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Potential of Biogas Power Plant Produced by Anaerobic Digestion of Biodegradable Materials

Biogas typically refers to a gas produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source, like solar and wind energy. Furthermore, biogas can be produced from regionally available raw materials and recycled waste and is environmentally friendly and CO2 neutral. Biogas is produced by the anaerobic digestion or fermentation of biodegradable materials such as manure, sewage, municipal waste, green waste, plant material, and crops. Biogas comprises primarily methane (CH4) and carbon dioxide (CO2) and may have small amounts of hydrogen sulphide (H2S), moisture and siloxanes. The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be compressed, much like natural gas, and used to power motor vehicles. Biogas is a renewable fuel so it qualifies for renewable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane. This paper will discuss the potential of biogas in order to provide a clean, easily controlled source of renewable energy from organic waste materials for a small labour input, replacing firewood or fossil fuels which are becoming more expensive as supply falls behind demand.

Keywords: *biogas, anaerobic digestion, waste management, anaerobic digestion, sewage, municipal waste,*

1. Introduction

Biogas can provide a clean, easily controlled source of renewable energy from organic waste materials for a small labor input, replacing firewood or fossil fuels which are becoming more expensive as supply falls behind demand. During the conversion process pathogen levels are reduced and plant nutrients made more readily available, so better crops can be grown while existing resources are conserved [1]. Since small scale units can be relatively simple to build and operate biogas should be used directly if possible for cooking, heating, lighting and absorption refrigeration, since both electricity generation and compression of gas for storage or use in vehicles use large amounts of energy for a small output of useful energy. This concept is suited to distributed systems where waste is treated near the source, and sludge is also reused locally, to minimize transport and initial capital cost compared to a centralized system. As the distributed system will need a support network biogas contributes to the triple bottom line, benefiting the environment, reducing costs and contributing to the social structure [1].

A biogas production system must be specially designed and requires regular attention by someone familiar with the needs and operation of the digester. Associated manure handling equipment and gas utilization components are also required. The digester does not remove significant nutrients and requires environmentally responsible manure storage and handling system. A well designed and operated digester will require modest daily attention and maintenance. The care and feeding of a digester is not unlike feeding a cow or a pig, it responds best to consistent feeding and the appropriate environmental for temperature and anaerobic- oxygen free conditions [2]. The earlier a problem in operation is identified the easier it is to fix and still maintain productivity.

Biogas generation is a chemical process whereby organic matter is decomposed. Slurry of cow dung and other similar feedstock is retained in the biogas plant for a period of time called the hydraulic retention time (HRT) of the plant. When organic matter like animal dung, human excreta, leafy plant materials, etc. are digested an aerobically (in the absence of oxygen), a highly combustible mixture of gases comprising 60% methane (CH_4) and 37% carbon dioxide (CO_2) with traces of sulphur dioxide and 3% Hydrogen (H_2) is produced. A batch of 25 kg of cow dung digested an aerobically for 40 days produces 1 cubic meter of biogas with a calorific value of calorific value of 5125 kcal/m3. The remaining slurry coming out of the plant is rich in manure value and useful for farming purposes [2].

Biogas production using anaerobic digestion which is oxygen free is a biological treatment process to reduce odour, produce energy and improve the storage and handling characteristics of manure. Anaerobic digestion is a series of processes in which micro-organisms break down biodegradable material in the absence of oxygen to produce a methane rich biogas. Anaerobic Digestion can be used to treat organic farm, industrial and domestic waste. The anaerobic digestion process produces biogas, usually around 60% methane, 40% Carbon dioxide. This biogas can be used to generate heat and electricity via a CHP engine, used directly in a biogas boiler, or cleaned and compressed for injection into the local gas grid or use as a vehicle fuel [3]. Anaerobic digestion is widely in the waste water industry, and is common in Europe treating farm, municipal and commercial waste. It is used as a renewable energy source because biogas can offset fossil fuel use. The nutrient-rich digestive which is also produced is a valuable fertiliser and can replace the use of chemical fertilisers. The anaerobic digestion process happens in four stages as been shown in Figure 1 as follows:

