*Mindanao Journal of Science and Technology Vol. 20 (2) (2022) 142-156*

# Influence of Digester Height-to-Diameter Ratio on Biomethanation of Market Vegetable Wastes

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Date received: February 3, 2022
Revision accepted: September 22, 2022

## Abstract

*Biogas digesters are used to produce methane gas from organic wastes such as vegetable wastes. They come in different sizes and designs depending on available space, costs, type of operations and other considerations. Fifteen types of vegetable wastes from Cagayan de Oro markets were anaerobically digested in a batch-type digester with cow manure as inoculum at ambient conditions for 40 days. Five 1-L plastic cylinders with different height-to-diameter ratios (0.77, 1.08, 1.58, 1.93 and 2.80) were used as digesters to determine the effect of digester height-to-diameter ratio on methane production using these vegetable wastes. Results revealed that the digester with the lowest height-to-diameter ratio produced the most methane (53.3%) after the retention time. In contrast, the digester with the highest height-to-diameter ratio yielded the least methane concentration (46.8%). This indicated that there was an inverse relationship between the ratio and the methane production of vegetable wastes mixed with cow manure. Although the results suggested a minor influence, the statistical analysis presented an insignificant influence of the height-to-diameter ratio on the biomethanation of vegetable wastes*.

***Keywords:*** anaerobic digestion, biogas, height-to-diameter ratio, methane, vegetable wastes

## 1. Introduction

Cagayan de Oro City is a highly urbanized city in Northern Mindanao, Philippines. It is a chartered city and the capital of the province of Misamis Oriental where governance is independent and separate from the province. It also serves as the regional center and business hub of Northern Mindanao (Region X), and part of the growing Metropolitan Cagayan de Oro area, which includes the city of El Salvador, municipality of Opol, Alubijid, Laguindingan and Gitagum in the western side, and municipality of Tagoloan, Villanueva, Jasaan and Claveria in the eastern side. The city has five major public markets, namely Cogon, Bulua, Carmen, Agora and Puerto, to cater to its increasing populace. These markets generate around 2.5 tons of vegetable wastes (Boco *et al*., 2013) and other organic wastes daily, which are then dumped at the sanitary landfill in Barangay Pagalungan.

Vegetable wastes pose several problems to the environment, community and the city government. While they are regularly collected for proper disposal, sometimes they litter up the streets, open drainages and bodies of water. They cause foul odor and clog drains, thereby contributing to the recurring problem of flooding which frequently hits Cagayan de Oro City. Rotting vegetable wastes also produce methane gas, which has a global warming potential of 28-36 times greater than $CO_2$ over 100 years (United States Environmental Protection Agency, 2017). Moreover, the pile-up of these wastes at landfills becomes a breeding ground for disease and various pests. Moreover, the 45-hectare landfill will require huge budgets to fund the city government's garbage collection and disposal program.

In light of rapidly rising costs associated with energy supply and increasing concern on waste disposal and environmental quality degradation, conversion of organic wastes to energy is a more economically viable solution (Zhang *et al*., 2007). Vegetable wastes have a relatively high moisture content, which makes anaerobic digestion more suitable than thermochemical conversions such as combustion and gasification.

Anaerobic digestion is the process by which organic matter such as animal or food waste is broken down to produce biogas and biofertilizer. This process happens in the absence of oxygen in a sealed, oxygen-free tank called an anaerobic digester. The biogas produced can be utilized as fuel for heating, electricity, or vehicle. Most studies on anaerobic digestion and optimization of biogas production have focused on feedstock properties, digester temperature, retention time, loading rate, mixing and co-digestion. The basic requirements of anaerobic digester design are to allow for a continuously high and sustainable organic loading rate, a short hydraulic retention time (to minimize digester volume) and to maximize biogas yield (Ward *et al*., 2008).

Some factors to consider when designing a digester include waste characteristics, rate of waste generation and local environmental conditions like ambient temperature (Igoni *et al*., 2008). For effective digestion, the digester shape must be considered for the construction practicalities of both mixing and heat loss (Ward *et al*., 2008). It is known that the bigger the digester capacity results in more biogas production provided that decomposition factor levels are kept at an optimum. Several studies have focused on the design parameters of digesters for optimum biogas production (Deganutti *et al*., 2002; Florentino, 2003; Thy *et al*., 2005; Umaru, 2012; Kaur *et al*., 2017). Such parameters ranged from digester surface area, diameter, and height; positioning of the inlet and outlet pipes; usable and gross volumes of the digester; and level of the substrate to the volume of biogas needed per day among many others. In addition, Okunwande and Akinjobi (2017) have used mathematical models to size digesters for effective biogas production. They studied the effect of digesters' configuration in terms of the surface area and height on biogas production. They also tried to determine the mathematical relationship between digester diameter to working height (substrate height) ratio. Their study reported that within the surface area investigated, biogas yield increased as digester surface area increased.

