International Journal on Emerging Technologies 11(3): 644-647(2020)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Design Approach of Bio-Gas Digester for Energy Harvesting by Municipal Solid Waste Management in Agartala City

Sukanta Chakraborty[1], Manish Pal[2], Kaberi Majumdar[3] and Pankaj Kumar Roy[4]
[1]Junior Engineer, Public Works Department, Govt. of Tripura, Tripura- 799005, India.
[2]Professor, Civil Engineering Department,
National Institute of Technology Agartala, Tripura- 799055, India.
[3]Assistant Professor, Electrical Engineering Department,
Tripura Institute of Technology Narsingarh, Tripura- 799009, India.
[4]Professor, School of Water Resources Engineering,
Jadavpur University, Kolkata- 700032, WB, India.

(Corresponding author: Sukanta Chakraborty)
(Received 26 March 2020, Revised 08 May 2020, Accepted 11 May 2020)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Municipal solid waste is considered as a potential source of energy as it can yield a good quantity of bio-gas through organic digestion process. At the same instant this mode of waste management can be implemented in large scale for the developing countries where the fraction of organic materials is higher in solid waste. Application of appropriate design principle as well as the optimization tools upon the controlling parameters of a particular biogas digester results in a drastic development of energy recovery from municipal solid waste (MSW). The present study illustrates the categories as well as the design aspects of biogas digester considering the baseline data of Agartala city, India. The design approach narrates the necessity of 18 nos of biogas digesters of 7.60 m dia and 7.00 m height for Agartala city by the year 2021. However shortage of field base data of solid waste production & characterization for newly developed urban bodies of the sate emerges as a major challenge in formulizing the bio-gas production plan for such areas. The study will serve as a baseline study for further project planning regarding energy source generation through bio-gas technology in urban and semi urban zones.

Keywords: MSW, Bio-gas, Bio-gas Digester, Energy.

Abbreviations: MSW, Municipal Solid Waste; BOD, Biochemical Oxygen Demand; COD, Chemical Oxygen Demand.

I. INTRODUCTION

The rapidly increasing population along with migrants from rural areas and industrial expansion, lead to enormous increase in the amount of municipal waste resulting in socio-economic and environmental issues worldwide [1]. Overall management of Municipal Solid Waste (MSW) is a challenge rather than an opportunity to obtain other commodities like recycling materials, energy etc [2]. Relying on the socio-economic status, climate, and energy sources, MSW composition varies from one country to another. Generally it is found that, the proportion of organic waste is highest in the low-income countries compared to the high income countries, where MSW is composed by inorganic materials in a predominant manner [3]. The World Bank estimates a report in which it is mentioned that currently 1.3 billion tonnes of waste is generated per year all over the world; and by 2025 this amount will increase to 2.2 billion tons per year [4]. This shows an urgent need of effective deftness to treat the increasing rate of MSW generation around the globe. However, in developed countries waste is used by a resource to produce energy, heat, fuel and compost, where as, in developing countries collection, transport and disposal of waste are current issues. The Waste-to-energy technologies (WTE-T) are promising technologies, particularly for the developing countries, to switch waste into resources. In the developed world Waste-to-energy technologies are being a part of their Integrated Solid Waste Management Systems to not only produce other by-products but also to locate global warming and climate change [5]. Waste-to-energy (WTE) processes aims to recuperate the energy from the waste through either direct combustion (e.g., incineration, paralysis, and gasification) or by producing combustible fuels in the forms of methane, hydrogen, and other synthetic fuels. Biogas which is a clean and renewable form of energy is produced through anaerobic degradation in a very complex process that requires certain environmental conditions as well as different bacteria populations [6, 7]. Conventionally Biogas reactors commonly known as digesters are utilized for generating biogas from organic feed through a series of bio-chemical reactions. Bio gas is a potential mode of solid waste management that ensures the energy recovery in a much cleaner manner which is eco-friendly too.