1) Hydrolysis, in which enzymes secreted by hydrolytic bacteria break down organic polymers (proteins, carbohydrates) into their monomer components (amino acids, sugars)
2) Acidogenesis, in which acidogenic bacteria break down the amino acids and sugars into volatile fatty acids (VFAs) and alcohols
3) Acetogenesis, in which acetogenic bacteria convert the VFAs into acetic (and propionic) acid and some CO2 is liberated and
4) Methanogenesis, in which the acetic acids are converted to methane and CO2 by methanogenic bacteria

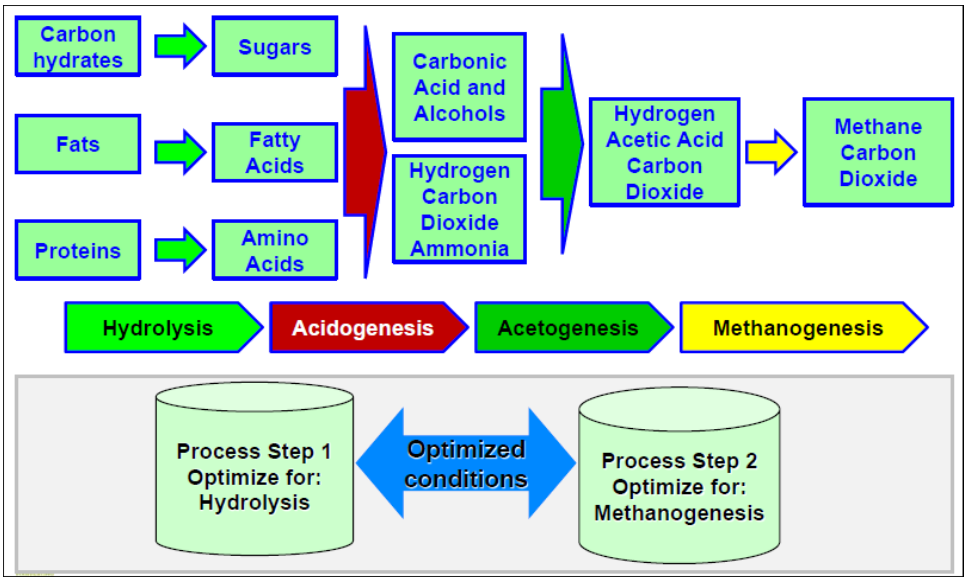

Figure 1. Anaerobic digestion process

The advantages of biogas are use as a renewable fuel, no additional greenhouse gas emissions (it removes and then releases the same amount of carbon dioxide) where biogas plants significantly lower the greenhouse effects on the earth's atmosphere and the plants lower methane emissions by entrapping the harmful gas and using it as fuel, waste is disposed of at the same time and in the same operation, consumes methane that might otherwise leak into the atmosphere and increase the greenhouse effect, visible improvement in rural hygiene where biogas contributes positively to rural health conditions [3]. Biogas plants lower the incidence of respiratory diseases. Diseases like asthma, lung problems, and eye infections have considerably decreased in the same area when compared to the pre-biogas plant times. Biogas plants also kill pathogens like cholera, dysentery, typhoid, and paratyphoid and the lastly biogas can also be used on a small scale, for example a pig farm. The disadvantages of biogas are the loss of the organic waste for compost or fertiliser, very limited in the quantity of electricity it can produce on the global scale and there is little or no control on the rate of gas production, although the gas can to some extent be stored and used as required.

Solar energy is the energy that we get from the sun, as a result of nuclear fission reactions going on inside it. This energy is in the form of heat and light. Solar Energy is essential for a majority of living organisms on earth to survive. The plants, animals, certain micro-organisms, all survive due to the solar energy or by consuming substances which require solar energy to evolve. Not only does it affect living organisms, but also non-living things. For instance, many phenomena in nature like the wind, storms, rains, and sea waves are all dependent on this form of energy. Having realized the true potential of solar energy and its importance, humans are now devising methods to utilize solar energy in our daily lives since it is a major source of renewable energy and in the fact that makes it all the more valuable [4]. Some well-known solar energy utilizing devices are solar cooker, water heater, solar cells which can be used in multiple devices. To make it mandatory to utilize this source of energy to the maximum, many countries have set norms for building green buildings. These are energy efficient and are dependent primarily on solar energy. They also help in cost cutting.

