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ORIGINAL PAPER

Selective digestion of industrial potato wastes for efficient biomethanation: a sustainable solution for safe environmental disposal

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Abstract Potato being the staple vegetable in India is widely cultivated and processed for different value additions. During processing of potato, a huge amount of waste is generated in the form of peel and meat (mash). These wastes constitute a potential feedstock for biogas generation. The present study is focused on mitigation of acidogenesis that occurs during early stages of anaerobic digestion (AD) of potato waste which eventually inhibits the process of methanogenesis. A novel strategy of selective digestion was adopted in which the leachate and solid slurry resulting from the first stage digestion were further subjected to second stage by separating the solid and liquid phases. The obtained results indicated that stepwise digestion enhanced biomethane yield with an increase in methane percent from 46.47 to 60.4 % and reduction in total COD to about 94 %. Another novel strategy adopted in this study was the use of specifically developed microbial consortia for AD of potato wastes instead of conventional inoculum for production of biogas. The obtained yield is at par with the conventional inoculums which suggests that the developed consortia could act as potential substitute. The present study paves the way for sustainable utilization of industrial potato wastes for bioenergy production by overcoming the problems associated with conventional processes.

Keywords Anaerobic digestion · Bioenergy · Biogas · Methane

Introduction

Potato production in Asia and the Pacific region is increasing, China and India being the first and third, respectively, in terms of quantity produced and area cultivated. Potatoes are processed into a variety of products such as mashed potato, chips, fries, deep frozen and dehydrated products such as granules and flakes that generate wastes in the form of peel, pulp and reject (FAO 2008). The quantum of wastes generated from a potato processing industry constitutes about 12–20 % of raw material processed (NDDB 2014).

Though potato is a starchy biomass, it also contains other nutrients such as protein and soluble sugars, the latter being mostly organic in nature. The wastes released from the potato processing industry are mostly in the form of unutilizable organic materials which, when disposed on land, create environmental pollution being prone to easy microbial attack. Open dumping is objectionable because of the odor, fly menace and unsightliness. When dumped in public sanitary landfills, high moisture content of the wastes results in leaching problems. A better solution to the disposal problem is to recycle the potato wastes through anaerobic digestion (AD) process. This will not only help in minimizing the objectionable problems but also recover energy as biomethane besides maintaining physical properties of the soil and utilizing valuable nutrients by application of residual slurry as biomanure.

Anaerobic microbial conversion of organic matter into a renewable energy source, so-called biogas, is a well-established process and state of the art. Advanced

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techniques and technologies leading to the possibilities for treatment of solid potato wastes are presently practiced through AD. AD of agro-industrial wastes is perhaps the most attractive method for solid treatment because the process enables an excellent waste stabilization as well as its upgradation by recovering both energy and compost (Singh et al. 2012; van Lier et al. 2001; Mata-Alvarez et al. 2000). Weiland (1993) reported that successful digestion of potato wastes such as pulp (18–21 % dry solid) and thick stillage (14–18 % dry solid) yielded 300–500 m^3 of biogas per ton of dry matter with 50–70 % degradation. Parawira et al. (2004) investigated the efficacy of anaerobic digestion process using potato waste along with sugar beet leaves in which methane production improved by 31–62 % by codigestion as compared to digestion of potato waste alone. There are further reports on anaerobic digestion of potato wastes and wastewater from industries (Zhu et al. 2014; Fang et al. 2011; Kryvoruchko et al. 2009; Ma et al. 2008; Monou et al. 2008). However, in Indian subcontinent scenario, there were no recent studies on anaerobic digestion of potato wastes generated from the processing industries.

The major problems associated with potato waste include easy degradability resulting in acidification which rapidly lowers the pH noticeably. This problem is associated with low pH of the substrate itself, poor buffering capacity and the possibility of potentially high volatile fatty acid (VFA) accumulation during digestion (Yadvika et al. 2004; Vietez and Ghosh 1999; Banks and Humphreys 1998). According to Brown and Li (2013) the start-up phase of anaerobic digestion is the most crucial step as the consequences of such action end up in process disruption and instabilities. In the worst case, methanogenesis is severely inhibited due to accumulation of VFA. Single-phase systems especially are affected by an uncontrolled acidification process. Methanogens are in general obligate anaerobes which are sensitive to low pH ($\leq$5).

Phase separation or two-phase anaerobic digestion is more efficient than the single-stage system because phase separation is helpful in providing the buffering effect of organic loading in the first stage. In addition, a stable environment for the methanogenic process can be achieved in the second stage by phase separation (Fezzani and ben Cheikh 2010; Zhang and Noike 1991). Effluent recirculation is an economic way of handling pH problems since the cost of using alkali can be considerably reduced (Cavinato et al. 2011). Bilgili et al. (2007) reported that recirculation could accelerate the rate of municipal waste degradation in anaerobic landfill. Lee et al. (2010) demonstrated that thermophilic two-stage anaerobic digestion of high-solid food waste for production of hydrogen and methane at three different organic loading rates with recirculation and pH adjustment by dilution resulted in improved methane yield.

