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Optimization and fabrication of a portable biogas reactor

Abu Yousuf*, Salma Akhter Iqbal, Niloy Chandra Sarker, Md. Nazmul Hasan, Mohammad Shahadat Hussain Sarker

Department of Chemical Engineering and Polymer Science, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh.

Abstract

The study was conducted to investigate the production of biogas from kitchen waste (KW) with co-digestion of cow manure (CM) by using anaerobic digestion process. The experimental protocol was defined to examine the effect of organic loading rate (OLR), temperature, and NaOH-treatment on the efficiency of the production of biogas. A portable biogas reactor was fabricated for efficient biogas production which included an agitation and a heating system. The KW and CM were co-digested at ratios of 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1 and 8:1 respectively at loading rates of 50, 100,150, 200, 250, 300, 350, and 400 g/L. The highest degradation rate of 7.96 ml/g was obtained from the loading rate of 200 g/L. Furthermore, KW was co-digested at different temperatures 25, 35, 40, 45, and 50^{0}C, maintaining the same loading rate of 200 g/L and the highest degradation rate of 7.98 ml/g was inspected at temperature 35^{0}C. The alkali (NaOH) was used to treat KW to improve biogas production and four NaOH doses 0.5%, 1.0%, 1.5%, and 2.0% on wet matter basis of KW were applied. The highest degradation rate 13.21ml/g was obtained from 1.5% NaOH which was almost double compared to untreated KW. In addition, 39.74 % more biogas could be produced from 1.5% NaOH-treated KW than untreated KW. The results were further verified by scaling up to a semi-continuously-operating pilot-plant reactor co-digesting KW with CM as bacterial seed and confirmed that no negative impact was imposed at optimized conditions.

1. INTRODUCTION

Disposal of municipal solid waste (MSW) is a major concern in large cities of Bangladesh. Kitchen waste, which is defined as the food residuals generated from restaurants, cafeterias, student dormitories, hotels, and households etc, is a main organic fraction of MSW. Anaerobic digestion of organic waste to produce biogas has been regarded as an attractive technology of treating waste biomass, for example, agriculture waste, organic fraction of MSW, as well as organic waste from food industry. In terms of high biodegradability of KW, it is a typical organic waste suitable for anaerobic digestion.

Although biodegradable organic matter could be used as sole feedstock in anaerobic digestion, the digestion process tends to fail without the addition of external nutrients and buffering agents [1]. Co-digestion with animal manure or sewage sludge as base feedstock is an effective way to improve buffer capacity and achieve stable performance [2-5]. On the other hand, the addition of readily biodegradable organic matter into animal manure digester could significantly increase biogas production due to the changes of feedstock characteristics. According to another report [6], co-digestion of cattle slurry with fruit and vegetable waste obtained more cumulative biogas production than the digestion of cattle slurry alone. While co-digestion of KW and CM was expected to achieve better performance due to the advantages of co-digestion such as more suitable physiochemical characteristics and improved nutrients balance [7].

The prime object of this work was to investigate the prospect of KW for biogas generation as a renewable energy sources by means of co-digestion with CM at different ratio in batch experiment, also investigate the effects of OLR, temperature and treatment of KW with NaOH. A portable biogas reactor was also fabricated for efficient biogas production and ultimate goal was to protect the environment from the bad effect MSW in terms of waste to energy.

2. MATERIALS AND METHODS

2.1 Waste collection and processing

The kitchen wastes used in this study were collected from the student dormitory, residential area of Shahjalal University of Science & Technology. Cow manures were collected from the village nearby the university. The kitchen waste contains mainly vegetables, non-used vegetable, cooked rice, etc. After removing the bones, metals, chopsticks, plastic bags and inorganic residuals, wastes were cut into small size then they were mashed into pest like substances by using hopper.

2.2 Experimental Design

A simple lab- scale experiment was designed using nine digesters which were made of glass. The volume of digester was 1 L each and working volume was 0.5 L. Each digester was connected with water chamber (plastic bottles) by a plastic pipe (gas pipe) which was used to allow the produced gas to flow through it to the water chamber and hence displaced the same volume of water from the chamber, which was then used to

* Corresponding Author: Abu Yousuf
E-mail: ayousufcep@yahoo.com

flow through another plastic pipe (water pipe) to the water collector. The set up is illustrated in Fig.1.