Solar Photovoltaic (SPV) systems utilize semiconductor-based materials which directly convert solar energy into electricity. These semiconductors, called solar cells, produce an electrical charge when exposed to sunlight. Solar cells are assembled together to produce solar modules. A group of solar modules connected together to produce the desired power is called a solar array. The first solar photovoltaic cell was developed in 1950. Very expensive at first, early applications of photovoltaic power systems were mainly for the space program. Terrestrial applications of solar photovoltaic started in late 1970's and were primarily for powering small, portable gadgets like calculators and watches [4]. By the 1980's a number of larger-scale but still niche markets for SPV systems had emerged, mostly for remote power needs such lighting, telecommunications, and pumping.

In spite of its high cost, SPV systems have steadily gained power generation market share due to their ability to produce electricity with no moving parts, no fuel requirements, zero emissions, no noise, and no need for grid connection. The modular nature of SPV, which allows systems to be configured to produce power from Watts to Mega-Watts, gives it a unique advantage over other technologies. An SPV system typically consists of an array of solar cells, power conditioning and/or controlling device such as inverter or regulator, an electricity storage device such as battery (except in grid applications), and support structure and cabling connecting the power system to either the load or the grid. Figure 2 shows the arrangement of Solar Photovoltaic (SPV) system [5].

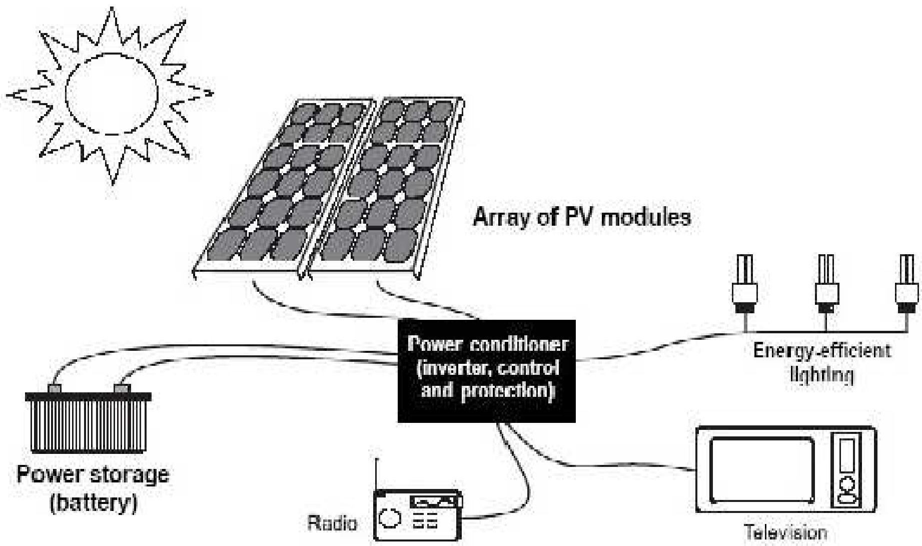

Figure 2. Typical Solar Photovoltaic (SPV) system arrangement

Solar photovoltaic systems can be classified according to three principal applications:

1. Stand alone solar devices purpose-built for a particular end use, such as solar HF radios, solar home lighting systems, or solar coolers. These dedicated SPV systems can either be configured to include some energy storage capacity or directly power electrical or mechanical loads, such as pumping or refrigeration.
2. Stand alone solar power plants, basically small power plants designed to provide electricity from a centralized solar photovoltaic power plant to a small locality like village or a building.
3. Grid connected SPV power plants, which are equivalent to any other generator supplying power to the electricity grid.

The advantages of solar energy are it is one of the most readily available sources of energy, it is an inexhaustible source of energy, it is an uninterrupted and continuous source, solar Energy does not give rise to any chemical or sound pollution, it can be used directly for baking, drying where devices like solar heater facilitate its use, solar devices can be installed in remote, inaccessible areas like forests, deserts, mountains, off-shore platforms, remote oceanic islands, it is possible to produce Solar Energy in large quantities, poor tropical countries have locations which are advantageous for solar energy production, more the number of solar units we have, the more units of energy will be produced [5]. It is directly proportional, it can be used directly in conjunction with other conventional or non-conventional energy supply systems and the cost of maintenance is low.

