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Experimental Investigation of Biogas Production from Kitchen Waste Mixed with Chicken Manure

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Abstract: Biogas produced from solid kitchen waste (KW) mixed with chicken manure (M) at different mass ratios was investigated. The effect of the ratio of the amount of water to the mixed solid waste on the amount of biogas produced was studied. The results showed that at a fixed ratio of water-to-solid waste, the amount of biogas increased as the amount of chicken M increased. At a fixed M-to-KW ratio, the amount of biogas produced increased as the solid content increased and then decreased, reaching its maximum value at a solid waste-to-water ratio of 1:1. The pH of the bioreactor containing the KW-M mixture dropped with time, resulting in a decrease in the amount of biogas produced. Controlling the pH value by titrating with NaOH solution improved the production of biogas. Investigating biogas produced from sludge showed that the pH of the reactor slightly decreased and then increased slightly. The results also showed that the amount of biogas produced from sludge containing 3% solid waste was larger than the amount produced from sludge containing 6% solid waste.

Keywords: Biogas, Waste to energy, Methane, Renewable energy, Bioreactor, Fermentation, Biodegradation.

بحث تجريبي لإنتاج الغاز الحيوي من مخلفات المطبخ المخلوطة مع روث الدجاج

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الملخص: تم دراسة الغاز الحيوي المنتج من مخلفات المطبخ الصلبة المخلوطة بنسب كتلية مختلفة من روث الدجاج. وتم تتبع نسب المياه المضافة الى هذا الخليط لمعرفة تأثيرها على كمية الغاز الحيوي المنتج. وأظهرت النتائج أنه مع تثبيت نسب المياه المضافة الى المخلفات الصلبة أن كمية الغاز الحيوي المنتج تزداد مع زيادة كمية روث الدجاج. أما عند تثبيت نسب روث الدجاج الى مخلفات المطبخ الصلبة فان كمية الغاز الحيوي المنتج تزداد مع زيادة مخلفات المطبخ الصلبة ثم تبدأ بالتناقص، بحيث تصل الى أقصى قيمه لها عندما تكون نسبة المخلفات الصلبة الى الماء ١:١. كما هبطت درجة الحموضة مع مرور الوقت في المفاعل الحيوي الذي يحتوي على خليط مخلفات المطبخ الصلبة وروث الدجاج، مؤديًا الى انخفاض في كمية الغاز الحيوي المنتج. ولكن عندما تم التحكم بقيمة الرقم الهيدروجيني للحموضة من خلال المعايرة بمحلول هيدروكسيد الصوديوم فان ذلك قام بتحسين إنتاجية الغاز الحيوي. كما إن تتبع الغاز الحيوي المنتج من مخلفات محطة التنقية أظهر أن الرقم الهيدروجيني للحموضة في المفاعل الحيوي قد انخفض قليلًا ثم ارتفع قليلًا. كما أظهرت النتائج أن كمية الغاز الحيوي المنتج من مخلفات محطة التنقية التي تحتوي على مخلفات صلبة بنسبة ٣٪ تكون أعلى من تلك التي تحتوي على مخلفات صلبة بنسبة ٦٪.

الكلمات المفتاحية: غاز حيوي، مخلفات الى طاقة، ميثان، طاقة متجددة، مفاعل حيوي، تخمير، تحلل عضوي.

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1. Introduction

One of the most important factors in human wellbeing is energy. Providing sufficient amounts of reasonably priced energy is necessary to reduce poverty, improve life conditions, and promote living standards. Currently, the main source of energy for the world's industries and individuals is fossil fuel; however, as it is a nonrenewable resource, it is becoming more and more precious. Another concern related to the use of fossil fuels is the environmental pollution it causes, resulting in global warming, and water, air, and soil contamination. As such, enormous efforts are being directed towards using renewable energy sources, mainly solar, wind, and bioenergy, in place of fossil fuels.

Biogas production from solid waste mainly in the form of kitchen waste (KW), has received special attention by governments, societies, and researchers. The literature contains vast amounts of research focusing on biogas produced from a combination of KW, sludge, and agricultural waste and determining the optimum conditions for biogas production.

