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Variation in Methane Concentration Produced from Anaerobically Digested Vegetables

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Abstract: Anaerobic fermentation is a highly promising technology for converting biomass waste into methane, which then may directly be used as an energy source. Attempts have been made to optimize various parameters in order to determine the most favorable recipe for maximum biogas production from fermented vegetable waste. The biogas production from many types of vegetable waste such as zucchini, orange peel, tomato, potato, and rice was studied in batch digesters. The effect of adding chicken dung and sludge to vegetable waste on the concentration of methane in the produced biogas was investigated. The experiments were conducted at room temperature (20°C) and at 35°C. The results revealed that methane concentration goes through maximum value with time. This maximum value is obtained faster when the rate of digestion is faster. The concentrations of methane in the biogas produced are ranked as follows: potato>rice>tomato>zucchini>orange peels. The concentrations of methane gas increased as chicken dung and sludge were mixed with the vegetables. The maximum value of methane concentration is reached faster in a mixture of chicken dung and sludge. For both chicken dung and sludge, the maximum value is reached at the same time.

Keywords: Biogas, Methane, Carbon dioxide, Renewable energy, Fermentation, Chicken dung, Sludge, Anaerobic digestion.

التغير في تركيز غاز الميثان المنتج من التحلل اللاهوائي للخضروات

حسن موسى، ومحمد السلوادي

المستخلص: إن عملية التخمير اللاهوائي هي تكنولوجيا واعدة للغاية من أجل تحويل مخلفات الكتلة الحيوية إلى ميثان، والذي يمكن استخدامه مباشرة كمصدر للطاقة. ولقد بذلت العديد من المحاولات لإيجاد العوامل المثلى من أجل تحديد الوصفة الأكثر ملاءمة لإنتاج الحد الأقصى من الغاز الحيوي من هذه المخلفات النباتية المخمرة. تم في هذا البحث دراسة إنتاج الغاز الحيوي من أنواع عديدة من المخلفات النباتية مثل الكوسا، وقشر البرتقال، والطماطم، والبطاطا، والأرز وذلك باستخدام مفاعل هاضم ثابت تقدم إليه المخلفات دفعة واحدة. كما تم بحث إضافة روث الدجاج والحمأة إلى المخلفات النباتية ودراسة تأثير هذه الإضافة على مستوى تركيز غاز الميثان في الغاز الحيوي المنتج ككل. لقد تم إجراء التجارب في درجة حرارة الغرفة (20 درجة مئوية) وكذلك في درجة حرارة 35 درجة مئوية. وكشفت النتائج أن تركيز غاز الميثان يمر خلال القيمة القصوى له مع مرور الوقت. ويتم الحصول على هذه القيمة القصوى بشكل أسرع كلما كان معدل الهضم اللاهوائي أسرع. لقد وجد أن تركيز الميثان في الغاز الحيوي المنتج يتبع الترتيب التالي: البطاطا، الأرز، الطماطم، الكوسا، وقشر البرتقال. هذا وقد وجد أن تركيز غاز الميثان يزداد عند إضافة روث الدجاج والحمأة إلى المخلفات النباتية وتم الحصول على نتائج أفضل مع روث الدجاج. وتم الوصول إلى الحد الأقصى لقيمة تركيز الميثان بشكل أسرع في وجود روث الدجاج والحمأة. وفي الحالتين، فإنه تم الوصول إلى القيمة القصوى للميثان في نفس الوقت.

الكلمات المفتاحية: الغاز الحيوي، الميثان، ثاني أكسيد الكربون، الطاقة المتجددة، عملية التخمير، روث الدجاج، الحمأة، التحلل اللاهوائي.