Anaerobic digestion of vegetable wastes under mesophilic conditions has been studied by several researchers from the Asian region. Sitorus *et al*. (2013) co-digested 80 and 20% vegetable and fruit wastes, respectively, and achieved a 65% methane yield using a single batch type digester. Gunaseelan (2004) used different types of vegetable wastes also employing a single batch type reactor and obtained 0.19-0.4 L/g volatile solids (VS). Velmurugan and Alwar Ramanujam (2011) anaerobically digested banana stem, cabbage and ladies' finger in a fed-batch reactor at a loading rate of 2.25 g/L.d. They attained a methane yield of 0.387 L/g VS added. Babaee and Shayegan (2011) used potatoes, lettuce, tomatoes, eggplant, cucumber and carrots at a loading rate of 1.4, 2 and 2.75 kg VS/$m^3$ per day. The biogas production recorded was between 0.12-0.4 $m^3$/kg VS added. Chinese cabbage and cabbage were utilized by Phetyim *et al*. (2015) at a loading rate of 0.5 and 1.0 kg per week, which produced 0.602 and 0.711 $m^3$ total biogas, respectively. Dhanalakshmi and Ramanujam (2012) used carrots, beans and brinjal to yield 0.423 and 0.576 l/g VS added of biogas from loading rates of 0.25 and 0.5 g VS/L.d, respectively. Lastly, Kaur *et al*. (2017) obtained a biogas yield of 0.15 $m^3$/kg TS from a loading rate of 5% total solids (TS).

Okunwande and Akinjobi (2017) studied the effect of digester surface area on biogas yield using poultry manure, cow dung and swine manure in a cube-shaped anaerobic digester of equal volume but different surface areas in a two-factor experiment. They concluded that as the digester surface area increased, the biogas yields also increased. Thy *et al*. (2005) compared the effect of the dimensions of plastic bio-digesters (width to length ratio) on gas production and composition of effluent. The experiment had three treatments consisting of different dimensions of plastic bio-digesters: 2-, 3- and 5-m length and 64-cm diameter. Fresh pig manures were charged daily at a loading rate of 4 kg DM/$m^3$ of liquid capacity into each digester. The design was a single changeover with experimental periods of 40 days on each retention time. The length:diameter ratios were 8:0.6, 5:0.6, 3:0.6 and 2:0.6 m with hydraulic retention times of 10 and 20 days. The results indicated that the gas production in all plastic tubular were almost identical. Thus, the diameter:length ratio did not affect the rate of gas production. The valid explanation is that microbes would consume all available substrates in the digester.

This study aimed to determine the effect or influence of the digester height-to-diameter ratio on methane production using market vegetable wastes as substrates by varying the digester diameter to height ratio while keeping the digester's volume constant. The results of the study will provide vital information when designing a biodigester based on its diameter and height to obtain high methane production.

## 2. Methodology

### *2.1 Waste Characteristics*

Fifteen vegetable wastes (eggplant, lady finger/okra, squash, Chinese pechay, cabbage, pechay, pepper, radish, cucumber, tomato, bitter gourd, potato, carrot, chayote and lettuce) were collected from the public markets in Cagayan de Oro City. They were then manually chopped into smaller pieces. The initial TS concentration of the mixed vegetable waste was 6.25% with a total VS content of about 92%. All were performed according to American Public Health Association (APHA) standards (APHA, 1995). The percentage composition and other characteristics of each vegetable waste used in this study are shown in Table 1.

### *2.2 Inoculum*

The inoculum used for this study was a one-day old, unscreened cow manure that was collected from Manresa Farm of Xavier University – Ateneo de Cagayan, Cagayan de Oro City.

