IFERP
connecting engineers... developing research

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 1, May 2016

Comparative Study of Various Digesters for a Rural Community Biogas Plant

[1] Rohan N. Khedekar, [2] Prashant Jain
[1] Student, M.Tech (Energy Engineering), [2] Faculty
[1][2]Department of Mechanical Engineering,
K. J. Somaiya College of Engineering, Mumbai-India

Abstract: -- **Energy requirement is increasing and fossil fuels resources are limited, therefore we should consider renewable energy as solution to our problem; but till today renewable energy is economically not an attractive option. Biogas is renewable fuel which generates from decomposition of bio-degradable waste under anaerobic condition; such condition can be maintained by biogas digester, which is important part of biogas plant and having 60-70% cost of total plant cost. Biogas and slurry produced from digester are renewable fuel and organic fertilizer; which makes it economical option, by choosing right digester it can be more economical, therefore The objective of this paper is to discuss the performance of various types of digester and a comparison between different digester. This comparison gives idea of which digester is better option for community Biogas Plant. Also it can empower communities by providing them with tools they can maintain and use themselves.**

Index Terms - **Bio-degradable Waste, Anaerobic Digestion Process and Parameter, Biogas Digester, Field Study**

I. INTRODUCTION

Problems of growing energy requirement and increasing cost of fossil fuels has lead us to find and use renewable energy sources and the development of new technological processes of energy production. One of the renewable energy sources is the biogas. Biogas is an environmentally friendly fuel which is part of nature's own cycle. When organic materials such as animal, agricultural, domestic, and industrial wastes decompose under anaerobic conditions then biogas produced.

Biogas digesters have low cost and maintenance is easy. This makes them an excellent tool for organizations which attempt to empower communities by providing them with tools they can maintain and use themselves [1].

II. LITERATURE REVIEW

The discovery of biogas can be first traced back to the 17th century when Van Helmot noticed flickering lights under the surface of swamps and connected it to a flammable gas produced by decaying organic matter [4].

The chemical composition of methane was established by Henry and Davy Dalton in 1810 via methane from coal mines. By 1884, a student of Pasteur in France, Gayon, had anaerobically produced biogas by suspending cattle manure in a water solution at 35 Celsius. At that time he was able to obtain 100 liters of biogas per meter cubed of manure [4]. The discovery and separation of certain kinds of bacteria involved in the digestion process were begun as early as 1906 by Sohngen. By the 1920's Buswell was able to track and record the movement and uses of nutrients such as nitrogen through the digestion process [4].

III. ANAEROBIC DIGESTION PROCESSES

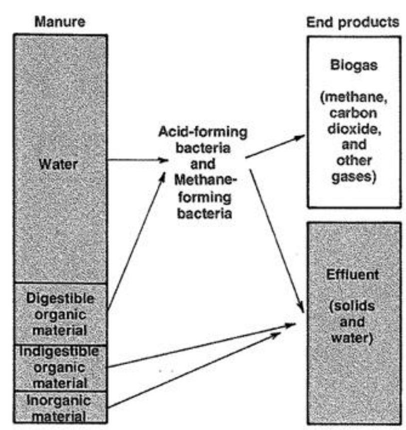

Fig. 1. The breakdown of manure in an anaerobic digester

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 1, May 2016

A. Hydrolysis

Hydrolysis is the first step of Anaerobic Digester, in which polymers like carbohydrates, lipids, nucleic acids and proteins are converted into glucose, glycerol, and pyridines. Micro-organisms excrete hydrolytic enzymes, converting bio-polymers into simpler and soluble compounds. Different micro-organisms are involved in hydrolysis, which decompose the undissolved particulate material. The products resulted from hydrolysis are further decomposed by the micro-organisms involved and used for their own metabolic processes [1].

