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Study of Biogas Production from Food Waste Using Anaerobic Digestion

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ABSTRACT

The primary goal of this research is to look at the feasibility of food waste biomass (fruits and vegetables) to produce biogas by anaerobic digestion. This study demonstrated the possibility of utilizing sludge and cow manure in energy production rather than being a source of pollution and treating it in natural ways. This study compares inoculums (tap water, 1:1 cows' manure, tap water slurry, and sewage sludge) for the best methane yield with weight ratios 1:1, 1:2, and 2:1 food waste: inoculum. Temperature varied from room temperature to 55◦C to determine the best operating conditions for methane production. The volatility of fatty acids (VFAs) and pH were measured during the experimental work. The results concluded that the cows' manure slurry and the sludge were more effective in increasing the pH than tap water, which ranged from 6.15 to 6.47 and from 5.53 to 6.47 for cow manure and sludge respectively. At the same time, Tap water neither increases the pH more than 5.7 nor produces any gas. The highest amount of methane (4.44%) was obtained by mixing food waste and cow manure slurry at a ratio of 1:1 and maintaining a temperature of 42◦C. Improving the operating conditions such as using a semi-batch reactor and controlling the pH and other parameters is necessary to increase the methane concentration further.

Keywords: Biogas production, food waste, anaerobic digestion, volatile fatty acids, inoculum.

دراسة إنتاج الغاز الحيوي من مخلفات الطعام باستخدام الهضم اللاهوائي

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ملخـــــــص البحـــــــث

الهدف الأساسي من هذا البحث هو النظر في جدوى الكتلة الحيوية للمخلفات الغذائية (الفواكه والخضروات) لإنتاج الغاز الحيوي عن طريق الهضم اللاهوائي. بينت هذه الدراسة إمكانية الاستفادة من الحمأة وروث الأبقار في إنتاج الطاقة بدلا

من كونها مصدر التلوث ومعالجتها بطرق طبيعية. تقارن هذه الدراسة خلط المخلفات الغذائية مع ماء الصنبور مرة وروث الأبقار (المختلطة مع الماء بنسبة 1:1) وكذلك مياه الصرف الصحي مرة اخري بتراكيز مختلفة بنسبة (1:1 و1:2، و2:1 نسبة وزنية) لمعرفة أفضل خليط لإنتاج غاز الميثان. كما تم دراسة تأثير درجات الحرارة على هذه العملية وهي (درجة حرارة الغرفة و42 و55 درجة مئوية) لتحديد أفضل ظروف التشغيل لإنتاج الميثان. كما تم قياس تركيز الأحماض الدهنية (VFAs) ودرجة الحموضة (pH) أثناء العمل التجريبي. وخلصت النتائج إلى أن روث الأبقار والحمأة كانا أكثر فعالية في زيادة الرقم الهيدروجيني من ماء الصنبور الذي تراوح من 6.15 إلى 6.47 ومن 5.53 إلى 6.47 لروث الأبقار والحمأة على التوالي. وفي الوقت نفسه، لا يزيد ماء الصنبور درجة الحموضة أكثر من 5.7 ولا ينتج أي غاز. تم الحصول على أعلى كمية من الميثان (4.44%) عن طريق خلط فضلات الطعام وروث البقر بنسبة 1:1 والحفاظ على درجة حرارة 42 درجة مئوية. لزيادة تركيز الميثان بشكل أكبر، من الضروري تحسين ظروف التشغيل مثل استخدام مفاعل نصف دفعة والتحكم في الرقم الهيدروجيني والمعلمات الأخرى.

الكلمات الدالة: إنتاج الغاز الحيوي، مخلفات الطعام، الهضم اللاهوائي، الأحماض الدهنية المتطايرة، اللقاح.

