STUDIES ON BIOMETHANATION OF COMMUNITY KITCHEN WASTE

THESIS SUBMITTED IN FULLFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY (ENGINEERING)

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BY

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PREFACE

This thesis has been written for the purpose of Doctor of Philosophy in Engineering. Hopefully you will also find it useful and instructive in search for more knowledge about technical and methodological aspect of waste recycle.

The present research work is not the ultimate; it is merely an attempt to learn more about the complex things that we call a sustainable development of the society and reality.

This thesis and the research behind it are my way of trying to contribute to a sustainable development of our society. This is because I am deeply concerned by what are life style and "modern" society bring about in the form of environmental disruption, depletion of natural resources, too great a dependence on renewable resources and weird social structure fostering people who are not understanding the problem and heading for disaster very shortly.

My belief is that if we continue "the race" in full speed straight ahead as we have done so far, it will end up in a crash, with enormous suffering *for the humans in existence in future.*

In theory, there is no difference between
theory and practice but in practice there is.

- Vint Cerf.

This is to certify that the thesis entitled **"Studies on Biomethanation of Community Kitchen Waste"** submitted by Shri Narayan Chandra Dey Sarker who got his name registered on 27/03/2003 for the award of Ph.D. (Engg.) degree of University of North Bengal, is absolutely based upon his own work under the supervision of Prof. Haripada Bhaumik and that neither this thesis nor any part of it has been submitted for any degree/diploma or any other academic award anywhere before.

Date: 7/12/08

Signature of Sole Supervisor
and Date with Office Seal

DECLERATION

I, hereby, declare that neither the thesis nor any part thereof have been submitted for any degree whatsoever.

Narayan Chandra Dey Sarkar

Date: 07/02/2008 (Signature of the candidate)

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(Narayan Chandra Dey Sarker)

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CHAPTER - 1

INTRODUCTION AND SCOPE OF WORK

Chapter -1

INTRODUCTION AND SCOPE OF WORK

1.1 INTRODUCTION

Energy is one of the most important requirements for the development of a nation, in fact per capita; consumption of energy is an index of a developed nation.

In this context, per capita energy consumption in U.S.A., Africa, China, India, is worth noting. Conventional energy sources, mainly fossil fuel such as coal, oil, gas etc. are limited, and cannot serve the society indefinitely. But the demand for energy is ever increasing as a result the whole world is going to face an energy crisis in near future unless alternate sources are developed to meet the growing energy demand.

Another associated problem with the use of fossil fuel is environmental pollution as a result of combustion of fossil fuels.

It is therefore, imperative to put efforts to find a solution for both these problems by developing alternative energy sources.

The alternatives that are being considered for exploitation are the following:

1. Solar energy
2. Bio-mass energy
3. Wind energy
4. Tidal energy
5. Fuel energy
6. Geothermal energy
7. Nuclear energy
8. Ocean thermal energy conversion (O.T.E.C.)

To encourage research and developmental work in the field of renewable energy Indian Renewable Energy Development Agency (I.R.E.D.A.) has been established under the Ministry of Non-conventional Energy Sources (M.N.E.S.), Govt. of India.

For a large country like India, energy development from food waste, agricultural residue and animal dung through bio-methanation is an attractive and viable proposal and deserves consideration for the following two reasons:

a) For energy potential &

b) For reduction of pollution load.

In India more than 600 million tons of agricultural wastes (i.e., agro-industrial waste & crop residue) are generated every year [1]. Most of this is burnt by the way of waste disposal, as the farmer wants his fields ready for next crop. A small part of the residues may be used for mulching, for fuel (for cooking) or as fodder. Instead of burning the agricultural waste directly, it is preferable to use the agricultural waste as feedstock for bio-methanation because the nuisance of smoke and ash can be avoided and thus pollution level can be minimized.

So far, these processes did not take off in a big way mostly because of the following difficulties:

1. Inadequate documentation and lack of past experiences.
2. Lack of techno commercial supports.
3. Shortage of qualified and experienced personnel for providing guidance right from design, manufacture, installation, marketing and training for maintenance as per the norms of Ministry of Non-conventional Energy Sources (M.N.E.S.)

Energy sources are classified as commercial and non-commercial: coal, oil, natural gas and electric power which are priced and easily marketable are commercial sources and bulk of non-commercial supplies come from vegetable waste, fuel wood& cow dung etc.

Asian Development Bank (A.D.B.) has approved a loan of $ 100 million for development of renewable energy resources in India and promoting the development of four major areas: Bio-methanation, bagasse- based co-generation, wind energy and solar thermal energy conversion system [2].

Biomass seems to be one of the most attractive and viable sources of renewable energy available on recurring basis for country like India as the large part of the country is rural.

Firstly biomass includes dedicated energy crops and trees, agricultural crop residues, wood and wood waste, aquatic plants, grasses, industrial waste and municipal waste. The process of bio-methanation involves a very low financial input per kWh of output. Anaerobic digestion of various feed stocks and their potential in terms of methane production is given in Table no 1.

Table No. 1: Production of biogas from various types of biomass

Nature of Biomass	**Biogas Production**
MARINE SEA GRASS	
Thalassia testidium shoot	10.4 lit/kg. (wet) weight
Root	7.4 -do-
Syringodium filiforme	7.377 -do-
ALGAE	
Gracilaria tikrahiae	22.2 to 32.4 lit/kg. (wet) weight
Ulva sp	32 to.40 -do-
Hypnia musciformis	7.6 -do-
Sargassum fluitans	8.5 -do-
AQUATIC BIOMASS	
Eichhornia caussipes (Water hyacinth)	7.045 lit/kg. (wet) weight
Fresh water aquatics	0.07- 0.43 m^3 per kg.V.S.
WASTE BIOMASS	
Sugar beet pulp	0.45 m3 per kg.V.S.
Lignocellulosics	0.02to 0.27 m^3 per kg.V.S.
Crop residue	0.08 to 0.53 m^3 per kg.V.S.
Wheat straw	162 to 249 lit/kgVS added
Rice straw	241 to 367 -do-
Mirabilis leaves	290 to 341 -do-
Cauliflower leaves	358 to 423 -do-

Ipomopa fistulosa	387 to 429 -do-
Dhiub grass	137 to 228 -do-
Banana peeling	271 to 409 -do-
Market organic waste	0.478 m^3 per kg.V.S.added
Mixed vegetable waste	0.6 -do-
Wheat straw	0.37 -do-
Potato tops	0.61 -do-
Maize tops	0.52 -do-
Beets leaves	0.46 -do-
Grass	0.56 -do-
Brassica (leafy vegetables)	22.6 lit/kg.wet biomass
Sotanum tuberosum (potato)	79.0 -do-
Calotropis procera	1.6 - 2.4 lit./day
Municipal sewage, sludge	0.60 m^3 per kg.V.S.added
Municipal sewage, skimmings	0.57 -do-
Municipal garbage	0.63 -do-
Waste paper	0.26 -do-
Municipal refuse	0.21 -do-
ABATTOIRES WASTE	
Cattle paunch contents	0.53 -do-
Intestines	0.09 -do-
Cattle blood	0.16 -do-
Diary waste, sludge	1.03 -do-
Yeast waste, sludge	0.80 -do-
Paper waste, sludge	0.25 m^3/ kg. dry solids
Horse manure	0.44 -do-
Cattle manure	0.32 -do-
Pig manure	0.42 -do-
Brewery waste	0.45 -do-

Sources: Green Energy (Biomass Processing and Technology), 2003, Capital Publishing Company, New Delhi, p109-110

Secondly, since generation of biogas mimics the natural environmental cycles, nutrients such as Nitrogen, Phosphorous and Potassium are conserved in the process and can be recycled back to the land in the form of soil nutrients.

Thirdly, through the digestion of degradable waste from large kitchens, hospital, hotels and hostels, can reduce various pathogens considerably thus reducing health hazard to a large extent.

Finally, since biogas is a clean fuel, its domestic use is free from health hazards particularly in respect of eye and lung problems. Bio-methanation of degradable waste has drawn considerable attention in the recent past as this process helps in improvement of environment. Thus anaerobic digestion (processing in the absence of air) of organic waste is going to be very commonplace in the near future to meet the ever-increasing energy demand.

Bio-methanation of organic waste through anaerobic digestion therefore will not only provide clean source of energy but also provide a means of boosting agricultural production through the use of nitrogen reach organic manure which is available from bio-methanation process. The process is thus going to play an important role in meeting the energy demand in near future and overall development of society.

It is estimated that there is potential of installing 12 million biogas plants in this country. However, up to March '94, 19 lac biogas plants have been installed under the national project on biogas development (N.P.B.D.) being promoted by the Ministry of Non-conventional Energy Sources (M.N.E.S.) [3].

During sixties and seventies Khadi and Village Industries Commission, State Agro-Industries Corporation and State Khadi boards were some of the major agencies that have promoted the biogas program in the country [4].

In India bio-mass co-generation potential has been estimated to be 3500 MW of which Indian Renewable Energy Development Agency (I.R.E.D.A.) has already sanctioned projects totaling 300 MW, Ministry of Non-conventional Energy Sources (M.N.E.S.) is continuously promoting installation of various bio-methanation units [5]. Enormous quantities of vegetable waste are dumped daily in the open air mainly in municipal and urban areas, which can be processed through anaerobic digestion to generate energy at the same time preserving the environment. This dumping causes the release of methane to the atmosphere thus contributing towards global warming.

Present research work has carried out a systematic study of bio-methanation of various kitchens waste and vegetables individually and then in the mixed form.

The study also includes the methods of material handling, slurry preparation and optimization of digestion period.

Attempt has also been made to find out a very practical methodology for the digester design, plant layout and analysis of solid remnants as organic manure.

1.2. SCOPE AND OBJECTIVE OF THE WORK

From time immemorial man has been dependent on nature's bounty of forest wealth and fossil fuels to meet to the energy needs. But this cannot continue indefinitely. The conventional method of generation of energy by burning of biomass is not energy efficient and further it adds to pollution load, hence the necessity of development of alternative method of generating energy from biomass has been felt. Following the energy crisis of 1973, a systematic study has been started. Electricity can be generated from a number of biomass sources i.e. renewable energy sources marketed as Green Power. Biomass also can be converted into transportation fuel such as ethanol, methanol, bio-diesel and gasoline.

Biomass resources can be converted to useful fuel using a number of conversion systems depending on the type of biomass and the end use. One of such conversion process is **Bio-methanation**.

In the present work particularly biomethanation of kitchen waste has been studied. Various problems related to handling the waste and feeding it to the digester has been studied. Attempt has also been made to co-relate the digester temperature, pH value of the slurry mixture and C/N ratio of the feedstock to the biogas output.

It has been observed in other countries that bio-methanation of organic matter is economic in large power plant. The problems encountered are mostly because of its volume (bulk density 30-180 kg/cu.m) [7] and low heat value and presence of nitrous oxide. Because of these problems and absence of an appropriate technology this conversion process of waste to wealth has not been adopted widely. As such it is imperative to design the most practical plant layout and also choice of handling equipment to be used in the biogas generation plant.

With the increasing population and increased consumerism more waste are being generated, hence it is essential to develop suitable methods for conversion of these waste to energy as a clean development mechanism (CDM) to meet the ever increasing energy demand while maintaining a clean environment.

Developed countries like Belgium, Denmark, Japan, Austria, Sweden, are using these waste as an alternative source of energy but in India we have yet to develop it in a large scale. That is how the present study is of great importance. The energy content of these waste ranges from 1900 kcal/ kg - 2300 kcal/kg [8] which is quite high energy and can be exploited via biomethanation mechanism.

Municipal solid waste in general (MSW) are having low contents of lignin, which is helpful for biological degradation, and thus this waste can be utilized for generating clean energy. The principal of bio-methanation has to be understood to enable suitable design and manufacture of equipment. The knowledge is also to be disseminated to the community to make them confident in the operation and maintenance of biogas plant with the aim of establishing a renewable source of clean energy.

It therefore, becomes essential to study bio-methanation using vegetable waste mainly from large kitchen of hotels, hospitals, hostels and market refuge. From literature survey it is found that lot of work has been done in various countries including India on bio-methanation of animal excreta, human excreta, crop residue but not much on vegetable waste particularly plant layout and handling equipment design. Thus the necessity of this study gains momentum.
In view of what has been stated so far, the present work has been undertaken with a view to study the following.

1. Optimization of digestion period for individual and mixed kitchen waste.
2. The development of an appropriate process for slurry preparation.
3. To develop the process for conveying feedstock to the digester in semi-batch and continuous digestion.
4. Up gradation of gas generated/produced in order to increase the calorific value per unit volume.
5. Evaluation of the remnants as organic manure.

CHAPTER-2

LITERATURE REVIEW

Chapter - 2

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND OF BIOMETHANATION

The phenomenon of biomethanation was first observed by Alessandro Volta of Italy in the year 1776. Volta observed that some bubbles are forming from the sediment of the lake in the vicinity of Como in Northern Italy [9]. In 1806, William Henry showed that Volta's gas was identical with methane gas. Humphrey Davy conducted the experiments in the year of 1808 to produce methane based on anaerobic fermentation of waste [10]. In1895 biogas from a waste treatment plant in Exter in England was collected and used to light nearby streets [11].

The industrialization of anaerobic digestion begun in 1859 with the first digestion plant in Bombay, India.By 1895,anaerobic digestion has made inroads in England where biogas was recovered from a well designed Sewage treatment facility and fuelled street lamps in Exeter.

Further anaerobic digestion advances where due to the development of microbiology. Research led by Buswell and others (Lusk, 1997) [12] in the 1930s identified anaerobic bacteria and the conditions that promote methane production.

Prior to 1920, most of the anaerobic digestion took place in anaerobic ponds. As the understanding of anaerobic digestion process control and its benefits improved, more sophisticated equipment and operational techniques emerged. The primary aim of waste stabilization in due course led to the basic municipal sludge digester. This design the spread throughout the world. Anaerobic digestion systems made a comeback during World War II with fuel shortage heating Europe but after the war anaerobic digestion was once again forgotten.

French scientist also showed the interest for installation of biogas plants in the French colony in Africa, during the Second World War.

Following the war several nation like U. S. A., U.K., Canada, Russia, Japan, Kenya, China, Uganda, South Africa, New Zealand and India showed interest in biomethanation. Realizing that the energy crisis will knock the door very soon, a large number of bio-gas plants based on community kitchen waste, M. S. W. and agricultural crops were installed mainly in the developing countries like China, India, Nepal, Philippines and also in Bangladesh.

China is the country with most installed units. More than 7 million units has been reported installed over the years with the peak in 1978 [13]. In these installed biogas plant, gas leakage was existing for 30-50 % of the total installed units which was the main bottle neck [14].

After 1975, 1.6 million digesters per year in China have been installed and up to 1982, more than seven million digesters were installed in China [15]. The methane fermentation has been known as microbe - based technology for producing biogas out of livestock manure and organic sludge. The two stage fermentation of methane, based on anaerobic microbes is expected not only to solve these problems, but also to contribute in obtaining renewable energy, reduced use of fossil fuels, suppression of carbon dioxide emission, lower the burden of waste disposal. B. R. Sauboll, a Belgian teacher at Godavari St. Xavier's School, had further developed the biogas plant in Nepal. He built a demonstration plant in 1955.In 1968 Khadi and Village Industries Commission (K.V.I.C.) built a plant for an exhibition in Katmandu. The department of agriculture installed 250 biogas plants during the fiscal year 1975/76. In 1974 Development and Consulting Services (D.C.S.) built forum biogas plants according to K.V.I.C. design.

Global Gas and Agriculture Equipment Development Company Pvt. Ltd., was formed in 1977. With investment of the United Mission of Nepal (U.M.N.), ABD/N and Nepal Fuel Corporation based on D.C.S. biogas extension organization. Biogas technology has been commercially introduced since the establishment of Gobar Gas Tatha Krishi Yantra Vikash (p) Ltd. in the year 1977.Various research has been carried out in designing and developing a biogas plant, biogas appliances of gas and slurry.

Many feedstock based on waste biomass [16-19] are already widely used as potential substrates for methane production. Cow dung, urban organic wastes, algae, vegetable wastes, human excreta and waste animal flesh are presently used as common substrates for methane generation [20-26].

2.2 BIOMETHANATION IN INDIA

The history of biogas introduction is divided into a number of phases, which are defined by occurrences and changes in society and programmed developments in Table no. 2.2 as follows: -

Table No. 2.2 Phases in the history of biogas technology in India

Year	Development
1960	First units constructed. Some research on the process and design
1950-1972	Industrial development of India and agriculture. First practical designs constructed, small projects, mainly one organization, involved, one design involved, one design disseminated.
1972-1975	Energy crisis attracts attention to the technology, start of national interests. Fossil fuel dependency identified.
1975-1980/81	National interests and research. National programmed developed.
1980/81-1985	Initiation of large national programmed relying on subsidized. Multi organization, Multi-design approach.
1985-1992	Improving designs, improving the organizations and results from dissemination
1992-1996	Decrease in subsidies, new structures of dissemination and extension.

Source: Mathias Gustav Sons, "Biogas Technology-Solution in Search of its Problem, Human Ecology Report Series 2000:1, PP –26.

Based on the series of investigations and experiments, all the scientists and engineers have developed and set up various types of biogas plants. Prof. N.V.Joshi of the Indian Agricultural Research Institute (IARI), New Delhi along with his other colleagues had conducted series of experiments in 1920 on bio-methanation based on anaerobic fermentation of various waste like banana skin, municipal waste including paper waste in order to produce biogas [27]. This process got more importance when Dr. S.V.Desai of IARI visited the sewage treatment plant in Dadar, Maharasthra in 1937. Later, Dr. S.V.Desai and S.C.Biswas of IARI produced bio-gas by fermenting the cattle waste through anaerobic process in the year of 1945.Further, in 1946, Prof. N.V.Joshi developed this process by making a small batch type bio-gas plant. Among these scientists, J. J. Patel (Agricultural College, Pune, Maharastra) had developed a well-known 'Gramlakshmi' Gas Plant in the year of 1951. Mr. Jasubhai. Patel is known as 'Father of Bio-gas' in our country for his pioneering contribution in this field. Scientist S.C.Dasgupta and C.N.Acharya along with Swami Vishwakarmanand had carried out enormous study and modified the earlier design of Gram- lakshmi gas plant in 1954 [28]. The modified design of grama- lakshmi gas plant became a major landmark for its suitability in various aspects and later it was adopted by Khadi and Village Industries Commission (K.V.I.C.) [29] throughout the country during sixties and seventies, There was another development took place with a Lucknow based agency named as Planning Research And Action Division (P.R.A.D.) based on modified design of "Gramlakshmi ".

The great scientist Dr. Rambux Singh has contributed lot in this field and promoted at Planning Research And Action Division (P.R.A.D.) the process of bio-methanation [30]. The K.V.I.C. and P.R.A.D. had tried to promote the gas plant of the Indian Agricultural Research Institute (I.A.R.I.) division. Khadi and Village Industries Commission (K.V.I.C.) also initiated the Research and developed activities during sixties and seventies and tried to remove all the existing problems faced in the design of digester based on floating type. Later on based on the Chinese design and field trials carried out at the Gobar Gas Research Station, Ajitmal, Etawah in U.P. Planning Research And Action Division (PRAD) has developed a gas plant based on fixed dome type of plant, which was later on called as Janata. Biogas Plant (J.B.P.) K.V.I.C. had launched in various places for setting up biogas plant from 1962 onwards and up to beginning of eights under the control of Department of Non-Conventional Energy Sources [31]. Swami Vimuktanand of Ramkhrishna mission at Belur, had developed a modified of Janata biogas plant and later on it was known as "Belur Math Model"[32].

Up to 1974 there had been about six thousand Biogas units installed in India. PRAD, Lucknow has developed an improved of fixed dome type digester at a cheaper price which is known as "Deenbandhu" model. During the period of 1980- 85, Govt. of India had set up National Bio-gas Development Board (N.B.D.B.) with a view to promote various bio-gas plants, To imparting knowledge, financial help mainly to the rural areas. It was planned to set up 15 lacs Biogas plant during seventh plan (1995-96) in our country. More than 24 lacs plant were already installed during 1985-86 under NPBD, which is equivalent of over 75 lacs tones of fuel wood amounting to rupees 375 cores per annum along with the generation of organic manure of 345lacs tones [33]. Based on the sources of implementation, eighth plan was revised and finally decided to install plant number over 25 lacs in the country [34]. The project on the development of high rate bio-methanation processes as means of reducing Green House gasses emission commenced in September 1994 for a duration of five years [35]. The National Bio-energy Board, a nodal body established under the chairperson ship of the M.N.E.S secretary, is implementing the bio-methanation project. Today, about fifteen such projects - in which biogas is generated from liquid as well as solid waste- have been completed in various industrial sectors while 17 are under way [36].

The major study carried out in 1992 by the National Council for

Applied Economic Research (NCAER) and estimates of the use of Biogas Plants installed between 1986 to 1989-90 was made 3600 villages spread in 251 Districts and 27000 units were monitored [37].

2.3 DEVELOPMENT STATUS OF ANAEROBIC DIGESTION TECHNOLOGY

Historical evidence indicates that the anaerobic digestion process is one of the oldest technologies. Biogas was used for heating bath water in Assyria during the 10^{th} century BC and in Persia during the 16^{th} century. Anaerobic digestion advances with scientific research and in the 17^{th} century, Jan Baptista Van Helmount established that flammable gases evolved from decaying organic matter. The industrialization of anaerobic digestion began in 1859 with the first digestion plant in Bombay, India. By 1895, anaerobic digestion had made inroads into England where biogas was recovered from a well – designed sewage treatment facility and fueled street lamps in Exeter. Further anaerobic digestion was an advance due to the development of microbiology. Research led by Buswell and promotes methane production.

As the understanding of anaerobic digestion process control improved, more sophisticated equipment and operational technique emerged. The primary aim of waste stabilization in due course led to the basic municipal sludge digester. This design then spread throughout the world.

The energy crisis in 1973 [38] and again in1979 triggered renewed interest in development of simple anaerobic digestion system for methane production as an energy source. India, China and Southeast Asia responded to the crisis with marked expansion of anaerobic digestion. Most of the anaerobic digestion systems were small digesters using combined human, animal and kitchen wastes.

In the beginning lot of failures were they're in the development in the country like U.S., Soviet Union, China and in Europe but all those designs were succeeded furthered, the interest in research and development of anaerobic digestion. Apart from biogas production, anaerobic digestion found wider acceptance as an inexpensive technology for waste stabilization, nutrient recovery, reduction in biological oxygen demand (BOD), and sludge treatment.

2.3.1 Rural Energy

In the rural areas people are mainly dependent on biomass fuels, such as firewood, cattle dung and crop residues for meeting the basic energy needs for cooking and heating purposes. Direct combustion of biomass involves health hazards and lower efficiency of burning of biomass. Women and girls of the rural areas, who are generally involved in collecting and storing the biomass fuels in their kitchens, suffer a lot in terms of drudgery [39]. This also leads to deforestation.

To provide technological solution and institutional arrangements for ensuring adequate and sustainable clean energy system this has been adopted as one of the important activities of the Ministry of Non-conventional Energy Sources (M.N.E.S.). Biogas technology produces cheap and clean gaseous fuel from cattle dung and waste of other livestock and human beings, without destroying their manure value [40]. It has the potential to meet the energy needs of not only cooking and heating but also lighting in rural households.

Biogas technology has often been regarded as an energy-supply project [41-45]. After study it is indicated that more than 30% of the total households in the country own 3 or more cattle heads and, therefore, can benefit a lot by setting up bio-gas plants. It is beneficial to use the scientifically designed improved chulhas in rural and semi-urban areas and thus it is possible to reduce the present level of consumption of firewood by at least 50%.

Developing entrepreneurship at the local level and generating awareness can ensure the energy services. The Ministry of Non-conventional Energy Sources (M.N.E.S.) has implemented some important National schemes in National Project on Bio-gas Development (N.P.B.D.), catering to family type biogas plants and the other is the National Program on Improved Chullas (N.P.I.C.), which is also covering the welfare of woman. Besides this to new pilot schemes, namely Rural Energy Entrepreneurship and Institutional Development (R.E.E.I.D.) and Woman and Renewable Energy Development (W.R.E.D.) were established during 2000-01 [46].

Production and utilization of biogas are beneficial in many ways. They have both direct and indirect economic benefits and social benefits .As a consequences anaerobic digestion process have been followed in many countries as an alternative to traditional energy sources [47].

A rural employment is generated through Biogas extension work had gained growing attention from the late eighties. In 1965 about 25% of the rural households in India received there major income from wages, in1988 this percentage had increased to 40% [48]. Thus biogas extension can be seen on a possible contributor to local employment [49-53].

When eco-development came alone biogas was adopted as a perfect technology to achieve the desired aims. From the appropriate technology side biogas technology can be seen as an almost perfect technology, easy to use and with high benefits, locally, manageable and profiting the rural households [54-56].

2.4 DEVELOPMENT OF BIO-REACTORS/DIGESTERS IN INDIA AND ABROAD

Bioreactors are classified on the basis of cubic meter of gas yield/ day/ unit volume of the digester as:

(a) Low yield reactors

(b) High yield reactors

In the following paragraph a brief description of various types of digester are presented to high light the development process.

2.4.1 KVIC Model

This is a floating dome type and is also called as "**Indian digester**" or "floating drum" plants. Fig. No. 2.4.1 shows the gasholder, mixing pit, inlet and out let pipe etc. of Khadi and Village Industries Commissions (KVIC) model. Most models have the basic design, which are similar to the design as shown in the figure no. 2.4.1. It is based on the continuous basis of feed material and is used for mostly cattle dung as input material. It has a partition wall mainly for the larger digester where volume is around 6 cu. m. and in this case the slurry material first take entry in the primary chamber. After digestion the slurry mixture reached to the top of the outlet chamber.

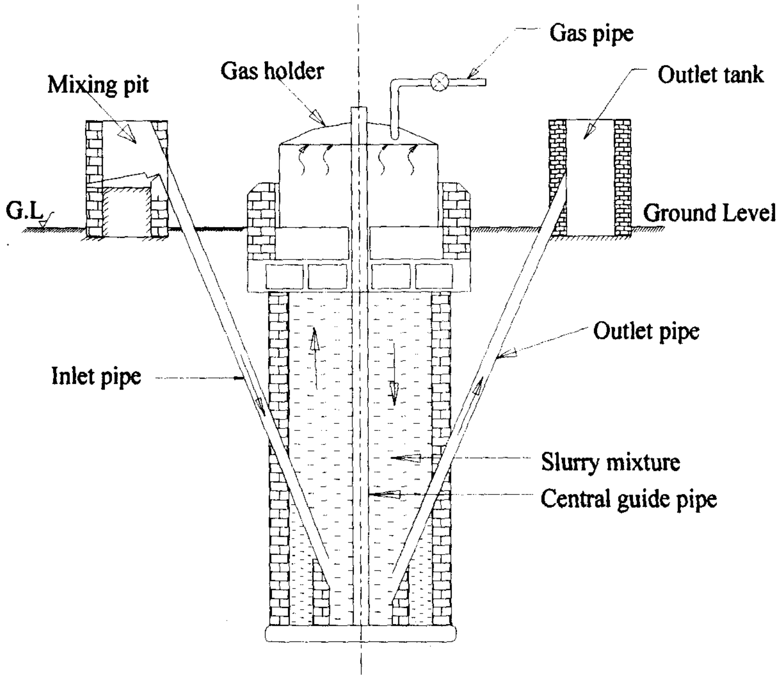


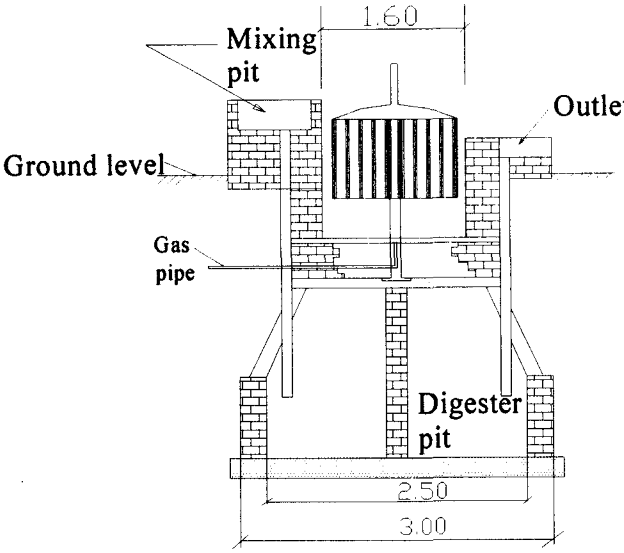
Fig. No. 2.4.1: Schematic Diagram of Floating Drum Digester (KVIC Model)

In the KVIC model retention ranges between 30-55 days, depending upon climatic conditions, and will decrease if loaded with more than its rated capacity, (KVIC, 1993) [57].

2.4.2 Nepal Model

In most Indian type biogas plants, the gas flow in to the users end is through a hose attached to the top of the gasholder, but these hoses are to be designed very carefully to withstand the gas pressure and to avoid deterioration and leakage since sometimes these hoses are responsible for gas leakage. These problems are avoided in Nepal's

Indian- type plant by the use of gas pipe as shown in Fig. No.2.4.2.



All dimensions are in m.

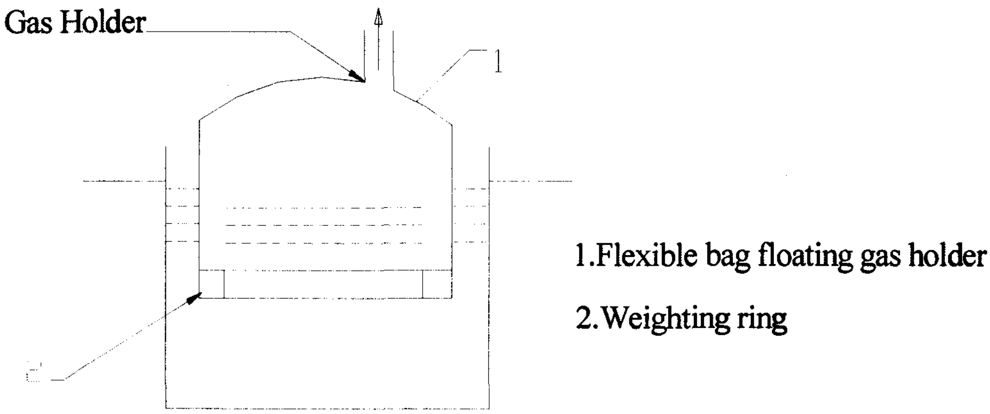
Fig.no.2.4.2: Nepal Model

2.4.3 Various Types of Indian Digester.

A few designs of these types are shown below in the following Fig. Nos 2.4.3 (a), 2.4.3 (b), 2.4.3 (c), 2.4.3(d), 2.4.3.(e), 2.4.3.(f), 2.4.3.(g) and 2.4.3.(h).

2.4.3.1 Separate Gasholder of Flexible Bag type

Detail of this type has been shown in Fig. No. 2.4.3. (a)



Seperate Gas Holder of Flexible Bag

Fig.no.2.4.3 (a): Separate Gas holder of Flexible Bag

2.4.3.2. Semi- Red Mud Plastic Bio gas digester

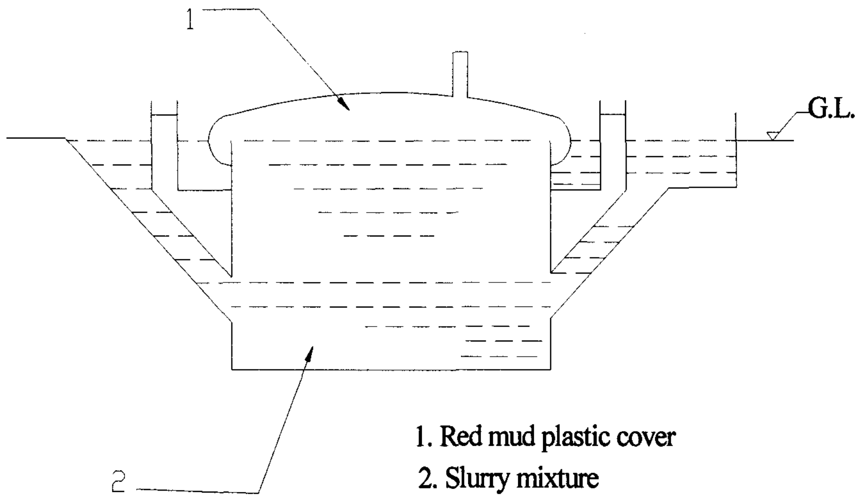


Fig. No. 2.4.3. (b): Semi-Red Mud Plastic Biogas Digester

2.4.3.3. Complete Red- Mud Plastic Bio gas Digester

This design was developed in 1960 s in Taiwan. It consists of a long cylinder made of PVC or Red mud plastic. The bag digester was developed to solve the problems experienced with brick and metal digesters [58-60].

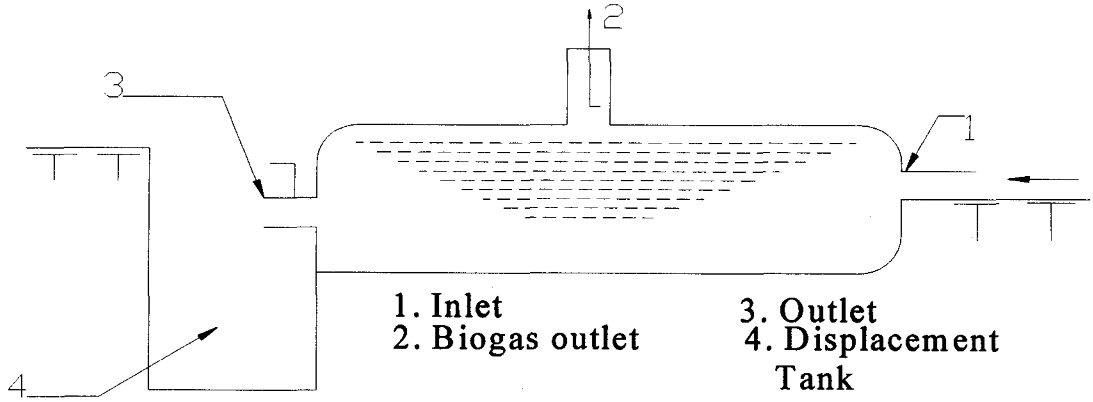
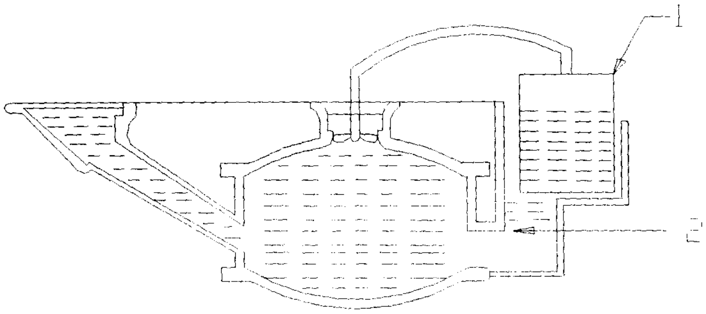


Fig. No. 2.4.3. (c): Complete Red Mud Plastic Bio Digester

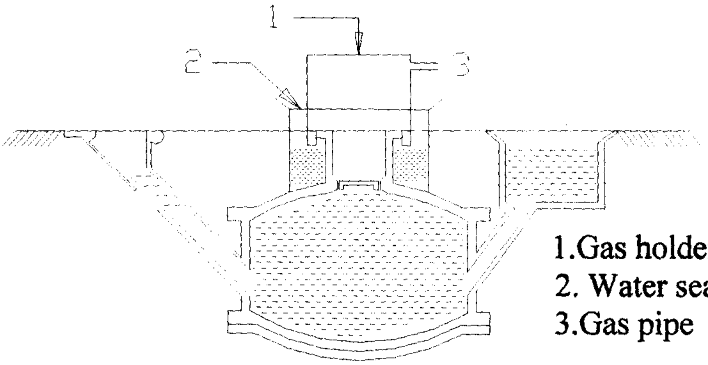
2.4.3.4 Separate Floating Gasholder Made from Ferro- cement



1.Seperate floating gas holder
2. Water sealing tank

Fig. No.: 2.4.3 (d): Separate Floating Gasholder Made from Ferro-cement

2.4.3.5 Gasholder Digester



1.Gas holder
2. Water sealing tank
3.Gas pipe

Fig. no.2.4.3. (e): Gasholder Digester

2.4.3.6 Biogas Digester With Separate Floating Gasholder

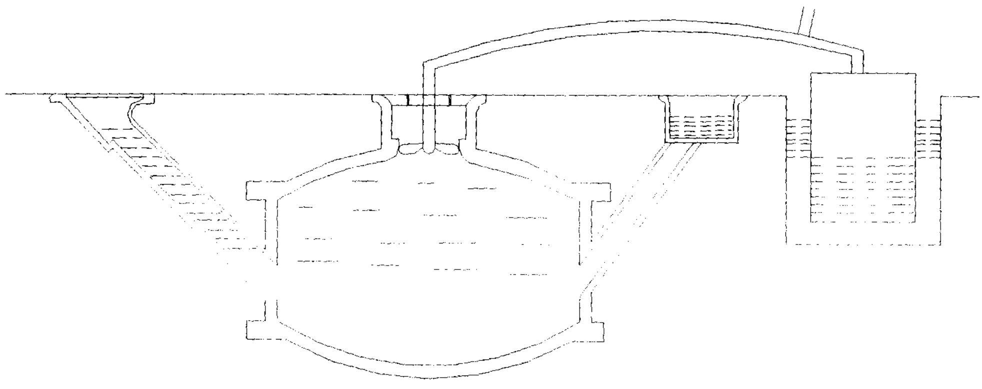
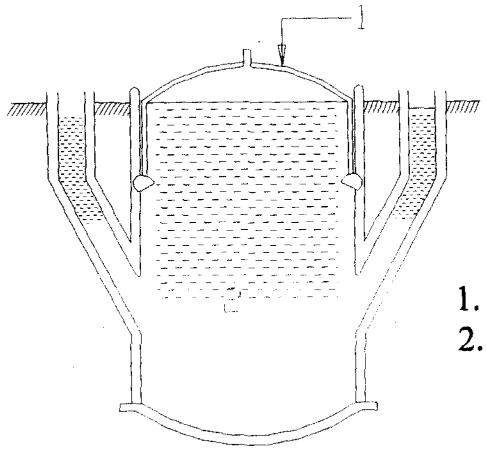


Fig. No. 2.4.3 (f): Biogas Digester with Separate Floating Gasholder

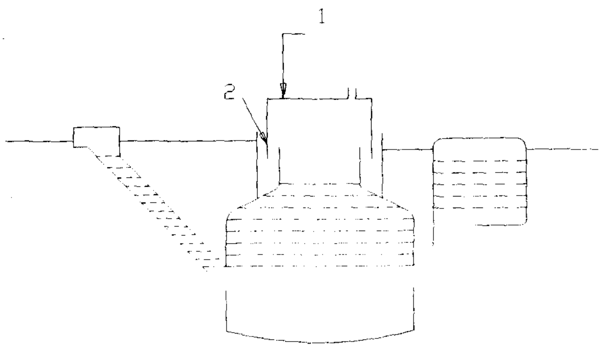
2.4.3.7 Top Floating Gasholder Digester Made of Glass Fiber



1. Floating gas holder
2. Fermentation tank

Fig. No. 2.3.4. (g): Top Floating Gasholder Digester Made of Glass Fiber

2.4.3.8.Biogas Digester with a cover for Collecting Gas



1.Cover for collecting gas

2.Water sealing trench

Fig. No. 2.4.3. (h): Biogas Digester with a cover for Collecting Gas

2.4.4 Ganesh Model

In this type of design, digester portion is made of an angle iron frame wrapped with a polythene sheet instead of a masonry structure. This design is similar to KVIC model, which has been shown in Fig. No. 2.4.4.

Constructional details of this model have been shown in Fig. No. 2.4.4. In this type of model a floating drum fitted on the top of the digester to accumulate the generated gas.

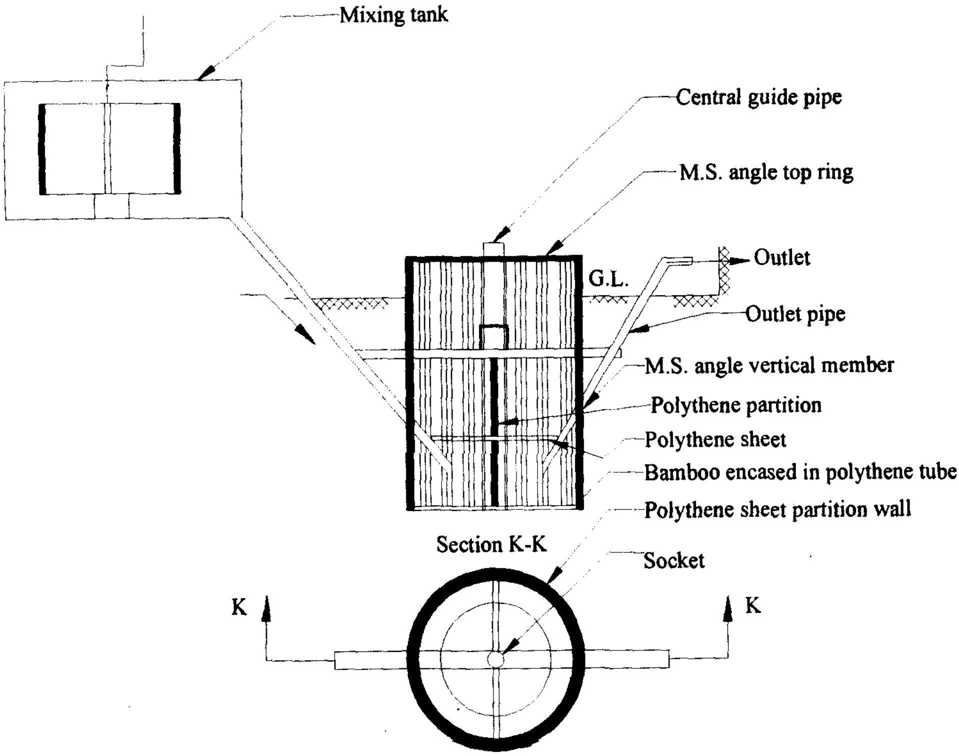


Fig No. 2.4.4 View of Ganesh model

2.4.5 Pragati Model

In this design height / diameter (H / D) ratio is less. The digester is hemispherical with slopping bottom slab. Fig. No. 2.4.5 shows the details of the digester of this model.

