Production of Biogas from Kitchen Waste with Inoculum and Study the Effect of Different Parameters

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Summary: Household kitchen waste quantity is increasing rapidly because of the population explosion. Agricultural growth and intensive animal farming are generating a large quantity of bio waste. Disposing of this huge amount of waste is a serious environmental issue of the world. This waste can be used as an alternative source for the generation of green fuel by converting it to biogas. Though, a lot of work has been done on biogas production from conventional feedstock. However, it is highly desired to improve and optimize the process with kitchen waste used as feedstock. In this paper, cost-effective, environmentally friendly and high-quality biogas is produced by anaerobic digestion of kitchen waste mixture with inoculum. Inoculum is used as a source of microbial population. It is prepared by mixing of cow dung and water with a weight ratio of 1:5. The effect of temperature, pH, and the weight ratio of inoculum/kitchen waste on the production of biogas has been studied. The results indicated that the optimum pH value is 7.5 and for the maximum production of biogas temperature should be 37 °C. The optimum weight ratio of inoculum/kitchen waste is 60/40. The quality of biogas is improved by the absorption of CO_2 from it with the aid of absorber contains 2 M solution of NaOH. The gas was burnt smoothly with a blue flame. This indicates the high content of CH_4 in biogas. It is a green heating and cooking fuel and can be used for transport and power generation.

Keywords: Anaerobic digester, Biogas, Inoculum, Kitchen waste, Optimum, Green fuel.

Introduction

Recently, energy crisis, environmental pollution, and disposal of all types of wastes are the major global challenges. Over the last two decades, rapid growth in population and urbanization has increased the solid waste management problem. Inadequate management of organic wastes and uncontrolled dumping has created environmental pollution and health-related issues. This has not only affected the standard of living area, but also created the threat of water pollution. It has stimulated the population of disease vectors [1, 2]. Especially, kitchen waste organic matter can cause some serious health and environmental problems. It has a high water content which can be a source of the odor, diseases, and environmental pollution. However, it has a sufficient quantity of nutrients which are essential for microorganisms to produce biogas [3]. It is highly desired to develop solid waste management technology to minimize kitchen waste [3, 4]. Anaerobic digestion has efficient application for digestion of kitchen, fruit and vegetable wastes [5]. Biogas production from the anaerobic digestion process depends on the composition of feedstock [5, 6].

Conventional fossil fuel resources will be depleted soon because of their extensive use. The energy demand will be increased with an increase in population and industrial growth. Renewable energy sources can fulfill the energy requirements without affecting the environment, and minimize the greenhouse gases. The most valuable renewable energy resources are biomass, geothermal, solar energy, and wind energy [7, 8]. Different sources are available for biogas production like kitchen waste, dairy manure, municipal waste, distillery spent, and animal manure. The most preferable feedstock is kitchen waste because it has maximum biodegradable materials [3]. Different technologies have been used for the conversion of organic materials to biogas. In the United States, anaerobic digestion is used to generate clean fuel and fertilizer [9]. In the past, research has been done on the production of biogas from the conventional feedstock, but kitchen waste was neglected as feedstock. Biogas has helped to meet the energy requirements and keep the environment clean [10]. The remaining feed sludge waste from biogas digester can be used as fertilizers [11]. There are some indirect benefits of biogas as well. It has the potential for partial sterilization of waste during formation and reduced the public health hazard [12, 13]. It will be a green heating and cooking fuel and can be used for transport and power generation. Biogas from kitchen waste generally contains methane 55-65 %, carbon dioxide, 30-35 %, and a trace amount of other gases such as hydrogen

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and nitrogen [14]. It has a heating value of 21 BTU/L depending upon methane content [15]. Its production depends on different factors like; temperature, nature of the substrate, pH, loading rate, slurry concentration, toxicity, stirring, nutrients, digester size and construction, retention time, chemical oxygen demand, alkalinity, total solid, and volatile liquids etc. [16].

