INTERACTION EFFECT OF CO-DIGESTION SEWAGE SLUDGE AND FOOD WASTE FOR PRODUCTION OF BIOGAS

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ABSTRACT: Increasing population, urbanization and industrial activities have increased the amount of solid waste worldwide. Food waste (FW) and sewage sludge (SS) are some of the solid wastes. Co-digesting of both substrates may improve process stabilization to increase biogas production and overcome the nutrients imbalance. Thus, anaerobic co-digestion has been recognized as a technology that could provide a clean renewable energy source and help reducing the landfill problem. In this study, the interaction between FW and SS as co-substrates in anaerobic digestion was studied under mesophilic temperature 36°C (± 0.5). The experiments were conducted using five batch reactors with different ratios of substrates. There are four different analyses used to identify the characteristics of FW and SS, which are pH, reducing sugar (RS), total solid (TS), and total carbohydrate (TC). Water displacement method was used to record biogas yield. The experimental results showed that the highest biogas yield was from the composition of 50:50 (FW: SS) with a biogas volume of 1150.14 mL, while the least was the composition of 0:100 (FW: SS) with 170.47 mL biogas produced. The results for substrate degradation showed that the composition of 100:0 (FW: SS) has the highest percentage degradation for reducing sugar with the percentage of 56%, while the minimum was 0:100 (FW: SS) with a percentage of 35%. Besides, for TC, the highest percentage of degradation was the composition 50:50 (FW: SS) with 84%, and the least was 0:100 (FW: SS) with 44%. This study proves that using FW and SS enhanced biogas production as well as reducing the current issues of waste disposal.

KEY WORDS: *Anaerobic co-digestion, Food waste, Sewage sludge, and Biogas.*

1. INTRODUCTION

Energy insecurity, as well as environmental pollution are the biggest threats which humanities have currently encountered. Due to the dramatic growth of population and changing patterns of consuming behavior, socioeconomic progression, rapid industrialization and urbanization, organic waste is being produced at such a rate that crosses the limit of natural ambiance to comprehend it and authorities to rule it. As a consequence, mitigation of CO_2 release and accompanied global warming enforce the pursuit of alternative energy sources in contrast to non-renewable energy sources. In Malaysia, the scenario is more critical like other developing countries. It is time to utilize bioenergy for sustainable development and improved the quality of life in emerging countries as organic wastes are a potential source of renewable energy. Anaerobic co-digestion (AcoD) is suggested to be a suitable approach for waste management and energy production [1, 2].

Anaerobic digestion (AD) is a complex biochemical process that converts organic compounds into biogas primarily comprises of methane and CO_2 with some trace elements in the absence of oxygen with the help of different microorganisms. Also, it is governed by different operational conditions, substrate types, ratio and structure [1, 3]. At present, AD is broadly used to treat a wide variety of natural wastes that facilitates better landfill management and generates potent bioenergy. FW and SS are considered two major attractive and potential substrates for AD owing to their high portion of waste generation, especially in Malaysia. The main problem is that most of the waste and SS would end up at a landfill or on land or river. Landfill transfer of FW represents a high hazard to human wellbeing by polluting the encompassing environment *i.e.* air, soil and groundwater and landfill inferable from high organics and dampness content [4, 5]. However, current research considers rapid and pulverizing FW treatment methodologies, for example, incineration, hydrothermal treatments [5-8]. Thermal technologies are energy escalated and don't restore any natural carbon to the soil. On the other hand, biological transformation advances, for instance, composting and AD (mono-and co-digestion or AcoD) are exceptionally plausible innovation for natural waste including FW [9-16]. In contrast with composting which contributes lesser economic incentives, AD and/or additionally AcoD is an increasingly alluring choice to produce extra bioenergy other than biofertilizers from FW [14, 17-19].