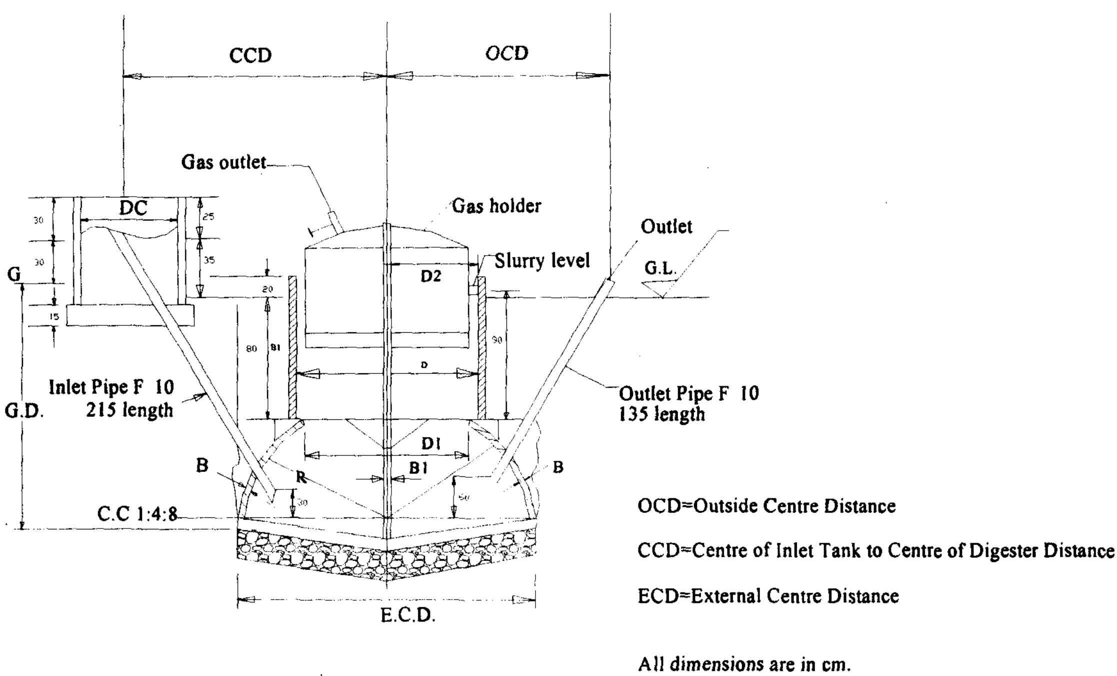


Fig. No 2.4.5: A Sectional view of Pragati model

2.4.6 Astra Model

In this type of model, a floating gasholder is incorporating with a solar water-heating device to maintain the slurry temperature. The merits of the ASTRA model are its reduced retention time, and reduced the cost and provision for maintaining the slurry temperature in a cold climate.

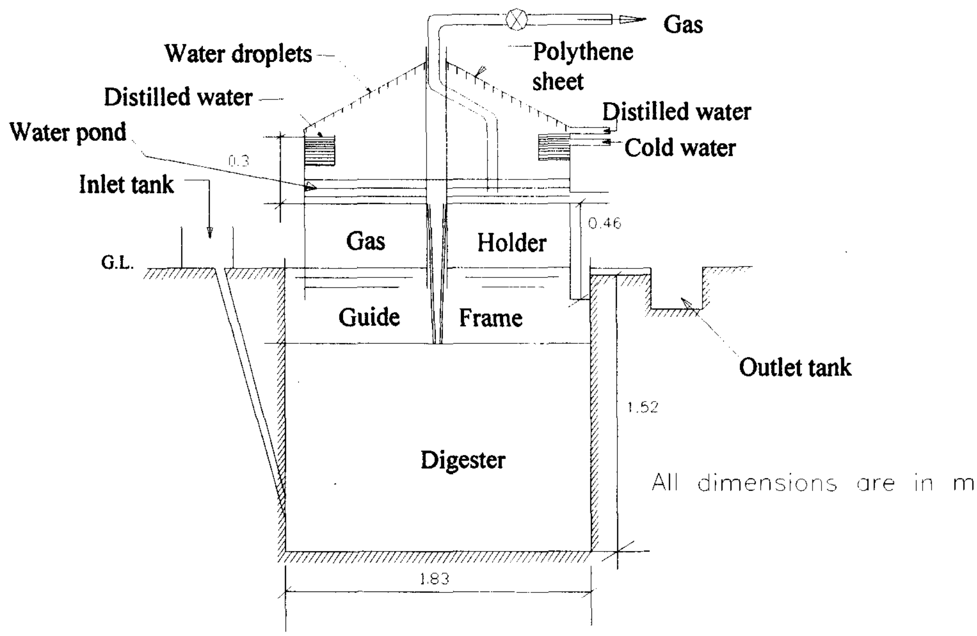


Fig. No. 2.4.6: A Sectional view of Astra Model

2.4.7 Jwala Biogas Model

In this model, the digester is of KVIC type, with a low-density polyethylene (LDPE) sheet together with a geodesic balloon constituting the gasholder. Scum breaking is achieved by means of a stirrer, which has both reciprocator and rotary motion. The Jwala model is considerably cheaper because no costly materials are involved in its construction. This model is being field- tested in a number of villages in Tamil Nadu, India. Fig. no.2.4.7. Shows the details of the construction.

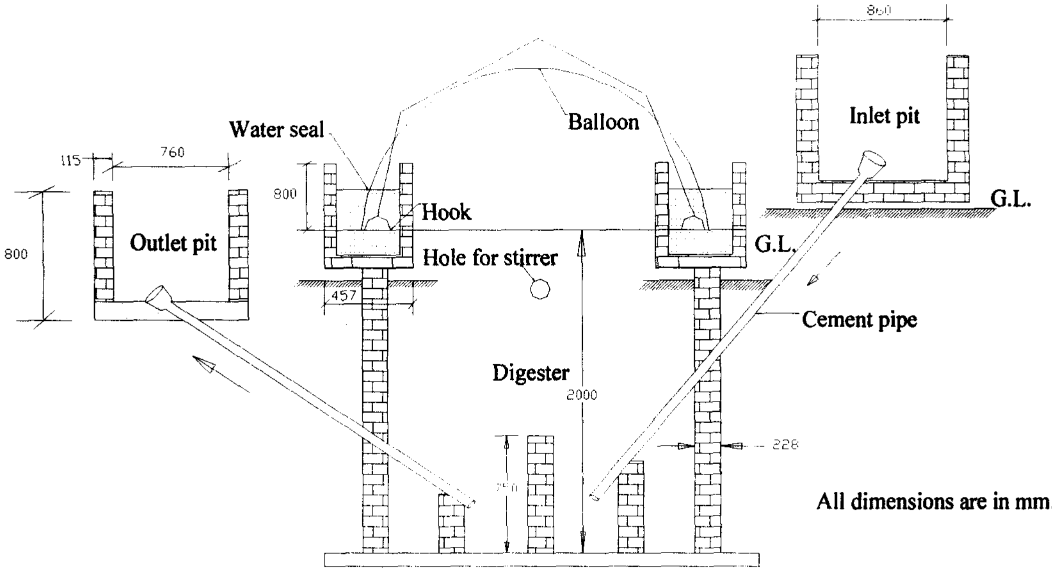


Fig. No. 2.4.7: Jwala Biogas Model

2.4.8 **Bostwana Model**

This model was designed by the Rural Industries Innovation Center in Botswana. The unit consists of one or more sealed steel drums functioning as the digestion compartment connected by piping to a gas collector storage tank. The gas collector is made of one 30-gallon drum upturned in a 45-gallon drum full of water with 1 cm steel bars used to guide the rise and falloff the collector. It is shown in fig. No.2.4.8.

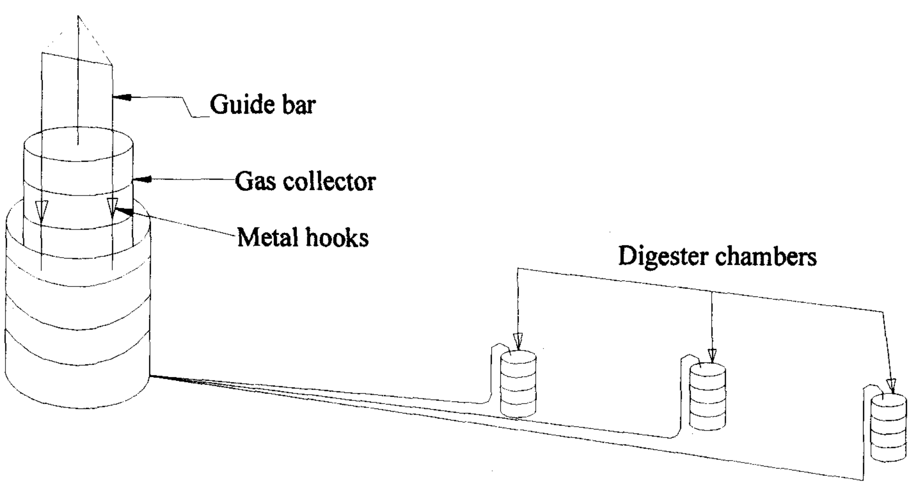


Fig. No. 2.4.8: Batch Fed Oil Drum for Biogas (Bostwana Model)

2.4.9. Guatemala-Olade Model

This is a batch-fed plant based on the separate gasholder design. To obtain regular gas production, two or more digester units with single gasholder can be used. This model is very expensive one; especially with its steel cover digesters and steel gasholder. The input materials used are cow manure plus agricultural waste like coffee and cocoa pulp. When loading the plant, the input material is put in the tank and then water is added to make a mixture of about 35% total solid. Generally the retention time in this model is 2 to 4 months.

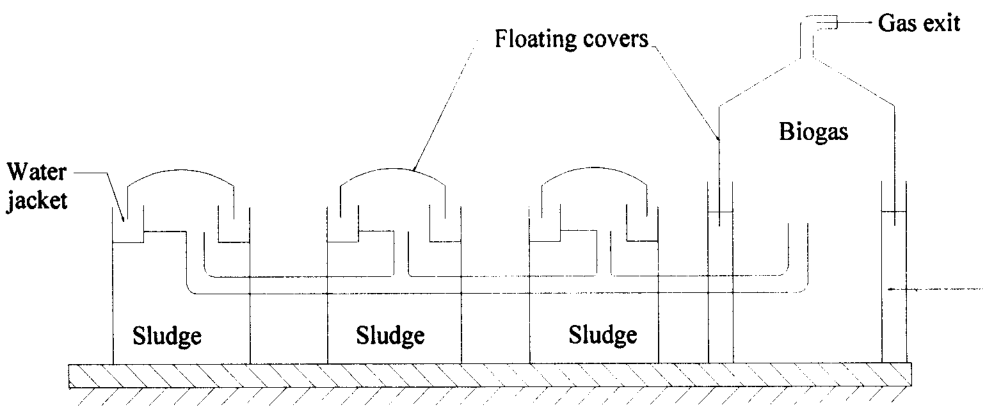
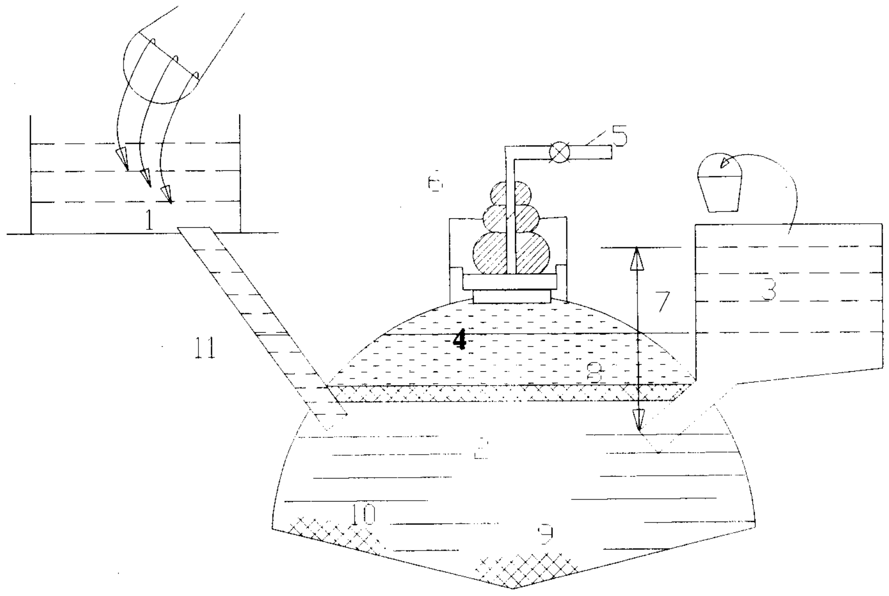


Fig. No. 2.4.9 Guatemala-Olade Model

2.4.10 Constant Volume Fixed Dome (CHINESE) Type Digester

These are fixed Dome biogas plants and are also termed as FED batch plants. Due to the continuous gas production and discontinuous flow of the digested slurry, they are classified under semi-continuous digester. A schematic figure is shown in fig. No.2.4.10. In this type of design, the digester is completely underground for better thermal insulation, avoiding cracking of dome frequently due to difference in temperature and moisture. The main digester is composed of a cylindrical shell wall with dome and bottom being segments of spherical thin shell.

The digester has two- fold function: accommodating digestible material as well as storage of gas. It is fully covered by affixed dome and it will be in perfect sealed condition to maintain anaerobic digestion

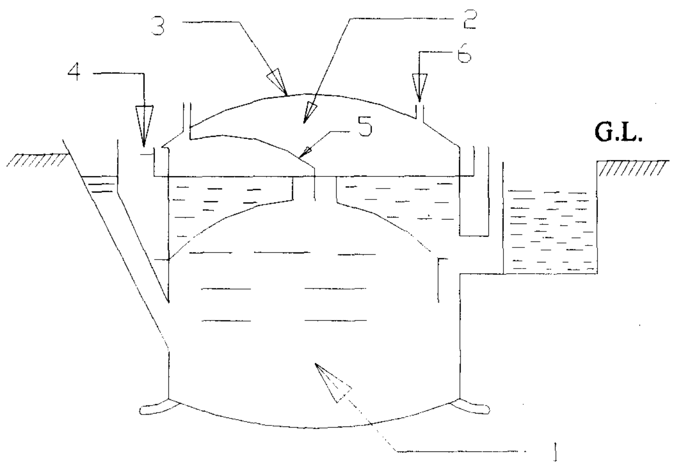


1. Mixing tank with inlet pipe,
2. Digester,
3. Compensating and removal tank,
4. Gasholder,
5. Gas pipe,
6. Entry hatch, with gas tight seal and weighted,
7. Difference in level = gas pressure in cm water column,
8. Supernatant scum; broken of by varying level,
9. Accumulation of thick sludge,
10. Accumulation of grit and stones,
11. Zero line filling height with out gas pressure

Fig. No. 2.4.10: Fixed–Dome Plant

Some of the variations in the basic Chinese type plants are the incorporation of spherical, oval and circular geometric are schematically shown in the following models:

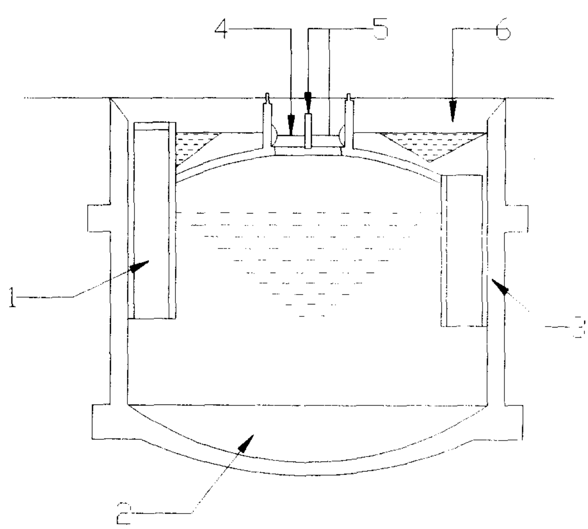
2.4.10.1 The Red Mud Plastic Biogas Digester for Dry and Wet Dual purpose



1. Wet Fermentation
2. Dry Fermentation
3.Gas Holder
4.Water Seal
5.Gas Outlet from Wet fermenter
6.Gas outlet from dry fermenter

Fig. No.2.4.10.1: The Red Mud Plastic Biogas Digester for Dry and Wet Dual purpose

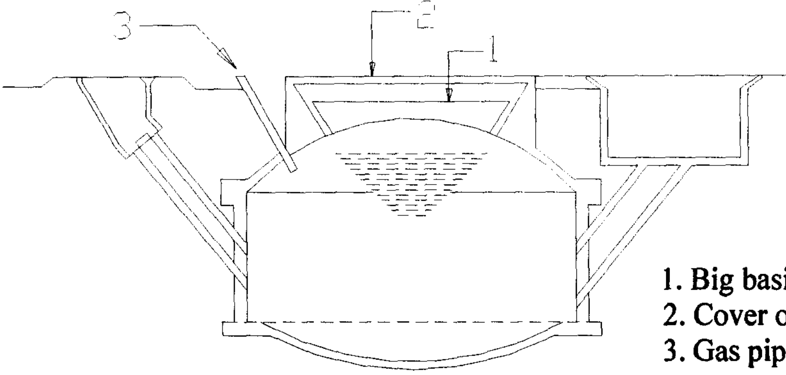
2.4.10.2 Top Water Pressure Biogas Digester



1.Inlet pipe 2.Fermentation digester
3.Connective pipe 4. Removable cover
5.Gas pipe 6.Top water pressure compartment

Fig. No. 2.4.10.2: Top Water Pressure Biogas Digester

2.4.10.3 Hydraulic Biogas Digester with a Big Basin- Shaped Removable Cover



1. Big basin-shaped removable cover
2. Cover of water container
3. Gas pipe

Fig. No. 2.4.10.3: Hydraulic Biogas Digester with a Big Basin-Shaped Removable Cover

2.4.10.4 Siphon Discharging Hydraulic Biogas Digester

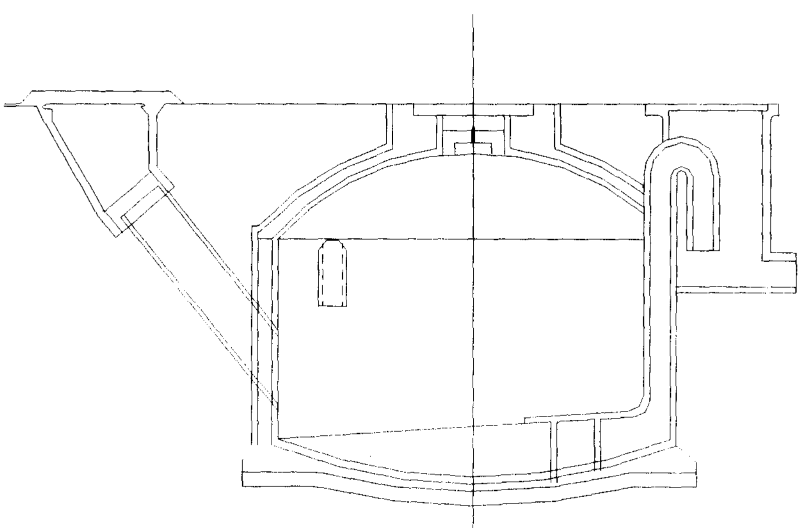
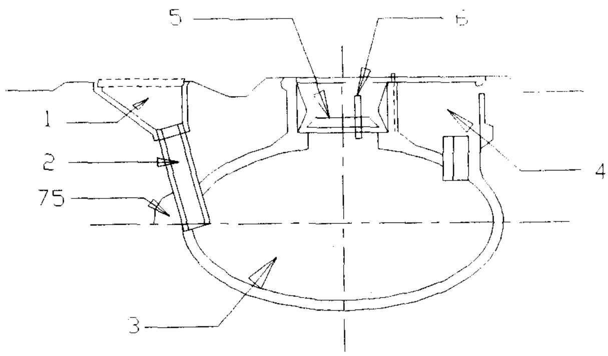


Fig. No. 2.4.10.4: Siphon Discharging Hydraulic Biogas Digester

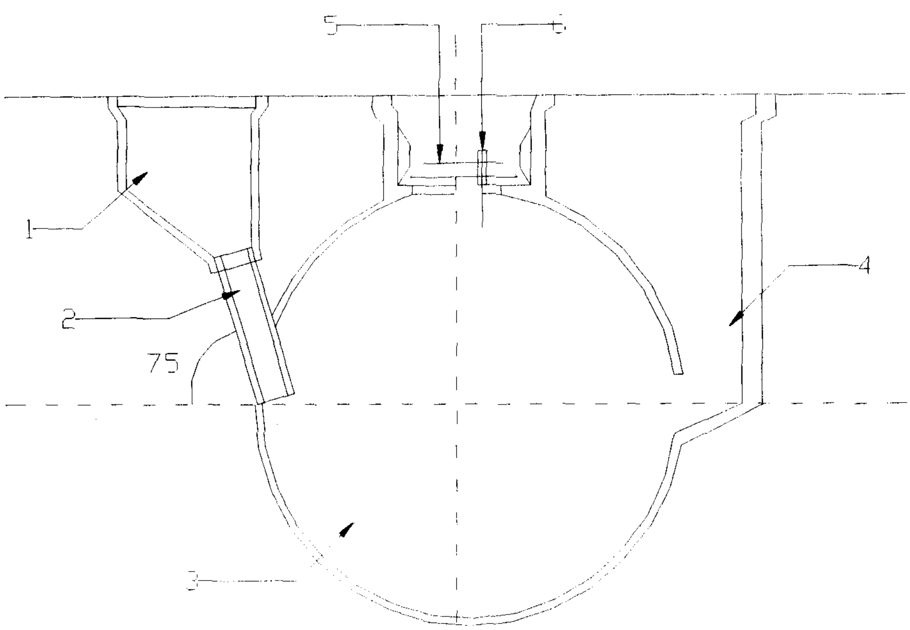
2.4.10.5 Elliptically ball-shaped Bio gas Digester



1. Inlet opening
2. Inlet ppipe
3. Fermentation compartment
4. Hydraulic compartment
5.Removable cover
6. Gas pipe

Fig. No. 2.4.10.5: Elliptical Ball-Shaped Biogas Digester

2.4.10.6 Ball Shaped Biogas Digester



1.Inlet opening
2.Inlet pipe
3.Fermentation compartment
4.Hydraulic compartment
5.Removable cover
6.Gas pipe

Fig. No. 2.4.10.6: Ball Shaped Biogas Digester

2.4.10.7 Separated Hydraulic Biogas Digester for Dry Fermentation

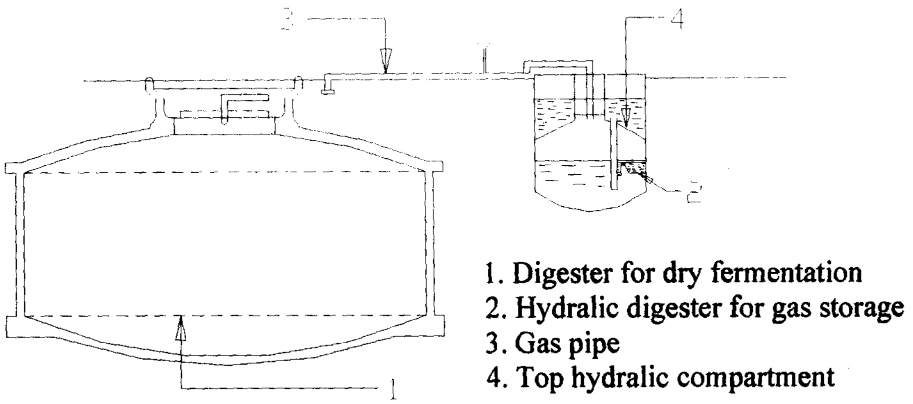


Fig. No. 2.4.10.7: Separated Hydraulic Biogas Digester for Dry Fermentation

2.4.10.8 Combination of fixed Dome and Floating Drum Plant

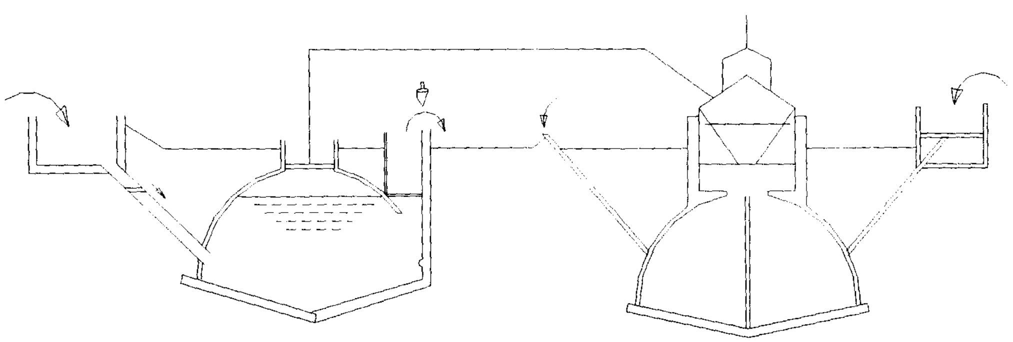


Fig. No. 2.4.10.8: Combination of fixed Dome and Floating Drum Plant

The above schematic figures have shown various types of fixed dome type digester.

2.4.11 Ball / Spherical Digester

The spherical biogas plant, a fixed- dome type low–cost model, has been developed by the Tata Energy Research Institute (TERI), New Delhi. In this design digester and gasholder together form a complete sphere, in which the top portion serves as the gasholder. The mixing tank and outlet are on either side of the digester. Fig. No. 2.4.11 shows the detail of the model.

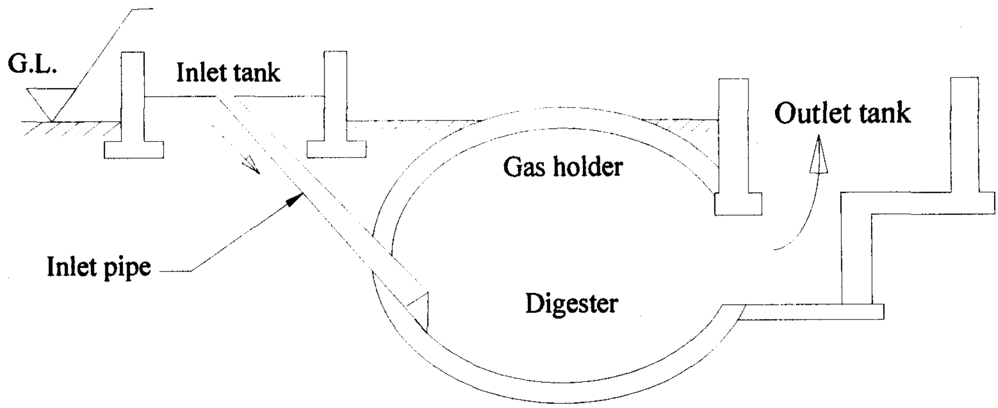


Fig. No. 2.4.11: Ball Digester

In this model the slurry inside the digester may contain higher particle, which may float on the top surface of the slurry and forms a thin-hard layer of scum. This hard layer will prevent to gas escape during digestion. To avoid this problem, nylon net has been spread on the top layer of the slurry. During digestion process gas accumulated in the gasholder. The slurry level of the digester goes down due to the pressure of gas. Thus slurry movement will be through the nylon net and as a result the formed scum will break.

2.4.12 Fixed Dome Type Janatha Biogas Plant

This plant developed in India is similar to the Chinese unit, except the manhole cover has been completely eliminated.

Dung slurry is allowed to ferment in the digester. When gas is formed, it rises upwards and gets collected in the dome. Fig. No 2.4.12 shown of this model.

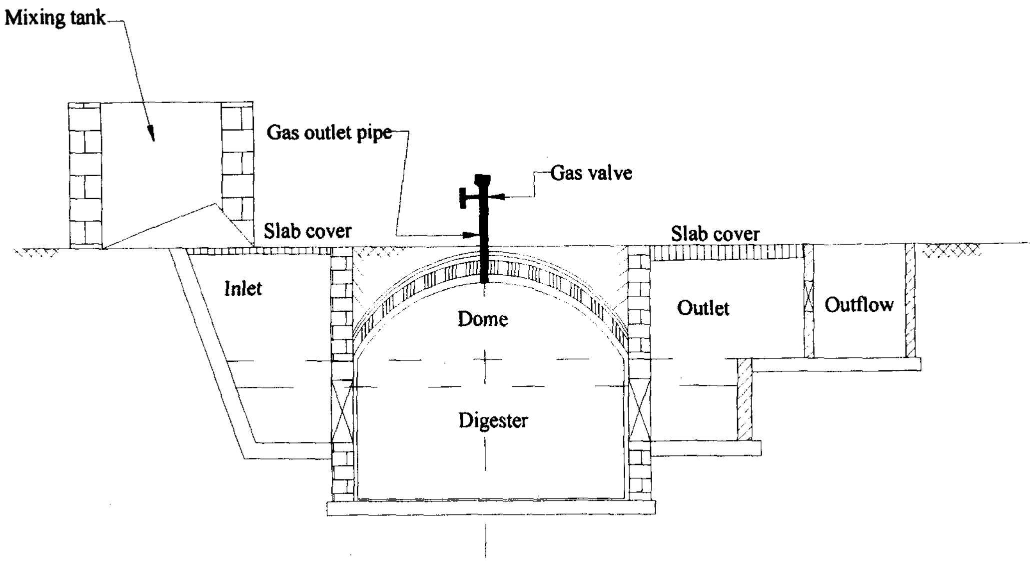


Fig. No. 2.4.12: Janatha Biogas Plant

2.4.13 Deenbandhu Biogas Plant

This model was developed in 1984, by Action for Food Production (AFPRO), New Delhi. Deenbandhu has probably been the most significant development in the entire biogas program of India as it reduced the cost of the plant to almost half that of KVIC model and this became popular in the poorer section of the people. Component of the bio gas plant of this model has been shown in Fig. No. 2.4.13.

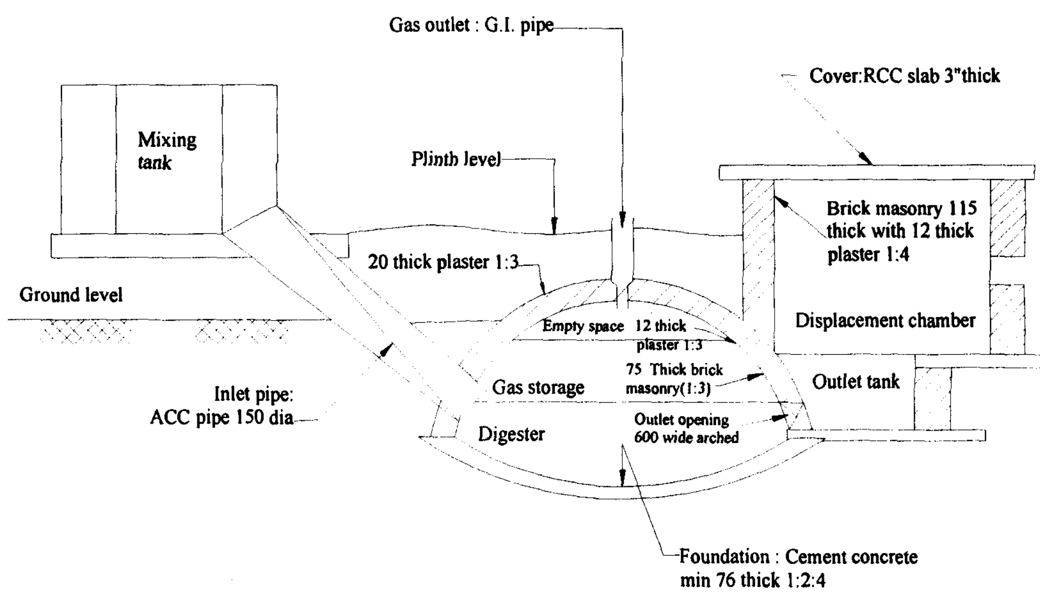


Fig. No. 2.4.13: Deenbandhu Biogas Plant

This model of biogas plant harboured higher methanogenic population than other model like KVIC, Ganesh, and Gayathri model of biogas.

2.4.14 Batch Digester

Very recently Chinese type reactors are being fitted with plastic storage bags to reduce the gas pressure and thus leakage problem is also reduced. This will also facilitate the maintenance work. Fig, no.2.4.14 shows the schematic view of this batch digester.

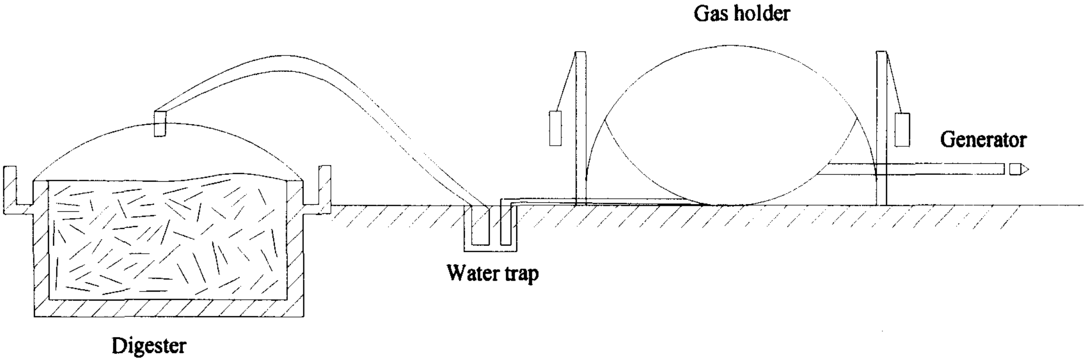


Fig. No.2.4.14: Batch Digester

2.4.15 Manawat Modified Chinese Type Digester

The National Research center in Egypt has developed the design with a few changes of the outlet chamber to reduce the loss of gas generated from slurry that is pushed in to the out let chamber. They have redesigned the out let chamber to minimize the movement of the slurry. Fig. No. 2.4.15 Shown illustrates the modification.

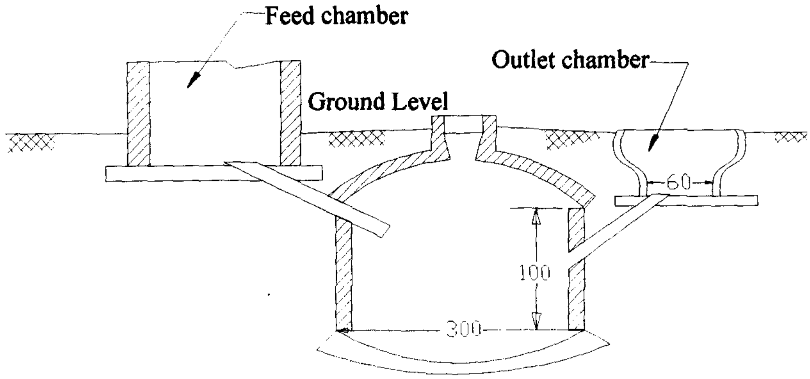
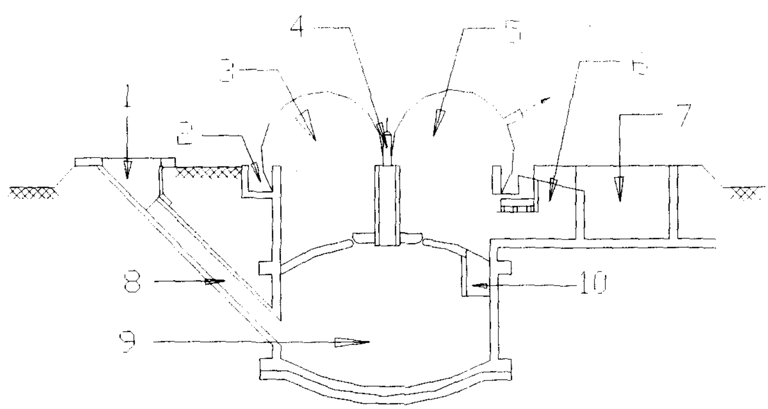


Fig.No.2.4.15: Manawat Modified Chinese Type Digester

2.4.16 Chinese Test Digester (Red- mud Plastic Gasholder Digester)

Fang Gouynan Chengdu et.al, Biogas Research Institute, China, conducted research on using the red –mud plastic film gasholder. The red-mud plastic chamber has the multi- functions of water pressure, gas storage, fermentation and heat absorption. Fig. No.2.4.16 shows the schematic diagram of the TEST Digester. Many plants of this type are circular with doomed roof.



1. Inlet
2. Water-sealing groove
3. Red mud plastic gasholder
4. Gas guiding pipe,removable cover
5. Second fermentation chamber
6. Overflow
7. Manure storage chamber
8. Inlet tube
9. First fermentation chamber
10. Water return tube

Fig. No. 2.4.16: Chinese Test Digester (Red- mud Plastic Gasholder Digester)

2.4.17 Borda / Sasse Digester

This type of digester is widely used in Germany Fig. No.2.4.17 Shows the fixed dome type plants. This type of fixed dome plants is recommended only under the close supervision of experienced technical experts.

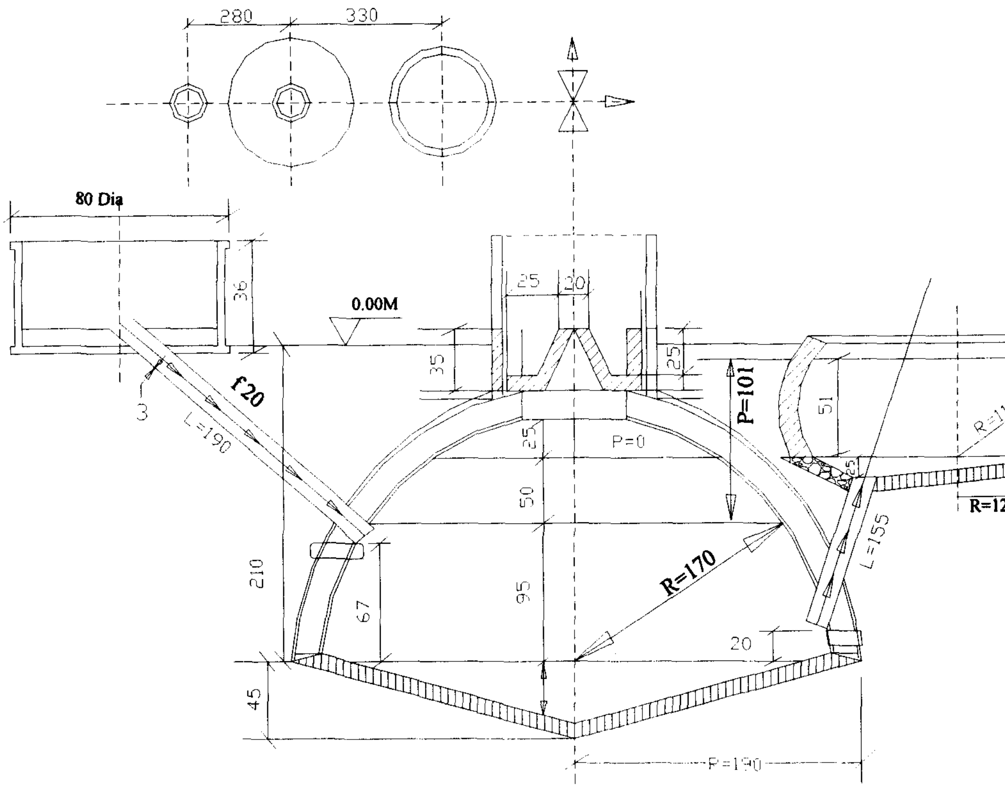


Fig. No. 2.4.17: Borda / Sasse Digester

2.4.18 RMP Model Digester

The most common type of digester is developed in Union Industrial Research Laboratories (UIRL) in Hsinchu, Taiwan, in 1974. "UIRL" developed a new material Red Mud Plastic (RMP), which is a mixture of new / used PVC, red mud waste from aluminum production, engine oil, etc. Its cost is very low.

Following Fig. No.2.4.18 Shows the RMP model.

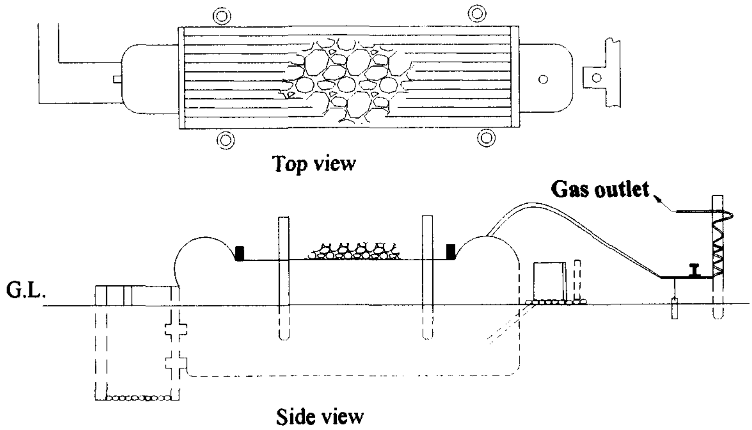


Fig. No. 2.4.18: Red Mud Plastic (R M P Model)

2.4.19 Bag or Tube Digester

Sanamatic Tanks Manufacturing Corporation, Australia, has developed large bio gas reactors made of butyl rubber The balloon plants in general consists of a plastic or rubber digester bag, in the upper part of which the gas is stored. These are placed on a sand base and supported by a steel cage, with rigid foam insulation and shown in fig. No.2.4.19.

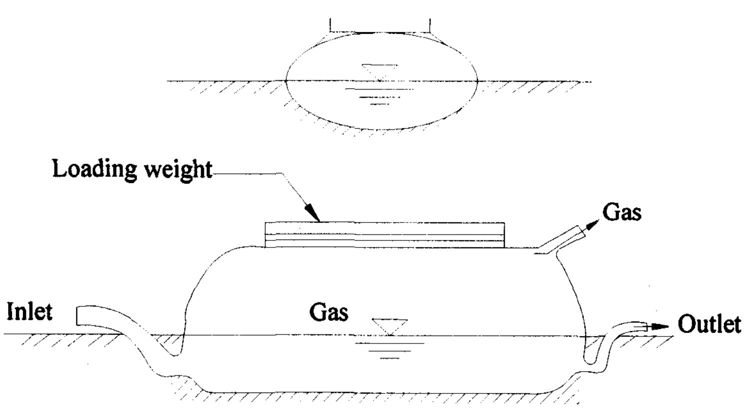


Fig. No. 2.4.19: Bag or Tube Digester

2.4.20 Portable Prefabricated Biogas Digester

This is a small-prefabricated portable digesters give better yields than conventional Indian or Chinese plants. Fig, no 2.4.20. Shows a view of a Pre- fabricated steel digester.

