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A Comparative Study of Biogas Production by Using Kitchen Waste and Water Hyacinth: A Case Study

Jasleen Bhatti[1] and G.N. Tiwari[2]

[1,2]Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 11 00 16, India
E-mail: [1]bhattijasleen@gmail.com, [2]gntiwari@ces.iitd.ac.in

Abstract—*Biogas technology is a viable economic option as it uses locally available digestible organic waste as the input material which is made to undergo anaerobic digestion. This process ensures maximum energy recovery and less discharge. In this communication an attempt has been made to carry out a comparative study between the use of kitchen waste and water hyacinth for biogas production. A major environmental concern in today's society is the continuously increasing production of organic wastes. Uncontrolled waste dumping is no longer acceptable today and even controlled landfill disposal and incineration of organic wastes are not considered optimal practices. As environmental standards are increasingly stricter and energy recovery and recycling of nutrients and organic matter is aimed. The various digestible organic wastes like - organic fraction of municipal waste from catering (vegetable and animal origin), digestible organic wastes from food and agro industries (vegetable and animal origin), agricultural residues and by-products, animal manure and slurry, sewage sludge etc can be used for the production of biogas. Thereby ensuring that the organic fraction from the overall waste stream is removed. The production of biogas from digestible organic wastes results in the conversion of these substrates into renewable energy and the by-product obtained that is the digestate is a rich source of nutrient for the soil. Mankind needs food for its survival. Large quantities of kitchen waste containing high content of organic matter is generated throughout the year. Utilizing this as a feedstock for biogas production is an effective and efficient way of reusing this waste. Water hyacinth (Jalkumbhi) is an aquatic plant that grows freely over water bodies. In India many rivers, irrigation canals, lakes both natural and man-made are choked by the explosive growth of water hyacinth. It has become a major problem in water bodies of many states in India like Assam, Kerala, West Bengal, Orissa, Madhya Pradesh and Uttar Pradesh. This aquatic weed renders the water bodies unfit for the survival of marine life. The best economical use of this plant is to use it as a source of biogas production. We concluded that kitchen waste is the best alternative for community level biogas plants that could be fed on organic waste collected from nearby households, hostel mess, banquets, community centre's, hotels and restaurants and comparatively water hyacinth would be an excellent option for biogas plants that are set up near the water body from where it is collected. This would result in reduced greenhouse gas emissions, reduced dependency on imported fossil fuels, creation of larger scale local jobs, reduced transportation cost and a closed nutrient cycle.*

Keywords*: biogas; kitchen waste; water hyacinth; organic manure*

1. INTRODUCTION

Biogas is produced from biomass which is a permanently renewable resource, biomass is a living storage of solar energy via the process of photosynthesis. Biogas will not only improve the energy balance of a country but also make an important contribution to the preservation of the natural resources and to environmental protection. Agrahari and Tiwari[1] have done a comparative study of biogas production from cow dung and kitchen waste. The observations have been recorded over a 12 weeks duration. The analysis has been done for cow dung and kitchen waste from July 1, 2010 to September 28, 2010. This season was under monsoonal effect. It was concluded that in the case of cow dung, biogas production and methane fraction started producing from the second (15th day) and third week (20th day), of the slurry feeding inside the biogas chamber. The rates of biogas production increased from the 2nd week to 4th week and then continuously started to decrease due to substrate availability and bacterial activity in cow dung. In the case of kitchen waste, biogas started getting generated from the second day of the slurry feeding inside the biogas chamber but methane fraction was obtained on third day. Solid waste present in the kitchen waste was rapidly disintegrated by the microorganism resulting in the stopping of biogas production after the 15th day. The retention period of biogas production are maximum 15 days in the case of kitchen waste and for cow dung it is 90 days in batch system. Kitchen waste has less solid content (organic material) as compared to cow dung so it is rapidly decomposed by the anaerobic microbes. We have collected this 5 kg kitchen waste from staff canteen in IIT Delhi, Hauz Khas, New Delhi, India. This kitchen waste is mainly carbon and nitrogen content organic waste like rice, pulses, kidney beans, potato and bread. There has no role of humidity and precipitation under biogas production. Initially solar intensity increases upto two weeks but after this it decreases due to cloudy weather condition. The slurry temperature is always more than ambient temperature during the whole experimentation period in both biogas plants. Agrahari and Tiwari[2] have also attempted to test the performance of different ratios of kitchen waste in a metal make portable floating type biogas plant of volume capacity 0.018 m^3 for outdoor climatic condition of New Delhi, India . Each of the biogas plant having a 30 Kg slurry capacity in batch system for all measurements. hey concluded that kitchen waste is an excellent feedstock for a community level biogas programme, where large quantities of LPG which is used for cooking purposes can be saved. Also, as per them women spend 2-4 hours per day in searching and carrying the firewood. Once a biogas is installed, they will have much extra time for herself and her children. This would help in improving their quality. They will get more time for education and interesting activities outside the home. Biogas plants also improve health conditions in the homes. The annual time saving for firewood collection and cooking average to almost 1000 hours in each household provided with a biogas plant.