It looks productive, but need more work to optimize different parameters for efficient production of biogas from kitchen waste. In this paper, kitchen waste mixture is used as feedstock with inoculum for production of biogas with the aid of anaerobic digester. The quality of biogas is improved by the absorption of CO_2 from it by using absorber contains 2 M solution of NaOH. The effect of temperature, pH value, and the weight percentage of inoculum in kitchen waste is studied and optimized.

Experimental

Experimental setup

Chemical bottle of five-liter capacity was used as an anaerobic digester. A hole with a size of 8 mm was made in the lid of the bottle with the help of drilling machine. PVC pipe of 3 cm of length with an outer diameter of 8 mm was fixed in the lid and sealed properly with silicone gum. The digester was placed in a water bath having a heating element and automatic temperature control system. The glass bottle of two-liter capacity was filled with 2 M solution of NaOH and used as an absorber to absorb CO_2 from biogas. It was fixed invertedly on a stand and placed above the digester. A measuring cylinder was used to calculate the amount of biogas produced. It was placed on the table near the digester. Two IV infusion set were used for gas pipeline. Their roller clamps were worked as control valves. The spike of a drip set (IV infusion) was fixed airtightly in PVC pipe on the lid of the digester and the other end with a needle was fixed in the lid at bottom of the absorber. The needle of the second drip set was fixed in the lid at the bottom of the absorber and the other end was placed in measuring cylinder. The PVC pipe was used to fix the spike (one end of the pipeline) into it so that the spike can be removed easily during operation or after completion of one batch. If the spike was fixed in the lid with silicone gum then it might be difficult to remove it after completion of one batch. The systematic diagram of the experimental setup is shown in Fig-1.

Methodology

The kitchen waste was collected from the boy's hostel, The University of Faisalabad, Pakistan. First, it was ground well and then blended with a fixed amount of water. The inoculum was used as a source of microbial population. It was prepared by mixing of cow dung and water with a weight ratio of 1:5. The kitchen waste and inoculum were mixed together with a fixed weight percentage to make slurry. The slurry was poured into the digester at fix pH and constant temperature. The digester was sealed properly. The experimental set up was assured airtight. The biogas produced in the digester was passed through the pipeline and entered into the absorber. As aforementioned, there was another pipeline with a control valve connected from the absorber to measuring cylinder. Principally, when the gas from the digester was entered in the absorber an equal volume of NaOH solution was displaced from the absorber into the measuring cylinder. The amount of biogas was measured by calculating the amount of displaced NaOH solution from the measuring cylinder (displacement method). When the absorber bottle was filled with biogas it was replaced by another absorber bottle. Burning test was performed with the help of a matchbox stick. The gas was burned smoothly with yellow and blue flame. This indicates the high content of CH_4.

Absorber function

Absorber has a dual function. First, it was used to absorb CO_2 from biogas and second, it was used to store biogas. Biogas from kitchen waste is generally contain methane 55-65 %, carbon dioxide 30-35 %, and a trace amount of other gases such as hydrogen and nitrogen [14]. It was reported that in the first 3-5 days of digestion, the CO_2 quantity in biogas was high as compared to CH_4 [17]. To improve the burning quality of biogas, it is essential to separate CO_2. This was achieved by absorbing it into 2 M NaOH inside the absorber.

Displacement method for biogas measurement

The volume of biogas was measured by displacement method [18]. When the biogas was entered in the absorber, an equal volume of NaOH solution was displaced from absorber into the measuring cylinder. The volume of biogas was determined by measuring the volume of NaOH solution from the cylinder. By followed this process, the volume of biogas produced in 15 days was measured from the volume of the displaced NaOH solution from the cylinder. The absorber bottle was replaced with another absorber bottle when it was filled with biogas.

