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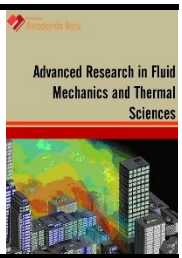

Experimental Study of the Biogas Production from Typical Food Waste in Iraq

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ABSTRACT

This work aimed to assess the production of biogas from locally widely available food waste likes; potatoes, tomatoes and carrots that are extensively used in Iraqi cuisine. Three digesters were used in the fermentation process, as well as two small digesters, where the effect of the buffer solution was tested. The effect of cellulose and starch content were studied since they are dominant in these food types. The highest amount of the biogas production was obtained from potatoes which contain a high amount of starch and an ideal ratio of carbon to nitrogen ratio. The lowest amount of biogas was from tomatoes which contain a high percentage of cellulose as well as the lowest carbon to nitrogen ratio. Tomato fermentation continued for 90 days, while potato and carrot continued for 105 days. Digestion in the smaller reactors gave better production by controlling the PH value. The production was 280 ml in 23 days while the uncontrolled digestion was 240 ml in 34 days. The production in the seventh week began to rise gradually until the end of the experiment. The proportion of methane in the digestion of tomato was almost 59. The digestion of potatoes associated with higher PH than that in tomato digestion. It began to produce methane in the fifth week of the experiment giving higher methane production of 69 proportion. Carrots produced methane in the fourth week of the experiment in a less period than potatoes. The proportion of methane was about 64. Potatoes production was better than carrot and tomatoes. The use of bio-active bacteria in the second test gave better results compared to the first test in reducing fermentation period as well as increase production.

Keywords:
Biogas; Food waste; Cellulose, PH; Starch

1. Introduction

Iraq like many undeveloped countries suffers from a high percentage of poor people in which their main food is vegetarian in nature. The most common food consumed in Iraq is either contains cellulose and/or starch as main constituents like potatoes, tomatoes, rice, wheat, etc. Nevertheless; unlike other countries, the use of biogas technology is rare in Iraq. It is intended to encourage households towards using green technologies and makes them common knowledge to most people.

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Therefore; an experiment was made to use different food wastes to produce biogas. These wastes contain various ratios of cellulose to starch since they are available in abundance. Generally, interest in biogas technology is increasing worldwide due to the need for more renewable energy production, reuse of materials and reduction of harmful emissions. Biogas technology offers multiple options and a capability of handling all the above objectives with simultaneous processing of various organic materials. It produces methane-rich biogas that can be uses as renewable energy in different ways. The remaining substance (digestate) contains all the nutrients of the original raw materials and provides a method for recycling. Biogas technology is, currently, the most sustainable way of extracting the energy content of biodegradable organic matter along with food recycling and emissions reduction [1]. Anaerobic digestion of solid organic wastes has gained increasing attention as a means of treating energy-rich biomass, destroying pathogens and reducing problems associated with organic waste disposal. Fundamentally it consists of four phases: hydrolysis, acidogenesis, acetogensis and methanogensis Current study objectives can be summarized as following Possibility of producing biogas and fertilizers from locally available types of bio waste, assess the effect of PH levels of the production rate, investigate the influence of C/N RATIO on the whole process and effect of retention time on the final quantifies produced [2].

Palm Oil Mill Effluent (POME) is a liquid waste of oil palm factory that pollutes the environment but is very useful as a raw material for producing biogas. POME processing has advantages to meet environmental requirements and to produce commercialized products. Although there are already enough biogas systems installed in oil palm factories, they are not designed optimally because it involves many parameters and quite complicated process. The purpose of this study is to obtain an anaerobic system utilizing POME at an oil palm plant in Muaro Jambi, Indonesia. The optimization is based on simulation results of some process parameters to produce maximum bio-methane gas discharged at the highest CH4 concentration. The processes occurring in the digester are stoichiometrically modelled for several variations of TSS (2-4%), temperature (30-60oC), operating pressure (1-2 bar), as well as digesting stages (1 and 2 stages). Pressure in the scrubber was varied between 9 and 12 bar, while the water flow was 1,000-15,000 kg/hour and had 3-12 stages. Calculations were performed using Aspen Plus Software. Based on this research finding, the optimum design and condition is found for 2-stages digestion where TSS = 4% and 1 bar, with temperature at first and second digester is 60oC and 42oC, respectively, which produces 7,725 kg/day biogas. The optimum methane purification is found in 5-stage scrubber at 10 bars, with water discharge of 11,000 kg/hr, which produces 7,627 kg/hour CH4 with 97.24% methane content [3]. Represented a biogas source of green energy that is of great interest as an alternative to the depletion of fossil fuel. In this work, the remains of maize crops were used as feed stock for biogas production through anaerobic digestion. The effect of alkaline treatment was also assessed. Experiments were performed in varying replicates on both particle size parameter (0.5mm, 1mm, 2mm, and natural) and vaccine ratio to the substrate (1: 1, 2: 1, and 3: 1). The largest amount of biogas (392.75 ml) of corn stalk was obtained without treatment using particle size 1mm and 1: 1 ratio in the inoculum to substrate (I: S). In addition, the highest yield (0.0692 m3 / kg of substrate SV) for the biomass of pre-treated corn leaves was achieved using natural particle size and ratio 3: 1, confirming that alkaline treatment facilitates hydrolysis during the anaerobic digestion process. These results indicate that alkaline treatment enhances the production of biogas from the remaining waste of maize crops [4].