The disadvantages of Solar Energy are solar energy is mostly available in tropical and sub-tropical areas. The region with maximum solar energy potential is lying between 50 degrees north and south of equator. As we move towards poles, proportion of solar energy received by earth goes on decreasing, it is seasonal in nature and cannot be utilized during monsoon or when weather is cloudy, the solar power technology is still at infant stage and is quite expensive, cost of installation of solar energy plant is very high, during night it is not possible to produce Solar Energy, storage of this form of energy is difficult, at present heavy machines are not possible to operate on this source, solar panels consume land, as power generation per unit square is low, silicon, used in production of SPV (Solar Photo Voltaic), is a pollutant and return of Investment(ROI)on solar energy takes around 3-5 years [5].

2. Biogas production by anaerobic digestion

Anaerobic digestion is a series of processes in which micro-organisms break down biodegradable material in the absence of oxygen to produce a methane rich biogas. Anaerobic Digestion can be used to treat organic farm, industrial and domestic waste. The anaerobic digestion process produces biogas, usually around 60% methane, 40% Carbon dioxide. This biogas can be used to generate heat and electricity via a CHP engine, used directly in a biogas boiler, or cleaned and compressed for injection into the local gas grid. Anaerobic digestion is widely in the waste water industry, and is common in Europe treating farm, municipal and commercial waste. It is used as a renewable energy source because biogas can offset fossil fuel use [6]. The nutrient-rich digestate which is also produced is a valuable fertiliser and can replace the use of chemical fertilisers. The market in the UK lags behind other countries where financial incentives have been in place for a while. Similar incentives have recently been introduced into the UK and the market is now slowly taking off. These incentives include Renewable Obligation Certificates (ROC's), Feed in Tariff (FiT) and the Renewable Heat Incentive (RHI) The anaerobic digestion process happens in four stages which are Hydrolysis, in which enzymes secreted by hydrolytic bacteria break down organic polymers (proteins, carbohydrates) into their monomer components (amino acids, sugars etc) Acidogenesis, in which acidogenic bacteria break down the amino acids and sugars into volatile fatty acids (VFAs) and alcohols Acetogenesis, in which acetogenic bacteria convert the VFAs into acetic (and propionic) acid and some CO_2 is liberated Methanogenesis, in which the acetic acids are converted to methane and CO_2 by methanogenic bacteria or use as a vehicle fuel [6].

Anaerobic digestion treatments have often been used for biological stabilization of solid wastes. These treatment processes generate biogas which can be used as a renewable energy sources. Recently, anaerobic digestion of solid wastes has attracted more interest because of current environmental problems, most especially those concerned with global warming. Thus, laboratory-scale research on this area has increased significantly. In this review paper, the summary of the most recent research activities covering production of biogas from solid wastes according to its origin via various anaerobic technologies was presented [6].

Anaerobic digestion is a biological method used to convert organic wastes into a stable product for land application with reduced environmental impacts [7]. The biogas produced can be used as an alternative renewable energy source. Dry anaerobic digestion [>15% total solid (TS)] has an advantage over wet digestion (<10% TS) because it allows for the use of a smaller volume of reactor and because it reduces wastewater production. In addition, it produces a fertilizer that is easier to transport. Performance of anaerobic digestion of animal manure switch grass mixture was evaluated under dry (15% TS) and thermophilic conditions (55 °C). Three different mixtures of animal manure (swine, poultry, and dairy) and switch grass were digested using batch-operated 1-L reactors. The swine manure test units showed 52.9% volatile solids (VS) removal during the 62-day trial, while dairy and poultry manure test units showed 9.3% and 20.2%, respectively [7]. Over the 62 day digestion, the swine manure test units yielded the highest amount of methane 0.337 L CH4 /g VS, while the dairy and poultry manure test units showed very poor methane yield 0.028 L CH4/g VS and 0.002 L CH4 /g VS, respectively. Although dairy and poultry manure performed poorly, they may still have high potential as biomass for dry anaerobic digestion if appropriate designs are developed to prevent significant volatile fatty acid (VFA) accumulation and pH drop [7].