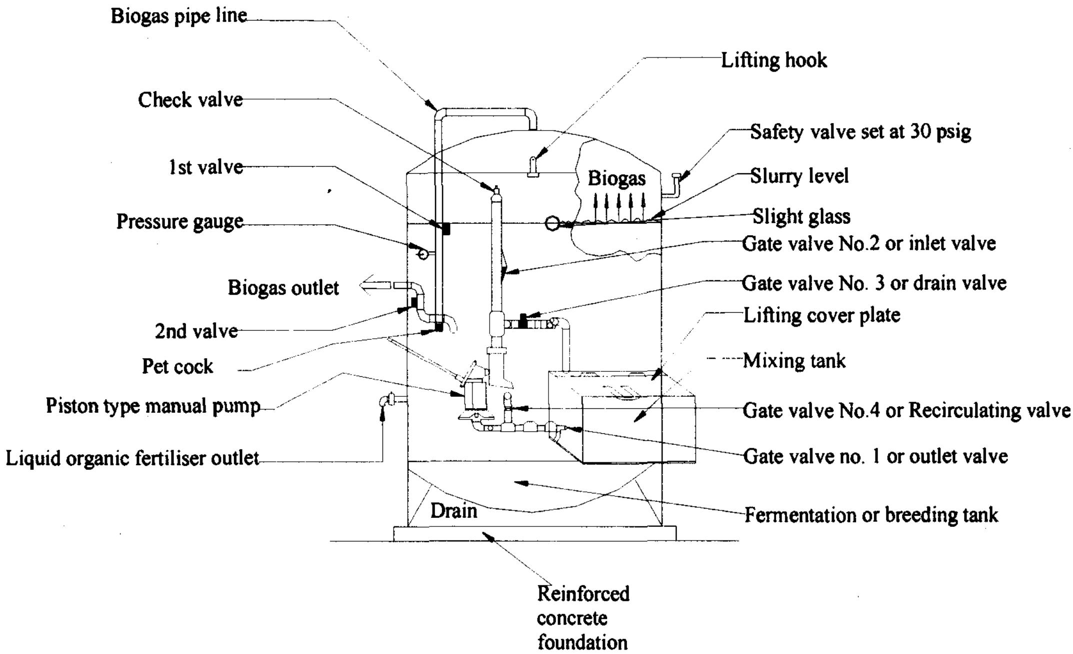


Fig. No. 2.4.20: Portable Prefabricated Biogas System

2.4.21 KHIRA Pre- Fabricated Steel Reactor

In this design the gas holders are made of thin mild steel sheet pre-treated with anti corrosion coating of phosphate and chromate passivation. The main advantages of this reactor are that it is more compact, economical, portable, does not necessitate cleaning and maintenance is easy, and it has no leakage problems or seepage problems. KHIRA digesters have been shown in fig. No. .4.21

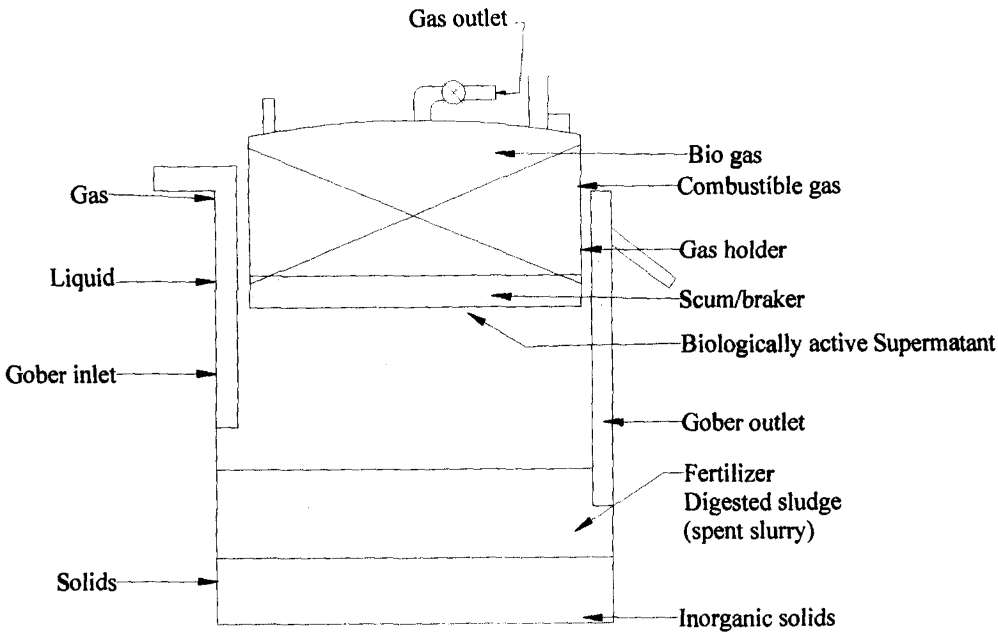


Fig. No. 2.4.21: KHIRA Pre- Fabricated Steel Reactor

2.4.22 Model (V- shaped Trough Reactor)

The Institute for Electrical Research (**I I E**) in Cuernavaca, Mexico, has developed a 10 cu.m. family version consisting of a 7m long V-shaped trough covered by a domed roof. The unit designed for use with dilute manure with about 8% total solids. The Reactor has a very little storage space; it is recommended that the gas be used on a steady state basis. Fig. No. 2.4.22 shows a V- shaped trough reactor.

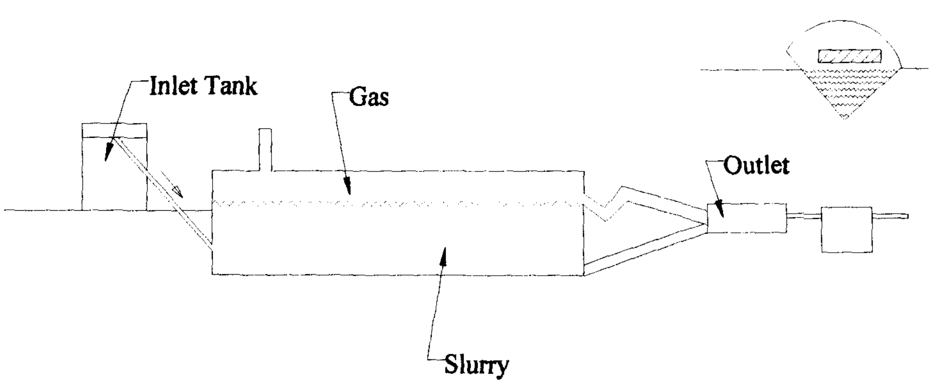


Fig. No. 2.4.22: I I E Model

2.4.23 Horizontal Digester

The Central American Research Institute for Industry (CARII) in Guatemala has developed many versions of horizontal digesters. Fig. No 2.4.23. Shows a horizontal reactor with a sloping floor and walls made of poured concrete beams filled in with concrete blocks; the slightly domed roof is of reinforced concrete. This behaves as a constant volume unit and actual gas volume to 20% of the reactor volume from the initial 10%. The capacity of the plant is 15 m3 capacity and shown in fig. No.2.4.23.

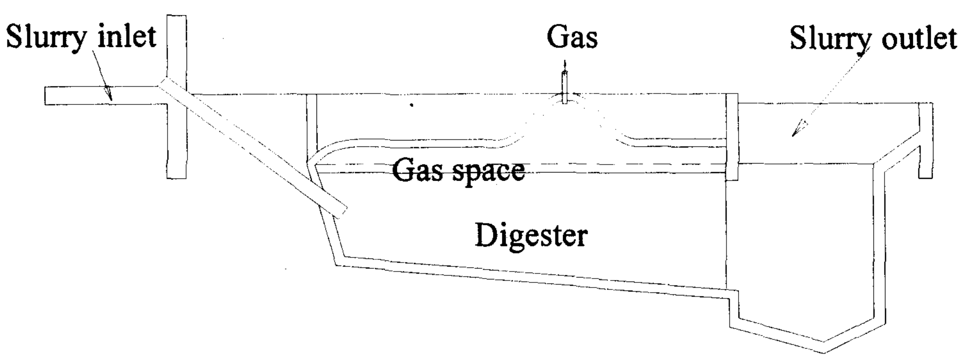
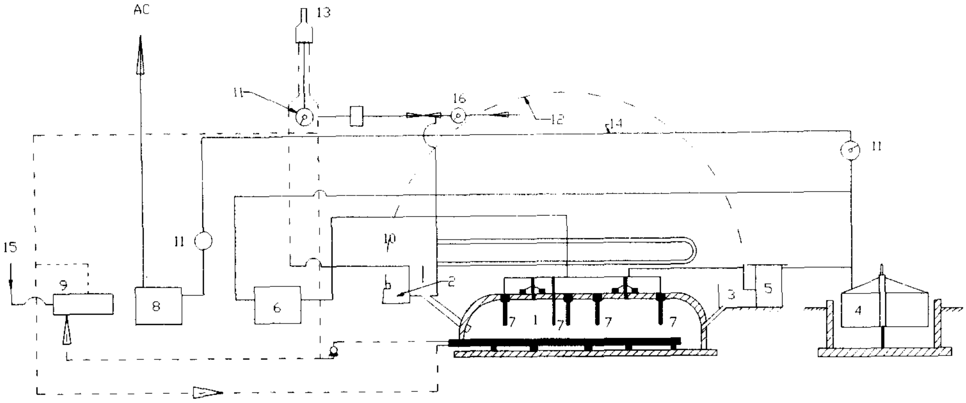


Fig No. 2.4.23: Horizontal Digester

2.4.24 Tunnel Type Digester (Shubrakass Village)

NRC of Egypt has constructed a specifically designed tunnel- type digester with arched roof with a separate floating gas collection system. In this model gas and slurry re circulation has been provided to obtain more efficient means of mixing and scum breaking.

This tunnel type digester is shown in Fig. No.2.4.24.



1.Tunnel digester
2.Feed chamber
3.Effluent outlet
4.Gas holder
5.Gas scrubber
6.Gas compressor
7.Gas mixing distributors
8.Electrical power generator
9.Engine waste-heat recycle
10.Solar water heater
11.Gas meters
12.Green house
13.Gas heater
14.Main Boigas line
15.Flue Gases
16.Water meter

Fig. No. 2.4.24: 50 m³ Tunnel type Digester

2.4.25 The MAYA Farms Model

Mr. F.D.Maramba, Sr., Maya Farms Division of Liberty Flour Mills, has designed the Maya Farms Model; Philippines .The model is basically designed of separate gasholder to suit large-scale application. The model is shown in fig. No.2.4.25

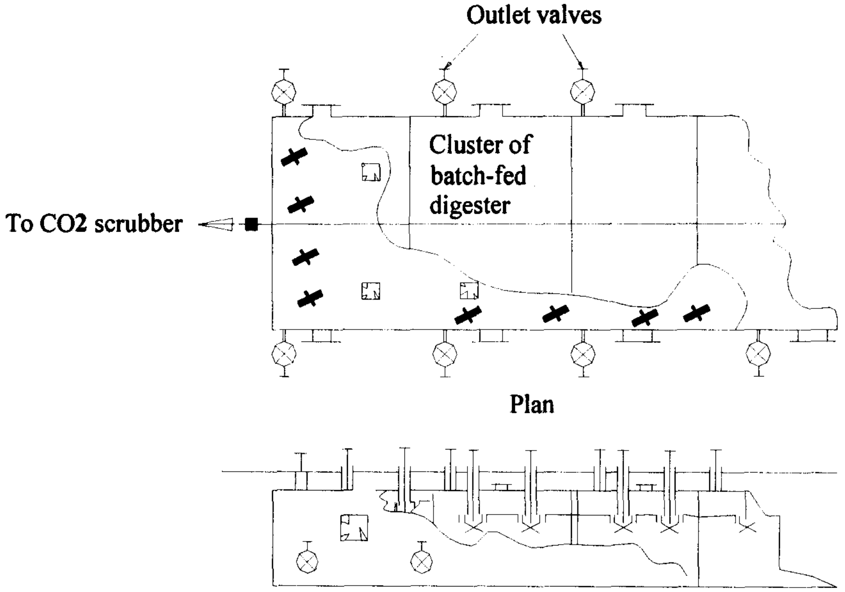


Fig. NO. 2.4.25: The MAYA Farms Model

2.4.26 Up flow Anaerobic Sludge Blanket (UASB) Digesters

This UASB design was developed in 1980 in Netherland.In this design no packing medium and the methane forming bacteria are concentrated in the dense blanket, which covers the lower part of the reactor. The feed (liquid) enters the bottom and releases biogas as the liquid flows upwards [61,62]. Some of the plants working on UASB Models are shown in the fig. No.2.4.26.(a) and 2.4.26(b)

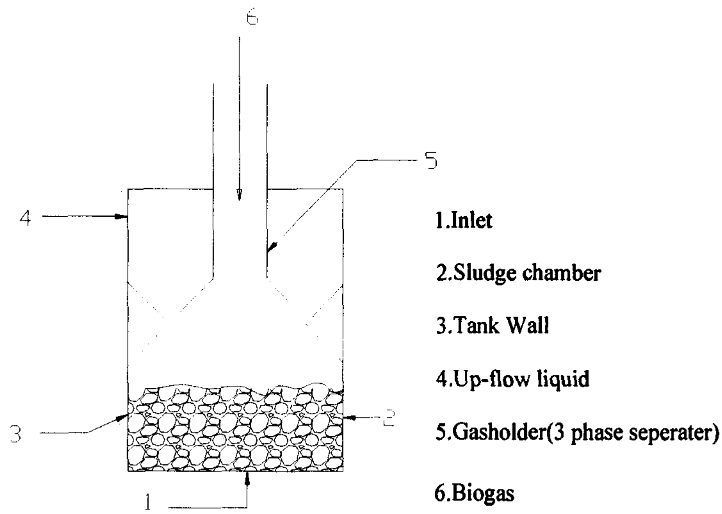


Fig No. 2.4.26(a). Up flow Anaerobic Sludge Blanket (UASB) Reactor

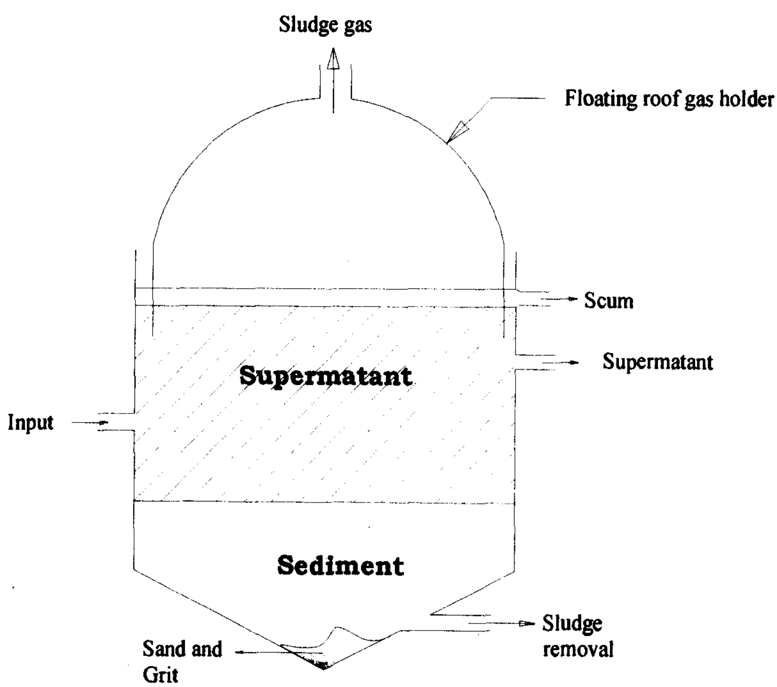
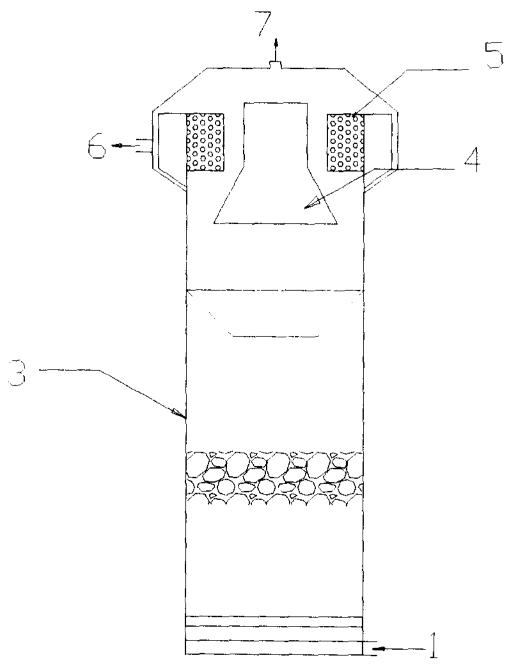


Fig.No.. 2.4.26(b) A Conventional Sewage Sludge Digester

2.4.27 Anaerobic Filter Reactors

These were developed in the 1950 s and are suitable for very dilute waste waters with low levels of suspended solid matter i.e. this type of digester is suitable for feedstock with low concentration. These include industrial organic wastewater, city sewage, and slaughterhouse sewage. Fig. No. 2.4.27 shows Anaerobic Filter Reactor.

A few other design of the Anaerobic Filter Reactor shown in Fig. No 2.4.27(a) and Fig. No.2.4.27 (b).



1.Inlet

2.Cobble for packing

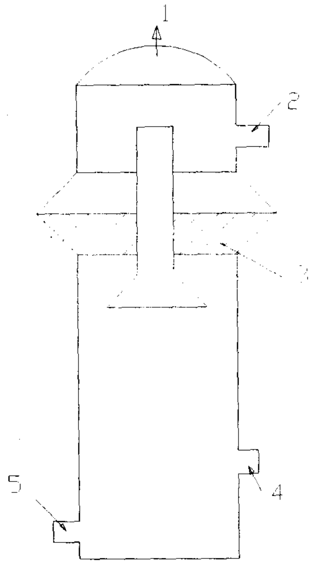
3.Reactor wall

4.3-Phase seperater

5.Cobble stone

6.Outlet

Fig.No.2.4.27 (a) Combination Type of Reactor of Pinsha Sugar Plant, Guangdong



1. Gas
2. Outlet
3. Honey comb plastic
4. Inlet
5. Sludge disposal

Fig.No.2.4.27 (b) Combination type of Reactor of Lougquandistillery, Liaolin

2.4.28 Flexible Top plug flow digester

The most common type of biogas system in U.S.A. Is an unmixed PLUG - FLOW System using an inflammable plastic gasholder. Schematic Fig. of the same type is shown in Fig. No. 2.4.28 (a) and Fig. No.2.4.28 (b)

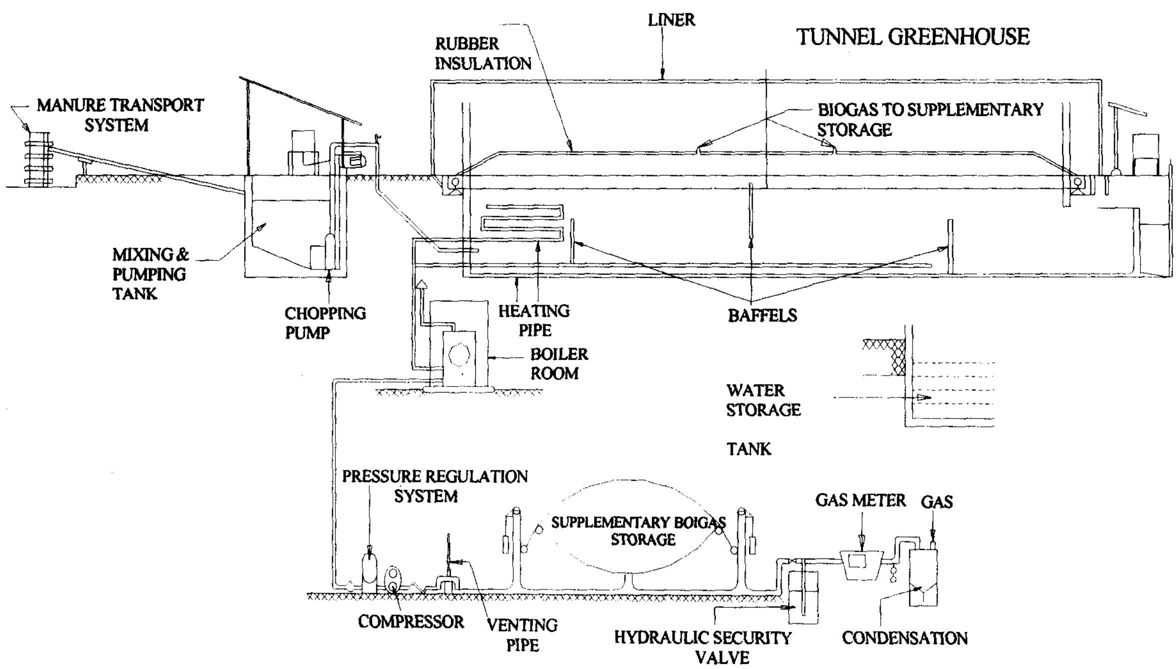


Fig. No.2.4.28 (a): Flexible top plug flow Digester

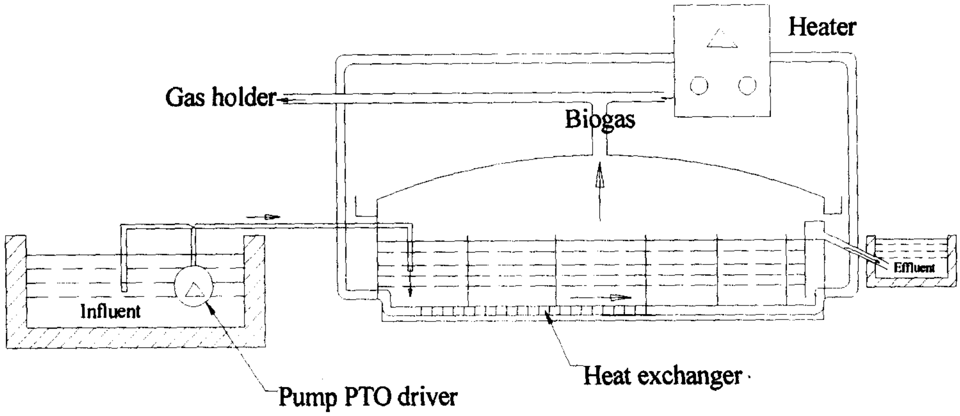


Fig. No.2.4.28 (b): Schematic view of the plug flow Digester

2.4.29 Bio-Funnel Reactor

This is an expanding, radial- overflow digester for continuous high solids loading. Fig. No2.4.29 shows the design of the same.

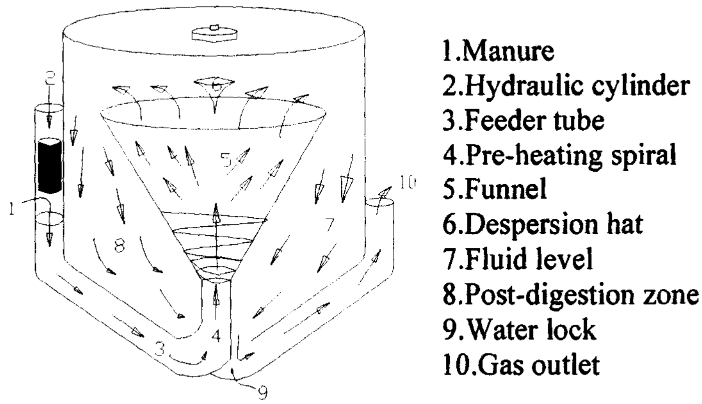


Fig. No. 2.4.29: Bio-Funnel Reactor

2.4.30 Anaerobic Baffle Reactor

Bachmann and McCartly at Stanford University evolved the design, which is very recent. The reactor is a simple rectangular tank, with physical dimensions similar to a septic tank, and is divided into 5 or 6 equal volume compartments by means of walls from the roof and bottom of the tank as shown in Fig. No.2.4.30.

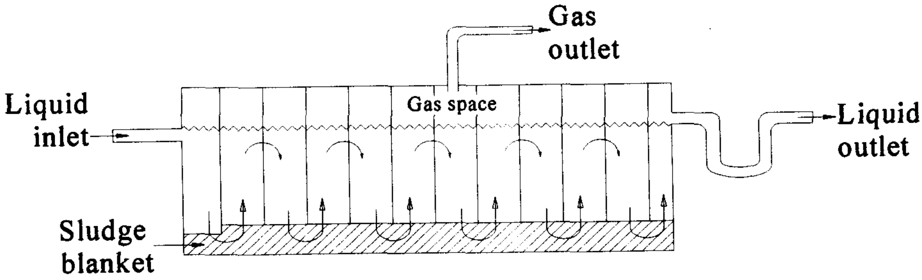


Fig.No.2.4.30.Anaerobic Baffle Reactor

2.4.31 Two Stage Digester with Internal Heat-Exchanger

This digester is designed based on two-stage reaction in digester with internal Heat Exchanger for 2000-3000 cu.ft. per day.

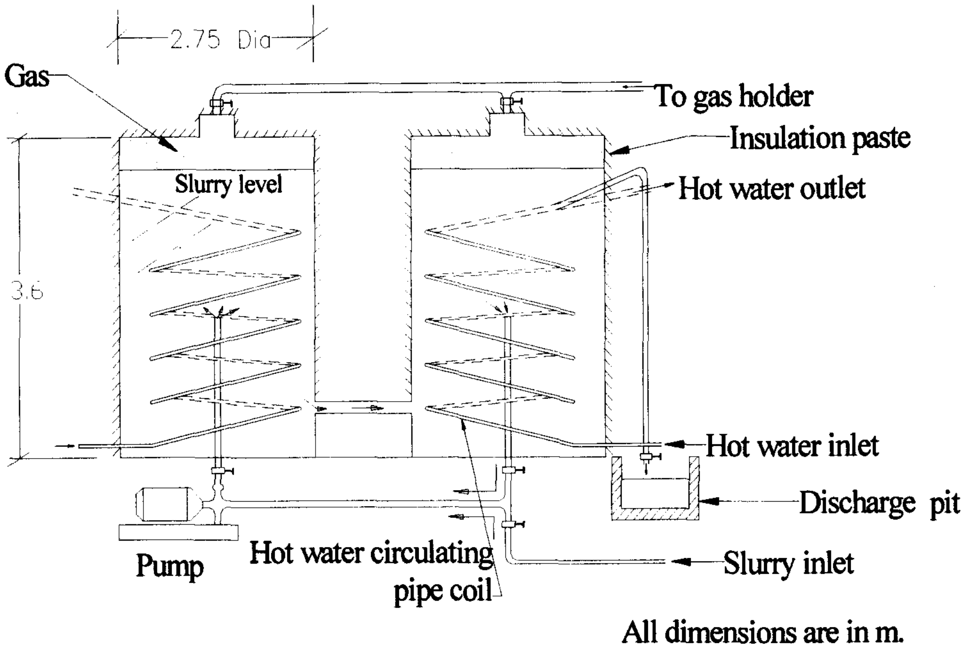


Fig. No. 2.4.31: Two Stage Digester with Internal Heat-Exchange

In the above figure no.2.4.31. hot water is circulated through the coils, regulated by a thermostat, the fermenting process may be kept at an efficient gas producing temperature. In fact, circulation only for a couple of hours in the morning and again in the evening should be sufficient in most climates [63].

2.4.32 Biogas Plant for Fibrous Feed Material

Depending upon the nature of the feed materials, biogas reactor is designed. For example, for long fibre feed material like banana stems the construction of biogas plant has been shown in figure no 2.4.32. In this type of biogas reactor a larger outlet diameter to cope with this is fitted. The feed material is light but hard fibrous content accumulate on the surface and form a floating scum. Scum breaker can break this deposited scum. It has been observed that one kg. of fresh banana stems (moisture content 95%) generates 25to 30 litre of biogas .One kg. of sun dried banana stems (moisture contents 15%) generates 330 litre to 350 litre of biogas.

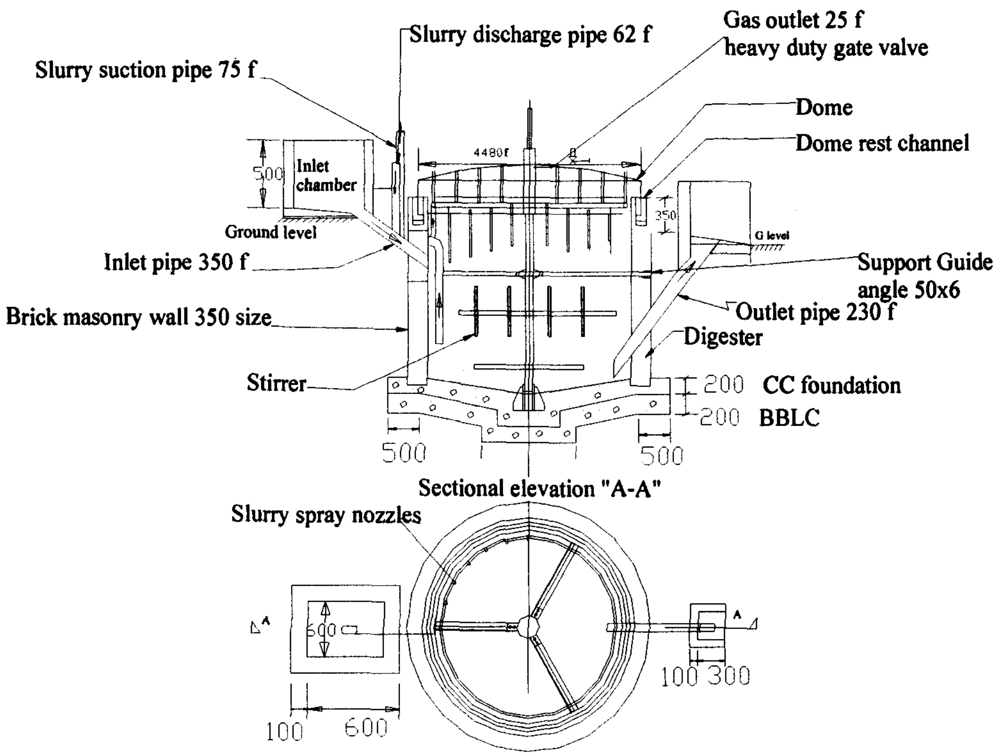


Fig. No. 2.4.32:Constructional drawings of a floating drum plant with Filter Funnel Long fiber feed material (Sasse)

CHAPTER - 3

CHARACTERIZATION OF BIOMASS

Chapter - 3

CHARACTERIZATION OF BIOMASS

3.1 INTRODUCTION

The term biomass refers to all the earth's vegetation and many products that come from it. Biomass covers all kinds of organic matters from fuel wood to marine vegetation. Biomass has high energy content, infact the energy content of dry biomass ranges from 3888 kcal/kg to 4720 kcal/kg [64] for wood. Bio-mass energy utilizes the energy content of such items as agricultural residue e.g. bagasse from sugarcane, corn fibers, rice straw and hulls, nut shell, urban yard clippings in municipal waste, energy crops. It is renewable as long it is grown or cultivated at a rate of equal to the rate of its consumption. On the other hand the principal organic matter in all plants constituting the major forms of biomass renews naturally and adds to itself in a very short span of time. This is a significant factor, which has classified Biomass as renewable source of energy [65].

Principal organic matter in the plants constituting the major form of biomass renews naturally. Thus all form of biomass has been classified as a renewable source of energy.

Sources of bio-mass

Biomass can be obtained from different sources comprising

(i) Organic waste, which accumulate at specific location such as municipal solid waste (M.S.W.) sewage sludge.

(ii) Residues left as plants materials in the field or during the post harvest period of agricultural crops or timber.

(iii) Bio-mass plantation like (a) Food crops with sugar cane, maize, cassova, sweet sorghum and potatoes, (b) Grasses, shrubs and particularly fast growing tree species such as eucalyptus and leguminous plants (ku-babul), (c) Some hydro-carbons producing plants such as *Euphorbia athyris and Euthorbia tirucolli,* crops like sunflower, rap seeds, soyabeans and ground nuts which are rich in vegetable oil.

About 370 million tons of agro wastes are generated every year, if fully utilized can generate 6000 MW of power yearly [66].

About 45 Million tons of solid waste and about 4500 million tons of liquid waste is generated every year in the urban areas of our country. This corresponds to an estimated potential of generatin about 1000MW of power from urban waste and about 700MW from Industrial waste generated by sugar mills, pulp and paper mills, etc [67].

3.2 PHYSICAL PROPERTIES

All biomass are mixture of major compound of carbon, hydrogen, oxygen and nitrogen. The Stoichiometric formula of biomass is $CH_{1.4}O_{0.6}$. Moisture content and specific gravity are the important physical properties, which influence the reaction pathways. Energy content of the biomass can be enhanced by removing the moisture [68]. The moisture content in the biomass greatly influences the reaction rate and also the hydraulic retention time. Proper particle size of processed biomass for conversion is also very important because a smaller size of it reduces the storage volume and facilitates handling of the material. The reduced sizes of particle also facilitate the easy movement of the slurry mixture. The particle size of biomass affects the conversion process in the bio-digester. Retention time for digestion is also a function of the density, which influences the biogas production. Retention time for the digestion will increase with the increase of density. The cost of shredding the biomass will also increase with the increase of density.

Biogas is about 20% lighter than air and has ignition temperature in the range of 650°C-750°C. It is an odourless and colourless gas that burns with clear blue flame similar to that of LPG gas [69]. Its calorific value is 20 Mega Joules (MJ) per m^3 (4700 $Kcal/m^3$) [70] and burns with 60% efficiency in a conventional Biogas stoves. The gas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel, and electricity, depending on the nature of use, local supply conditions and constraints [71].

3.3 CHEMICAL PROPERTIES

Chemical properties govern in general the volatility, heat content, chemical reaction and characteristics of biomass. The volatility of biomass materials can be evaluated from proximate analysis. This is a function of the chemical composition as evidenced by the molecular arrangements. Calorific value is also an important chemical parameter determining its suitability to use as a fuel. About 70% of the terrestrial bio mass are obtained from forest [72-74]. The structural components of wood are shown in table 3.3 [75,76]. The woody tissues are mainly composed of cellulose, hemicelluloses in particular pattern with other compounds such as lipids, hydrocarbons, etc. Chemical analysis shows that wood contain 50% carbon. The second major component of wood is oxygen (44%). The amount of hydrogen (6%), nitrogen (1%) and ash is supposed to be negligible [77]. The wood, like coal, can be gasified to carbon monoxide and hydrogen and it may also be liquefied and pyrolysed to yield ammonia, carbon, methanol, hydrocarbon etc. Biomasses are oxygenated complex compound as it is composed of cellulose, hemi-cellulose and lignin. The contents like carbon, hydrogen, nitrogen, oxygen, sulphur is to be analysed accurately for understanding their conversion to bio-fuel.

Table No. 3.3 Chemical composition of different woods

Wood	Cellulose	Hemi-cellulose	Lignin
Trembling Aspen	56.6		16.3
Beech	5.8	32.7	22.1
White Birch	44.5	36.6	18.9
Red Maple	44.8	31.2	24
Jack Pine	45	26.4	28.6
White Spruce	48.5	21.4	27.1
Eastern White Cedar	48.9	20.4	30.7
Eastern Hemlock	45.2	22.3	32.5
Oak Wood	44	20	26
Sycamore Wood	46	14	22
Grasses (Palums, bamboos, sugar, cane,)	25.4	25.5	10.3
Soft Wood (pine etc.)	42	27	28

Source: Green Energy (Biomass Processing and Technology), 2003, Capital Publishing Company, New Delhi, p 26.

3.3.1 Carbon / Nitrogen (C / N) Ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon / Nitrogen (C/N) ratio. A Carbon/Nitrogen ratio ranging from 20 to 30 is considered optimum for anaerobic digestion [78].

It is important that the bacterial elements present in the waste uses up carbon 30 times faster than they use up nitrogen. This is why the fixation of carbon to nitrogen ratio in the right proportion is essential along with monitoring of temperature, pH, etc. Considering the optimum values of pH, temperature etc. a Carbon to Nitrogen (C/N) ratio of 30:1 is maintained for obtaining optimum digestion rate [79].

If the C/N ratio is very high the nitrogen will be consumed rapidly by methanogen for meeting their protein requirements and will no longer react with the left over carbon content of the material. As a result gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_4) [80]. Ammonia will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population [81]

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8.

C/N ratio of some of the commonly used materials is presented in table no. 3.3.1.1 [82].

Table No.3.3.1.1 C/N ratio of some organic materials is mentioned below:

Raw Materials	C/N Ratio
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Pig dung	18
Sheep dung	19
Cow/ buffalo dung	24
Water hyacinth	25
Elephant dung	43
Straw (maize)	60
Straw (rice)	70
Straw (wheat)	90
Saw dust	Above 200

Source: " Bio-gas technology: a training manual for extension", (FAO/CMS, 1996).

The general quality of biogas can be estimated from the C/N ratio of the raw materials as mentioned in the table no.3.3.1.1.

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. Infact, as means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged.

Table No. 3.3.1.2 Gas Productions according to C/N Ratio of various waste

	Wastes	CH_4	CO_2	H_2	N_2
C/N Low (High Nitrogen)	Blood, urine	Low	High	Low	High
C/N High (low nitrogen)	Saw dust, straw, sugar and starches such as potatoes, corn, sugar beet wastes	Low	High	High	Low
C/N Balanced (C/N = near 30)	Manures, garbage	High	Some	Low	Low

Source: Fry L.John, 19, Methane Digester for Fuel Gas and Fertilizer, 2004.

3.3.2 pH value of slurry mixture

The optimum biogas production is achieved when the pH value of the input mixture in the digester is between 6 and 7. The pH in a bio-digester is also a function of the retention time. In the initial period of fermentation as large amount of organic acids are produced by acidogenic bacteria, the pH inside the digester can decrease to below 5. Low pH inhibits the growth of the methanogen bacteria and hence gas generation is often the result of over loading [84]. Acetate and fatty acids produced during digestion tends to lower the pH of digester liquor [85]. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, the concentration of ammonia increases due to digestion of nitrogen, which can increase the pH value to above 8. When the methane production level is stabilized the pH range remains buffered between 7.2 to 8.2 (FAO/CMS, 1996b) [86]. A pH higher than 8.5 will start showing toxic effect on methanogen population. Hansen et al. (1998) states that acetate - utilizing methanogens are responsible for 70% of the methane produced in biogas reactors) [87].

3.3.3 B.O.D. and C.O.D. ratio

BOD is a measure of the amount of O_2 required for the Biological oxidation of the organic matter under aerobic condition at 20°C and for a period of 5 days. Microorganism consumes biodegradable materials and amount of material consumed is proportional to the amount of oxygen present in the stream. In anaerobic digestion no oxidizing agents are added and hence amount of BOD resume is proportional to methane produced [88]. The rate of BOD reaction depends on the type of waste present and temperature and is assumed to vary indirectly with the amount of organic matter (Organic Carbon) present.

Chemical Oxygen demand is a measure if any kind of oxidisable impurities present in the organic compounds [89], most of the organic matter are completely oxidized by a boiling mixture of chromic acid and H_2SO_4 to produce CO_2 and H_2O.and the results are on a mass basis in term of the amount of O_2 that would be required if it were electron acceptor.

Expected BOD /COD ratio is always greater than 0.5 to ensure proper biodegradability during anaerobic digestion. Anaerobic digestion is not preferred if BOD/ COD is < 0.33. The BOD for kitchen waste observed was 44000 mg/lit. and COD 57000 mg/lit [90].

3.4 RELATIONSHIP OF BIOMASS PROPERTIES AND CONVERSION PROCESS

Exploitation of biomass as an energy source will not to be to its fullest extent if used as a fuel for cooking. However, converting into combustible gasses by biotechnological mean [91-94], it has wider application and can be used as an alternative fuel for cooking, generating Electricity by driving an Engine.

The biomass conversion techniques mainly of three fundamental types namely combustion process, dry chemical process and aqueous process and the choice depends on the biomass water contents. The principal routes and product involved in these techniques are given in fig. nos. 3.4.1.and 3.4.2.