The term co-digestion is being heard these days. The concept will increase as the world is moving towards a more renewable economy. AcoD displays preferred procedure proficiency over the mono-digestion by offering reciprocal advantages, for examples better product yield, supplements accessibility, mass thickness, lower feed volume, substrate fluctuation, toxicity attenuation, synergism, divers and vigorous microbiome. However, there are more difficulties and less yield in individual AD activity of FW and SS [20-22]. In AcoD of FW with SS, due to accumulation of VFAs and alcohols, alkalinity and pH need to be controlled to maintain a strategic distance from the reactor failure. Different facultative and obligatory anaerobic microscopic organisms have been recorded in FW and SS co-digestion in contrast to mono-digestion [23-24]. In subsequent stages, the syntrophic acetogenic microorganisms use alcohols and short-chain unsaturated fats into acetic acid derivation, CO_2, and hydrogen or formate. Principally, acetic acid can be oxidized into CO_2 by syntrophic acetate oxidizing bacteria (SAOB) and along these lines changed over into methane by hydrogenotrophic methanogens [25-27].

Anaerobic co-digestion is where at least two substrates are assorted for combined treatment. Usually, the large quantity of the main substrate such as SS is mixed. Next, it is combined with the little amounts of a single, or a different kinds of extra substrate. The utilization of co-substrates ordinarily enhanced biogas yield from anaerobic digester because of positive synergism set up in the digestion medium and the supply of missing supplements by the co-substrates. A general principle of co-digestion is that FW and sludge characteristics would decide the co-digestion feasibility and its operational parameters. De Clercq et al [28] reported that food waste originates from canteen and restaurant responsible for half of the total amount of FW. The same scenario has also been observed in IIUM and action needs to be taken to decrease it. An investigation carried out by [3] found that batch AcoD of FW from a university canteen with SS provides additional advantage such as carbon/nitrogen(C/N) ratio adjustment as well as better stability of the process. Accordingly, in this study, characteristics of different compositions of FW and SS were identified as well as biogas production by different combinations of substrates. Physicochemical characteristics including pH, total solid (TS), reducing sugar, and total carbohydrate (TC) were measured throughout the anaerobic digestion process.

2. MATERIALS AND METHODS

2.1. Experimental methods

2.1.1. Collection and preparation of substrates

FW was collected daily to minimize the nutritional variations among different cafeterias located at International Islamic University Malaysia (IIUM), Gombak campus. Solid particles including bone, plastic, metal, etc. were separated before homogenization. A food blender was used to homogenize the food waste into particles less than 2 mm in diameter. The blended food wastes were stored in a refrigerator at 4˚C prior to use. SS was collected from Indah Water Konsortium (IWK) Bunus in Titiwangsa and samples were kept in the cold room (4˚C) prior to use.

2.1.2. Mixture of FW and SS

About 1L of the substrate was prepared by mixing FW and SS in a beaker. Batch experiments involving different sets of FW and SS composition which were fixed to the ratios of percentage (% w/v) as shown in Table 1 were prepared and stored in a cold room at 4˚C prior to use.

Table 1: Composition of FW and SS

FW [%]	SS [%]
100	1
75	25
50	50
25	75
0	100

2.1.3. Anaerobic fermentation

In this study, five different compositions of substrates were investigated. The fermentation was done in a modified Schott bottle with a working volume of 500 mL as a reactor and tubing for feeding, sample collection, and biogas collection. About 90% of the substrate was mixed in a beaker with 10% of inoculum. The pH was adjusted to 7 by adding 5 M of NaOH. Then, using a 50-mL syringe, the mixture was diffused inside the silicon tube into the reactor. The reactor was maintained at a constant temperature of 36°C (± 0.5) for 14 days. A sample of 10 mL was taken every day to measure the pH and characterization analyses.

2.1.4. Biogas collection

Biogas was collected using the water displacement method. The gases were collected over water. The gas was bubbled through the water and into an upside-down gas jar filled with water. The gas bubbles were collected in the upper part of the gas jar and eventually pushed the water out of the bottom. The pH of the water was maintained at 3 at all times.

2.2 Analytical methods

2.2.1. Measurement of reducing sugar

The reducing sugar was quantified by using 3,5-dinitrosalicylic acids (DNS) [29] modified by Chong et al [30] method. The samples were measured using a spectrophotometer at 540 nm absorbance. The absorbance values were recorded and glucose concentration was calculated using a glucose standard curve.