Another important area of concern in AD process is inoculum. Usually conventional inoculum sources such as cattle manure and sewage sludge are used for most of the biogas production process. Obtaining stable inoculums in required quantity at a particular location and duration during implementation of large-scale biomethanation plants is a huge problem. Thus, there is a need to replace the conventional sources with specifically developed consortia of microorganisms for anaerobic digestion of organic wastes.

Visualizing the practical difficulties associated with AD of potato wastes, the present work deals on two aspects, firstly reduction in the bottleneck caused by VFA accumulation through adoption of stepwise digestion and secondly utilization of potent anaerobic microbial consortia (MAC) to produce biomethane in order to reduce the dependency on conventional inoculum sources. The present study was carried out at Microbial Biotechnology and Downstream Processing Laboratory, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India, during the year 2013–2014.

Materials and methods

Substrate

Potato waste generated during different stages of processing was procured from M/s. Basukinath Food Processors Limited, Kharagpur, West Bengal, India. The collected wastes were blended, characterized and stored at 4 °C for further use.

Inoculum

A consortium of bacterial solution comprising *Corynebacterium nuruki, Aneurinibacillus migulans*, *Staphylococcus epidermidis*, *Enterobacter cloacae*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Methanosarcina barkeri* and *Methanosaeta* sp. was employed for biomethanation. It was obtained from the Microbial Biotechnology and Downstream Processing Laboratory, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, West Bengal, India. This inoculum was well maintained in the laboratory with appropriate feeding of nutrients and adaptation to the treatment of organic wastes. Specific methanogenic activity (SMA) of the inoculum was calculated according to the standard protocol as described by Sorensen and Ahring (1993) and found to have a potential of generating 0.403 g-CODCOD$_{CH_4}$/g-VSS.d. It has been observed that SMA of the newly developed

Table 1 Role of individual microorganisms in MAC

S. no.	Microorganism	Functional role in anaerobic digestion	References
1	*Aneurinibacillus migulans*	Involved in the degradation of lignin a recalcitrant present in the lignocellulosic biomass	Shi et al. (2013)
2	*Staphylococcus epidermidis*	Involved in hydrogen production and most prominent species found in biogas plant	Wirth et al. (2012)
3	*Corynebacterium nuruki*	Involved in alcohol fermentation	Shin et al. (2011)
4	*Enterobacter cloacae*	Hydrogen producer	Harun et al. (2012)
5	*Bacillus subtilis*	Producer of α-amylase for degradation of starch and especially have prominent growth in the presence of fruit/vegetable wastes	Gupta et al. (2010)
6	*Pseudomonas aeruginosa*	Producer of alkaline protease which involved in the conversion of proteins into ammonia and also degrade the lipid into fatty acid and glycerol	Cryz and Iglewski (1980)
7	*Methanosarcina barkeri*	Methanogen which utilizes the acetic acid as the substrate for production of methane and carbon dioxide	Rao and Seenayya (1994)
8	*Methanosaeta* sp.		

inoculum was in the range of reported SMA values of industrial and laboratory anaerobic inoculums (Punal et al. 2000; Soto et al. 1993). Table 1 represents the functional role of individual microbe of the consortia as demonstrated by previous studies which provide concerted effect for biomethanation.

Experimental setup for biomethanation

A 2 L reactor was used for the study with working volume of 1.5 L. The reactor was fed with potato wastes to make a final concentration of 7 % total solid (TS) (w/v). The organic loading was selected based on the experiments performed by Parawira et al. (2004) on solid potato wastes. The reactor was inoculated with the anaerobic inoculum [80 % (volatile solid VS/VS)]. The volume of reactor was made up to the working volume with water and final pH adjusted to 7 using calcium hydroxide (slaked lime). The reactor was completely sealed, and the outlet tube connected to a gas collector. The biogas produced was periodically collected and measured through water displacement technique. The experiment was performed in duplicates, and the results were presented as mean values. The schematic representation of laboratory reactor setup is shown in Fig. 1a. After completion of biomethane production, leachate was separated, characterized and subjected to second-stage digestion. Similarly, solid residue from the first stage was further subjected for biomethanation by addition of fresh inoculum. The process of stepwise digestion is shown in Fig. 1b.

Methods

To begin with, wastes were characterized before digestion and after cessation of biogas production. Moisture, total solid (TS), volatile solid (VS) and ash contents were measured as per standard methods (Eaton et al. 1998). Chemical oxygen demand (COD) was determined following the open reflux method. Total carbohydrate was determined by anthrone method (Sadasivam and Manickam 1992). Total protein was calculated by multiplying the total nitrogen content with the factor 6.25. Total VFA was estimated by distillation method (Eaton et al. 1998). Compositional analysis of biogas was performed through gas chromatograph (Agilent 6820, Agilent Technologies, USA) equipped with HP PLOT-Q (porous layer open tubular) column with thermal conductivity detector (TCD) having nitrogen as carrier gas. Total C, H, N and S were determined using elemental analyzer (Elementar Vario Micro cube, Germany). The P and K contents in the potato wastes were, respectively, estimated by spectrophotometric and flame photometric methods (Hegedus and Pungor 1955).

