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Effect of Mixture Ratio of Food Waste and Vetiver Grass on Biogas Production

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Abstract

The objectives of this research were to study the optimum percentage ratios of food waste and vetiver grass (*Vetiveria zizaniodes* (L.) Nash) for biogas production and process stability in anaerobic digestion system. The nine mixture ratios of food waste (FM) and vetiver grass (VG) were 100:0, 80:20, 75:25, 66.67:33.33, 50:50, 33.33:66.67, 25:75, 20:80 and 0:100. The biogas production was subjected to anaerobic batch with working volume of 1.8 L and had digestion time 60 d at 35 ± 2 °C. High specific methane yield of 0.30 L g^{-1} VS removed was obtained from the fermentation at ratio of FW:VG at 80:20 with C/N ratio of 28.20. The specific methane yield of the single digestion of food waste (100:0) and single digestion of vetiver grass (0:100) were only 0.18 and 0.11 L g^{-1} VS removed, respectively. It was found that the cumulative methane production of FW: VG ratio of 80:20 was increased 34.89% and 96.93% compared to single substrate of food waste and vetiver grass, respectively. The results also showed the highest COD, VS and TS removal with a percentage ratio of FW: VG at 80:20, while the single vetiver grass digestion was the lowest COD, VS and TS removal. VFAs/Total alkalinity ratio of all ratio of food waste to vetiver at digestion time 40 d remained in 0.0895±0.0007 to 0.1944±0.0027 were steadied for this digester. It can be concluded that co-digestion of food waste and vetiver improve the biogas yield and degradation efficiency.

Keywords: Biogas production; Food waste; Vetiver grass; Methane; Anaerobic digestion

Introduction

In Thailand, 15 million ton of food waste was produced in year 2016, that rationalized a large of solid waste [1]. Treatment of food waste methods such as landfill, animal feed, aerobic composting and anaerobic digestion [2]. Food waste demonstrate the chance for the production of renewable fuels and one of the least used of all organic waste [3]. The anaerobic digestion has proved to be effective

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technology to treat food waste due to easily biodegradable. It is offering the benefits in term of methane, waste reduction and stabilization, low carbon emission and limited pollution [4]. The 12.7–28.84 of C/N ratio and 4.1–6.5 of pH were presented in individual food waste [5]. Tanimu et al. studied methane from food waste with 17, 26 and 30 of C/N ratio in a batch mesophilic anaerobic digester and found that only food waste with C/N ratio 30 gave the highest methane [6]. The digestion of only food waste is poor because of low C/N ratio and high acidification [2]. The co-digestion of food waste with other waste has become increasingly popular due to the fact that the C/N ratio adjustment could increase the methane yield and improve the utilization efficiency. For a number of literatures have informed the improvement of biogas yield as a result of co-digestion of food waste such as rice husk [7], rice straw [8], de-oiled grease tap waste [3], maize husk [9], Spirulina platensis [10] and tall fescue [11].

Vetiver grass (*Vetveria zizaniodes* (L.) Nash) is a perennial tufted grass in Poaceae family. It is known as a miracle grass with value for soil and water conservation, rehabilitation, and remediation, and waste water treatment [12]. In Thailand, the amount of vetiver grass increased due to campaign of planting. Anerobic digestion for biogas of vetiver grass alone was interesting but there was some shortcoming, such as nitrogen deficiency due to it high C/N ratio of vetiver grass. In this experiment found that the C/N ratio of vetiver grass was quite high (45.03), while C/N ratio of food waste has lower (19.54) may cause ammonia release, reduction of degradation and inhibition of methanogenesis [2]. The co-digestion between food waste and vetiver grass in a new opportunity for nutrients balance. Moreover, there are no research reports on the co-digestion of food waste and vertiver grass as raw material for biogas production. The purposes of this research were to evaluate the potential of co-digestion food waste and vetiver grass in anaerobic digestion system along with the effect of effect of mixture ratio of food waste and vetiver grass for biogas production and process stability.