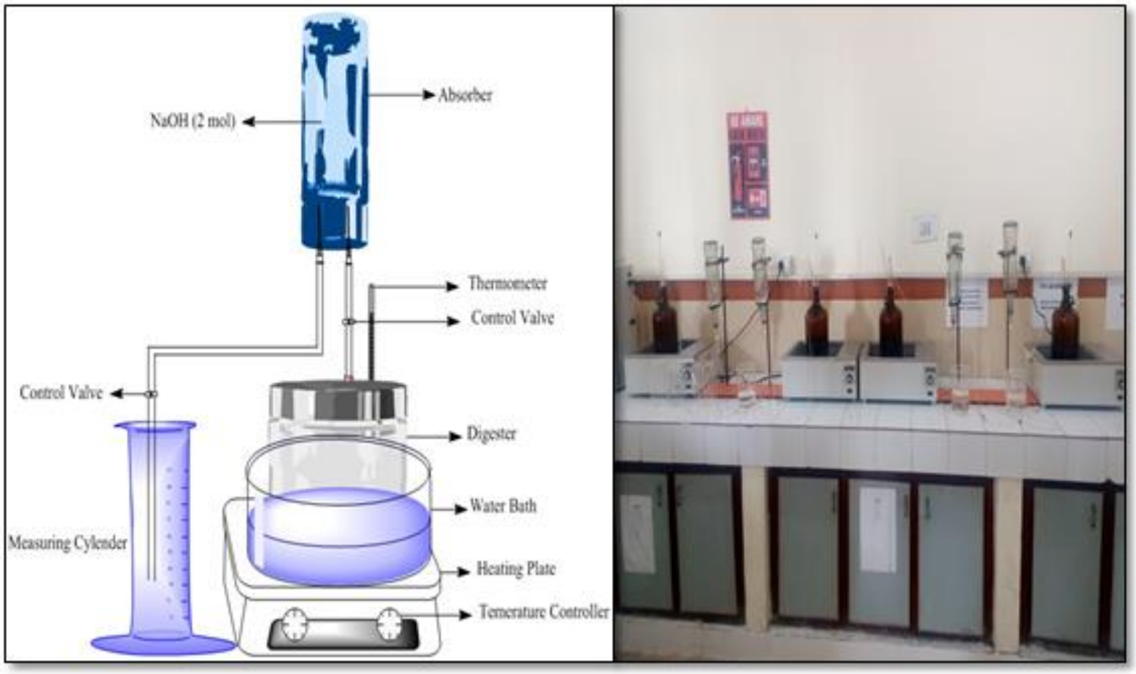


Fig. 1: Laboratory scale experimental setup for biogas production: equipment detail (left); actual setup (right).

Results and Discussion

Effect of inoculum on biogas production

Kitchen waste which includes vegetables, fruit waste (apple pumice, banana peels etc.), cooked and uncooked food was collected from boys hostel, The University of Faisalabad, Pakistan. It was crushed, ground and blended with an equal weight of water. The inoculum was used as a source of microbial population. It was prepared by mixing of cow dung and water with a weight ratio of 1:5. The kitchen waste and inoculum were mixed together to make a slurry, used as feedstock for the production of biogas. Inoculum and kitchen waste were mixed together in the different ratio as shown in Table-1. Six samples were prepared with a variation of the inoculum weight percentage. The other factors which can affect the production of biogas were kept constant.

Table-1: Digester feedstock with different inoculum wt.%

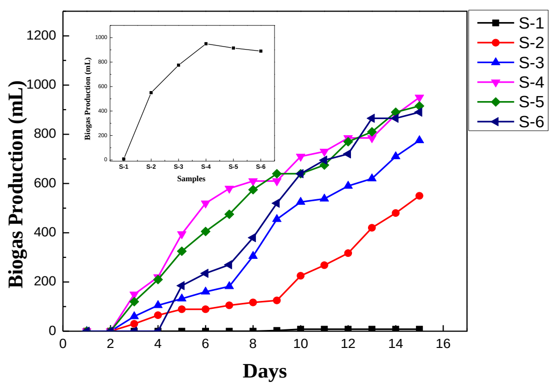
Samples	Kitchen waste + Water (Kg)	Inoculum (Kg)	Inoculum (wt.%)	Biogas production in 15 days (ml)
S-1	2	0	0	8
S-2	1.6	0.4	20%	214.65
S-3	1.2	0.8	40%	336.21
S-4	0.8	1.2	60%	503.93
S-5	0.4	1.6	80%	494.64
S-6	0	2	100%	478.57

pH = 7.5, T = 37 °C, t = 15 days

The pH value was fixed at 7.5 and the temperature was fixed at 37 °C. The digester was airtight. It has been observed that biogas was not produced when the air was entered into the digester.