Biogas and biofertilizer production from anaerobic digestion of local organic solid waste in Algeria is an attractive choice for greener and cleaner environment. In this paper, the study focused on the effect of co-digestion of municipal solid organic wastes (MSW) and camel dung (CD) for the quality production of biogas (methane) and bio fertilizer products. The concentration of methane production is the preeminent aim of this work. The experiment was set by feedstocks preparation where organic waste was mixed with tap water at 1:1 ratio and it allowed to digest at temperature of 40 °C. The operating hydraulic retention time (HRT) was set at 35 days. Physicochemical properties of feedstocks and constituent elements of the digestate were determined by American Public Health Association methods. The experimental study indicated that underdefined operational conditions such as constant organic loading rate (OLR) of 0.6 kg per day, hydraulic retention time (HRT) of 35 days and temperature of 40C from MSW and MSW and CD mixtures of ratio at one to one resulted in a higher methane production (57.3%) compared to monodigestion of camel dung that produced 45.6% of CH4) in a pH range between 7.0 to8.1. The improvement has also found related to high biodegradability of the MSW, the slight ammonium concentration, the optimization of the carbon-to-nitrogen ratio (C/N 25.8:1) and to the well-balanced nutrients content of the feedstock. The digestate coming from anaerobic co-digestion has also used as bio-fertilizer and this by-product has a benefit to avoid the harmful effect in the digester system and in the surrounding environment. It is shown clearly that the MSW and CD are highly desirable substrates for anaerobic co-digestion with regards to their good biodegradability, high methane yield and good bio-fertilizer quality [5]. In anaerobic digestion for enhancement of biogas production, various types of pre-treatment method have been used with some limitations in terms of sustainable environmental management. Although acid and alkali pretreatment have significant effect on the degradation of biomass, these methods have some negative impacts on environment due to their hazardous nature, while the enzymatic pre-treatment is more environmentally friendly. One of the constrains of using enzyme in pretreatment process for biogas production is high cost which is currently focused to reduce cost through using locally produced enzyme. The hydrolytic enzymes, cellulase and lipase were applied to evaluate the pretreatment and hydrolysis process for POME based biogas production. The results showed that about 66.67% more free fatty acid (FFA) was obtained in this study in compared to untreated sample as the control (POME) by using 15 U/ml lipase at the pH of 4.5. About 3-fold higher reducing sugar was recorded at the loading of 2.4 FPU/ml Cellulose enzyme as compared to the control at the pH range 4. Both enzymes were effective in the pretreatment process in conversion of complex substances in the POME into monomars towards biogas production [6]. Have examined the anaerobic digestion common to three different substrates that were cow dung, food waste and fruit waste. The digestion process in the mesophilic group has been accomplished in a 25-liter plastic batch model digester. The waste was mixed with water by (1: 1). They were studied the use of single digestion and multiple digestion of these different species. They found that the multiplicity of food digestion and cow dung provided maximum production of biogas. In other words, multiple digestions were preferable to mono-digestion in terms of the biogas production [7]. Examined the anaerobic co-digestion of three various substrates which were cow dung, food waste, fruit waste. The digestion process was accomplished at mesophilic range in batch 25-liters plastic prototype digester. wastes were mixed with water at ratio of 1. The study examined the use of mono-digestion and multiple-digestion of these different types. They found that multiple-digestion of food waste and cow dung have provided maximum biogas yielding. In other words, the multiple-digestion was preferred over mono-digestion in terms of biogas production. The mesophilic temperatures range attained within the testing period were (25 - 28.4 ° C) the result obtained from the biogas Production showed that the combined digestion of cow dung and food waste produced the highest biogas by 164.8%, followed by the joint digestion of the three wastes (cow dung, fruit waste and food waste) of which 91.0% - cow dung and fruit waste (83.9% By 79.8%, food waste by 77.4% and fruit waste by 76.4% during this retention period. During the digestion period Moreover, they found that the pH value was decreased when retention time was increased. Also, they recommended that anaerobic digestion was suitable method for waste management and can be an alternative for fossil fuel [8]. Studied anaerobic co-digestion of food waste (FW) and Palm Oil Mill Effluent (POME). In this case, there is considerable amount of a required nutrient for efficient digestion process. They assumed that anaerobic co-digestion was an effective method to achieve the desired reduction rate in terms of total solid and volatile solid. This fact was proven when they concluded that the higher reduction rate was obtained at a ratio of 70%: 30% of FW and POME which were equal to 45% and 41% of total solid and volatile solid respectively [9]. Starch is the commonest polysaccharide in major dietary items such as potatoes, rice and pasta. It consists of straight or branched chains of glucose and digests relatively easily. Retention time needed depends partly on the composition of the substrate and the digestion temperature. Microorganisms generally manage to decompose a substrate rich in sugar and starch, which is easily broken down, in a short time. On the other hand, microorganisms may need significantly more time to effectively attack and break down fibre-rich and cellulose-rich plant matter. For such material, it is often hydrolysis and not methanogenesis that limits the rate of decomposition. In Germany, among other places, retention time of up to 50-100 days is used to ensure stable operation and satisfactory digestion of energy crops [10]. Bioenergy crop residues can also cause self-heating of the process. A recently published scientific article showed that about half of all (20 of 41) biogas plants in Austria, which digests bioenergy crops, show an increase in process temperature. Instead of the planned process temperature of between 35-39 °C, they were 42-49°C. Calculations with data from these plants showed that the temperature increase was between 0.15-0.5°C per day. The reason for heating was considered to be the release of energy during the breakdown of carbohydrates, which could happen if the substrate has a high energy density, that is, contains a high percentage of starch, and at a relatively high load [11]. Studied the anaerobic process of the waste of fruit-mixed vegetables as substrates in a dietary anaerobic digestion for biogas production. Fodder consists of mixed vegetable and fruit waste from a traditional market in Pontianak. The waste was taken on the basis of sampling using a combination of 78% waste of vegetable waste, 4% of tuber waste and 18% of fruit waste. The total waste weight was 160kg, manually mixed once in feeding. Chemical analysis of primary and bioreactor reactors using standard methods was performed. The Chemical Oxygen Demand (COD) the leachate was in the range of 7.2-56.4 g / L, the pH was between 5.3-6.8 and the temperature was 28-46 °C. The highest methane content in biogas was 65% with biogas flow of 20-40 ml [12]. Has tested the Biological Methane Potential (BMP) of Iraqi date palm through thermophilc co-digestion with activated sludge in 300-ml glass jars to investigate the effect of provided nutrients added to the mixture. The produced biogas was saved in sealed jars jointed by special sensors to record biogas pressure continuously. Methane percentage was 67% and BMP was 0.57 L/g VS. Also, the addition of 1% of yeast extract solution has improved generated biogas by 5.9%. The study suggested that the date palm is promising a source for biogas production due to high volatile solid content and a short time required for biogas production [13]. Were studied the production of biogas from agricultural wastes including Banana and banana peel. The experiment was conducted using a 10-liter digestion device and a 35-week holding period. The volume of gas produced from bananas beels and bananas was about (2409 cm^3 and 8800 cm^3). However, the largest amount of biogas was obtained in a digestion device containing equal proportions of banana and banana beels about of 13356cm^3 as feed stocks. The pH value during the study was 7.7, and the temperature was relatively constant in an average range of (32-35°C) throughout the experiment period [14].