Materials and Methods

1) Preparation of food waste and vetiver grass

The food waste (FW) was collected from Maejo University's canteen, Chiangmai, Thailand, which mainly contained of rice, noodles, vegetables and meats. The food waste was crushed to 1-2 mm. with an electrical grinder.

Vetiver grass (VG) was harvested at 45 d from plantation in the area at Chiangmai Province, Thailand. After collection, vetiver grass was dried at room temperature for 3 d before cut to 1 cm. Then, vetiver grass was fermented in a reactor for 60 d before using in the experiment.

The lignocellulose such as cellulose, hemicellulose and lignin in the vetiver grass were analyzed by Van Soest et al. (1991) procedure [13].

2) Experimental setup

The anaerobic bioreactor was conducted in 2 L of glass bottles, with working volume of 1.8 L, using 15% w/v of seed sludge as inoculum (Figure 1). Therefore, the ratio between inoculum and substrate was 1:5.6. Anaerobic sludge from swine farm was used as inoculum to the digester. The bioreactors were set at 35 ± 2 °C. The anaerobic bioreactor was connected to 3-way stopcock control value. The biogas was taken by biogas sampling bag. While, the total volume of biogas was measured by water displacement method on daily basis considering the volume of generated biogas equal to that expelled water in the water collection. All reactors were mixed by manually shaking for 3 min, twice a day.

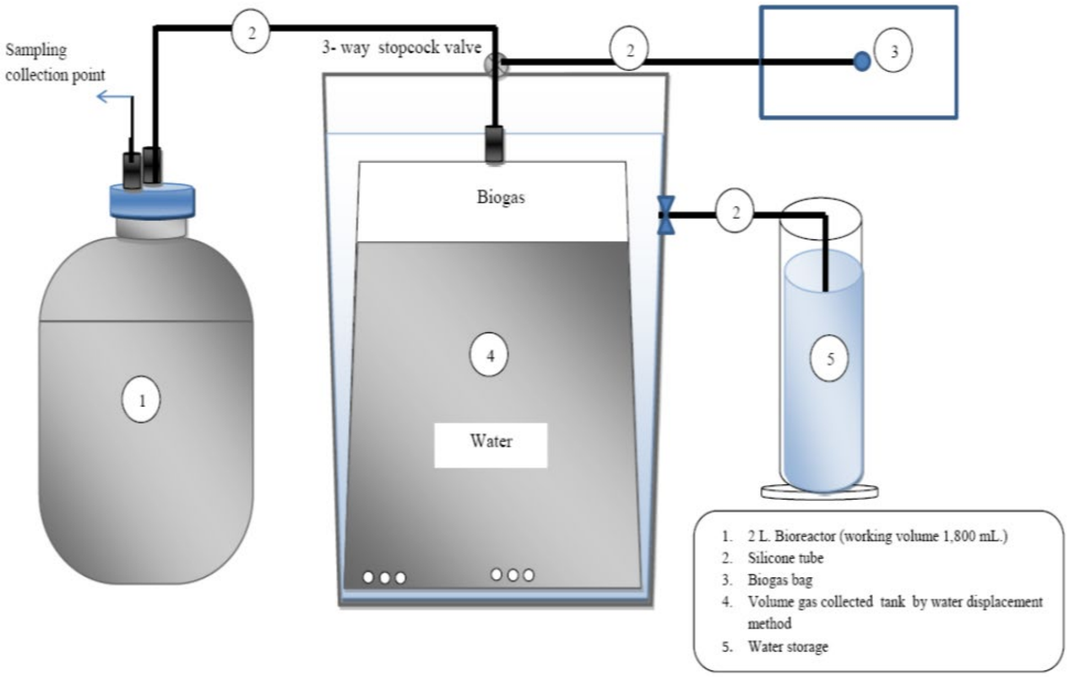

Figure 1 Scheme of experimental set up for anaerobic digestion reactor.