Several controlling factors are normally considered in the design of suchlike digesters suitable for the biodegradation and indeed stabilization of MSW, with the attendant production of biogas, and an in depth analysis both qualitatively and quantitatively is needed for developing waste to energy plan for a city by means of biogas production. In the present study, an attempt is made for analyzing such factors essentially related to biogas production considering the case study of Agartala city.

II. ENERGY STATISTICS OF INDIA

As on 31.03.16, the estimated coal reserve in India were 308.80 billion tonnes and that of crude oil stood at 621.10 million tonnes (MT). The estimated reserves of Natural Gas in India as on 31.03.2016 stood at 1227.23 Billion Cubic Meters (BCM) as against 1251.90 BCM as on 31.03.2015. There is high potential for generation of renewable energy from various sources like wind, solar, biomass, small hydro etc in India. The total potential for renewable power generation in the country as on 31.03.16 is estimated at 1198856 MW including Biomass power of 17,538 MW (1.46%), 5000 MW (0.42%) from bagasse-based cogeneration in sugar mills, and 2556 MW (0.21%) from waste to energy. Despite of having a good potential the contribution of the state of Tripura is merely 0.18% including a share of 3 MW of biomass based energy and 2 MW of waste to energy in the wise distribution of renewable energy, as per the reports of the Ministry of New and Renewable Energy. The commercial sources shows the production of energy in peta joules which mentions that Coal was the major source of energy, accounting for about 70.25% of the total production during 2015-16. Crude Petroleum was the second (11.24%), while Natural Gas (9.02%) was the third major source. Fig. 1 depicts the gradual increment of availability of electricity in the country [8].

The growing trend shows that the demand of electricity in the country is increasing in a steady rate with the urban as well as rural development schemes. To cope up with this trend it becomes an urgent necessity to increase the electricity production at the same pace. At the same instant it is also essential to ascertain the sustainability with respect to the energy resources of the country. In this particular platform, the renewable sources appear to as a promising alternative to fulfil the growing energy demand. With this concept the option of biogas and waste to energy can be further harnessed in order to extract maximum output from those sources.

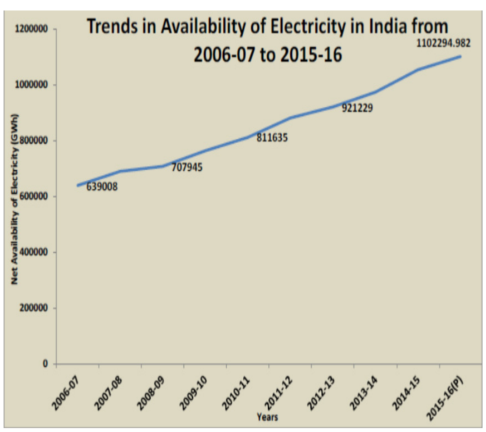

Fig. 1. Electricity availability statistics of India [8].

III. MECHANISM OF BIOGAS PRODUCTION

Biogas technology is an idealized technology which inflicts an attractive route to utilize a range of lingo-cellulosic biomass and other organic refuses, such as crop residues, vegetable wastes, food waste and even the organic fraction of MSW. Biogas production process, an anaerobic fermentation process, involves decomposition of biomass, through four groups of microorganisms into energy and manure [9].

Fig. 2 shows diagrammatically the four steps involved in the biogas production process along with a schematic representation of major chemical reactions involved [10].