Table 1. Vegetable waste characteristics (per 100g)
(United States Department of Agriculture, 2017)

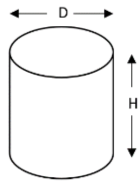
| Vegetable waste | Weight percentage (%) | Moisture content (%) | Carbo-hydrates (g) | Protein (g) | Lipid (Total fat) (g) | Fiber (g) |
|---|---|---|---|---|---|---|
| Bitter gourd | 8 | 94.03 | 3.70 | 1.00 | 0.17 | 2.8 |
| Cabbage | 11 | 92.18 | 5.80 | 1.28 | 0.10 | 2.5 |
| Carrot | 8 | 88.29 | 9.58 | 0.93 | 0.24 | 2.8 |
| Chayote | 10 | 94.24 | 4.51 | 0.82 | 0.13 | 1.7 |
| Chinese pechay | 7 | 95.32 | 3.23 | 1.50 | 0.20 | 1.0 |
| Cucumber | 6 | 95.23 | 3.63 | 0.65 | 0.11 | 0.5 |
| Eggplant | 5 | 92.30 | 5.88 | 0.98 | 0.18 | 3.0 |
| Lady's finger | 3 | 89.58 | 7.45 | 1.93 | 0.19 | 3.2 |
| Lettuce | 7 | 94.61 | 3.29 | 1.23 | 0.30 | 2.1 |
| Pechay | 7 | 94.39 | 3.23 | 1.20 | 0.20 | 1.2 |
| Pepper | 2 | 92.21 | 6.03 | 0.99 | 0.30 | 2.1 |
| Potato | 7 | 79.25 | 17.49 | 2.05 | 0.09 | 2.1 |
| Radish | 5 | 95.27 | 3.40 | 0.68 | 0.10 | 1.6 |
| Squash | 10 | 91.60 | 6.50 | 1.00 | 0.10 | 0.5 |
| Tomato | 4 | 94.52 | 3.89 | 0.88 | 0.20 | 1.2 |

### *2.3 Experimental Setup*

Five cylindrical plastic containers having the same volume of 1 L but with different height-to-diameter ratios were used as digesters. Each digester contained 100 g of mixed vegetable wastes (VW), 100 g of cow manure (CM) and 300 mL of water to produce a slurry. The digesters were properly sealed with elastomeric sealant to avoid any type of leakage and kept in an open space but away from direct sunlight. Each digester was manually mixed for 1 min once a day by shaking and swirling. Note that although mixing is a critical factor in anaerobic digestion, only manual shaking and swirling are applicable for small digester sizes (Filer, 2018). Due to the rapid acidification of the vegetable wastes, each slurry was pH treated by adding an alkalinity buffer of 1N sodium bicarbonate ($NaHCO_3$) to obtain an acceptable pH. The batch-type digesters were discharged after a retention time of 40 days. The experiment was duplicated to achieve consistent and accurate results. Table 2 presents the dimensions of the digesters, while Figure 1 displays the actual digesters used in the experiments.

Table 2. Digester dimensions

| Digester | Height (H) (mm) | Diameter (D) (mm) | Height-to-diameter ratio $\left(\frac{H}{D}\right)$ |
|---|---|---|---|
| D1 | 92 | 120 | 0.77 |
| D2 | 115 | 106 | 1.08 |
| D3 | 147 | 93 | 1.58 |
| D4 | 168 | 87 | 1.93 |
| D5 | 216 | 77 | 2.80 |



