The effect of pH adjustment together with different substrate to inoculum ratios on biogas production from sugar beet wastes in an anaerobic digester

MISAGH KERAMATI[1] **AND HOSSEIN BEIKI**[2]

[1,2] *Department of Chemical Engineering, Quchan University of Technology, 94771-67335, Quchan, Iran*
[*] *Corresponding author: hbeiki@qiet.ac.ir*

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The effect of pH adjustment together with substrate to inoculum ratio on biogas production from sugar beet wastes, which are chopped parts of the sugar beet that do not go through the sugar extraction process, was investigated in a lab-scale batch reactor. The pH was set on 7, 8, and 9 for the first 4 days and 0.5:1, 1.5:1, and 2.5:1 substrate to inoculum ratios were used at the same time. There was one sample without pH adjustment for each substrate to inoculum ratio. The results showed that sugar beet wastes have good potential for biogas production. Whilst there was no biogas production in 2.5:1 substrate to inoculum ratio, pH adjustment made it possible to generate biogas. pH adjustment on 7 lead to approximately 1.87 and 10.48 times higher specific biogas production in 0.5:1 and 1.5:1 substrate to inoculum ratios, respectively. Methane content from anaerobic digestion of sugar beet wastes slightly increased with substrate to inoculum ratio increasing. The highest specific biogas production was recorded at a 0.5:1 substrate to inoculum ratio and pH adjustment on 7. © 2017 Journal of Energy Management and Technology

keywords: *biogas; anaerobic digestion; sugar beet wastes; pH adjustment.*

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1. INTRODUCTION

As industrialization continues globally, countries and organizations have to deal with more industrial and agricultural wastes. This issue is specifically bolder in food processing companies such as sugar factories. In Iran alone there are 28 sugar factories producing 60% of the country's annual sugar demand [1]. This amount of produced sugar beets results in large amounts of wastes. Conventional ways of treating these wastes are using them as cattle feed or dumping them in landfills [2] while there are better options to deal with this valuable waste.

On the other hand, with fossil fuel supplies being finite, finding and using renewable and eco-friendly sources of energy is a must [3, 4]. Many researchers have worked on finding new energy sources and fuels [5–8]. A lot of these efforts were dedicated to biogas production from food wastes [9–16].

Anaerobic digestion (AD) is described as the process of degrading complex organic matter in the absence of oxygen [17]. AD has been referred to as an attractive technology which converts organic solid wastes such as food wastes, animal manure, and municipal wastes into a value-added product called biogas [11]. Using AD leads to less agricultural and industrial pollution and offsets the usage of fossil fuels at the same time [18].

In addition, sugar beet has been reported to have good potential for biogas production, mostly due to good biodegradability and high sugar content [2, 9, 13, 19, 20]. Hutnan et al. [2] worked on biodegradation of sugar beet pulp in a lab scale reactor. Their work resulted in a 0.360 m3/kg methane yield. For the purpose of investigating biogas production of sugar beet pulp in a pilot scale, Hutnan et al. [21] employed a two-step process. The first step (acidogenic reactor) and the second one (methanogenic reactor) were 5.13 m^3 and 3.5 m^3 large. The average specific biogas production yielded was 0.391 m^3 per kg of dried beet pulp. They also acquired a methane content of 60-70%. By co-digestion of exhausted sugar beet cossettes with pig manure, Abudi et al. [9] reached an optimum methane production rate and volatile solid reduction of 2.91 LCH4/LReactor and 57.5% respectively. Their reactor was made of stainless steel with agitation at 12 rpm. The temperature was set on 37±0.5oC in all their experiments. Montas et al. [20] studied anaerobic co-digestion of sugar beet pulp lixiviation (SBPL) and sewage sludge (SS) in batch reactors with different temperature regimes and SS to SBPL ratios. They reported that methane production is higher in mesophilic thermal conditions than in thermophilic ones. Suhartini et al. [22] noted that mesophilic thermal condition resulted in higher biogas and methane production and mesophilic reactors were also able to perform at higher organic loading rates. Whereas, thermophilic thermal condition showed signs of instability. Using sugar factory waste water with beet-pulp enhances the biogas production resulting from AD of sugar beet pulp [19]. Fang et al. [13] investigated co-digestion of sugar beet leaves, sugar beet tops, sugar beet pulp and desugared molasses with cow manure. They stated that all these sugar beet by-products are easily degradable to biogas. Meanwhile, using cow manure as co-substrate provides nutrients and buffer capacity to the substrate and helps the process. Many researchers have worked on biodegradability of sugar beet by-products but to the best of our knowledge, there have been no studies on sugar beet wastes (SBW). In this paper, SBW refers to chopped parts of the sugar beet that do not go through the sugar extraction process and are conventionally used as cattle feed or dumped in landfills.