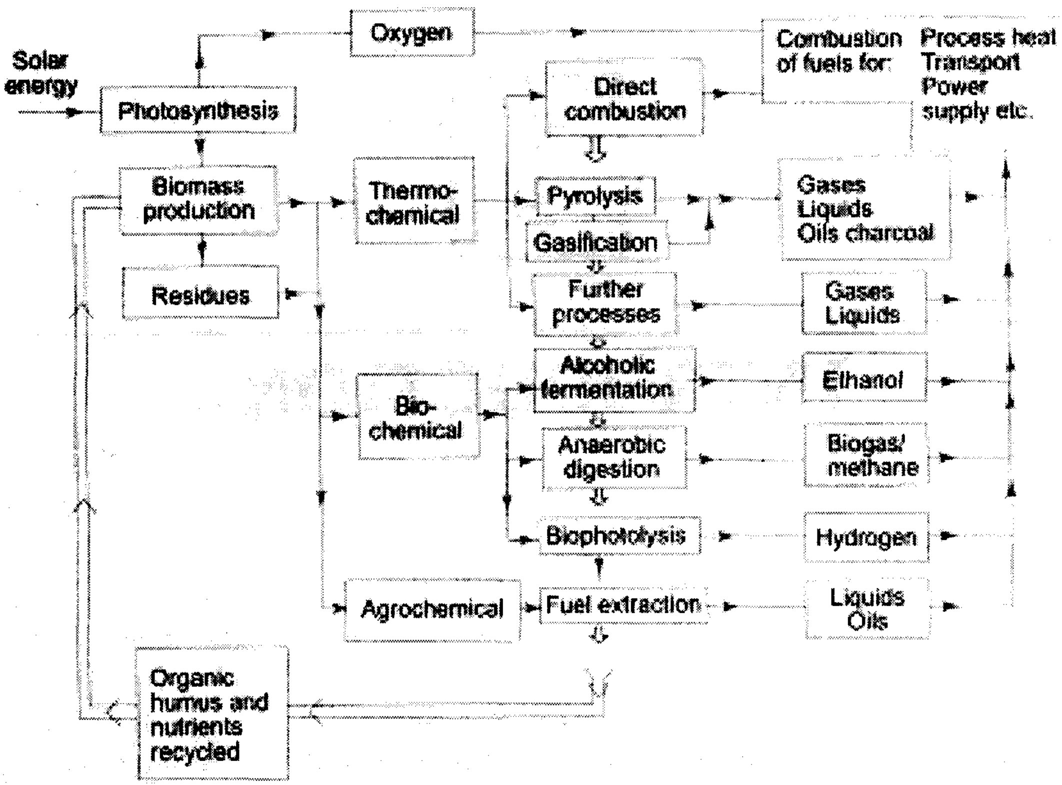


Fig. No. 3.4.1: Biomass Conversion Route to Bio fuel

Source: Nijaguna, B.T., "Biogas Technology", Published by New Age International (P), 2002, p 2

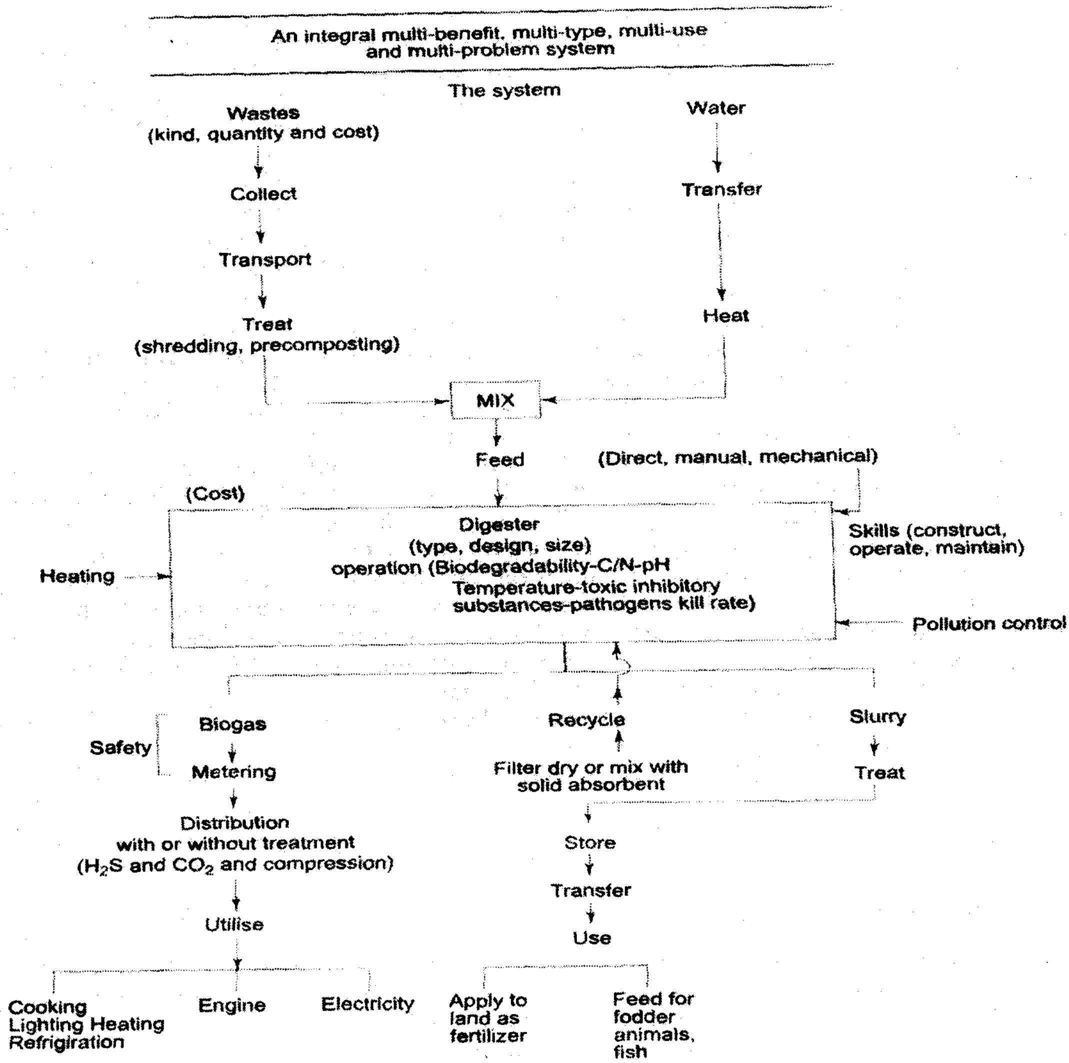


Fig. no. 3.4.2. The Biogas/ Biomethanation System

Source: Nijaguna, B.T. , "Biogas Technology" , Published by International (P), 2002, p 3

Based on the above conversion process -Biomass can be converted into energy, either in the form of liquid fuel or gaseous fuel by means of suitable microbes.

3.5 BIOMASS ENERGY CONVERSION TECHNOLOGY

Biomass has been used for many thousand years as a source of energy. Direct combustion of biomass considered as a source of fuel throughout the history of human civilization. The process of direct use of biomass as a fuel for cooking and heating purpose rather inefficient. But conversion to combustible gas by bio technological means will have wider application purpose. Biomass conversion techniques, mainly of three fundamental types i.e. (i) combustion, (ii) dry chemical process, (iii) aqueous process are chiefly used depending on the biomass water contents [95].

The principal routes and product involved in these techniques are given in fig. no. 3.5.

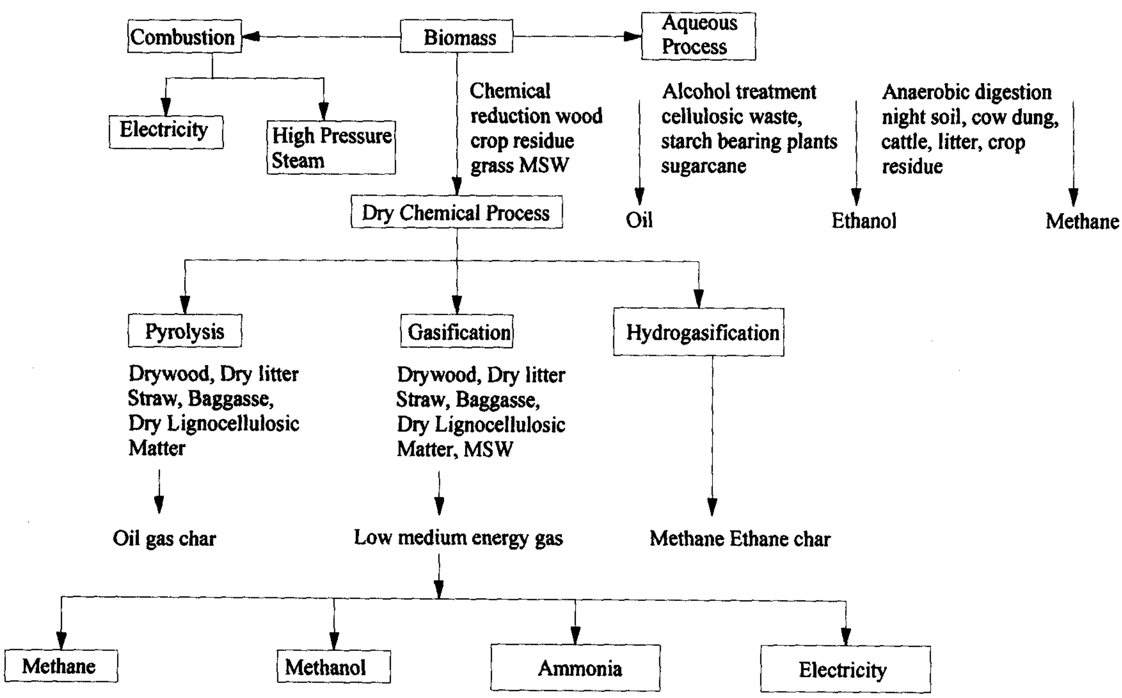


Fig. No. 3.5: Biomass Energy Conversion Technology

Source: Green Energy (Biomass Processing and Technology), 2003,Capital Publishing Company, P 103.

Biomass that contains high percentage of moisture and for this reason thermal gasification or pyrolysis of the feed is not recommended. On the other hand, it is very much suitable to follow the anaerobic digestion of the feedstock where moisture removal is not necessary. So the conversion process should be considered depending on the characteristic of the feedstock.

3.5.1 Advantage of methane

Biomass can be converted to a variety of energy forms including heat (via burning), steam, electricity, hydrogen, ethanol, methanol, and methane. Selection of a product for conversion is dependent upon a number of factors, including need for direct heat or steam, conversion efficiencies, energy transport, conversion and use of hardware, economics of scale, and environmental impact of conversion process of waste and product use. Under most circumstances methane is an ideal fuel.

Compared to other fossil fuels, methane produces few atmospheric pollutants and generates less carbon dioxide per unit energy. Because methane is comparatively a clean fuel, the trend is toward its increased use for appliances like vehicle, industrial applications, and power generation. Other fuels such as methanol and hydrogen are not well developed commercially for production and use are more difficult to produce from biomass.

3.5.2 The benefits of anaerobic digestion

The benefits of anaerobic digestion include the following such as odour reduction, reduction in the biological oxygen demand of treated effluent by up to 90%, reducing the risk for water contamination, Improved nutrient application control, because up to 70% of the nitrogen in the waste is converted to ammonia, the primary nitrogen constituent of fertilizer, reduced pathogens, viruses, protozoa and other disease- causing organisms in lagoon water, resulting in

improved mainly health and possible reduced water requirements, and potential to generate electricity and process heat.
Laboratory and pilot studies have been carried out at different places in India to convert various biomass feed stocks to biogas, notably with water weeds such as water- hyacinth (*Eichhornia* sp.) and salvia [96]. These feedstock was simply fed to the pulverizer in order to obtain small particles and render them into slurry [Hobson et al.1981] and feed them to the conventional type of biogas plant. Similar efforts have been made with kitchen waste [97], crops residues such as rice straw [98].

3.6 ANAEROBIC DIGESTION OF VARIOUS ORGANIC WASTE

The people throughout the world in recent years are very much concerned about the environmental pollution caused by the large quantity of garbage and waste materials, which are generated in urban areas, and also by the industrials sectors. The generated waste materials thus needs scientific treatment in order to maintain the pollution control levels and also recovering the huge energy potential from them. The quantity generated every year in class-1 cities in our country is estimated to be about 30 million tones of municipal solid waste and about 440 million cubic meters of sewage [99]. In addition to these large quantities of waste are also produced by manufacturing and other processing industries like sugar mills, distilleries, pulp and paper mills, dairies, slaughter houses, tanneries, pharmaceutical units, etc. These waste have energy potential equivalent to 1700 MW (1000 MW from urban waste and about 700 MW from industrial waste) [100].
Treatment of these waste are mostly organic in composition and have the potential of energy recovery with multiple benefit such as abatement of environmental pollution.

In view of the above, the ministry has implemented projects throughout the country. One such program with the help of UNDP/GEF have been stabilized on development of high rate bio-methanation process to reduce the emission of green house gases. The National Environmental Engineering Research Institute (NERI) has taken of a pilot project for de-sulfurization of biogas as R&D projects at M/S Vam Organic Chemical Ltd., Gajraula (UP), and Nagpur sponsored by the MNES. [101].

3.6.1 Biomethanation of Industrial Effluents

Indian Renewable Energy Development Agency Limited (IREDA), was established under ministry of non-conventional energy sources (MNES), Govt. of India with the following objectives:

(i) To promote renewable sources of energy,

(ii) To provide financial support to manufactures and users,

(ii) To assist in rapid commercialisation,

(iv)To provide consultancy.

The Process:

The process called anaerobic fermentation of the organic waste generates biogas. Anaerobic digestion or bio methanation is a complete process carried out by a number of species of bacteria with varied characteristics. The anaerobic digestion takes place in two different bio-chemical stages. First the acid forming bacteria act and degrade long chain organic compounds effluents to acetic, propionic and butyric acids and in the second phase the methanogenic bacteria act to generate biogas comprising methane, carbon dioxide and hydrogen sulphide. The bacteria feed upon the BOD contributors of the effluents and convert them into methane gas [Source: IREDA, Energy forever].

3.6.2 Methane production by anaerobic digestion using Water-Hyacinth (*Eichhomia crassipas*).

Water hyacinth a native of South America is abundantly found in India, Bangladesh, South East Asia and in Philippines Island. Under favourable conditions a growth rate as high as 17.5 metric tones of water hyacinth per hector per day has been reported. [102-104].

Water hyacinth is a wetland plant and aquatic biomass species and grows submerged in water and show various adaptation to this habitat (Visual dictionary, page 158) [105]. It has been suggested that this plant is a strong candidate for producing methane by anaerobic digestion method. The study was carried out in a batch fed digester (fixed dome type), [106].

Water hyacinth is chopped and mixed with plant sludge for obtaining rich compost, which can be utilized in sugarcane cultivation. The entire process was developed as a natural and inexpensive technique of recycling liquid waste [107]. Attempts have been made to reach at an optimum condition for the production of maximum amount of gas by the addition of lower volatile fatty acids, cow dung and inoculums. Addition of cow dung increases the gas production as well as it lowers the retention period. This has been observed that the total volatile solid content of the system increases with the increase amount of cow dung. The lowering of the retention period in the case of cow dung +water hyacinth system is due to the fact that the bacteria responsible for the degradation of biomass is facilitated by the addition of cow dung [108]. After digestion of water hyacinth inoculums can be used as good manure for soil fertility, which is free from harmful chemicals and is a boon for sustainable practices [109].

It has been observed that a blend of water hyacinth cow dung in the ratio of 2:3 by weight is most suitable for biogas production. But rate of production of biogas from water hyacinth is higher as compared to cow dung slurry. The digested slurry can be used as useful chemical free eco- friendly manure [110].

3.6.3 Biogas from slaughter house wastes

Study reveals that huge quantity of waste generated from the slaughter houses is about 3600 tones per day in India which consists of: floor washings, stomach contents, small bone and meat pieces. Floor washings mostly contain blood, small meat and bone pieces, which is collected in a pit and dumped to the dumping sites.

All the above waste is biological in nature and hence bio-methanation is the real solution for generating biogas from these wastes and also to reduce the pollution load.

Multiple models of anaerobic decomposition for the production of methane rich biogas from slaughterhouse waste had been designed and developed by G.D. Lindaur and their co-workers [111]. In these types of models two numbers of tanks were made, one for storing the half of daily amount of substrates as a first batch. After storing the same is heated and stirred in a pasteurisation tank. Once the pasteurised temperature reached, the substrate is stored until the other half of the substrate is fed into the other pasteurised tank. The pasteurised substrate is cooled by circulation and the heat, which it gives off, is used to heat the second amount of substrate. The substrate is cooled to 37^0 C in the decomposition tank and injected into the agitation process. The substrate in the pasteurised tank is agitated by a motorized stirrer and thus produces two types of circulation by which creation of any scum in the top surface is eliminated. The decomposed substrate than passes to a tank for dehydration process. The dehydrated residue is then transported to the land as fertilizer.

3.6.4 Biomethanation of Tannery waste

Biomethanation of tannery waste was first developed by the Centre for Leather for Leather Technology, CTC, Lyons, France.

It has been studied from the recent literature that the daily solid waste generated from leather processing units in Kolkata is approximately 175- 180 metric tones having an energy potential of 2.3 x 10^6 MJ which once again is equivalent to about 80 metric tones of coal [112]. Hides and skins are very rich in organic carbon content to the extent of about 50% on dry weight basis. The hydrogen content of the collagen is about 6.7% on dry weight basis. Another important feature is about 16 – 17% on dry weight basis presence of nitrogen. This is responsible for 30% of the digested solid waste remaining as residue after energy recovery which is a nitrogen rich manure. It has been observed that bio-gas generated from tanneries contain 70- 80% methane as compared to collection from cow dung, piggery waste etc which is only in the range of 50-55%. [113].

3.6.5 Bio-gas produced from kitchen waste

Kitchen waste has a good potential for generation of power and fertilizer. In big kitchen in the hostel, restaurant, hotel, there is large quantity of remnants of vegetable, fruit peel and other residues are generated. Disposal of these waste in the open area create problems of pollution. To solve this problem, one of the solutions is bio-methanation of this waste [114].

Yeole et al., [115] reported the feasibility of using the canteen waste as a feedstock in biogas digester. They suggested reduction in particle size of the waste below 2 cm, for successful operation of the biogas plant. After study it further revealed that biogas could be generated to 60 m^3 per day from the generated kitchen waste of 600 kg/day. This biogas can be used for cooking in the kitchen and can replace L.P.G. of 30 kg/day approximately. Wastewater generated from the kitchen waste plant (KWP) can be used for gardening purpose. A typical kitchen waste to energy plant scheme is shown in fig. no. 3.6.5.

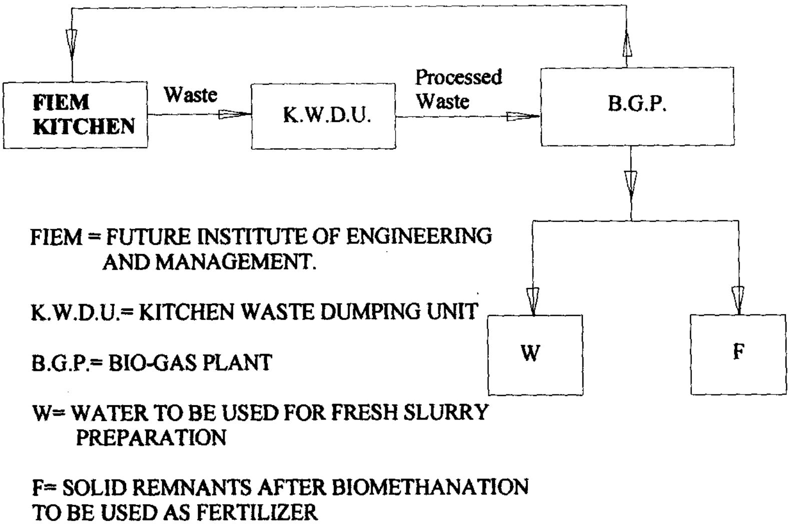


Fig. No. 3.6.5: Biogas production from Kitchen waste

It is estimated that 10- 15 % fuel requirement of a kitchen can be met with biogas obtained from kitchen waste. Kitchen waste based biogas plant set up by Bhava Atomic Research Center (BARC) at Trombay. The plant produces biogas from kitchen waste by using thermophillic microorganism that flourish in extreme environment. A kitchen waste based biogas plant has been installed at nursery site for environmental friendly disposal of the waste generated in kitchens of various canteens in BARC premises. The waste generated in kitchen in the form of vegetables refuge, cooked and uncooked food extracted tealeaves, and waste milk and milk products can all be processed in this plant. They designed and developed mixed manure by a 5 HP motor to process the waste in the form of slurry, which would be far more accessible for the microbial action. The waste is converted in slurry by mixing with water (1: 1) in this mixing tank. Sarder Patel Renewable Energy Research Institute (SPRERI),Vallabh Bidhyanagar, Gujrat, conducted experiments on generation of biogas from kitchen waste. Based on the data obtained, a prototype of a 10m³ biogas plant was designed. To such plants were installed at two-community kitchen serving food to the students in Vallabh Vidyanagar.

3.6.6 Biomathanation of market waste

In our country there are about 400 districts with about 4000 towns and bazaar places having large vegetable market. The vegetable waste generated from these markets to be around 50000 tones per day. These vegetable wastes have the potential to generate 4million m^3 of biogas per day. Moisture content of this waste is around 70% [116]. This material is usually high in fibrous content.

To eliminate the transportation cost for transporting this waste to the site of biogas plant, it will be beneficial to set up bio-methanation plant nearby the market area. By bio-methanation process of this waste, biogas can be generated and the effluent can be used as good fertilizer. In addition the process would be environment friendly, hence improve sanitation. If such waste is recycled in biogas plant it will be a source of energy, health and wealth [117]. Because of the high content of moisture in the waste, it is not recommended for incineration, bio-methanation is most suitable for decomposition of this waste. A biogas plant was commissioned in November 1992, in Pune, India for producing biogas using market waste. Digester is floating type gasholder with water sealed type. The methane content observed is around 70% [118].

3.6.7 Biogas from Paper Mill Waste

The growing environmental concern and stringent government legislation have brought biological treatment system into spot light as means of treating pulp and paper with effluents

Pulp and Paper Mill effluent is a potential source for conversion of waste to energy. Treatment of paper mill waste through UASB not only helps in environmental preservation but also produces energy by converting waste to energy. The additional advantage is that the biogas produced from the anaerobic treatment plant is used as a fuel in the boilers and meets up to 18 % of the thermal energy required for cooking the meals.

A biogas plant was set by nuclear fuel complex in Hyderabad, India, July 1991 to utilize the paper waste in order to get methane [119]. The waste paper fed initially to a shredder for size reduction then mixed with water to produce slurry at about 5- 10 % consistency. The slurry mixture is than dropped through screen to the preliminary digester where the previously weighted food waste is added. The waste then mixed with the help of mechanical agitator for an hour to form pulper. This mixture is finally transferred to pre- digester. Sometime a measured quantity of urea and caustic soda is added for faster process in the digester. After 24 hours of reaction time, the mixture is transferred to first anaerobic digester for acid formation and finally it is fed to the second anaerobic digester for methanation. It was found satisfactory production of biogas from the plant.

3.6.8 Bio-gas production from cow dung

Dr. Ram Bux Singh and his co-workers have designed and set up a biogas plant in the name of Gobar Gas Research Station at Ajitmal [120] in India in 1960 having capacity of 100 to 9000 cubic feet of methane per day. They have experimented with different mixture of manure and vegetable waste.

Cow dung gas having 55- 65% methane, 30- 35% carbon dioxide with some hydrogen, nitrogen and other traces. Its heat value is about 600 BTU per cubic feet. Gobar gas may be improved by passing it through limewater to reduce CO_2, iron fillings to absorb hydrogen sulphides and calcium chloride to extract water vapour. It has been observed that after degradation, the cow dung slurry is composed of (1.8- 2.4) % nitrogen, 1.0- 1.2% of phosphorous (P_2O_5), 0.6- 0.8% potassium dioxide (K_2O) and 50- 75% organic manure [121].

S.Singh and S.K. Singh has produced approximately 22% more bio-gas from the cow dung as compared to the normal decomposition by adding cupric nitrate {Cu $(No_3)_2$} as an accelerator in the digester and in the process gas production is increased by about 22% [122].

Punjab Energy Development Agency (PEDA) has developed non-conventional sources by utilizing the cow dung originating from the dairy units in the Haebowal complex in Ludhiana for the production of electricity, [123]. Biogas technology has been commercially introduced in Nepal since the establishment of a unit by Gobar Gas Tatha Krishi Jantra Vikas (P) Ltd in the year of 1977.

3.6.9 Biogas production from cotton waste

It has been observed that cotton textile dust is a good raw material for the purpose of anaerobic fermentation and could be economically converted into biogas and manure. One kg of micro-dust can generate about 200 m^3 of biogas in 50 days.

At present there is no use of this cotton waste except to some extent it is composed for cultivating vegetables, this can be a good source of generating thermal energy through biomethanation.. The country can generate useful fuel from the available cotton waste, equivalent to 30 lacs liter of petrol or 18,26,086 kg LPG [124].

3.6.10 Biogas production from human excreta (night soil)

Originally, it was envisioned that the waste of the latrine would be collected into a settling tank and the excess of liquid would be drained into a soaking pit. The settling tank, which was conceived as a manhole chamber substituted pre-storage tank. Thus, the faecal raw sludge from the latrine is first collected into this manhole compartment from where it is led into the bio digester. Excess of urine can create toxicity to the methanogenic bacteria for which a provision was made to drain it into a soak pit particularly from the urinals constructed in the male section of the latrines. The concept of the integrated production and use of biogas and stabilized manure from the community latrine-cum biogas plant has been shown in the figure no.3.6.10

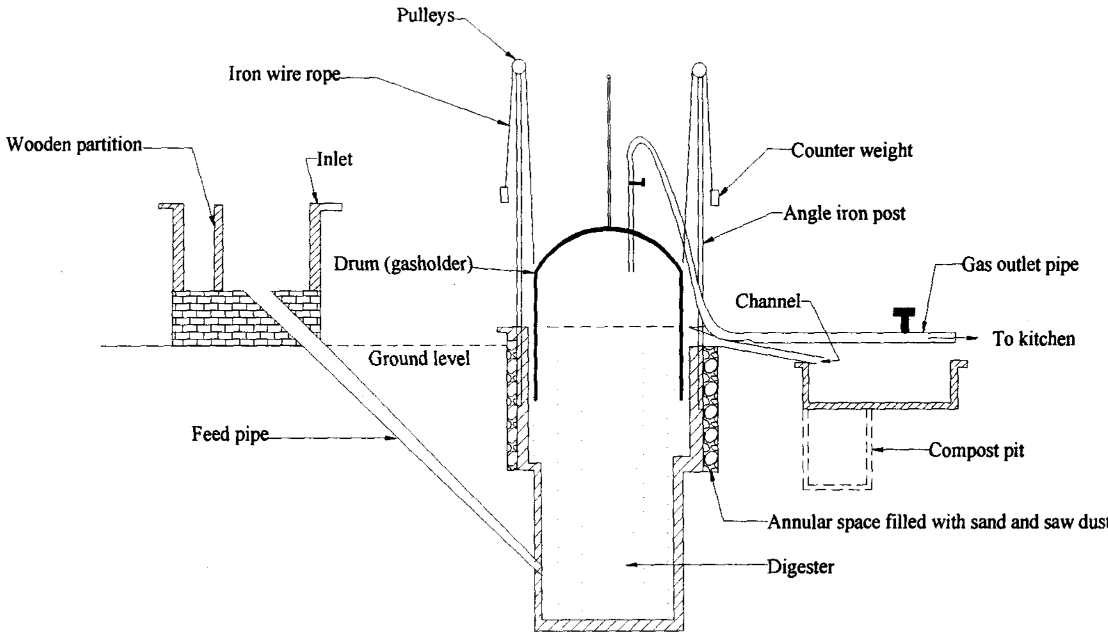


Fig No. 3.6.10: Biogas Plant based on human excreta

Chinese are the first front in using human excreta at mass scale level [125,126].

A fixed dome Chinese type Gobar gas plant of 15 m^3 capacity was installed by Agricultural Equipment Development Company as approved by biogas support program of the Netherlands development organization (SNV/ Nepal) was installed to produce bio-gas and stabilized manure Human excreta is also an excellent feed material for anaerobic fermentation. On an average 85% volatile solids are present in human excreta and the carbon to nitrogen (C/N) ratio is low [127-132]. The excess of ammonia present/ produced during digestion is generally neutralized by volatile fatty acids accumulated in the digester, due to over loading. Besides this night soil is rich in organic content, nutrients are easily susceptible for microbial digestion. For these reasons it is often responsible for environmental pollution and a host of diseases. With proper technique of microbial treatment night soil can be processed production of value added gases and low cost fertilizer. This means bio-methanation of human excreta has two important aspects; environmental sanitation and energy generation. In India, utilization of night soil in biogas plant was first initiated by "Appa Saheb, Patwardhan of Maharastra Gandhi Smarak Nidhi, Pune, in the year of 1953." The biogas generated from such plant is used for cooking, lighting and generation of electricity [133-134]. Estimated Human excreta and animal wastes available in Indian conditions are mentioned in the table no. 3.6.10

Table No. 3.6.10

Source (Waste)	Total Waste (Kg./day/head)	Collectable Kg./day/head
(a) Cattle	10-15	5-8
(b) Pigs	1.3	0.3
(c) Sheep	0.75	0.25
(d) Man /person	0.75	0.75
(e) Kitchen Waste/ person	0.25	0.25
(f) poultry	0.06	0.06

Source: Nijaguna, B.T., " Biogas Technology", New Age International Publishers (P) Ltd, page 28.

It has been observed that addition of inoculums from an operating digester and a little amount of molasses to a fresh digester reduces time of gas production [135].

3.6.11 Biogas generation by plug flow type of digestion using pig manure.

The first effort to produce biogas in a controlled way and in quantity was done by a South African pig farmer, L. John Fry, R.A.F. Retired [136]. Mr. Fry built the first "continuous – feed displacement digester"- A closed concrete tank, 50 ft. long, 11 ft. wide and 5 ft. deep. A few sealed hatches were left for access points and a pipe led to a huge gas storage tank. Raw manure from 500 pigs was mixed with water poured into a loading pit, and pumped into a digester. In every 24 hour, the mixed daily load in the digester transferred to the adjoining digester by injecting fresh material at the input end. The mixed slurry was retained in the digester for 30 days.

The sludge was odourless, entirely free from harmful bacteria and much richer in nitrogen than manure composted in an open-air heap. About 3000 cubic feet of biogas per day was generated continuously. Part of the gas was used for heating and cooking; the rest was used for generating electricity.

3.6.12 Metals supplementation enhances biogas generation.

Heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria. But their higher concentration has toxic effects. Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of minerals ions also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effects. The inhibiting levels of some major substrates that produce toxicity on bacterial growth are given in table no.3.6.12

Table No. 3.6.12 Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate ($SO_4{}^{2-}$)	5000 p.p.m.
Sodium Chloride or Common salt (NaCl)	40000 p.p.m.
Nitrate (calculated as N)	0.05 mg/ml
Copper (Cu^{2+})	100mg/l
Chromium (Cr^{3+})	200mg/l
Nickel (Ni^{3+})	300-500mg/l
Sodium (Na^{+})	3500-5500mg/l
Potassium (K^{+})	2500-4500mg/l
Calcium (Ca^{2+})	2500-4500mg/l
Magnesium (Mg^{2+})	1000-1500mg/l
Manganese (Mn^{2+})	Above 1500mg/l

Source : Biogas Technology in China, BRTC, China (1989)

3.6.13 Bio-methanation potential of municipal waste water

Municipal wastewater is a potential feedstock for bio-methanation. It reveals from Literature Survey that thousand gallons of municipal wastewater yield about 0.25 m^3 of biogas. It is anticipated that about 46000 NM^3 of biogas can be produced per day from 340 million litres daily from municipal wastewater. There is a possibility to generate 99450 kwh. per day of electrical energy from the installed biogas plant in 21 cities under Ganga Action Plan [137].

Apart from municipal wastewater, the other waste generated from industries like dairies, distilleries, tanneries, paper and pulp industries, has the potential to generate nearly 700 MW of power [138].

3.6.14 Bio-methanation of market organic waste

Large vegetable and fruit markets in big cities contribute much to the accumulation of this waste which is disposed –off by composting, spreading on the land or some times as an animal feed [139, 140]. Over 600 tonnes of fruits vegetables are produced annually in India, of which only one percents processed in fruit and vegetable processing industry [141]. Market waste consists of mainly seasonal vegetables waste; fruit waste, packing materials, plastic, etc. Types of these waste has been shown in the fig. no.3.6.14.1

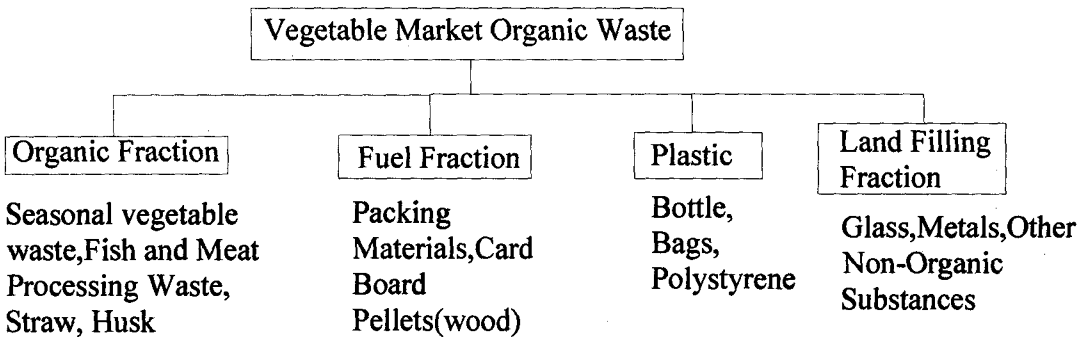


Fig.No.3.6.14.1: A schematic diagram of vegetable market organic waste (Based on general appearance)

Composition of typical organic waste from vegetable market is given in Fig. no.3.6.14.2

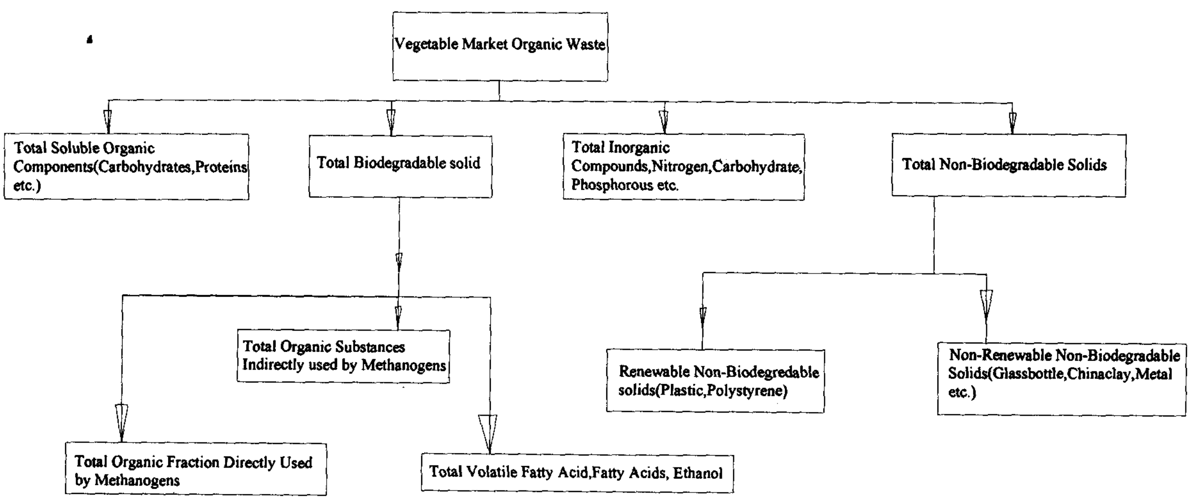


Fig No.3.6.14.2: Composition of Market Organic Wastes

Production of biogas from market organic waste (M.O.W.), depends on the composition of seasonal vegetables and other organic waste present. It has been observed that the total carbon content in market organic waste is 40% and nitrogen is in the wide range of 21.32 – 76.5 [142].

In order to get maximum biogas the ratio of C/N is generally maintained between 20-30.

However in case of paper and sewage waste maximum yield of biogas has been noticed at C/N ratio of 52. [143]

3.6.15 Biogas from Banana Stems

Banana stems are fibrous and has very high moisture content; 83% of its local solids are volatile which offer potential for anaerobic digestion. Its C/N ratio is 25 and cellulose content is 17% of dry weight, both of which are good for anaerobes. From extensive studies at laboratory and pilot scales, the following observations are reported:

i. One Kg of fresh banana stems (moisture content 95%) generates 25- 30 litres of biogas. One Kg of sun dried banana stems (moisture content) generates 330- 350 litres of biogas [144].

ii. Methane content in biogas generated from banana stems is in the range of 60- 70% compared to 50- 55% in the biogas produced from cattle dung. Hence, the biogas produced from banana has higher calorific value.

iii. The retention period for the degradation of banana is 40 days compared to 30- 35 days for cattle dung. Specific gravity of banana stems is 0.5 compared to 1.01 for cattle dung. The substrate to water ratio for the degradation of banana stems is 1:2 compared to 1:1 for cattle dung. Hence, the degradation for banana stems requires more volume than that of cattle dung degradation.

iv. Behaviour of banana stems under anaerobic digestion is different from that of cattle dung. Fresh banana stems float over the water surface and digested material sinks to bottom.

Fully digested material is in the form of powder.

v. The fresh and floating material forms a mat over the water surface and sticks to the vertical sides of the floating gasholder.

vi. As the behaviour of banana stems mentioned above is different from cattle dung, the traditional designs of biogas plant (KVIC, Janata) are not suitable for banana stems.

This plant has the following features:

i. Input material is provided through a masonry wall near the top of the digester and the output chamber is connected to the bottom of the digester to facilitate the feeding of fresh material and discharging the digested slurry.

ii. Hopper bottom is provided to prevent accumulation of digested material.

iii. A stirrer is fitted centrally to the digester having the horizontal and vertical bars so that the slurry material inside the digester being stirred throughout the depth of the slurry and also to break the scum appeared over the top surface of the slurry.

3.6.16 Biomethanation of Municipal Solid Waste (MSW)

Anaerobic digestion systems for digesting Municipal Solid Waste are now widely used through out the world. The majority of plants are large scale, processing over 2,500 tonnes of waste per day and thus involve complex plant design including the handling system of the voluminous waste. Most of the technology is based in Europe, with Germany and Denmark leading the field in technology and in the number of successful plants in operation. [145].

In municipal solid waste, acetic and lactic acids are produced during storage, and in source-separated organic waste, these acids can reduce the pH value to 4-5 [146]. The initial period of low pH can be significantly reduced if the temperature in compost stays below 40^0C

until pH rises [147].

To increase the rate of digestion and biogas production multi-stage processes are often used. Most of the larger scale, industrial systems process MSW alone, however the simpler, smaller scale systems are more successful when co-digestion with animal manure is used.

Breakdown of facility by the different country is shown in table no. 3.6.16

Table No.3.6.16 Breakdown by various countries of Anaerobic Digestion Plants (capacity of 2500 Tonnes per year).

Country	No. of plants in operation	No. of plants under construction
Austria	10	0
Belgium	1	2
China	0	1
Denmark	21	1
Finland	1	0
France	1	0
Germany	30	9
India	0	4
Italy	4	2
Japan	0	1
Netherlands	4	0
Poland	0	1
Spain	0	1
Sweden	7	2
Switzerland	9	1
Thailand	0	1
U.K.	0	1
Ukraine	1	0
U.S.A.	1	2

Source:IEA Bio Energy Report 1997-System and Market Overview of Anaerobic Digestion.

The following sequences are being followed of Anaerobic Digestion of MSW

(i) Digester Material

Only Waste of organic origin can be processed in an anaerobic digestion about 30-60% of household waste there is a considerable benefits in diverting this waste from landfill, MSW is composed of: -

a) Digestible organic fraction-readily biodegradable organic matter, eg. Kitchen waste, Food residue, Vegetable waste, Grass cutting etc.

b) Combustible fraction-Slowly digestible organic matter such as coarser wood, papers, cardboard.

c) Inert fraction-Stones, glass, sand, metal etc. Some of these products are suitable for recycling, the reminder can be land filled

(ii) Separation

Source separation: Recyclable materials separated from organic waste in the source. The production obtained is more contaminated which will affect the heavy metal and plastic content of the final digested composting product.

(iii) Pre-Treatment

Having separated any recyclable or unwanted material from the waste, the organic material must be chopped / shredded before it is fed into digester.

(iv) Anaerobic digestion

The process of digestion follows three stage,

(a) Hydrolysis or liquification

(b) Acetogenesis/Fermentation

(c) Methanogenesis

(v) Final Product

The gas produced through anaerobic digestion is methane, carbon-dioxide, hydrogen sulphide.

(vi) Up gradation

The generated gas should be upgraded by eliminating CO_2, H_2S and water vapour so that the up graded gas can be used for cooking, as an alternative fuel for I.C. engines.

(vii) Composting

Drying of the substrate is often a key objective of composting [148,149]. In household waste composting, the waste normally has as solids contents of 30-60 % and the concentration of readily available substrate is high. This makes the compost susceptible to high temperatures and excessive drying. In fact, water addition can often speed up the composting process [150].

Advantages of MSW anaerobic digestion

Following advantages can be noticed by anaerobic digestion of MSW:-

(i) Makes land fills easier to manage by removing problematic organic waste material

(ii) An end product can be used as a soil conditioner is produced.

Anaerobic digestion for solid waste can be processed through one stage dry system and the same has been inspired for digestion of organic waste, during the 80`s.

Later the conversion technology is mediated by two stage systems that lead to large overall reaction rate of biogas yield.

CHAPTER-4

ANEAROBIC DIGESTION

Chapter - 4

ANAEROBIC DIGESTION

4.1 ANAEROBIC DIGESTION AND CHEMISTRY OF BIOMETHANATION

Anaerobic digestion (AD) is a process of converting organic materials in to methane (CH_4), Carbon dioxide (CO_2), and water vapour (H_2O) through microbial fermentation in the absence of oxygen [151]. At the end of the process the left over slurry is rich in nitrogen. In fact anaerobic digestion is a process that is taking place in nature.

A typical anaerobic digestion process shown in figure no. 4.1 as a block diagram.

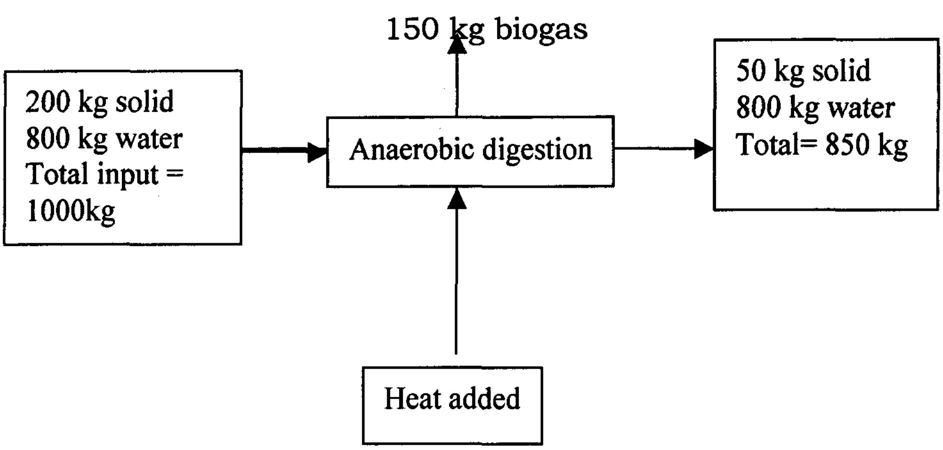


Fig. No. 4.1. Anaerobic Digestion Process

Source: Advanced Biological Treatment of MST, DEFRA,

Anaerobic digestion is a wet process used for solids with moisture content ranging between 60%-95%. Anaerobic digestion processes create much lower amount of biologically produced heat on the contrary additional heat may be required to maintain optimal temperature at 35°-40°C [152].

Methane is produced during the anaerobic catabolism of organic substances such as Napier grasses, rabbit waste, cow manure, cattle dung, night soil, tomato waste, vegetable processing waste, market waste, cauliflower, rotten cabbage, wheat straw, rice straw, etc. [153]. Rice husks, sediments of lake, ponds and puddles, salt marshes, sandy lagoons, sewage digester are the sources of methane.