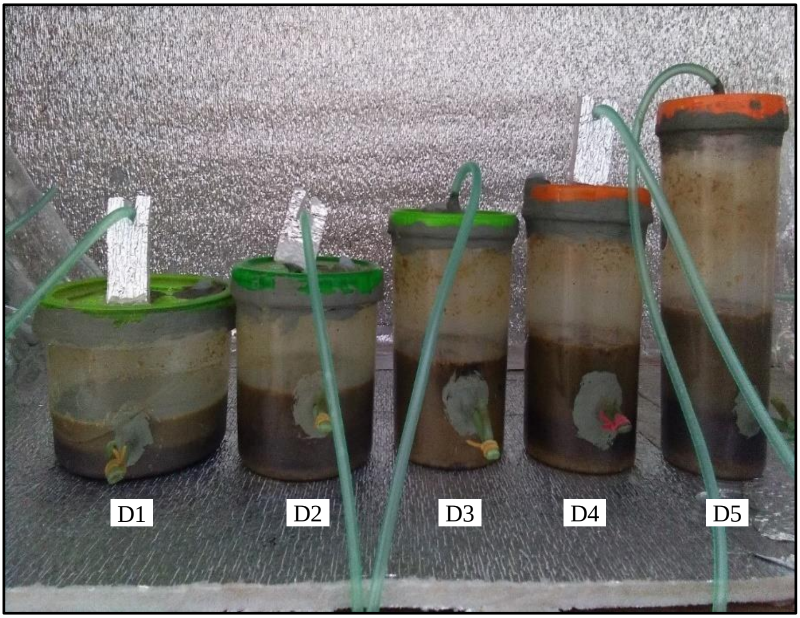




Figure 1. Digester sizes

## *2.4 Analytical Methods*

The temperature, pressure and pH of each digester were monitored using an infrared thermometer (GM900, Benetech, China) digital manometer (FU-P1, KKmoon, China) and digital pH meter (THE01100, Yieryi, China), respectively. The daily biogas production of each digester was determined using the water displacement method (Figure 2). In this method, the volume of water displaced from the bottle was equivalent to the volume of gas generated (Capareda, 2013). The majority of laboratory volumetric gas meters are based on this method because they can be constructed with simple materials like glass/plastic jars or cylinders. They are also simple, economical and durable (Parajuli, 2011). Biogas samples were then collected to determine the methane concentration using a portable infrared-type methane gas analyzer (BH-90A, Bosean, China).

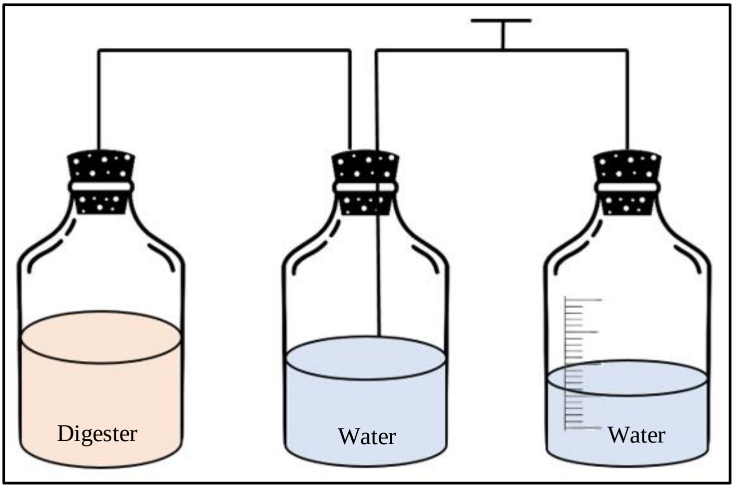



Figure 2. Water displacement method

*2.5 Statistical Analysis*

The biogas production and methane results were subjected to single-factor analysis of variance (ANOVA) using Microsoft Excel to test the level of significance (P-value ≤ 0.05) of the height to diameter ratio on biogas and methane production.

## 3. Results and Discussion

*3.1 Digester Temperature and Pressure*

The daily temperature of the digesters ranged between 27.4 and 33.3 °C during the experiment (Figure 3). There was a minuscule temperature difference between the digesters because of the very small working volume of 500 mL only.

Conversely, the daily digester pressure change ranged from 0.00-10.11 inches $H_2O$. As with the temperature, the pressure changes were minimal only. From Figure 4, it was observed that the pressure changes initially rose on days one to three because of the addition of 1N sodium bicarbonate to the slurries for three straight days (starting at day zero). However, the pressures dropped back to zero or near-zero levels on days four to seven because of the formation of volatile fatty acids. Then on day eight, the pressure started to increase again until day 40. The steady increase in digester pressure meant that methane production was taking place. This stage is known as methanogenesis when methanogens eat up the acids formed in the earlier stages to produce methane (Enzmann *et al*., 2018; Zhe *et al*., 2018).