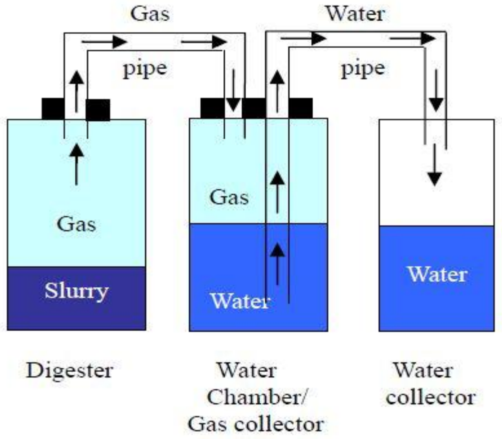

Fig.1: Schematic diagram of the lab-scale experimental set-up. (Adapted from [8]).

2.3 Anaerobic digester operation

Lab- scale experiments were operated in batch mode. Firstly we prepared two digesters, D-1.1 and D-1.2 for only KW and co-digested KW with CM. The digesters were run at room temperature (28-30^{0}C). The substrate composition of the digesters is shown in the **Table-1.**

Table-1: Composition of digester for pre-experimental studies

Digester	Organic biomass, KW (g)	Bacteria seed, CM (g)
D-1.1	100	00
D-1.2	100	25

For the subsequent studies, nine digesters were set up as described in the Table-2 maintaing loading rate, mixing ratio and temperature. All digester were put into water bath to maintain temperature. Retention time of digestion was 10- 13 days depending on the gas production. The digestion experiment for each loading rate was triplicate.

Table-2: Digesters specification

Digester	Mixing ratio of KW to CM	KW (g)	CM (g)	Loading rate of KW (g/L)	Parameter to be optimized
Optimization of loading rate					Loading rate (g/L)
D-2.1	0:1	00	25	0	0
D-2.2	1:1	25	25	50	50
D-2.3	2:1	50	25	100	100
D-2.4	3:1	75	25	150	150
D-2.5	4:1	100	25	200	200
D-2.6	5:1	125	25	250	250
D-2.7	6:1	150	25	300	300
D-2.8	7:1	175	25	350	350
D-2.9	8:1	200	25	400	400
Optimization of temperature					Temperature (^{0}C)
D-3.1	4:1	100	25	200	25
D-3.2	4:1	100	25	200	35
D-3.3	4:1	100	25	200	40
D-3.4	4:1	100	25	200	45
D-3.5	4:1	100	25	200	50
Optimization of alkalinity					NaOH (%)
D-4.1	4:1	100	25	200	0.5
D-4.2	4:1	100	25	200	1.0
D-4.3	4:1	100	25	200	1.5
D-4.4	4:1	100	25	200	2.0

2.4 Pilot-scale

The pilot-scale experiments were operated in semi-continuous mode. According to the lab-scale experiment, the loading rate of 200 g/L was carried out in this trial. Subsequently, the total amount of water 31 liters, 6.2 Kg of KW and 1.55 Kg of CM were putted into the digester. The agitator was stirred up manually.

3. RESULTS AND DISCUSSION

3.1 Biogas production from KW and co-digested KW with CM

Currently, almost all household digesters are using animal manure as feedstock to produce biogas. However, manure has limited availability in many places particularly in urban areas. Therefore, alternative feedstocks need to be developed. Biogas technology have been using mainly in rural area but there is also a plenty of biomass in urban area. The main composition of MSW is KW and it is mostly unused in all cities of Bangladesh. The biogas components and biogas yield depend on a feed material due to the difference of their characteristics.

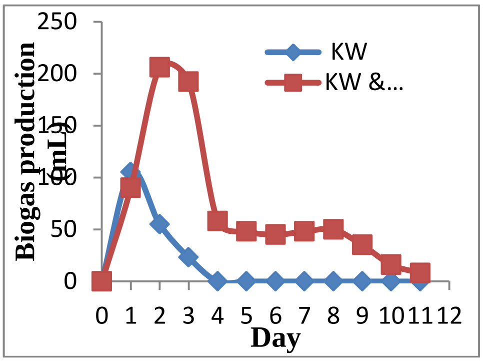

Fig.2: Comparisons on biogas production from KW co-digested KW & CM at temperature (35^{0}C) and loading rate 200 g/L.