Results and discussion

Characterization of potato waste

The proximate and biochemical composition of potato waste is given in Table 2. As can be noted, potato waste

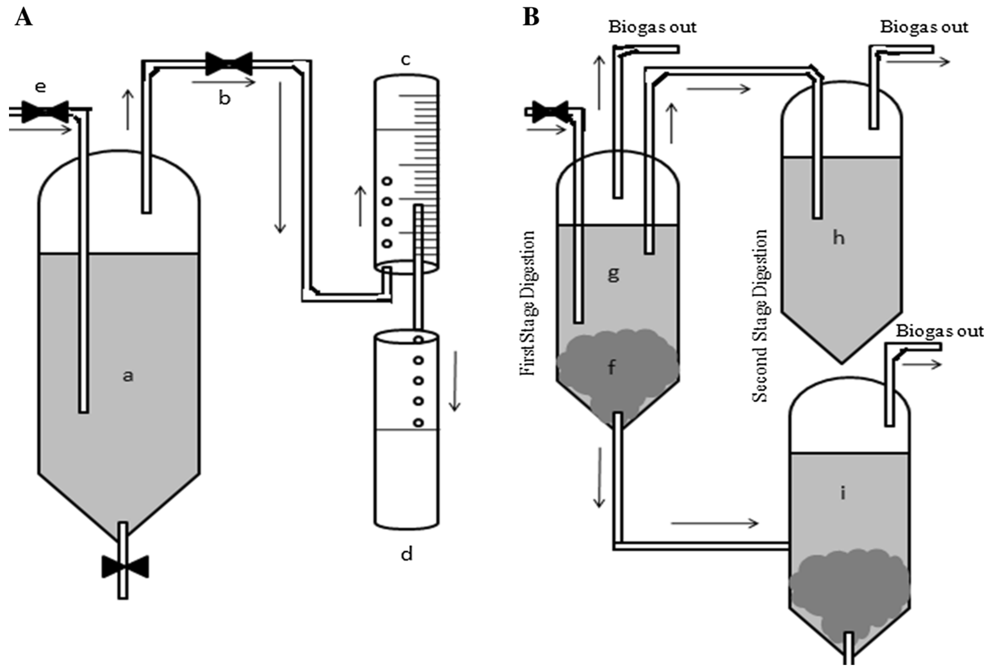

Fig. 1 **a** Experimental setup; (*a*) reaction mixture; (*b*) biogas outlet; (*c*) gas collector; (*d*) water collection vessel; and (*e*) inlet pipe, **b** schematic representation of stepwise digestion; (*f*) solid slurry; (*g*) leachate; (*h*) leachate + fresh inoculum; and (*i*) solid slurry + fresh inoculum

Table 2 Characteristics of potato wastes

Parameter	Unit	Potato waste
Moisture	(%, w/w)[a]	84 ± 4.5
Total solid	(%, w/w)[a]	16 ± 5.5
Total volatile solid	(%, w/w)[b]	90 ± 2.3
Ash	(%, w/w)[b]	10 ± 7.7
Carbohydrate	(%, w/w)[b]	43 ± 2.2
Protein	(%, w/w)[b]	8.75 ± 0.4
C	(%, w/w)[b]	40 ± 2.2
N	(%, w/w)[b]	1.4 ± 0.71
H	(%, w/w)[b]	6.9 ± 0.06
S	(%, w/w)[b]	0.17 ± 0.07
C:N	–	28.57
COD	(g/L)	14.85 ± 0.75
Phosphorous (P)	(%, w/w)[b]	0.3 ± 0.021
Potassium (K)	(%, w/w)[b]	1.05 ± 0.045

[a] Wet weight basis, [b] dry weight basis

has high moisture (84 %) and volatile solid (90 % of TS) content. On further biochemical characterization, it is found to contain total carbohydrates 43–45 % (w/w), 1.4 % (w/w) nitrogen, 8.75 % (w/w) protein and COD 14.85 g L^{-1}. C:N was observed to be 28.57. From the initial nutrient profile, it can easily be concluded that the selected potato waste is highly biodegradable and not only shows the potentiality for biological treatment but also the quantum of useful resources that remain unutilized.

Biogas production profile of potato waste

First stage digestion

After compositional analysis of potato wastes, substrate concentration of 7 % TS (w/v) was chosen for initiation of the experimental process. The inoculum used in this study was a novel consortium having different microorganisms participating in biomethanation process. The entire experimental procedure was carried out by taking this inoculum and its effect on biomethanation.