The amount of biogas was measured with a fixed time interval of one day. The operation time for one batch was 15 days. Biogas production from all the samples was measured. The general observation was that production of biogas was not started within the first 9 days with inoculum 0 wt.% (Graph-1). The results were demonstrated that only 8 ml of biogas was produced within 15 days with inoculum 0 wt.% as shown in Table-1. Biogas production was increased with increase in inoculum up to 60 wt.%. This is because inoculum is a source of microbial population, which is essential for the fermentation process. Fermentation was occurred slowly without inoculum. It was noted that biogas production was started just after one day in S-2, S-3, S-4, and S-5 with inoculum 20 wt.%, 40 wt.%, 60 wt.%, and 80 wt.% respectively. But in S-6 with inoculum 100 wt.%, production of biogas was started after 3 days. After initiation, its production rate was high in S-6 as compared to other samples. The maximum production of biogas was observed in S-4 with inoculum 60 wt.% and its value was 503.93 ml/15 days. Total production of biogas from each sample with respect to time is shown in the Graph-1. After 13 days, the productions of biogas from all the samples become constant except S-6. This is because the production from S-6 was started three days later than the other samples and it has no kitchen waste as well. But the average production of biogas is higher in S-4 with inoculum of 60 wt.%.

Therefore, a binary mixture of kitchen waste and inoculum is recommended for the quick and efficient production of biogas in a short time period.



Graph-1: Biogas production with different inoculum wt.%

Effect of feedstock pH

Feedstock pH is an important parameter becauseit can affect microorganism activity to destroy organic matter for biogas production [16]. As aforementioned, the kitchen waste ingredients (vegetables, fruit waste, apple pumice, banana peels, cooked and uncooked food) and inoculum were mixed together to make a slurry which was used as feedstock in the digester. From the previous set of experiments, it has been observed that the optimum weight ratio of kitchen waste/inoculum was 40/60. Thus, this ratio was fixed for the study of the pH effect. The pH of the slurry was measured with a pH meter. Initially, it was 6.3. The slurry was poured into the anaerobic digester. It was observed that at pH 6.3, biogas was not produced. It was because at low pH microorganisms were inactive and feedstock fermentation was not started [16-19]. Therefore, it can be easily understood that low pH is not favorable for biogas production.

The pH of the feedstock was increased gradually up to 7.5, before pouring into digester by adding 2 M solution of $Ca(OH)_2$. It was observed that at pH of 7.5, the biogas production was started after 2 days. The pH value was further increased up to 10. It was observed that at pH 10, the biogas was not produced as shown in Table-2. This was because at high and low pH value microorganism cannot survive [16]. The maximum production of biogas was 503.93 ml in 15 days with pH 7.5. Therefore, it can be concluded that the optimum pH value was 7.5. Both very high (10) and low pH (6.3) are not favorable for microorganism growth. The production of biogas with a change in pH is shown in Table-2.

Table-2: Effect of pH value.

Sample	pH	Biogas production in 15 days (ml)
S-1	6.3	*
S-2	7.5	503.93
S-3	10	*

T = 37 ˚C, Inoculum /kitchen waste = 60 /40, t = 15 days
* Biogas was not produced