B. Acidogenesis

During Acidogenesis, simple and soluble polymers are converted by acidogenic (fermentative) bacteria into methanogenic substrates. Simple sugars, amino acids and fatty acids are converted into acetate, carbon dioxide and hydrogen (70%) as well as into volatile fatty acids (VFA) and alcohols (30%) [1].

C. Acetogenesis

Simple and soluble compound, which cannot be directly converted to methane by methanogenic bacteria, are converted into methanogenic substrates during Acetogenesis. VFA and alcohols are oxidized into methanogenic substrates like acetate, hydrogen and carbon dioxide [1].

D. Methanogenesis

Methanogenesis is an important step in the entire anaerobic digestion process, as actual biogas production takes place in it. It is the slowest bio-chemical reaction of the process. Methanogenesis is severely affected by operation conditions. Composition of feedstock, feeding rate, temperature, pH, Digester overloading, temperature changes and large entry of oxygen can result in termination of methane production [1].

IV. ANAEROBIC DIGESTION PARAMETER

The effectiveness of AD is affected by some basic parameters, thus it is important that favorable conditions for anaerobic micro-organisms are provided. The development and activity of anaerobic micro-organisms is significantly affected by conditions such as exclusion of oxygen, temperature fluctuation, pH-value, nutrient supply, agitation intensity as well as presence of amount of inhibitors (e.g. ammonia). The methane bacteria are anaerobic in nature, so that the presence of oxygen into the digestion process must be strictly avoided [1].

A. Temperature

The AD process can work at different temperatures, there are three temperature ranges: psychrophilic (below 25^0C), mesophilic (25^oC – 45^oC), and thermophilic (45^oC – 70^oC) [1].

In thermophilic range biogas production per unit weight is maximum. Ammonia toxicity rises with rising temperature and can be relieved by decreasing the process temperature, but temperature should not decrease to 50°C or below, if it does then growth rate of the thermophilic micro-organisms will drop [1].

B. Volatile Fatty Acid (VFA)

The VFA are intermediate compounds which produced during acidogenesis, with a carbon chain of up to six atoms. Acetate, propionate, butyrate, lactate are present inside digester. Accumulation of VFA occurs due to instability in AD process, which can lead to a drop of pH-value. However, the accumulation of VFA will not always lead to drop of pH value, due to the buffer capacity of the digester [1]. Biogas production is directly proportional to amount of VFA inside digester.

C. pH value

In acidogenesis and Methanogenesis stages optimal pH values are different. In acidogenesis, pH falls because acetic, lactic and propionic acids are formed. Acidic environment as pH below 6.4 is toxic for methane-forming bacteria. An optimal pH range for all stages is between 6.4 and 7.2 [1].

D. Carbon to Nitrogen Ratio (C:N)

C: N ratio represents how much amount of carbon and nitrogen present in organic material and relationship between them. If C: N ratio is high then rapid consumption of nitrogen takes place by the Methanogenesis and results in a lower gas production. On the other hand, if C: N ratio is lower than ammonia is accumulated and pH values exceed 8.5, which is toxic to methanogenic bacteria. Optimum C: N ratios in anaerobic digesters are between 20 and 30, which can be achieved by mixing waste of low and high C: N ratio [1].

IFERP connecting engineers... developing research
ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 1, May 2016

V. BIOGAS DIGESTER

In a biogas digester, anaerobic digestion of bio-degradable waste take place and biogas is produced, and then gas is stored in storage container. The biogas can be used as fuel for cooking, process heating, and electricity generation. The slurry which comes out from biogas digester after the fermentation process is complete can be used as fertilizer in farm; it helps to reduce use of chemical fertilizer [1].

There are many digester design present today, so we will consider digester with basic design.