The cumulative biogas profile of potato waste is shown in Fig. 2. Biogas production started after 24 h of inoculation. The rapid initiation of the biogas production was due to the availability of easily biodegradable organic matter present in the waste. The pH of the reaction mixture decreased from 7 to about 5–6 in 96 h. This showed the production of VFA due to the hydrolytic action of microbes on the substrate. After 144 h, biogas production showed an increasing pattern due to the methanogenic activity. The methanogenic action involves the utilization of VFA produced by the acidogenic/acetogenic microorganisms, and the methane detection was observed from 216 to 240 h by a characteristic blue flame. Maximum biogas production was attained at 264 h when it reached up to 4.1 L of biogas with average methane content of 46.47 %. The trend in production stabilized after 336 h (14 days) indicating the cessation of the biogas production. The final pH was about 5 with a corresponding total VFA concentration of 9874.29 mg L^{-1}. Total biogas production in 14-day

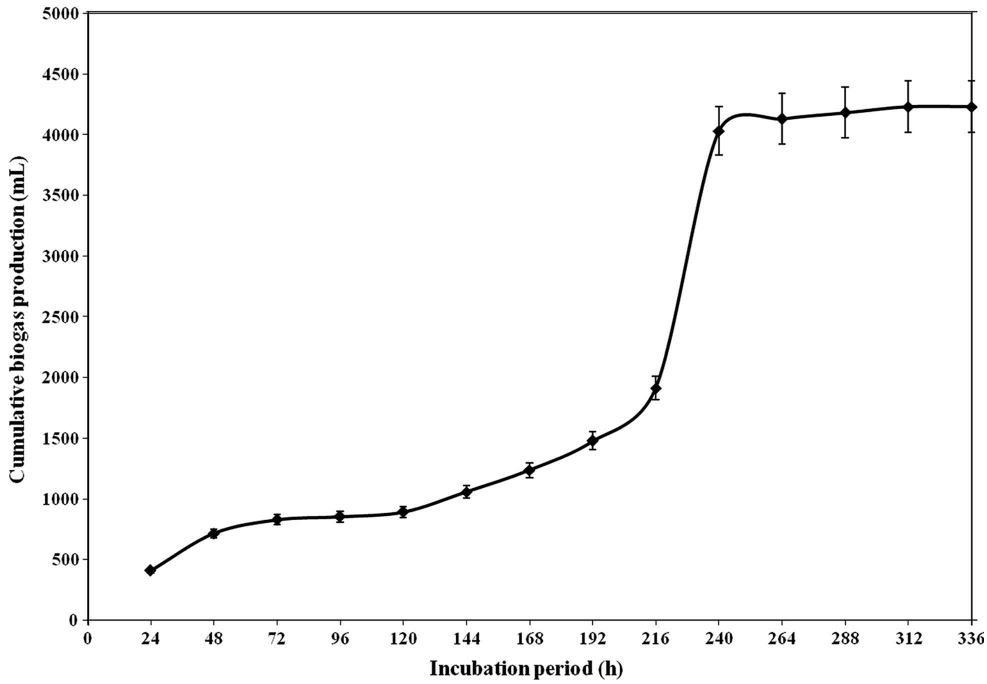

Fig. 2 Biogas production profile of first cycle digestion

retention period was about 553.31 L kg^{-1} $VS_{degraded}$ with methane content of 46.47 %, i.e., methane yield of 257 L kg^{-1} $VS_{degraded}$, whereas Parawira et al. (2004) reported 320 L kg^{-1} $VS_{degraded}$ using sewage sludge as inoculum. At the end of the digestion process, it was observed that reduction in COD was about 56.89 %. It is a well-established fact that in AD, hydrolysis is the rate-limiting step (Gujer and Zehnder 1983). In the present study, due to rapid acidification during hydrolysis, the process was irreversibly inhibited by 14 days of incubation. Similar results have been observed in potato (Landine et al. 1983) and vegetable wastes (Bouallagui et al. 2005). The knowledge on inhibition of VFA with concentration higher than 5000 mg L^{-1} has been well documented (Babel et al. 2004). To overcome this problem, either the system should be buffered adequately or the two phases (acidogenesis and methanogenesis) separated. In the present investigation, even after adequate buffering and adjusting the pH whenever there was a decline, the leachate remained acidic (pH 4–5) which is an inhibitory range for methanogenesis. Thus, the alternate option is separation of the two phases. During management of organic waste at landfill sites, leachate recirculation is found to enhance the microbial activity and shorten the time for waste conversion and stabilization (Han et al. 2013; Zuo et al. 2013; Reinhart and Al-Yousfi 1996). Correlating the aforesaid phenomenon with our study, leachate from acidogenic reaction and recirculation in methanogenic reactor may be the way to enhance the degradation of organic matter from the treated potato wastes.

Second stage digestion

The prime objective of AD process is to reduce the strength of the waste with subsequent production of biogas. To attain the above-mentioned target, it has been identified that recycling of the waste can be done until maximum biodegradation of organic components of the waste. Here, the recycling of wastes both solid and liquid phases from the first stage has been subjected for the second stage of AD. From the first stage, leachate which was the liquid part of the digestion process had COD of about 32 g L^{-1}. The magnitude of this strength was very high which has to be reduced further. The leachate from the reactor was collected and found to have a low pH (5) which was adjusted to 7 followed by addition of inoculum in the second stage.

Leachate digestion in second stage

The pattern of the biogas production from the liquid waste (leachate) in second stage is given in Fig. 3a.