3) Effect of mixture ratio of food to vetiver grass on biogas production

Nine mixtures were prepared by mixing the co-substrate in various proportions. The percentages of the substrate (FW and VG) were based on total fresh weight (g) of FW:VG at 100:0, 80:20, 75:25, 66.67:33.33, 50:50, 33.33:66.67, 25:75, 20:80 and 0:100. The stability of digestion system was investigated by measuring the pH, chemical oxygen demand (COD), total solids (TS), volatile solid (VS) and volatile fatty acids (VFAs). The optimum percentage ratio of FW and vetiver grass was determined by comparing methane production rate. The composition of biogas was analyzed by gas chromatography (HP6890, Agilent Technologies, Wilmington, USA) equipped with alumina/KCl deactivation column (30 m x 0.53 mm x 10 mm) and a thermal conductivity detector (TCD). The helium gas was used as a carrier gas at flow rate of 52.2 mL min^{-1}. Temperatures of the injector, column, and detector were set at 150, 40 and 200 °C, respectively. For process stability, pH, COD, VS and TS concentration were measured every 5 d until 60 d of the digestion. The pH was determined by a pH meter (Delta 340, Mettler Toledo). VS, TS were determined based on gravimetric analysis. Total chemical oxygen demand (tCOD) was analyzed according to closed reflux method. VFAs was also determined by direct titration method. Moreover, carbon and nitrogen in each condition were analyzed by elemental analyzer (LECO CHNS-932) [14].

Results and discussion

1) Characteristic of substrate

Food waste with high solids content (more than 15%) can block the pipe in bioreactor. Dilution food waste with water can solved this problem. The compositions of food waste and vetiver grass were shown in Table 1. COD, VS and TS of food waste were relatively high as 435.6±3.56 g L^{-1}, 1208.33±3.78, and 1427.08± 0.25 g L^{-1}, respectively. Then, the food waste was diluted with 90% w/v of water to reduce the concentration of COD, VS and TS for preparing in this experiment to prevent the shock load of the anaerobic system with working volume of 1.8 L.

Table 1 Characteristic of food waste and vetiver grass used in anaerobic digestion

Parameters	Food waste	Vertiver grass
pH	7.06±0.05	7.26±0.05
tCOD (g L^{-1})	103±1.86	8±0.20
VS (g L^{-1})	66±2.65	7±0.32
TS (g L^{-1})	53±0.85	7±0.25
Alkalinity (mg $CaCO_3$ L^{-1})	2,780±20	3,316±20.81
TKN (mg L^{-1})	54±0.88	171±0.88
TP (mg L^{-1})	11±0.38	34±0.32

The cellulose, hemicellulose and lignin were 31, 35, and 5%, respectively. The sum of cellulose, hemicellulose and lignin of vetiver grass (71%) was below the straw (73.12%) [2] and higher than the tall fescue (66.5%) [11]. This indicated that the characteristic varied among different green wastes.

2) The effect of co-substrate mixture ratios on biogas production

The overall performance of digesters was shown in Table 2. The cumulative and specific methane yield of 9 substrate mixtures were shown in Figure 2 and Figure 3. The results showed that the percentage ratio of FW: VG at 80:20 indicated highest cumulative methane production (21, 123 mL) and specific methane yield (0.30 L g^{-1} VS removed) among all conditions, while mixture ratio of 0:100, individual vetiver grass, showed lowest specific methane yield (0.11 L g^{-1} VS removed). Compared with individual FW fermentation (100:0) and vetiver grass (0:100), the cumulative methane production of the percentage ratio of FW:VG at 80:20 was increased by34.89 and 96.93%, respectively.

Specific methane yield and cumulative methane production were highest when the percentage ratio FW to vetiver was 80:20, having C/N ratio of approximate 28.12. The C/N ratio is respected to be a very significant factor when investigating anaerobic digestion and co-digestion of different substrates and mixtures of substrates.