Bhatti et al.[3] have conducted exergy analysis of photovoltaic thermal integrated biogas system for the month of January for Srinagar (Kashmir), India. It was concluded that the system consisting of partially covered flat plate collectors as discussed in case (ii) is highly sustainable and efficient for functioning in harsh cold climatic conditions that exists in Srinagar (Kashmir), India because it produces both thermal as well as electrical energy simultaneously.

Bhatti et al.[4] have derived an analytical expression for slurry temperature (T_s) for an active N- flat plate collector integrated biogas (N-FPCIB) plant in order to evaluate the thermal performance of the system. The calculations were performed by using MATLAB 2010a. A detailed parametric analysis were performed. The effects of the design parameters such as the mass of the slurry (M_s), the length of the collector pipe (L), the number of collectors in series (N) and the mass flow rate of the slurry $(\dot{m}_f)$ had also been presented to design an active system. This N-FPCIB system had been observed to be self sustainable and showed a superior performance as compared to a simple biogas plant.

Bhatti and Tiwari[5] have derived an analytical expression for slurry temperature (T_s) for an active N- flat plate collector's (N-FPC's) integrated biogas plant has been derived for conducting exergy analysis. The calculations were performed by using MATLAB 2010a. In this study, it was found that the maximum annual exergy for flat plate collector and slurry were obtained for the months of June and July. The influences of various design parameters such as the mass of the slurry (M_s), the length of the collector pipe (L), the number of collectors in series (N) and the mass flow rate of the slurry $(\dot{m}_f)$; on slurry temperature has been studied for an optimum slurry temperature ($\sim 37°C$). Further the above parameters have also been optimised to design an active system for the heating of the slurry. This flat plate collector integrated biogas plant has been observed to be self sustainable and showed a superior performance as compared to a simple biogas plant.

Tiwari and Chandra[6] have reported that the rate of biogas production and the retention period are functions of slurry temperature. Subramanyam S.[7] have found that in northern India in winter season there is a 2°C drop in ambient air temperature (T_a) which either reduces or stops the production of biogas. Therefore, to increase the biogas production, the increase of slurry temperature (T_s) was recommended. Tiwari et al.[8] have suggested the slurry heating in the digester through a heat exchanger connected to flat plate collectors in series under forced mode of operation. In the International Energy Outlook (IEO) 2009[9], the total world consumption of marketed energy is projected to increase by 44% from 2006 to 2030.

Chen[10] conducted a case study in seven households (family farms) in the Meixian, Guangdong, South China region in 1994. The analysis showed that the three major components of this system functioned in harmony for the mutual benefit of these farmers and their environment. Pomelo (Citrus grandis) farming was the most profitable component of the system. Pomelo litter fall and pig dung were fed into the biogas digester underneath the pigsty. The digester supplied biogas as domestic fuel and sludge as fertilizer. Chickens were raised in the orchard where they fed on weeds and pests, and deposited excreta as fertilizer. Recycling of wastes improved soil texture, and thereby decreased input of chemical fertilizers. This system helped natural enemies function well in these case studies, and therefore decreased the application of pesticides. Serving as a key link between fruit farming and animal husbandry, biogas production alleviated the scarcity of rural energy in Meixian.