Liu *et al*. (2008) investigated methane production from a mixture of stover and food waste mixed with activated sludge (inoculums) in a batch reactor under mesophilic (35°C) and thermophilic (55°C) conditions. The effect of the pH and solid content on the biogas productivity was investigated. The results showed that biogas productivity under mesophilic conditions yielded a pH of 7 with a higher solid content. Similarly, biogas produced from grass (cocksfoot, tall fescue, reed canary, and timothy) was studied by Seppl *et al*. (2009). They found that the methane yield per hectare of the first harvest was always higher than that of the second harvest; however, all the grass types were suitable producers of biogas.

Bouallagui *et al.* (2003) studied the production of biogas from fruit and vegetable waste under mesophilic conditions in a semi-continuous tubular digester. The effect of the hydraulic retention time (HRT) and feed concentration on the extent of the degradation of the waste was investigated. The results showed that the biogas produced contained 64% methane. Similar results were found by Lianhua *et al.* (2010) and Sánchez *et al.* (2000). Production of biogas from wastewater sludge was studied by Ferrera *et al.* (2008) under thermophilic conditions in a semi-continuous reactor. Their results showed that biogas production increased by 30% upon pretreatment of the sludge under thermophilic conditions. Noutsopoulos *et al*. (2012) investigated the increase in biogas production by co-digesting lipids in sewage sludge. They found that biogas production increased when the lipid was mixed with the sludge, and the production was proportional to the lipid concentration. The effect of adding fatty acids to sludge on biogas production under thermophilic conditions was studied by Lins and Illmer (2012). It was found that after certain concentrations, fatty acids initially prevented biogas production; however, production then continued. Sludge pretreatment at 70°C in a microwave showed that biogas production could be improved up to 35% (Kuglarz *et al*. 2013).

Castrillón *et al.* (2013) studied methane production from cattle manure (M) supplemented with crude glycerin from the biodiesel industry in a continuously stirred tank reactor (CSTR) and induced bed reactor. The results showed that biogas production greatly depends on the organic loading rate (OLR). Biogas production from whey mixed with poultry M was investigated by Gelegenisa *et al.* (2007a) in a CSTR with an OLR of 4.9g COD/L-d. It was found that biogas production increased by 40%. Similar results were found by Castrillón *et al.* (2011) when glycerin was mixed with cattle M. Biogas production from cow and llama M was studied by Alvareza *et al*. (2006), showing that the llama M gave better results than cow M since it contains a higher volatile solid (VS) content. Biogas production from food waste mixed with animal M was also investigated by Marañón *et al*. (2012); Budiyono *et al.* (2014); and Azadeh and Jalal (2011).

The objective of the current research was to investigate the production of biogas from solid KW mixed with chicken M at different KW-M mass ratios. The effect of the solid content and pH on the amount of biogas produced was also studied. Biogas production from sludge and sludge mixed with KW was also investigated.

2. Methodology

2.1 Setup

One-liter squeeze bottles were used as bioreactors. The required amount of water, solid waste prepared *a priori*, and M were well mixed and placed in the bottles. The bottles' temperatures were held constant at 35 ± 1°C by immersing the bottles in a water bath where the temperature was held constant by an external heater and controller. The bottle mouth was connected to a syringe to measure the volume (V) of the biogas produced over time. Under the assumption that the gas was ideal, the moles of the biogas produced (n) were calculated using the ideal gas law

$$n = \frac{PV}{RT} \quad (1)$$

where T is the temperature, P is the atmospheric pressure, and R is the universal gas constant.

2.2 Materials

A mixture of vegetables and fruits (200 g of cucumber, tomatoes, orange peel, rice, cabbage, apple, and carrot in equal amounts) represented the KW and was used in this study. The vegetables and fruits were cut into small species (0.5 cm × 0.5 cm x 0.5 cm) and mixed with the required amount of chicken was then added as required, and the mixture was well agitated and introduced to the bottles, which were submersed in the water bath.