1. Introduction

The proper disposal of solid waste is a major issue that affects both urban and rural areas worldwide. It is crucial that ensure that adequate waste management practices are in place [1]. Organic wastes cause adverse environmental and health problems such as pathogen contamination, odor, airborne ammonia, greenhouse gases, etc. At the same time, Management waste in developing countries often includes methods that have significant drawbacks including contamination of soil and groundwater, environmental pollution, and impact on human health like landfilling, incineration, and unscientific dumping [2], [3]. One of the solid waste management systems is to convert the waste to biogas, which is then converted to energy (heat or electricity) [4]. Biogas production is a key technology in the development of sustainable energy supply systems that aims to cover the energy demand using renewable sources and mitigate greenhouse gas emissions [5]. Biogas has promising potential for power generation using biomass sources at low costs for domestic and industrial scales [6]. Anaerobic digestion (AD) is used to produce biogas from organic resources and is a significant contributor to the global food waste problem. A viable option to improve methane production is through (AD) of two or more waste materials such as sewage sludge with fruit and vegetable wastes. Anaerobic digestion includes four key biochemical stages, which are hydrolysis, acidogenesis, acetogenesis, and methanogenesis [7]. The biogas production is affected by some parameters such as temperature, feed-sock, HRT, pH etc [8]. Also, the efficacy of the digestion process varies depending on the substrate and inoculum used, as well as the mixing of the feedstock [9]. The purpose of this research is to explore methods for decreasing pollution caused by solid bio-waste, such as fruit and vegetable waste (FVW), wastewater sludge (WS), and cow manure (CM), through the use of anaerobic digestion. The study will investigate how certain parameters affect the production of biogas from this bio-waste.

2. Materials and Methods

Lab-scale experiments will be operated in the Specific Training Center for Oil Industries in Zawia city. A lab-scale experiment will be in batch mode and fabricated using 27 digesters made of glass. The setup of this study is described in detail in the following sections:

2.1 Experiment Design

In the design step, it was important to choose the right design to prevent leakage or breakage problems. Glass containers were used as digesters, with a net capacity of 700 g and a well-fitted iron lid. Holes were made through the lid to fix a copper tip where plastic tubes fitted and connected to plastic bags. The plastic bags have valves that make the gas flow easily from the digester to the bag when it is in its open state. The glass containers that were used as digesters were sanitized at 70◦C for about 2 hours, then the gas bags were connected to the digesters through the plastic tubes as shown in Figure 1. The glass containers were covered with aluminum foil to prevent light from entering.

Figure 1. Glass Container.

2.2 Food Waste Collection and Preparation

Food waste Samples were collected from kitchens and vegetable and fruit markets, which generally included: cabbage, potatoes, tomatoes, cucumber, lettuce, beetroot, kiwi, mango, banana peels, watermelon, and apple. The samples were then stored in the fridge at 4ºC until the start of the experiments. Before the food waste is mixed with the inoculums, it should be shredded using the food processor to provide small particles, which leads to faster digestion.

2.3 Feed-stock Preparation

The experiments were conducted with a variety of additives and mixing ratios. Three additives were used, including tap water, sewage water, and a slurry of cow manure and tap water with a 1:1 weight ratio. All the additives were mixed with the food waste in three weight mixing ratios (1:1, 1:2, and 2:1), and each run included three digesters. The total load was 350 g so the amount of food waste was mixed with the additives used, as shown in Table 1.

2.4 Running the Experiments at Different Temperatures

After that, all the digesters with the different mixing ratios were kept at room temperature and water baths were used to provide temperatures of 42˚C and 55˚C.

2.5 PH and VFAs Measurement

A combo pH-EC meter was used to measure the pH of the mixtures inside the extra digesters, which were prepared for daily pH observation. During each run, 50 g of filtered samples were taken from the extra digesters to measure the level of pH using an electronic pH meter.

Table (1): Anaerobic digestion batches.

Mixing ratio	Food wastes (g)	Cow manure (g)	Sewage sludge (g)	Tap water (g)
1:1	175	175	175	175
1:2	116.66	233.34	233.34	233.34
2:1	233.34	116.66	116.66	116.66

The daily value of VFAs for the filtrated samples was evaluated for each run using a titration method with sulfuric acid (0.1N). The pH of the filtered 50g sample was measured, then mixed with 50 ml of distilled water, and the pH was recorded again. Sulfuric acid was added to the sample slowly, and well-mixing was achieved using a magnitude stirrer. The pH was monitored, and the amount of sulfuric acid consumed to change the pH to 4.4 was evaluated. The total volatile fatty acids (tVFA) as digestion monitoring information was also determined. The values of tVFA will be calculated using Nordmann's empirical Eq (1) [9].

$$tVFAs = (20/A \times B \times 1.66 - 0.15)\,500 \qquad (1)$$

where:

A: The volume of the sample used (mg).
B: The volume of acid (0.1 N H_2SO_4) used to go from pH 5 to pH 4.4 (mg).

