Chapter 9
Optimization of F/M Ratio During Anaerobic Codigestion of Yard Waste with Food Waste: Biogas Production and System Stability

Sagarika Panigrahi, Hari Bhakta Sharma, and Brajesh K. Dubey

1 Introduction

As the two major organic fractions of municipal solid waste, food waste (FW) has lower carbon to nitrogen (C/N) ratio and yard waste (YW) has high C/N ratio. Carbon acts as the energy source for the microorganisms, whereas nitrogen plays a major role in increasing the microbial population. The C/N ratio indicates the nutrient level of a feedstock. Microorganisms need a suitable ratio of C/N for their metabolic process, and thus, anaerobic digestion (AD) process is sensitive to C/N ratio. A low C/N ratio may cause excess ammonia inside the digester, which may hamper the degradation of organic matter and may inhibit methanogens (Brown and Li 2013). In this scenario, co-digestion of FW and YW is a new opportunity for the C/N balance during AD. In most of the literature it has been reported that C/N ratio should be in the range of 20:1–30:1 with a fixed ratio of 25:1 optimum for bacterial growth in an AD system (Khalid et al. 2011).

Beside the C/N ratio another crucial factor affecting AD process is the food to mass (F/M) ratio expressed as the amount of feedstock added per amount of inoculum on volatile solid (VS) basis (Cheng and Zhong 2014). Theoretically F/M ratio can affect the kinetics of AD process, and it doesn't have any effect on ultimate methane yield (which depends only on the food or feed stock). However, experimental results have concluded that high F/M ratio can be toxic and low F/M ratio can inhibit enzyme induction for organic matter degradation or fasten the startup period to obtain higher experimental methane yield (Cheng and Zhong 2014; Krishania et al. 2013). In this situation, it is important to minimize the requirement of active inoculum and avoid the toxic condition inside the digester. Previous studies on F/M ratio optimization during AD of organic fraction of municipal solid waste were

S. Panigrahi · H. B. Sharma · B. K. Dubey (✉)
Civil Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India
e-mail: bkdubey@civil.iitkgp.ac.in

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complementary. In the study of Neves et al. (2004) F/M ratio of 0.5–2.3 was recommended for AD process whereas in the study of Brown and Li (2013), a decrease in biogas production was observed with increase in F/M ratio from 1.6 to 5.0. In the study of Elbeshbishy et al. (2012), optimization of F/M ratio for AD of FW was conducted at a constant pH 7. However, maintaining a constant pH externally may not be feasible. Based on the above research gaps, this work investigates about the optimization of F/M ratio during anaerobic co-digestion of FW and YW under an uncontrolled pH.

In the present research, a lab scale batch anaerobic co-digestion of FW and YW was conducted. The purpose of co-digestion was (i) optimize F/M ratio during co-digestion based on biogas production; and (ii) effect of different F/M ratio on reactor stability during anaerobic co-digestion.

2 Material and Methodology

2.1 Collection and Characterization of Yard Waste, Food Waste and Inoculum

The YW was collected from the Indian Institute of Technology Kharagpur campus, India, Inorganic contaminants (debris, plastic, metal contaminants etc.) were separated manually. The quartering method was adopted to collect the representative sample and the representative sample mainly composed of grass (33% by wt.), dry leaves (33%) and fallen sticks (2%). The collected YW was grounded by a domestic mixture and stored in an air-tight plastic bag for further use. FW used in this study was collected from girls' hostel canteen. The collected FW mainly composed of cooked rice, vegetables, bread, and meat. Then the collected FW was homogenised by a domestic mixture grinder and stored at a temperature of 4 °C, for further use. Fresh waste activated sludge (WAS) was collected from the mesophilic AD plant, running inside the campus. The collected WAS was centrifuged to increase the total solid (TS) content from 6.7% to 10.5%. The collected WAS was used as an inoculum for batch AD study. The initial characteristics of YW, FW and WAS is presented in Table 9.1.

Table 9.1 Composition of substrate and inoculum used for batch anaerobic digestion

F/I ratio	Yard waste (g)	Food waste (g)	Total amount of feedstock (g)	Inoculum (g)	Total weight (g)
1.0	36	108	144	144	288
1.5	43	130	173	115	288
2.0	48	144	192	96	288
2.5	51	154	206	82	288

2.2 Batch Biochemical Methane Potential Study

All substrates and inoculum (YW, FW and WAS) were added into the digestion reactor, the proportion of feedstock is mentioned in Table 9.1. The composition of FW and YW were selected in order to maintain a C/N ratio of 25.0, calculated using Eq. 9.1. The proportion of feedstock (YW and FW) and WAS was calculated based on Eq. 9.2. Then nitrogen gas was purged into the reactor for 4 min to create a complete anaerobic condition. Soon after that the digestion reactors were connected to the displacement tank filled with 1.5 N NaOH through a plastic pipe. A collector tank was arranged with the displacement tank (Fig. 9.1) to collect the displaced water from displacement tank (Esposito 2012). Thymol blue was added to the NaOH solution and used as an indicator of alkalinity of the solution. The batch AD experiment was conducted for 30 days until the cumulative biogas production reached a stable value.