2.3 Procedure

The effect of the solid content was tested by adding the required amount of water to the KW-M mixture, which was termed as solid (S). The following S-water ratios were tested: 1:0 (100% S; no water added), 3:1, 1:1, and 1:3, hence obtaining a S content of 100%, 75%, 50%, and 25%, respectively.

The effect of the amount of M to the KW was tested by adding certain amounts of M to the KW so that the ratio of KW:M was 1:0, 3:1, 1:1, and 1:3, hence obtaining percentages of KW in the KW-M mixture of 100% (pure KW), 75%, 50% and 25%, respectively.

The produced gas samples were analyzed for methane content using an Eagle gas analyzer (RKI Instruments, Union City, California, USA). The pH of the mixture was measured via a pH meter WTW Wissenschaftlich-Technische Werkstätten GmbH, Weilheim in Oberbayern, Germany). The VS contents were measured according to the standard procedures.

3. Results and Discussion

3.1 Effect of Solid: Water Ratio

The effect of the S: Water ratio on the amount of biogas produced is depicted in Fig. 1. When the ratio of KW: M in the solid mixture was 1:1, the VS content in the solid mixture was 78%. Figure 1 shows that the production rate was fast on the first day and then slowed down, possibly because the acidogensis bacteria degraded the manure faster compared to the vegetables. The fatty acid concentrations increased in the mixture as a result of this step. Accordingly, the pH dropped, reducing the activity of the methanogenic bacteria and, consequently the production of biogas (Beam 2011; Dearman *et al.* 2006; Raposo *et al*. 2006; Xu *et al*. 2002; Yadvika *et al.* 2004). Figure 1 also shows that an optimum S:Water ratio of 1:1 existed at the point where the highest production of biogas was obtained, which is a result similar to that obtained by Gelegenis *et al.* (2007b).

3.2 Effect of KW: M Ratio

The effect of the ratio of KW: M on biogas production when the S: Water ratio equaled 1:1 is depicted in Fig. 2. As expected, the amount of biogas produced increased as the amount of M increased, or as the ratio of KW: M decreased, since M degrades faster than KW. It should be noted that the VS content of the solid mixture (KW + M) was 78%.

3.3 Biogas Production from Sludge

Biogas produced from sludge containing 94% water and 97% water is portrayed in Fig. 3. The sludge was obtained from a nearby waste water treatment plant and contained 94% water. The sludge was then diluted further with water to obtain a saturation level of 97%. The rate of biogas production was faster for the diluted sludge, and a larger amount of biogas was obtained. This result is in accordance with the results obtained by AbdAlaal (2012).

3.4 Effect of pH on the Biogas Production

As the fermentation process proceeds, fatty acids are produced from organic waste by the acidogenesis of bacteria; accordingly, the pH value of the mixture drops. This causes a drop in the activity of the bacteria, especially the ethanogenic bacteria (Dearman *et al.* 2006; Raposao *et al.* 2006; Ryan 2011; Yadvika *et al.* 2004).

A measurement of the pH of the mixture as a function of time during the digestion of the KW-M concoction is shown in Fig. 4. The rate of biogas production was high at the beginning of the process, but after day four it stopped. The pH value, however, dropped from 6.5 to 3.5 and