Usmani et al.[11] studied the performance of a greenhouse integrated biogas plant in order to reduce the thermal loss to ambient in harsh cold . Due to the lower temperature, biogas production decreases drastically and may even stop. Thus, to enhance biogas production, a higher digester temperature than ambient temperature is required.

2. OPERATIONAL PARAMETERS THAT AFFECT ANAEROBIC DIGESTION

The efficiency of anaerobic digestion is influenced by some critical parameters, thus it is crucial that appropriate conditions for anaerobic microorganisms are provided. The growth and activity of anaerobic microorganisms is significantly influenced by conditions such as exclusion of oxygen, constant temperature, pH-value, nutrient supply, stirring intensity as well as presence and amount of inhibitors (e.g. ammonia).

1. Temperature - The anaerobic digestion process can take place at different temperatures, divided into three temperature ranges: psychrophilic (below 20° C), mesophilic (30°C – 42°C), and thermophilic (43°C – 55°

C). There is a direct relation between the process temperature and the retention time. The temperature stability is decisive for anaerobic digestion. In practice, the operation temperature is chosen with consideration to the feedstock used.

Many modern biogas plants operate at thermophilic process temperatures (43^{o} C – 55^{o} C) as the thermophilic process provides many advantages, compared to mesophilic and psychrophilic processes, some them are as stated below:

- Effective destruction of pathogens.
- Higher growth rate of methanogenic bacteria at higher temperature.
- Reduced retention time, making the process faster and more efficient.
- Improved digestibility and availability of substrates.
- Better degradation of solid substrates and better substrate utilization.
- Better possibility for separating liquid and solid fractions.

The thermophilic process also has some disadvantages:

- Larger degree of imbalance.
- Larger energy demand due to high temperature.
- Higher risk of ammonia inhibition.

1. pH- values and optimum intervals - The pH-value is the measure of acidity/alkalinity of a solution (of the substrate mixture) and is expressed in parts per million (ppm). The pH value of the anaerobic digestion substrate influences the growth of methanogenic microorganisms. Experience shows that methane formation takes place within a relatively narrow pH interval, from about 5.5 to 8.5 , with an optimum interval between 7.0-8.0 for most methanogens. The value of pH can be increased by ammonia, produced during degradation of proteins or by the presence of ammonia in the feedstock.

2. Ammonia (NH_3) - It is an important compound, with a significant function in the anaerobic digestion process. NH_3 is an important nutrient, serving as a precursor to foodstuffs and fertilizers and is normally encountered as a gas, with a characteristic pungent smell. Proteins are the main source of ammonia in Anaerobic Digestion process. Too high ammonia concentration inside the digester, especially free ammonia, is considered to be responsible for process inhibition as it results in significant increase in the value of pH of the substrate inside the digester. Animal slurries have high concentration of ammonia. For its inhibitory effect, ammonia concentration should be kept below 80 mg/l. Methanogenic bacteria are especially sensitive to ammonia inhibition. The concentration of free ammonia is directly proportional to temperature, so there is an increased risk of ammonia inhibition for the processes operated at thermophilic temperatures, compared to mesophilic ones.

3. C/N Ratios - The carbon to nitrogen (C/N) ratio in the feedstock being used is a critical parameter because high nitrogen levels (greater than 80 mg/ as undissociated ammonia) with low C/N ratios can cause toxicity, and low levels (high C/N ratios) can inhibit the rate of digestion. A C/N ratio of 30:1 is considered to be optimal.

3. WATER HYACINTH (JALKUMBHI) IS AN EXCELLENT FEEDSTOCK FOR BIOGAS PRODUCTION

As can be seen from Fig. 1. aquatic plants due to over growth make the water bodies unfit and eventually take the shape of noxious aquatic vegetation, these may be called as aquatic weeds for example Water Hyacinth. Which has become a major problem in the water bodies in states like Assam, Kerala, West Bengal, Orissa, Madhya Pradesh and Uttar Pradesh.