In such anaerobic location organic substances are fermented to acetate, carbon dioxide and molecular hydrogen. It is these products of the breakdown that are utilized by the methanogenic bacteria (methanogens). The methanogenic bacteria are found all over the world but live only in the environment where no or very small concentration of oxygen is present. As time passes the methanogenic bacteria dispersed to environment where oxygen was absent. It can now be found in the bottom sediments of lakes and in marshy lands. The intestine of animals prevails and insects are another place where suitable conditions for the methanogenic bacteria prevail. The anaerobic process is generally characterized by small heat emission per unit-decomposed substrate [154]. This is in contrast to the aerobic processes where large heat emissions per unit-decomposed substrate take place.

There are basically three different phases of biomethanation namely [155-157]:

1. Solubilization: In the first phase facultative microorganisms act upon the organic substrates.
2. Hydrolysis is taking place in which polymers are the substrates for the second phase, converted into soluble monomers. These monomers form the non-methanogenic phase (acidification): The dissolved organic substrates are reduced from their incoming state to soluble simple organic acids (mainly acetic acid, CH_3COOH).

3. Methanogenic phase (methanogenesis): Methanogenic bacteria reduce the soluble organic compounds to methane and carbon dioxide. There are two ways by which the bacteria work. Either they ferment the acetic acid to methane and carbon dioxide or by reduction of carbon dioxide to methane by using hydrogen gas, which is a product of other bacteria.

In the process the amount of oxygen demanding material is reduced which results in a stable end product in comparison to the input in other words BOD of the input materials is being reduced [158].

The anaerobic bacteria that are involved in the last step being strictly anaerobic, will not work properly if there is oxygen present. The main bottleneck in this process is the solubilization of the organic polymers [159,160]. The main objective being to maintain an absolute oxygen free environment, however the initial phase will be less efficient due to presence of some air to start with. The facultative microorganisms will have better environment for growth and improvement of the solubilization phase initially [161]. Other characteristics of the processes are the symbiosis between different groups of microorganisms. Different groups of bacteria are involved in the different stages. These bacteria are sensitive to heat changes. According to Fulford, D. (1988) [162] a temperature variation in the slurry over a day of 5°c can cause the bacteria to stop work, which will result in a build up of organic compounds from the second phase (acetic acid mainly), which can cause the unit to go sour. Normal operating temperature range of a biogas plant under mesophilic condition is 30°C- 35°C.

The basic content of biogas is methane (CH_4) and carbon dioxide (CO_2), which is found in different proportions depending on: input to the system and the conditions during the fermentation process.

Traces of hydrogen sulphide, ammonia and oxygen can also be found in biogas in various degrees depending on feedstock and process. However presence of hydrogen sulphide (H_2S), which is a poisonous, and corrosive gas and is rather undesirable [163].

Composition of biogas as reported by different researchers is shown in table no. 4.1 below:

Table No. 4.1 Composition of Biogas

Methane (vol. %)	Carbon dioxide (vol.%)	Others	Sources
55-70 %	30-35 %	traces	(Meynell 1976)
50-70 %	30-35 %	traces	(Engel et al.1977)
55-70%	30-45%	1-2%	(Myles 1985)
58 %	42 %	traces	(Fulford 1988)
65-85 %	30-35 %	traces	(Singh 1994)
50%	50%	traces	(Chawla, 1996)

Source: Gustavsson , Mathias., Biogas Technology- Solution in search of its problem, Human Ecology Reports Series, 2000-01, P85.

It is therefore evident from the above table that biogas generally contains methane in the range of 50-70%.

4.1.1 Principles of Anaerobic Digestion

Anaerobic digestion is an application of biological methanogenesis that is a digestion process, which refers to various reactions, and interaction that takes place among the methanogens, non-methanogens and substrates fed into the digester as inputs. This is a complex physio-chemical and biological process involving different bacteria in different stages. This process of digestion is summarized below. The breaking down of inputs that are complex organic materials is achieved through the process, which can be divided into three stages as described below:

Stage 1-Hydrolysis/Liquifaction:

Complex organic compounds converted into soluble sugars, fats, and amino acids. The waste material of plant and animal origin consists mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilised into simpler ones with the help of extra-cellular enzymes released by the bacteria. This stage is also known as polymer breakdown stage. For example, the cellulose consisting of polymerized glucose is broken down to dimetric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria [164]

The polymers (large molecules) are reduced to monomers (basic molecules) and the resulting products are as follows

Lipids $\longrightarrow$ Fatty Acids

Polysaccharides $\longrightarrow$ Monosaccharides

Fat $\longrightarrow$ Fatty Acids

Protein $\longrightarrow$ Amino Acids

Nucleic Acids $\longrightarrow$ Purines and Pyrimidines

Carbohydrates $\longrightarrow$ Sugar

Stage 2- Acidification:

(i) Acidogenesis: The above organic compounds converted into organic acids, alcohols, carbon dioxide, hydrogen and ammonia. The monomer such as glucose that is produced in stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid- forming bacteria breaksdown molecules of 6 atoms of carbon (glucose) into simpler molecules containing less number of atoms of carbon (acids) which are in a more reduced stage than glucose [165]. On an average, acidogens grow much quickly than methanogen. They are also much hardier organisms, able to survive in a wider range of temperature and pH.

(ii) Acidogenesis: The above conversion is followed by acidogenesis to convert the above products to acids like acetic acid, propionic acid, butyric acid and ethanol.

Stage 3- Methanogenesis / Methanization:

The principal acids produced in stage 2 are processed by methanogenic bacteria to produce methane. The reaction that takes place in the process of methane production is called methanization and is expressed by the following equation [166].

CH_3COOH	$\rightarrow$	CH_4	$+ CO_2$
Acetic acid		Methane	Carbon dioxide

$2CH_3CH_2OH$	$+ CO_2$	$\rightarrow$	CH_4	$+ 2CH_3COOH$
Ethanol	Carbon dioxide		Methane	Acetic acid

CO_2	$+ 4H_2$	$\rightarrow$	CH_4	$+ 2H_2O$
Carbon dioxide	Hydrogen		Methane	Water

The above equation shows that many products, by-products and intermediate products are produced in the process of digestion of inputs in an anaerobic condition before the final product (methane) is produced. Obviously, there are many facilitating and inhibiting factors that play their role in the processes [167].

Methane production is higher from reduction of carbon dioxide but limited hydrogen concentration in digesters results in that the acetate reaction is the primary producer of methane [168]. The methanogenic bacteria include *methano bacterium, methano bacillus, methano coccus*, and *methano sarcia.* Methanogens can also be divided into two groups- one is acetate consumer and the other is H_2 / CO_2 consumer.

4.1.2 Microbes involved in methane production.

The methanogens belong to a special group of bacteria strictly anaerobic in nature and on the basis of this and other differences within the prokaryotes; the methanogens are assigned to the archaebacteria [169]. They differ from other bacteria not only in their type of metabolism but also in a number of characteristic features in the composition of their cell constituents. They lack a typical peptydoblican skeleton. *Methanococcus* has only a protein envelope, a peptide sheath is found in *methanospirillum,* whilst the cell wall of *methanosarcina barkeri* consists of a polysssacharide composed of uronic acids, neutral sugars and amino sugars. Besides these, there are mesophillic and thermophillic species. The cytopalsmic membrane of the methanogens contains lipids consisting of glycerol ethers of isoprenoid hydrocarbons [170].

4.1.3 General mechanism.

It has been noticed that the methanogens are in close association with hydrogen producing bacteria. During such association hydrogen is rarely liberated in gaseous form, rather, hydrogen dissolved in the aquatic medium is directly used by methanogens for producing methane. This sort of mutual symbiotic process for generation of methane is commonly noticed in anaerobic area, in sediment water or soil, which are rich in cellulosic or such other detritus organic matter. Methanogenic bacteria are able to act on hydrogen and couple its oxidation to the reduction of carbon dioxide. The microbial synthesis of methane is sometimes, regarded analogues to carbonate respiration [171].

$$4 H_2 + CO_2 \rightarrow CH_4 + 2 H_2O$$

The above equation of biochemical conversion of H_2 and CO_2 to methane is common in methanogens.

4.1.4 Methanogenic bacteria or methanogens

These are the bacteria that act upon organic materials and produce methane and other gases in the process of completing their life- cycle in an anaerobic condition. As living organisms, they tend to prefer certain conditions and are sensitive to micro- climate within the digester. There are many species of methanogens and their characteristics vary. The different methane forming bacteria have many physiological properties in common, but they are heterogeneous in cellular morphology. Some are rods, some cocci, while other occur in clusters of cocci known as sarcine. The family of methanogens (Methanobacteriacea) is divided into following four genera on the basis of cytological differences [172]:

- A rod- shaped bacteria
  - (a) Non- Sporulating, Methanobacterium.
  - (b) Sporulating, Methanobacillus
- B. Spherical
  - (a) Sarcinae, Methanosarcina
  - [b] Not in sarcinal groups, Methanococcus

A considerable level of scientific knowledge and skill is required to isolate methanogenic bacteria in pure culture and to let them survive in a laboratory. Methanogenic bacteria develop slowly and are sensitive to a sudden change in physical and chemical conditions. For example, a sudden fall in the slurry temperature even by 20°C may significantly affect their growth and gas production rate [173].

4.1.5 Pathogenic bacteria and diseases

The digestion process results in the killing of pathogenic bacteria especially those found in animal and human faeces (*Salmonella* bacteria) thus reducing by over 90% in a digester [174].
The more fully the sludge is digested, the more pathogens are killed. High temperature and long retention time kills bacteria hence hygienic. The following are the principal organisms killed in biogas plants: Typhoid, paratyphoid, cholera and dysentery bacteria (in one or two weeks) hookworm and bilharzias (in three weeks) [175,176].

4.2 MICROBIOLOGY OF BIOMETHANATION

Anaerobic digestion technology or the methane- generating bioconversion yields both fuel (biogas) and organic fertilizer (sludge), products that are the final result of microbial action on cellulose. These substrates are obtained through a series of degradative steps that involve a variety of bacteria. In the first step, complex polymeric organic substrates proteins, carbohydrates, and fats-are transformed by non- methanogenic bacteria into essentially non-methanogenic substrates like butyrates, propionate, lactate, and alcohol. Through a second step that involves the acetogenic bacteria, the composition and identity of which still remain to be determined, these compounds are transformed into methanogenic substrates, i.e, acetate, H_2 and Cl compounds that are converted into methane and carbon dioxide by the methane bacteria, obligate anaerobes that multiply in a neutral or slightly alkaline environment [177].

The smooth cooperation of the three groups of bacteria has to be well regulated which was exemplified by Bryants. In his discovery it was found that two mutually inter- dependent species existed in a symbiotic association in a pure culture under the name of

Methanobacillus omelianskii [178]. The association is comprised of two symbionts: an acetogenic organism and a methanogenic organism. The acetogen produces acetate, hydrogen and carbon dioxide, thereby disrupting the process of auto- inhibition with the acetogen, which succumbs to the hydrogen, it's products.

Again, it is necessary that both aspects of the anaerobic digestion process- liquefaction and gasification be well balanced. If the methane bacteria are absent the digestion process may only succeed in liquefying the material and may render it more offensive than the original material. On the other hand, if liquefaction occurs at a faster rate than gasification, the resulted accumulation of acids may inhibit the methane bacteria and the bioconversion processes well.

4.3 ORGANIC MATERIALS FOR BIOGAS PRODUCTION AND THEIR CHARACTERISTICS

Most forms of organic matter containing proteins, fats or carbohydrate, cellulose (except mineral oils and lignin) can be microbiologically transformed into biogas (methane and carbon dioxide). These three groups of organic material theoretically lead to different compositions of methane and carbon dioxide as shown in table no.4.3

Table No. 4.3 Theoretical Methane and Carbon dioxide Composition in Biogas

Sub strate	Gas yield (litre per kg of dry substrate)	CH_4 %	CO_2%
Protein	700	70	30
Fat	1200	77	23
Carbohydrate	800	50	50

Source: Nijaguna, B.T., "Biogas Technology", Published by New age International (P), 2002, p 25.

The following are the various kinds of organic matter with potential for methane production (broadly they are land based, animal based and water based resources).

4.3.1 Land based resources

Crop wastes, Sugarcane trash, Weeds, Corn and related crops, Straw, spoilt Fodder, Forest litter like leaves, urban solid wastes, etc.

By-products from agro-based industries: Oil cakes, Bagasse, Rice bran, Tobacco wastes and seeds, Waste from fruits and vegetables processing, Press mud from sugar factories, Tea wastes, Cotton dust from textile mills etc and Municipal sewages

4. 3. 2 Animal based resources:

Animal Wastes, Cattle shed wastes (dung, urine, litter), Poultry litter, Sheep droppings, Slaughter house waste (blood, meat), Fishery waste, Human wastes like excreta, urine, etc.

Amount of Biogas generated from animal waste has been shown in table no. 4.3.2

Table No.4.3.2 Biogas yield from various animal waste.

Animal Waste	Gas yield (Litre/Kg-of solid)	Gas yield (m^3/kg. of dung)
Pig	340-550	0.040-0.059
Cattle (Cows & Buffaloes)	90-310	0.023-0.040
Poultry (Chickens)	310-620	0.065-0.116
Horse	200-300	0.051-0.039
Sheep	90-310	0.023-0.059
Human	80-218	0.020-0.028

Source: Updated guide book on Biogas Development, 1984

4.3. 3 Water based materials:

Marine, Sea-weeds, Water hyacinth.

4.3.4 Land Based Materials

Table 4.3.4. Break- up yield of different crop residues per hectare area

Type of residue	Yield (Tones/ Hectare)
Rice Husk	1.0-1.3
Leaves and stalk from corn	6.0-10.0
Bagasse	220.0-25.0
Pulp from sugar beat	8.0-15.0
Groundnut shells	0.6-2.3
Jute and Mesra fiber	0.6-2.3
Forest wastes	1.2
Sunflower stalks	2.5
Wheat straw struble	3.0-3.5

Source: Nijaguna, B.T., Biogas Technology, New Age International (P) Ltd. New Delhi, 2002, p26.

The rate of biogas production varies from one type of waste to the other. Chief among the parameter deciding the amount of biogas generated from substrate are its TS content, % of VS destruction, %C and % N.

4.4 FACTORS AFFECTING METHANE PRODUCTION

Various factors such as bio-gas potential of feed stock, design of digester, inoculums, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C/N ratio, volatile fatty acids (VFA) Seeding, Uniform feeding, Diameter to depth ratio of the digester, Nutrients, stirring or agitation of contents of the digester, toxicity, due end product pressure, acid accumulation inside the digester etc, influence the methane production [179].

4.4.1 Biodegradability

The waste treated by anaerobic digestion may constitute a biodegradable organic fraction, a combustible and an inert fraction. The biodegradable organic fraction includes kitchen scraps, food residue, grass and tree cuttings. The combustible fraction includes slowly degrading ligno cellulosic organic matter containing coarser wood paper and cardboard. As these ligno cellulosic organic materials do not readily degrade under anaerobic conditions, they are better suited for waste to energy plants. Finally, the inert fraction contains, stones, glass, sand, metal etc. This fraction ideally should be removed, recycled or used as landfill. The removal of inert fraction prior to digestion is important because it increases digester volume and wear of equipment.

The composition of the feed materials to the digester is variable and rarely any of the natural digester feeds completely and breaks down or transformed to biogas. The natural substrate is 100% biodegradable. This due to imperfect physico chemical factors, non-degradable components, conversion to cell mass etc. In the ideal condition a small fraction (2-5 %) of the volatile solids (VS) destroyed is converted to cell mass. The major factor in hindrance for biodegrability is lignin present in the digester feed (20).

For any substrate, it is possible to predict the gas yield by using the following formulae [180,181].

$C_nH_aO_b$ + (n –a/4-b/2) H_2O +(n/2-a/8 +b/2) CO_2 + (n/2 + a/8 –b/4) CH_4 ------- (1)

Using the above equation the gas yield from glucose will be as shown below

$C_6H_{12}O_6 + H_2O$ ------------$3CH_4+3CO_2$ ---------------- (2)

4.4.2 Slurry or effluent inside the Digester

This is the residue left after the methanogenic bacteria in an anaerobic condition inside the digester act upon the substrate. After extraction of biogas (energy) the slurry, which is commonly known as effluent, comes out of the digester as by-product of the anaerobic digestion system. It is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different layer inside the digester as mentioned below:

A light rather solid fraction, mainly fibrous material which float on the top forming the scum; a light and watery fraction remaining in the middle layer of the digester; a viscous fraction below which is the sludge; and heavy solids, mainly sand and soil that deposit at the bottom. There is less separation in the slurry if the feed materials are homogeneous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogenous slurry.

4.4. 3 Digestion temperature

The bacteria are very sensitive to temperature changes. According to Fulford (1988), a temperature variation in the slurry over a day of 5°C can cause the bacteria to stop work which will result in a build-up of organic compounds from the middle layer, acetic acids mainly, which can cause the unit to go sour.

Temperature is an essential parameter in respect of bacterial activity in the digester. Methane bacteria works best in the temperature range of 30- 35°C and satisfactory gas production takes place in the mesophillic range, which is between 25°- 30°C [182]. The fall in gas production starts at 20°C and virtually stops at a temperature of 10°C. The methanogens are inactive in extreme high and low temperature [183-185]. The proper insulation of digester helps to increase gas production in the cold season. When the ambient temperature is 30°C or less, the average temperature within the dome remains about 4°C above the ambient temperature [186-191].

4. 4. 4 pH. Value

The pH of the slurry in the digester is a function of the concentration of volatile fatty acids produced, bicarbonate alkalinity of the system, and the amount of CO_2 produced.

The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6&7. The pH in a biogas digester is also a function of the retention time .In the period of fermentation, large amount of organic acids are produced by acid forming bacteria, the pH inside the digester can go below 5 [192]. This inhibits or even stops the digestion or fermentation process. Methanogen bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of NH_4 increases due to digestion of nitrogen, which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2 [193-195].

4. 4. 5 Loading Rate

Loading rate is the amount of raw materials fed per unit volume of the digester capacity per day. If the plant is over fed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will be low.

In other words, organic loading rate (OLR) is a measure of the biological conversion capacity of the anaerobic digestion system. Feeding the system about its sustainable OLR results in low biogas yield due to accumulation of inhibiting substances such as fatty acids in the digester slurry. In such a case, the feeding rate to the system must be reduced. OLR is a particular important control parameter in continuous system. It is reported that many plants failed due to overloading [196].

The concentration of total solids in the input suspension can be varied within the range of 20 to 100 gm/litre. In practice it is recommended to limit the total solids concentration to the range of 20 to 30 gm/litre [197].

4. 4. 6 Retention Time

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. Retention period is found to reduce if temperature is raised, or more nutrients are added to the digester. In a cow dung plant, the retention time is calculated by dividing the total volume of the digester by the volume of inputs added daily. A digester should have a volume of 50 to 60 times the slurry added daily. For a night soil biogas digester, a longer retention time (70 –80 days) is needed so that the input materials are completely acted upon by the methanogenic bacteria. Hydraulic Retention Time (HRT) is the most important factor in determining the volume of the digester which in turn determines the cost of the plant, the larger the retention period, higher the construction cost. Digestion period can be calculated from the following: - Digestion Period =Volume of Reactor/Daily slurry input.

4. 4. 7 Toxicity

Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester [198]. Small quantity of mineral ions (sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect [199]. Heavy metals such as copper, nickel, chromium, zinc, lead etc. in small quantities are essential for growth of bacteria but their concentration has toxic effects [200]. The inhibiting levels of some of the major ones are given in table no. 4.4.7

Table No: 4.4.7 Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate (SO_4^{--})	5,000 ppm
Sodium Chloride or Common salt (NaCl)	40,000 ppm
Nitrate (Calculated as N)	0.05 mg/ ml
Copper (Cu^{++})	100 mg/l
Chromium (Cr^{+++})	200 mg/l
Nickel (Ni^{+++})	200-500 mg/l
Sodium (Na^{+})	500-5,500mg/l
Potassium (K^{+})	2,500-4,500 mg/l
Calcium (Ca^{++})	2,500-4,500 mg/l
Magnesium (Mg^{++})	1,000-1,500mg/l
Manganese (Mn^{++})	Above 1,500mg/l

Source: The Biogas Technology in China, BRTC, China (1989)

4.4.8 Influence of Volatile Solid Concentration

The volatile solids (V.S.) in organic waste are measured as total solids minus the ash content as obtained by complete combustion of the feed waste. The volatile solids comprise the biodegradable volatile solids (BVS) fraction and the refractory volatile solids (RVS), [201], showed that knowledge of the BVS fraction of MSW helps in better estimation of the biodegradability of waste, biogas generation, organic loading rate and C/N ratio, lignin is a complex organic material that is not easily degraded by anaerobic bacteria and constitutes the refractory volatile solids (RVS) in organic MSW. The composition of waste affects both the yield and biogas quality and as well as the compost quality.

The methane yield drops when the effluent volatile solids concentration increases above 40 kg./m^3 at 10 days retention time. At long retention times, the drop of the methane yield at high volatile solids concentration is not as pronounced as compared to short retention times.

4.4.9 Effects of Particle size of the feed material

Biogas production from kitchen waste, food waste and from different biomass needs pre-treatment in order to reduce the sizes of the feedstock. It has been observed that for getting better yield of gas, particle sizes are to be reduced [202,203].

Sharma et al., (1988) [204], have shown that biogas generation is increased when the particle size of organic material is small, in this case less than 1 mm.

4.5 Benefits and Limitation of Biogas System

Biogas technology has a number of potential benefits as mentioned below:

(i) Energy-related benefits

(ii) Fertilizer-related benefits

(iii) Health-related benefits

(iv) Development-related benefits

(v) Economic benefits

A brief summary of the above potential benefits from biogas technology is mentioned table no. 4.5

Table No. 4.5 Potential benefits from biogas technology

	National Level	Regional Level and Local Level	Individual Level
Energy,replace commercial fuels	Improve BOP	Reduce transportation and need for infrastructure	Reduced spending
Energy replace non commercial fuels	Reduced cost for afforestation	Environmental impact	Less time spent on collecting fuel
Fertilizer, if manure not used prior	Improve BOP	Reduce transportation and need for infrastructure	Reduced spending on fertilizers
Health	Reduced spending on health care	Increased labour availability and equality	Improved health
Development	Rural development Sustainable development	Create employment	Convenient fuel
Economy	Not applicable	Not applicable	Not applicable

Source: - Mathias Gustavsson, Biogas technology solution in search of its problem, 2000, p 18

At face value there are potential benefits at all levels in the society the benefits are here considered at four levels: national, regional, local and individual level.

The national level accounts for India as a country, while the regional level is state, district and in some cases block depending on size.

Panchayats or city urinals and villages account for the local level, while individual level concerns the person(s) involved with the use of the gas and management of the unit. It is normally the women of the households that are in charge of carrying out these chores.

Biogas has the potential to reduce deforestation, as it is usable as a fuel. As a cooking fuel, biogas is cheap and extremely convenient to use. Based on the effective heat produced, a 2 cu. m. biogas plant could replace, in a month, fuel equivalent of 26 kg. of LPG or 37 litres of kerosene or 88 kg of charcoal or 210 kg of fuel wood or 740 kg of animal dung [205].

Biogas is a clean fuel and does not cause any pollution. It is considered as a better fuel than natural gas and liquefied petroleum gas. Biogas contains 4500-6000 calories/m^3, thus providing convenient source of heat at low cost. One cu.m. of gas having calorific value of 6000 calories is equivalent to the other type of fuel has been shown in the following table no. 4.5.1 [206].

Table no. 4.5.1 Equivalent quantity of other fuels for one m^3 of biogas

Type of fuel	Quantity
Biogas at 6000 calories	1 cu. m.
Alcohol	1.000 lit.
Petrol	0.800 lit.
Crude oil	0.600 lit.
Citygas(commonly manufactured)	1.5 m3
Charcoal	1.40 kg.
Electrical energy	2.20 kwh

Use of biogas would reduce the normal practice of indiscrimate felling of trees and consequent soil erosion and floods. Besides the above benefits, biogas mimics natural environmental cycles; nutrients such as Nitrogen, Potassium and Phosphorous are present in the feedstock and can be recycled back to the land in the form of slurry. Use of organic waste as fertilizer in agriculture is a means to decrease the dependence on imported chemical fertilizer, where as burning of the biomass, most of the nutrients are lost. Complete digestions of the waste, kills' seeds of weeds, organism causing plant diseases are also killed. It has been observed that the use of digested slurry as manure improve soil fertility and increases crop yield by 10 to 20 %. [207].

Limitations

Despite its many benefits, it has a number of drawbacks as well, the major one being the availability of suitable design and the initial investment of the plant particularly in the rural areas. The skilled workmanship needed to ensure leak proof construction mainly bioreactor, gasholder and also the proper maintenance of the plant are also some of the limitation. Maintenance of the essential parameters of the feedstock like feed ratio, pH value of the slurry, temperature, C/N ratio and uniform mixing etc in order to get the maximum yield of the gas are also very important.

Benefits and limitations of biogas system are summarized below:

Benefits:

1. In the context of our continued search for energy to meet the developmental needs of the country biogas technology is a very appropriate addition.
2. It is an eco-friendly and sustainable technology.

3. It reduces the deforestation and save fuel woods [210-212]
4. Biogas is a smoke free, pollution free fuel for cooking, lighting and running agro- machinery. A smoke-free and ash-free kitchen means women are no longer prone to lung and throat infections and can look forward to a longer life expectancy [213-216].
5. In rural areas where there is generally no electricity supply, the introduction of biogas has given women more time to engage in some alternative productive activities.

Approximate gas requirements and storage for different domestic uses has been mentioned below: -

(i) Domestic cooking-2m^3 for family of five or six people.

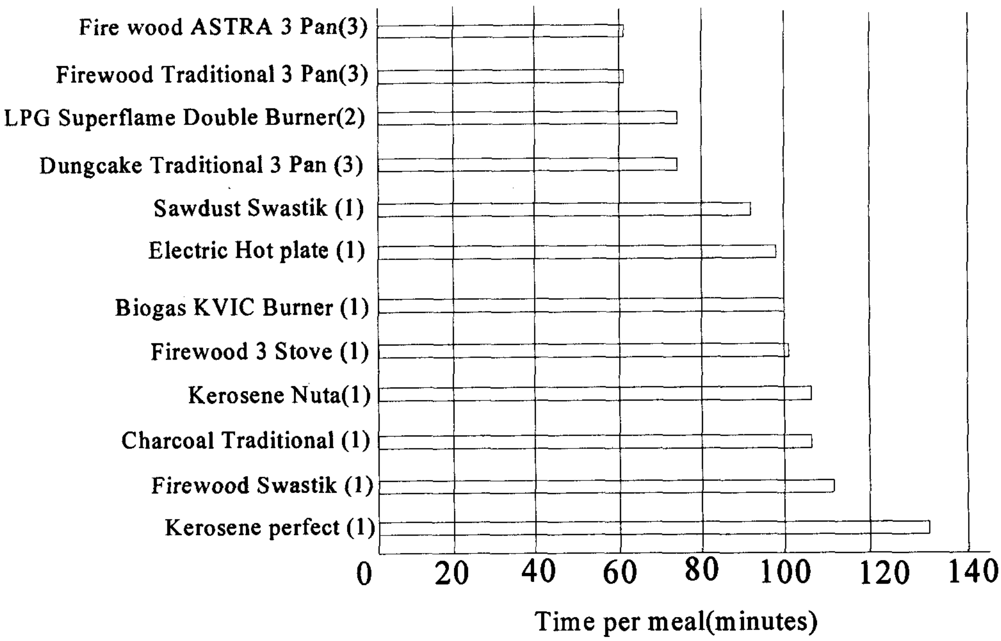
(ii) Water heating-3m^3 per day for a 100litre tank or 0.600m^3 for a tub bath and 0.35m^3 for a shower bath.

(iii) Domestic food refrigeration-2.5-3.0m^3 per day for a family of five or six people.

(iv) Lighting - 0.100- 0.150 m^3 per hour per light (60 Watt).

Cooking Time-The efficiency of the stove does not tell so much about actual cooking time, it is merely a relation between input –and useful energy. The following table no. 4.5 shows the difference in time taken for cooking the meal with various fuel [219-221].

Table No. 4.5 Cooking time against various fuel



In the above figure numbers within bracket indicates number of cooking holes or burners.

Source: Gustavsson, Mathias, "Biogas Technology-Solution in search of its problems", Human Ecology Reports Series 2001,p60.

6. It is a nitrogen rich fertilizer and improves the agricultural productivity. In the biogas plants, nitrogen does not take part in anaerobic digestion, the effluent sludge displaced from the biogas plant contains the same mass of nitrogen as the input slurry. Thus, biogas plants are often called biofertilizer plant [222-224].
7. It has the positive effects on the health of rural people and reduces disease carrying pathogens and parasites
8. Improve sanitation and thus maintain cleaner environment. It also reduces the fly menace. [225-227].

9. Save the woman from the drudgery and lung disease, prevent the damage of eyesight as they get the opportunity to cook the meal in a clean smoke free kitchen [228].
10. Increase employment potential for construction work and maintenance of biogas plant [229].
11. Biogas technology can be made compatible with local village condition and the available biomass can be utilized in a better way.
12. It is a decentralized, self-promoting technology that reduces energy transmission problem.

Limitations

1. Availability of optimum design to suit the variety of local conditions.
2. High cost of installation of the plant some times offsets the benefits.
3. Non-availability of proper skilled workmen for construction of the plant.
4. Operational problem like, leakage, scum removal, pH value, water condensation in gas line, burner problem etc.
5. Availability of required water for feeding the plant, particularly in dry areas.
6. Maintaining continuous feeding of animal waste / feed stock.
7. Problems of co-operation and co-ordination among the users for community plants [230-232].

Despite the above the drawbacks, there are large number of biogas plants which have been installed in China and India. Proper methodology in respect of design, construction and installation are being introduced to the common people under the guidance of WBREDA and MNES in the state. Efforts are on to minimize problems coming in the way of popularization of biogas plants through a process continuous interaction with the users and organizing discussions/meeting with prospective users.

CHAPTER-5

EXPERIMENTAL SET UP AND PLANT LAYOUT

Chapter - 5

EXPERIMENTAL SET UP AND PLANT LAYOUT

5.1 EXPERIMENTAL SET UP AND PROCEDURE

In the experimental study kitchen waste mainly food and vegetable waste is used. The maximum amount of waste is 5 kg for laboratory set up.

Considering the feeding system to the digester two setup arranged

(i) Semi- batch digestion system.

(ii) Continuous digestion system.

5.1.1 Semi- batch digestion system

The study has been conducted by using a high-density polyurethane-tapered vessel as a bioreactor and it has been placed inside the thermostatically controlled bath where any temperature in between -5 to 60^0 C can be maintained as shown in the fig. no. 5.1.1

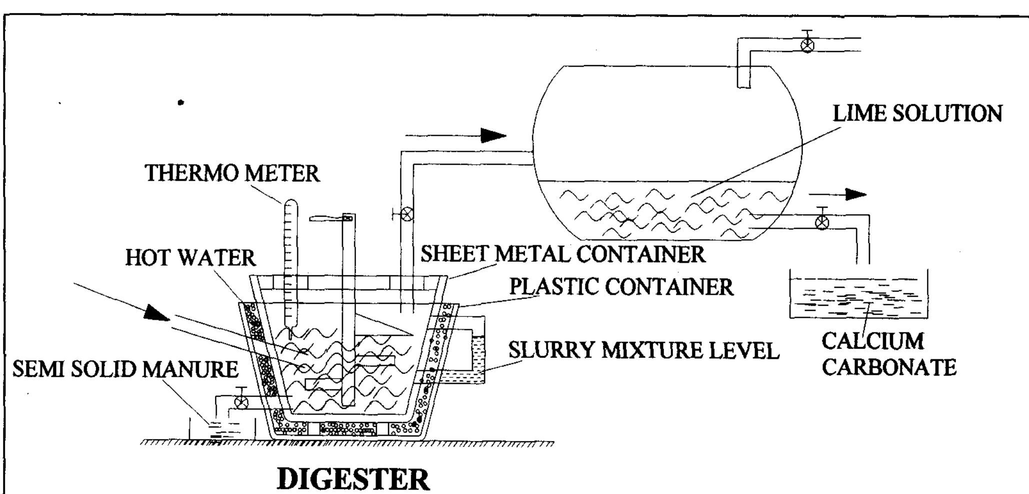
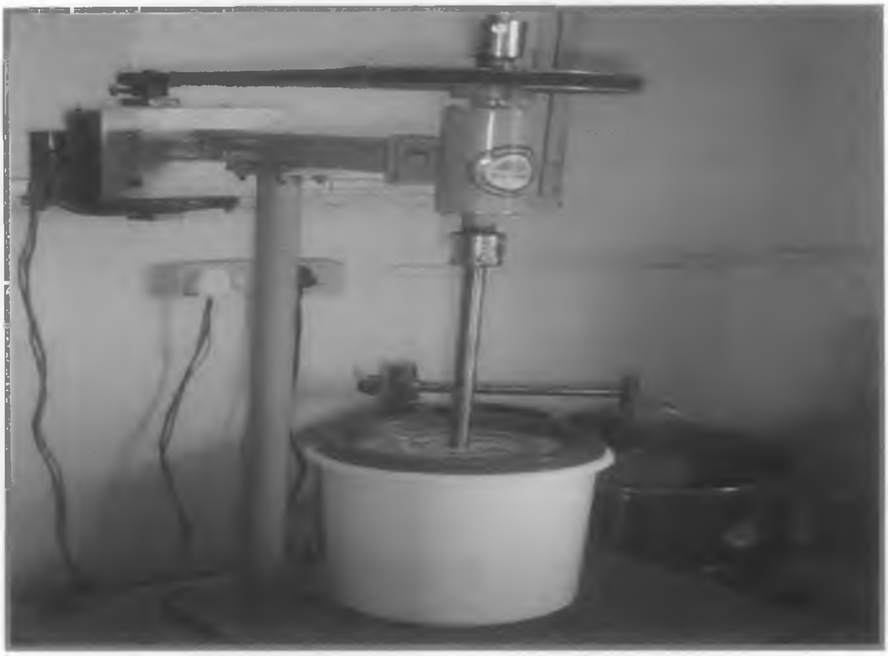


Fig. No.5.1.1 Semi- batch Digestion System



Photograph of Mixing Machine Fig. no.5.1.1 (b)

A stirrer has been placed from the top of the digester and it has been operated by a 0.25 H.P. electric motor. The gas outlet pipeline from the top of the reactor has been connected to a water displacement system for the gas collection. Subsequently the gas sample has been analyzed using Orsat apparatus and gas chromatograph.

Operational Procedure

At first a mixture of dried, specific sized vegetable waste and water has been prepared in the separate mixing tank as shown in fig. No.5.1.1 (a)

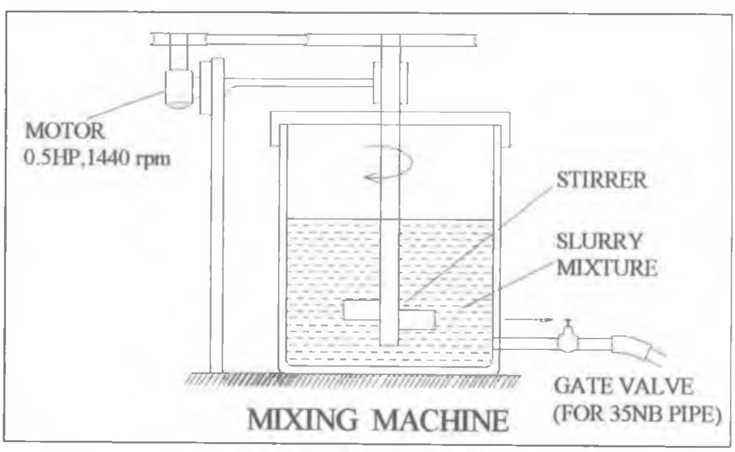


Fig.no.5.1.1 (a)

A slurry of definite concentration is prepared and same is fed to the digester. The digester is sealed from the top by a rubber wound cover in order to obtain the anaerobic condition inside the digester.

The composition of the gaseous products and its volume has been determined after each 24 hours and it has been continued till gas output drops to below 25 c.c. The change of pH of the slurry with time has also been recorded. Arrangement for periodical agitation of the slurry in the digester for almost half an hour at interval of 12 hours has been made. Gas has been collected through displacement of water mixed with 2% glycerol solution to prevent the absorption of CO_2 in water. Gas composition, has been checked through Orsat apparatus. Finding the difference of volume of CO2 from the total volume of makes estimation of methane gas-produced. During experiment pH value of slurry mixture has been maintained in-between 6.8 to 7.0 automatically by auto pH controller as shown in the fig.5.3.

5.1.2 Continuous Digestion System

After segregation of dried vegetable waste it is fed to the vibrating screen in order to obtain the required sizes of particles and larger sizes of waste are to be shredded by a cutting machine. The feedstock containing a definite sized particle has been mixed with equal amount of water in the mixing unit before feeding to the digester, so that suitable solid liquid ratio needed for biomethanation is obtained. The experimental arrangement has been shown in the fig. no 5.1.1(a).

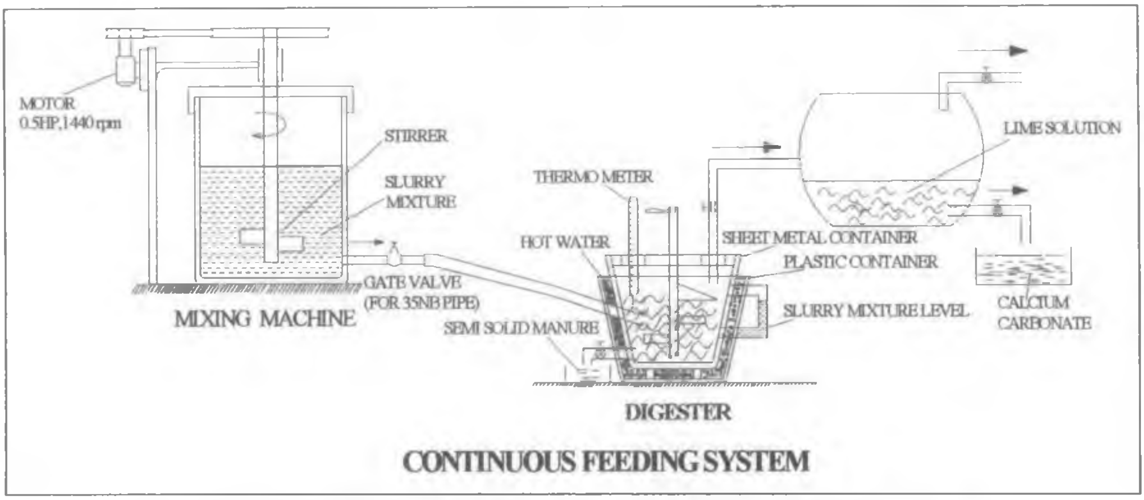


Fig. No. 5.1.2 Continuous Digestion System

Fig. No.5.1.2. (a) Photograph of Digester shown

With this arrangement thus concentration of the mixture is being known.

Two stage digester

As explained earlier the biomethanation process involves two different stages viz, acidogenesis and methanogenesis. Conventionally the two phases are allowed to be carried out in one digester. It is however possible to have the two reactions to take place in separate digester. Thus separating the two phases, allowing flexibility of operation and thereby improve digestion of the total mass. Maintenance of the plant is also convenient.

In the first reactor, the reaction rate is limited by the rate of hydrolysis of cellulose; in the second by the rate of microbial growth .The two-reactor process allows to increase the rate of hydrolysis.

For methanogenesis, the optimum growth rate of microbes is achieved by designing the reactor to provide a longer biomass retention time with high cell densities (also know as fixed film reaction, where the microbes responsible for conversion of the organic matter are attached to an inert medium such as rocks, plastic materials in the reactor). With this arrangement, complete digestion is achieved during less period of retention time.

Several experiments have been carried out with various feedstock received from kitchen feeding the bioreactor having the total volume of 10 liters in a continuous manner. The set up is shown in fig. No.5.1.2

With this arrangement slurry of definite concentration is prepared and fed to the digester. pH value of the slurry in the digester has been checked continuously and the same is maintained in the range 6.8 to 7.2 for optimum gas generation from the digester. Digester temperature is controlled by circulation of hot water in to the jacket around the digester to study the effect of temperature variation on gas yield. Gas yield at an interval of 24 hours interval has been recorded. Gas collection has been done by downward displacement of water. To prevent carbon dioxide absorption by water, 2% glycerol added to water so as to get record of total gas produced from the setup. The digester is fitted with a motor driven stirrer from the top for proper agitation. pH value in side the digester monitored continuously to maintain the value in the range 6.8 to 7.2.

Operational Procedure

Prepared sample of known slurry concentration and particle size has been fed to the digester with constant loading rate. When the system has been stabilized, the retention time and temperature of digestion has been recorded. Again by changing the digestion temperature with constant loading rate and constant particle size, the production of gas has been measured. Gas composition, mainly methane and carbon dioxide has been checked through Orsat apparatus. Finding the difference of volume of CO_2 from the total volume of gas produced makes estimation of methane. As a check volumetric analysis has also been carried out using gas chromatograph.

5.2 DESIGN OF PROPOSED DIGESTER FOR ANAEROIBIC DIGESTION

A biogas digester is essentially a chemical reactor which is linked to both inflow and outflow channels. Rate of gas production is dependant not only on microbial growth rate but also on the effectiveness of dispersion of solid, liquid and gas flows and on the retention time of the slurry mixture inside the digester. The digester has two-fold function i.e., accommodating digestible material as well as storage of gas.

Digester design is of utmost importance to get optimum gas output and for that the following points are to be kept in view:

(i) Optimum gas yield
(ii) Biodegradability of feed stock
(iii) Retention time
(iv) Slurry temperature inside the digester
(v) Loading of digester
(vi) C/N ratio

The digester is composed of a tapered cylindrical shell wall with dome as shown in the fig. no.5.2.1. The upper part of the digester is fully covered by a top cover so that it will be a perfect seal to maintain anaerobic condition.

The digester is to be fitted with motorized stirrer from the top and also a jacket for circulation of hot water for temperature control. The temperature of the slurry is maintained in the mesophilic condition.

In the experiments two-phase digestion technique has been proposed for separating the acid and methane forming phases as it has several advantages. It has been observed that the duration of acid phase is in the range of 4-6 days depending on the type of feed materials. The slurry from acid phase is immediately fed to the adjoining reactor for methanogenic bacterial reactions. Thus, the methane-producing bacteria can work continuously without any acidic effect on them.

5.2.1 Design Calculation for Fixed Dome Type Digester

The design is based on the following data:.

Assuming:

Active slurry volume V_S in cu.m.