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1. Introduction

Due to its high biodegradability, the anaerobic digestion (AD) of organic waste could play a role as an unconventional nonrenewable source of energy. A great deal of research has been conducted to study biogas production from different mixtures of organic waste (Bouallangui 2005; Berlian *et al*. 2013; Demirbas 2006; Singh *et al*. 2012; Velmurugan and Ramanujam 2011; Yogita *et al*. 2012). Various studies have been performed investigating biogas production from fruits and vegetable such as rice (Okeh *et al*. 2014; Ofoefule *et al*. 2011), potatoes (Cheng *et al*. 2011; Bernd 2006; Kryvoruchko *et al*. 2009; Mayer 1998; Parawira *et al*. 2004; Parawira *et al*. 2005), orange peels (Nguyen 2013; Wikandari *et al*. 2014; Periyasamy and Nagarajan 2012), zucchini (Salter 2007), tomatoes (Saev *et al*. 2009; Sarada and Joseph 1994), olive pomace (Tekin and Dalgic 2000), banana peels (Nirmala *et al*. 1996) as well as many other types of organic waste (Velmurugan and Ramanujam 2011). Past research has shown that on average 200-400 ml of biogas can be produced per gram of volatile organic solids (Velmurugan *et al*. 2011). The productivity of the biogas is affected by the pH of the reactor, the organic loading rate, the temperature of the waste, the type of organic waste used, and the mixture of the reactor and water contents (Babaee and Shayegan 2010; Bouallagui *et al*. 2004; Bouallagui *et al*. 2005; Weiland 2011). The biogas produced by the AD process contains 60% methane and 40% CO_2 as well as traces of other gases such as hydrogen sulfide, ammonia, nitrogen, and hydrogen. The anaerobic conversion of organic waste to biogas goes through four main steps: hydrolysis, acidogenesis, acetogenesis, and methanogenisis, with the latter responsible for methane gas production. Accordingly, the digestion time, called hydraulic retention time (HRT), is a crucial parameter in maximizing the quantity of the biogas and its methane content. Accordingly, the methane composition of the biogas is expected to increase with time, reaching a maximum value at which it is recommended to withdraw the biogas for energy generation purposes. In this paper, the maximum concentration of methane gas in the biogas produced from potatoes, zucchini, orange peels, rice, and tomatoes will be determined. The effect of mixing such vegetables with sludge and chicken manure as well as the digestion temperature and the time at which the maxima is reached will also be investigated.

2. Experimental Setup

The experiments were carried out in 2.25 L plastic bottles, which were used as bioreactors. To ease gas sampling, the caps of the bottles were pierced, allowing hollow screws to go through. The screws were tightened well to the bottles' cap to prevent any gas leak. Plastic pipes were connected tightly to the outer part of the screws and sealed by clamps. When gas analysis was needed, the clamps were slightly loosened to allow the gas to be released [Fig. 1]. The study was conducted using potatoes, zucchini, tomatoes, and orange peels which were bought from the local market, cut into pieces ~2 cm in dimension. Then, 500 grams of a given vegetable were placed in a bottle and 500 grams of tap water were added so that the ratio of the solid waste to water was 1:1. Three sets of these bottles were prepared. To each bottle in the second set, 25 ml of chicken dung was added and mixed with the water and vegetable waste. Likewise, 25 ml of sludge was added to each bottle in set three and mixed with its contents. This allowed a study of the effect of chicken manure and sludge on the concentration of methane in the produced biogas. The bottles were prepared in triplicate in order to assure reproducibility of the results. The chicken dung was obtained from a nearby agricultural school and the sludge was obtained from the waste water treatment plant at Jordan University of Science and Technology (JUST). The experiments were performed at room temperature (20°C) by placing the bottles on the shelves in the lab and at 35°C by placing the third set of bottles in an incubator. The produced biogas was analyzed by withdrawing the gas via a 20 ml syringe and then introducing the withdrawn sample to the gas analyzer (EAGLE Type gas analyzer, Union City, California, USA). The volatile solid content (VS) of each batch of vegetable waste, chicken dung, and sludge was determined *a priori* according to standard methods (APHA, 1995).