A tremendous number of studies were dedicated to AD of food wastes [9,10,13,16,23]. One of the main problems in AD is the pH drop which leads to less biogas production and inhibits methanogens 12, 16. Yang et al. 16 inspected the effect of pH adjustment on biogas production from food wastes in 500 ml reactors. They adjusted the pH in [3] reactors on [7–9] during the first five days of the process. There was also a control sample. They reported that pH adjustment caused an enhancement in reactor performance. The highest methane yield and methane content were achieved from reactor with a pH set on 8 with 171.0 mL/g TS and 53.1% respectively. These amounts were 7.57 and 5.06 times higher than the control sample. Zhang et al. 24 also stated that pH adjustment has helped the biogas production and yield while co-digesting yard wastes together with food wastes. In a similar effort Dai et al. 25 initially adjusted the pH values on [4–13]. They reported pH [12] to be the optimum initial pH adjustment for co-digestion of waste activated sludge and perennial ryegrass. Their results showed a 1.5 and 3.8-fold increase in maximal methane production compared to those of sole waste activated sludge and sole perennial ryegrass, respectively. On a similar effort, by adjusting the pH value on 6.5 for the first 8 days of AD of municipal solid waste, a 67% increase was observed in biogas production [24]. The present study tried to fill a gap in the literature by investigating the effect of initial pH adjustment effect alongside with different substrate to inoculum (S/I) ratios on biogas production from SBW in lab-scale anaerobic digesters.

Bouallagui et al. reported that feed concentration was a limiting parameter [14]. They observed that high feed concentration inhibits the activity of methanogenic organisms and accelerates the growth of non-methanogenic organisms, especially the acidogenic ones. For this purpose, finding the optimal S/I ratio can be of significant importance and inhibit the process if not taken into account. The present study aims to investigate the effect of S/I ratio together with pH adjustment in order to find the suitable conditions for anaerobic digestion of SBW.

2. MATERIALS AND METHODS

A. Sugar beet wastes and inoculum

Due to unavailability of fresh sugar beet in all months, sugar beet needed to be stored at $4oC$ [9,10] for the purpose of our study. Ohuchi et al. [25] reported that storing sugar beet doesn't have a noticeable effect on biogas production. Five-month-stored sugar beet was used in this experiment. Sugar beet was washed and chopped (as done in sugar factories). Then the waste parts in root were chopped into semi-cubic pieces smaller than 1 cm in size.

Anaerobic sludge was collected from the wastewater treatment plant (WWTP) of Quchan Industrial Town. The physiochemical characteristics of inoculum and sugar beet are mentioned in Table 1.

Table 1. Physiochemical characteristics of substrate and inoculum

-	TS(mg/L)	DM (%)	VS(mg/L)	VS(%)
SBW	-	43.46	-	95.68
Anaerobic Sludge	24,500	-	14,300	58.37