The results in Table 2 demonstrated that the percentage ratio of FW:VG at 80:20 had the highest % CH_4 of biogas production (64.10%) among all conditions. Furthermore, the individual food waste (100:0) and vetiver grass (0:100) digestion produced 51.43 and 44.96% CH_4, respectively. This is similar to the Yong et al. (2015) which found that the methane content for individual and food waste (0:5) and straw substrate (5:0) was only 52.43 and 57.35% CH_4, respectively [2].

Table 2 Performance parameters in different co-substrate mixing ratios

FW:VG (%) (w/w), based on the total weight (g)	Operation condition					Digester performance		
	C/N	pH at 15 d of digestion	pH at 60 d of digestion	VFAs at 15 d of digestion (mg L^{-1})	VFAs at 60 d of digestion (mg L^{-1})	CMP[a] (mL)	SMY[b] (L g^{-1} VS removed)	% CH_4
100:0	19.54	6.57	7.07	1009	426	13,753	0.18	51.43
80:20	28.12	6.68	7.10	961	401	21,123	0.30	64.10
75:25	30.05	6.75	7.15	946	385	15,332	0.24	56.70
66.67:33.33	31.08	6.81	7.16	895	370	13,276	0.23	54.91
50:50	32.28	6.85	7.22	850	356	8,816	0.20	53.60
33.33:66.67	34.15	6.86	7.24	795	342	4,811	0.17	52.50
25:75	35.32	6.88	7.26	784	328	3,465	0.16	51.80
20:80	36.22	6.92	7.30	719	319	2,678	0.15	50.16
0:100	45.03	7.02	7.40	493	282	648	0.11	44.96

Remark: [a] Cumulative methane production
[b] Specific methane yield
C/N = ratio of carbon (%) to nitrogen (%) of food waste mixed with vetiver grass in reactor

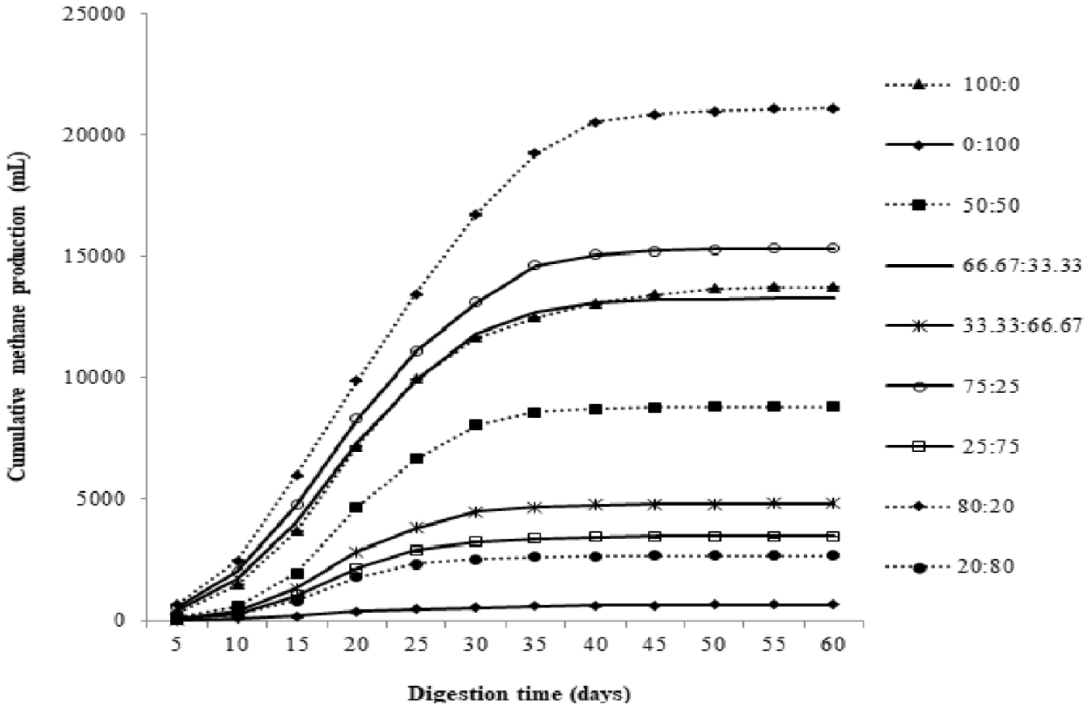

Figure 2 Cumulative methane production of substrate mixtures at different mixing ratio.