3. Results and Discussion

3.1 Water and Volatile Solids Content

The percentage of water of the selected organics is shown in Table 1. The dried samples were analyzed for their volatile solid (VS) contents and the results are presented as kilograms of VS/kg of dry solids [Table 1]. The results indicate that rice contains the lowest water content and the maximum VS whereas wastewater sludge has the highest amount of water and the lowest amount of VS.

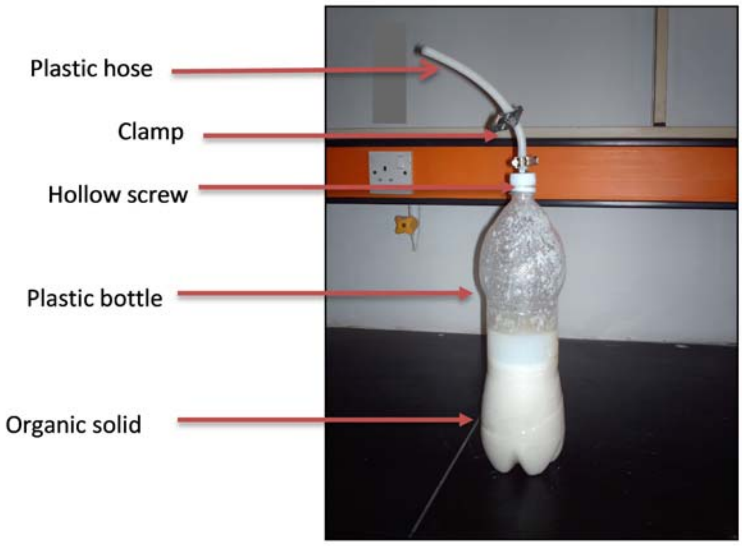

Figure 1. A photograph of the bottle containing solid waste.

Table 1. Water content of tested solid wastes.

Waste type	% water content	VS (VS/kg dry solid) x 100%
Rice	65.82 ± 3.3	99.14 ± 0.25
Potato	81.46 ± 2.44	95.15 ± 0.42
Tomato	95.19 ± 0.36	82.44 ± 1.59
Zucchini	94.55 ± 0.53	83.62 ± 0.82
Orange peel	77.17 ± 0.02	96.84 ± 0.8
Chicken dung	20.96 ± 0.43	86.28 ± 0.49
Sludge	97.05 ± 0.15	71.28 ± 0.8

3.2 *CH_4 Concentration in the Produced Biogas*

A comparison between the concentrations of methane gas in the biogas produced by the solid waste tested at 35°C is shown in Fig. 2. Potato was found to give biogas with a higher CH_4 content compared to rice. Table 2 shows that potato has higher potassium content compared to rice, explaining the higher content of methane in the biogas produced (Machnica *et al.* 2008). Orange peels, however, have a higher VS content but contain D-limonene oil that upsets the function of the anaerobic bacteria which explains the low methane content of the biogas (Martin *et al.* 2010). The acidity of tomatoes negatively affects the productivity of the bacteria causing lower methane production. Figure 2 shows that methane concentration is achieved through a maximum time value which is reached at different times according to the solid used. It can be noted that the faster the biodegradation process, the higher the maximum. The time necessary follows an order from high to low: potatoes > rice > tomatoes > zucchini > orange peels. This point needs further investigation and must be related to the amount of biogas produced to draw a solid conclusion. The amount of biogas produced and its methane concentration are important factors to determine the optimum HRT.