A. Floating Drum Biogas Digester (KVIC Model)

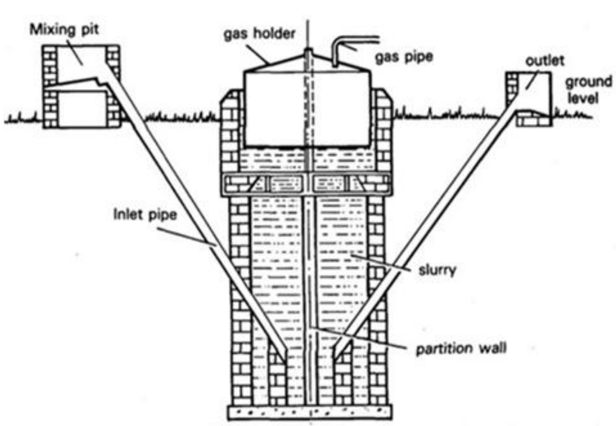

Fig. 2. Floating Drum Biogas Digester (KVIC Model) [7].

In figure 2 we can see that partition wall help to optimize gas production from two stages. In the first stage, acid forming bacteria cut down complex, organic polymers present in bio-degradable waste in to small chain of volatile fatty acid. In second stage, methane forming bacteria digest volatile fatty acid and generate methane and carbon dioxide [7].

The floating drum in which gas is stored is made up of mild steel sheets or reinforced fiber glass can be used to save some cost. When gas is not in floating drum then it sinks in due to its own weight and when gas is generated then drum rises and floats freely on the surface of slurry [7].

In water-jacket plants drum floats on water jacket outside digester instead of slurry. They are easy to maintain and drum never get stuck in a scum layer. Water-jacket plants has long useful life and aesthetic appearance. They are recommended for use in the fermentation of night soil.

B. Fixed Dome Biogas Digester (Janata Model)

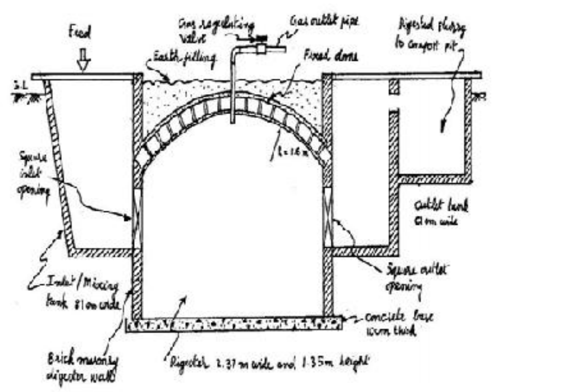

Fig. 3. Fixed Dome Biogas Digester (Janata Model)[13].

Design of this plant is very simple so local mason can construct it. While constructing locally available good quality material like bricks and cement should be used otherwise due to pressure fluctuation cracking may occur in dome and it will lead to leakage of biogas.

In this model higher total solid waste can be used when compared with KVIC model. This plant life is longer than KVIC models if plant is built with good quality material. In this plant MSW (municipal solid waste) and plant residues can also be used. The plant design has well sort of digester build by bricks and cement. It has dome shaped roof which remains below the ground level [13].

At two sides of digester, there are rectangular openings confronting each other and coming up to somewhat over the ground level, they work as inlet and outlet of the plant. For gas outlet pipe with valve is given on dome top. The biogas is gathered in the limited space of the altered dome; henceforth the weight of gas is much higher, which is around 90 cm of water section [13].

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 1, May 2016

C. Fixed Dome Biogas Digester (Deenbandhu Model)

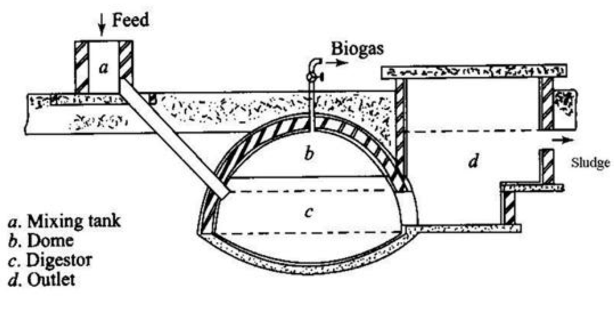

Fig. 4. Fixed Dome Biogas Digester (Deenbandhu Model)[AFPRO].