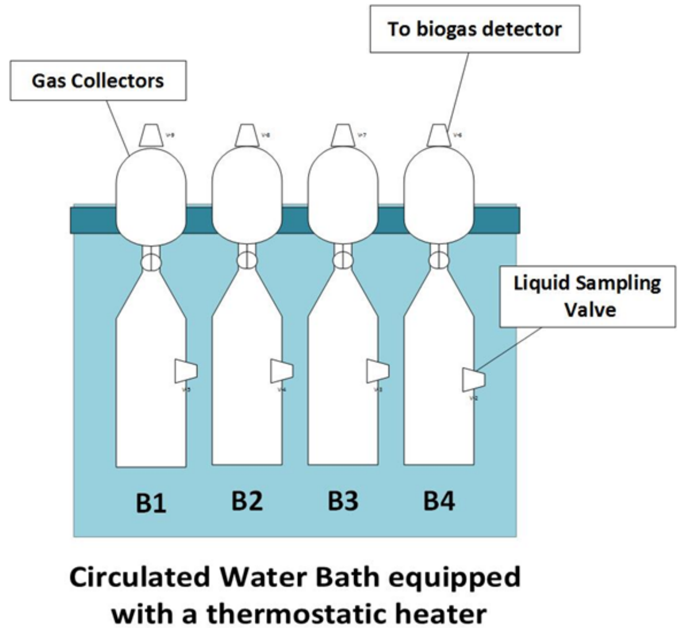

Fig. 1. Schematic design of the setup

B. Experimental Setup and procedures

The reactors used for this experiment were made of plastic with the volume of 500 mL. For the purpose of sample collection, a hole was punched in the body and then the area was sealed with aquarium glue so that liquid samples could be collected at any time without the system being exposed to the environment. The produced gas was regularly tested in order to determine its methane content. All four reactors were put in a circulated water bath equipped with a thermostatic heater. The experimental setup used in this experiment is shown in Fig. 1.

300 mL of the inoculum was added alongside with different S/I ratios of 0.5, 1.5 and 2.5 to 1. At the same time, the effect of pH adjustment was investigated. Specifications of the reactors are shown in Table 2. pH was adjusted in the reactors for the first 4 days using NaOH 2 Molar and HCl 2 Molar. This method was described by Yang et al. [16]. In order to avoid stratification, all the reactors were stirred 100 times per day manually [23] . Reactors were initially bubbled and flushed with an inert gas for 2 minutes in order to replace air. All reactors were put in the water baths and the temperature was set at $37 \pm 1oC$.

The TS, VS and DM were determined according to Standard Methods [26]. Samples from liquid phase were taken on a daily basis from all the [12] reactors. Gas samples were collected on a periodic manner. The collected gas was tested using Portable Gas Detector Smart Charger Type PGDC2 (portable gas detector,

Table 2. Physiochemical characteristics of substrate and inoculum

Batch	S/I ratio	pH Adjustment
B1	0.5:1	No Adjustment
B2	0.5:1	7± 0.05
B3	0.5:1	8±0.05
B4	0.5:1	9±0.05
B5	1.5:1	No Adjustment
B6	1.5:1	7±0.05
B7	1.5:1	8±0.05
B8	1.5:1	9±0.05
B9	2.5:1	No Adjustment
B10	2.5:1	7±0.05
B11	2.5:1	8±0.05
B12	2.5:1	9±0.05

Table 3. Maximum STDEV for pH and volume of biogas measurements

Sample	S/I ratio	Maximum STDEV (%)
pH of No Adjustment	1.5:1	3.16
pH of adjustment on 7	2.5:1	6.52
pH of adjustment on 8	1.5:1	2.73
pH of adjustment on 9	0.5:1	4.57
Volume of biogas from adjustment on 7	1.5:1	16.75
Volume of biogas from adjustment on 8	1.5:1	18.19
Volume of biogas from adjustment on 9	0.5:1	10.02

United Kingdom).

3. RESULTS AND DISCUSSION

To validate the results, the experiments were done in triplicate. The values of pH and volume of biogas production were measured. Standard deviation (STDEV) amounts were calculated for different S/I ratios. The maximum amounts were chosen and reported in Table 3. For instance, the maximum STDEV amount for pH measurement of systems with pH adjustment on [7] was observed from the sample with a 2.5:1 S/I ratio. As can be seen the results for pH measurement are highly accurate with a maximum STDEV of 6.52%. The biogas volume measurements were quite accurate as well with a maximum STDEV of 18.19%. Therefore, the results from other experiments can be trusted within an acceptable error range.

A. The pH Adjustment

pH has been reported as one of the dominant parameters for the stability of Anaerobic Digesters [27]. pH drop has been reported as a serious problem in the literature. It can inhibit methanogenesis and lead to less biogas production [12, 15, 28]. Yang et al. [16] suggested that pH adjustment leads to an increase in methane yield and biogas production from food wastes. On the other hand, a minimum pH of 6.5 was necessary to obtain the methanogen activity of anaerobic digestion [29]. Thus, pH of each set of reactors was initially adjusted on values [7–9] for the first 4 days. There were four reactors in each set and consequently pH of the fourth reactor was not adjusted, so that it could be used as the control sample. Sets 1, 2, and 3 were loaded with S/I ratios of 0.5:1, 1.5:1, and 2.5:1 respectively. Fig.

Compared to previous efforts [2, 9, 16], biogas production was within an acceptable range. However, due to high VFA concentration the control sample loaded with S/I ratio of 2.5:1 could not produce any biogas. In other words, it was overloaded due to high VFA concentration and irreversible pH decrease. Thus, pH adjustment was found to be indispensable for the 2.5:1 S/I ratio.

