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Modeling and optimization of anaerobic codigestion of potato waste and aquatic weed by response surface methodology and artificial neural network coupled genetic algorithm

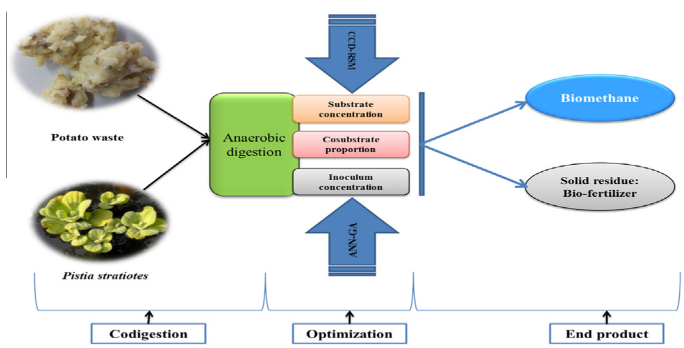
Samuel Jacob, Rintu Banerjee *

Microbial Biotechnology and Downstream Processing Laboratory, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur 721302, West Bengal, India

HIGHLIGHTS

- Utilization of PS as a cosubstrate with PW for efficient biomethanation.
- Application of mixed anaerobic consortia (MAC) as an inoculum.
- Optimization of biomethanation process based on CCD-RSM and ANN-GA.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel approach to overcome the acidification problem has been attempted in the present study by codigesting industrial potato waste (PW) with *Pistia stratiotes* (PS, an aquatic weed). The effectiveness of codigestion of the weed and PW was tested in an equal (1:1) proportion by weight with substrate concentration of 5 g total solid (TS)/L (2.5 g PW + 2.5 g PS) which resulted in enhancement of methane yield by 76.45% as compared to monodigestion of PW with a positive synergistic effect. Optimization of process parameters was conducted using central composite design (CCD) based response surface methodology (RSM) and artificial neural network (ANN) coupled genetic algorithm (GA) model. Upon comparison of these two optimization techniques, ANN-GA model obtained through feed forward back propagation methodology was found to be efficient and yielded 447.4 ± 21.43 L CH_4/kg VS_{fed} (0.279 g CH_4/kg COD_{vs}) which is 6% higher as compared to the CCD-RSM based approach.

1. Introduction

Anaerobic digestion of agro-food industrial wastes is known to be the most efficient method for treatment as it not only enables stabilization of waste but also helps in recovering both energy (as biogas) and compost (Ge et al., 2016; Yang et al., 2015). According to recent statistics for the year 2013–14, potato production in India amounts to 44.3 million tonnes cultivated in a massive scale of 2.02 million ha (Agricultural at a Glance, 2014). About 2% of total production has been diverted for processing sector to manufacture different value added products like chips, flakes and frozen potato (Pandey et al., 2009). Consequently, the quantum of wastes generated from processing industries has increased dramatically. It has been estimated that of the raw material used in potato processing

* Corresponding author.
E-mail address: rb@iitkgp.ac.in (R. Banerjee).

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unit 12–20% is released in the form of wastes (NDDB, 2014). Mostly the wastes comprise of peel, drum and decanter mash, rejects, pulp etc.

Industrial potato wastes (PW) are known to be a potential substrate for anaerobic digestion (Parawira et al., 2004, 2005; Weiland, 1993). Recently, Liang and McDonald (2015) reported a feasibility study for utilization of potato peel waste (PPW) from processing plant as a feedstock for biogas production. Methane yields from raw and pre-fermented PPW were found to be 239 L/kg VS_{fed} and 273 L/kg VS_{fed} respectively. However, no worthwhile research has so far been carried out on biomethanation of industrial potato waste in India.

Two principle factors play a significant role in anaerobic digestion and biomethanation process which includes substrate itself as well as adopted operating conditions for that system (Wang et al., 2015). From the report of Wang et al. (2016) it can be revealed that while handling waste activated sludge (WAS) for biomethanation process, it has been observed that hydrolysis and acidification rate goes down with the accumulation of polyhydroxyalkanoates (PHA) content in the WAS. As a result the acid accumulation in the reactor goes down which favours higher methanation, as the problem associated with the acidifications are automatically taken care of with the PHA accumulation. Thus the process of biomethanation becomes attractive not only because of enhanced methane production but also valorization of waste.