Anaerobic digestion is a waste-treatment and renewable-energy technology for wastewater and solid organic waste streams (for example food processing, agricultural, and municipal solid waste) [5]. The system was tested over 10 months with 229 t cannery waste, producing 650 m 3 biogas per ton of volatile solids loaded (53% methane). In addition to operational testing, heat transfer in the reactors was modelled to improve the energy balance for the system. A steady-state model was used to determine heat transfer coefficients at the insulated wall and uninsulated roof and floor, revealing that the majority of heat loss may have occurred through the floor and roof of the reactor. Wind speed, solar gain, radioactive losses and air temperature appreciably influenced heat transfer rate while mixing velocity did not. The transient solution to the model matched reactor temperature over time and total heat demand at the pilot plant. An axisymmetric model was also developed to evaluate spatial temperature distribution in the reactor. In addition to digesting food waste, laboratory experiments were designed to test the anaerobic digestion of sugar beet leaves. Sugar beets are a high-yield feedstock for bioethanol with beneficial agronomic characteristics [7]. The methane potential of sugar beet leaves was determined with and without pretreatments (i.e. sodium hydroxide and water soaking). The pretreatments were found to be moderately beneficial, but digestion without pretreatment consumed 80-85% of the volatile solids with VS-based methane yields of 280-320 mL/g.

Furthermore, process modelling revealed that a digester co-located with a 38 dam 3 /y sugar-beet-to-ethanol fermentation facility could convert 726 t/d wet sugar beet leaves to 824 GJ/d as biogas (50% methane) in four 5,374 m3 reactors drawing 540 kW of electrical power, which could be produced from 14% of the biogas. After heating the digester, there would be 545 GJ/d of additional heat which could provide 55% of the energy required for ethanol production.

3. Production of biogas

Biogas is normally produced by using the excreta of animals as the source material. In most of the countries where biogas is produced, the excreta of the cattle and other farm animals are used. In India cow dung is used for the purpose of making biogas. 20% of the excreta of animals are made up of dust particles that are inorganic in nature. The percentage of the inorganic dust particles is brought down by combining water with the excreta in a 1:1 ratio. The rate of feeding of any biogas manufacturing plant that is based on dung is 3,500 kilograms per day. Under normal circumstances the microbial content of the biogas is maintained by the addition of 2% of the expended slurry of the slurry of the fresh dung. 1% calcium ammonium nitrate of the dung is combined with the slurry in such cases [2]. At times waste of kitchens and excrement of human bodies is used in these processes. The human excreta are supposed to occupy, at the most, 3% of the slurry. The addition of human excreta is crucial in this context as it increases the amount of production of biogas. This is because human excreta have high nitrogen content. The ideal temperature for producing biogas is within 35 to 38 degrees Celsius. If the temperature is lower than that then the production of biogas may go down as well. If the temperature is 15 degree Celsius then it would be impossible to produce any biogas [1].

This is precisely the reason as to why thermal insulation is necessary to produce biogas when it is the winter season or at places where the temperatures are normally lower than the requisite level. The heating of digesters is also pretty important in this regard. The pH of the slurry has to be close to 7. This is pretty much possible provided that cow dung is employed in the form of a substrate. If favourable conditions may be provided then as much as sixty liters of biogas may be produced for one kilogram of cow dung [3]. The digesters that are used for the purpose of production of biogas can be used in mesophilic conditions, which mean a temperature range of 20 to 25 degrees Celsius to 40 to 45 degrees Celsius. The digesters can also be run in thermophilic conditions, where the temperature range is from 50 to 55 degrees Celsius to 60 to 65 degrees Celsius. Both these conditions call for separate species of bacteria. It is thought that the mesophilic operations are more safe and stable than the thermophilic operations that are capable of inactivating the parasites of animals and the various pathogens.