2.2.2. Measurement of total carbohydrates (TC)

Measurement of total carbohydrates was done by a method developed by Dubois et al [31]. Reagents used were 4% (w/v) of phenol (40 g of phenol was dissolved in 1 L of distilled water) and 96% sulphuric acid. Firstly, 1 mL of samples was added in 10-mL test tubes. Then, 1 mL of 4% phenol was added with 5 mL of 96% sulphuric acid. The test tubes were incubated at the room temperature in fume hood for around 30 minutes. Lastly, OD of the sample was taken using a spectrophotometer at the wavelength of 490 nm. A glucose standard curve was used to calculate the total carbohydrates.

2.2.3. Total solids

The analysis of TS content was done according to the Standard Methods for the Examination of Water and Wastewater [32]. The TS is calculated using Eq. (1),

$$TS\ (mg/L) = \frac{A-B}{V} \tag{1}$$

Where; *A*= mass of filter + dried residue (mg), *B*= mass of filter (tare weight) (mg), *V*= volume of sample filtered (L)

3. RESULTS AND DISCUSSION

3.1. Characteristics of substrates

Before the substrates were used in fermentation, the reducing sugar and TC analyses were done for different ratios of substrates as shown in Table 1. The results for reducing sugar with two dilution factors (DF) of 100 and 500, TC and TS are presented in Table 2. It indicates that the composition of 100:0 (FW: SS) has the highest concentration for reducing sugar while 0:100 (FW: SS) has the lowest concentration. It was also observed that the highest amount of TC and TS were 100:0 (FW: SS) composition in contrast to the least was 0:100 (FW: SS). Demirbas and Balat [33] reported that the composition of carbohydrates, protein and fat in solid waste affected the amount of biogas produced. Thus, 100% FW has more carbohydrate content compared to 100% SS. Based on characterization analyses, FW was acidic (pH 5.80) due to the hydrolysis of microbial digestion whereas the sewage sludge was neutral (pH 7.10). The pH of the respective samples was suitable for the growth of microorganisms involved in anaerobic digestion [3, 34-26].

Table 2: Characteristics of FW and SS

Run	Substrate Composition [FW: SS]	Glucose concentration [g/L]			TS [mg/L]
		Reducing sugar		TC	
		500 DF	100 DF		
1	100:0	105.97	296.77	399.62	113.3
2	75:25	48.41	166.76	267.66	57.7
3	50:50	52.49	134.90	369.60	38.0
4	25:75	42.34	96.67	188.58	35.0
5	0:100	9.45	33.33	137.00	4.0

3.2 Percentage of substrate degradation

The analysis for reducing sugar, TC, and TS were conducted for every three days for 15 days of fermentation. Fig. 1 and 2 represent both percentage degradation for reducing sugar and TC. The percentage of degradation was calculated using Eq. (2):

$$\%\ of\ substrate\ degradation = \frac{Day\ 1\ sample - Day\ 0\ sample}{Day\ 0\ sample} \quad (2)$$

Based on Fig. 1, the highest degradation for reducing sugar was the composition of 100:0 (FW: SS) with 56% while the least was the composition of 0:100 (FW: SS) with 35%. However, in Fig. 2, the highest percentage degradation for TC was composition 50:50 (FW: SS) with a value of 84% followed by 100:0, 75:25, 25:75 and 0:100, with the values of 69%, 64%, 51% and 44% respectively. The above phenomenon showed that, during fermentation, more microorganisms used glucose and carbohydrates to produce biogas. During acidogenesis, the acidogenic bacteria will convert the soluble organic monomers of sugars and amino acids to ethanol and acids [6]. Then, the acetogenic bacteria convert the acids and alcohols into hydrogen, carbon dioxide, and acetic acid. This proved that as biogas was produced, the organic compounds used up the glucose and carbohydrates and decomposed them into smaller molecules.