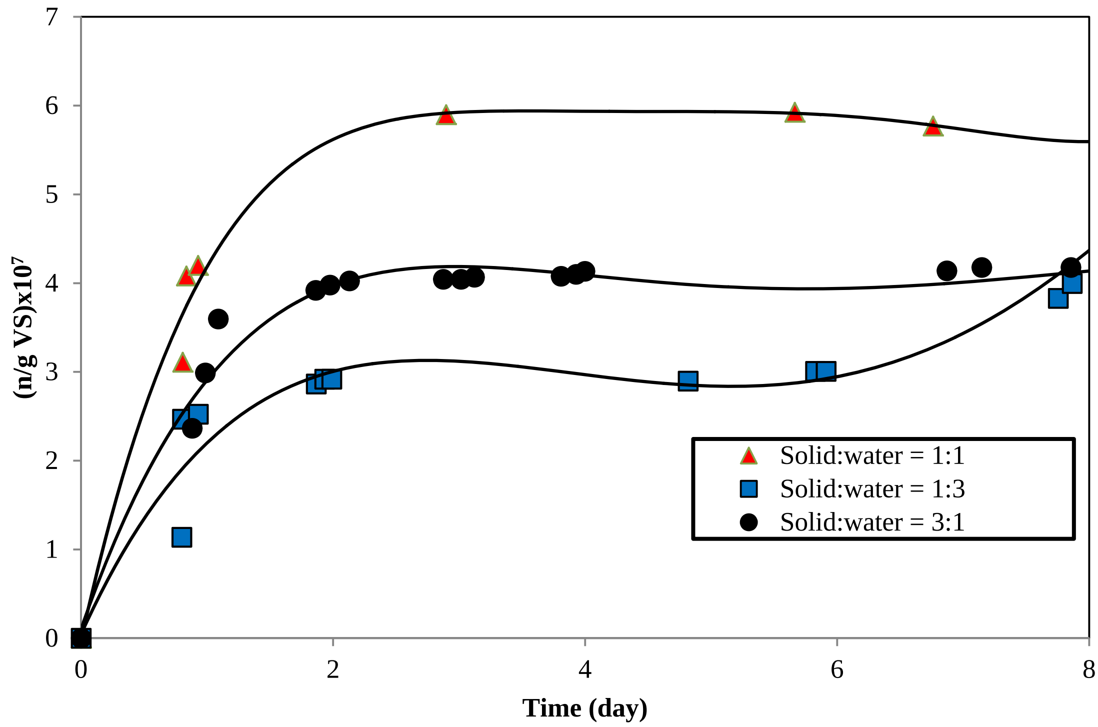

Figure 1. Amount of biogas produced versus time at 35˚C for various solids, water ratios with KW: M ratio of 1:1.