The effect of temperature on the amount of bigas produced is presented in Figs. 3a–d for zucchini, potatoes, tomatoes, and orange peels, respectively. The results are in accordance with other researchers' findings where biogas of higher methane concentrations is produced at higher temperatures (Beam 2011; Nallathambi 2004; Chua

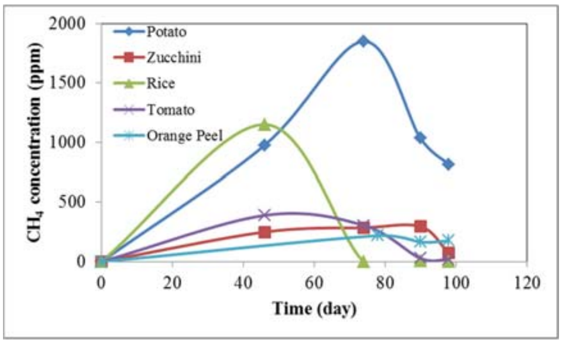

Figure 2. Methane concentration in the biogas produced from the various solid wastes at 35°C.

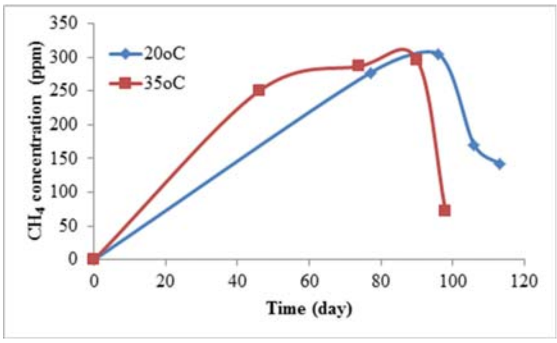

Figure 3a. Methane concentration in biogas produced from zucchini at 20°C and 35°C.

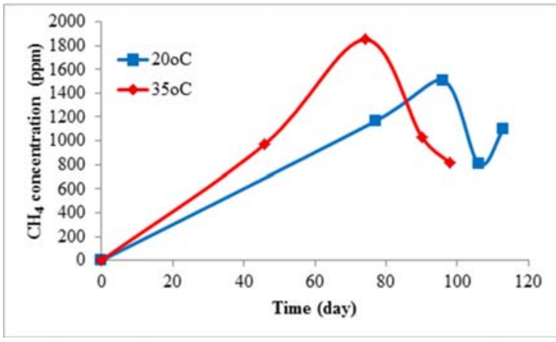

Figure 3b. Methane concentration in the biogas produced from potato at 20°C and 35°C.

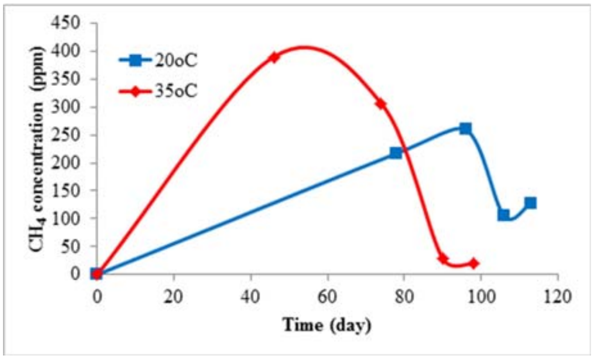

Figure 3c. Methane concentrations in the biogas produced from tomatoes at 20°C and 35°C.

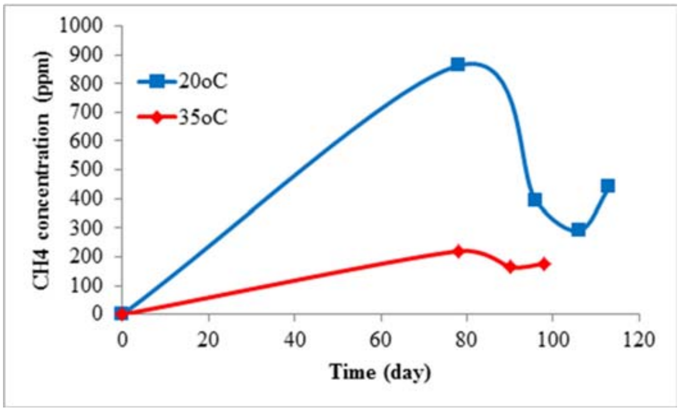

Figure 3d. Methane concentration in the biogas produced from orange peels at 20°C and 35°C.