In the present study, the major bottleneck with easily digestible substrates like PW is the accumulation of volatile fatty acid (VFA) that results in lowering of the pH level (4–5) leading to process failure owing the inability of methanogens to survive under such physiological conditions (Kim et al., 2016). In order to overcome the accumulation of VFA, codigestion of one or more substrates which aid in balancing the pH level could be adopted. Selection of codigestion substrate should be done based on its abundance, availability and exhibition of synergistic effects by supplying missing nutrients or minimizing the concentration of inhibitory substances. Anaerobic digestion of PW along with sugar beet leaves was found to increase the accumulated methane production by 31–62% as compared to digestion of PW alone (Parawira et al., 2004). Bayr et al. (2014) demonstrated a codigestion study using PW and rendering waste (RW) in order to overcome the inhibition caused by the intermediates such as volatile fatty acids (VFA), long chain VFA and NH_3. Monodigestion of RW resulted in methane yield of 450 L/kg VS_{fed} whereas codigestion with PW at proportion of 60% (w/w) yielded 500–680 L/kg VS_{fed} under thermophilic condition. Ge et al. (2014) attempted anaerobic codigestion of tropical food waste which included papaya, sweet potato and taro with tropical forestry waste such as *Albizia* wood chips and leaves. Methane production of 345–411 L/kg VS_{fed} was achieved that indicated the robustness of anaerobic codigestion process. In general, manures, terrestrial energy crops, agro-residues and rejects of vegetable processing have been extensively utilized for codigestion leaving behind the aquatic flora. In the present investigation, *Pistia stratiotes* (PS), an aquatic weed, has been used as cosubstrate for anaerobic digestion of PW. PS is a fast growing menacing weed and is widely distributed in the tropical and sub-tropical regions of the world (Parsons and Cuthbertson, 2001). It has been used as a potential substrate for biogas production with an ultimate methane yield of 380–410 L/kg VS_{fed}. However, there were no recent studies on utilizing this biomass as potential candidate for bioenergy production (Abbasi et al., 1991; Nipaney and Panholzer, 1987). According to authors, codigestion of PW with PS is not documented so far.

Optimization of process parameters plays a vital role for efficient biogas production. Application of model based optimization approach such as central composite design (CCD) based response surface methodology (RSM) and artificial intelligence model like artificial neural network (ANN) coupled genetic algorithm (GA) for biological process have already been well documented (Betiku and Taiwo, 2015; Kana et al., 2012). In the present study, both the models (CCD-RSM and ANN-GA) have been employed for efficient process optimization of anaerobic codigestion using PW and PS.

Another important aspect of this study is inoculum. Mostly, dairy manure, rumen contents or digested sludge from wastewater treatment plants have been used as inocula for anaerobic treatment of wastes. However, either non-availability or availability in insufficient quantity of the inoculum (at a particular place and duration) poses a limitation for commercial production of methane especially in developing countries like India. It is, however, not desirable to rely on a single source and technology needs to be developed for replacement of the conventional inocula using a consortium of microorganisms that would participate in anaerobic digestion. The present work is an attempt at using specifically isolated bacteria in a consortium – Mixed Anaerobic Consortia (MAC) – as an inoculum for biomethane generation with PW and PS as substrates.

2. Materials and methods

2.1. Substrates and inoculum

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

PS was collected from the ponds in the campus of IIT Kharagpur (22°19′48.86″N, 87°19′25.15″E 22.330239, 87.323653). The harvested plants were washed thoroughly under running tap water to remove the debris adhering to the roots. The plants were then air dried, pulverized to 0.5 mm mesh size and stored for further use. The proximate and biochemical characteristics of the substrates have been tabulated in Table 1.

MAC used for biomethanation is a consortium of bacterial solution comprising *Corynebacterium nuruki*, *Aneurinibacillus migulans*,

Table 1
Characteristics of the substrates and inoculum.

Parameters	Units	Potato waste	*Pistia stratiotes*
Proximate analysis			
Moisture	(% of WW[a])	84.0 ± 2.43	90 ± 4.7
Total solid	(% of WW[a])	16.0 ± 5.3	10 ± 3.72
Total volatile solid	(% of DW[b])	92 ± 3.7	86 ± 6.44
Ash	(% of DW[b])	8 ± 1.3	14 ± 5.37
Biochemical analysis			
Total carbohydrate	(% of DW[b])	45.0 ± 2.3	23.5 ± 1.06
Total starch	(% of DW[b])	24.0 ± 6.25	10 ± 2
Total protein	(% of DW[b])	16.4 ± 0.25	9.9 ± 1.3
Total cellulose	(% of DW[b])	13.4 ± 0.12	9.7 ± 0.31
Total hemicelluloses	(% of DW[b])	9.5 ± 2.6	12 ± 1.3
Lignin	(% of DW[b])	8.0 ± 1.7	10 ± 2.1
Total carbon	(% of DW[b])	46.6 ± 1.53	25.8 ± 1.71
Total nitrogen	(% of DW[b])	1.3 ± 0.04	2.59 ± 0.02
Phosphorus	(% of DW[b])	0.26 ± 0.009	0.2 ± 0.018
Potassium	(% of DW[b])	1.05 ± 0.033	0.93 ± 0.047
Chemical oxygen demand	(g/g DW)	1190 ± 23	1200 ± 17
Inoculum (MAC)			
Volatile solid	(g VS/L)	4.37	
SMA	g COD_{CH4}/g COD_{vss} d	0.29	
pH	–	7.3 ± 1.8	

[a] WW – Wet weight.
[b] DW – Dry weight.