For reactors with the 1.5:1 S/I ratio, the pH adjustment seems necessary because the unadjusted reactor took longer to start producing biogas and stabilize (the biogas production started from day 10) compared to the adjusted ones (biogas production started on day 4). Therefore, pH adjustment is advised to a decrease in hydraulic retention time (HRT).

There wasn't a significant change in reactor stability of samples with S/I ratio of 0.5:1 due to pH adjustment. There was no need to adjust the pH in this case according to good stability of the reactor and acceptable biogas production.

B. S/I ratios

To investigate the effect of feed concentration on biogas production, three S/I ratios (0.5:1, 1.5:1, and 2.5:1) were used in this study. To obtain the suitable condition for these ratios, amount of biogas production and methane content were compared.

The highest specific biogas production occurred at 0.5:1 S/I ratio. As can be seen in Fig. 3 (a) there was a maximum of 271.26 mL/g VS whereas the highest Fig for S/I ratios of 1.5:1 and 2.5:1 were 116.67 and 138.21 mL/g VS, respectively. It is worth mentioning that the highest specific methane production achieved was 113.01 mL/g VS from reactor B2. Thus, employing lower S/I ratios is recommended by the authors. Although in all cases adjusting pH is advisable, it is essential in cases with S/I ratios higher than 0.5:1.

C. Biogas Production and Methane Content

The effect of S/I ratios of (a) 0.5:1, (b) 1.5:1, and (c) 2.5:1 and different pH adjustments on cumulative biogas production from SBW is shown in Fig. 3. As it can be seen, regarding all S/I ratios, biogas production started sooner when the pH was adjusted on 9. This must be due to neutralization of the VFA produced in the reactors and a balance achieved in the rate of organic matter degrading to VFA and methanogenic activities. Although all these acids being neutralized saved the reactors from methane inhibition, it was not suitable for lower S/I ratios. Because the organic matter needed for methane production was neutralized in the middle of the process without being converted into methane.

As shown in Fig.3 the highest biogas production was achieved with pH being adjusted on 7. Furthermore, pH adjustment seemed necessary with S/I ratios higher than 0.5:1. Although there was no need for pH adjustment for S/I ratio of 0.5:1, but as Fig. 3(a) suggests, there was a 63.36% increase in specific biogas production with pH adjustment on 7.

As seen in Fig.3 (b) adjusting pH accelerates biogas production. With pH adjusted on 9, 8 and 7, biogas production started on the 7th, 10th, and 10th day of operation, respectively, whereas without pH adjustment it started on the 18th day.

Even at high S/I ratios like 2.5:1, pH adjustment made it plausible for all the reactors to produce biogas. Except for batch

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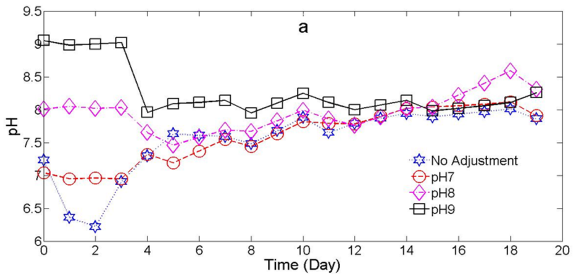

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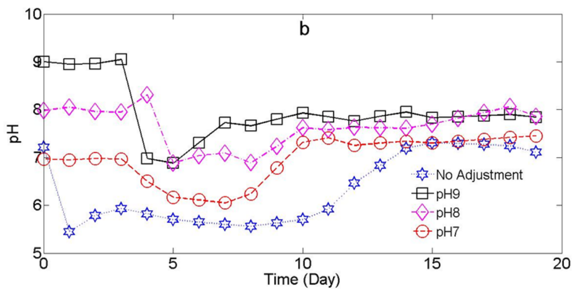

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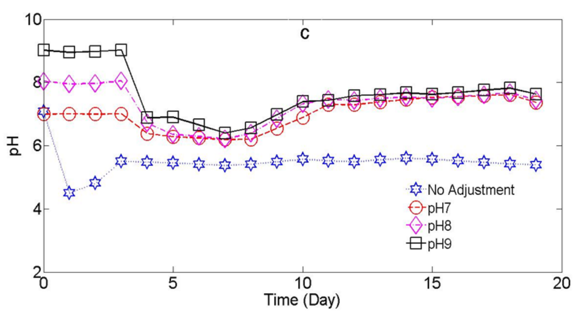