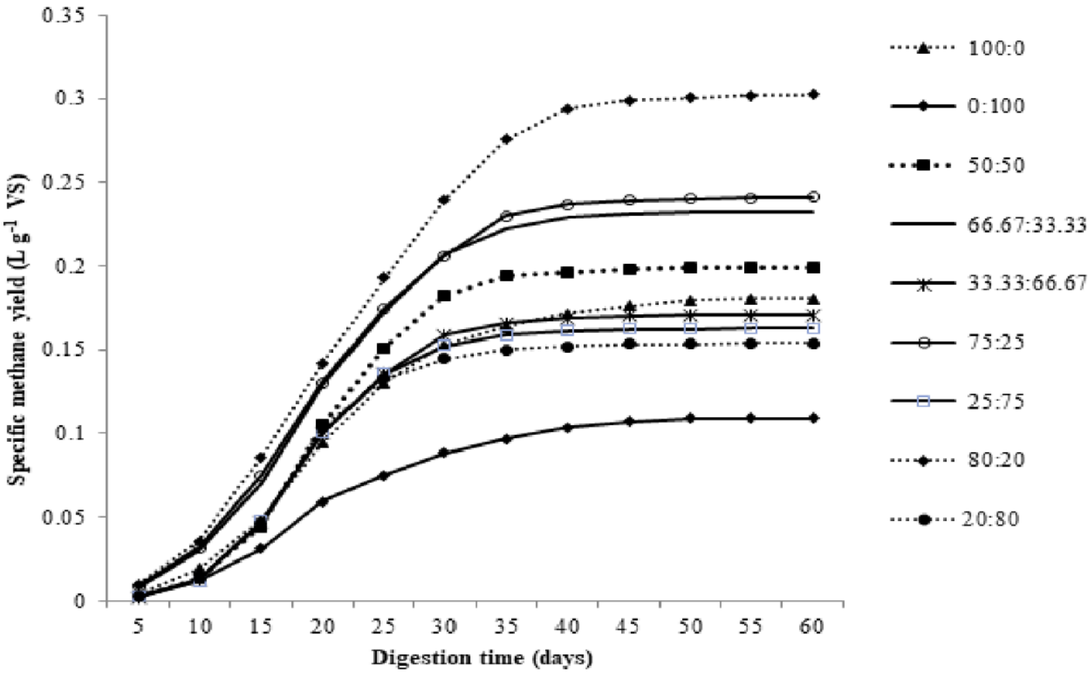

Figure 3 Specific biogas yield of substrate mixtures at different mixing ratio.

The C/N ratio of 28.12 (FW:VG=80:20) had highest the specific methane yield and cumulative methane. The optimal C/N ratio for anaerobic digestion is reported in range of 20–30 [5]. Lower C/N ratio of feedstock lead to accumulation of ammonia nitrogen which can inhibit methanogenisis, On the other hand, higher C/N ratio of feedstock, methanogens consume nitrogen more rapidly, resulting in nitrogen deficiency and cause to low biogas production [15].

The suitable pH for anaerobic digestion is between 6.5–8.00. The methanogens were inhibited if pH lower than 6.5 or more than 8 [9]. There was very slight decrease in pH during the first 15 d of digestion in all reactors. After that, the pH slightly increased until 60 d of the digestion. However, this pH was not high enough to affect the methanogenic activity and remained above minimum suitable pH of 6.5 required for the methanogenic system [7, 16].

It is found that using food waste and vetiver grass as feed stock had methane yield (0.30 L g^{-1} VS) close to the co-digestion of food waste and tall fescue (0.296 L g^{-1} VS) [11]. However, the methane yield produced from co-digestion of food waste and vetiver grass had lower than co-digestion of food waste and rice husk (0.584 L g^{-1} VS) and co-digestion between food waste and straw (0.392 L g^{-1} VS).