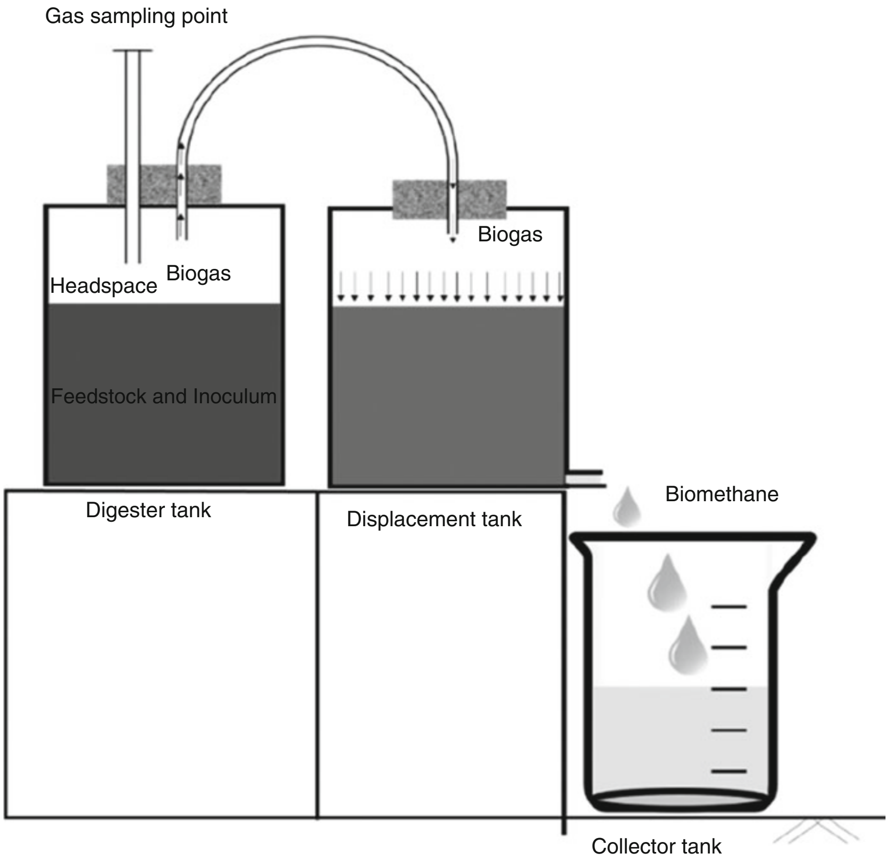

Fig. 9.1 Batch biochemical methane potential setup for codigestion of yard waste and food waste

2.3 Analytical Methods

The TS, VS, pH and soluble COD (sCOD) were measured according to the standard protocols of the American Public Health Association (APHA 1995). Volatile fatty acid (VFA) was measured by the direct titration method with 0.1 N H_2SO_4 up to pH 3.3 and then 0.1 N NaOH up to pH 7.0, according to the procedure described by DiLallo and Albertson (1961). The methane production was measured daily by adopting water displacement method and substrate characteristics in the reactor were measured after every 6 days during 30 days of digestion period. Compositional analysis: cellulose (Updegraff 1969), hemicellulose (Goering and Van 1975), lignin (National renewable energy laboratory procedure) (Sluiter et al. 2008) contents of the untreated and pretreated reactors were measured. Ultimate analysis in terms of carbon (C), hydrogen (H) and nitrogen (N) contents and ratio of C/N was carried out using standard procedure of CHNS analysis by using a fully automatic elemental analyser (EURO EA, Germany).

2.4 Calculation Methods

The total C/N of the mixed material was calculated using Eq. (9.1):

$$(\mathrm{C/N})_{\mathrm{Mixture}} = \frac{W_{\mathrm{FW}} \times C_{\mathrm{FW}} + W_{\mathrm{YW}} \times C_{\mathrm{YW}}}{W_{\mathrm{FW}} \times N_{\mathrm{FW}} + W_{\mathrm{YW}} \times N_{\mathrm{YW}}} \tag{9.1}$$

F/M was calculated with Eq. (9.2):

$$\frac{F}{M} = \frac{W_{\mathrm{FW}} \times VS_{\mathrm{FW}} + TS_{\mathrm{YW}} \times VS_{\mathrm{YW}}}{VS_{\mathrm{WAS}}} \tag{9.2}$$

where W_{FW} and W_{YW} are the amount (g TS); C_{FW} and C_{YW} are the carbon content (% TS); N_{FW} and N_{YW} are the nitrogen content (% TS); and VS_{FW} and VS_{YW} are the VS content (% of TS), in FW and YW respectively.