2. Materials and Methods

2.1 Food Wastes

The main substrate loaded in the digester which consists of waste of food, collected from groceries, are tomatoes, potatoes, carrots. Tomato 6.65kg mixed with water 3.3 litters, the proportion of waste of potatoes 5.7 kg mixed with water 4.3 litter and carrot waste was 5kg mixed with water 5 litters. These materials were used because they are available in the Iraqi markets as well as in the homes and materials were selected and classified into different groups of cellulose and starch where the lowest of cellulose is tomatoes and the higher starch is potatoes and the medium between the two cases is carrots. Waste was cut into very small pieces to increase the process of decomposition. The ratios below are based on the Table 1, according to the tests conducted in the Agricultural Research Department.

Table 1
Laboratory examination of waste

Waste	Moisture %	TS %	Ash %	VS %	Cellulose %	Starch %	TS/VS %
Tomato	0.8255	0.1745	0.12	0.88	32	18	0.198
Potato	0.684	0.316	0.06	0.94	17	30	0.336
Carrot	0.574	0.426	0.04	0.96	22	12	0.444

2.2 Bio-Active Bacteria

The cow dung was collected from the areas where the cows reproduce, and it is known that the droppings of the cows are rich in anaerobic microbes and thus a small amount is mixed with waste. 2 kg of substrate (cow dung) mixed with water 2 litters and added to the mentioned waste used. Figure 1 as shown as an illustration of the used digester.

