Bioresource Technology 254 (2018) 139–144

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Biomethanation potential for co-digestion of municipal solid waste and rice straw: A batch study

Suraj Negi[a,b], Hiya Dhar[b], Athar Hussain[a], Sunil Kumar[b,*]

[a] C.B.P. Government Engineering College, Jaffarpur, New Delhi 110 073, India
[b] CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur 440 020, India

ARTICLE INFO

Keywords:
Methane generation rate
Sludge activity
Anaerobic digestion
MSW
Rice straw

ABSTRACT

Rice straw (RS) contains a high amount of lignocellulosic materials which are difficult to degrade without thermal pretreatment. In the present study, co-digestion of municipal solid waste (MSW) and RS was carried out in three different ratios i.e., 1:1, 2:1, and 3:1 to get the maximum biomethanation potential and methane generation rate constant (k). The biogas and methane (CH_4) potential increased by 60% and 57%, respectively for MSW and RS in the ratio 2:1 as compared to other combination. The values of k, biochemical methane potential (μ_b) and sludge activity were measured as 0.1 d^{-1}, 0.99 CH_4-COD/COD_{fed} and 0.50 g CH_4-COD/g VSS, respectively. The sludge activity was found to be 100% for 2:1 ratio. Co-digestion of RS with MSW can also optimize the C/N ratio which is an essential parameter in the anaerobic digestion process.

1. Introduction

India being a land of agriculture generate more than 0.5 billion tonnes of crop residues per year (Gupta and Dadlani, 2012). Residues generated from agriculture are being used for thatching of homes, animal feeding, and in the form of domestic and industrial energy sources. A major portion of crop residue is still burnt openly in the field due to the high cost incurred towards removal of agricultural waste and non-availability of labors. Various pollutants are produced due to the burning which might cause many environmental and health problems (Gupta and Dadlani, 2012). Rice straw (RS) is the third largest agricultural waste behind maize and wheat (Kadam et al., 2000; Arvanitoyannis and Tserkezou, 2008; Zhao et al., 2010; Abbasi and Abbasi, 2010). Due to the intricate lignocellulosic structure of RS, it is problematic to decompose and hence RS has not been selected as a substrate for energy production. Due to reasons, such as abundance of RS, efficient pretreatment method, better and appropriate inoculum, and greenhouse gases (GHGs), such as methane (CH_4) and carbon dioxide (CO_2) emissions from wastes biomass, RS can no longer be ignored and must be used as a renewable source of energy (Ghosh and Bhattacharyya, 1999; Zhang and Zhang, 1999; Kadam et al., 2000; Mussoline, 2013).

In recent time, there is a trend of population shift as the urban population has been increasing far more than the rural population. The portion of the population living in urban areas has increased from 27.8% (2001) to 31.80% (2011) and likely to reach 50% (2030). About 1.5 lakh tonnes of municipal solid wastes (MSWs) are generated per day in Urban India. In metro cities, waste production ranges from 200 to 600 g/capita/day (MSWM Manual, 2016). It was estimated by The Energy and Resources Institute (TERI) that Indian cities would generate about 260 million tonnes of waste per year by 2947 (Asnani, 2006). The major portion of MSW in India is organic in nature which is about 40–60% of total solid waste generated (MSWM manual, 2016).

Anaerobic digestion is the process in which organic solid wastes are decomposed to produce CH_4, CO_2, and other trace gases by some specific microbes under oxygen deficient environment. In the digestion process, first organic substrates are hydrolyzed followed by the formation of volatile fatty acids (VFAs) due to fermentation of organic materials by acidogenic bacteria. Acetogenic bacteria's are then oxidized VFAs into acetate, hydrogen, and CO_2 which are the suitable substrate for methanogens (Pavlostathis and Geraldo-Gomez, 1991). Another term biochemical methane potential (BMP) is useful to test the substrate biodegradability under optimal anaerobic conditions.