Deenbandhu model was created in 1984, by Action for Food Production (AFPRO), a deliberate association situated in New Delhi. Whole biogas program get success in India as it reduce the expense of the plant by half of that of KVIC model and therefore poor farmers can get benefited. By joining the fragments of two circles of various diameters across their bases, they minimizing the surface area and therefore cost also decreases [AFPRO].

The Deenbandhu biogas plant has a hemispherical dome sort of gas holder, not like the floating drum of the KVIC model. The dome is produced using pre-manufactured fortified concrete and appended to the digester, which has a bended base. The slurry is allowed to flow from a blending tank through a channel funnel associated with the digester. After maturation, the biogas gathers in the space under the dome. It is taken out for use through a channel associated with the highest point of the dome, digested slurry, turns out through an opening in the side of the digester. Around 90 percent of the biogas plants in India are of the Deenbandhu type. The expense of a Deenbandhu plant having a limit 2 m3/day is about Rs.8000 [AFPRO].

D. Plug Flow Digester

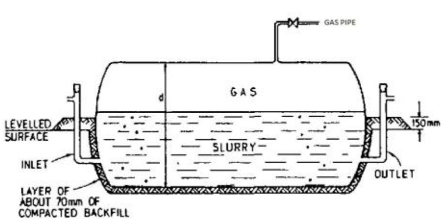

Fig. 5. Plug Flow Digester [7].

Design of Plug flow digesters is horizontal so it has ability to treat animal manure with 11-14% Total Solids. In this design Length to width ratio for flow path for manure should be in the range of 3.5:1 to 5:1 [6].

Plug flow digesters are built either above or under the ground, or half part is above ground and rest is below ground. Above ground digesters made up of steel structures to withstand the pressure. Underground digester is made up of bricks and cement so; it is cheaper to build the digester underground. Above ground digesters are easy to Maintain; a black coating on digester will help provide some heating effect by solar radiation [7].

Mechanical stirrer is usually used in continuously Stirred Tank Reactor (CSTR); as the capacity of the plug flow digester increases it required proper agitation and mixing of feedstock inside the digester; also it helps to increase production rate of Biogas. It increases the operating cost and maintenance cost, but it is balance by increased Biogas production rate.

E. BARC's a Nisargruna plant

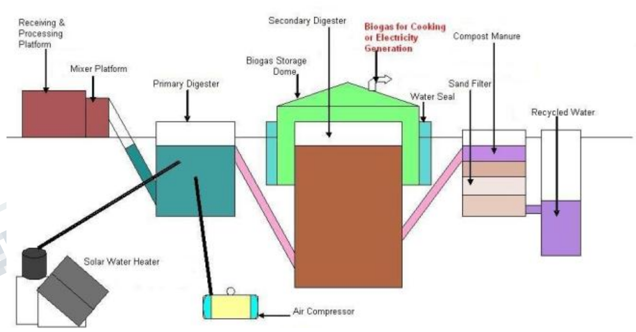

Fig. 6. Basic layout of Nisargrun Biogas Plant [22]

Senior scientist Dr. Sharad Kale at Nuclear Agriculture and Biotechnology Division of Bhabha Atomic Research Centre (BARC) in Mumbai; have developed Nisargruna biogas plant for renewable energy.

Technical details of the plant

A crusher with 5 HP motor(s) for crushing if we are using canteen waste or municipal solid waste, mixing tank, a primary digester tank, an air compressor, a flat plate collector, a secondary digestion tank, a gas delivery system, manure pits, a tank for recycling water, a water pump, slurry pump and a gas utilization system these are major components of BARC's a Nisargruna plant. The waste is thoroughly mixed in a mixer using water. (Dr.S Kale, 2005) [23].