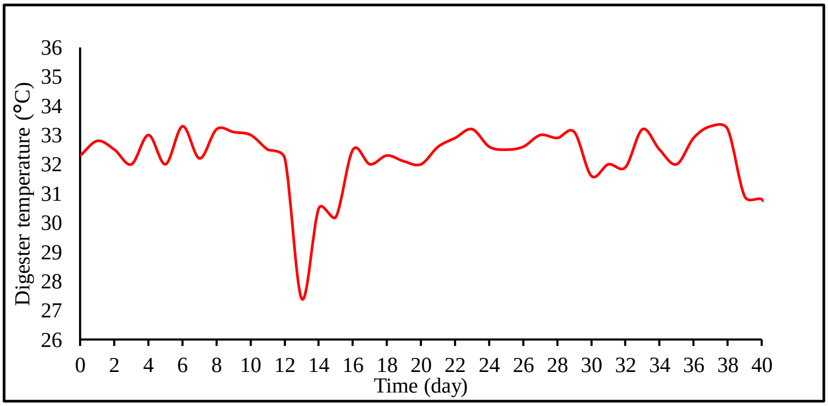



Figure 3. Average daily digester temperature versus time

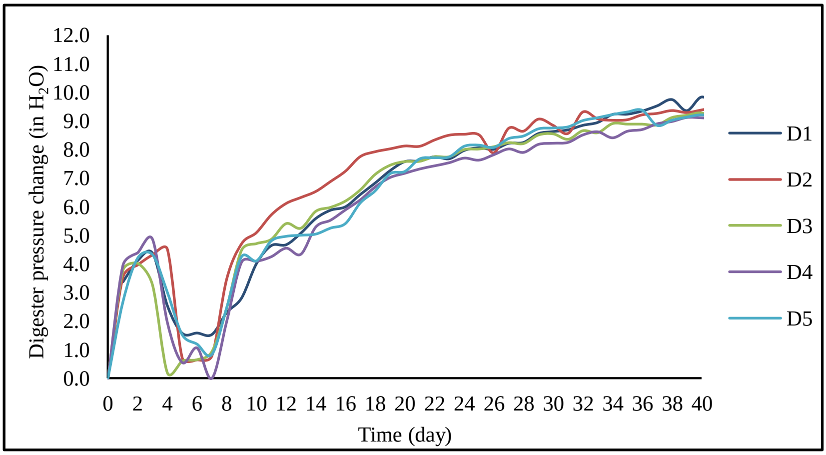



Figure 4. Daily digester pressure change versus time

*3.2 pH*

The pH for all sets dropped substantially in the first few days due to high volatile fatty acids formation. The rapid acidification of vegetable wastes caused the pH to decrease to 6.4 from an initial value of 7.4-7.6 even when sodium bicarbonate was added. Further, alkalinity buffer solution was, therefore, required to increase the pH to a near ideal value of 6.6.

Comparable pH drops were also noted in the studies of Velmurugan and Ramanujam (2011), Sitorus *et al.* (2013), Phetyim *et al.* (2015), Dhanalakshmi and Ramanujam (2012) and Thu Hien *et al.* (2014). The pH was maintained for another few days then started to rise on the 9th to 11th day and finally stabilized at around 7.4-7.5. As methane-forming bacteria consume the volatile acids and alkalinity is produced, the pH of the digester increases and then stabilizes (Gerardi, 2003). Figure 5 shows the pH curve of each digester.

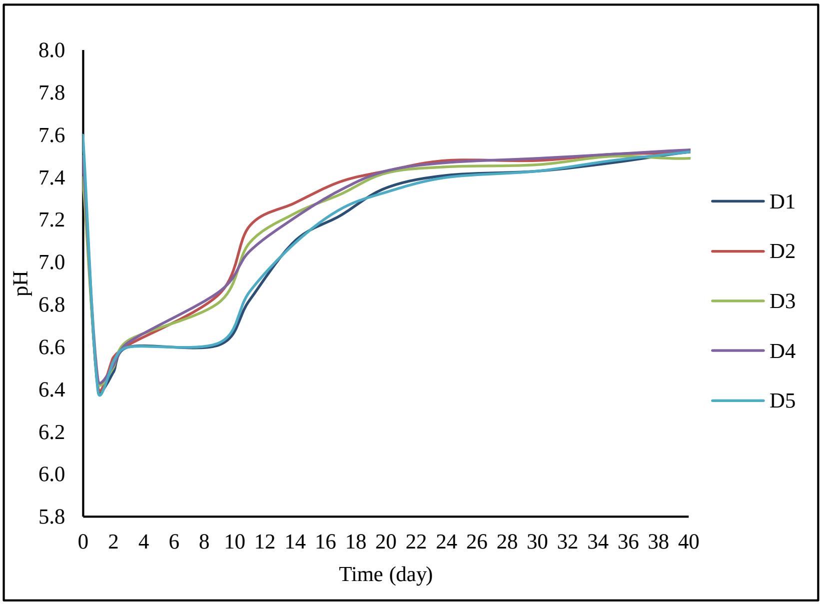



Figure 5. pH versus time

### *3.3 Biogas Production*

Daily and cumulative biogas productions for all digesters were relatively the same. The first four days showed a sharp rise in biogas production because of the organic degradation and the addition of sodium bicarbonate (Gerardi, 2003). Afterward, the biogas production ceased for a few days and only resumed during the 9th to 11th day when methanogens began to multiply and consume the acetic acids.