2.3 Materials and Procedure
2.3.1 Determining moisture content and the total solids (TS)

A sample of 50g weight of waste was taken and placed in a thermal oven at 105 °C for one hour. It is then extracted to cooled, and then weighted the sample by using balance later calculating the moisture through using the equation shown below

$$\text{Moisture } \% = \frac{W_1 - W_2}{W_1} * \% \, 100 \quad (1)$$

W_1: weight of waste before drying (kg).
W_2: weight of waste after drying (kg).

Total solids = 100%-moisture (2)

2.3.2 Determining ash content and volatile solids

The proportion of volatiles was calculated from dried wastes by placing them inside the furnace at 550°C for four hours and then left to cool. Their weight was measured and the volatiles can be calculated from

$$\text{Ash}\% = \frac{W_3 - W_4}{w1} * 100\% \quad (3)$$

W_3: weight of crucible and sample after burning (kg)
W_4: weight of crucible (kg)

Volatile solids =100%-ash % (4)

2.4 Materials and Procedure
2.4.1 First test

Three digesters made from plastic were used. The capacity of each digester is 40 litters. Three holes were drilled in each digester, the first hole is of 50 mm diameter to insert waste, second hole is of 36 mm diameter for the extraction of waste, and the third hole is of 25 mm diameter to extract the gas and connected to the gas storage. Various proportions of food waste were used according to the moisture content of the waste. The amount of waste in the first digester was (1: 0.5) in which about 6.65 kg of tomato waste is mixed with 3.3 litters of water. In addition, to 2 kg bacteria rich substrate mixed with 2 litters of water. In the second digester, the ratio of waste is (1: 0.75) in which 5.7 kg of potatoes waste was mixed with 4.3 litters of water. As well as an equal amount of co-substrate was used. In the third digester the proportion of the waste was (1: 1), carrot waste of 5kg mixed with 5 litters of water, as shown in Table 2. Figure 1 shows the digester used in the experiment and an illustrated chart.

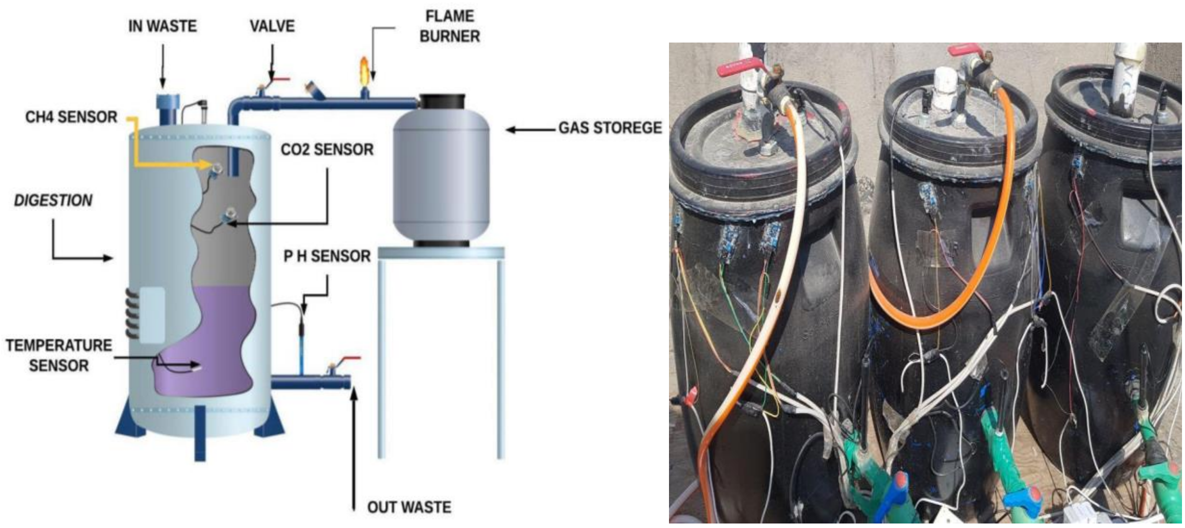

Fig. 1. Schematic of anaerobic bio-digester

Table 2
Ratio process of digestion

Sample	Mixing ratio	Wt (kgm)	C/N Ratio	Initial pH
Tomato	1:0.5	6.65	13	6.45
Carrot	1:1	5	40.1	5.9
Potato	1:0.75	5.7	25	6.1

2.4.2 Second Test

A second experiment of the fermentation process was carried out with the same steps as the first test. The gas was discharged to see how it affected the production process.

3. Results and Discussion

The current study examined the feasibility of the biogas production from food waste locally available in abundance. Tomato, potato and carrot wastes were used as in Table 2. Tomatoes contain a high percentage of cellulose and low starch, which affects the amount of production due to the difficulty of disintegration of its fibers while the potato contains a lower amount of cellulose and high starch.