The initiation of biogas generation was observed from 48 h with slow progression rate up to 12 days. Thereafter, the production increased exponentially from 12 to 21 days with maximum methane content of 63 %. Then onwards, the trend remained stationary from 21 to 30 days when pH drifted from 7 to 6. After this period, there was a slight increase in production up to 36 days which got stabilized after 39 days. The total biogas and methane yield from leachate digestion at the end of second stage were found to

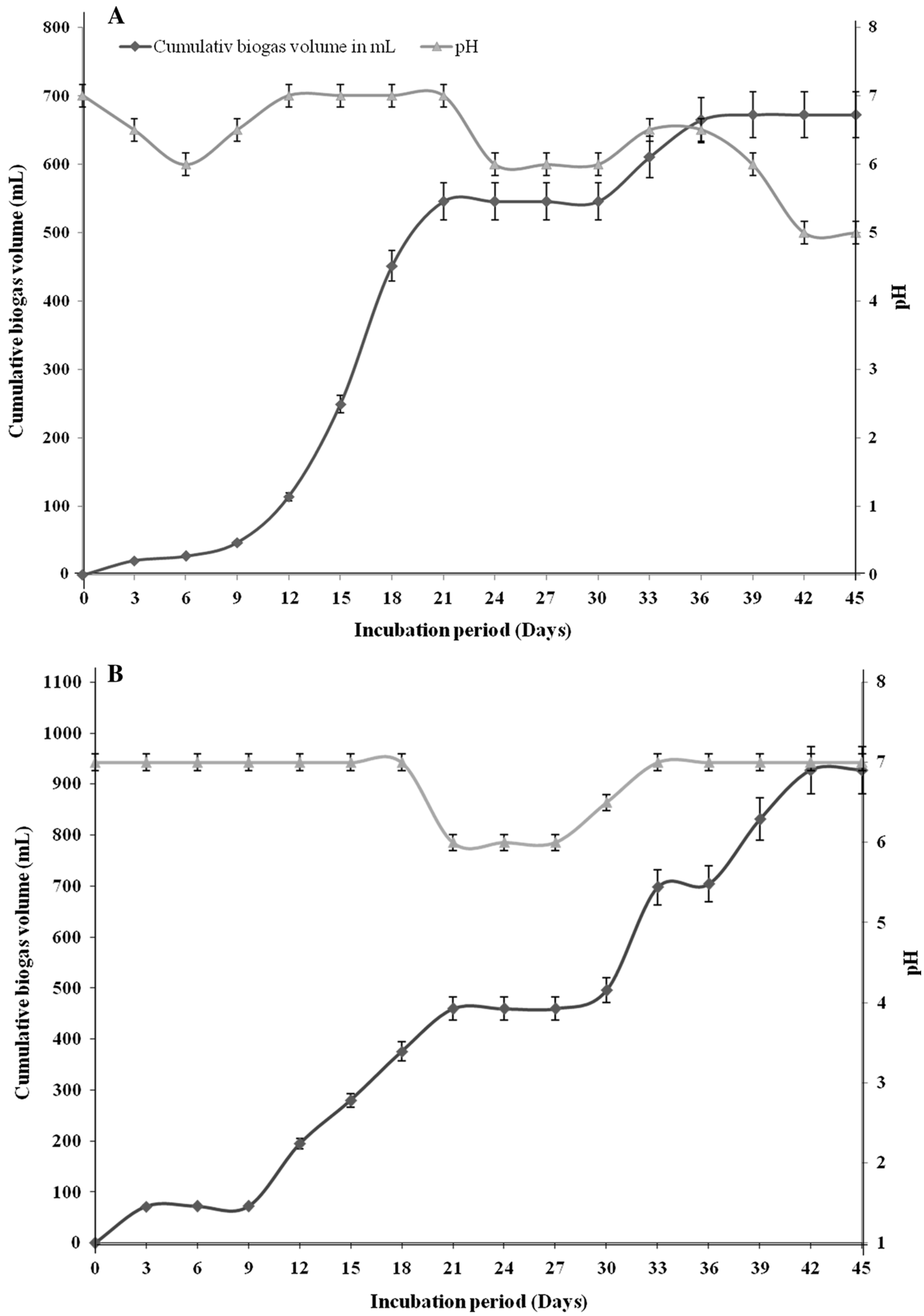

Fig. 3 Biogas production and pH profile during second cycle digestion of **a** leachate; **b** solid slurry

be 226.09 L kg^{-1} $VS_{degraded}$ (methane content 63 %) and 142.43 L kg^{-1} $VS_{degraded,}$ respectively. The total solid destruction was about 53 % which resulted in the corresponding decrease in turbidity of the leachate. Figure 4 depicts the characteristics of leachate before and after stepwise digestion.