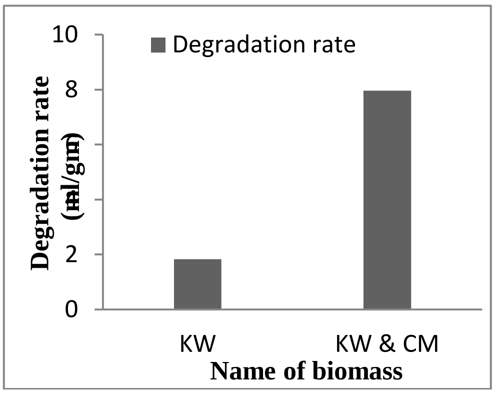

Fig.3: Comparisons on degradation rate (mL/g) between KW and co-digested KW & CM at temperature (35^{0}C) and loading rate 200 g/L.

Fig.3 shows that the digester D-1.2 (KW and CM) produced more biogas. The degradation rate for digester D-1.2 (KW & CM) was 7.96 ml/g and that of D-1.1 was 1.83 mL/g. KW contains more readily biodegradable compositions and it is easily converted to biogas but it has low buffer capacity and is easy to acidify [9]. So, the co-digestion of KW and CM would combine together the positive characteristics of the both feed stocks and could potentially bring better digestion performance. The benefits of co-digestion included improved biogas yield, economic advantages derived from the sharing of equipment and easier handled of mixed waste etc [10].

3.2. Effect of organic loading rate

One of the main objectives of this study was to determine the performance of the anaerobic digestion process when operated at different loading rates. Therefore, it was important to evaluate process performance in term of biogas production or degradation rates. To optimize the loading rate, several batches were run at ambient temperature and at 35^{0}C.

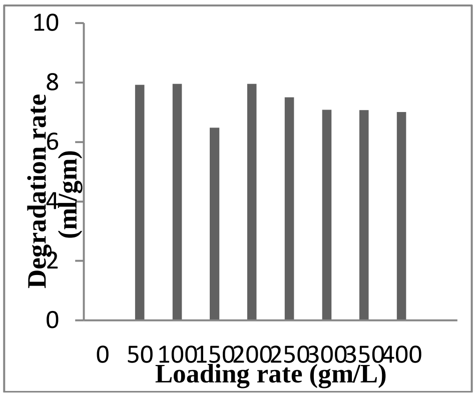

Fig.4: Degradation rate (mL/g) of KW at temperature 35^{0}C for various loading rates

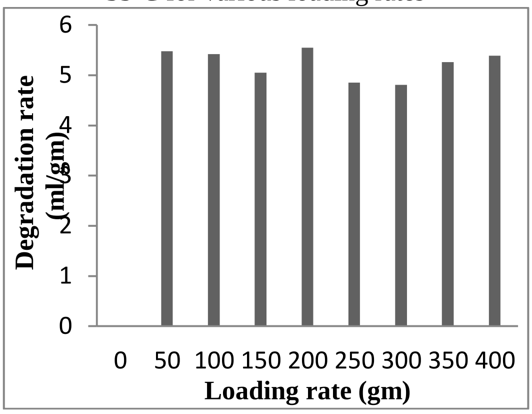

Fig.5: Degradation rate (mL/g) of KW at room temperature for various loading rates

Fig.4 represented the biogas production for per gram of KW during the digester's operation at different loading rates. The degradation rates were 7.92, 7.96, 6.48, 7.96, 7.5, 7.08, 7.08 & 7.00 respectively corresponding loading rate of 50, 100, 150, 200, 250, 300, 350, & 400 g/L. The degradation rate KW for 200 g/L and 100 g/L were same and higher than other loading rate. According to Fig.5, when digestion were carried out at room temperature, the degradation rates were 5.48, 5.42, 5.06, 5.55, 4.84, 4.81, 5.26 and 5.39 ml/g respectively corresponding to same loading rates. In both cases, maximum biogas was produced when the reactor was loaded at the rate of 200 g/L of KW. However, manure has limited availability in many places particularly in urban areas. Therefore, it was tried to use maximum amount of KW and minimum amount of CM.