Figure 2 shows the variation digesters temperature during producing the biogas with time for different waste foods. It can be seen from the figure that there is a gradual increase in the temperature during digestion, the maximum temperature was in the digestion of potatoes. This is due to reasons, the most important being the ratio of carbon and nitrogen, the ideal ratio for the biogas production and high starch content. The temperature in the second digestion ranged from 16 to 40°C within the scope of the mesophlic bacteria throughout the experiment. The higher the temperature the higher the biogas production, but when the temperature rises more than expected, it will react negatively to production, as mentioned in previous studies.

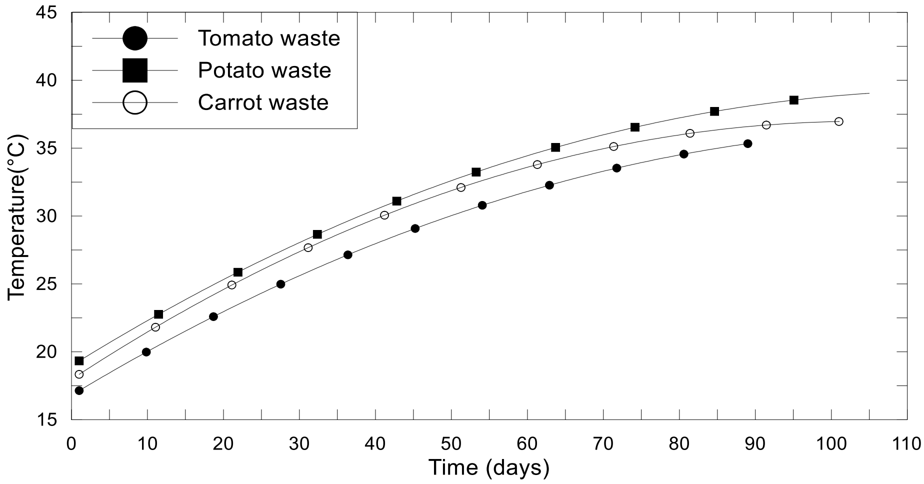

Fig. 2. The variation of daily temperature during the digestion process

Figure 3, 4 and 5 illustrate the pH value during anaerobic digestion. The pH value begins to decrease within twenty-five days of digestion and then gradually increases, as bacteria change from the process of decomposition to acid formation. Where PH has an effect on gas production. The higher the pH of the equivalent phase, the higher the methane production. The highest pH value obtained was in the digestion of potatoes. Increasing the pH causes the bacteria to switch from the acid formation stage to the methane formation stage and this leads to an increase in biogas.