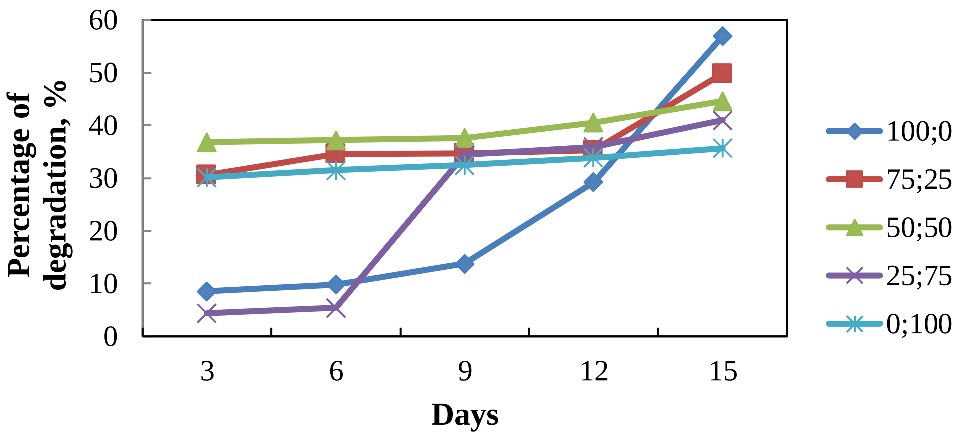

Fig. 1. The rate of reducing sugar degradation in percentage during 15 days of fermentation for different ratios of FW and SS.

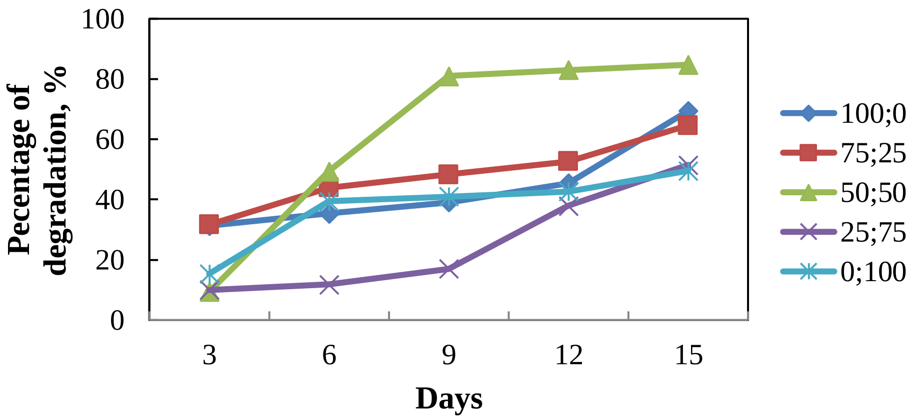

Fig. 2. The rate of TC degradation in percentage during 15 days of fermentation for different ratios of FW and SS.

Then, the relationship between percentage degradation of TS and different compositions of FW and SS was analyzed. From Fig. 3, the highest amount of percentage degradation for TS was achieved by the composition of 0:100 (FW: SS) with a value of 87%. This is due to SS has a low initial concentration of TS [38]. Hence, microbes prefer to use the solids in FW to produced biogas. The percentage of degradation was followed by the composition of 100:0, 75:25, 50:50 and 25:75 (FW: SS) with the values of 67%, 52%, 51% and 38%, respectively. The high amount of TS would not essentially influence the increasing volume of biogas produced because as TS increasing, the amount of water decreases, resulting in a lower rate of microbial activities [39]. Besides, a low amount of TS is not desirable as there will be small amount of biogas production. Thus, it is important to have a good composition of substrates to achieve the optimum amount of biogas production.