3 Result and Discussion

3.1 Properties of Feedstocks

The initial characteristics of YW, FW and WAS used in this study for experimental methane yield are given in Table 9.2. The high initial TS and VS content in YW (89.5 ± 0.6%, 97.3 ± 2.2% TS), and FW (22.6 ± 0.8, 99.8 ± 0.1% TS), made the substrates suitable for solid state AD. Although the initial pH of FW is below 4.0,

Table 9.2 Initial characteristics of yard waste (YW), food waste (FW) and waste activated sludge (WAS)

Parameter	Unit	YW	FW	WAS
TS	%	89.5 ± 0.6	22.6 ± 0.8	10.0 ± 2.5
VS	% TS	97.3 ± 0.6	99.8 ± 0.1	99.2 ± 0.1
pH		7.5 ± 0.05	3.7 ± 0.7	7.8 ± 0.46
VFA	mg/L	363.75 ± 20.16	970 ± 127	157.45 ± 13.16
sCOD	mg/g TS	189.35 ± 15.45	634.8 ± 19	216.30 ± 24.92
C	%	46.2	42.7	
H	%	5.83	9.1	
O	%	46.9	46.2	
N	%	1.03	1.98	
S	%	< 0.3	0.3	
C/N		44.8	21.6	9.43

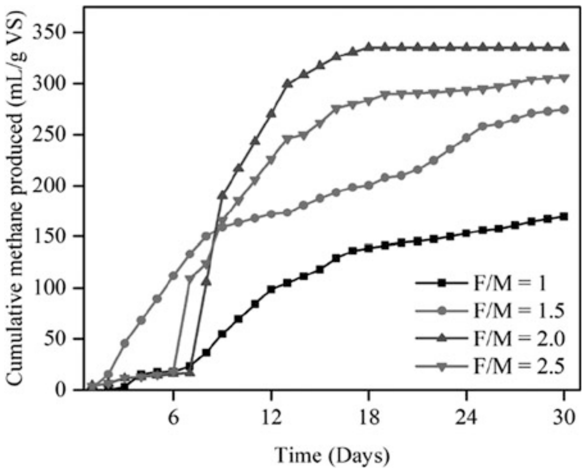

Fig. 9.2 Cumulative methane yield for different F/M ratios during anaerobic co-digestion of food waste and yard waste

initial pH of the YW and WAS were 7.5 ± 0.05 and 7.8 ± 0.46%. The initial C/N ratio of YW and FW were 44.83 and 21.57, respectively. In order to maintain an optimum C/N ratio (25.0) YW and FW were mixed in a proportion of 1:3.

3.2 Effect of F/M Ratio on Methane Yield

The effect of four different F/M ratios (1.0, 1.5, 2.0 and 2.5) on cumulative methane production during anaerobic co-digestion of FW and YW is shown in Fig. 9.2. The biogas production in the initial days was low due to hydrolysis of complex organic matter. The higher initial biogas production for low F/M ratios (F/M ratios 1.0 and 1.5) was likely due to the high amount of WAS, which provided relatively large