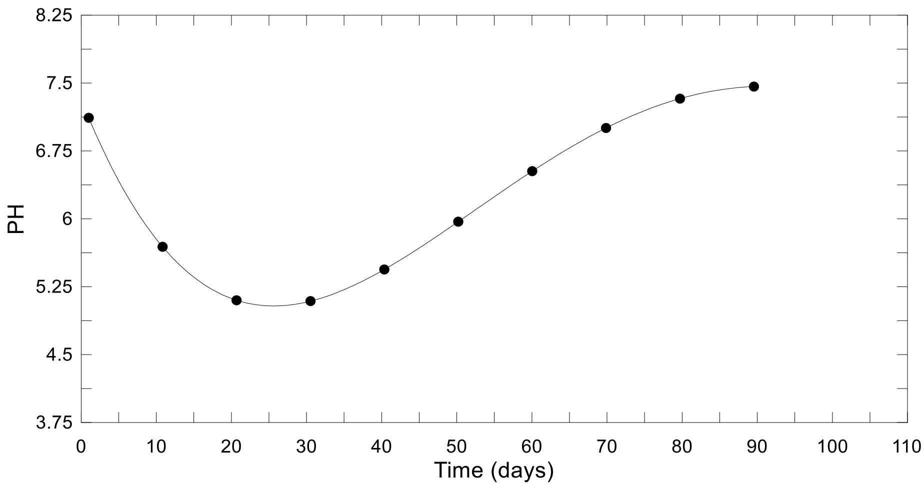

Fig. 3. The variation of pH tomato waste with time

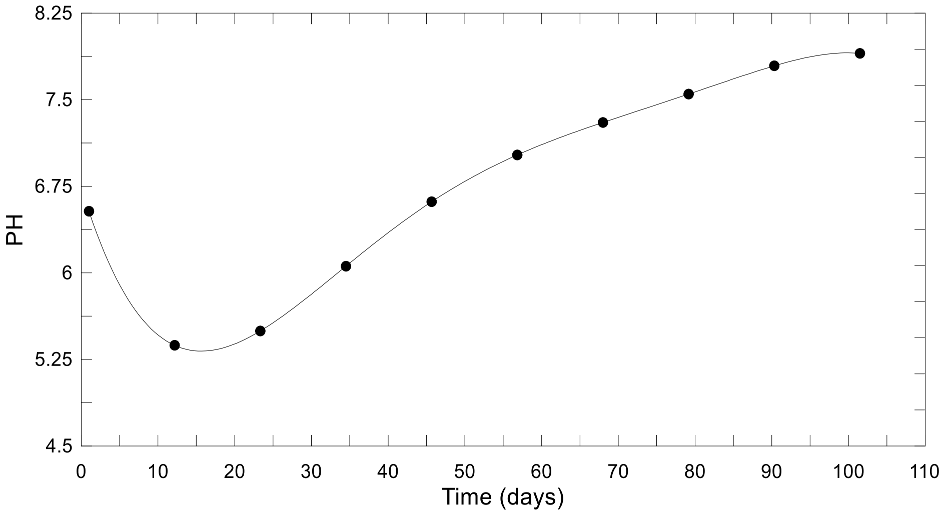

Fig. 4. The variation of pH potato waste with time

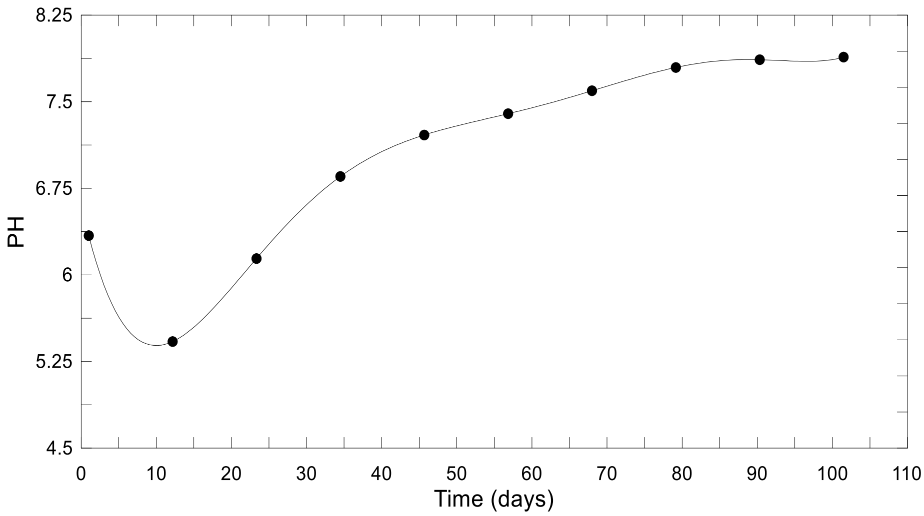

Fig. 5. The variation of pH carrot waste with time

Figure 6, 7 and 8 illustrate methane production in the digestion process, where the average PH value in the potato digester was 6 to 7. 4. This value is ideal for methane production. The higher the pH value in the ideal limits, the higher the methane production. Methane producing from potato higher than tomatoes and carrots. The production of methane potato is higher than the tomato and carrot as for the reasons. The most important of these is potato containing a high proportion of starch compared to tomatoes and carrots, which helps the starch to break down the bonds faster .Because of its structure and chemical composition easier to digest than cellulose, the starch helps to transform the bacteria from decomposition in water to the acid faster and this leads to accelerate the gas production. The second reason is that they contain an optimal proportion of carbon and nitrogen as previously mentioned in the studies, where methane-producing bacteria operate within the optimal phase temperatures in the mesophilic (28.7-40.23 C). The best results were obtained from potatoes where methane production was about 5.7g / v, while carrots and tomatoes had 4.8 - 4.1g / v.