3) The effect of co-substrate mixing ratios on stability of anaerobic digestion

The stability of the anaerobic digestion system was determined by studying the relationship of VFAs and pH change, as shown in Table 2. The pH of all the reactors remained between 6.57–7.40 during the entire digestion period.

In the first 15 d digestion, the rank-ordered decrease in pH of anaerobic reactors were as follows: 100:0> 80:20> 75:25> 50:50> 66.67: 33.33> 33.33:66.67> 25:75> 20:80> 0:100. This was due to the fact that the increasing food waste proportion in the mixture lead to increased labile organic fraction, which were further converted to VFAs in the first 15 d of digestion, resulting in decreased pH values [2].

In the current study, reactors' pH was naturally maintained within the optimum range due to the addition of co-substrate and alkali addition was not needed throughout digestion period for pH adjustment. The co-digestion of fruits and vegetables waste with food waste was interrupted the high level of acidification. Therefore, the co-digestion with optimal ratios could supplement the pH for the consistency of reactor.

Volatile fatty acids are produced during fermentation stage, and their concentrations in the reactor indicate the stability of anaerobic digestion process [7]. The concentration of VFAs increases with increasing organic load in the digester. In the current study, FW: VG ratio with 100:0 (mono substrate only food waste) had higher VFA concentration at 15 d digestion compared to other mixtures because of higher proportion of food waste used in this 100:0 ratio. After 15 d digestion, VFAs concentration started declining until 60 d digestion. However, the VFAs were within optimum range and did not cause inhibition during whole digestion period. VFA concentration of more than 5000 mg L^{-1} may cause inhibition of digester [7, 17].

Another good indicator of process stability is VFA/Alkalinity ratio. In current study, VFA/ Alkalinity ratios of all the reactors remained in between 0.0895 and 0.1944. Prior research has observed that VFA/Alkalinity ratios of less than 0.4 are optimum for anaerobic digestion [7, 18].

4) The effect of co-substrate mixing ratios on COD, VS, TS reduction

COD, VS and TS reduction from all substrate mixtures were present in Figure 4. The significantly highest COD, VS and TS removal was observed for substrate mixture ratio of FW:VG at 80:20 when compared among all FW:VG ratios (p<0.05), while the individual vetiver grass (0:100) for fermentation had the lowest efficiency of COD, VS and TS removal.