3.3 Effect of temperature

Biogas production from organic substrates is strongly affected by the temperature where anaerobic digestion takes place. The process of organic material anaerobic digestion takes place in three main temperature ranges: from 10-25°C **(**psychrophilic conditions**),** from 30-37°C(mesophilic conditions) and from 48-55°C (thermophilic conditions). The majority of methanogens (the microorganisms that form methane from organic matter) belong to the mesophilic. They grow quickly in this temperature range and exhibit high degrees of conversion. In practice, this has direct implications in the design of biogas plants as they are the most stable operating plants. The stability and growth conditions in the digester at mesophilic conditions make the process more balanced, more resistant to chemicals that inhibit digestion (e.g. ammonia) and capable of treating efficiently a great variety of different types of biomass and waste. The effect of temperature was studied with maintaining same loading rate of 200 g/L.

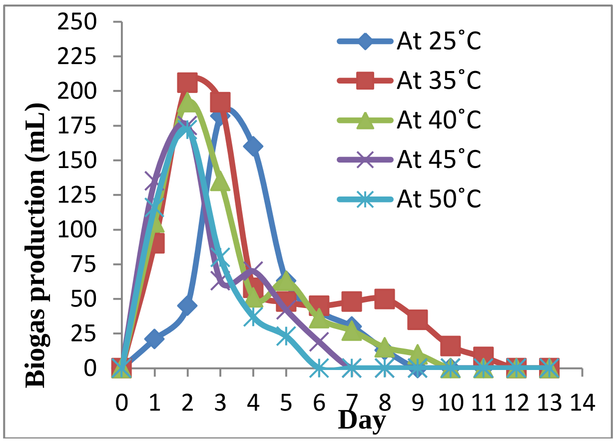

Fig.6: Daily biogas production from KW for loading rate of 200 g/L at different temperature.

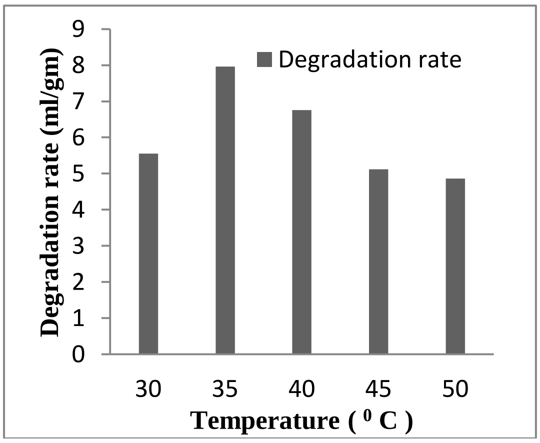

Fig.7: Degradation rate (mL/g) of KW for loading rate of 200 g/L at different temperature.

When temperature dropped down microbial activity decreased, as a result biogas production or degradation rate was also decreased. On the other hand with the increased of temperature some microorganisms begun to die, once again the production of biogas or degradation rate gradually decreased. From the Fig.6 and 7, it was observed that at 35^{o}C the biodegradability was high and biogas production was maximum. So, the optimum temperature of biogas production was recorded at 35^{o}C.

3.4 Effect of addition of NaOH

Sodium hydroxide (NaOH) was added with KW in liquid state at 35^{o}C temperature to improve biodegradability and anaerobic biogas production. Four NaOH doses of 0.5%, 1.0%, 1.5%, and 2% on wet matter basis of KW were applied. The raw and NaOH-added KW were then anaerobically digested at loading rate of 200g/L.

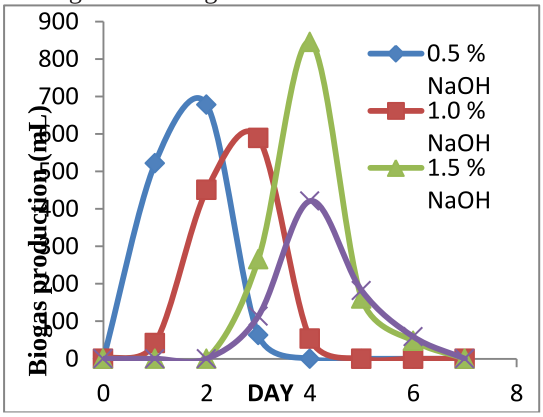

Fig.8: Daily biogas production from KW with treated by various percentages NaOH in loading rate of 200 g/L at temperature 35^{0}C.