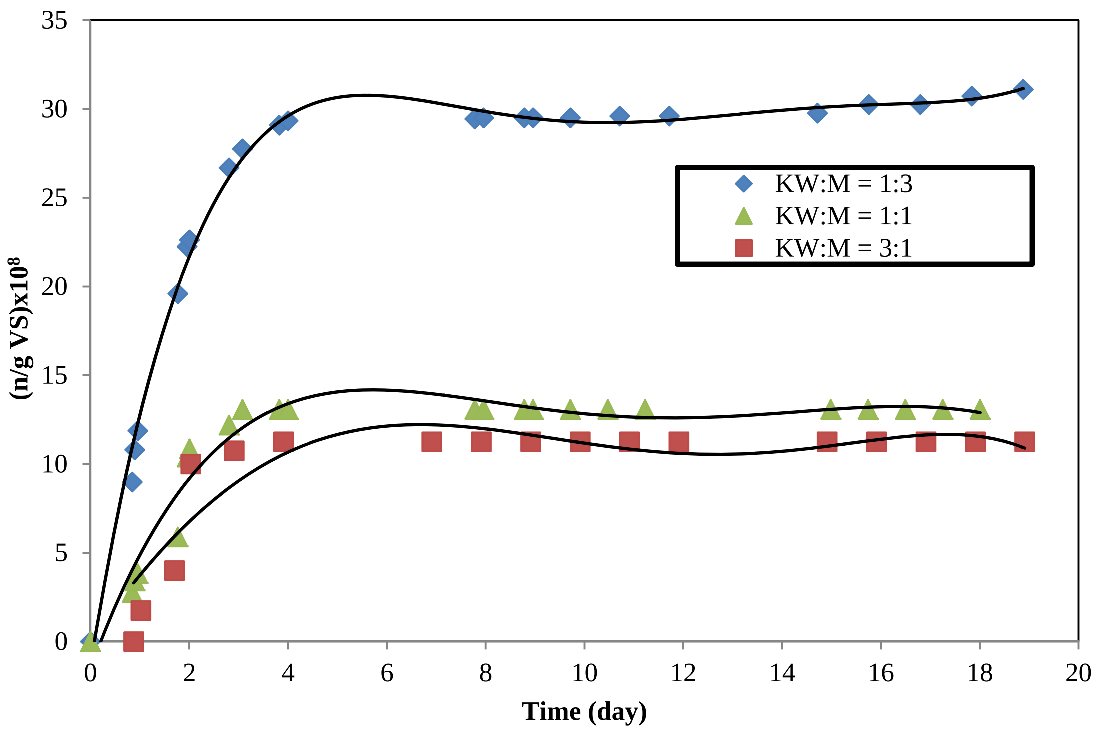

Figure 2. Effect of KW : M ratio on the amount of biogas produced with solid : water ratio of 1:1.

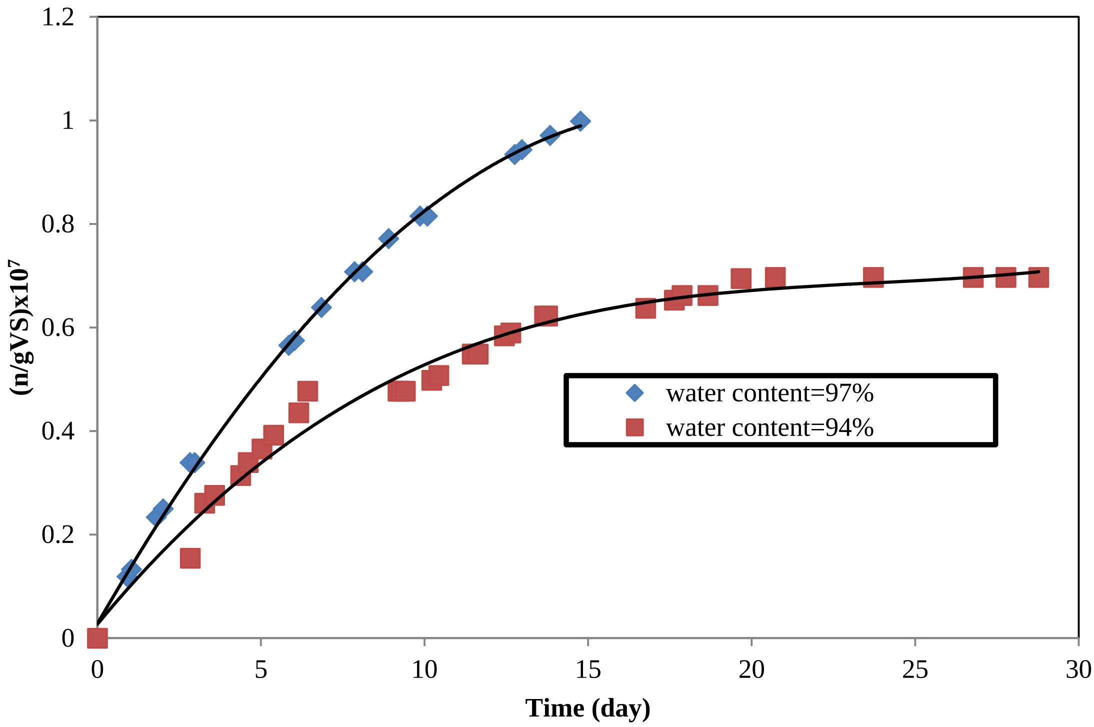

Figure 3. The amount of biogas produced versus time from waste water sludge at 35˚C.

then stopped, indicating that there was no bacterial activity after four days, which also reflected on the biogas production as no biogas was produced after four days.

To study this point further, the same experiment was repeated under the same conditions except that the pH was kept constant at 6 by adding a NaOH solution. The results are illustrated in Fig. 5, where it can be seen that the process of biogas production continued for 12 days and then stopped.