2.6 Biogas Analysis

The gas collected from the digesters was then analyzed using the gas chromatograph to determine the methane concentration, which is the key to optimum conditions. The sample for biogas analysis was taken at the end of the experiment. It was carried inside the gas bag of size 0.5 liters and analyzed by the natural gas analyzer device, model No. CP 3800.

3. Results and Discussion

3.1 The Effect of Temperature and Different Feed Stock

Temperature plays an important role in controlling the anaerobic digestion processes. The change in temperature leads to a change in the pH and tVFAs depending on the mixing ratio and the feed used.

3.1.1 The Effect of Temperature and Different Feed Stock on the pH

Through laboratory-scale work, three feedstocks were used. The main component used as a substrate (S) was food waste, which consisted of vegetables and fruits. The other additives that worked as inoculums (I) were tap water, cow manure, and sewage sludge with a neutral pH. Figure 2, clarifies the effect of the additives and the temperature on the pH of the mixtures used as feedstocks.

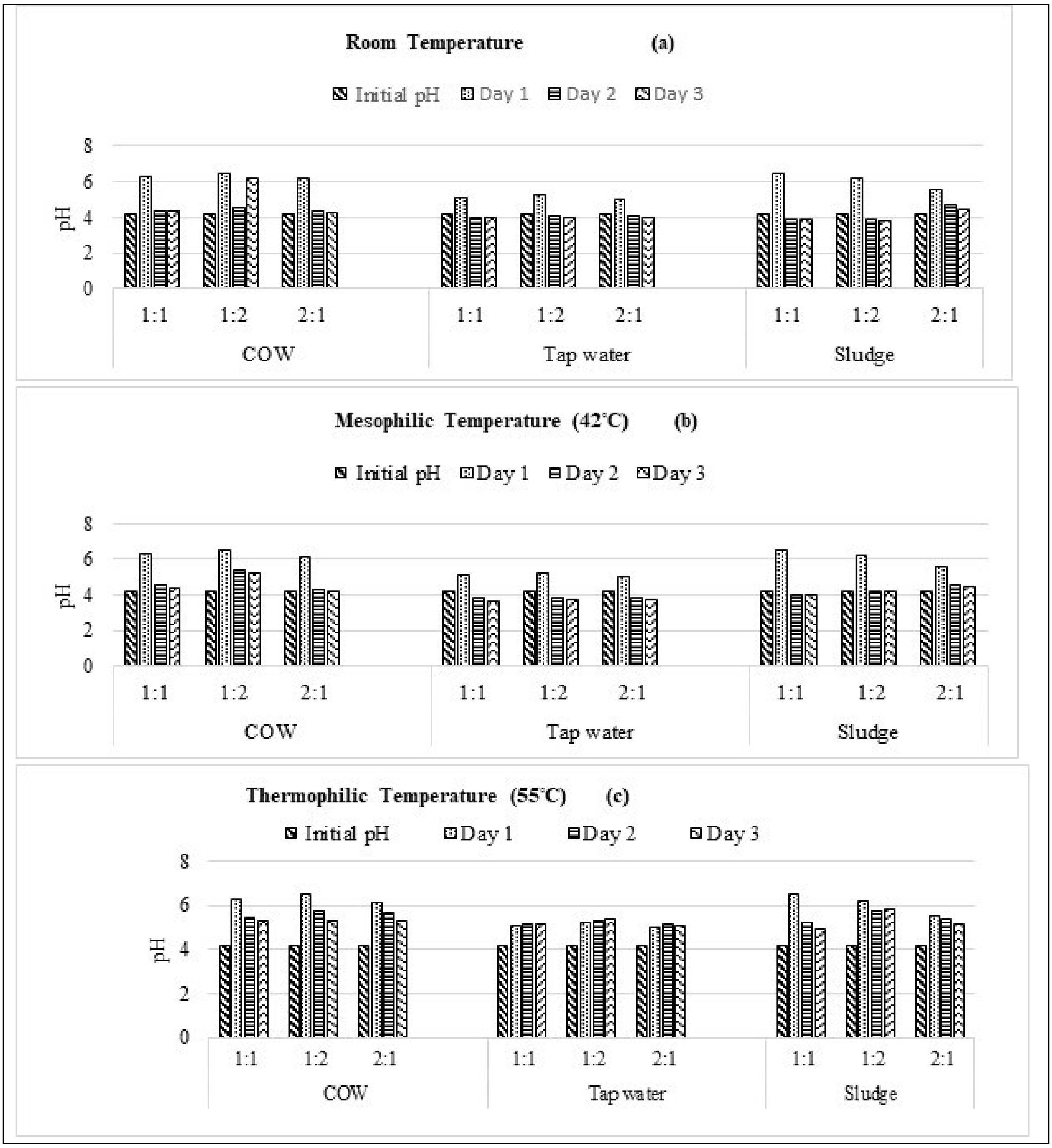

Figure 2. The Effect of temperature on the pH of different mixtures and different Compositions.

From the results indicated in Figure 2, it is clear that the effect of adding all inoculums increased the pH level of food waste, which was naturally 4.18. The greatest pH value was 6.47 for both the cow mixture at 1:2 and the sludge mixture at 1:1. The other mixtures pH exceeded 6 except for the sludge at 2:1, which was 5.53. In general, the majority of the pH decreased very quickly for all mixtures and at all different temperatures.

This decrease in pH continued until the third day and ranged from 4.48 to 3.8 for all mixtures except the cow mixture, which was 6.19 with a ratio of 1:2 for room temperature ranging between 27 and 32 ◦C as shown in Figure 2 (a). Figure 2 (b) for mesophilic (42 ◦C) represented that the pH ranged from 3.61-3.72, 3.96-4.47, and 4.23-5.22 for tap water, sludge, and cow manure mixture, respectively, for all concentrations. With the thermophilic temperature of (55 ◦C), the pH was higher than other temperatures, which were almost more than 5. pH for this temperature range between 4.95 and 5.81, as shown in Figure 2 (c). All the following conditions of strong acidity may cause none of the soluble acids to be converted to acetic acid and further to methane, as stated by Wang K, et al [10]. Methanogenesis is more sensitive to pH levels as Paramaguru et al stated [11]. Banks & Lo reported that a pH range from 6.0 to 8.5 enhances VS degradation and methane production [12].