Pre-treatment Stage

This slurry enters the primary digester tank and high temperature water is introduce through flat plate collector where aerobic thermophilic bacteria proliferate and convert part of this waste into organic acids like acetic acid, butyric acid, propionic acid and formic acid; they also breakdown some toxic products that may be present in the waste. An aerobic condition is maintained by air compressor [23].

Anaerobic Digestion Stage

In the second stage strictly anaerobic condition is maintained, where methane forming bacteria produced biogas by digesting organic acids which produced in first stage. The two stage digestion improves the percentage of methane in biogas, up to 90%, thereby increasing its fuel quality when burned. However, this purity is dependent on how effectively the primary digester temperatures are maintained and the quality of the waste that enters the system [23].

Table I. Comparative Performance of Various Digesters

SR. NO.	Digesters	Cost Rs.*	Biogas production (lit/kg)	Design	Capacity (m3/day)	Retention Time
1	Floating Drum Biogas Digester	14000	34 [10]	Moderate	1-100 [15]	35-50 days [14]
2	Fixed Dome Digester (Janata Model)	10000-11000	28 [13]	Simple	1-100 [13]	35-45 days [14]
3	Fixed Dome Digester (Deenbandhu Model)	8000	25 [14]	Simple	1-10 [13]	35-45 days [14]
4	Plug Flow Digester	10000 [13]	33.5 [13]	Simple	2-80 [16]	20-25 days [11]
5	BARC's Nisargruna plant	NA	50-60 [22]	Moderate	5-250 [22]	21 days [22]

VI. FIELD STUDY

A. Bio-methanation Plant in Pune

Decentralized Bio-methanation-Cum power Generation Plant of Capacity is 1*5 TPD is situated at Ward No. 34, Pune, to Treat Segregated Organic Municipal Solid Waste (MSW). The basic reason of setting up this plant is to treat the wet organic wastes in a decentralized manner at source point itself in a most environmental friendly manner. This helps Pune Municipal Corporation (PMC) directly in saving on transportation of such wastes to the landfill site which is at 22 Kms [17].

A case study has been carried out at Bio-Methanation Plant, at Model Colony Pune with an objective to estimate Capacity of plant and observation and understanding of different processes done on bio-degradable waste in the plant; also what is biogas scrubbing process. During the observation, various analytical data, has been accumulated from the data collection center of the site.

Bio-methanation Process

The major portion of MSW is the organic waste (40-60%) which can be easily treated by anaerobic digestion in digester.

Apart from this, the solid wastes generated in urban areas from vegetable markets, hotels, hostels, kitchen wastes etc. are best option for this process due to the presence of high moisture and organic fractions (up to 90%).

The total solids in the organic waste decompose rapidly (i.e. is highly putrescible) and therefore these wastes can be treated by Bio-methanation process (more commonly called Anaerobic Digestion, AD) in more effective manner [17].

Data Collected

The Pune Plant involves the following data which includes its process components to its product generation

Process Components:

Table II. Components of Decentralized Bio Methanation Plant [17]

Sr. No.	Component Name	Quantity	Materials involved with Specification
1	Waste Reception and Fine Segregation Section	1	-
2	Mechanical Crushers	2	5 HP Motor
3	Two Stage Anaerobic Reactors	200 Cum	With Aeration, Biogas & Leachate Recirculation facility
4	Manure Handling Section	35 m^2	In BBM
5	Biogas Collection Section	2 Nos. 75 Cum. Each	Neoprene Rubber with enclosure
6	Biogas Cleaning System	1	CO_2 & H_2S Scrubbers, Pressure Vessel & Vacuum Pump.
7	Power Generator	40 kVA	100% Biogas based Indian Engine
8	Leachate Recirculation System	1	-
9	Solar Water Heating System	500litres/day	-

Expected Biogas, Electricity and Manure Generation:
Table III. Product generation at Bio Methanation Plant [17]