A similar experiment on sludge with a water content of 94% was performed. No effort was made to control the pH. The results are shown in Fig. 6, where it can be seen that the rate of biogas production continued until day 12 after which it slowed down. It can be also seen that the pH dropped slightly after the first day and then slowly increased. This result was different from that obtained for KW-M (Fig. 4) where the pH continuously decreased. This might be attributed to the high amount of water in the sludge sample. This result was in accordance with the results of AbdAlaal (2012) and Kalloum *et al.* (2011). However, the current researchers believe that this point needs further investigation.

3.5 Effect of Temperature

The effect of temperature is shown in Fig. 7 where, as expected, biogas gas production rates increased as the temperature increased. This result is in accordance with other researches' results (Beam 2011; Chua *et al.* 2013).

4. Conclusion

Biogas produced from the anaerobic digestion of KW mixed with chicken M was investigated. The effect of the ratio of KW mass to that of M in a mixture containing a constant amount of water on the production rate of biogas was studied. The results showed that the lower the ratio of KW:M the higher the quantity of biogas that was produced. Investigating the effect of water on biogas production showed that the amount of biogas produced versus the S:W ratio went through a maxima which existed at a S:W ratio of 1:1. Controlling the pH at ~6 resulted in the highest yield of biogas. Acidic or basic conditions negatively affected the biogas production. Sludge with a lower solid content yielded a better biogas production rate. Biogas production at 35˚C was greater than at 25˚C.

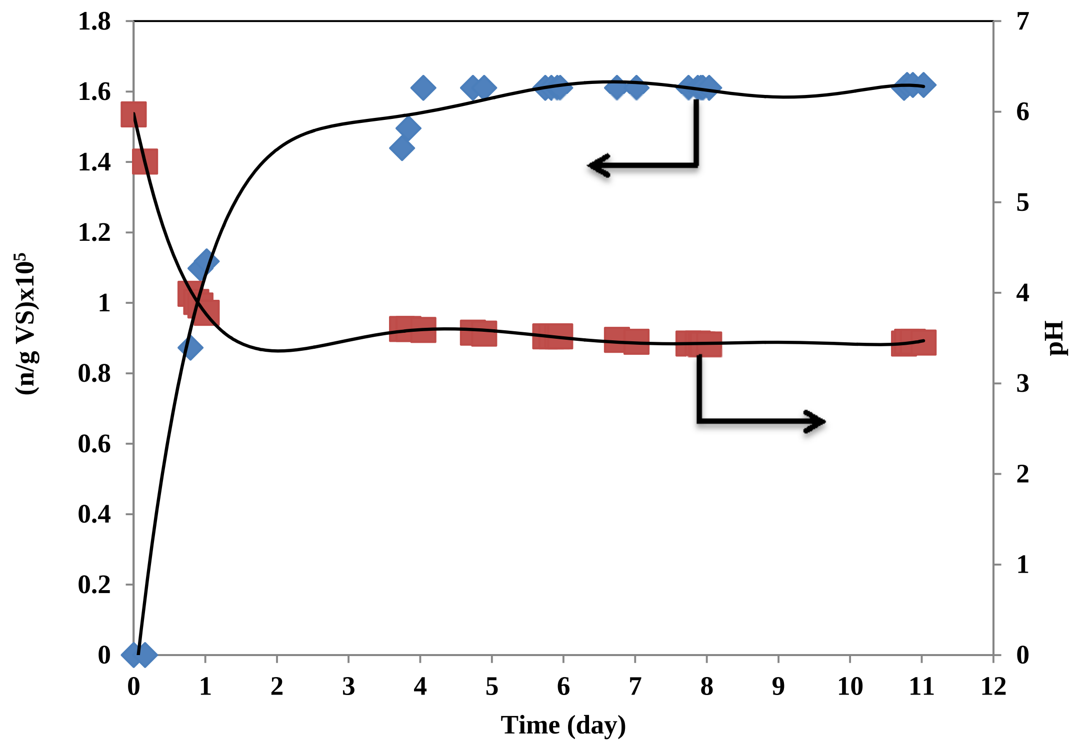

Figure 4. Measured the pH and the amount of biogas produced for KW : M ratio of 1:1 and solid : water ratio of 1:1 at 35˚C.