The total biogas production for each digester ranged between 2,800-2,900 mL after the 40-day hydraulic retention time. This implied that there was very little effect of the digester height-to-diameter ratio on biogas production. The non-significance in the biogas yield difference may be related to the very small digester volume (1 L) and working volume (500 mL). Figures 6 and 7 present the daily and cumulative biogas production, respectively.

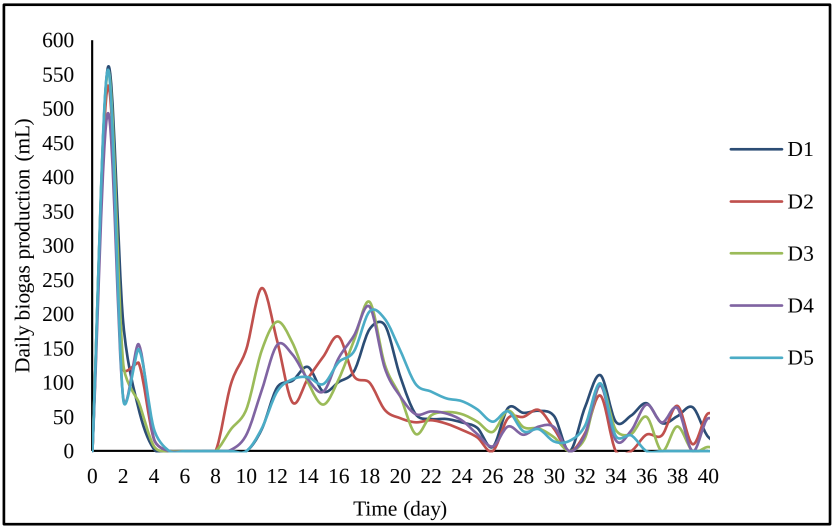



Figure 6. Daily biogas production versus time

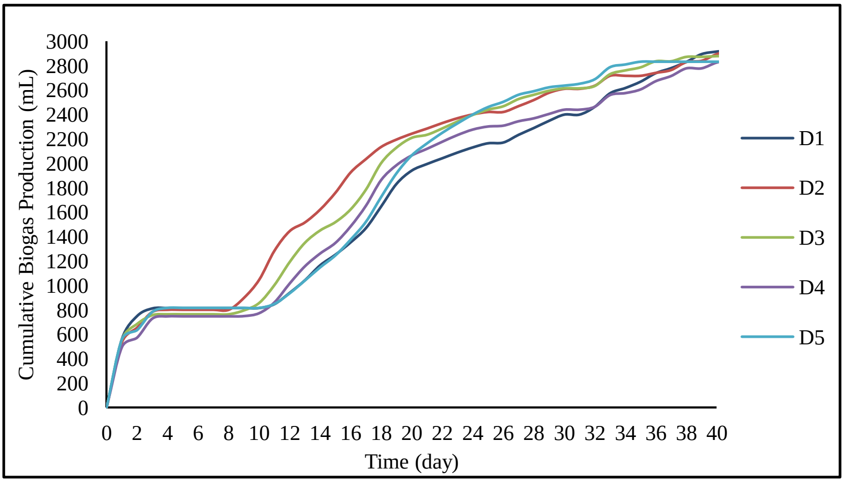



Figure 7. Cumulative biogas production versus time

*3.4 Methane Content*

From the daily biogas production curve (Figure 6), it is noteworthy that there was a sharp rise in the biogas produced in the first three days but they only contained a small amount of methane (1.2-3.8%); mostly are carbon dioxide because of the organic degradation and addition of alkalinity solution (sodium bicarbonate).

Digester 1 (D1), which had the smallest height-to-diameter ratio, obtained the highest methane concentration at 53.3% during the 40-day experiment followed by D2 (51.3%), D3 (50.7%), D4 (49.4%) and D5 (46.8%), which also had the biggest height-to-diameter ratio. The trend followed that as the height-to-diameter ratio of the digester becomes bigger, the methane content of the biogas produced becomes smaller. Thus, there was an inverse relationship between the digester geometry (height-to-diameter ratio) and methane production. This relationship is reflected in Figure 8.