He et al. (2005) demonstrated that leachate recirculation in a methanogenic reactor might be an efficient way to improve waste stabilization and enhance the rate of biogas production. Lim et al. (2013) had reported that methane production in two-phase digestion was found to be 23 % higher during anaerobic digestion of food waste and brown

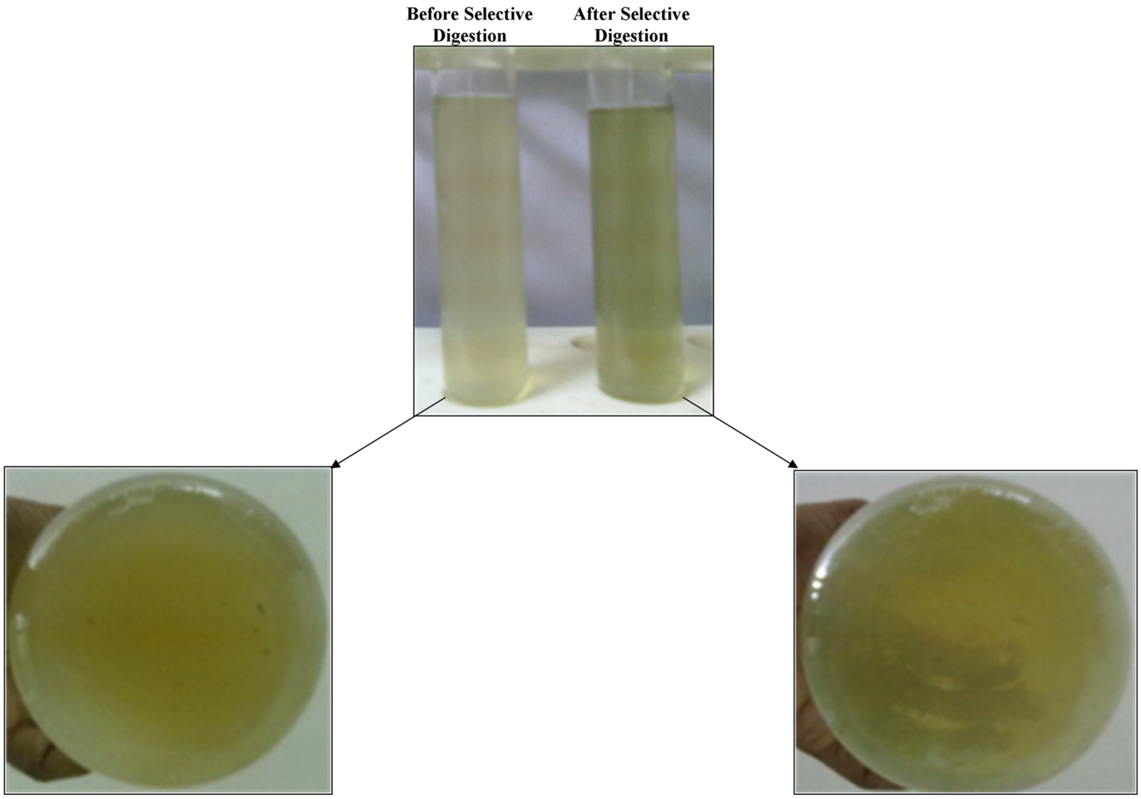

Fig. 4 Appearance of leachate before (turbid) and after (transparent and clear) stepwise digestion

water when compared to the single phase. This was probably due to improved solubilization and acidification observed in the two-phase system. A similar observation has been made in the present study where 16.53 % enhanced methane production was recorded during the second stage of digestion.

Solid slurry digestion in second stage

In case of solid slurry digestion (Fig. 3b), it has been observed that there was only a slight drift in pH during the initial period unlike in leachate digestion. There was a lag from 3 to 9 days, but after that, biogas generation increased rapidly up to 21 days. From day-21 to day-27, there was a decrease in pH from 7 to 6 which indicated the accumulation of VFAs in the system. After day-27, pH stabilized at 7 indicating the proliferation of methanogens during that period which are the potential utilizers of the VFA that can be further metabolized into biomethane. The production of biogas extended up to day-39; thereafter, it remained stationary which indicated the stabilization of the digestion. Biogas yield from solid slurry at the end of second stage digestion was observed to be 22.88 L kg^{-1} $VS_{degraded}$ (methane content of 58 %) with an ultimate methane yield of 13.27 L kg^{-1} $VS_{degraded}$.

Total methane yield from the potato wastes from leachate and solid slurry after second stage digestion was found to be 155.63 L kg^{-1} $VS_{degraded}$. The characteristics of the waste before and after second stage digestion are shown in Table 3.

Effect of stepwise digestion on methane content

Methane is the fuel part of biogas where its concentration plays a significant role in determining its calorific value. On an average, biogas comprises 50–60 % CH_4 and 40–45 % CO_2 (Bhattacharyya and Banerjee 2007). Hence, in order to compare and improve the fuel efficiency of biogas, the pattern of methane concentration in biogas was observed throughout the digestion process in both first and second stage of anaerobic digestion. During the first-stage digestion, methane content in the biogas was found to initiate on day-5 (Fig. 5a) with maximum content of 46.47 % on day-9.