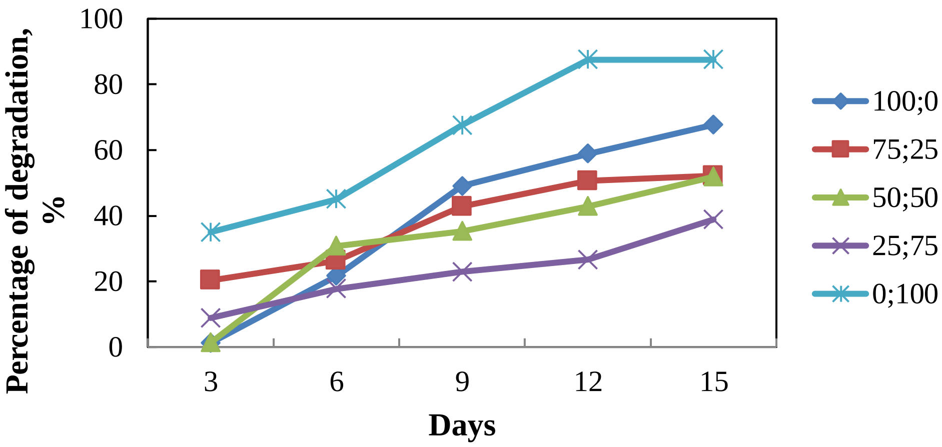

Fig. 3. TC degradation for various ratio of FW and SS for 15 days of fermentation period.

3.3 Biogas yield

The fermentation period to observe biogas production was 15 days in which gas production and pH were recorded each day. The curve of daily pH and gas yield for different composition of substrates are shown in Fig. 4 and Fig. 5. In Fig. 4, the pH values for initial fermentation on day one were around 6-7. With longer fermentation time, the pH began to reduce to 4 and kept constant throughout the fermentation period. According to Kangle et al [40], during anaerobic digestion, the fermentation and methanogenesis processes require distinctive pH levels for ideal process control. Particularly in a batch bioreactor, acetogenesis happens at a quick pace. Thus, this prompts the accumulation of organic acids and hence bringing the pH underneath 5.

After analysis, the relationship between gas production and fermentation time can be deduced. Experiments were carried out for 15 days, where biogas started to produce from the first day. As can be seen from Fig. 5, on the first day, the generation of gas for the composition of 25:75, 50:50 and 75:25 (FW: SS) achieved approximately 100 mL, 841 mL, and 26 mL, respectively. Comparative outcomes have been reported [3, 41-46]. However, others do not produce gas. The fast aggregation of biogas during the early period may be due to the expansion of the inoculum, which contained biohydrogen-producing microorganisms [42].

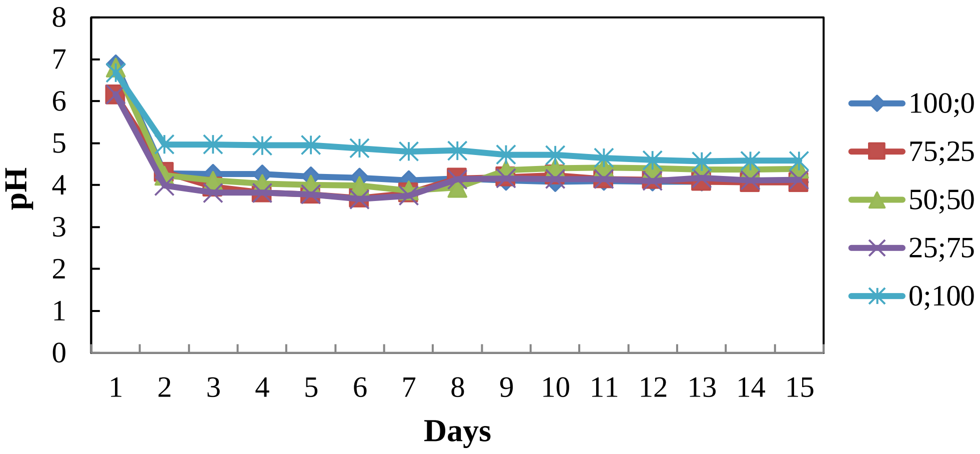

Fig. 4. Changes of pH during fermentation.

Besides that, for the composition of 100:0 (FW: SS), the range of gas production was between 0 mL to 1045 mL while for 75:25 (FW: SS) the range of gas production was between 26 mL to 991 mL. Compositions of 50:50, 25:75 and 0:100 (FW: SS) produced gas at a range between 841 mL to 1150 mL, 100 mL to 750 mL and 0 mL to 170 mL, respectively. Anaerobic co-digestion of FW and SS conducted by Kim et al [9] at the ratio of 25:75, 50:50, 80:20 produced biogas of 439, 215, 157 mL, respectively. A similar experiment done by Heo et al [43] by using activated sludge and FW with 90:10, 50:50, 10:90 composition attained biogas yield of 186, 321, 346 mL, respectively. As the composition of substrate changed, gas production would be affected too [44]. In this study, referring to Table 3 and Fig. 5, it is obvious that the maximum biogas yield achieved was 1150.14 mL using substrate at the composition of 50:50 (FW: SS). Furthermore, less biogas was recorded in the reactors with additional SS (Table 3 and Fig. 1) because of the presence of organic materials in the sludge that is difficult to hydrolyze [45].