Hydrolysis is the foremost step of biochemical reaction involved in the production of biogas. The organic molecules of biomass which are complex in nature (carbohydrates, lipids, and proteins) are broken down by cellulolytic, lipolytic, and proteolytic bacteria, respectively, into smaller unit like monomer sugars, amino acids, alcohols, and fatty acids. The bacterial population undertaking such reactions belong to genera *Bacteroides, Lactobacillus, Propionibacterium, Sphingomonas, Sporobacterium, Megasphaera, Bifidobacteriumetc* [11]. The acidogenic group bacteria further break down the products obtained in hydrolysis, into short chain organic acids like lactic acid, propionic acid , and butyric acids along with gases like NH_3, H_2S, CO_2 and H_2 in the acidogenesis stage of biogas production involving facultative and obligate anaerobic fermentative bacteria, like *Clostridium* spp., *Desulphovibrio* spp., *Corynebacterium* spp., *Lactobacillus* spp., *Staphylococcus* spp., *Escherichia coli* etc [12]. Acetogenesis is the next step to produce biogas, in which the volatile fatty acids and ethanol are further converted into acetic acid, hydrogen, and CO_2 by acetogenic bacteria [10]. In the final stage the oxygen demand (BOD, COD) of residual waste decreases by transforming acetic acid to the gaseous products like CH_4 and CO_2. Some microbial species, which are known ashydrogenotrophic methanogens, can generate methane from the CO_2 and H_2 formed as products in previous stages during the final stage [13].

The chemical kinetics is an important tool to analyze any sort of chemical reactions. Accordingly certain kinetic models have been manifested to explain the anaerobic fermentation process. Among these the Monod model is one which is presented as most prominent kinetic relationship where it explains a hyperbolical relation among the exponential microbial growth rate and substrate concentration. In this model, the two kinetic parameters, particularly, microbial growth rate and half velocity constant determines, and predict the circumstances of the timing of highest biological activity and its cessation. The rate of substrate utilization can be evaluated by this model using the following equation [14]:

$r_S = q_{max}Sx/K + S,$

Where, S is the limiting substrate concentration, K is half constant, x is a concentration of bacterial cells, and q_{max} is the maximum substrate utilization rate.

The aforesaid equation is contextual for low substrate concentration. However, for high substrate concentration, the equation is rewritten as:

$r_S = q_{max} \cdot x.$

An alternative equation was developed by Hashimoto to describe the kinetics of methane fermentation regarding certain parameters. In accordance with this equation, for a given loading rate S_o/q everyday volume of methane per size of digester depended on the biodegradability of the biomass and kinetic parameters μm and K [10].

$r_V = (B_o \,´\, S_o/q) \cdot \{1-(K/q\ \mu m - 1 + K)\}$

where, r_v is volumetric methane production rate, $[CH_4]^{-1}$ digester d^{-1}

S_o is influent total volatile solids (VS) concentration, gl^{-1}

B_o is ultimate methane yield
q is hydraulic retention time d^{-1}
μm is maximum specific growth of microorganism d^{-1}
K is a kinetic parameter.

IV. TYPES OF BIOGAS DIGESTORS

There are three prime technologies for biogas plant. These are:
1. Floating type model Biogas plant.
2. Plug flow digester.
3. Fixed dome model biogas plant.

In 1956, a design of floating drum biogas plant popularly known as Gobar Gas plant was developed by Jashu Bhai J. Patel in India which the Khadi and Village Industries Commission (KVIC) of India approved in later years and soon it became popular by the name KVIC model [15]. The tank consists of cylindrical dome which is made of stainless steel that floats on the slurry and collects the gas generated. The gas can be taken out by an outlet pipe. The plug-flow type of anaerobic digester having a narrow horizontal tank in which manure is added at a constant rate and that force other material to move through the tank and be digested. Generally the plug flow digesters are made up of reinforced concrete, steel or fiberglass. Fixed dome also called as Chinese model biogas plant or drum less digester was built in China during the year 1936. Fixed dome digesters are usually built underground with cement concrete [16]. The used slurry is expanded and is overflowed into the overflow tank.