The BMP is a bench-scale study to measure the maximum CH_4 potential/gram VS. It is usually done for 30 days (Nizami and Murphy, 2010). In BMP study, the substrate is tested in a laboratory under optimal conditions. The results from BMP test showed the concentration of organics in a substrate that can be anaerobically converted to biogas (Kaparaju et al., 2009). The study should be carried out at neutral pH ranges from 7.0 to 7.8 as pH value below 6.5 inhibits the methanogenic activity (Esposito et al., 2012). The contact between substrates and microorganism gets maximize the intensity of stirring providing

---

[*] Corresponding author.
E-mail address: s_kumar@neeri.res.in (S. Kumar).

https://doi.org/10.1016/j.biortech.2018.01.070
Received 14 November 2017; Received in revised form 10 January 2018; Accepted 15 January 2018

uniform moisture content (MC) (Esposito et al., 2012). Substrate/inoculum (S/I) ratio can influence the performance of BMP study. S/I ratio between 0.5 and 2.3 gVS/gVS of inoculum can prevent acidification (Esposito et al., 2012). Despite many benefits of anaerobic digestion, there are technical limitations and process stability issues for its implementation. Balancing nutrients, parameters like temperature, mixing, S/I ratio, pH and toxicity should be considered for the anaerobic digestion process. Co-digestion can be a viable solution to address these problems. By co-digestion process, utilization of the vital nutrients and bacterial colonies in different wastes can optimize the anaerobic digestion process (Macias-Corral et al., 2008).

Previous studies on straw as a substrate with different co-substrates, such as kitchen waste (Ye et al., 2013), sewage sludge (Kim et al., 2012), dairy and chicken manure (Wang et al., 2012), pig manure (Jimenez et al., 2015), cow manure (Li et al., 2015a,b), swine feces (Chen et al., 2009) were executed and analyzed which indicated the effect of co-digested substrate on the digestion rate of RS. Digestion of pig manure, RS and kitchen waste in optimum ratio 1.6:1:0.4 generates 10.41 and 71.67% more biogas production than mono digestion of pig manure and RS, respectively (Ye et al., 2013). Maximum CH_4 production was observed in co-digested dairy manure/chicken manure in the ratio 40.3:59.7 (Wang et al., 2012). Co-digestion of RS and cow manure produced 383.5 mL/g (Li et al., 2015a,b). The average CH_4 content was up to 62.88% when RS was co-digested with swine feces (Chen et al., 2009). Fish ensilage, manure and whey used as a feedstock for co-digestion provided CH_4 yield up to 84% higher than the individual digestion of the substrates (Vivekanand et al., 2018). Substrates like dairy manure, cotton grin and grass clippings in co-digestion give 96.5 mL of biogas production per gram of waste with an average CH_4 content of 70.5% (Macias-Corral et al., 2017). Microalgae chlorella sp. and chicken manure in the optimal ratio of 2:8 gave 14.20% and 76.86% enhanced CH_4 production than mono digestion of the individual substrates (Li et al., 2017). When fruits and vegetable waste were added with cow manure and corn straw, the production of CH_4 improved and the mean CH_4 yield was increased up to 22.4% (Wang et al., 2018).

Another study was also carried out using organic fraction of MSW and RS focused on kinetic parameters of biogas yield by Gompertz model (Abudi et al., 2016). Co-digestion of two wastes can reduce inhibition of methanogenesis process and increase CH_4 yield (Carucci et al., 2005). Due to the lignocellulosic structure of RS, Mono digestion of straw is unfavourable without any pretreatment. Anaerobic co-digestion of RS with MSW is an efficient and economical treatment method. Straw (high nitrogen content) mixed with MSW (high carbon content) provides optimal carbon/nitrogen (C/N) ratio. The pretreatment of RS either by chemical or thermal process requires capital investment and also affects the environment. In treatment of wastewater, the Quasi Newton algorithm is used to calculate different kinetic parameters (Hussain et al., 2009). Also, in UASB treating potato starch processing wastewater, the Quasi Newton algorithm is used to calculate kinetic parameters related to CH_4 (Antwi et al., 2017). There is a lacuna in studying the kinetic parameters of solid waste using Quasi Newton algorithm. Considering these facts, the objective of the present study was to compare the maximum biomethanation potential using co-digestion of MSW and RS to digest the RS without any pretreatment. Various kinetic parameters, such as methane generation rate constant (k), sludge activity and biochemical methane potential (μ_b) were measured using Quasi-Newton algorithm.