Table 3 Characteristics of wastes before and after second-stage digestion

Parameter	Unit		Before digestion	After digestion	% loss
Total solid	g	Leachate	7.17 ± 0.03	3.37 ± 0.02	53.14
		Solid slurry	100.5 ± 1.46	42.56 ± 0.89	57.66
COD	mg L^{-1}	Leachate	32,000 ± 1213.4	1920 ± 21.06	94.00
		Solid slurry	37,600 ± 1980.5	3060 ± 23.07	91.86
pH	–	Leachate	7	5	–
		Solid slurry	7	7	–

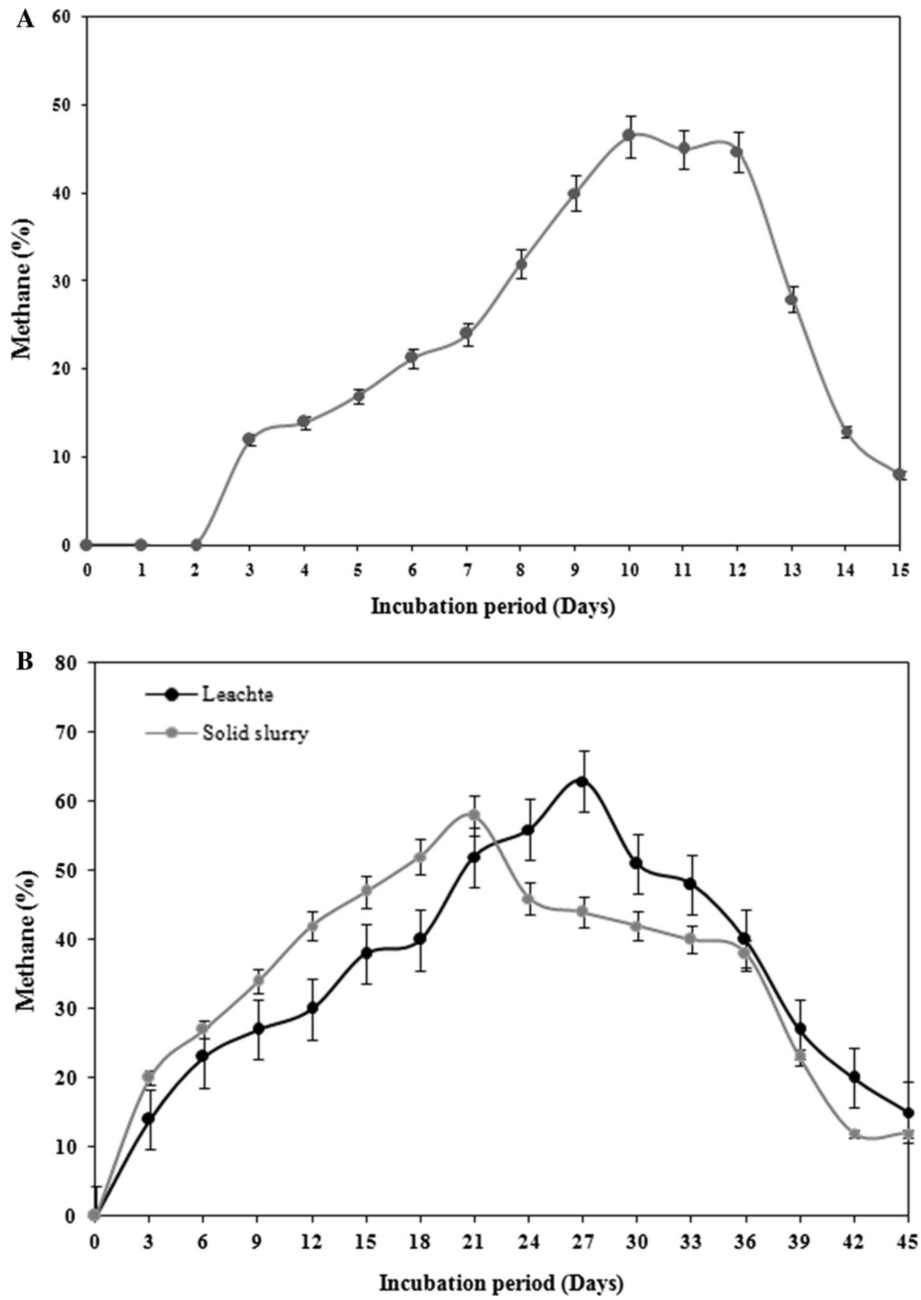

Fig. 5 Methane production profile of **a** first-stage digestion; **b** second-stage digestion

Table 4 Energy production potential from the potato wastes

Potential	Values
Total solid wastes produced from potato processing industries in India[a]	27, 20, 640 tonnes/year
11.5 % of solid waste constitute potato mash waste[b]	3, 12, 873.6 tonnes/year
Dry weight of solid available from the waste (~16 % of fresh weight)[c]	50,059.8 tonnes/year
Biodegradable portion of the wastes (~90 % of TS)[c]	45,053.79 tonnes/year
Methane production capacity (412.7 L kg^{-1} VS)[c]	18.6 million m^3/year
Electrical power production potential (1 m^3 = 2 kWh)[d]	37.2×10^3 MWh/year
Heating value equivalent (LHV 26 MJ/m^3)[d]	483.6 GJ/year
(HHV 30 MJ m^{-3})[d]	558 GJ/year
Amount of residual solid available for biomanure preparation (42.34 % dry solid)[c]	21,195.32 tonnes/year

[a] Pandey et al. (2009), [b] Guttormsen and Carlson (1969), [c] based on the outcome of this study, [d] de Mes et al. (2003); *LHV* lower heating value, *HHV* higher heating value