Table 3: The cumulative gas production

Composition of substrate [FW: SS]	Cumulative gas production [mL]
100:0	1045.35
75:25	991.03
50:50	1150.14
25:75	750.09
0:100	170.47

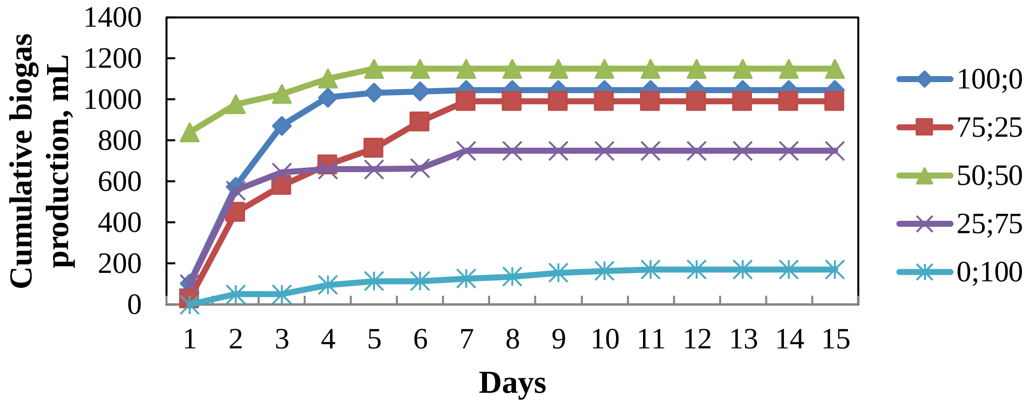

Fig. 5. Comparison of biogas production during 15 days of fermentation for different FW:SS ratios.

3. CONCLUSION

Anaerobic co-digestion between food waste (FW) and sewage sludge (SS) was studied by identifying the characteristics of the different compositions of the substrates and investigating the feasibility of biogas production using different combinations of FW and SS. The experiments were conducted using a Schott bottle which was modified as a reactor with a working volume of 500 mL. There were five different combinations of substrates which are 0:100, 25:75, 50:50, 75:25, and 100:0 (FW: SS). The reactor was maintained at a constant temperature of 36°C (±0.5). The substrate was filled in the reactor and was left for fermentation for 15 days. There are four different parameters used to identify the characteristics of FW and SS, which are pH, Dinitrosalicylic Acid (DNS), Total Suspended Solid (TS), and Total Carbohydrate (TC). The percentage of degradation was calculated for each parameter. 100:0 (FW: SS) has the highest percentage of degradation for reducing sugar with 56% while the minimum was 0:100 (FW: SS) with 35%. Besides, for TC, the highest percentage degradation was composition 50:50 (FW: SS) with value of 84% followed by, 100:0, 75:25, 25:75 and 0:100, with values of 69%, 64%, 51% and 44% respectively. The highest biogas yield was from the composition of 50:50 (FW: SS) with biogas volume of 1150.14 mL, while the least was the composition of 0:100 (FW: SS) with 170.47 mL biogas produced. The result indicated that the most suitable combination of substrates for biogas production is 50:50 (FW: SS). This proved that the amount of biogas production is highly dependent on the composition of the mixture undergoing the process of fermentation. To be utilized as a co-substrate, further study should be needed by expanding the amounts and sorts of different FW resources of the representative sample. The stable biogas generation in this study from different combinations of substrates can be used to amplify the pilot-scale production in future engineering applications. The outcome of this study is recommended for the implementations of food waste management alternatives in university canteens globally.

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