2. Materials and methods

2.1. Sampling of substrate

The organic portion of MSW was collected from multiple household waste of urban area. RS was collected from various agricultural fields from a rural area near by Nagpur. Samples were preserved at 4 °C in the freezer to avoid any decomposition. In order to prepare a homogeneous and reduced size sample, the same was grinded. For seeding and effective degradation of start-up of the study. the inoculum(sludge) was collected from a real scale cow dung anaerobic digester located near Nagpur and then added in airtight drum.

2.2. Experimental set-up

BMP bottles of 175 mL capacity with 150 mL total working volume were used for this study. Based on substrate VS percentage, inoculum volume was decided and filled into the bottles, and then the substrate was added. The remaining portion was filled with media, with the space left blank to fill nitrogen gas to maintain anaerobic condition. The different ratios of samples were taken: Control (Inoculum), MSW, RS, MSW: RS (1:1, 2:1, 3:1). Anaerobic sludge was used as inoculum. Sufficient amount of substrates was transferred to each bottle. Detailed characteristics of substrates are explained in Section 3.1. All the samples were taken on triplicate basis. The bottles were fitted with silicon and aluminum cap and kept in a shaker incubator at 37 °C with 100 rpm.

2.3. Analytical methods

MC, total solids (TS) and volatile solids (VS) of the substrates and inoculum were measured as per standard method (Bureau of Indian Standards (BIS) No. 10158-1982). Gas produced in each BMP bottle was measured on a daily basis. Blanks reactors were running parallel to the reactors in all the phases of the study. Batch experiment was performed in triplicate basis. The values considered and reported were the average. Frictionless glass syringe was used to determine the biogas volume during the bio-methanation period. The gas volumes were measured at a temperature of 37 °C and standard pressure at STP using the Ideal Gas Law. Agilent Technologies 7890A series was used at room temperature to analyze CH_4 composition.

2.4. Statistical analysis

The experimental data was used to calculate the value of k. Time t starts after the lag phase. Y_1, the initial CH_4 equivalent to 0.1 mL after blank error correction was assumed to correlate with the initial time after the lag phase. The cumulative CH_4 production profiles appeared to follow exponential growth curve (Kumar et al., 2016).

The rate of CH_4 production from the organic substrate is a function of biomass concentration to be digested (Kumar et al., 2016). Rate constant Eq. (1) was used to determine the kinetics of CH_4 production.

$$dY/dt = k(Y_{max}-Y) \tag{1}$$

where, Y_{max} = maximum CH_4 yield (mL); Y = cumulative CH_4 yield (mL); k = rate constant expressed in d^{-1}; t = time in days.

On integrating the above Eq. (1) within the limits t = 0 to t = t, the Eq. (1) is now presented as a

$$Y = Y_o(1-e^{-kt}) \tag{2}$$

Eqs. (1) and (2) provide the rate of change of organic substrate and CH_4 generation. The experimental data was used to calculate the value of k. The curve formed with the experimental data was analyzed and the best fit to the curve was obtained by using the Quasi-Newton algorithm. This algorithm uses non-linear regression and evaluates model parameters values by depreciating the sum of squared differences between the calculated and experimental values using a Ky plot software to evaluate the value of k.

3. Results and discussion

Biodegradability results are subjective to the methodology adopted, type and source of inoculum, adaptability of the sludge and storage conditions. Dhar et al., 2016 recommended that the seeding condition