Effect of temperature on biogas production

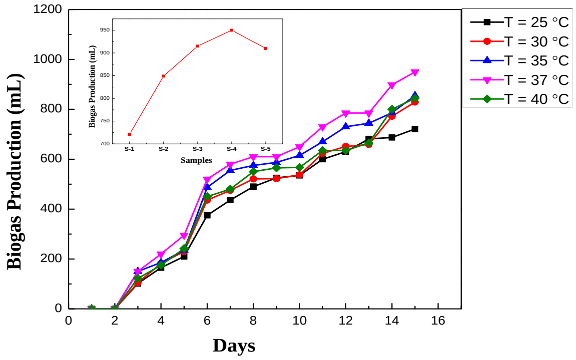
Earlier, it is found that the optimum weight ratio of inoculum/kitchen waste was 60/40. The optimum pH value was 7.5. Therefore, to study the effect of temperature, the inoculum percentage was fixed at 60 wt.% and the pH value was fixed at 7.5. The temperature was varied from 25 ˚C to 40 ˚C with an interval of 5 ˚C. The production of biogas from each sample was measured and recorded on a daily basis as shown in Graph-2.

Table-3: Effect of temperature.

Sample	Temperature (˚C)	Biogas production in 15 days (ml)
S-1	25	378.93
S-2	30	432.51
S-3	35	474.86
S-4	37	503.93
S-5	40	481.29

pH = 7.5 , Inoculum / Kitchen waste = 60 /40, t = 15 days

It was observed that biogas production was increased with increase in temperature up to 37 ˚C. The maximum production of biogas was 503.93 ml at the temperature of 37 ˚C and the minimum production of biogas was 378.93 ml at the temperature of 25 ˚C in 15 days as shown in Table-3. It was because 37 ˚C might be an ideal temperature for microbial growth [3,16]. The fermentation process was speeded up at a temperature of 37 ˚C, below this temperature the microbial population for the production of biogas was decreased. The microorganisms are temperature sensitive. Therefore, they were deactivated at both low and high temperature [16-17, 19]. At the temperature below 35 ˚C, the fermenting microorganisms can produce various fatty acids and alcohols, decreased the pH and consequently stops the digestion process [19]. It can be concluded that both temperature and inoculum percentage have a great impact on the production of biogas. The optimum inoculum percentage was 60 wt.% and the optimum temperature was 37 ˚C.



Graph-2: Biogas production at different temperature.

Biogas composition

Table-4: Approximate biogas composition [14].

Description	Formula	Concentration
Methane	CH_4	60-70%
Carbon dioxide	CO_2	30-35%
Nitrogen	N_2	1%
Hydrogen	H_2	0.1-0.5%
Carbon monoxide	CO	0.1%
Hydrogen sulfide	H_2S	Traces

Biogas from kitchen waste is generally contains methane 55-65 %, carbon dioxide, 30-35 %, and a trace amount of other gases such as hydrogen, nitrogen, carbon monoxide, and hydrogen sulfide as shown in table-4 [14].

Burning test

When the absorber bottle was completely filled with biogas, the outlet control valve was closed. Burning test was performed with the help of a matchbox stick. The burning matchbox stick was placed in front of the outlet of pipe and control valve was opened gradually as shown in Fig. 2 (right). The gas was burnt smoothly with yellow and blue flame. By carefully control the flow of biogas with control valve (roller clamp), the blue color of burning flame was observed with naked eyes; indicates the high content of CH_4.

Conclusions

High quality, environment-friendly and cost-effective biogas is successfully produced from the mixture of kitchen waste and inoculum. It is found that the biogas production is high when kitchen waste/inoculum ratio was 40/60. Temperature and pH are very important parameters for biogas production. The optimum temperature is 37 °C and the pH value is 7.5 for maximum biogas production from the mixture of kitchen waste with inoculum. The gas was burned smoothly with blue flame indicating the high content of CH_4. A binary mixture of kitchen waste and inoculum was recommended for the quick and efficient production of biogas in a short time period.

Fig. 2: Smooth burning of biogas (right); experiment setup (left).

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Conflict of interest

All the authors have no conflict of interest.