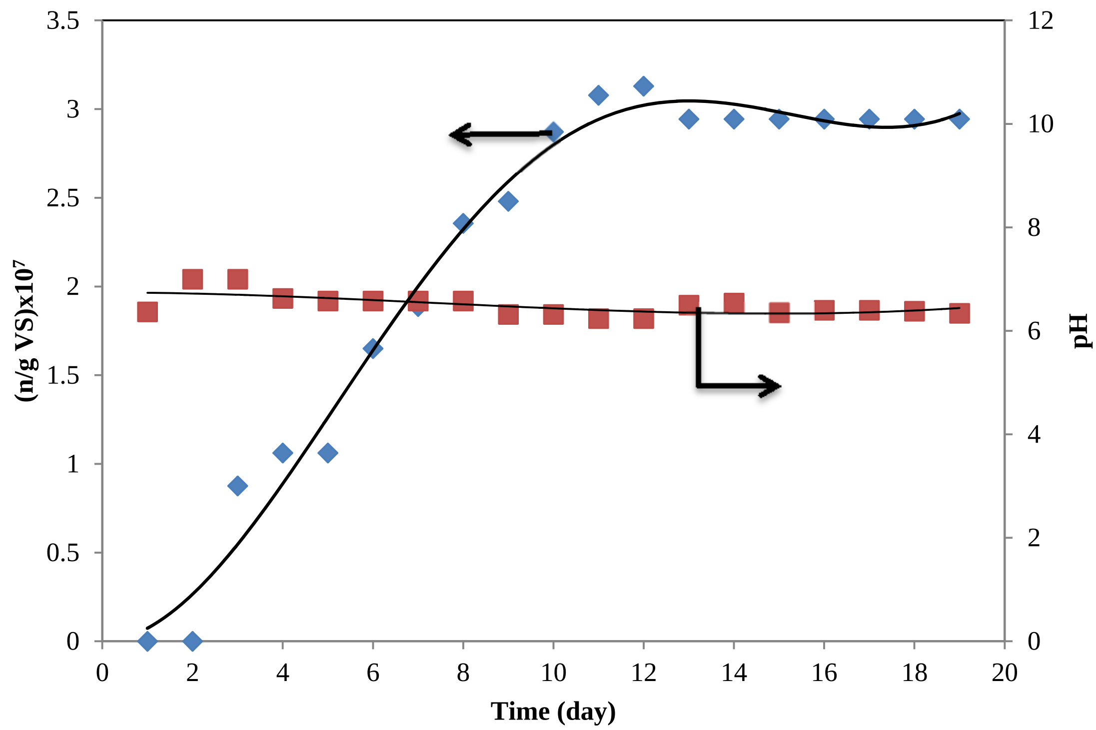

Figure 5. Measured amount of biogas produced at constant pH value for a KW : M ratio of 1:1 at 35˚C.