3.1.2 The Effect of Temperature and Different Feed Stock on tVFAs

Volatile fatty acids are generated during anaerobic digestion during the middle stages (acidogenesis and acetogenesis) as microorganisms interact to transform the organic matter first into intermediate products (VFAs) and finally into biogas [13]. The tVFAs production is influenced by the pH. As a sequence of the significant effects of temperature on the pH. Figure 3 shows the productivity of tVFAs at different temperature ranges.

Figure 3 (a) shows the variation in VFAs concentration in the digesters at different pH conditions at ambient temperature. Generally speaking, under all pH conditions, the concentration was high at first and then relatively stable and changed little. The maximum VFAs concentrations were found on the first day for the sludge mixtures, and the tVFAs were 13537, 9885, and 7395 mg L-1 for mixing ratios 1:1, 1:2, and 2:1 respectively. Also, for cow mixtures 1:1 and 1:2, the tVFAs were 4573 mg L-1. Whereas it was 4241 mg L-1 for 2:1. The cow 1:2 experienced an increase in pH on the third day, resulting in tVFAs growth to 9221mg L-1. indicating that the greatest productivity occurred at pH 5.5 and above, which was similar to Lim et al. [14]. The VFA concentration was low when the pH was lower than 5.5, as happened in water mixtures on all days. Also, on the second and third days, the pH was in the range between 3.8 and 4,71 for all sludge mixtures and with the cow mixtures at 1:1 and 2:1. This is because VFAs are undissociated at this low pH. This inhibits microbial growth. Figure 3 (b) demonstrates the effect of mesophilic conditions on the tVFAs' productivity. The tVFAs for sludge and cow mixtures with all mixing ratios were higher than 4000 mg L-1 with a pH higher than 5. The maximum tVFAs concentration obtained from the sludge was for a mixing ratio of 1:1, where it was found to be 13537 mg L-1. In contrast, the total acid productivity of the tap water mixture was the lowest. The maximum concentration was obtained from the mixture with a mixing ratio of 2:1 at 2083 mg L-1 while the other mixtures produced fewer acids. On the second day, the acids are consumed in the methanogenesis step. The exception was for cow mixture 1:2, which increased to 9885 mg L-1 as the pH was higher than 5, and considered to be optimum to produce more acids. The final pH values were lower than 5 and the tVFAs continued to diminish to less than 4000 mg L-1 for all feeds and mixing ratios.