There was stabilization of methane content up to day-12 which rapidly declined thereafter and completely ceased on day-14. When the leachate and solid slurry were removed and reinoculated in second stage, there was a progressive increase in methane content from day-3 onwards (Fig. 5b). Maximum methane content from leachate was observed between day-23 and day-32 with an average methane content of 63 % which was quite high as compared to the first-stage digestion (46.47 %). In case of solid slurry, there was an elongated period of stabilized methane production from day-20 to day-37 with maximum methane of 58 %. On an average, second-stage digestion yielded 60.4 % methane which was almost similar to the ideal biogas composition. This methane profile clearly indicated the efficient biodegradation of potato wastes and further conversion into biomethane when stepwise digestion process was adopted.

Effect of stepwise selective digestion on COD reduction

High COD concentration in wastes or wastewater is toxic to biological life and affects aquatic flora and fauna when released untreated. Usually, anaerobic digestion is used to treat the wastes with high COD content followed by aerobic treatment which can treat wastes of lower COD range (Woodard and Curan Inc. 2006). In the present study, initial COD concentration was about 88.16 g L^{-1}. There was a decrease in COD content to about 56.89 % after the first stage digestion with corresponding concentration of 38.02 g L^{-1}. Once biogas production ceased in the first stage digestion, leachate and solid slurry were separated and characterized for further digestion. It was found that COD content in the leachate was 32 g L^{-1}, whereas solid slurry had 37.6 g L^{-1}. The high COD content needed to be reduced for its further treatment and disposal. When the leachate and solid slurry were subjected to second stage digestion, the final COD content was found to be 1.94 and 3.06 g L^{-1}, respectively. Reduction in COD in second stage digestion was about 94 % for leachate and 91.6 % for solid slurry. Parawira et al. (2006) reported that >90 % COD degradation was attained with potato leachate when it was recirculated in anaerobic packed bed reactor which is similar to the outcome of the present study. This low-strength waste can be used for further aerobic treatment process or as biomanure application. Recently, Chintagunta et al. (2015) used the industrial potato wastes for the bioethanol production followed by utilization of the residual solid for biomanure preparation by enriching with 7 different cyanobacterial cultures. The biomanure obtained from the enrichment process was found to contain NPK ratio of 4:2:2. In the present study, the residual solid obtained after biomethantion process was found to contain ~42 % TS which can be further channelized for biomanure preparation and thus representing a zero waste discharge process.

Based on the outcome of the present study, from the quantum of waste generated in India, the annual energy and manure production potential was calculated and represented in Table 4.

Volatile solid destruction

Volatile solids in the waste represent its biodegradable organic content. Hence, destruction of VS leads to waste strength reduction with concomitant biogas production. In

Table 5 Comparison of biogas yield from potato wastes using different inoculum sources

Substrate	Biogas yield	Type of inoculum	Incubation period/ reactor type	References
Potato wastes	412.7 L kg^{-1} $VS_{degraded}$	Mixed anaerobic consortia (MAC) (mesophilic)	48 days, batch	This study
Liquid waste from potato (simulated)	183 L kg^{-1} $VS_{degraded}$	Digested sludge (mesophilic)	30 days, CSTR	Zhu et al. (2008)
Potato waste	650–850 L kg^{-1} VS_{fed}	Effluent from processing plant (thermophilic)	50 days, CSTR	Linke (2006)
Potato waste	320 L kg^{-1} $VS_{degraded}$	Sewage sludge (esophilic)	50 days, batch	Parawira et al. (2004)
Potato pulp	300–500 L kg^{-1} $VS_{degraded}$	NA	NA, batch	Weiland (1993)

NA not available

the present study, volatile solid present before and after digestion was found to be 93.84 and 34.33 g, respectively. The efficiency of volatile solid destruction was 63.41 % which is in accordance with the reported batch digestion studies results (Velmurugan and Ramanujam 2011). The total biomethane yield (first stage and second stage) obtained from the destructed volatile solid was observed to be 412.7 L kg^{-1} $VS_{degraded}$. Weiland (1993) has found biomethane yield to range between 300 and 400 L kg^{-1} VS for potato wastes under mesophilic condition. The yield obtained under the present study using mixed anaerobic consortia (MAC) is comparable to the yield from the conventional inoculum sources and acts as a potential substitute for conventional sources. A comparison between the reported methane yield obtained using different conventional inoculums and the results of the present study is shown in Table 5.

Conclusion

The present study reveals the potential of industrial potato wastes to be used as a source of biomethane production by overcoming the acidification problem associated during early stage of anaerobic digestion. Through stepwise selective digestion, it has been seen that there was an increase in methane yield by 60.5 % as compared to first stage coupled with reduction in waste strength. Mitigation of problems caused by the intermediates through adoption of techniques such as leachate recirculation or staged digestion could lead to efficient handling of industrial potato wastes for safe environmental disposal. Considering the ultimate benefits such as biofuel in the form of biogas obtained from the treatment of potato wastes, the outcome of this study could serve as a potential source of revenue for both the industry and the farming community.

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