et al. 2013). Except for orange peels, biogas of a higher methane concentration is produced at 35°C compared to 20°C. The effect is strong for potato and tomato and weak for zucchini. Moreover the maxima are achieved at shorter times when the temperature is higher and the rate of degredation is faster. For orange peels, biogas of a lower methane concentration is produced at 35°C as compared to 20°C because D-limonene becomes unstable at low temperatures. Since D-limonene negatively affects the bacterial activity, oxidation causes its concentration to drop, enhancing the activity of the bacteria and leading to higher biogas production at 20°C compared to 35°C (Martin *et al*. 2010; Paramita *et al*. 2010).

The effect of adding sludge to the vegetable waste on the concentration of methane in the biogas is depicted in Fig. 4a–d. The presence of sludge increases the concentration of methane gas produced and its maximum is achieved faster. This is obvious since sludge enhances the rate of methane production a result similar to that obtained by (Liu *et al*. 2009; Satayanarayana *et al*. 2008; Gelegenis *et al*. 2007). A comparison between the effect of adding sludge and chicken dung to zucchini is depicted in Fig. 4a. Biogas with a higher methane concentration is produced when chicken dung is added; however, chicken dung and sludge achieve maximum methane levels at the same time. A careful inspection of the figures shows that after the methane gas concentration drops from its maximum value, it reaches a minimum value and again increases. A possible explanation is that methanogenic bacteria transforms the volatile fatty acids (VFA) formed by the acidogenesis bacteria into methane gas. Accordingly, the VFA concentration drops and so does the methane gas level. This drives the activity of acidogenesis bacteria to produce VFA, producing an acidic environment (low pH). As a consequence of this drop, the activity of acidogenesis bacteria drops and metthanogenic bacteria utilize VFA to produce methane, causing an increase in its concentration and the cycle repeats. This point is not proven in this work but worth investigation in future research.

4. Conclusions

In the current study, anaerobic digestion of vegetable waste was carried out in batch digesters. The concentration of methane in the biogas produced from zucchini, potatoes, tomatoes, rice, and orange peels was measured. The effect of adding chicken dung and sludge to the above named vegetables on the concentration of methane was investigated. The work was carried out at 20°C and 35°C. The concentration of methane excreted from the vegetables studied is as follows: potato>rice>tomato>zucchini>orange peel. The concentration of methane achieves a maximum, and that maximum is achieved faster in tandem with the rate of digestion. Sludge, chicken dung, and temperature improved the concentration of methane in the biogas, and the maximum value is reached earlier. The produced biogas has a higher methane concentration when chicken dung is used; however, a maximum methane concentration is reached at nearly the same time whether chicken dung or sludge is used.

Table 2. Chemical composition per 100 grams of vegetables studied[a].

Component	Rice	Potatoes	Zucchini	Orange Peels	Tomatoes
Protein (g)	7.1	2.0	1.2	1.5	0.9
Fat (g)	0.66	0.09	0.2	0.2	0.2
Carbohydrates (g)	**80**	17	2.9	25	4.7
Fiber (g)	1.3	2.2	1.1	10.6	1.2
Sugar (g)	0.12	0.78	-	-	2.6
Calcium (mg)	28	12	21.4	161	13
Iron (mg)	0.8	0.78	0.35	0.8	0.5
Magnesium (mg)	25	23	17	22	11
Phosphorus (mg)	115	57	51.4	21	24
Potassium (mg)	115	421	262	212	237
Sodium (mg)	5	6	10	3	3
Zinc (mg)	1.09	0.29	0.29	0.25	-
Copper (mg)	0.22	0.11	.051	-	-
Manganese (mg)	1.09	0.15	0.175	-	0.114
Selenium (µg)	15.1	0.3	0.58	-	-
Vitamin C (mg)	0	19.7	17	136	14
Thiamin (mg)	0.07	0.08	-	0.12	0.037
Riboflavin (mg)	0.05	0.03	-	0.09	-
Niacin (mg)	1.6	1.05	0.487	0.9	0.594
Pantothenic acid (mg)	**1.01**	0.30	0.155	-	-
Vitamin B6 (mg)	0.16	0.30	0.218	0.176	0.08
Folate total (µg)	8	16	48	-	-
Vitamin A (IU)	0	2	-	420	42
Vitamin E, alpha-tocopherol (mg)	0.11	0.01	-	0.25	0.54
Vitamin K1 (µg)	0.1	1.9	-	-	7.9
Beta-carotene (µg)	0	1	-	-	449
Lutein + zeaxanthin (µg)	0	8	-	-	123
Saturated fatty acids (g)	0.18	0.03	0	0.024	-
Monounsaturated fatty acids (g)	0.21	0.00	0	0.036	-
Polyunsaturated fatty acids (g)	0.18	0.04	0.1	0.04	-