1	Plant capacity	1*5 TPD per day segregated organic biodegradable municipal solid waste
2	Type of process	Bio-methanation through two stage process
3	Biogas generation	300 Cum/day
4	Electricity generation	375kWh/day
5	Manure generation	500kg/day(50% moisture basis)

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 1, May 2016

B. Community biogas plant by "SUMUL" in Gujrat

This plant was constructed by Surat District Co-operative Milk Producer's Union Ltd, abbreviated as "SUMUL" with the support and co-operation of local villagers. The plant produces biogas which is distributed to the villagers through underground pipes. The gas supplied is used as a fuel for cooking by the villagers. The production of vermicompost from the output slurry makes this project economically viable. The Ministry of New & Renewable Energy took a note of this project and formulated a scheme which is known as BFFP (Biogas & fertilizer plant) [15].

Birth of the idea

Idea of the biogas plant was triggered in order to have a proper disposal system for the cow dung. Before the establishment of biogas plant, the dung would be collected in households, streets, empty spaces and left there itself till it was sold to some external contractor. The contractor would collect the dung once in a year which resulted in dung being piled up in large quantities. This was an unhygienic practice and raised health concerns. The health hazard was further emphasized by subsequent outbreak of *bird flu* in Navapur. Thus, these public health and sanitation issues were the main contributing factors for the construction and smooth functioning of the plant [15].

Biogas production

Every morning around 6:00 am villagers bring the dung collected during the previous day to the plant. Normally, this is carried in overhead containers (*ghamelas*) by men or women. In case the beneficiary's stall is far from the plant, he has the option to deliver the cow dung to the plant on a weekly basis. Gas is generated through Floating Drum Bio-Digester having a capacity of 85 m^3. The gas is supplied to the beneficiaries daily twice-once at 6 am and next at 6 pm. The gas generated daily is sufficient enough to give a continuous supply to all the beneficiaries for 2- 2.5 hours each in the morning and the evening. The plant supervisor and 4 workers oversee the plant operations [15].

Expected Biogas and Manure Generation:

Table IV: Product generation at community biogas plants by SUMUL [15].

1	Plant capacity	Two Digester total capacity of 4.5 Ton per day Cow Dung
2	Type of process	Single stage Floating Drum Bio-Digester
3	Biogas generation	2*85 m^3 /day
4	Manure generation	2.5 Ton of slurry per day
5	vermicompost	0.66-1.166 Ton per day

VII. SUMMARY

As we have discussed and compare different digester for biogas generation in rural Indian context, so selecting right digester is important, with the help of some basic criteria we can choose appropriate digester for our system.

Some basic criteria given below:-

Nisargruna Plant has higher efficiency because of two stages; it helps to optimize methane producing condition. Every day operation is easy, no skilled labor required because there is no any complex mechanism involved.

Higher biogas production is obtained as it is working in Thermophilic range. Hot water coming from Flat Plate Collector is mixed with Bio-degradable waste and feed to primary digester. Life of this plant is at least 15 year if proper care is taken of the plant.

Manufacturing cost of Nisargruna plant is not least among discussed bio-digesters, because of two stages its cost higher than single stage digester, but its cost is balance by higher biogas production, 1-5 Ton/day would cost 17-20 lacs per Ton. From this BARC's Nisargrun Biogas Digester is most appropriate for community biogas plant.