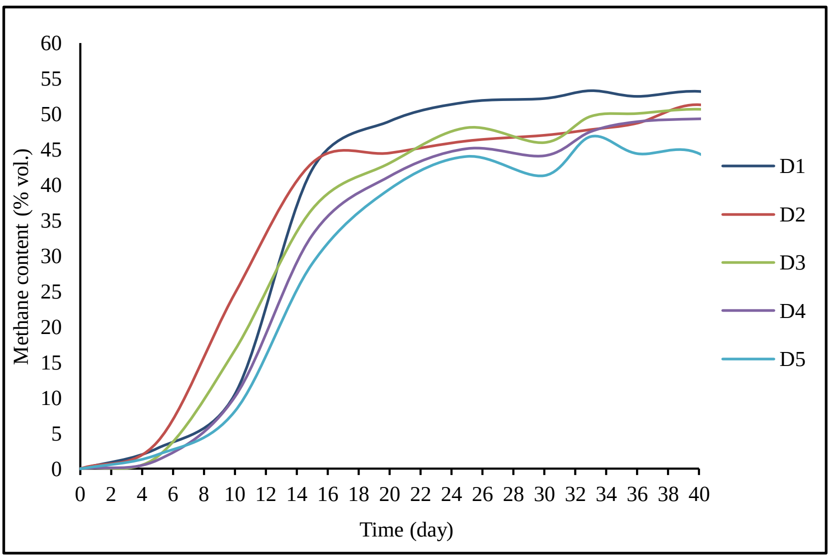



Figure 8. Methane content versus time

*3.5 Results of Statistical Analysis*

The results of the single-factor ANOVA verified that the height-to-diameter ratio of a digester did not significantly influence the biogas production or the methane content of the biogas. The P-values for both results were considerably large at 0.890268338 (Table 3) and 0.295344 (Table 4), respectively.

Table 3. ANOVA for methane content

| *Summary* | | | | | | |
|---|---|---|---|---|---|---|
| Groups | Count | Sum | Average | Variance | | |
| D1 | 9 | 367.5 | 40.8333333 | 389.92 | | |
| D2 | 9 | 357.1 | 39.6777778 | 240.639444 | | |
| D3 | 9 | 342.7 | 38.0777778 | 301.236944 | | |
| D4 | 9 | 320.3 | 35.5888889 | 317.618611 | | |
| D5 | 9 | 299.2 | 33.2444444 | 284.527778 | | |
| *ANOVA* | | | | | | |
| Source of variation | SS | df | MS | F | P-value | F-crit. |
| Between groups | 341.5368889 | 4 | 85.3842222 | 0.27831619 | 0.890268338 | 2.605974949 |
| Within groups | 12271.54222 | 40 | 306.788556 | | | |
| Total | 12613.07911 | 44 | | | | |

Table 4. ANOVA for biogas production

| *Summary* | | | | | | |
|---|---|---|---|---|---|---|
| Groups | Count | Sum | Average | Variance | | |
| D1 | 9 | 12505 | 1389.444 | 643391.8 | | |
| D2 | 9 | 19242 | 2138 | 590563 | | |
| D3 | 9 | 18846 | 2094 | 702443.3 | | |
| D4 | 9 | 17782 | 1975.778 | 666415.4 | | |
| D5 | 9 | 18540 | 2060 | 758350.5 | | |
| *ANOVA* | | | | | | |
| Source of variation | SS | df | MS | F | P-value | F-crit. |
| Between groups | 3432109 | 4 | 858027.3 | 1.276384 | 0.295344 | 2.605975 |
| Within groups | 26889312 | 40 | 672232.8 | | | |
| Total | 30321421 | 44 | | | | |

## 4. Conclusion and Recommendation

The results from the study demonstrated that market vegetable wastes were good substrates for biomethanation using anaerobic digestion. However, due to the rapid acidification of these wastes, alkali addition is necessary to avert digester failure. The digester height-to-diameter ratio had little effect on total biogas production as both daily and cumulative biogas yield achieved nearly identical values for all digesters. Moreover, the results indicated that the height-to-diameter ratio of the digester had a minor influence on methane production since there was an inverse relationship between the two variables as a wider digester produced more methane than a taller digester of equal volume. Furthermore, the statistical analysis pointed out that the influence was not conclusively significant. Thus, further studies should be made using bigger digester volumes and continuous substrate loading to compare with the results of this study.

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