Typical anaerobic digestion, methane accounts for 62–70% (v/v) of the biogas composition [4]. The uncontrolled release of CH4 and CO2 to the atmosphere from the traditional ponding system can cause greenhouse gases (GHG) effect. Recovery of methane gas from anaerobic treatment of POME as a renewable energy represents a more acceptable alternative under the Kyoto Protocol with the objective of reducing the GHG emissions. Anaerobic digestion is a complex multistage process of organic compound degradation to methane and CO2 by the action of numerous anaerobic microorganisms. Generally, anaerobic processes are easily perturbed. Process instability is usually indicated by the accumulation of volatile acids, with a concurrent decrease in methane gas production. Acid forming bacteria displace methanogens, and result in increasing volatile acids concentration and reducing the pH of the system. Various methods for retaining cells in the system have been developed.

COD removal of 96.2% from anaerobic digestion of POME was achieved in an immobilized cell bioreactor at a volumetric loading rate of 10.6 kg COD/m3/day The organic loading rate was increased to 30 kg COD/m3/day with an overall 90% COD reduction by recirculation of the treated palm oil mill effluent in a two-stage up-flow anaerobic sludge blanket (UASB) system [6]. However, the anaerobic digestion for this system was conducted in two separated up flow anaerobic reactors for acidogenesis and methanogenesis, respectively. Zinatizadeh et al. (2006) demonstrated the anaerobic digestion of POME in a laboratory-scale up-flow anaerobic sludge fixed film (UASFF) bioreactor at organic loading rates ranged 0.88–34.73 kg COD/m3/day with a methane production rate between 0.278 and 0.348 m3 CH4/kg COD removed/day [1].

Biogenic methane is produced when specific microorganisms metabolize organic compounds under strict anaerobic conditions. Its presence in the natural environment was first documented in 1776 by Alessandro Volta, who collected "combustible air" from a shallow lake by stirring the bottom with a cane. 1 The same process can potentially occur in any organic-rich, anaerobic environment, such as rice paddies or swamps, or within landfills. Huge quantities of biogenic methane are also produced by microbes in the rumen of cattle and the hindgut of termites. The same microbial process takes place in modern wastewater treatment systems during anaerobic sludge digestion, converting a portion of the solid waste stream into a valuable methane by-product. The production of microbial methane from landfills and anaerobic sludge digesters has been studied in some detail, as there is economic benefit from optimization of methanogenesis [7].

Microbiology of methanogenesis, (Methanogens) is a special class of microorganisms that produce methane gas as the end product of their metabolism. They are the strictest of anaerobes, as they will not grow or produce methane in the presence of oxygen; the redox potential of their environment needs to be less than -300 mV. These organisms use a limited number of simple carbon compounds as substrates, most commonly H2-CO2 and acetate. Other methanogenic substrates include formate, methanol, methylamines, dimethyl sulfide, ethanol and isopropanol thus, for the conversion of complex organic substrates (such as coal) to methane, other microbes known as fermentative and acetogenic bacteria must also be present [6].

4. Advantages and types of biogas digester

The use of biogas for day-to-day activities is something that happens on a large scale worldwide. In countries like China and India the waste produced by large factories and households flats etc is being used to produce biogas. It has also helped to reduce environmental pollution. The production of biogas is an easy method of obtaining combustible fuel required for domestic consumption though the systematic management of waste [8]. The advantages of biogas digester:

i. As a substitute for firewood or LP gas used for cooking. There is no need to use firewood or LP Gas for cooking. (This means you need not cut down trees. The environment will be preserved. There is no need to spend time collecting firewood or to spend money on LP Gas. This means it is good for the pocket too). There is no smoke and there is no soot when cooking. This means it is better for your health.
ii. As a substitute to the traditional oil lamps used to light the household. No need kerosene oil to light the house. This means the money spent on Kerosene is saved. Also, the hazards and dangers of using kerosene are reduced.
iii. If the biogas digester is large it can be used as a substitute for the fuel used to run an engine.
iv. As a method of obtaining fertiliser that can be used instead of chemical fertilisers used for cultivation. In the end will receive a very high quality fertiliser (the advantages of using fertiliser is endless. It especially saves money. Apart from this, as you are producing organic vegetables that do not use chemical fertilisers they can be sold at a higher price).
v. To manage waste, these pollute the air, and transform that waste into something beneficial to the environment.