V. DESIGN OF BIOGAS DIGESTER

The design of the digester is done for MSW of Agartala city with the data available in different literatures.
The design of the digester has been divided in three parts
Part 1: Design of Biogas Digester
Part 2: Design of Gas Collecting Dome
Part 3: Design of Inlet and Outlet Arrangements
At the very first step the daily inflow of slurry along with the detention time is calculated using the following equation

$$t = \frac{1}{kd.n.\sigma} - 1$$

where,
t = detention time
k_d = rate co-efficient of sludge BVSS anaerobic destruction = 0.272 (1.048) (θ^{-33})
n = residual fraction of BVSS at the end of digestion
σ = Correction factor for actual raw sludge BVSS content
Using these values the volume, surface area and detailed size of the digester is calculated. Further the size of gas dome is calculated based on the theoretical yield of biogas per day adding sufficient provision of free board. Suitable inlet outlet valve should be provided in the tank in order to control the flow pattern in both of the ways [17-19].
The predicted MSW generation of Agartala city for the year 2021 is 249.41 MT/day having a organic percentage of 55.46% approximately [20]. A design of pilot unit for stated waste quantum of biogas plant framed depending upon certain assumptions is presented in Table 1.

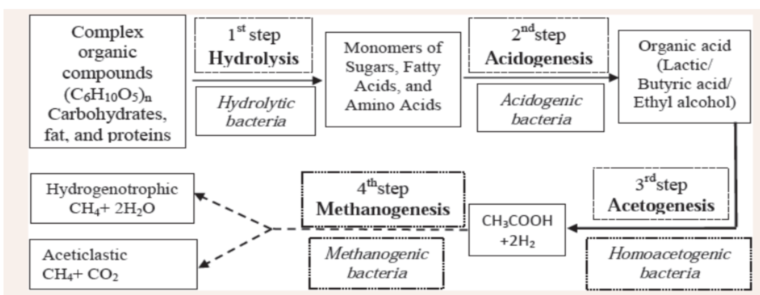

Fig. 2. Schematic representation of steps involved in Biogas Production [9].

Table 1: Design of Biogas Digester.

Total quantity of MSW	**249.41**	**MT**
Organic Fraction	55.46%	
Quantum of MSW for Biogas production	138.32	MT
	138320	Kg
Assuming 6 nos of digester in each zone of Agartala Municipal Corporation, no. of digesters	18	
Waste quantity per reactor	7684.44	Kg
Add 20% water for diluation	1536.89	Kg
Waste inflow	9221.33	kg/day
	9221.33	lit/day
k_d (Assuming digester temperature to be 38°C)	0.344	
N (Assumed)	0.15	
Σ (Assumed)	1	
Detention time (t)	20	days
Volume of each digester	184.43	cum
Assuming hydraulic loading rate (HLR) for an anaerobic digester as 200L/day/m², surface area of each reactor	46.11	sqm
Approximate diameter corresponding to the surface area	7.60	m
Height of the digester adding necessary free board	7.00	M

VI. CONCLUSION

A sizeable part of organic waste is converted into a convenient source of energy and it is a precious asset. The simultaneous generation of digestate, which can be turned into a soil amendment, may be an added advantage. Furthermore, the output efficiency of such digesters can be maximized by appropriate design and optimization of controlling factors. In the present study different types of digesters has been explained and the design step of commonly used biogas digester has also been discussed in the light of energy statistics of the country considering the case study of Agartala city. The case study indicates that theoretically 18 nos of biogas digesters of 7.60 m dia and 7.00 m height are essential to digest the organic fraction of MSW of Agartala city by the year 2021. This particular approach can be utilized in the establishment of biogas plants to convert municipal solid waste into energy by considering the field base data and optimization techniques which can be further improved by simulation studies in future course of studies.

Conflict of Interest. No.

REFERENCES

[1]. Vitorino de Souza Melaré, A., Montenegro González, S., Faceli, K., & Casadei, V. (2017). Technologies and decision support systems to aid solid-waste management: A systematic review. *Waste Management, 59*, 567-584.

[2]. Portugal-Pereira, J., & Lee, L. (2016). Economic and environmental benefits of waste-to-energy technologies for debris recovery in disasterhit Northeast Japan. *Journal of Cleaner Production, 112*(5), 4419-4429.