From Figure 3 (c), it is clear that the mixtures of cows and sludge could produce large quantities of volatile fatty acids throughout the experiment days. This is due to the pH of these mixtures, which allows the production of acids. Also, the effect of thermophilic temperature was clear on the second day of the experiment. The production of acids increased for cows and sludge mixtures with mixing ratios of 1:2 and 2:1. The highest value of acids was for the mixture of sludge 1:2, which increased tVFAs to 15197 mg L-1. However, the matter was different for the sludge mixture 1:1, which recorded a slightly lower value than on the first day. The matter was completely different for the water mixtures, as the number of volatile fatty acids during the experiment was low and the production levels did not exceed 2348.6 mg L-1. It was low from the beginning and witnessed a slight increase with a slight increase in the pH concentration. This can be explained by the fact that the concentration of carbohydrates, proteins, and fats was low due to their low concentration in fruits and vegetables, the main components of the mixture, and also because the added water did not contain these components.

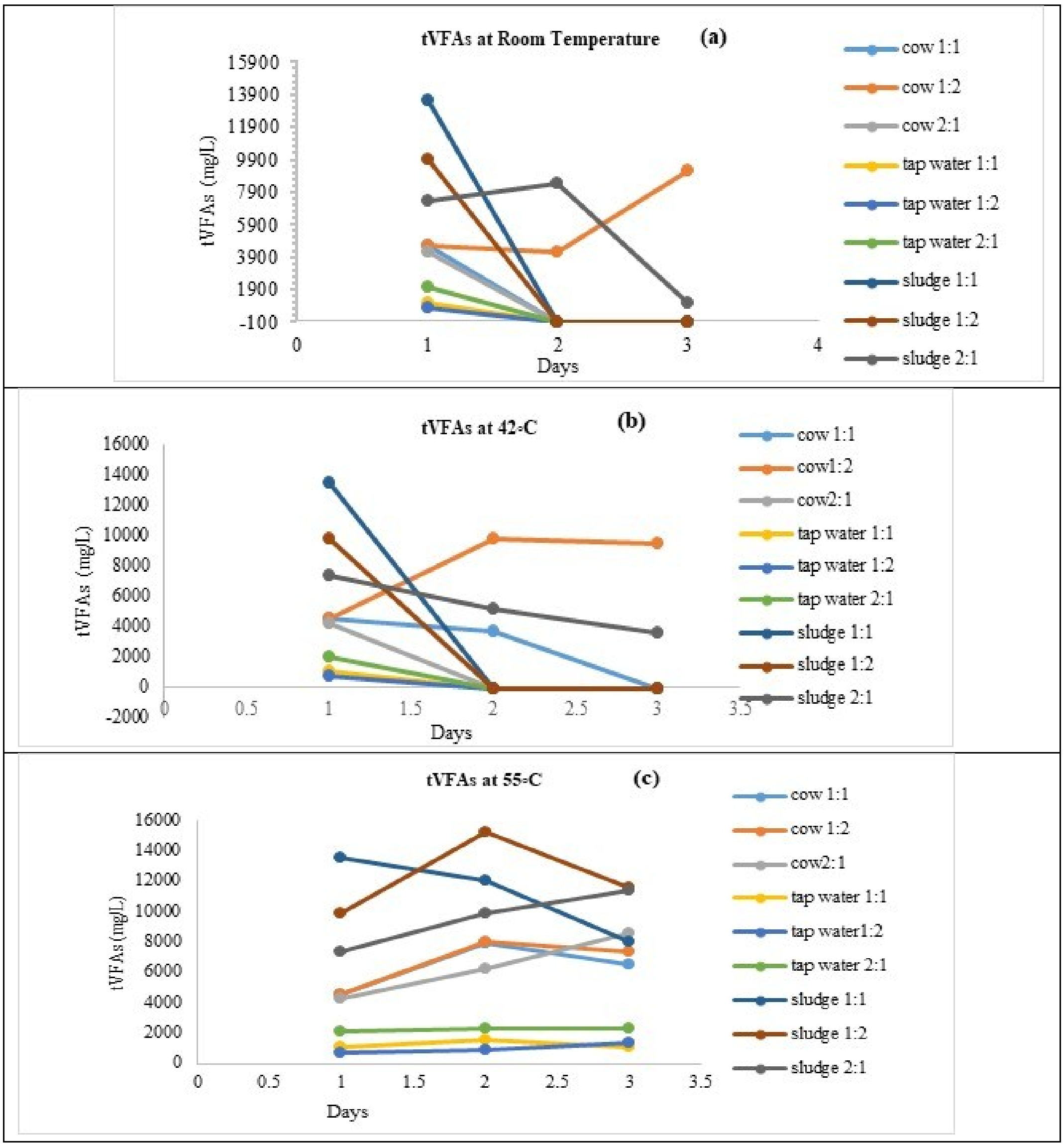

Figure 3 (a, b, c). The Effect of Temperature and Different Feed Stock on tVFAs.

Also, during AD, protein degradation results in the release of ammonium and free ammonia into the medium. According to a study by Jose Antonio Magdalena et al., these compounds are toxic to methanogenic archaea, which promotes the accumulation of VFAs [13].