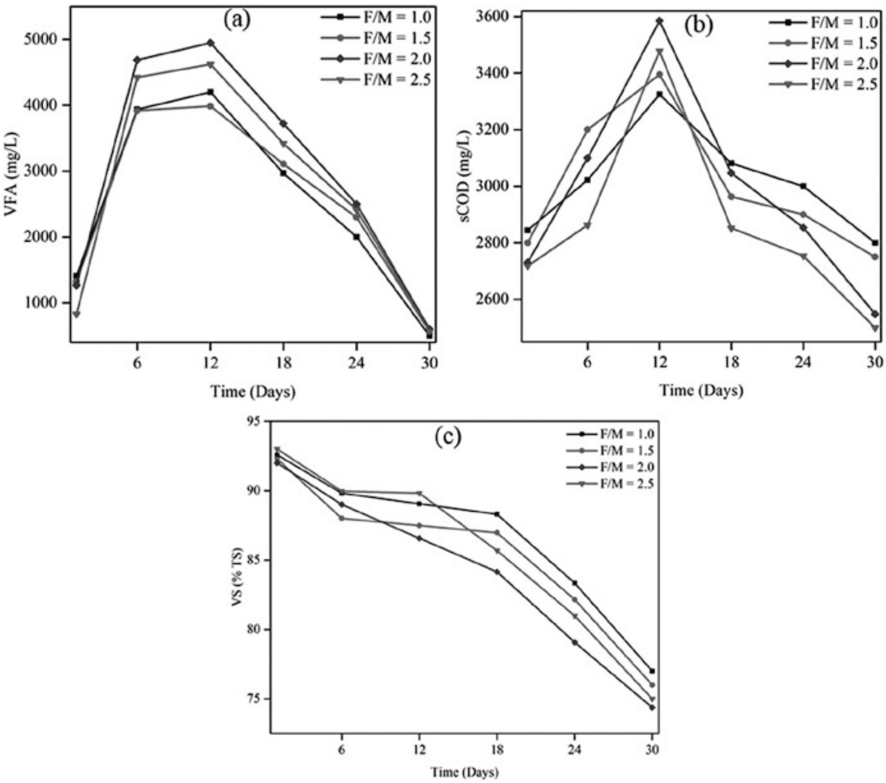

Fig. 9.3 Variation in VFA (**a**), sCOD (**b**), and VS (**c**) for different F/M ratios during anaerobic co-digestion of food waste and yard waste

concentrations of hydrolytic enzymes, fermenting and methanogenic bacteria. After initial lag phase, the biogas production was increased for F/M ratios 2.0 and 2.5, and the production rate was higher than F/M ratios 1.0 and 1.5. The cumulative experimental methane yield was: 169 mL/g VS (F/M = 1.0), 274 mL/g VS (F/M =1.5), 335 mL/g VS (F/M = 2.0), and 306 mL/g VS (F/M = 2.5).

3.3 Effect of F/M Ratio on VFA Production

The variation of VFA obtained during anaerobic co-digestion of YW and FW for different F/M ratios is presented in Fig. 9.3a. The initial VFA concentration was 1412.75 mg/L for F/M ratio of 1.0, 1325.41 mg/L for F/M ratio of 1.5, 1268.75 mg/L for F/M ratio of 2.0, and 831.25 mg/L for F/M ratio of 2.5. The initial VFA concentration was found decreasing with increasing F/M ratio, due to increase in inoculum concentration. A rapid increase in VFA production was noticed within 6 days; this is due to conversion of organic matter into simpler monomeric compounds (Elbeshbishy et al. 2012). The VFA production was increased up to 12th day, and the highest VFA production (4950.45 mg/L) was found for F/M ratio 2.0. The decrease in VFA concentration after 12th day can be marked as the initiation of methanogenesis stage. The VFA concentration throughout the digestion period was lower than the inhibiting concentration i.e., 13,000 mg/L indicating favourable conditions for the growth and activity of acid-producing microorganisms.

3.4 Effect of F/M Ratio on Organic Matter Solubilisation

The variation in sCOD throughout digestion period is depicted in Fig. 9.3b. The initial sCOD was high (2844.44 mg/L) for low F/M ratio (1.0) due to higher fraction of inoculum and further increase in F/M ratio led to decrease in sCOD to 2804.15 mg/L for F/M ratio 1.5, 2730.08 mg/L for F/M ratio 2.0 and 2718.3 mg/L for F/M ratio 2.5. The sCOD concentration was increased on 6th day, achieved a highest value on 12th day and after that sCOD started decreasing. The highest sCOD was found for F/M ratio 2.0 (3584.52 mg/L) followed by 2.5 (3478.87 mg/L), 1.5 (3395.74 mg/L), and 1.0 (3325.45 mg/L). The final sCOD measured on 30th day was higher for F/M ratios 1.0 and 1.5 in comparison to F/M ratios of 2.0 and 2.5, which indicates digester instability for F/M ratios 1.0 and 1.5.

3.5 Effect of F/M Ratio on VS Degradation

The degradation in VS throughout the study period is presented in Fig. 9.3c. As expected, no significant difference in initial VS was observed for different F/M ratios because the F/M ratio was maintained based on the VS content. VS is an important parameter in AD; the amount of VS removed is directly related to biogas production (Zhu et al. 2010). A sharp decrease in VS content in the initial 6 days is related to removal of easily biodegradable structural components. The rate of decrease was quite moderate between 6th and 12th days, may be due to hydrolysis of structural components (cellulose, hemicellulose and lignin). After 18th day, a sharp decrease in VS reduction was noticed, which is related to the methanogenesis phase. A highest VS reduction (74.38% TS) was noticed for F/M ratio of 2.0 indicating highest amount of biogas production, which was also confirmed from Fig. 9.2.

4 Conclusion

The present study made an effort to handle two major organic fractions of municipal solid waste (food waste and yard waste) through anaerobic co-digestion. Optimization of F/M ratio was also done to improve biogas production. Highest biogas production was observed for F/M ratio of 2.0. As expected, the highest organic matter solubilisation, VFA production and VS degradation were also observed for the same F/M ratio.

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