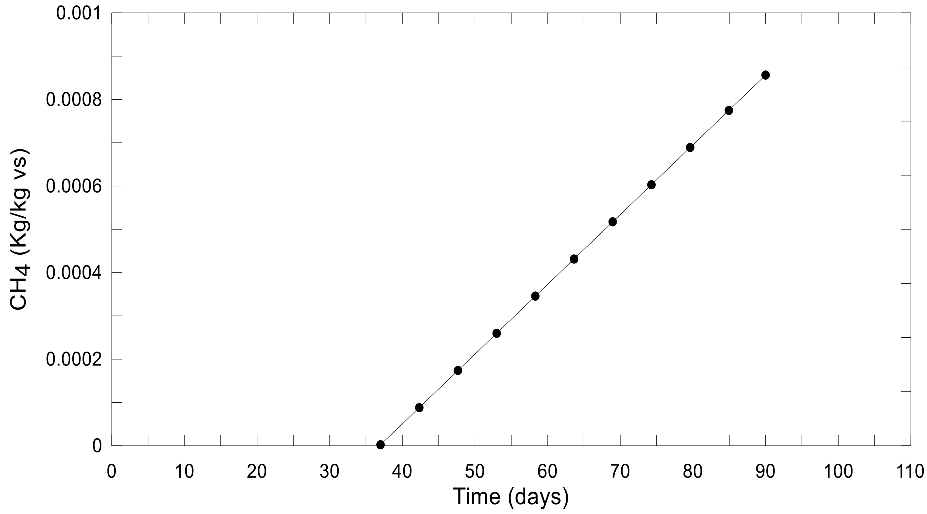

Fig. 6. Methane production in tomato digester

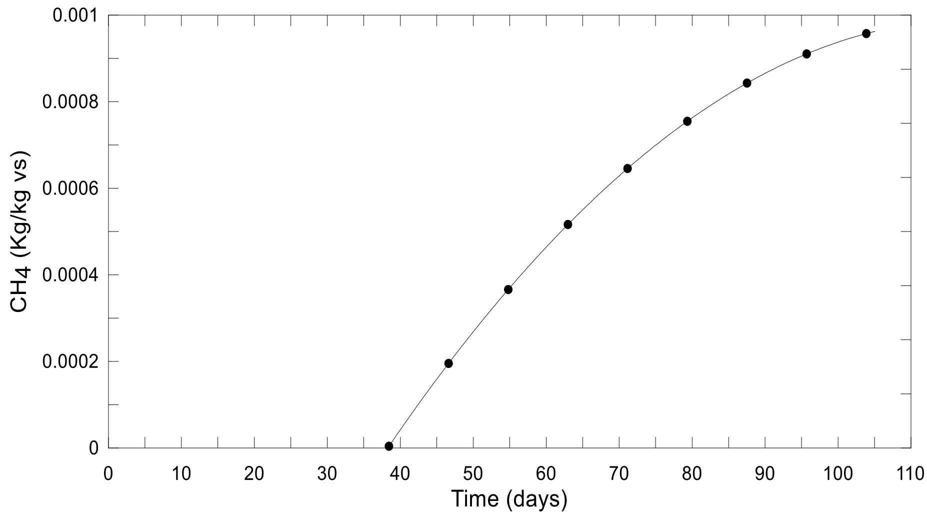

Fig. 7. Methane production in potato digester

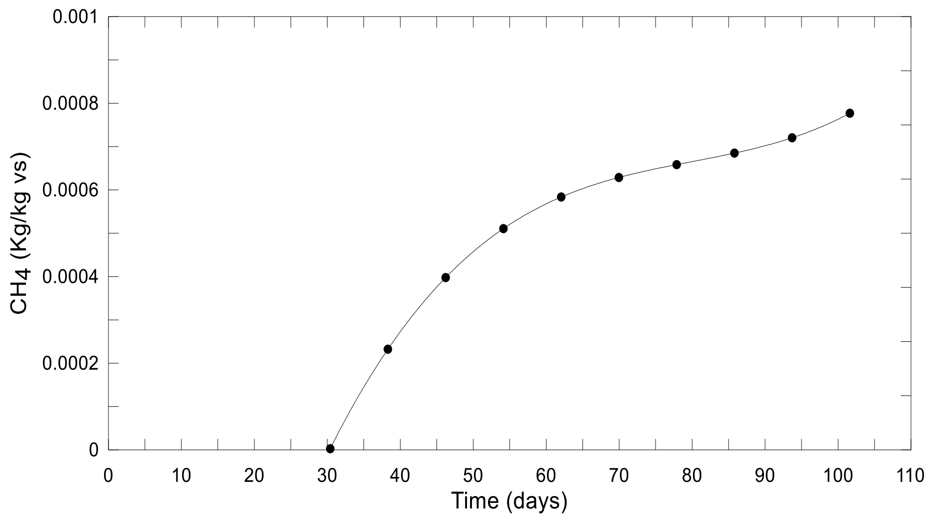

Fig. 8. Methane production in carrot digester

A second test was conducted to assess some additional factors on the biogas production and the possibility of reducing the fermentation period. The most important factor studied in this test is the effect of bacteria co-substrate. The co-substrate played an important role in increasing the quantity of production as well as in reducing the duration of fermentation than in the first test. Compared to the gradual rise of temperature observed in the first test, the second test recorded higher temperatures. The pH of the first experiment was 7.34. While for the second experiment was 7.7 and the third gave a pH of 7.56. The production began much earlier than the first experiment and the amount of production is greater because of the remaining active co-substrate. A second probable reason is the increase in temperature which may accommodate a better environment for the bacteria leading to increase in gas production. Higher pH also contributes to the increase in gas production, since it is preferable to methanogensis bacteria.