3.2 Biogas Analysis Result

From Figure 4, it is obvious that at room temperature, the gas was obtained from all sludge mixtures and only from the cow mixture with a concentration ratio of 1:1. The maximum gas concentration was obtained from the cow mixture at 1:1. Maybe due to the value of tVFA produced being lower than 1000 mg L-1 and the pH being higher than 6, where the accumulation of methane was 1.188%. At mesophilic temperature (42°C), the methane was produced only from the cow and the sludge mixture with a concentration ratio of 1:1. At thermophilic conditions, the gas was produced only from the cow mixture at 1:1 and the sludge mixture at 1:1 and 1:2. During the experiment, the results indicated that the highest concentration of methane production was from a cow mixture with a concentration ratio of 1:1 at mesophilic temperature (42°C) which was nearly 4.5%. This means that operating in the middle range (37–42 °C) has a relatively higher gaseous yield and good process stability. These results were consistent with the results of the study conducted by Theodorita Al-Saidi T., et al [15]. On the other hand, the thermophilic conditions allowed the cow (1:1 ratio) to produce only 1.067% of methane. This may be because of the high reaction rate of acidogenesis in the thermophilic process involving accumulation of acids in the digester and inhabit the methanogens step which led to lower methane concentration that is consistent with what was stated by Akuzawa, M., et al [16].