REFERENCES

[1] Biogas Hand Book Authors Teodorita Al Seadi, Dominikrutz, Heinz Prassl, Michael Köttner, Tobias Finsterwalder, Silke Volk, Rainer Janssenuniversity Of Southern Denmark Esbjerg, Nielsbohrsvej 9-10,DK-6700 Esbjerg, Denmark, 2008

[2] Chrish Kavuma (821231-A172) Variation of Methane and Carbon dioxide Yield in a biogas

plant,Department ofEnergy TechnologyRoyal Institute of TechnologyStockholm, Sweden

[3] Fabien Monnet. An Introduction to Anaerobic Digestion of Organic Wastes, Final Report, Scotland November 2003

[4] Marchaim,U.(1992). Biogas Processes for Sustainable Development Rome: FAO Ag Services Bulletin. (Literature)

[5] T.Z.D. de Mes, A.J.M. Stams, J.H. Reith and G. Zeeman,Methane production by anaerobic digestion of wastewater and solid wastes

[6] Natural Resources Conservation Service, “Anaerobic digester controlled temperature”;2004Code366 http://efotg.sc.egov.usda.gov//references/public/CA/366std-9-04.pdf

[7] Biogas Plant Constructions M. Samer, Cairo University, Faculty of Agriculture, Department of Agricultural Engineering, Egypt

[8] Carl Nelson John Lamb,Final Report:Haubenschild Farms Anaerobic Digester

[9] Roediger, H. Die anaerobe alkalischeSchlammfaulung. Wasser-Abwasser, H.1, Verlag R. Oldenbourg, Muchen u. Wien. 1967.

[10] Jerome NdamMungwe Department of Energy Politecnico di Milano Milan, Italy; School of Engineering Catholic University of Cameroon Bamenda, Cameroon, Domestic Biogas Digesters in Developing Countries

[11] A.O. Adebayo, S.O. Jekayinfa, O. V. Akinloye, A. M. Babalola, and F. O. UsmanDepartment of Agricultural Engineering, Faculty of Engineering and Technology, LadokeAkintola University ofTechnology, Ogbomoso, Oyo state. September, 2014.Design, Construction and Testing of a Plug Flow Digester for Converting Agricultural Residues to Biogas,International Research Journal on Engineering Vol. 2(4), pp. 052-060, September, 2014

[12] Jerzy Dudek and PiotrKlimek, M.Sc. Landfill Gas Energy Technologies Krakow 2010

[13] Anjan K. Kalia, Bio-Energy Laboratory, H. P. KrishiVishvaVidyalaya, Palampur, 176062 India, Development and Evaluation of a Fixed Dome Plug FlowAnaerobicDigester May 1988

[14] Harilal S. Sorathia , Dr. Pravin P. Rathod, Arvind S. Sorathiya, Department of Mechanical Engineering, Government Engineering College, Kutch, Gujarat, BIO-GAS GENERATION AND FACTORS AFFECTING THE BIO-GAS GENERATION – A REVIEW STUDY (E-ISSN 0976-3945), International Journal of Advanced Engineering Technology.

[15] VaibhavNasery,Center for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay May 2011, biogas for rural communities, Study report.

[16] Minnesota Department of Commerce State Energy Office, April 2003, Minnesota’s Potential for Electricity Production Using Manure Biogas Resources, Final Report

[17] Akshay Urja, A bi-monthly newsletter of the ministry of New and Renewable Energy,Government of India,Volume 5 Issue 6 ,June 2012; 38-40.

[18] TejoPydipati Biogas in India Submitted as coursework for Physics 240, Stanford University, Fall 2010

[19] K. M. Mital Biogas Systems: Policies, Progress and Prospects

[20] http://gbes.in/financial-analyses-of-biogas-to-bio-cng-Projects-in-india-projections-based-case-study-analyses/

[21] P. Lusk, Resource Development Associates, Methane Recovery from Animal Manures The Current Opportunities Casebook, A national laboratory of the U.S. Department of Energy Managed by Midwest Research Institute for the U.S

[22] Dr.Sharad P. Kale,**Decentralized waste resource management: Nisargruna** BHABHA ATOMIC RESEARCH CENTRE MUMBAI

[23] Omkumar Priyavadan Shah,Sustainable Waste Processing in Mumbai using the Nisargruna Technology, A Diploma Project in Implementation of Sustainable Technology