Hydraulic retention time, (HRT) as 30 days

Total quantity to be fed to the digester = 100kg. + 100 kg. (Solid +water)

To increase the rate of hydrolysis and to facilitate maintenance work, provision for two nos. of digesters has been made.

Hence actual quantity to be fed to the each digester = 200/2 = 100 kg.

Density of slurry mixture = 1090 kg. / cu. m.(by lab. measurement)

Volume of the digester = 200/1090 = 0.183486 cu.m. ≈ 0.184 cu.m.

Required slurry volume,Vs of digester considering 30 days retention time, Vs. =0.184 × 30 = 5.5 cu.m.

Actual volume of the digester V_d, considering 10 % over loading,

V_d =5.5 ×1.1 = 6.06 cu.m. -------------------(i)

Calculation of diameter, D and height, H of the digester

Considering the ratio D/H is 1.0,

Knowing the actual (active) slurry volume, V_d from equation (i), height of the digester can be calculated as follows:

$V_d = (\pi/4) \times D^2 \times H$

Since, D = H

$D^3 = V_d / 0.785$ i.e. D = H = 2 m

Diameter of the digester, D = 2 m and Height of the digester, H = 2 m

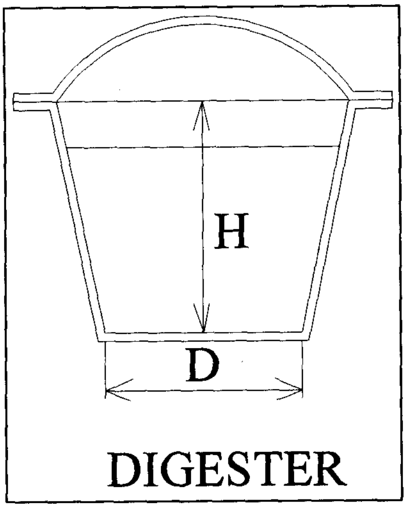


Fig. No. 5.2.1

5.2. 2 Design of gasholder

Gas production rate:

1 kg of waste (undiluted) yields about 0.04 cu m of gas.

The gas production rate, G for the available waste is thus

$G = W \times 0.04$cu.m. /day,

Where, W = available waste from the kitchen per day i.e. 200 kg

Thus, total quantity of gas produced per day= $200 \times 0.04 = 8$cu.m

Considering 6 hours cooking per day basis in the kitchen,

Considering 10% over loading,

Volume of gasholder required $= (1-6/24) \times 1.1 \times 8 = 6.6$ cu.m.

From the above, it can be said that the capacity of the proposed plant is 8 cu. m. i.e. the plant shall be able to produce 8 cu.m. of gas per day on continuous basis.

In this case, it has been considered that the gasholder is common for both the digesters and the connecting tubes from both the digesters are being attached to the gasholder as shown in the fig. no.5.2.2

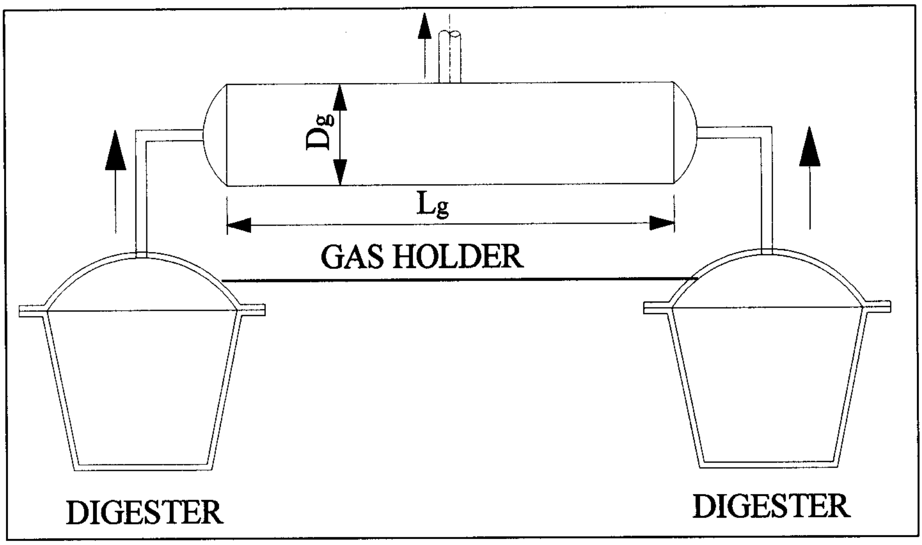


Fig. No. 5.2.2 Gasholder

The gasholder is placed horizontally to avoid to large static head inside the gasholder

Thus, considering diameter/depth ratio is 1:2, (Dg: Lg)

We get, $(\pi/4) \times Dg^2 \times Lg = 6.6$ where Dg and Lg are the diameter and length of the gasholder respectively.

Therefore, Dg= 1.6134 m. and Lg = 3.226 m.

Let us consider, Diameter of the gasholder, Lg =3.2 m. and

Length, Dg = 1.6 m.

5.2.3 Slurry displacement volume inside the digester

Slurry displacement volume depends on the gas consumption pattern. As cooking is usually done two times in a day, 50% of the gas produced in a day should be made available for one cooking span. Since there is a continuous production of gas from the digester, the gas generated during cooking time is also considered while designing the digester. If the total time of cooking is about 6 hours per day., the variable slurry displacement volume, Vsd is obtained from the following equation

$Vsd = (6/24) \times 0.5\ G$, where, G = total volume of gas produced per day i.e. 8 cu.m.

Or, Vsd = 1.0 cu.m.

From the above equation, the value of slurry displacement height, h_{sl} as = $(\pi/4) \times D^2 \times h_{sl}$ = Vsd, where, D is the diameter of the digester or, $h_{sl} = (\pi/4) \times 2^2 \times h_{sl} = 1.0$ m.

From the above, we get, slurry displacement height, h_{sl} = 0.32 m

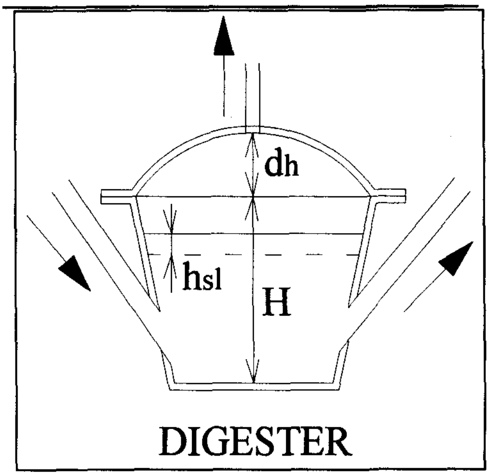


Fig. No. 5.2.3 Slurry Displacement height (h_{sl})

Slurry movement in the digester

At the starting time no gas can be withdrawn from the digester when pressure inside the digester is atmospheric. The slurry level at the inlet and outlet tanks will be as shown in the figure no. 5.2.3. When gas accumulates in the space above than slurry level, the slurry in the digester get compressed and pushed down, as a result slurry level in the inlet and outlet tank raises to a point such that the pressure of the generated gas is balanced by the pressure of the slurry column in the inlet and outlet tank.

Thus under ideal operating conditions, the volume of slurry flowing out from the digester in a day would be exactly equal to the volume of the daily input slurry.

In the proposed design, cylindrical shape of bioreactor having flat bottom has been considered. The relevant dimensions of the digester with other related parameters are as given below:

W = weight of the vegetable waste available per day (Kg / day) from canteen

G = gas production rate (cu m/ day)

V_s = active slurry volume in the digester (cu m)

V_{sd} = slurry displacement volume (cu m)

V_d= dome volume (cu m)

H = height of the cylindrical portion of the digester

h_{sl}= slurry displacement height(m)

D = diameter of the digester (m)

D_h = height of the dome

R_d= radius of the dome

5.2.4 Calculation of the Dome Height (d_h)

The volume of the dome, which is a section of a sphere, is given by

$V_{sd} = (\pi/6)\, d_h \; [3(D/2)^2 + d_h^2]$-------------------------------eq. No. (5)

Where, V_{sd} = slurry displacement volume

d_h = dome height

D = diameter of the digester

The total volume of the gas space in each digester, as mentioned earlier, is taken as equal to G/2, since we have considered two no. of digesters. As the slurry or gas displacement volume V_{sd} is already found out as1.0, the remaining gas space volume will be the volume of the dome.

The value of d_h to be evaluated by solving the cubic equation (5). It can be easily done by iteration or by analytical method. The value of d_h is found to be 0.30895 m from the above cubic equation (5)

Let us take Dome height, d_h = 0.35 m

5.2.4 Radius of the Dome (Rd)

Dome radius can be obtained by the equation

$Rd = (D/2)^2 + d_h^2 / 2d_h$

Or, $Rd = 2/2 + (0.35)^2 /2x\, 0.35 = 1.607$ m = 1.61 m

Considering, Rd = 1.61 m.

5.3 AUTO CONTROL OF pH OF SLURRY MIXTURE

In order to maintain the required pH value for slurry mixture inside the digester in the range of 6.8 - 7.2, it is necessary to maintain this range to enable the anaerobic digestion.

In view of the above a microprocessor (8050 core) based control system has been proposed to control the pH in the specified range as mentioned above. There are two chambers one containing the slaked lime solution and the other the acetic acid (CH_3COOH) solution which have been incorporated in the system and are controlled by the solenoid valves attached to it and these valves are controlled by the microprocessor unit as shown in the figure 5.3.

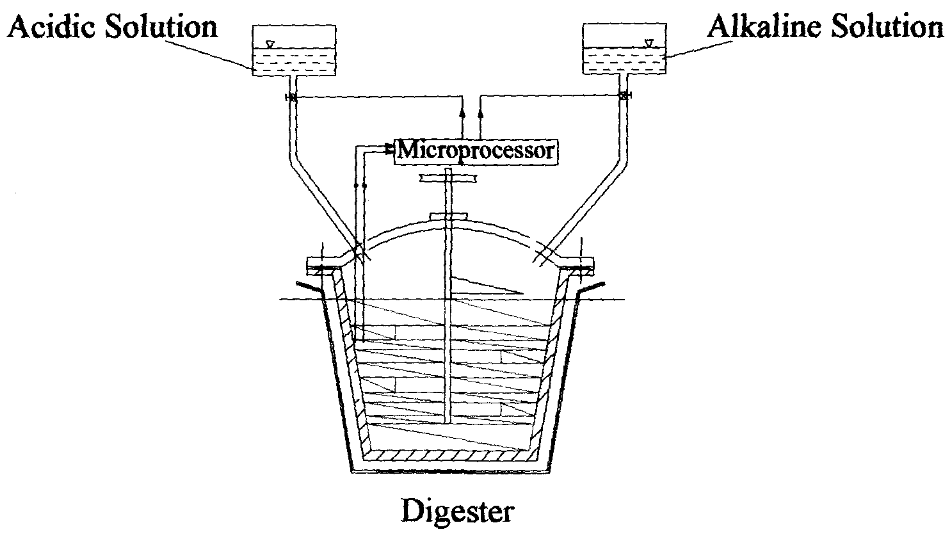


Fig. No.: 5.3 Auto control of pH of slurry mixture

A pH sensor is dipped inside the slurry. The sensor will detect the pH value of the slurry material and convert the same into an equivalent voltage. The voltage is calibrated according to the pH of slurry material.

5.4 Weighing Device for Maintaining Solid – Liquid ratio

One of the prerequisites of good digestion is proper maintenance of solid and liquid ratio of the slurry mixture in the digester.

To maintain the required ratio of solid and liquid, an auto control device has been incorporated in the process. In this process a motorized stirrer is inserted in the digester. The motor will take more current when the density of the slurry mixture is high. The motor input current is tapped by using current- transformer and fed to the micro controller system. The amount of current will depend on the ratio of the solid to liquid in the digester with proper calibration by measuring the input current to the motor; the solid- liquid ratio can be evaluated. Now, the micro controller system controls the solid-liquid ratio by measuring the input current to the motor when the valves are open for a specified time interval. For example, if the ratio is greater than the required ratio it means less quantity of water mixed during the preparation of slurry mixture, then solenoid valve connected to the water line will open for a particular time until solid and liquid ratio maintained at desired level. Again in reverse case when solid- liquid ratio is less than the required one, in that case the solenoid valve connected to the solid tank will open until the solid-liquid ratio brings back to the required value. The arrangement of all these equipment including stirring system inside the digester is shown in the fig. no. 5.4.

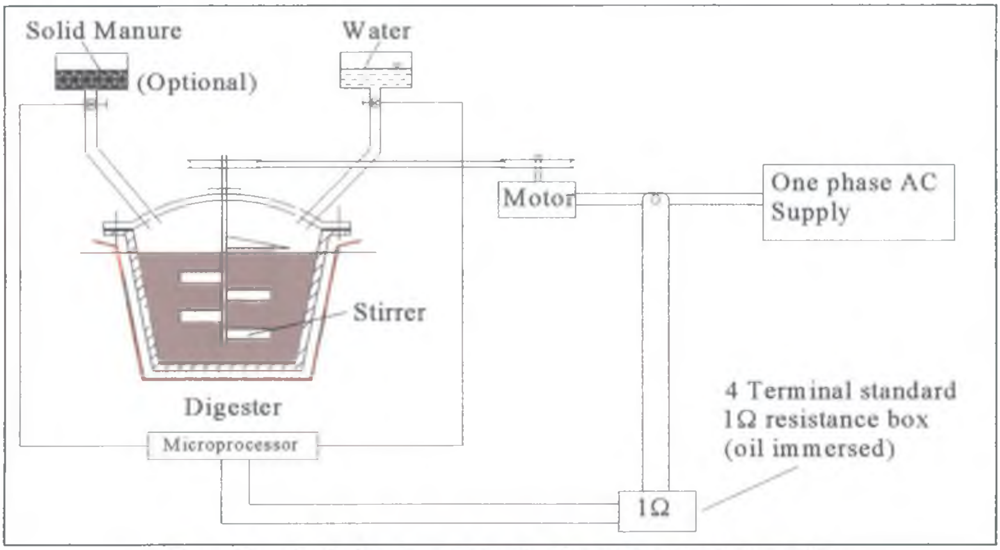


Fig. No. 5.4 Auto control of solid- liquid ratio

5.5 DRIVE MECHANISM OF SCUM BREAKER

A flap having 0.9 times of inside radius of the digester tank is welded with the rotating shaft of stirrer so that flap can rotate while stirring the slurry mixture twice or thrice a day. The flap is designed in such a way that the same can move vertically up and down according to level of the slurry and is shown in adjoining fig. no.5.5

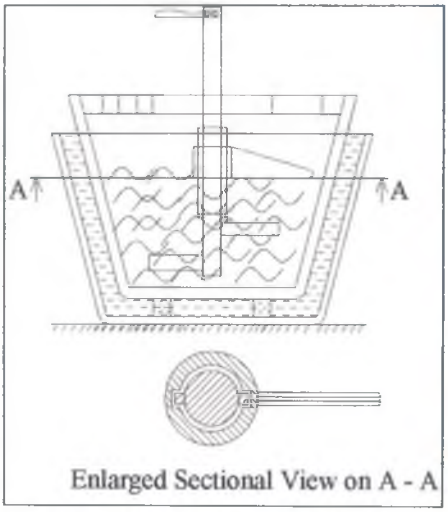


Fig. No. 5.5 Scum Breaker

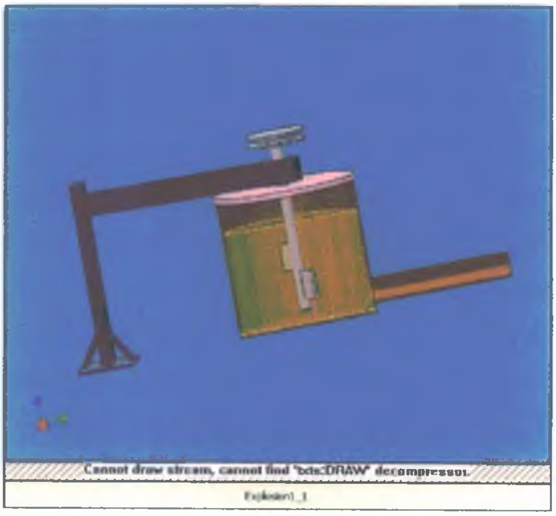


Fig. No. 5.5(a) Photograph of Scum breaker

Thus generated scum in the top layer of slurry will break as soon as the flap rotates which will facilitate gas exit. The flap is fitted with the boss of the rotating shaft with the help of a grub screw.

5.6 SPECIFICATION OF EQUIPMENT AND INSTRUMENTS

5.6.I DIGITAL pH METER WITH AUTO TEMPERATURE COMPENSATION

Make: EI Products, India Model: 111E/ 101E

pH range : 0 to 14

Accuracy: pH : + 0.01 Ph

Temperature range: 0 to 100 C

5.6.2 ORSAT APPARATUS

Make: Bhattacharya &Co, Kolkata

5.6.3 Shredding Machine (Motorized)

Make: Manufactured at Institutes Workshop

Blade Diameter: 180 mm

Motor Specification: Single phase, 0.25 hp, and @1430 r.p.m.

5.6.4 Laboratory Test Sieve

Make: S.C.Dey & Co., Kolkata

Motor: Single phase, 1h.p. and 1430 r.p.m.

5.6.5 Precision Balance

Make: Bombay Tools Supplying Agency, Kolkata

Accuracy: 1 gm.

Fig, No. 5.6.5 Photograph of Precision Balance

5.6.6 **Weighing Machine**:

Range: Up to 2 Kg

Make: S.C. Dey & Co., Kolkata, India

Accuracy: 10 gms

Fig. No. 5.6.6 Photograph of Weighing Machine

5.6.7 **Bomb Calorie Meter**

Make: S. C. Dey & Co.Pvt. Ltd, Kolkata, India

Type :Vertical cylinder, differential digital temperature gauge

Power: 120/220 Volts, 70 Watt.

5.6.8 Air Oven

Make: S. C. Dey & Co.Pvt. Ltd, Kolkata, India

Temperature Range: 0 to 250 C

5.5.9 Muffle Furnace

Make: Dey Brothers, Kolkata

Temperature Range: 0 to 1200^0 C

5.5.10 Willey Mill

Make: S. C. Dey & Co.Pvt. Ltd. Kolkata, India

Sl. No.: 11R 00105.

Model No. F183

Power: 2.4 Watt, 2.4 amps. @ 1440 r.p.m.

5.6.11 Elemental (CHN) Analyzer

Measured at Central Laboratory of West Bengal Pollution Control Board, Kolkata

5.6.12 Filter Pres

Make: Oriental Machinery (1923) Pvt. Ltd., Kolkata

Capacity: 2 Lit.

Fig, no. 5.12 (a):

5.6.13 Mixing Machine

Make: Oriental Machinery (1923) Pvt. Ltd., Kolkata, India

Capacity: 2 Lit

Motor Capacity: 0.5 h.p., Single phase ,1440 r.p.m.

Shown in Fig. no. 5.1.1 (a)

5.6.14.Grinding Machine

Make Oriental Machinery (1923) Pvt Ltd. Kolkata, India

Motor Capacity: 0.5 h.p, Single phase, 1440 r.p.m.

5.5.15 Gauge Glass for detecting slurry level

A gauge glass is fitted to the digester wall in order to detect the slurry level inside the digester.

5.6.16 Pressure Gauge

A pressure gauge is fitted on the top of the spherical cover of digester to observe the gas pressure inside the digester. This has been shown in fig. no.5.12 (d)

Make: Essab India Ltd.

Range:1 bar to 7 bar

5.7 METHODS AND PREPARATION OF SOLUTIONS USED IN ORSAT APPARATUS

5.7.1 Preparation of Solutions used for ORSAT APPARATUS for gas analysis.

Different chemical solutions have been used for absorption of different components of the produced gas in the Orsat apparatus [233]. The methods of preparation of different solutions are given below:

5.7.1.1 Potassium Hydroxide Solution (KOH):

This is prepared by dissolving 500 gms of Stick Potassium Hydroxide in 500 ml of distilled water and stored in a stopper bottle.

Alkaline Pyrogallol Solution

The alkaline pyrogallol solution has been prepared by dissolving 25 grams of pyrogallic acid in 500 ml of caustic potash solution as prepared for carbon dioxide absorption.

5.7.1.2 Ammoniacal cuprous Chloride Solution

The solution has been prepared by the addition of 275 grams of ammonium chloride 1n 1000ml. of distilled water. Sufficient quantity of liquor ammonia is then added just to dissolve the solids.

Quantity of liquor ammonia in this 1000ml of solution would be such so as to just dissolve the solids, and solution, when correctly prepared, should smell only faintly of ammonia.

Absorbents used:

(1). For CO_2 absorption, Potassium hydroxide, (KOH) solution

(2) For Oxygen, (O), absorption Alkaline pyrogallol solution

(3) For Carbon monoxide, (CO), absorption Ammonia cal cuprous chloride solution

Fig. No. 5.7.1.2 Photograph of Orsat apparatus

5.8 ANALYSIS OF BIOGAS USING GAS CHROMATOGRAPH

Produced biogas has been initially analyzed by Orsat apparatus where mainly carbon dioxide has been detected and remaining gas has been considered to be methane. To conduct the confirmatory test of methane presence in the biogas gas liquid chromatograph is used.

5.8.1 Operational procedure

5.8.1.1 Detectors

Thermal conductivity detector (TCD) has been used. Detector temperature has been maintained at 80-85° C during the operation.

5.8.1.2 Column

Porapak Qs has been used as column for the separation of methane, carbon dioxide and ammonia gas. The column temperature has been maintained at 60°c- 65°c.

5.8.1.3 Oven

The oven temperature has been maintained at 55- 60°C.

5.8.1.4 Injection

0.1 to 0.2 micro liter samples has been injected through auto sampler. The temperature of the injection port has been maintained at 65-70° C.

5.8.1.5 Carrier gas and its flow rate

Hydrogen has been used as carrier gas. The flow rate of the carrier gas has been maintained at 30ml/ min.

5.8.2 Operational Procedure

Product gas from the digester has been collected into a gas-collecting unit. The collected gas has been transferred into a tedler bag, which is directly connected with the injection port through auto gas sampler device. 6 feet Porapak Qs column having 1/8-inch diameter has been connected in between injection port and detector. Gas chromatography has been switched on and the flow rate of carrier gas, the temperature of oven, detector and injection port have been fixed up at 30ml/ min, 65° C, 65° C and 60° C respectively. The gas sample has been injected through injection port. Response of the detector has directly recorded in PC through winchrom software where carbon dioxide, methane and ammonia have been separated individually by three different peaks.

5.9 RAW MATERIALS AND CHEMICALS USED

5.9.1 The materials used in the present investigative work have been listed with their sources in table no.5.9.1

Table No. 5.9.1

SI. No.	Materials	Source
01.	Vegetable waste	College canteen
02.	Water hyacinth	Inside college pond
03.	Cow dung	Local market
04.	Flowers	Local cremation ground
05.	Cooked flesh and meat	Institute canteen
06	Hydrochloric acid (HCl)	International Chemicals Calcutta, India
07.	Ammonia solution	Bhattacharya & Co. Kolkata
08.	Potassium Hydroxide (KOH) Pallets	Bhattacharya & Co. Kolkata
09.	Cuprous Chloride ($Cu\ Cl_2$)	Bhattacharya & Co. Kolkata
10.	Pyrogallol ($C_6H_6\ O_3$)	Bhattacharya & Co. Kolkata
11.	Ferric Chloride	Bhattacharya & Co. Kolkata
12	Calcium Chloride	Bhattacharya & Co. Kolkata
13.	Glass Wool	Bhattacharya & Co. Kolkata
14.	Magnesium Sulfate	Bhattacharya & Co. Kolkata
15.	Ferric Chloride	Bhattacharya & Co. Kolkata
16.	Potassium Iodide	Bhattacharya & Co. Kolkata
17.	Calcium Hydroxide in dust form	Bhattacharya & Co. Kolkata
18.	Silica Gel	Bhattacharya & Co. Kolkata
19.	Manganese Sulfate ($MnSO_4$)	Bhattacharya & Co. Kolkata
20.	Sodium Iodide (Na I)	Bhattacharya & Co. Kolkata
21.	Sulfuric acid (H_2SO_4)	Bhattacharya & Co. Kolkata
22.	Potassium dichromate($K_2Cr_2\ O_7$]	Bhattacharya & Co. Kolkata

5.10 CHARECTERIZATION OF KITCHEN WASTE

5.10.1 Proximate analysis

Proximate analysis determines the moisture, fixed carbon, volatile matter and ash content of a material of interest. The sample has been ground to pass 72 meshes British Standard Test Sieve before any step of characterization process has been taken. The moisture, volatile matter and ash content of biomass sample have been determined by standard methods as recommended by the Fuel Research Board of UK and the British Standards Institutions, and the fixed carbon has been determined by difference.

5.10.1.1 Determination of moisture content

Apparatus required: Oven, Petridish with cover, Desiccators, Weight box and Balance.

Procedure:

Approximately 5gms of finely powdered air-dry biomass sample has been weighed in a petridish provided with a well-fitted cover. The area of the petridish should be such that the weight of the sample per sq cm does not exceeding 0.3 gms. The uncovered sample has been heated for about an hour at a temperature of 105- 110°c in an air oven. Then the sample has been taken from the oven with the cover in it and cooled in a desiccator's over calcium chloride or sulphuric acid and weighed along with the cover. The heating has been continued at the specified temperature till the wt. of the sample reaches a constant value. Then the moisture content has been determined by calculating the loss in wt by a percentage.

Calculations:

Wt of the petridish with cover = W1

Wt of the petridish with cover and biomass sample = W2

Wt of biomass sample taken = W2 – W1 = W3

Wt of petridish with cover plus biomass after the completion of heating = W4

Loss in weight = W2- W4

Percent moisture content in the biomass sample taken = $[(W_2 - W_4) / W_3] \times 100$

5.10.1.2 Determination of volatile matter

Apparatus required: Muffle furnace, crucible with lid, tongs, stopwatch, desiccators, wt. box and balance.

Procedure:

One gram of finely powdered air-dried sample has been weighed in a silica crucible. The sample has been sprayed in uniform layer by slight tapping of the crucible on the table.

The lid has been fitted and the crucible has been transferred to a muffle furnace which has been maintained at a temperature of 925°c + 25°c and the door of the furnace has been properly closed.

The sample has been kept in the furnace for exactly 7 minutes and the crucible has been removed and placed on a cold iron plate to ensure rapid cooling.

The crucible, while still warm, has been transferred to desiccators and than weighed when it has been cold.

The loss in weight has been calculated to a percentage of the biomass taken. The percentage of moisture has been deducted and the final result has been reported as percent volatile matter content.

Calculations:

Wt of crucible with lid = W1

Wt of crucible with lid + biomass sample = W2

Wt of biomass sample taken = W2 – W1 = W3

Wt of crucible with lid + residue after heating for 7 minutes = W4

Loss in weight = W2 – W4

Loss in weight to a percentage = (W2 – W4)/ W3 X 100 = W5

Percentage of volatile matter content in the biomass sample taken = W5- % moisture content

5.10.1.3 Determination of ash

Apparatus required: Muffle furnace, crucible with lid, tongs, stopwatch, desiccators, wt. box and balance.

Procedure:

About 1 gm of finely powdered air-dry sample has been weighed in a silica crucible and placed in a muffle furnace at room te4mperature without lid.

The sample has been heated to 400°C to 450°C in 30 minutes for duration of 30 minutes. Then the incineration has been completed by heating for one hour at a temperature of 775°C (+ 25°C).

When heating has been completed, the crucible with the residue has been placed on a cold iron plate for rapid cooling and when it is still warm; it has been placed in desiccators and weighed when it has become cold. It has been desirable to cover the crucible with a lid before it has been placed into the desiccators since rush of air sometimes might cause light ash to be blown away when it has been opened.

If incomplete combustion has been suspected, the incineration should be repeated until the weight is constant.

The residue remaining after heating has been calculated to a percentage on the sample taken to report the ash content.

Calculations:

Wt of crucible = W1

Wt of crucible biomass = W2

Wt of biomass sample taken = W2 – W1 = W3

Wt of crucible with the residue after the completion of heating = W4

Wt of the residue = W4 – W1

: Percent of ash content in the biomass sample taken = (W4 – W1)/ W3X 100

5.10.1.4 Determination of fixed carbon

It has been calculated to a percentage by subtracting moisture content, volatile matter and ash from 100.

5.10.2 Determination of C, H and N

C H N analyzer of the given sample of biomass has determined C, H and N at West Bengal Pollution Control Board, Kolkata, India.

5.10.3 Determination of Calorific value of Biogas

The higher heating value of oven- dried biomass sample has been determined in a bomb calorimeter according to ASTM D2075-77. The lower heating value is calculated by subtracting the heat of condensation of water vapour. The water vapour content has been known from the hydrogen content, determined from the ultimate analysis, which after combustion forms water. The determination of lower heating value is more of a calculated procedure than experimental. The calorific value of biomass has been determined in a bomb calorimeter at constant volume under precisely defined condition. These conditions must be adhered to since any alteration will cause a change in the determined calorific value.

A sample of biomass ground to pass a 72-mesh B.S. sieve has been burnt in oxygen in a bomb calorimeter of known heat capacity. The heat release has been obtained from the corrected temperature rise of water in the calorimeter vessel. Deduction have been made for:

i. The constant heat gain due to heat release by the cotton thread and the firing wire.
ii. The difference between the heats of formation of H_2SO_4 and SO_2.
iii. The heat of formation of Nitric acid.

But in practice, the following correction has been made after the experiment is over:

i) Cooling correction
ii) Thermometric correction

iii) Correction for source of constant heat gain by cotton thread and firing wire

iv) Correction for acid formed.

5.10.4 Results of Analysis of Kitchen Waste

5.10.4.1 Proximate Analysis (air dried basis)

Moisture: 15.24 %

Volatile Matter: 53.77 %

Ash: 15.85%

Fixed Carbon: 15.14 %

Gas has been collected into a gas-collecting unit. The collected gas has been transferred into a tedler bag, which is directly connected with the injection port through auto gas sampler device. 6 feet Porapak Qs column having 1/8/-inch diameter has been connected bin between injection port and detector. Gas chromatography has been switched on and the flow rate of carrier gas, the temperatures of oven, detector and injection port have been fixed up at 30ml/ min, 65°c, 65°c and 60°c are respectively. The gas sample has been injected through injection port. Response of the detector has directly recorded in PC through winchrom software where carbon dioxide, methane and ammonia have been separated individually by three different peaks.

5.10.4.2 Elementary Composition (air dried basis)

Carbon (C) : 36.52 %

Nitrogen (N) : 2.62 %

Hydrogen (H) : 5.12 %

C/N ratio : 13.94

5.10.4.3 Particle Size

Equivalent diameter of the vegetable waste is

i) 1.80×10^{-3} m

ii) 1.50×10^{-3} m

iii) 1.10×10^{-3} m

iv) 7.50×10^{-4} m

5.10.4.4 Calorific Value

2055 cals/gm

5.11 Determination of Mean Particle Sizes

It is very much essential to do the size reduction of the feedstock. Since the feedstocks are too tenacious or too resilient and hence it is very difficult to be broken either by compression or by impact. To achieve this a device for shearing/ shredding of the feedstock is being designed as shown in fig. No.5.11 (a)

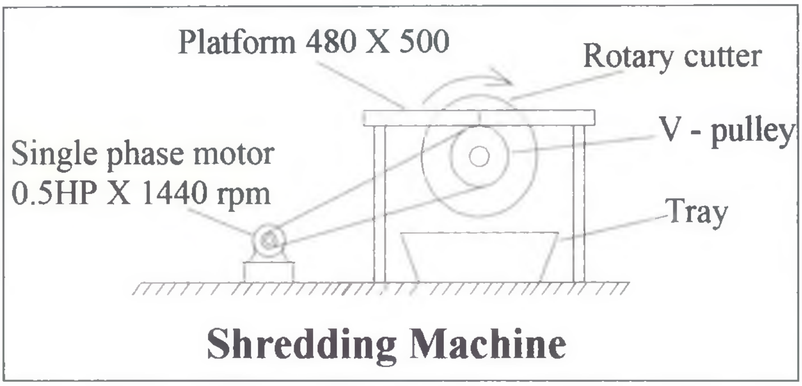


Fig. No. 5.11 (a)

Fig. no. 5.11 (b)Photograph of Shredding machine

Shredding Machine

In this machine a rotary cutter powered by an electric motor is fitted on the spindle to cut the feed stick in desired sizes. After shearing the feedstocks it is further fed to the grinder in order to achieve the required sizes of feedstocks as shown in the fig. No.5.11 (b)

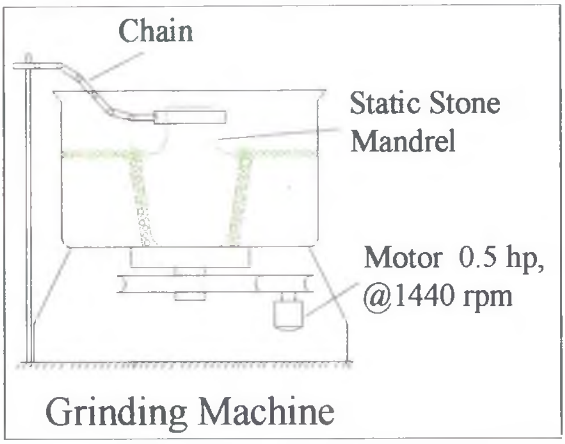


Fig.no.5.11 (b) Grinding Machine

Fig. No.5.11 (c) Photograph of grinding machine

The mean particle size for each run has been determined from the total fictitious area.

For this, the product from the crushing unit has been first weighed and then screened through a set of standard sieves as shown in the fig.no.5.11(c)

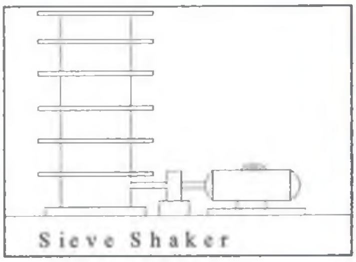


Fig. No. 5.11 (e) &Fig.No.5.11 (f) Photograph of Sieve shaker

5.11.1 Methods of Calculation of mean Particle Size

Let us assume that each particle is a perfect cube with a linear dimension D and its surface area is A_l

Then its surface area, $A_l = 6D^2$ and volume, $V_1 = D^3$.

Knowing that the particle sizes are not exactly cube, it has been assumed, on the average, their areas and volumes are proportional to the areas and volumes of the cubes of the same screen size.

Therefore, we can write, $A_1 = a D^2$----------- (i)

and , $V_1 = bD^3$--------------------------------- (ii), where , a and b are constants for a given waste material.

We have considered D is the average screen size and the materials are passed through it.

Let us consider no. of particles is N for the uniform size fraction and total weight is W.

Or, $W = N \times [V1 \times \rho]$,

Or, $N = W/[V_1 \times \rho]$, V_1 is volume of each particle and is the density of the feed material.

Or, $N = W / b \rho \ x. \ D^3 = W / c. D^3$, ------------------------(iii)

Where, c is a constant and equal to b. ρ

Let, total area for all the particles passed through the same fraction of screen is,

$A = N. A_1 = W / c D^3 \times a D^2 = (a/c) \times W/D$-----------(iv)

Now, considering the total fictitious surface area for all the particles in the product is A,

Therefore, $A = (a/c) \times W/D$

Let us consider, Dm is the mean particle size in a total weight W, for all the particles, then, $W = A. Dm \times \rho$

Or, $W = [(a/c) \times W/D]. Dm \times \rho$, where, $A = (a/c) W/D$

Or, $Dm = W/ A \times \rho$

From the above equations, (i), (ii), (iii) and (iv), we can find the value for Dm.

The mean particle size of the feed material has been determined by the method as described above and four different particle sizes have considered for anaerobic digestion.

5.12 PROPOSED PLANT LAYOUT INCLUDING MATERIAL HANDLING SYSTEM

In the propose plant layout we have considered four sections of the total processing unit such as:

(a) Preparation of desired feedstock

(b) Generation of Biogas

(c) Up gradation of biogas

(d) Separation of water and slurry mixture

The machinery are shown in the modular form in the fig nos.5.12 (c), 5.12(d), 5.12(e) and 5.12 (f).

All these machinery selected for processing of 200 kg. of waste available daily from kitchen. Design and detail engineering of various machinery like digester, gasholder are being mentioned in the previous sections. All these selected machinery shall be suitable for optimum utilization of the waste, purification of the generated gas, recycle of the used water after proper filtration and to obtain the retaining manure from the digester. The remaining solid manure after digestion will be taken out from the reactor and the same will be pressed by a filter press in order to separate the semi-solid manure and water. Detail of the filter is shown in the following fig. 5.12(a)

BLOCK DIAGRAM OF BIOGAS PLANT (HARI NARAYAN MODEL)

A block diagram showing all the equipment considered for the proposed plant for anaerobic digestion of kitchen waste has been shown in fig. no. 5.12(g)

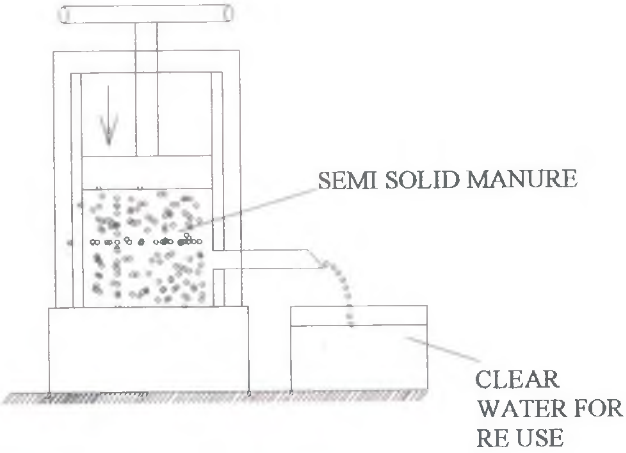


Fig.no.5.12 (a) Filter Press

Fig. no. 5.12 (b) Photograph of Filter press

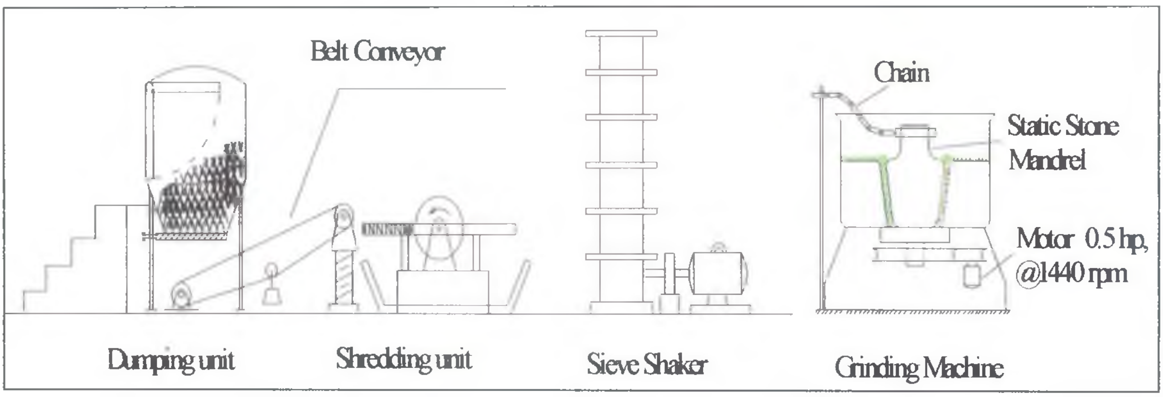


Fig. No. 5.12 (c) Feed Stock Preparation

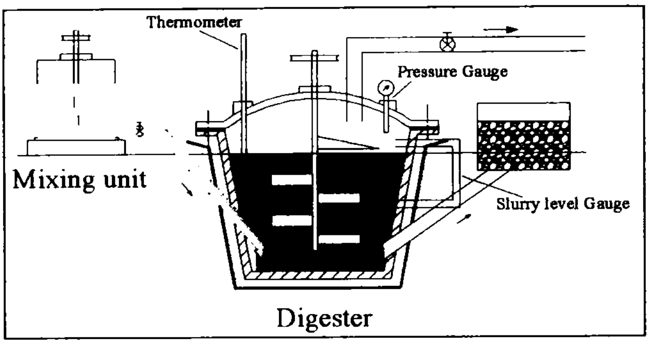


Fig. No. 5.12 (d) Generation of Biogas by Anaerobic Digestion Process

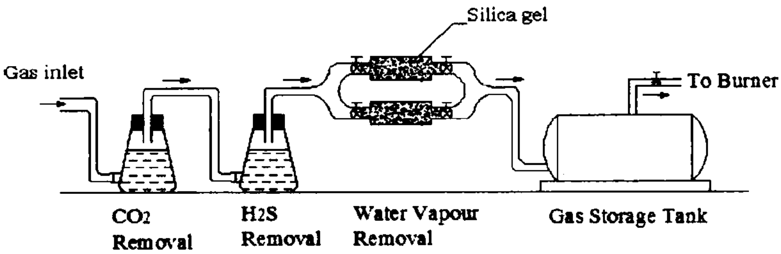


Fig. No. 5.12(e) Up Gradation of Biogas

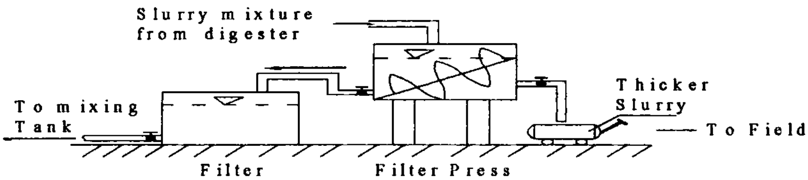
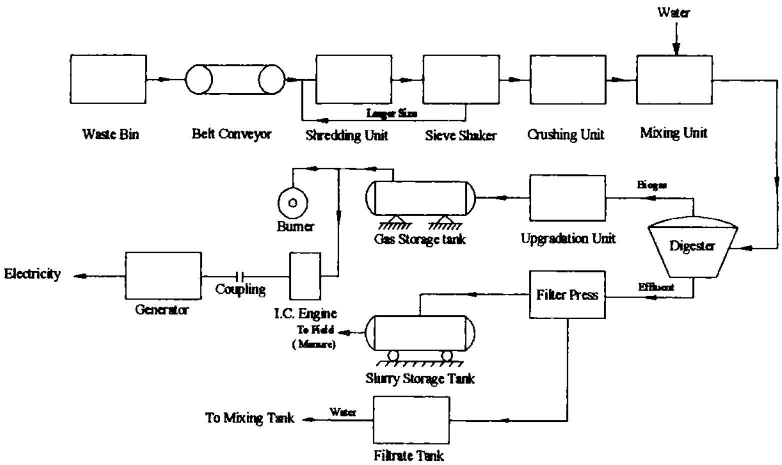


Fig. No. 5.12 (f) Dewatering of Slurry



BLOCK DIAGRAM OF BIOGAS PLANT

Fig. No. 5.12 (g) Block Diagram

Fig.No.5.12 Proposed Plant Layout (HARI NARAYAN MODEL)

5.13 Maintenance of Biogas Plants

The biogas plants require periodic maintenance to function properly. For example, the gasholders must be painted every two years with chlorinated rubber black paint or with any anti-rust paint to prevent corrosion. The selected material should be designed to be rust free i.e. it should be primed with non-corrosive primer followed by two coats of chlorinated rubber paint.