References

1. L. Lama, S. P. Lohani, R. Lama and J. R. Adhikari, Production of Biogas from Kitchen Waste, *Rentech Symp. Compend*., **2**, 14 (2012).
2. S. Banerjee, G. Aditya and G. K. Saha, Household Wastes as Larval Habitats of Dengue Vectors: Comparison Between Urban and Rural Areas of Kolkata, India, *Plos One*, **10**, 1 (2015).
3. D. Vikrant and P. Shekhar, Generation of Biogas from Kitchen Waste-Experimental Analysis, *Int. J. Eng. Sci. Inv.*, **2**, 15 (2013).
4. B. S. Lim, B. Kim and I. Chung, Anaerobic Treatment of Food Waste Leachate for Biogas Production Using a Novel Digestion System, *Environ. Eng. Res*., **17**, 41 (2012).
5. K. Paritosh, S. K. Kushwaha, M. Yadav, N. Pareek, A. Chawade and V. Vivekanand, Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling, *BioMed Res. Int*., **2017,** 1 (2017).
6. D. Sridevi and R.A. Ramanujam, Biogas Generation in a Vegetable Waste Anaerobic Digester: An Analytical Approach, *Res. J. Recent Sci*., **1**, 41 (2012).
7. G. S. A. Nava, V. H. C. Flores, D. L. C. Chávez, R. D. Chavez, N. Scarlat, J. Mahlknecht, J. F. Dallemand and R. Parra, Renewable Energy Research Progress in Mexico: A Review, *Renew. Sust. Energ. Rev.*, **32**, 140 (2014).
8. A. H. Igoni, M. F. N. Abowei, M. J. Ayotamuno and C. L. Eze, Effect of Total Solids Concentration of Municipal Solid Waste on the Biogas Produced in an Anaerobic Continuous Digester, *Agri. Eng. Int: CIGR. J,* **10**, 1 (2008).
9. S. Elsasser, B.Sc. Thesis, *Anaerobic Digester Use in Dairy Farms in the United States,* University of Nevada, (2006).
10. S. Kumar, S.A. Gaikwad, A.V. Shekdar, P.S. Kshirsagar and R.N. Singh, Estimation Method for National Methane Emission from Solid Waste Landfills, *Atmospheric Environ*., **38**, 3481 (2004).
11. A. Pertiwiningrum, E. C. Budyanto, M. Hidayat, Rochijan, Y. Soeherman and M. F. Habibi, Making Organic Fertilizer Using Sludge from Biogas Production as Carrier Agent of Trichoderma Harzianum, *J. Biol. Sci.*, **17**, 21 (2017)
12. B. S. Sagagi, B. Garba and N. S. Usman, Studies on Biogas Production from Fruits and Vegetable Waste, *Bajopas*, **2**, 115-118 (2009)
13. V. Vaid and S. Garg, Food as Fuel: Prospects of Biogas Generation from Food Waste, *Int. J. Agri. Food Sci. Tech*., **4**, 68 (2013).
14. N. H. S. Ray, M. K. Mohanty and R. C. Mohanty, Anaerobic Digestion of Kitchen Wastes: Biogas Production and Pretreatment of Wastes, A Review, *Int. J. Sci. Res. Pub*., **3**, 286 (2013).
15. O. Abimbola and O. Olumide, Evaluation of Biogas Production from Food Waste, *Int. J. Eng. Sci*, **3**, 1 (2014).
16. R. Goswami1, P. Chattopadhyay, A. Shome, S. N. Banerjee, A. K. Chakraborty, A. K. Mathew and S. Chaudhury, An Overview of Physico-Chemical Mechanisms of Biogas Production by Microbial Communities: A Step Towards Sustainable Waste Management, *3 Biotech*., **6**, 1 (2016).
17. C. Kavuma, M.Sc. Thesis, *Variation of Methane and Carbon Dioxide Yield in a Biogas Plant*, Royal Institute of Technology Stockholm, (2013).
18. S. A. Iqbal, S. Rahaman, M. Rahman and A. Yousuf, Anaerobic Digestion of Kitchen Waste to Produce Biogas, *Procedia Eng*., **90**, 657 (2014).
19. A. Schnürer and Å. Jarvis, In *Microbiological handbook for biogas plants*, Swedish Gas Center SGC Sweden, p.31 (2009).