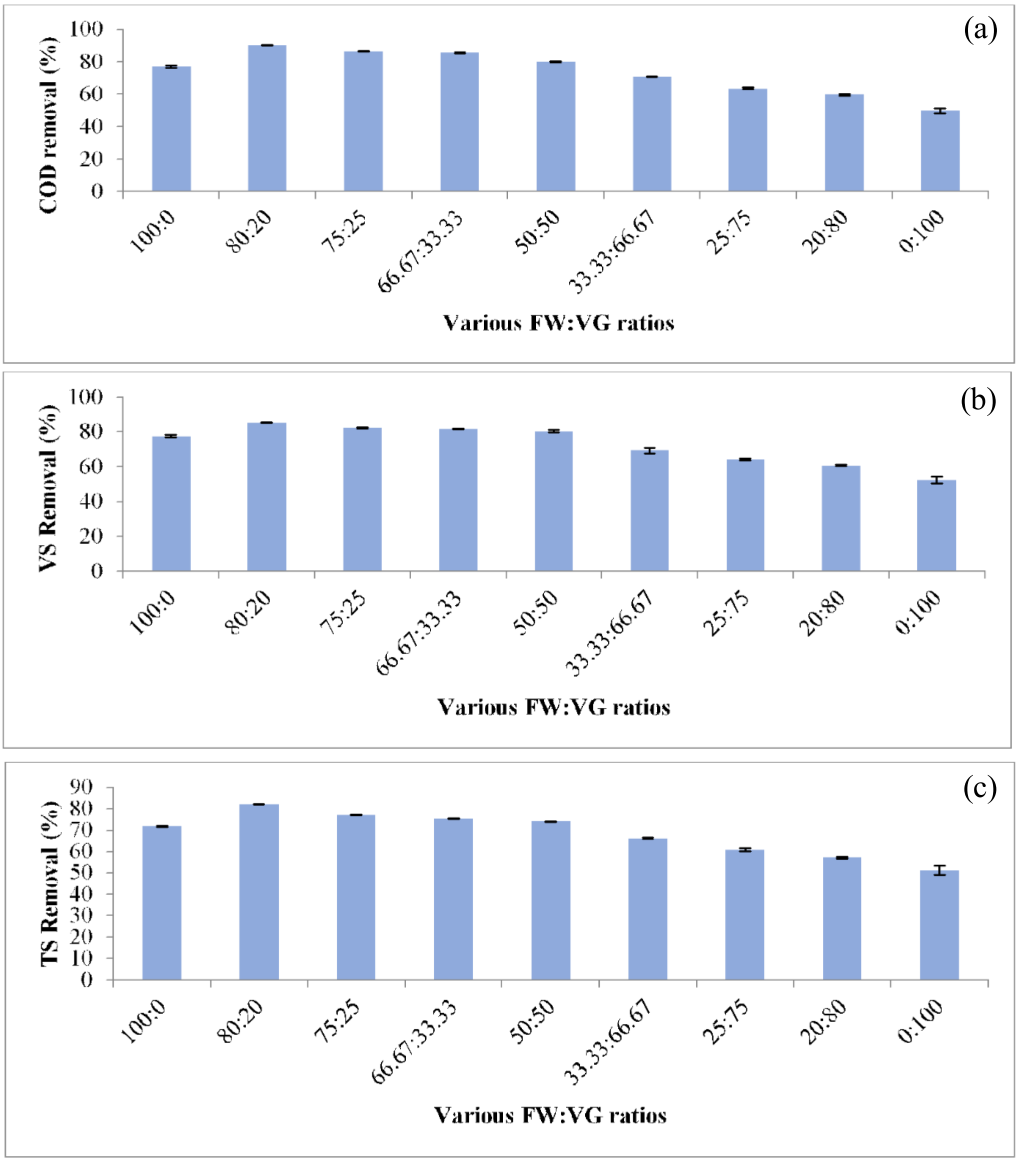

Figure 4 COD (a), VS (b) and TS removal (c) of various FW: VG ratios in anaerobic digester.

The results indicated that higher COD, VS and TS reduction were indicative of higher specific methane yield (Figure 4 and Table 2). High methane yield was because of high specific growth rate of methanogens in anaerobic reactors [11].

Removal of TS from all substrate mixtures was lower than its respective VS removal, but the trend of TS removal was similar to that of VS removal. [7, 11]. Figure 4 also demonstrates that VS reduction from substrate mixture of FW:VG at 80:20 was 1.10 and 1.63 times higher and the TS reduction was 1.14 and 1.60 times higher than the mono-substrate food waste (100:0) and vetiver grass (0:100) treatments, respectively. This is due to the higher fraction of food waste for co substrate used in the 80:20 ratio. It is well known that food waste consists of approximately 75% of very easily biodegradable organic matter [19]. Similar results have also been reported by several researchers in which higher VS reduction were obtained with high levels of food waste in substrate mixtures [17, 20-21].

Conclusions

The specific methane yield for individual food waste and vetiver grass obtained was 0.180 and 0.11 L g^{-1} VS removed, respectively. The suitable percentage mixing ratio for co-digestion of FW and vetiver grass was found to be 80:20, with the approximate C/N of 28.82, and corresponded to the maximum cumulative methane production and specific methane yield of 21,123 mL and 0.30 L g^{-1} VS removed, respectively. Compared with individual food waste or vetiver grass digestion, the cumulative methane production was increased by 34.89 and 96.93%, respectively.

Acknowledgements

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