4. Conclusion

This study was devoted to investigate the potential of anaerobic digestion for the biogas production employing food waste materials with no economic value such as the substrate. The digestion process was analysed using alternatively three types of waste materials. Tomato waste (TW), Potatoes waste (PW), and Carrot waste (CW). The main conclusions that can be drawn from this study are as follows.

i. The results showed that food waste has the capability to produce biogas according to the order of PW> CW> TW.
ii. The pH value played an important role in the methane production process. As the pH value approached the parity phase. Methane production increased abundantly.
iii. The results obtained from methane were in bacteria mesophlic. In batch systems, the best results appeared when using a solution that controls the pH value, where the biogas production reached to 280 ml.
iv. The best results were obtained by studying the potatoes which is produced the ideal ratio of carbon and nitrogen.
v. Tomato recorded the lowest amount of gas in the study, because it is contained a high cellulose ratio compared to potatoes and carrots.

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References
[1] Vogel, Telse, Matthias Ahlhaus, and Mirko Barz. "Optimisation of biogas production from grass by dry-wet fermentation." In *Eighth international scientific conference—engineering for rural development. Jelgava*, pp. 21-6. 2009.
[2] Sinaga, Nazaruddin, Syukran Bestari Nasution, and Maizirwan Mel. "Process optimization of biogas production from palm oil mill effluent: a case study of a crude palm oil factory in muaro jambi, indonesia." *Journal of advanced research in fluid mechanics and thermal sciences* 49, no. 2 (2018): 155-169.
[3] Angulo-Padilla, Julián, Luisa Lozano-De La Ossa, Ángel González-Delgado, Eduardo Sánchez-Tuirán, and Karina Ojeda-Delgado. "Effect of Alkaline Pretreatment on Biogas Production from Corn (Zea mays) Crop Residues Biomass." *Contemp. Eng. Sci.* 11 (2018): 973-981. https://doi.org/10.12988/ces.2018.8272

[4] Kheira, Benaissa Nawel, Belkheir Dadamoussa, Abdelaziz Bendraoua, Maizirwan Mel, and Brahim Labed. "Effects of Co-digestion of Camel Dung and Municipal Solid Wastes on Quality of Biogas, Methane and Biofertilizer Production." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 40, no. 1 (2017): 7-17.

[5] Islam, M. T., Md Zahangir Alam, Abdullah Al-Mamun, Amal A. Elgharbawy, and Fatimah A. Riyadi. "Development of enzymatic pretreatment of palm oil mill effluent for monomers towards biogas production." *Journal of Advanced Research in Materials Science* 38, no. 1 (2017): 39-44.

[6] Selaman, Rafidah, and Newati Wid. "Anaerobic Co-Digestion of Food Waste and Palm Oil Mill Effluent for Phosphorus Recovery: Effect on Reduction of Total Solids, Volatile Solids and Cations." *Transactions on Science and Technology* 3, no. 1-2 (2016): 265-270.

[7] Otun, T. F., O. M. Ojo, F. O. Ajibade, and J. O. Babatola. "Evaluation of biogas production from the digestion and codigestion of animal waste, food waste and fruit waste." *International Journal of Energy and Environmental Research* 3, no. 3 (2015): 12-24.

[8] Ismail, Zainab Ziad, and Ali Raad Talib. "Biogas Recovery from Anaerobic Co-Digestion of Poultry House Wastes for Clean Energy Production." *Journal of Engineering* 20, no. 5 (2014): 95-108.

[9] Monlau, F., Cecilia Sambusiti, A. Barakat, Marianne Quéméneur, E. Trably, J-P. Steyer, and H. Carrère. "Do furanic and phenolic compounds of lignocellulosic and algae biomass hydrolyzate inhibit anaerobic mixed cultures? A comprehensive review." *Biotechnology advances* 32, no. 5 (2014): 934-951. https://doi.org/10.1016/j.biotechadv.2014.04.007

[10] Wellinger, Arthur, Jerry D. Murphy, and David Baxter, eds. *The biogas handbook: science, production and applications*. Elsevier, 2013. https://doi.org/10.1533/9780857097415

[11] Sitorus, Berlian, and Seno D. Panjaitan. "Biogas recovery from anaerobic digestion process of mixed fruit-vegetable wastes." *Energy Procedia* 32 (2013): 176-182. https://doi.org/10.1016/j.egypro.2013.05.023

[12] Jaafar, Khalidah A. "Biogas production by anaerobic digestion of date palm pulp waste." *Al-Khwarizmi Engineering Journal* 6, no. 3 (2010): 14-20.

[13] Ilori, Matthew O., Sunday A. Adebusoye, A. K. Iawal, and Oluwatoyin A. Awotiwon. "Production of biogas from banana and plantain peels." *Advances in Environmental Biology* (2007): 33-39.

[14] Lindorfer, H., R. Waltenberger, K. Köllner, R. Braun, and R. Kirchmayr. "New data on temperature optimum and temperature changes in energy crop digesters." *Bioresource technology* 99, no. 15 (2008): 7011-7019. https://doi.org/10.1016/j.biortech.2008.01.034