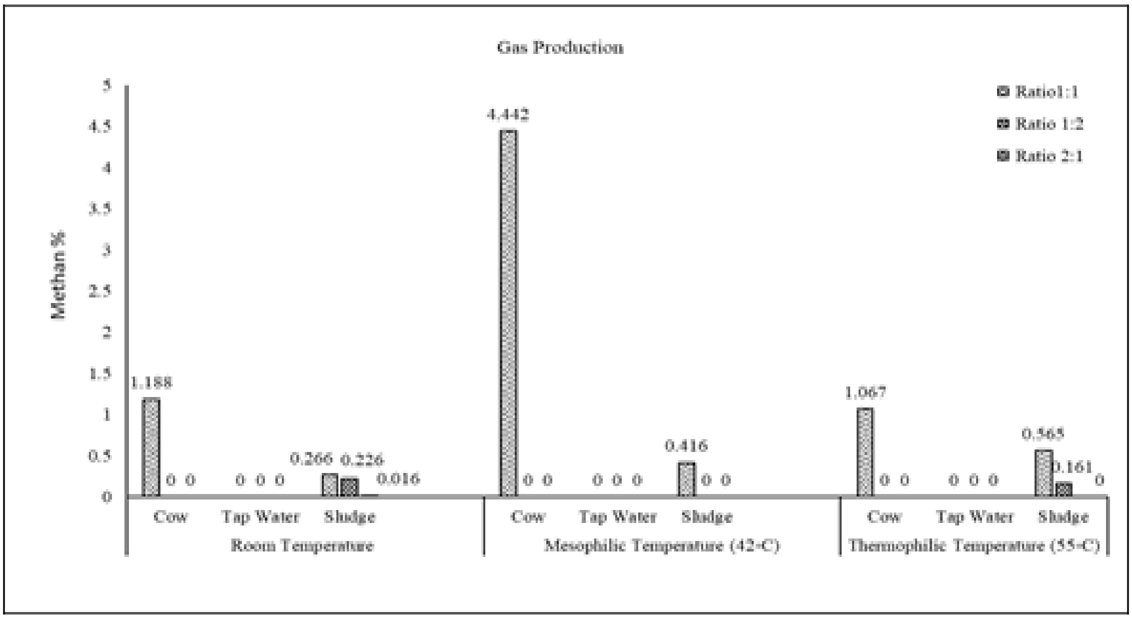

Figure 4: Gas chromatography results.

Despite the fact that the percentage of methane in sludge mixtures was very low. An imbalance between acidogenic and methanogenic organisms during anaerobic digestion can result in increased accumulation of volatile fatty acids, decreased reactor pH, and inhibition of methane-producing Archaea [17]. The accumulation of volatile fatty acids and a drop in pH result in process failure and a 22-fold decline in cumulative methane production. In the failure phase of methane production, the syntrophic and methanogenic activities of the anaerobic digester microbiota are disrupted by a significant decrease in the abundance of syntrophic populations such as Syntrophomonas, Syntrophorhabdus, Sedimentibacter, and Levilinea, and the phylum Euryarchaeota. Bioaugmentation of the failed digesters by adding bacterial along with the adjustment of pH resulted in the prompt recovery of methane productivity with a 15.7-fold higher yield and sped up the rate of degradation of a contaminant [18]. Also, Wanli Zhang et al., enhanced digesters under VFA inhibition by controlling single ecological factor pH at 6.5, 7.0, and 7.5. Maximum methane recovery was obtained with pH control at 7.5 [19].

The food waste can be digested anaerobically using a 1:1 sludge mixture at thermophilic temperature as the methane concentration was the best with 0.565 % of methane. The percentage was lower for sludge 1:2 with only 0.161%. That follows what Muhammad Shahbaz reported, that the lower biogas production from a high mixing ratio digester reflected the inappropriate balance of anaerobic microbes to organic substrate present in the digester bottles [20]. Talking about food waste and tape water mixtures, it was observed that due to the high acidity which leads to the accumulation of total volatile fatty acids none of the food waste and tape water mixtures converted to biogas. However, in this study, the highest accumulative yield was obtained from cow mixture at a mixing ratio of 1:1. which confirms the research conducted by Aakash Khadka [21]. Aakash proved that the highest production yield was obtained at the mixing ratio of 1:1, which is substantially higher, possibly due to the reactive nature of readily biodegradable FW used in this study. The results obtained in this study signify that the mixing ratio can be crucial in obtaining higher energy recovery from the AD of FW.

4. Conclusions

The results indicated that all additives affect the pH, which was raised higher than 5. The addition of cow manure slurry and sludge allowed the production of methane, but the mixture with the addition of tap water did not produce any methane. The mixture of food waste and cow manure slurry in a ratio of 1:1 at a temperature of 42 ºC is the best in terms of methane productivity, which reached approximately 4.5% when the pH was higher than 6 and the concentration of volatile fatty acids was lower than 4000 mg L^{-1}. In general, raising the efficiency of methane production may be achieved by adding bioaugmentation by adding bacteria along with the adjustment of pH and using a semi-continuous system.

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