[a] United States Department of Agriculture (USDA), National Nutrient Data Base for Standards Reference Release 27, http://ndb.nal.usda.gov/ndb/search.

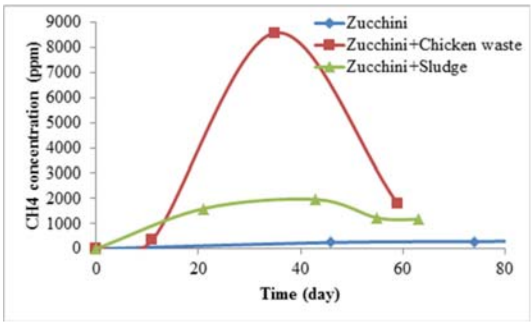

Figure 4-a. Methane gas concentration in the biogas produced from zucchini in the presence of sludge, and chicken dung as an inoculum 35°C.

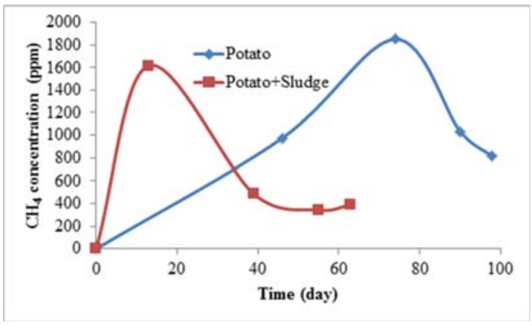

Figure 4-b. Methane gas concentration in the biogas produced from potatoes with and without sludge (T=35°C).

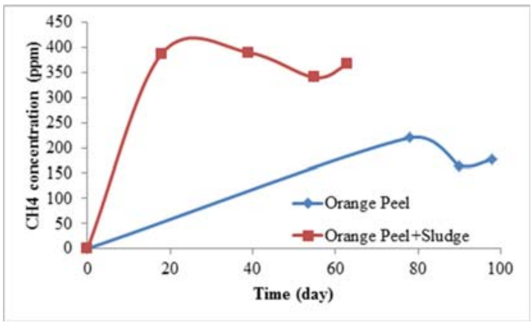

Figure 4-c. Methane gas concentration in the biogas produced from orange peels with and without sludge (T = 35°C).

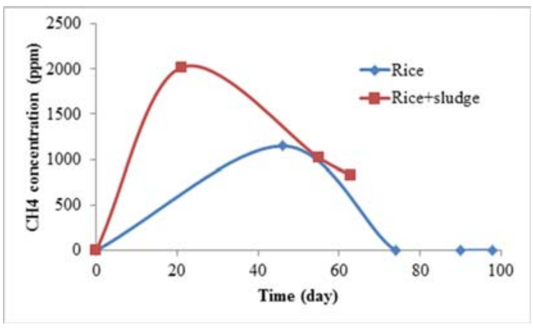

Figure 4d. Methane gas concentration in the biogas produced from rice with and without sludge (T = 35°C).

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