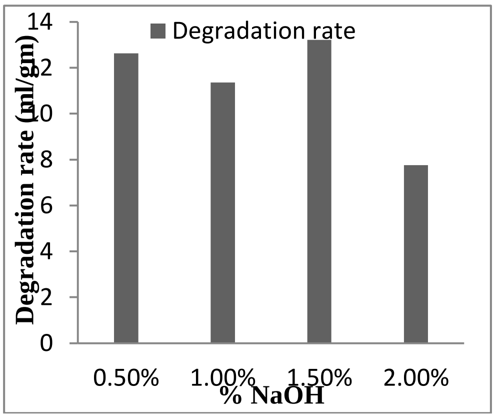

Fig.9: Degradation rate (mL/g) of KW treated by different percentages of NaOH for loading rate of 200g/L at temperature 35^{0}C.

From Fig.8 and 9, it was detected that for 0.5%, 1.0%, 1.5% and 2.0% of NaOH the daily biogas production and degradation rates (ml/g) were 12.63, 11.36, 13.21 and 7.76 respectively. It also found that first two (0.5% & 1.0%) digesters took retention time 6 days and next two (1.5% & 2.0%) digesters took retention time 8 days. Although, retention time was longer for 1.5% of NaOH but biogas production or degradation rate was also higher than others. Therefore, KW incorporated by 1.5% NaOH was optimum in this experiment.

3.5 Fabrication of portable biogas reactor

Portable biogas reactor was fabricated and run out in semi-continuous system. The digester volume was about 62 liters. Fig.10 illustrates the experimental set-up. The biogas plant could be constructed over earth surface or underground. In Bangladesh, underground biogas plants are mostly used in rural areas. Bangladesh is a flood prone country and large parts of Bangladesh have experience of flood almost every year. So, entering of flood water into the digester will break down its operational capacity. Temperature is another important factor for biogas production. But underground biogas plant has low temperature as a result they can not run with full efficiency to produce biogas. Homogeneous mixing of slurry in the underground digester is not maintained. This digester is not user friendly as it is not carried out one place to another. This type of plant is mostly used in rural areas but not used in urban areas.

The portable biogas plant prepared in our study, easy to carry from one place to another, it will not affected by flood water, temperature also can be maintained at desire condition. Heating system can easily be installed. Even heat can be supplied to the system when it is needed (e.g. in winter). For homogeneous mixing of biomass, agitator can be used in plant. This type of digester or plant can be widely used in both urban and rural areas, and even in multi storied building.

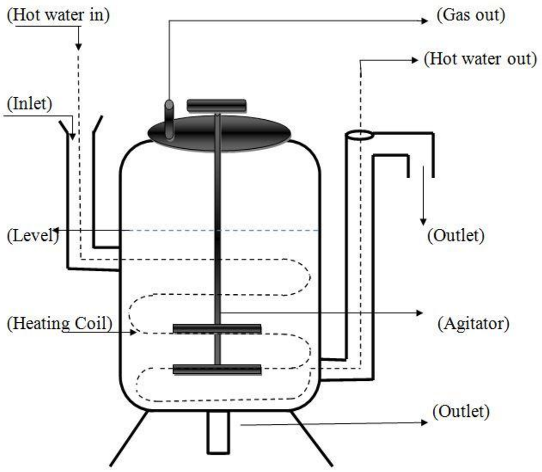

Fig.10: A portable biogas digester set-up.

4. CONCLUSIONS

Anaerobic digestion is promising process for reducing the amounts of biodegradable waste in MSW stream and is also an energy producer from renewable resources. Considering the characteristics of the high-moisture solid waste, anaerobic digestion represents a feasible and effective method to convert the waste to biogas fuel. Maximum biogas (13.21ml/g) was produced under the conditions- temperature 35^0C, OLR 200g/L and treated with 1.5% NaOH. When KW was treated by 1.5% NaOH, it could be achieved 39.74% more biogas production. Finally a portable biogas digester was fabricated and it was working efficiently under the optimum conditions. The reactor was mainly designed for use in the top of multistoried building. Successful implementation of anaerobic digestion as the method of waste treatment leads to the regional utilization of renewable energy resources, as well as the disposal of high moistening content of KW.

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