Fig. 1: Water Hyacinth growing freely in stagnant water bodies

4. KITCHEN WASTE IS AN EXCELLENT FEEDSTOCK FOR BIOGAS PRODUCTION

In households located in rural or urban areas, a large amount of kitchen waste is obtained daily which can be utilized for better purposes.

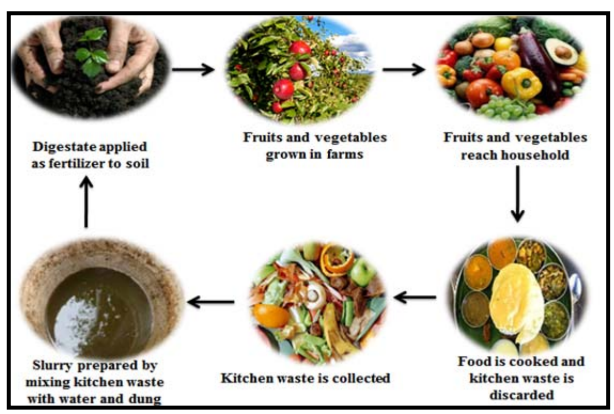

Fig. 2: Kitchen waste originates from crops and results in crop growth - the whole cycle

The major concern behind effective management of such solid waste is to ensure minimal risk to human health and the environment. Another concern is to look for economically feasible solutions. One of the methods is to convert this kitchen waste into energy by making it undergo anaerobic digestion.

As can be seen from Fig. 2. kitchen waste originates from soil and ultimately reaches the same in the form of digestate which is a by- product of anaerobic digestion. Another benefit of carrying out anaerobic digestion of kitchen waste is that the feedstock is available free of cost throughout the year. Also, this method would result in maximum energy recovery and lesser discharge making it an economically viable option.

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About the Author

Ms. Jasleen Bhatti is a research scholar at Centre for energy studies, Indian Institute of Technology Delhi, India. Ms. Bhatti was born on July 2, 1982 at New Delhi, India. She has completed her Masters in Analytical Chemistry from Dr. B. R. Ambedkar University, Agra (U.P.) India in 2007. Thereafter, she has worked with Genpact, American Express and Foundation for Innovation and Technology Transfer at I.I.T Delhi, India. She has over 4 years of rich experience in industrial research and operations. She joined as a Research Scholar under the supervision of Prof. G. N. Tiwari in December 2011. Her fields of interest include environment and development, socio economic impact assessment, sustainable energy, solar energy and its applications and biogas issues.

Dr. Gopal Nath Tiwari was born on July 1, 1951 at Adarsh Nagar, Sagarpali, Ballia (U.P.) in India. He has completed his M.Sc. (Physics) and Ph.D in 1972 and 1976 from Banaras Hindu University, Varanasi (U.P.), India. He is recipient of JRF, SRF and PDF from CSIR, Govt. of India during 1972-1978. He joined as a Research Associate at I.I.T Delhi, New Delhi in 1978. He is holding a position of Professor at Centre of Energy Studies, I.I.T Delhi, New Delhi since 1997. He had been energy expert in University of Papua New Guinea, Port Morshy, PNG during 1987-89. Dr. Tiwari was visiting European Fellow at University of Ulster, Northern Ireland (UK) during 1993 for six months. He has visited many other countries namely Canada, USA, Italy, Australia for short terms as an energy expert. He is recipient of National Hari Om Ashram Prerit S.S. Bhatnagar Award in 1982 for his seminal contribution in the field of solar distillation. Dr. Tiwari has published to his credit more than five hundred research papers in different National and International Journals. He is the author of eight text and reference books on solar energy, greenhouse, passive heating/cooling, Renewable Energy Resources etc. He had been nominated for International IDEA Award for his work on solar distillation in 1992. Dr. Tiwari has supervised more than seventy five Ph.D students in various research areas of interest. His current areas of research interest are Solar Energy and its applications in solar distillation, passive heating/cooling of building, controlled environment greenhouse, aquaculture, water/air heating system, crop production and drying, renewable energy resources, energy analysis of all systems, techno-economic analysis, hybrid PV/thermal systems, clean environment and rural energy etc.