In addition, sand and mud tend to settle at the bottom of the digester in spite of efforts to keep the charge free of sand. The daily operation and maintenance activities of the operators should be simpler and routine by means of a flow chart and a problem- cause with remedies chart.

The proper training should be imparted to the users so that the technical awareness in respect of operating the plant to be increased.

5.14 Plant Location

It is proposed to install the biogas plant with the consideration of certain aspects as mentioned below: -

(i) The biogas unit should be placed at a short distance from the kitchen and a safe distance from the cattle shed if any.

The short distance will minimize pressure drop in the pipelines connected in between the gasholder and the users end.

(ii) There should be no trees close to the biogas unit. This is to avoid mechanical damage caused by roots, but also to avoid shedding from trees.

(iii) The biogas unit should be placed in such a way that mechanical damage caused by cattle can be avoided.

(iv) Due to the risk of leakage of liquids from the unit, it should not be placed near any wells

The space requirement depends on the size of the unit.

CHAPTER-6

UPGRADATION OF BIOGAS

Chapter - 6

UPGRADATION OF BIOGAS

6.1 BIOGAS COMPOSITION

Gas recovery from biodegradable waste is an established technology for energy recovery, it also reduces pollution load and in the process makes available nitrogen rich organic manure. Use of biogas is increasing in combined heat & power engine or as a fuel for cooking. More than 1000 high- rate anaerobic digester are in operation world – wide to treat organic waste from large kitchen of hostels, market and industrial units [234].

The product of anaerobic digestion is a mixture of methane and carbon dioxide with smaller amount of hydrogen sulphide and water vapor and this is commonly known as biogas.

Usually, the mixed gas is saturated with water vapor and may contain dust particles and Siloxanes.

Composition of a representative sample of biogas is given below:

Composition of biogas generated from kitchen

Components	Symbol	Percentage
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Trace

Source: Yadav and Hesse, 1981 [235]

6.2 BIOLOGICAL PROCESS AND PRODUCTS

In the anaerobic digestion process high- molecular size organic material is cracked to low – molecular size, in organic substances and gas by means of anaerobic (in the absence of oxygen) bacteria. [236].

The process may be described by the following expressions:

In element terms the input output relationship is as follows:

Biomass + Bacteria > Gasses + Nutrients

C, H, O (N, P, K, S) > CH_4, CO_2, + N, P, K, S

In particular, biogas as a fuel could bring substantial reductions in green house gases, particulate matter and dust or nitrogen oxide emissions. When biogas is used as a vehicle fuel it has to be up graded. A number of technologies have been developed. A few processes have been described for up gradation of biogas and its utilization.

For many applications the quality of biogas has to be improved. The main parameters that may require removal in upgrading systems are H_2S, water vapour, and CO_2.

Desulphurisation to prevent corrosion and avoid toxic H_2S concentrations. When biogas is burnt SO_2 / SO_3 is emitted which is even more poisonous than H_2S. At the same time SO_2 lowers the dew point in stack gas. The sulphurous acid formed (H_2SO_3) is highly corrosive.

Removal of water because of potential accumulation of condensate in the gas line, the formation of a corrosive acidic solution when hydrogen sulphide is dissolved or to achieve low dew points when biogas is stored under elevated pressures in order to avoid condensation and freezing.

Removal of CO_2 will be required if the biogas needs to be upgraded to natural gas standards for use as vehicle fuel. It enhances the energy content of the biogas but has no significant environmental impact.

6.3 EFFECTS OF H_2S ON BIOGAS PLANT AND DEVICES

H_2S is a very poisonous, colorless gas. It is inflammable and forms explosive mixture with air (oxygen). H_2S has characteristic smell of rotten eggs. Combustion product of H_2S and SO_2 forms a very corrosive acid (H_2SO_4), which contaminates the environment (acid rain).

Dissolved H_2S in the fermentation slurry can inhibit the production of biogas and causing its composition to alter. The presence of H_2S causes corrosion to the metal parts. The effect of H_2S on non-ferrous metals in components such as pressure regulators, gas meters valves and mountings is much more serious. The combustion product SO_2 combined with water vapour badly corrodes burners, gas lamps and engines. Burning biogas in stoves and boilers can cause damage to the chimney. The acid formed by hydrogen sulfides and sulphur di-oxide corrodes engine parts in the combustion chamber, exhaust system and bearings. The sulphur contents of biogas used in engines shorten the time between the oil changes. SO_2 dissolves in lubricating oil and changes its properties. The benefits of up gradation are high calorific value and combustion rate will be higher.

6.4 GAS UPGRADATION TECHNOLOGIES

A number of gas upgrading technologies have been developed for the treatment of natural gas, town gas, sewage gas, landfill gas etc. However, not all of them are recommended for the application with biogas because of price and/ or for environmental concerns.

6.4.1 Carbon dioxide removal

Carbon dioxide being noncombustible element of biogas lowers its heat value. Number of methods has been developed for removal of CO_2

To use of biogas as vehicles fuel it has to be enriched in methane. This is primarily achieved by carbon dioxide removal, which then enhances the energy value of the gas to give longer driving distances with a fixed gas storage volume. At present four different methods are used commercially for removal of carbon dioxide from biogas either to reach vehicle fuel standard or to reach natural gas quality.

These methods are:

(i) Water scrubbing

(ii) Polyethylene glycol absorption,

(iii) Carbon molecular sieves,

(iv) Membrane separation

6.4.2 Water scrubbing

In this method gas is passing through the water, which absorbs carbon dioxide and also hydrogen sulphide from biogas to some extent. Since these gases are more soluble in water than methane. The absorption process is purely physical.

Water scrubbing can also be used for selective removal of hydrogen sulphide since hydrogen sulphide is more soluble than carbon dioxide in water. The water, which absorbed carbon dioxide and hydrogen sulphide, can be regenerated and recirculated back to the absorption column.

Schematic flow sheet for water absorption is shown in the following fig.no.6.4.2

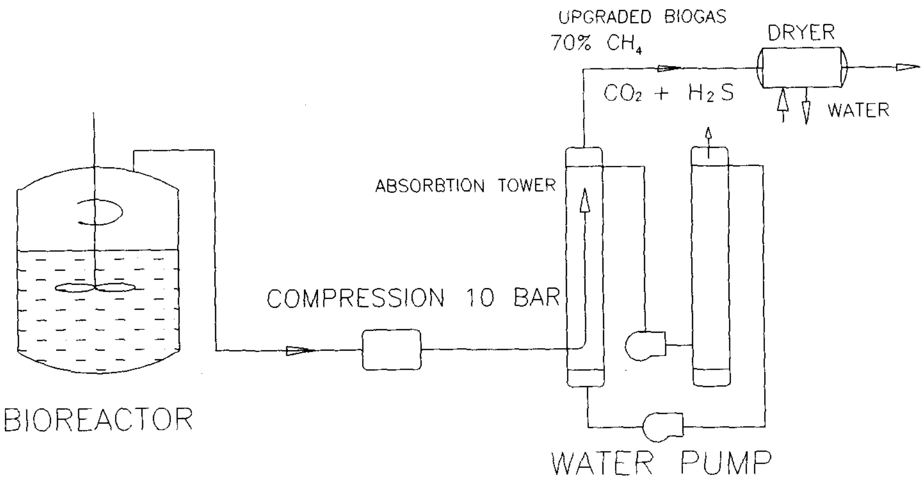


Fig. No. 6.4.2 Water Scrubbing

Based on the studies carried out by H, M. Lapp [236] it is observed that 12.3 litre of water required for purification of 0.2 cum of bio gas at 20 °C and at 1 atmospheric pressure (1.03kg/cm^2.)

6.4.3 Limewater Scrubbing

Biogas containing carbon dioxide when passing through limewater, carbon dioxide is absorbed and calcium carbonate is formed, according to the following chemical reaction:

$Ca(OH)_2 + CO_2 \quad = Ca(CO)_3 + H_2O$

Calcium hydroxide is preferred for biogas scrubbing as this chemical is readily available and cost of operation is less. The main limitation of limewater scrubbing is difficulties faced in controlling solution strength, & removal of large amounts of precipitate from mixing tank and scrubber. This precipitated calcium carbonate, has many uses, one of them can be in producing chalk sticks for writing, may be used in talcum powder manufacturing company. It has also many uses in pharmaceutical laboratories.

6.4.4 Methods for Removal of Hydrogen Sulfide from Biogas

Cleaning of biogas is recommended because of the very corrosive effect of H_2S which biogas contain. There are many process for removal of H_2S from biogas, in principle, there are two basic procedures:

(i) Absorption of H_2S by ferric oxide and

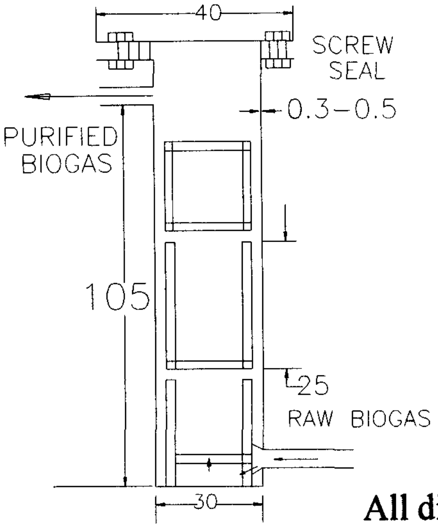
(ii) Microbial desulphurisation by the addition of air

Among all the process, only the dry process is suitable for small-scale biogas plats. In this process, the desulphurisation of biogas is based on a chemical reaction of H_2S with suitable substances.

6.4.5 The Desulphurising Apparatus

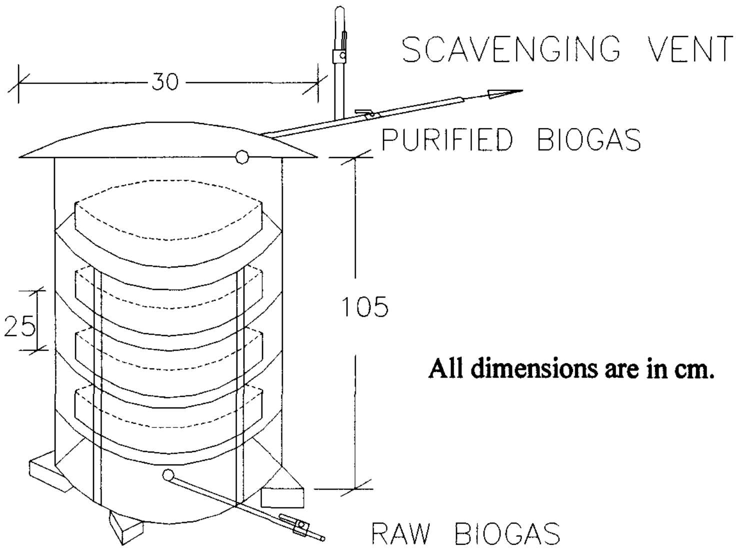
The absorbent is brought in to immediate contact with the raw gas. This takes place in closed purification chamber. This chamber is made of steel. The size of the chamber is designed in such a way that the raw gas should pass through absorbent and get sufficient time for purification. The chamber is having sufficient space for containing enough absorbent for the gas to be in contact with the absorbent with a sufficient distance and to avoid short refining cycle. The purification chamber contains several intermediate trays. A layer of absorbent 20 to 30 cm. is placed in each tray. These trays are perforated made from steel sheet (12 swg.) The sealed cover is placed from the top of the chamber to access to the whole chamber of cross section. The control valves are installed in the inflow and exit pipes of the purification chamber. These are used to disconnect the chamber when the absorbents to be changed. The above arrangement is shown in the fig. no.6.4.5. (a)

A scavenging vent is used for flushing air out of the chamber with biogas after exchanging the absorbent and sealing the chamber. When the absorbing agent is saturated with sulfur and can be regenerated either inside the chamber or outside through natural ventilation with air. The absorbent material can be used several times. Fig. nos. 6.4.5(a), 6.4.5.(b), 6.4.5.(c) and 6.4.5 (d)shows some aspects of the desulphurisation apparatus designed for a 1.5 m^3 per hour capacity desulphurising plants.



All dimensions are in cm.

Fig. No. 6.4.5 (a): Desulphurisation Chamber for Biogas



All dimensions are in cm.

Fig. No. 6.4.5 (b): Cylindrical Purification Chamber

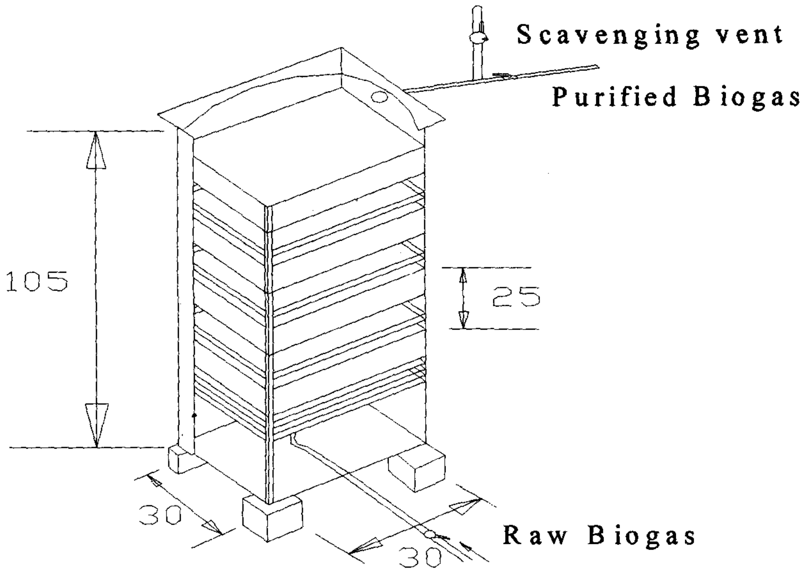


Fig. No. 6.4.5 (c): Rectangular Purification Chamber

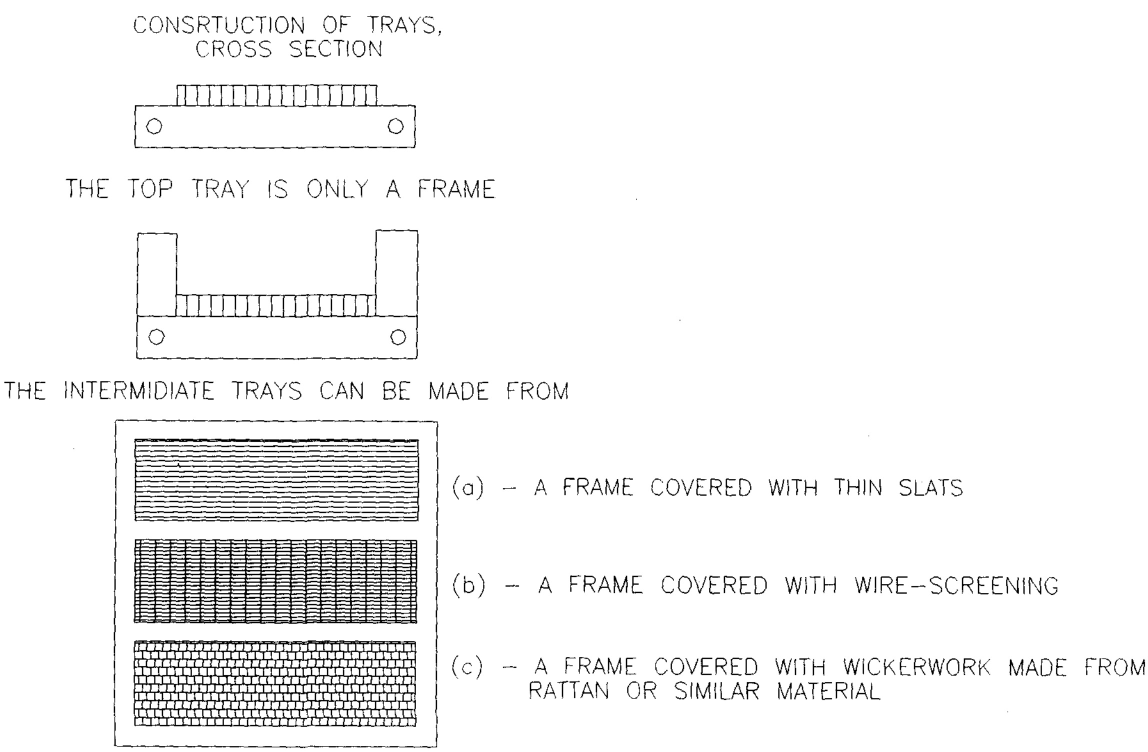


Fig. No. 6.4.5 (d): Construction of Trays

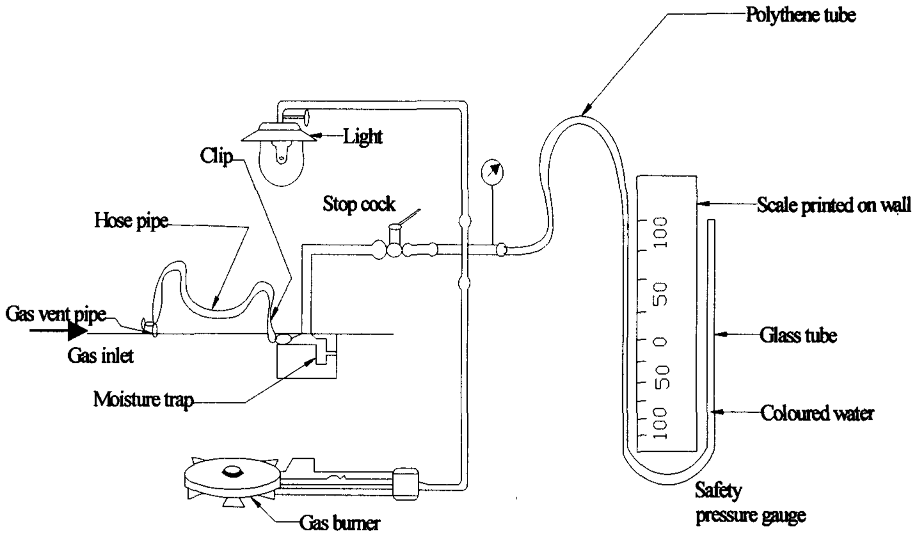


Fig. 6.4.6 Trapping of Moisture

Biogas contains water vapour, which condense in the pipeline. Provision is made for removal of water from the pipeline by means of providing a correct slope to the pipe, which is nearest the gas plant. The pipe having a slope towards the moisture trap. The recommended slop is 1: 100 as shown in figure no. 6.4.7

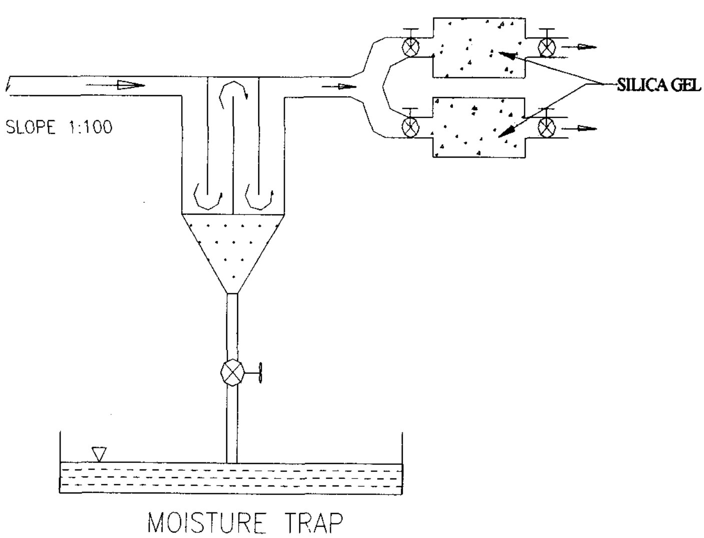


Fig. No. 6.4.7 Removal of water vapour

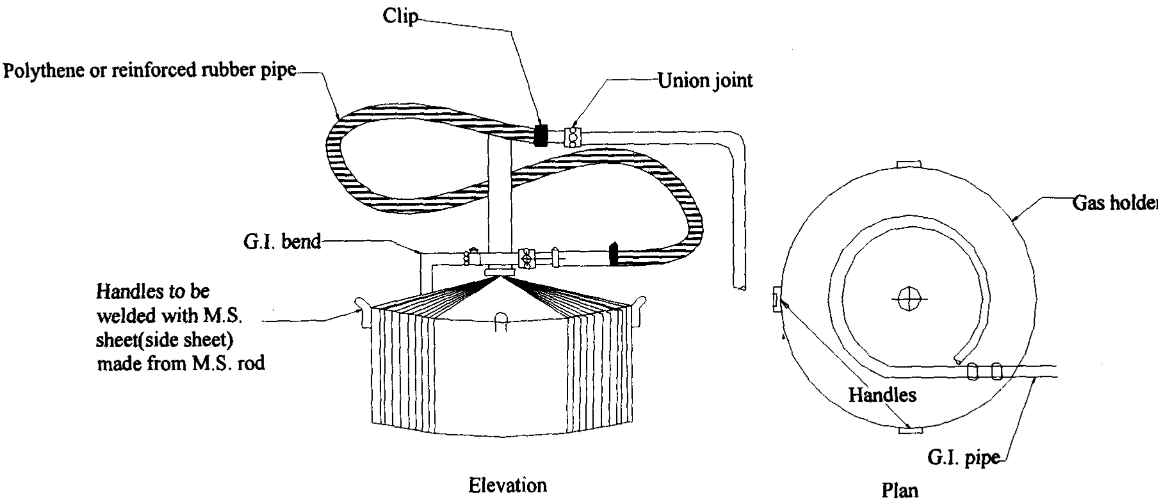


Fig. No. 6.4.8: Joining Gasholder to Main Gas pipeline

After trapping the moisture from the pipe line, the gas is further passed through a chamber containing silica gel in order to absorbed water vapour content as shown in fig. No.6.4.7

Following chemical reactions is taking place in this process

(i) $2Fe_2O_3 + 6\ H_2S \xrightarrow{H_2O} 2\ Fe_2S_3 + 6\ H_2O$

(ii) $2Fe_2S_3 + 3O_2 \xrightarrow[\text{Regeneration}]{} 2\ Fe_2O_3 + 3\ S_2$

The above reaction is slightly endothermic; a temperature of approximately 12^0 C is required to provide the necessary energy. The reaction is optimal between 25^0 and 50^0 C.

The reaction (ii) shows that the iron sulphides formed can be oxidized with air i.e. .the iron oxide or hydroxide is recovered with elementary sulphur. The proeess is highly exothermic, i.e., a lot of heat is released during regeneration [237].

6.4.7 Removal of Siloxane

Organic compounds are occasionally present in biogas, which can cause severe damage to combine heating and power (CHP) engines. During combustion the oxides convert to silicon oxide, which deposits at spark plugs, valves and cylinder heads abrading the surfaces and eventually causing serious damage. Particularly in case of Otto engines this might lead to major repairs. Siloxanes can be removed by absorption in a liquid media, a mixture of hydrocarbons with a special ability to absorb the silicon compounds.

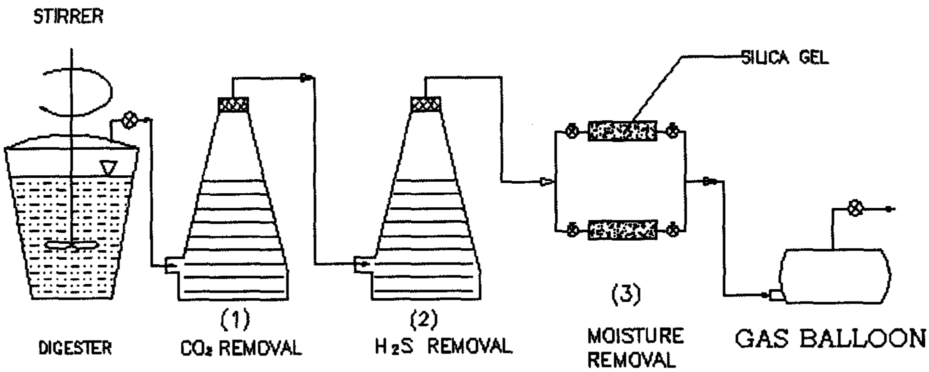


Fig. No. 6.4.9 Removal Process (CO_2, H_2S and Water Vapour)

6.4.8 Smell and odor control

Smells are the most apparent form of air pollution. The smells from decomposing manure are usually caused by the release of compounds like ammonia, volatile organic acids and sulphides. The sulphides, the worst smelling are produced by sulphate reducing bacteria. The smell increases with the storage time of manure. In an open storage tank, the smell escapes to the atmosphere. In an anaerobic digestion tank, however, the smells are contained both in the digester and in the gasholder before the gas is burnt. The remaining sludge has no offensive smell.

6.4.9 Pathogen Removal

The kitchen waste contain a vast number of bacteria such as pathogenic and salmonella types which cause typhoid in humans and salmonellas in poultry and cattle and brucella which cause brucellosis. If these wastes are sprayed in land without treatment, there is a serious danger of infection to the animals, which graze in the field. The bacteria may also harm human if this waste is thrown on the road, drain, etc.

In view of the above it is recommended that the manure should be kept for at least one month before using to avoid infection. Anaerobic digestion reduces the number of pathogenic bacteria since the digestion happened inside the reactor without oxygen for a length of time between 30- 40 days at about 35°c [238].

6.4.10 Improvement of biogas after purification

After purification of biogas through different ways there are many improvement in properties of the biogas as compare to raw gas.

A comparison of raw gas and upgraded gas is mentioned below:

Type of gas	Raw gas	Purified gas
Methane (CH_4)	66% v/v	99.5% v/v
Carbon dioxide (CO_2)	34% v/v	0.5 % v/v
Hydrogen sulphide (H_2S)	300 ppm v/v	3 ppm v/v

6.4.10.1 Fuel values of Biogas

The fuel value of biogas is directly proportional to the amount of methane it contains (the more methane, the more combustible the biogas). This is because the gases, other than methane, are either non-combustible, or occur in quantities so small that they are insignificant.

Fuel value after up gradation of biogas has been shown in Table No. 6.4.10.1.

Table No. 6.4.10.1:Fuel value of Biogas and other major fuel gases

Fuel gas	Fuel value, Kcal/m^3 (BTU/ft^3)	
Coal (Town) Gas	4000-4450	(450-500)
Biogas	4800-6230	(540-700)
Methane	7970-9500	(896-1069)
Natural gas (Methane or propane based)	9350-19570	(1050-2200)
Propane	1960-23125	(220-2600)
Butane	25800-30250	(2900-3400)

Source: L.John Fry., "Methane digester for fuel gas and fertilizer",

CHAPTER -7

ANALYSIS OF SOLID REMANTS AND ITS EVALUATION AS ORGANIC MANURE

Chapter -7

ANALYSIS OF SOLID REMNANTS AND IT'S EVALUATION AS ORGANIC MANURE

The effluent from the biogas unit constitutes good quality manure free from weed seeds, foul smell and pathogens. It holds value both as soil conditioner and organic fertilizer. It contains a full range of plant nutrients in the digester slurry as nitrogen (N), phosphorous (P_2O_5) and potash (K_2O).

The fertilizer benefit has been claimed to reduce economic spending both for the farmers and for the nation. The content (in absolute term) of nutrients and minerals in the manure will not change to any great extent due to the fermentation process. Compared to farmyard manure, N_2, K and P found will be formed in the effluent in forms that one more easily absorbed by plants conversion of amino acids and proteins to ammonia and soluble ammonium compounds take place.

Organic material, in the form of dead bacteria will also be produced.

The affluent has been composed and there after be used where soil conditioning and fertilizer is needed. The compost will be designed and managed properly ensure that a high degree of the minerals and nutrients can be preserved.

A number of experiments have been carried out in order to find out the value of the fertilizer. The results from these tests indicate that the effluent from a biogas digester is at least as good a fertilizer as the farmyard manure and chemical fertilizers.

This manure is acknowledged as a valuable soil conditioner and fertilizer in rural areas.

If well managed the effluent could actually prove to be more profitable for the farmer than the gas.

It has been observed that depending upon the input material used the sludge contains elements like nitrogen, phosphorous, potassium and also several trace elements may be present in the slurry like bromium, calcium, copper, iron, manganese, zinc etc.

From the above study it becomes necessary to evaluate the presence of the element like carbon, nitrogen, phosphorous for the manure. Several experiments done for chemical analysis of manure of kitchen waste (dust form) in the central laboratory of West Bengal Pollution Control Board, kolkata and obtained the following results as shown in table no. 7.1

Table No. 7.1 Chemical analysis of manure

Elements	Value		
	(Sample no. 1)	(Sample no.2)	(Sample no. 3)
Carbon (%)	45.92	43.85	44.25
Nitrogen (mg/Kg)	1281.00	1210.00	1250.00
Phosphorous (mg/Kg)	61.26	58.54	60.30

From the above results it reveals that the manure can be used as a good fertilizer because of its high value of nitrogen and phosphorous contents.

Fertilizer value of the manure from biogas plant equivalent to chemical fertilizer is mentioned in the following table no. 7.2

Table No. 7.2 Fertilizer value of manure (N, P, K) to other chemical fertilizers

N, P and K in Biogas manure	Other chemical fertilizer
1 Kg. N_2	2.2 Kg Urea
1 Kg. P_2O_5	6.3 Kg. Super phosphate
1 Kg. K_2O	1.7 Kg. muriate of potash

Source: Nijaguna, B.T., Biogas Technology, New Age International (P) Ltd. New Delhi, p41

Apart from its use as a soil conditioner and organic fertilizer, the slurry after digestion can be used as a feed for fish in the ponds/lake. An ideal feed for Singhi and Magur and a breathing catfish.

After the solids are removed from the sludge, the remaining liquid that contains nutrients and trace materials is considered to be good promoter of algae. Chlorella a single allowed high protein algae could be harvested with the liquid portion of the sludge. This chlorella can be used as animal feed to replace soybean soil meal or protein supplement. Recently, Spirullina is also being cultivated in the supernatant liquid.

CHAPTER - 8

RESULTS AND DISCUSSIONS

Chapter - 8

RESULTS AND DISCUSSIONS

It has been observed from sets of trial experiments that the pH value changes during the initial digestion stage, due to the change in the chemical composition. It has been observed during experiments based on the various mixed kitchen waste (cooked), the pH falls below neutral in the beginning due to the formation of organic acids and later rises above neutral because the acids are consumed due to the ammonia is released. Variation of pH with respect to the digestion for considering 12 consecutive days has been shown in the Table No.8 (a) and 8(b).

Table No.8 (a). pH Value Vs. Digestion Period (Mixed Kitchen Waste)

Days	pH. Value
1	3.40
2	3.30
3	2.9
4	4.00
5	4.25
6	4.85
7	5.60
8	6.20
9	6.80
10	6.80
11	6.86
12	6.86

It has been further observed during experiments based on the mixed food waste, pH Value falls initially with respect to the digestion period and again goes up nearer to neutral point ie,7. The observed values have been mentioned in the Table No. 8(b).

Table No. 8(b). pH Value Vs. Digestion Period (Mixed Food waste)

Days	pH. Value
1	3.20
2	3.20
3	3.20
4	3.15
5	3.10
6	2.97
7	2.06
8	4.00
9	4.15
10	4.50
11	5.20
12	5.60

The observed values as mentioned in the above Tables Nos. 8(a) and 8(b), the variation of pH values against the various digestion period have been plotted in the following Fig. Nos 8(a) and 8(b).

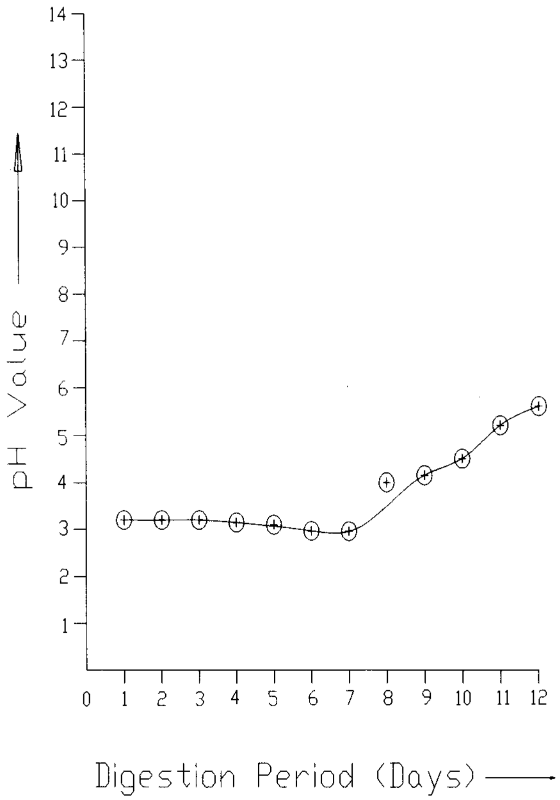


Fig. No. 8 (a) Digestion Period (Days) Vs pH (Mixed kitchen waste)

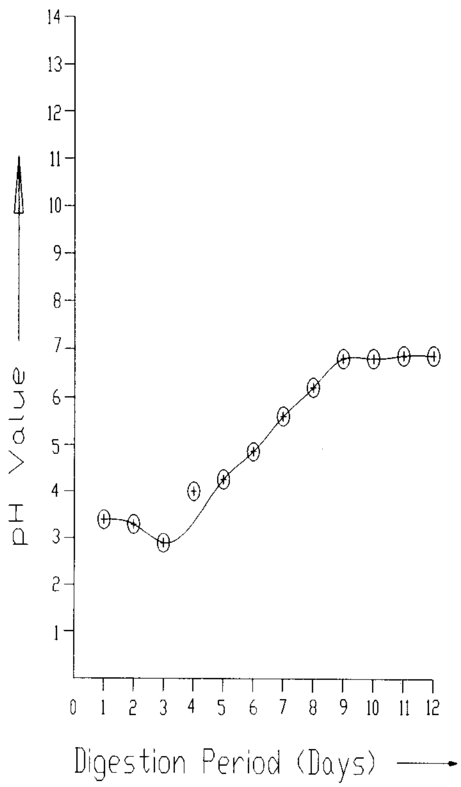


Fig. No. 8 (b) Digestion Period (Days) Vs pH (Mixed food waste)

The above results confirmed the tests performed by Beck-Friis. et al., 2003.

Since organic acids are formed at a lower pH, little amount of methane is generated. It has also been noticed that in order to get a stable anaerobic digestion, the system should have pH value in the range of 6.7 to 7.5 with an optimum range of 6.9 to 7.2 because in neutral pH range, methane forming bacteria are more stable. When pH is decreased volatile acid concentration increases, as a result less amount of methane is formed due to the instability of methanogenic bacteria. In more extreme cases formation of methane may be stopped. To overcome this problem alkaline solution is buffered in the digester in order to maintain pH value in the range of 6.9 to 7.2 for all the experiments.

An anaerobic digestion process is highly dependant on the parameter like loading rate (Klapwiik, A., 1999) [239] temperature, concentration, retention time and particle size (Mondal, C, et al., 1999) [240] solid- liquid ratio, scum removal and also on extent of agitation of slurry. The presence of impurities particularly toxic substances influences the reactions. A systematic study has been carried out for both semi- batch and continuous digestion of various mixed and individual kitchen waste to examine the effect of concentration, particle size, temperature of slurry mixture inside the digester and biogas production .The effect of each parameter on biogas yield has been discussed in detail.

In the experiments two-phase digestion techniques are being adopted for separating the acid and methane-forming phase. It has been observed that the duration of acid phase is 4 to 5 days at the time of beginning and the slurry fed to the adjoining digester immediately when the same has reached to the neutral. Thus the methane forming bacteria can work in the methanogen phase without any acidic phase effects.

8.1 CONTINUOUS DIGESTION

8.1.1 Effect of Loading Rate and Retention Time on Methane Yield at Different digestion temperature

Table no.8.1.1 shows the variation of methane yield against different loading rate for varying retention time ranging from 3 to 12 days, depending on digestion temperature at steady state condition.

Table No. 8.1.1

Loading Rate (litre/day)	Retention Time (days) (R)	MethaneYield (litre/day)	Methane Yeild(m^3/kg of BOD added)
	Digestion Temperature **303 K**		
1.0	12	6.80	0.155
0.9	10	6.09	0.154
0.8	9	5.36	0.152
0.7	8	4.62	0.150
0.6	7	3.78	0.143
0.5	5	3.02	0.137
0.4	4	2.25	0.128
0.3	3	1.58	0.120
	Digestion Temperature **308K**		
1.0	12	6.55	0.149
0.9	10	5.82	0.147
0.8	9	5.10	0.145
0.7	8	4.40	0.143
0.6	7	3.75	0.142
0.5	5	3.08	0.140
0.4	4	2.39	0.136
0.3	3	1.74	0.132
	Digestion Temperature **313 K**		
1.0	8	7.04	0.160
0.9	7	6.22	0.157
0.8	5	5.35	0.152
0.7	4	4.56	0.148
0.6	3	3.64	0.138
	Digestion Temperature **328K**		
1.0	8	6.78	0.154
0.9	7	6.02	0.152
0.8	6	5.32	0.151
0.7	5	4.50	0.146
0.6	4	3.75	0.142
0.5	3	2.90	0.132

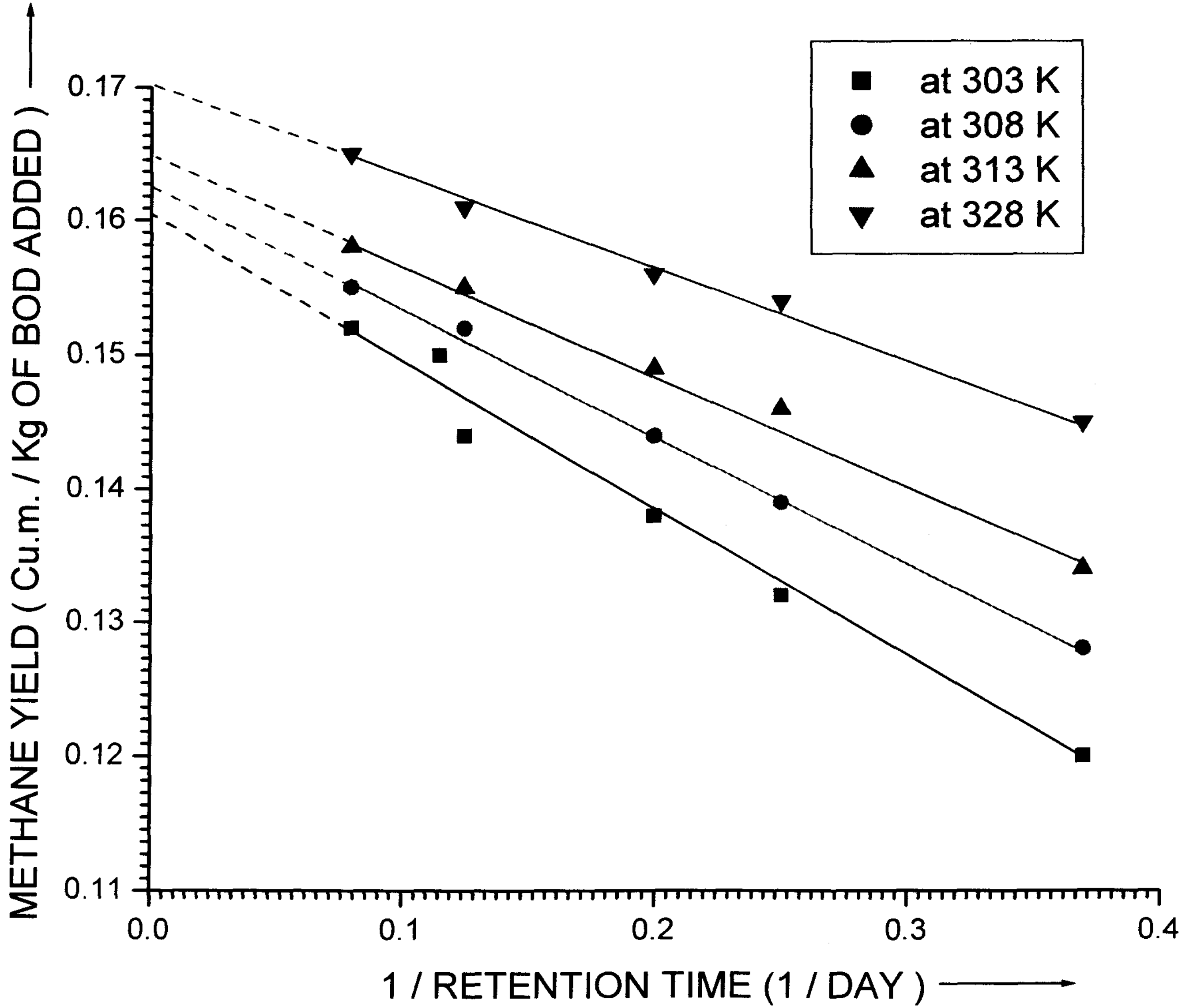


Fig. no. 8.1.1. Plot of Methane yield against 1 / Retention time at different temperature of continuous digestion.

Fig. no. 8.1.1 shows the variation of methane yield at different loading rate against 1/retention time (R) with digestion temperature as a parameter at steady state condition.

Assuming Y denotes the amount of methane produced in cu. m. per Kg of BOD added and $Y\alpha$ is ultimate methane produced in cu. m. per Kg of BOD added i.e. at infinite retention time which is obtained by extrapolation of the line as shown by the dotted line in Fig. no. 8.1.1. The plot of Y versus (1/Retention time) is as shown in Fig. no.8.1.1. As seen from the curve methane yield is having an almost linear relationship with reciprocal of retention time and the same can be expressed as;

$Y = - mT' + Y\alpha$ ------------(i), where, T' is the inverse of retention time (1/R) and m is the slope of the straight line characteristic.

From Fig. no. 8.1.1 the average value of m and $Y\alpha$ are found to be 0.50439 and 0.1667 respectively from Fig.8.1.1.