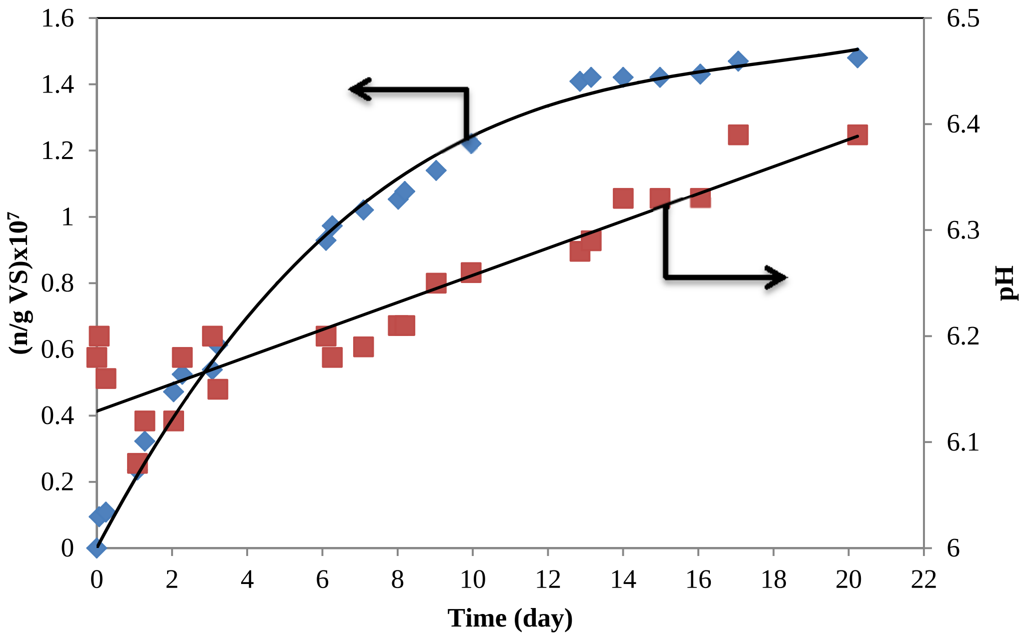

Figure 6. Amount of biogas produce from sludge sample of water content of 94% at T=35˚C.

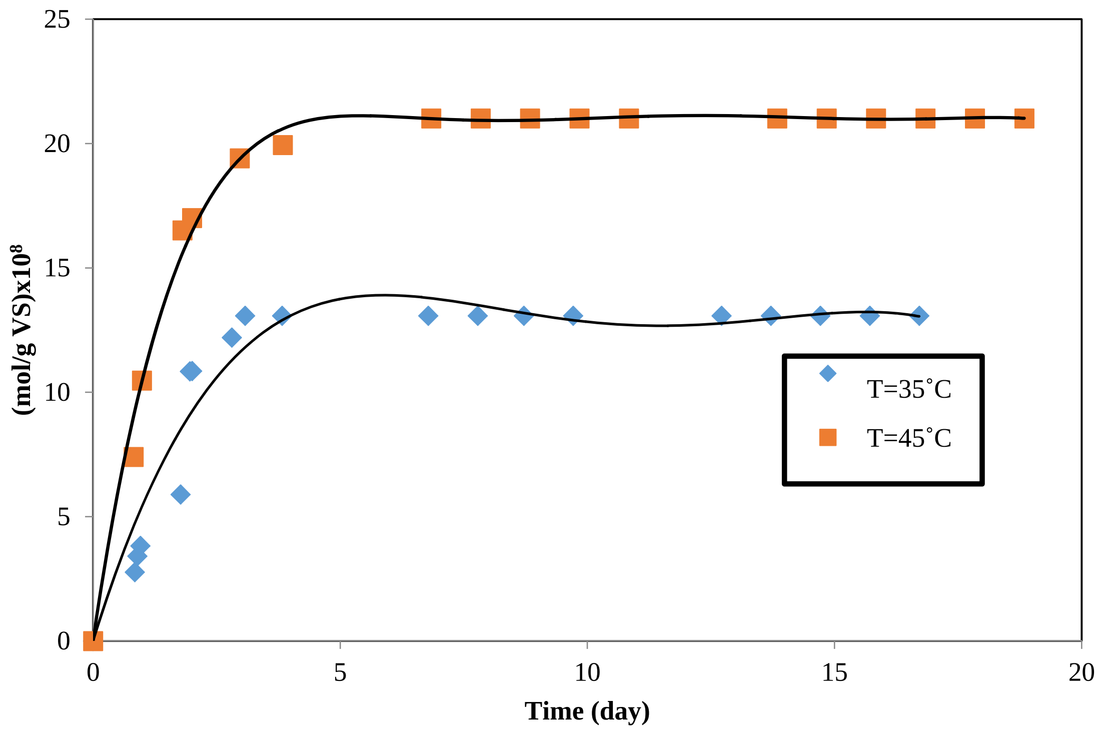

Figure 7. Effect of temperature on the amount of gas produced solid : water = 1:1 and KW : M=1:1.

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