[3]. Trang, P. T. T., Dong, H. Q., Toan, D. Q., Hanh, N. T. X., & Thu, N. T. (2017). The Effects of Socio-economic Factors on Household Solid Waste Generation and Composition: A Case Study in Thu Dau Mot, Vietnam. *Energy Procedia, 107,* 253-258.

[4]. Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management.

[5]. Diego Moyaa, Clay Aldás, GermánicoLópez, Prasad Kaparaju (2017). Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-To-Energy Technologies. *Energy Procedia, 134*, 286–295.

[6]. Salomon, K. R., & Lora, E. E. S. (2009). Estimate of the electric energy generating potential for different sources of biogas in Brazil. *Biomass and Bioenergy, 33*(9), 1101-1107.

[7]. Akinbani, J. F. K., Ilori, M. O., & Oyebisi, T. O. (2001). Biogas energy use in Nigeria: current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews, 5*(1), 97-112.

[8]. Energy statistics (2017). Central Statistics Office Ministry of Statistics and Programme Implementation, Government of India, New Delhi.

[9]. Zeikus, J. G. (1980). Microbial populations in digestors, in Anaerobic Digestion. DA Stafford, BI Wheatley and DE Hughes, Editors. *Applied Science Publishers: London*, 61-89.

[10]. Prasad, S., Rathore, D., & Singh, A. (2017). Recent Advances in Biogas Production. *Chem. Eng. Process Tech, 3*(2), 1038.

[11]. Sharma, K. R. (2008). Kinetics and Modeling in Anaerobic Processes, in Anaerobic Technology for Bioenergy Production: Principles and Applications, S K Khanal Editor. Wiley-Blackwell: Ames, Iowa.

[12]. Vavilin, V. A., Qu, X., Mazéas, L., Lemunier, M., Duquennoi, C., He, P., & Bouchez, T. (2008). Methanosarcina as the dominant aceticlastic methanogens during mesophilic anaerobic digestion of putrescible waste. *Antonie van Leeuwenhoek, 94*, 593-605.

[13]. Alexander, M. (1961). Introduction to Soil Microbiology. John Wiley & Sons, Inc.

[14]. Nagamani, B., & Ramasamy, K. (2010). Biogas production technology: An Indian perspective Fermentation Laboratory. Tamil Nadu Agricultural University, Coimbatore 641003, India.

[15]. Singh, S. P., Vatsa, D. K., & Verma, H. N. (1997). Problems with biogas plants in Himachal Pradesh. *Bio resource Technology, 59,* 69–71.

[16]. Santerre, M. T. & Smith, K. R. (1982). Measures of appropriateness The resource requirements of anaerobic digestion (biogas) systems. *World Dev.*, *10*, 239–261.

[17]. Bhole, A. G., & Ingole, N. W. (2000). Comparative study of biogas production from water hyacinth by single dysphasic tri-phasic digestion process. *Journal of IWWA, 32*(2), 132-140.

[18]. Thomsen, A. B., Lissens, G., Baere, L., Verstraete, W. & Ahring, B. (2004). Thermal wet oxidation improves anaerobic biodegradability of raw and digested bio waste. *Environmental Science and Technology, 38,* 3418-3424.

[19]. Ingole, N. W. (2015). Development and Design of Biogas Plant for Treatment of Kitchen Waste. *IJREST*, *1*(5), 132-140.

[20]. Chakraborty, S., Majumdar, K., Pal, M., & Roy, P. K. (2019). Assessment of Bio-Gas from Municipal Solid Waste for Generation of Electricity- A case study of Agartala city. *IJAER, 14*(6), 1265-1268.

How to cite this article: Chakraborty, S., Pal, M., Majumdar, K. and Roy, P. K. (2020). Design Approach of Bio-Gas Digester for Energy Harvesting by Municipal Solid Waste Management in Agartala City. *International Journal on Emerging Technologies*, *11*(3): 644–647.