Fig. 2. Change of pH during anaerobic digestion process for S/I ratios of (a) 0.5:1, (b) 1.5:1, and (c) 2.5:1

B9 due to rapid pH drop and system instability, all the other reactors were able to produce sufficient amount of biogas. The highest methane content achieved was 72.75% from batch B11. According to Table 4, the highest methane content for each S/I ratio was observed with pH adjusted on 8, which comes to surprise because the gas production was less in those cases compared to pH adjustment on 7. Due to high biogas production with pH adjustment on 7 and negligible difference between the methane content achieved from pH adjustment on 7 and 8, pH adjustment on 7 is recommended.

SBW was used as a solo substrate in these experiments. Due to lack of nutrients such as nitrogen (N) and phosphorus (P), it is considered as a poor solo substrate [10] . According to Table 4, the average methane content was in the range of 36-57 volume percent that slightly increased as S/I ratio increased. As shown in table 4, there has been no biogas production in the reactor without pH adjustment and 2.5:1 S/I ratio.

4. CONCLUSION

Biogas production from SBW was investigated in the lab-scale anaerobic digesters. SBW showed good potential for biogas production. Results reveal that pH adjustment favored the process of biogas production and was mandatory. pH adjustment on 7 lead to 1.87 and a 10.48 times more biogas production for 0.5:1 and 1.5:1 S/I ratios, respectively. The highest methane content observed was 72.75% from reactor with pH adjustment on 8

Table 4. Maximum STDEV for pH and volume of biogas measurements

Batch	Average methane content (vol.%)	Maximum methane content (vol.%)
B1	41.13	46.38
B2	41.66	47.25
B3	47.1	55.25
B4	42.13	45
B5	50.88	50.88
B6	49.79	53.75
B7	51.44	64.75
B8	45.13	56.88
B9	0	0
B10	56.68	70.13
B11	48.98	72.75
B12	35.84	70.63

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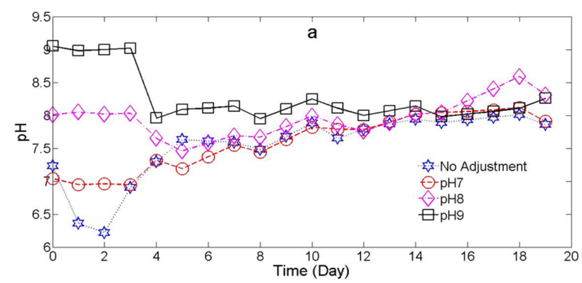

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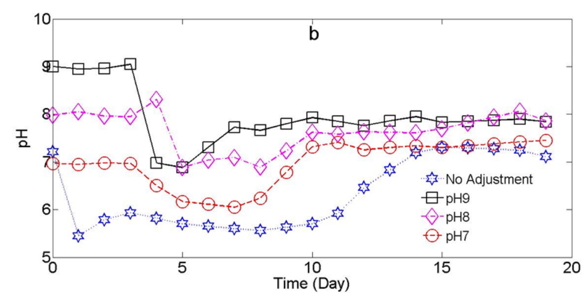

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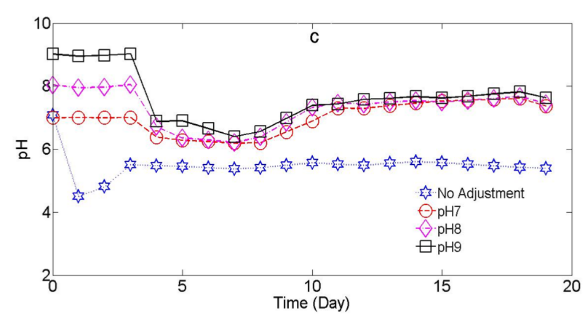

Fig. 3. Change of pH during anaerobic digestion process for S/I ratios of (a) 0.5:1, (b) 1.5:1, and (c) 2.5:1

and a 2.5:1 S/I ratio. Furthermore, adjusting pH of the samples on 9 caused a revers effect on biogas production and is not advised. Using pH adjustment on 7 and a 0.5:1 S/I ratio was recommended because the highest specific biogas yield, 271.26 mL/g VS, was achieved under this condition.

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