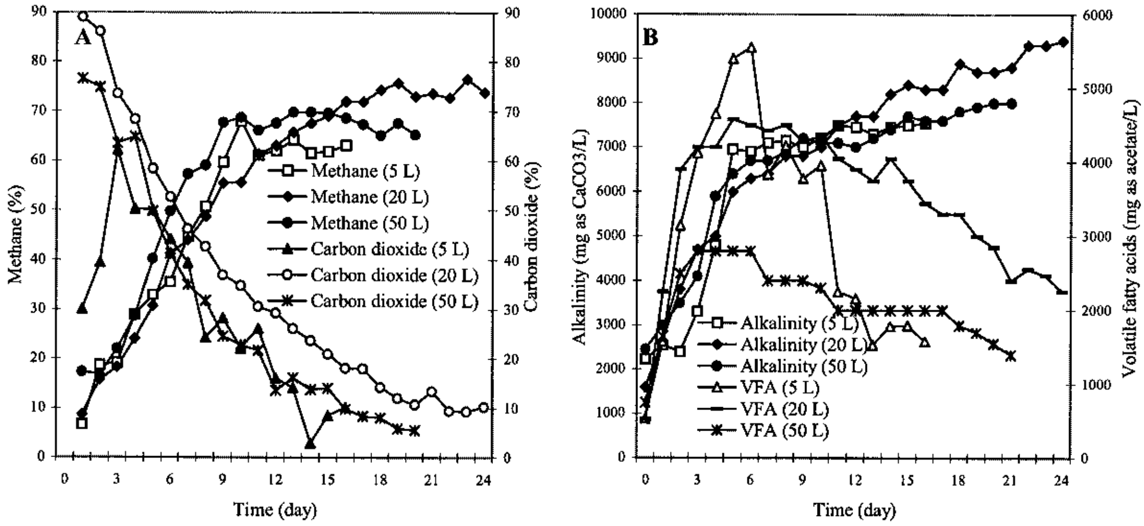

Figure 2: Methane and carbon dioxide composition of gas, and alkalinity and volatile fatty acids (VFA) measured during biogas production from cassava roots in the single-state digesters of 5-L, 20-L, and 50-L working volumes

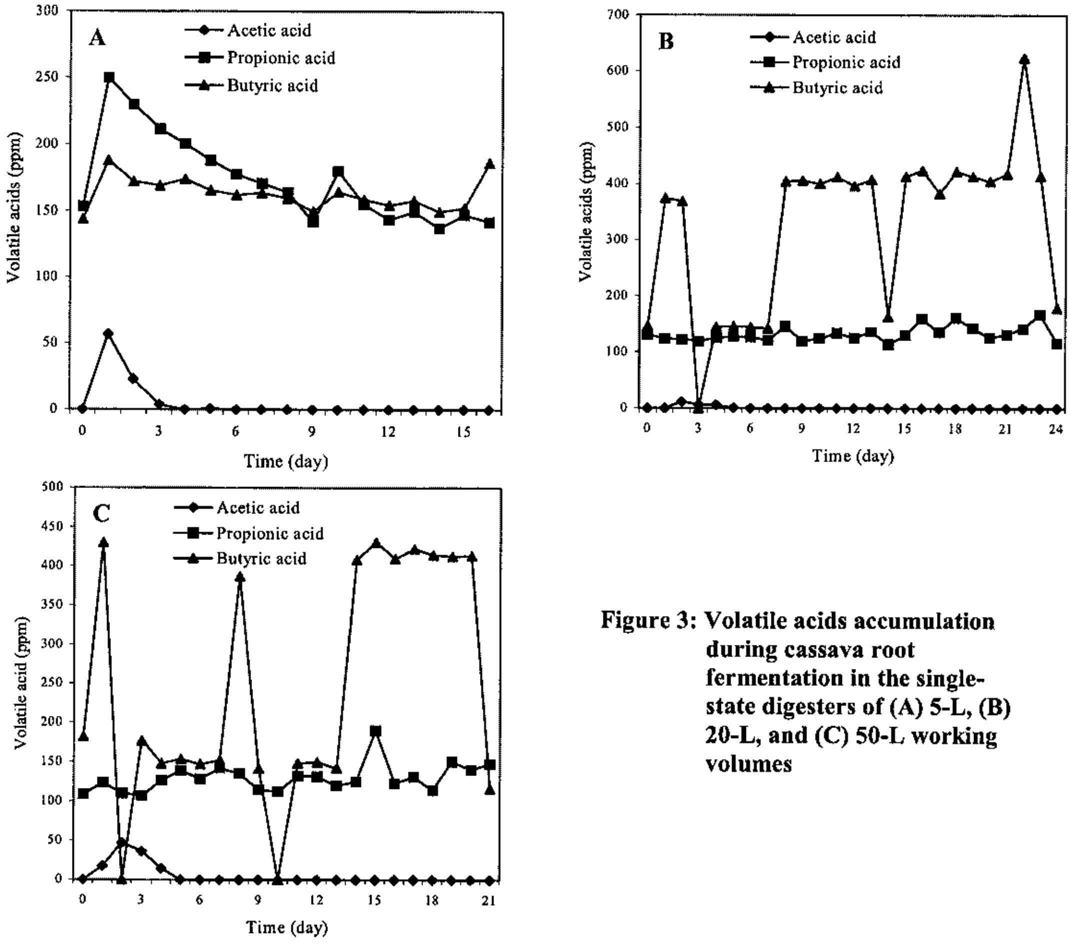

Figure 3: Volatile acids accumulation during cassava root fermentation in the single-state digesters of (A) 5-L, (B) 20-L, and (C) 50-L working volumes

total dry mass of the whole root. And one kg of the dry cassava mass was achieved from 2.11 kg of fresh cassava root (61.66% of moisture content). From this investigation, the total biogas and methane yields, which were obtained from 50-L digestion volume, were 611.54 and 337.69 L/kg TS fed, respectively. Thus, one kg of dry cassava root could be biologically converted to 497.19 L of biogas and 274.54 L of methane. And one kg of fresh cassava root would produce 235.63 L of biogas and 130.12 L of methane.

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