Based on the average value of m and $Y\alpha$, the above equation) can also be written as $Y = - (0.50439)\ T' + 0.1887$

The value of $Y\alpha$ (ultimate methane yield) as found from Fig. No.8.1.1 is shown in Table no 8.1.2.

Table No. 8.1.2

Temperature (K)	Ultimate methane yield (m^3 /kg of BOD added)
303	0. 1609
308	0. 1672
313	0. 1697
328	0. 1680

It, therefore, reveals that the microbial growth within the temperature range from 303 K to 328 K is rather prominent, which is the mesophilic range. It is also found that continuous anaerobic digestion gives rise to maximum yield of methane at313 K. It has been further observed from the Figure no.8.1.2 that volumetric methane production rate is the function of temperature at different retention times ranging 3 to 10 days for kitchen waste. The effect of temperature on methane yield will be more at short retention time and the same will be less at long retention time. It has also been observed from the graph that volumetric methane production rate at short retention time is higher than that at long retention time for the same digestion temperature at a slurry concentration of 6% solid by weight and particle size of 1.10 X 10^{-3} m.

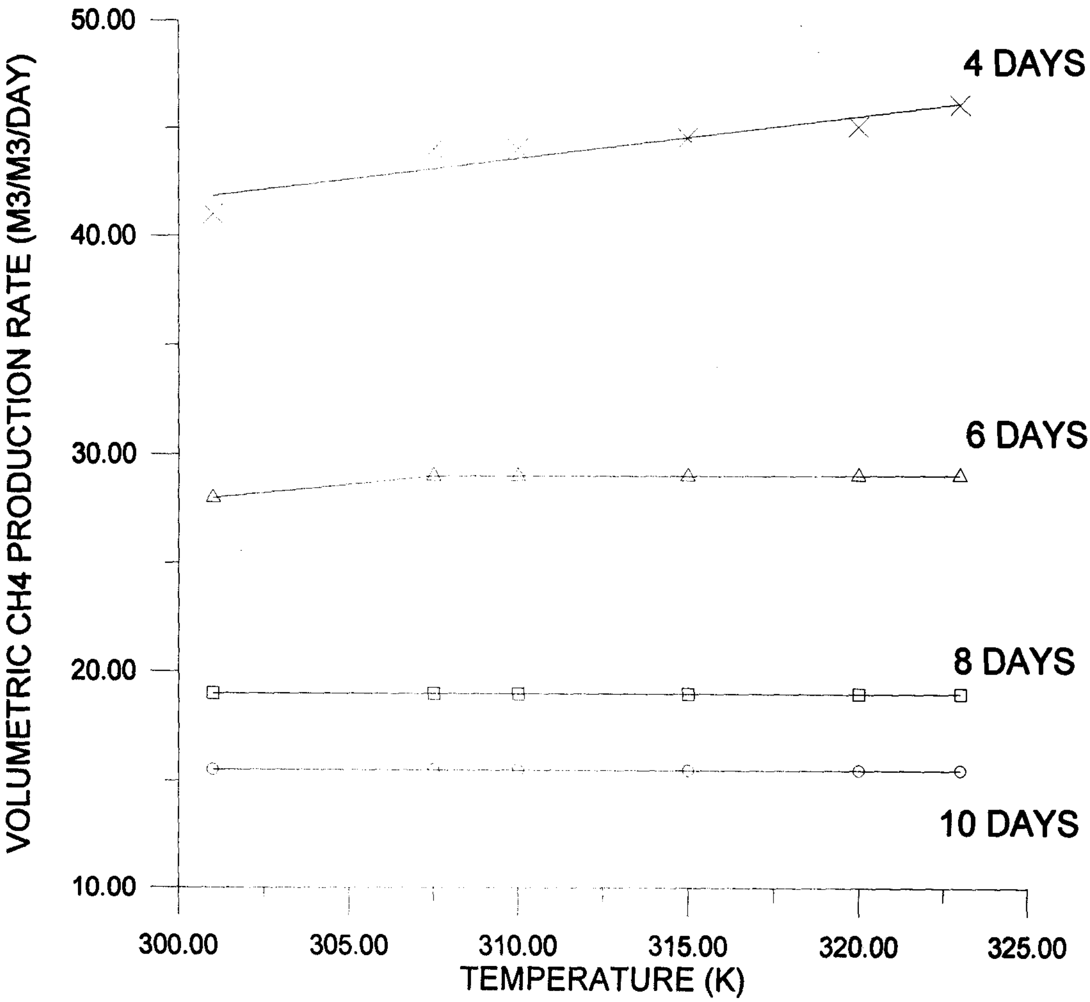


Figure No.8.1.2 Variation of volumetric Methane Production Rate Vs. temperature.

Slurry concentration: 6% solid by weight

Particle size: 1.10 x 10^{-3} m

8.2 SEMI- BATCH DIGESTION

8.2.1.Variation of Slurry concentration with Gas Yield

Several experiments have carried out for anaerobic semi-batch digestion using kitchen waste and the experimental data are shown in Figure no.8.2.1

8.2.2. Effect of concentration on Bio-digestion

Experimental data shows the effect of slurry concentration on production of methane also yields of biogas are shown in appendix A, in Table A-1, A-2, A-3, A-4, A-5, and A-6. The variation of biogas and methane yield with slurry concentration at digestion temperature 303 K, and retention time 12 days using particle size of 1,10X10 $^{-3}$ m controlling pH at 6.9 have been shown in Table no. 8.2.1 and the concentration has been plotted against gas yield in Figure no. 8.2.1 It has been found that there is certain limit of concentration of slurry to be maintained after which rate of production of methane and total yield of biogas would decrease. It is also found from the graph that total yield of gas is enhanced up to 6% slurry concentration keeping the temperature and particle size constant as 303K and 1.10X10^{-3} m respectively.

Table No. 8.2.1

Concentration %Solid by Wt	Biogas Yield /Unit Digester Vol./Unit Time ($m^3/m^3/day$)	Methane Yield /Unit DigesterVol/ Unit Time ($m^3/m^3/day$)
3	0.185	0.111
4	0.191	0.123
5	0.623	0.410
6	0.745	0.499
7	0.250	0.142
8	0.191	0.130

It has been also found that rate of increase of methane concentration in biogas produced has been found to be remarkable when slurry concentration is between 5 and 6%. Further increase of concentration decreases methane concentration in biogas. But for higher concentration digester volume decreases, and, therefore, capital cost would be less. Therefore, optimum slurry concentration should be ascertained for economy of the digestion process.

8.2.3 Effect of Particle Size on gas Yield

Several experiments have been performed in order to obtain the particle size (d_{pmean}) as 1.80 $\times 10^{-3}$, 1.50 $\times 10^{-3}$, 1.10 $\times 10^{-3}$,and 7.5 $\times 10^{-4}$ m. for a constant temperature and concentration 303 K and 6% solid by wt. respectively. The biogas yield and methane yield for different particle size for constant temperature and concentration are tabulated as given in the Appendix –A in Table A-7, A-8, A-9, and A-10. The variation of biogas yield with retention time for different sized particle are shown in the figure no. 8.2.3. It has been observed that for a constant retention time biogas yield generally increased as particle size decreased, when temperature and concentration remain unchanged. The total cumulative biogas yield with different particle size is tabulated as given in Table no.8.2.3 and total cumulative biogas yield against particle size has been plotted in figure no. 8.2.3.

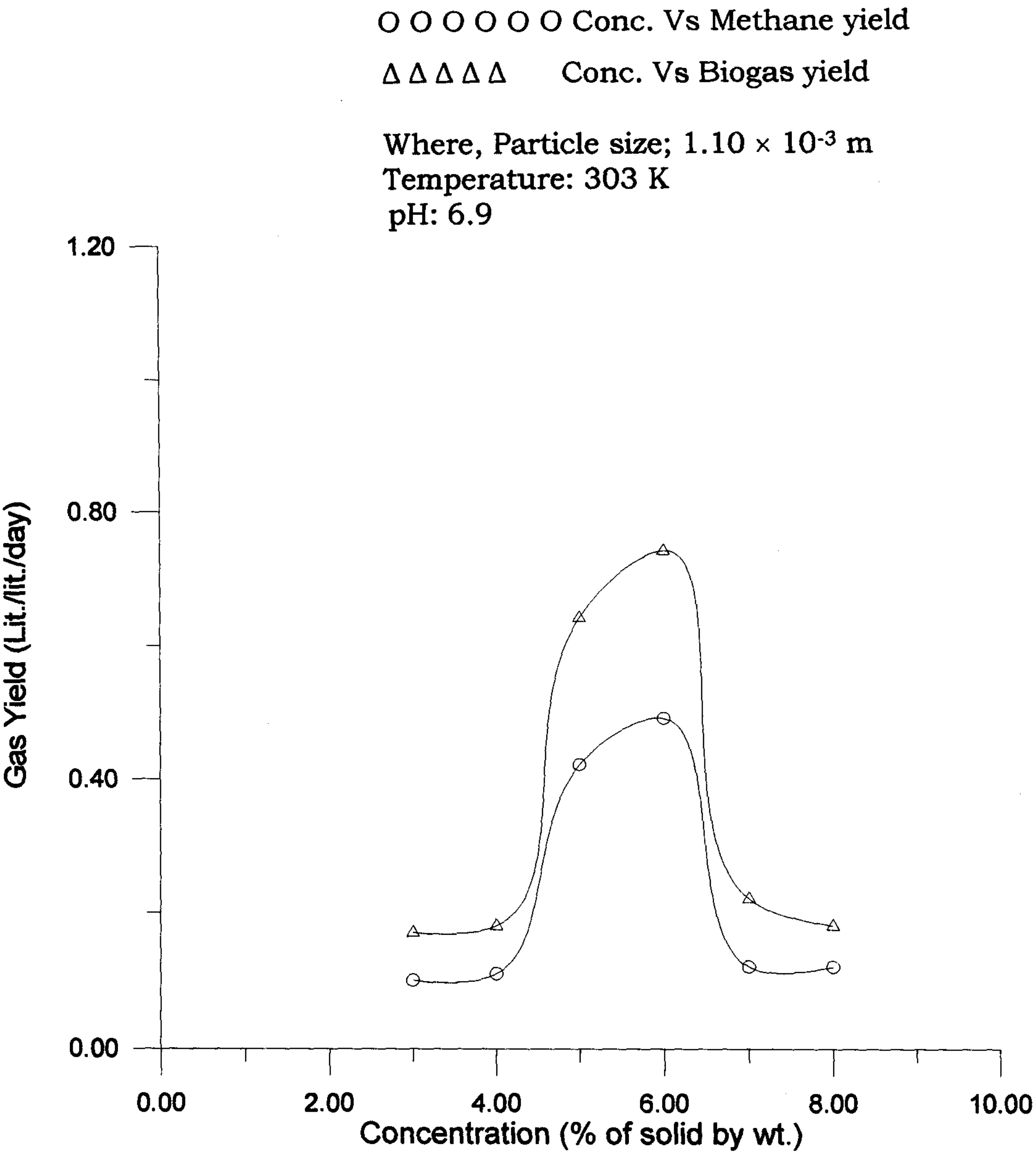


Figure No. 8.2.1 Variation of biogas yield and methane yield with different slurry coneentration for semi-batch digestion.

Table 8.2.3

Particle Size (metre)	Biogas Yield/Unit Digester Vol./Unit Time ($m^3/m^3/day$)	Methane Yield/Unit Digester Vol./Unit Time ($m^3/m^3/day$)	Methane Yield (%)
1.80×10^{-3}	0.083	0.053	63.40
1.50×10^{-3}	0.289	0.189	65.39
1.10×10^{-3}	0.752	0.509	67.69
7.50×10^{-4}	0.801	0.572	71.41

It has been observed that there is a great role of particle size on production of methane, and it is found that gas production increased considerably for smaller particle size containing higher percentage of methane. Total yield of biogas increased considerably for smaller particle size at the same temperature and it is found to be more than double for particle size 1.10 x10-3 m to that for particle size 1.50 x10-3 m at 303 K as might be predicted from the figure 8.2.3.1. After analysis the generated biogas showed that it contain methane 67% to 70% and the rest is carbon dioxide. Methane, therefore, decreased considerably with the increase of particle size as might be observed from the above stated figures for same concentration of slurry of 6% solid by weight. There is a dropping in biogas and methane production beyond the particle size of 1.10 $x10^{-3}$ m, which reflects that larger particles offer hindrance to bacterial growth and as a result causing resistance to bacterial growth.

O O O O O O for particle size : 1.80×10^{-3} m
□ □ □ □ □ □ for particle size: 1.10×10^{-3} m
Δ Δ Δ Δ Δ for particle size: 1.50×10^{-3} m
+ + + + + + + for particle size: 7.50×10^{-4} m

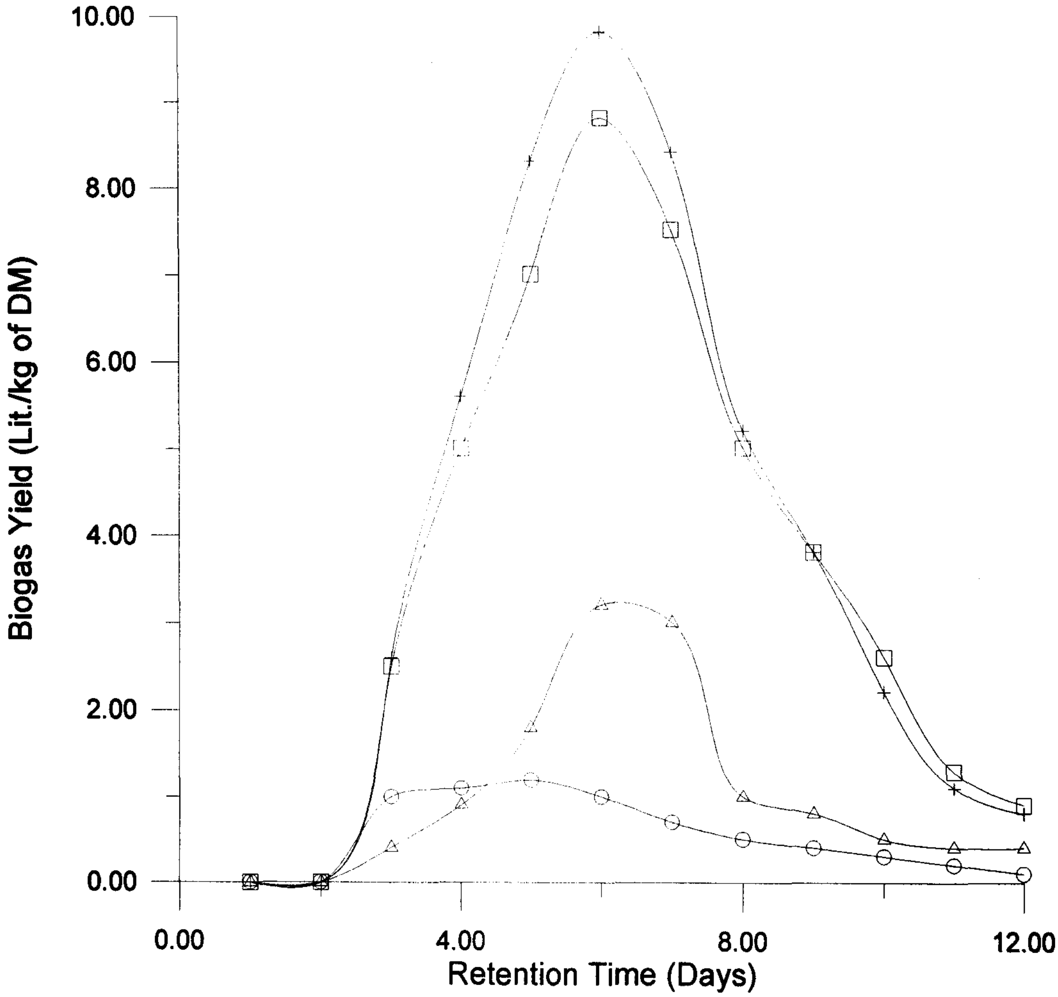


Figure No. 8.2.3 Biogas yield Vs Retention time (Days)

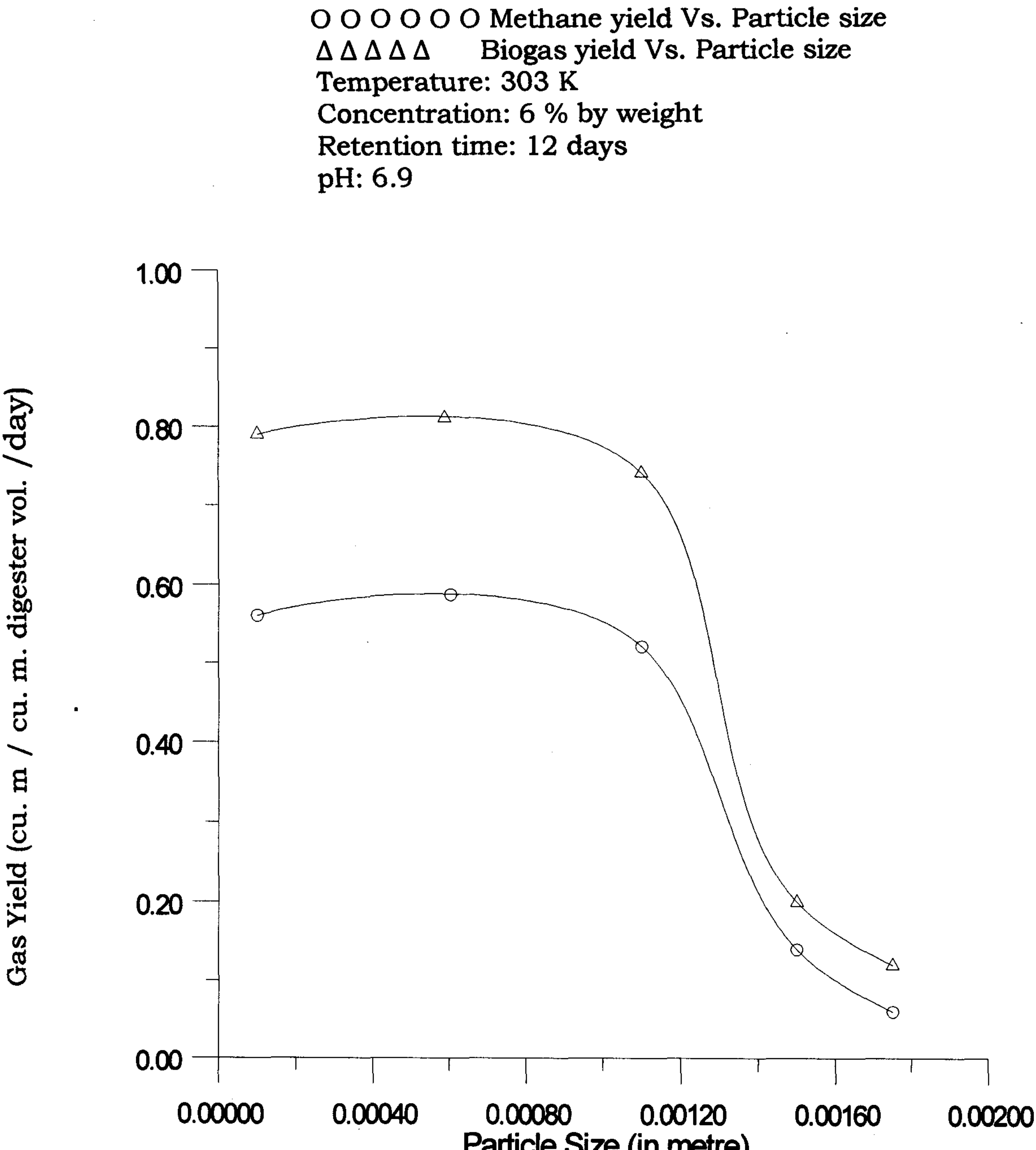


Figure No. 8.2.3.1 Variation of gas yield with particle size

8.2.4 Effect of Temperature on Biogas Yield

Biogas yield with the variation of temperatures several experiments have been carried out at eight different temperatures ranging from 293 K to 328 K and the variation of biogas yield with the temperature have been tabulated as shown in the Appendix-A as Table A-11, A-12, A-13, A-14, A-15, A-16, A-17 and A-18.Generated biogas with retention time for different temperatures at constant particle size, concentration and retention time are shown in the figure: 8.2.4. It has been observed that the temperature of digestion has predominant effect on production of biogas. Figures 8.2.4 show that yield of biogas and production of methane gradually increased with increase of slurry concentration of 6% solid by weight and particle size 1.10 $\times 10^{-3}$ metre. The total gas yield as well as methane production at 313 K are approximately 9.5 times to those at 293 K at the same slurry concentration of 6% solid by weight and particle size of 1.10 $\times 10^{-3}$ m. for retention time of 12 days as may be observed from the figure 8.2.4

The experimental values of yield of biogas, methane and carbon dioxide and also maximum methane yield in 12 days retention period at temperature 293K, 298 K, 303 K, 308 K, 311 K, 318 K, 323 K and 328 K have been tabulated as given in Table 8.2.4, and the variation of yield of biogas, methane and carbon dioxide with different temperatures are shown in the figure 8.2.4 for slurry concentration of 6% solid by wt. and particle size 1.10 $\times 10^{-3}$ m. It has been observed from Figure 8.2.4, that total gas yield as well as methane production increased to a maximum value at temperature 311 K for constant concentration, retention time and particle size. But further increase of temperature has led to gradual decrease in gas yield showing that there is decay in bacterial growth beyond the temperature 311 K. It has also been observed from table 8.2.4 that the total methane yield is maximum at digestion temperature of 311 K, which is about 85% of the ultimate methane yield. It, therefore, reveals that microbial growth due to methanogenic bacteria is greatly favored up to temperature of 311 K being maximum at 311 K for 6% slurry concentration and particle size of 1.10 $X10^{-3}$ m.

Table No. 8.2.4

Temp. (K)	Biogas Yield/Unit Digester Vol. /Unit Time (m^3/m^3/day)	CH_4Yield/ Unit Digester Vol/Unit Time (m^3/m^3/ day)	Methane Yield (%)	CO_2Yield/ Unit Digester Vol/Unit Time (m^3/m^3/day	CO_2 Yield (%)
293	0.184	0.112	60.87	0.07	38.04
298	0.192	0.116	60.42	0.075	39.06
303	0.740	0.470	63.51	0.265	35.81
308	1.60	1.02	63.75	0.56	35.0
311	1.72	1.12	65.11	0.58	33.72
318	1.65	1.10	66.67	0.53	32.12
323	1.05	0.65	61.90	0.40	38.09
328	0.95	0.55	57.89	0.38	40.0

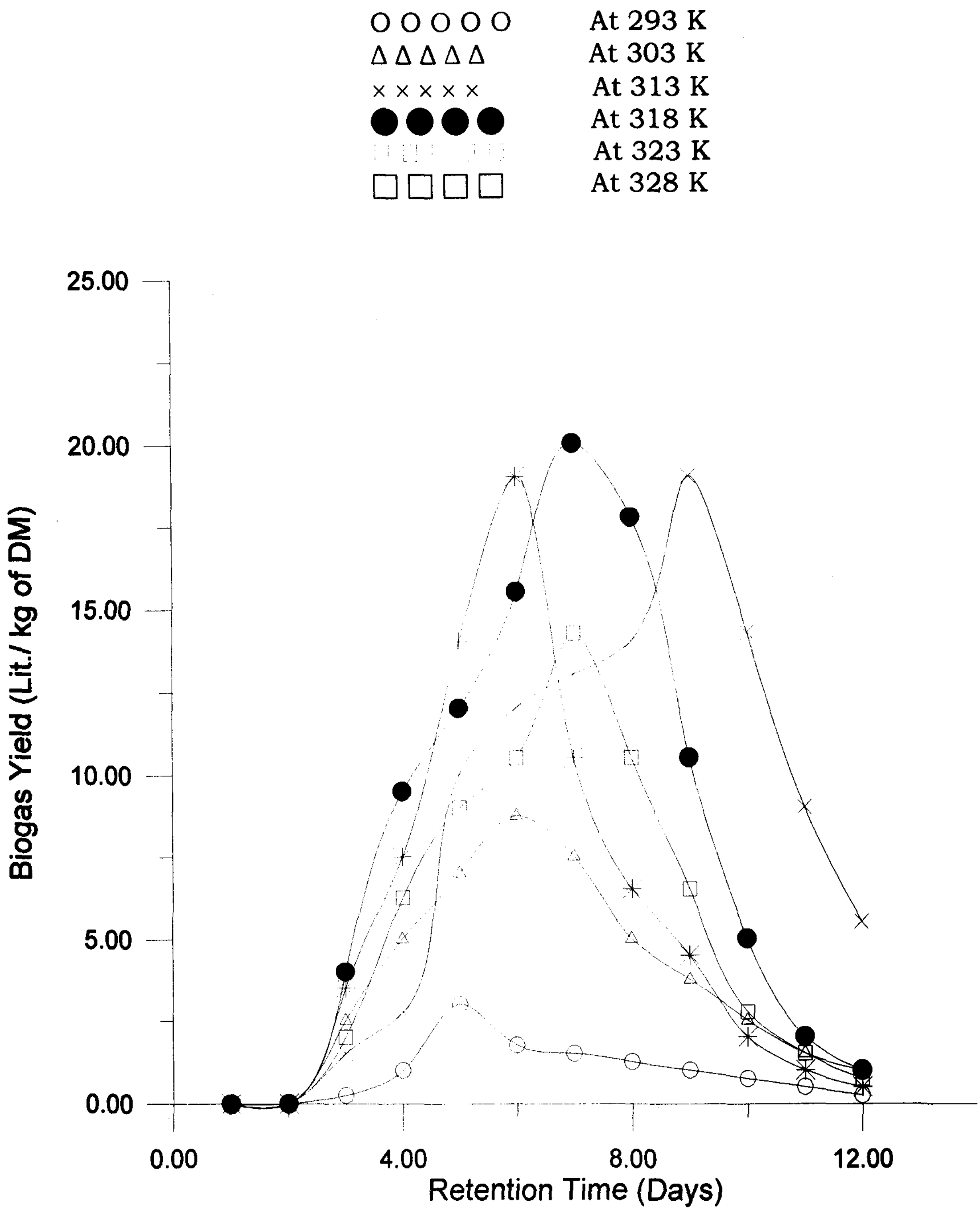


Figure No. 8.2.4 Gas yield versus retention time

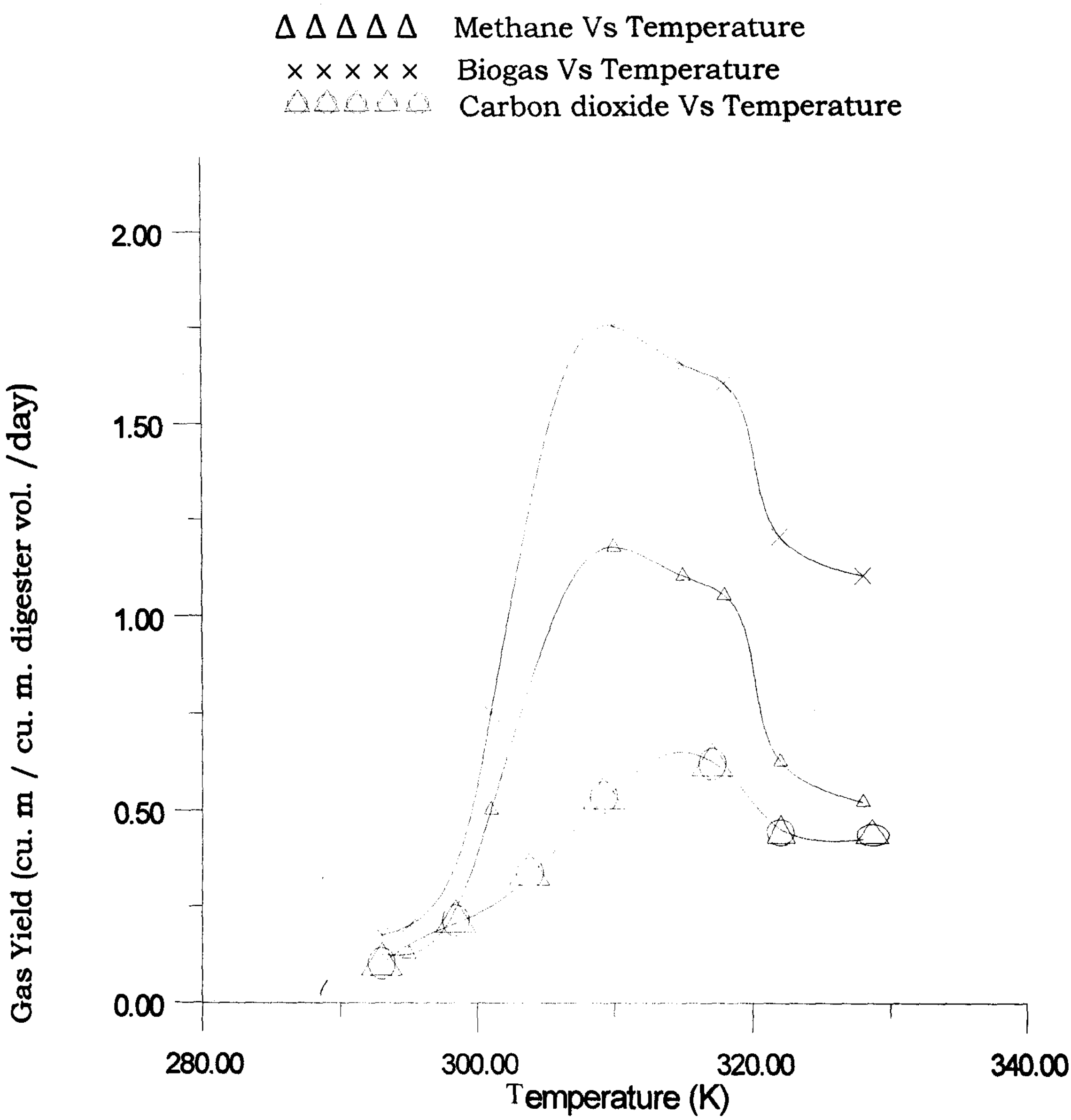


Figure No. 8.2.5 Gas yield Versus Temperature

CHAPTER -9

CONCLUSION

Chapter - 9

CONCLUSIONS

The present study provides information regarding fruitful utilization of kitchen waste adopting anaerobic digestion both continuous and semi–batch process for the production of biogas, which has great potential of energy and also about useful byproducts, obtained from the process of biomethanation.

It has been observed that the huge quantity of house hold refuses have enormous energy potential which may be used for cooking and heating purposes. The same is true for market waste also. Thus by recycling these waste, pollution hazards will be minimized and eco-friendly environment will be obtained.

For a very efficient biomethanation process parameters like pH, temperature, particle size, concentration ratio, etc, needs to be monitored and controlled.

During experiment, it has been observed that at the beginning of the digestion period, the pH value decreased to 2.90 and 3.15 for mixed kitchen waste (cooked) and food waste respectively as shown in the fig.no.8 (a) and fig. no. 8 (b) but after a few days pH value attains near neutral value of 7.

The study shows that continuous digestion process has many advantages giving better performance at lower temperature, which gives rise to more yield of methane at lower digestion temperature as compared to that for semi-batch process. It is observed that lower concentration of slurry and lower particle size enhances the biomethanation reaction. Moreover, vegetable wastes having low lignin content are easily biodegradable leading to higher net gas yield.

This study showed that two stage process provide biological stability by keeping the acidogenesis and methanogenesis phase separately and thus allowing higher organic loading rate without shock to methanogenic bacteria. Two- stage digestion system would be right for developing countries like India as it is easy to operate and also facilitates better maintenance as compared to multi -stage digestion system.

It has been further observed that maximum yield of methane in continuous process is more as compared to semi-batch process. For optimum gas yield, loading rate, retention time, C/N ratio, toxicity and agitation of slurry inside the digester needs to be controlled.

Proper design of system for scum breaking, auto control of pH and maintaining solid –liquid ratio are very essential to obtain biogas continuously. The quality of biogas can be improved by removal of carbon dioxide, hydrogen sulfide, water vapour following various methods and the same can be used as auto fuel also.

As the digester is the heart of the biogas generation system proper emphasis on the design of the digester is of paramount importance and deserves due consideration so that optimum gas yield is ensured. It also reveals that gas yield mostly is dependent on the type of biomass rather than processes.

The digester has been designed in such a way that the slurry can be stirred periodically with the help of a motorized stirrer fitted from the top of the lid and the flap fitted with the shaft can helps for scum breaking. The digester is also jacked for circulation of hot water for temperature control.

Design of digester model for continuous digestion and semi-batch digestion process as proposed would produce useful guide for the production of biogas using kitchen waste as feed material.

Further more, attempt has been made to design suitable bioreactors, gasholder, machinery for the preparation of feedstock, separation of water and suspended solids.

Another factor that strongly favours energy recovery from waste is the Kyoto protocol and CDM, as waste processing via this rout is also a means of reducing green house gas and thus helps in reducing global warming.

Women particularly in developing countries like ours will be highly benefited by using biogas for cooking since the working condition in kitchen will be improved. They will face less drudgery in collection of firewood and also cooking in an unhygienic condition, as with the use of biogas- a smoke free environment will be ensured.

The solid left over after biomethanation is rich in nitrogen and also contains some amount of nitrogen(N), phosphorous(P) and potassium(K) making the material a very useful fertilizer for agricultural operation. .

The waste water (used for cleaning and washing the vegetables, fruits, cereals and pulses in the kitchen) containing organic substances should also be recycled back to the mixing tank for further processing.

During the digestion process most of the pathogens in the manure are killed due to operational temperature and long retention period, which helps in maintaining hygienic condition.

The best practicable environmental option is to treat the kitchen waste via biomethanation route. It is clear that the most practicable option is to use the kitchen waste as feedstock for methanogenesis, so that benefits are additional energy, which goes to boost economic development and also preserve the environment. This in fact is a triple benefit scheme i.e., a booster for " Energy, Environment and Economy".

This indicates that the technology transfer is not complete and that it requires coordinated efforts of scientists, and engineers to overcome these limitations in order to translate this "high potential technology into a common place technology" or rather a household technology to enable common men to benefit from this technology. Then only sustainability will be ensured.

Large scale plant and equipment design to handle huge quantity of waste like municipal solid waste, market waste and also sewage should attract the attention of future researcher to enable the society to treat these waste for all round social benefits i.e., preservation of environment and boosting the economy.

CHAPTER -10

REFERENCES

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Appendix-A

Appendix-A

Table A-1: Gas yield / kg. of digested material (D.M) using slurry concentration of 3 % solid

Retention Time (days)	Gas yield (Litre/kg, of D.M)	CH_4 (Litre/kg,of D.M)	CO_2 (Litre/kg,of D.M)
1	0	0	0
2	0	0	0
3	0	0	0
4	0.025	0.012	0.009
6	1.125	0.695	0.410
8	2.250	1.380	0.685
10	4.625	2.895	1.496
11	2.958	2.124	1.045
12	1.995	1.150	0.759

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-2: Gas yield/ kg. of digested material (D.M) using slurry concentration of 4 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0	0	0
4	0.245	0.18	0.065
5	0.45	0.28	0.16
6	0.52	0.32	0.18
7	0.92	0.60	0.30
8	1.15	0.73	0.41
9	1.61	1.12	0.45
10	2.50	1.83	0.65
11	2.20	1.60	0.58
12	1.65	1.09	0.56

Temperature of the slurry = 303 K

Particle Size: 1.10 x10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-3: Gas yield/ kg. of digested material (D.M) using slurry concentration of 5 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.45	1.48	0.95
4	4.72	2.98	1.72
5	6.95	4.58	2.35
6	7.95	5.18	2.75
7	7.35	4.72	2.60
8	5.30	3.61	1.68
9	4.82	3.15	1.65
10	2.85	1.72	1.09
11	1.95	1.10	0.82
12	1.50	0.81	0.665

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-4: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.55	1.82	0.71
4	5.20	3.56	1.60
5	7.10	4.88	2.20
6	8.65	6.05	2.58
7	7.40	4.80	2.55
8	4.58	2.94	1.61
9	3.60	2.35	1.20
10	2.45	1.76	0.65
11	1.10	0.65	0.42
12	0.68	0.48	0.18

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-5: Gas yield/ kg. of digested material (D.M) using slurry concentration of 7% solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0.421	0.258	0.158
4	0.575	0.320	0.250
5	1.020	0.642	0.375
6	1.610	1.045	0.561
7	2.900	1.82	1.050
8	3.450	2.217	1.250
9	1.920	1.170	0.720
10	1.010	0.595	0.350
11	0.938	0.590	0.332
12	0.385	0.248	0.131

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-6: Gas yield/ kg. of digested material (D.M) using slurry concentration of 8 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0.385	0.262	0.120
4	0.610	0.425	0.180
5	1.020	0.725	0.285
6	1.410	1.956	0.450
7	2.250	1.60	0.635
8	2.860	2.01	0.819
9	1.870	1.22	0.610
10	1.100	0.78	0.310
11	0.940	0.63	0.310
12	0.415	0.275	0.140

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A- 7: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	1.10	0.788	0.310
4	1.105	0.76	0.335
5	1.490	0.795	0.352
6	1.150	0.860	0.280
7	0.681	0.45	0.225
8	0.410	0.271	0.132
9	0.185	0.101	0.082
10	0.172	0.110	0.059
11	0.092	0.062	0.029
12	0.077	0.045	0.028

Temperature of the slurry = 303 K

Particle Size: 1.80×10^{-3} m

Ph of the slurry = 6.9

Appendix-A

Table A-8: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0.41	0.28	0.13
4	0.95	0.67	0.26
5	1.89	1.28	0.61
6	3.15	2.00	1.10
7	3.05	2.11	0.92
8	1.10	0.85	0.25
9	0.76	0.48	0.26
10	0.41	0.26	0.15
11	0.17	0.11	0.058
12	0.165	0.105	0.052

Temperature of the slurry = 303 K

Particle Size: 1.50×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-9: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.80	2.11	0.69
4	4.91	2.89	1.99
5	6.87	4.55	2.27
6	8.20	5.40	2.79
7	7.35	4.42	2.90
8	5.25	3.31	1.85
9	3.81	2.50	1.62
10	2.73	1.80	0.91
11	1.70	1.20	0.45
12	0.69	0.38	0.31

Temperature of the slurry = 303 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-10: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.62	1.80	0.81
4	5.72	3.81	1.89
5	8.25	5.71	2.52
6	9.10	6.25	2.81
7	8.61	5.82	2.75
8	5.50	3.65	1.80
9	3.95	2.50	1.44
10	2.18	1.28	0.89
11	1.10	0.60	0.48
12	0.68	0.38	0.30

Temperature of the slurry = 303 K

Particle Size: 7.50×10^{-4} m

pH of the slurry = 6.9

Appendix-A

Table A-11: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0.32	0.20	0.120
4	1.109	0.816	0.291
5	3.10	1.990	1.061
6	1.61	1.08	0.520
7	1.45	0.95	0.460
8	1.15	0.72	0.410
9	1.10	0.77	0.325
10	0.81	0.53	0.274
11	0.41	0.27	0.138
12	0.195	0.125	0.070

Temperature of the slurry = 293 K

Particle Size: 1.10 $\times 10^{-3}$ m

pH of the slurry = 6.9

Appendix-A

Table A-12: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	0.325	0.22	0.099
4	1.320	0.81	0.504
5	3.210	2.05	1.135
6	1.85	1.20	0.620
7	1.50	1.10	0.495
8	1.19	0.78	0.410
9	1.10	0.70	0.385
10	0.845	0.50	0.335
11	0.450	0.261	0.180
12	0.220	0.128	0.085

Temperature of the slurry = 295 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-13: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.51	1.80	0.71
4	4.90	3.30	156
5	6.85	4.70	2.10
6	8.585	6.02	2.525
7	7.20	4.60	2.530
8	4.95	3.25	1.65
9	3.65	2.31	1.285
10	2.45	1.58	0.86
11	1.35	0.85	0.455
12	0.80	0.55	0.250

Temperature of the slurry = 301K

Particle Size: 1.10 $\times 10^{-3}$ m

pH of the slurry = 6.9

Appendix-A

Table A-14: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	1.438	1.958	0.48
4	2.850	1.87	0.98
5	9.55	6.37	3.18
6	10.590	7.02	3.53
7	11.99	8.05	3.90
8	14.10	10.50	4.85
9	17.69	11.84	5.80
10	13.953	9.30	4.59
11	7.95	5.20	2.75
12	5.68	4.98	1.85
13	2.95	0.61	1.20
14	1.52	0.90	0.60

Temperature of the slurry = 311K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-15: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.895	1.73	1.15
4	9.10	5.52	3.51
5	11.85	7.40	4.41
6	14.995	9.60	5.31
7	19.50	13.08	6.42
8	18.65	12.10	6.40
9	10.95	7.00	3.95
10	5.75	3.51	2.20
11	2.62	1.52	1.10
12	1.10	0.60	0.48

Temperature of the slurry = 315K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-16: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	2.995	1.78	1.21
4	9.710	5.795	3.85
5	12.120	7.32	4.76
6	15.420	9.50	5.875
7	20.10	12.85	7.25
8	17.75	11.25	6.416
9	10.45	6.60	3.823
10	5.30	3.35	1.95
11	1.61	0.92	0.655
12	0.885	0.450	0.410

Temperature of the slurry = 318 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-17: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	3.91	2.31	1.55
4	7.725	4.725	2.995
5	13.95	9.00	4.95
6	19.10	12.80	6.21
7	10.40	6.55	3.81
8	6.55	4.02	2.515
9	4.62	2.71	1.90
10	2.41	1.40	0.995
11	1.01	0.50	0.505
12	0.52	0.251	0.225

Temperature of the slurry = 323 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9

Appendix-A

Table A-18: Gas yield/ kg. of digested material (D.M) using slurry concentration of 6 % solid

Retention Time (days)	Gas Yield (Litre/kg.ofD.M)	CH_4 (Litre/kg.ofD.M)	CO_2 (Litre/kg.ofD.M)
1	0	0	0
2	0	0	0
3	1.95	1.15	0.805
4	6.005	3.80	2.195
5	7.95	4.85	3.10
6	9.95	6.15	3.791
7	13.98	8.85	5.105
8	11.502	7.495	4.005
9	6.25	3.625	2.610
10	2.455	1.44	1.01
11	1.001	0.520	0.425
12	0.840	0.460	0.371

Temperature of the slurry = 328 K

Particle Size: 1.10×10^{-3} m

pH of the slurry = 6.9