There are three main types of biogas digesters:

i. The Indian biogas digester

This is a digester with an expandable gas cylinder or dome. As shown in Figure 3, the waste is being sent and collected from drains on either side. The digester is made using bricks and cement. The cylindrical dome is made of metal sheets and moves up and down as it stores and releases the gas [8].

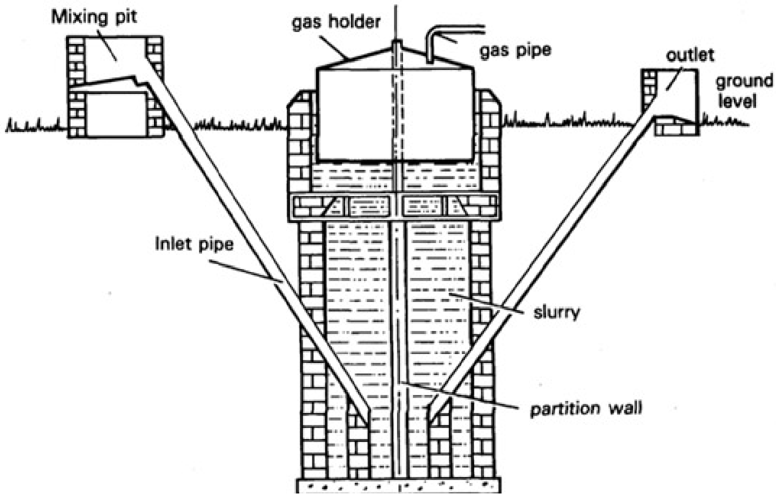

Figure 3. Indian biogas digester with floating gas holder and no water seal [8]

ii. The Chinese biogas digester

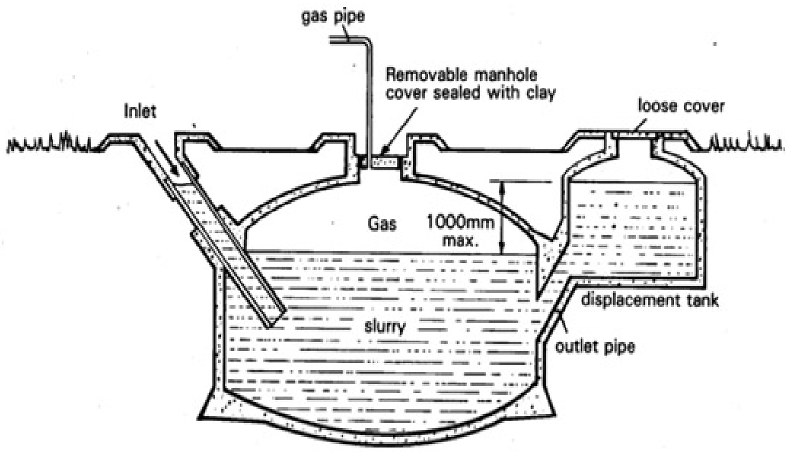

Figure 4. Chinese Dome Biogas disester [8]

The bio digester and the composter are made together using cement and bricks and it is a permanent structure as per shown in Figure 4. The biogas is collected in the upper chamber and the waste decomposes in the lower chamber. Just as in the Indian digester this has two drains to feed waste and to collect the composted waste. In both the Indian and Chinese digesters the waste needs to be put in daily. Therefore the best option is to connect the digester to the cattle shed or pigs sty [8]. Avoid heavy inorganic material such as stones, soil and sand getting into the cylinder (If the above materials get into the digester, they will collect inside the digester and reduce the capacity and therefore reduce the amount of biogas produced).

iii. The Sri Lankan biogas digester

This is a method identified by the Sri Lanka National Engineering and Research Institute. It also won the silver medal at the International New Developers contest held in Geneva, Switzerland, 1996. As shown in Figure 5, the cylinder is made using brick and cement. The cambers used to collect the biogas are made of low-cost 45 gallon barrels, which can be bought from a normal market. As shown in the picture these barrels are kept separately and connected with air pipes [8].

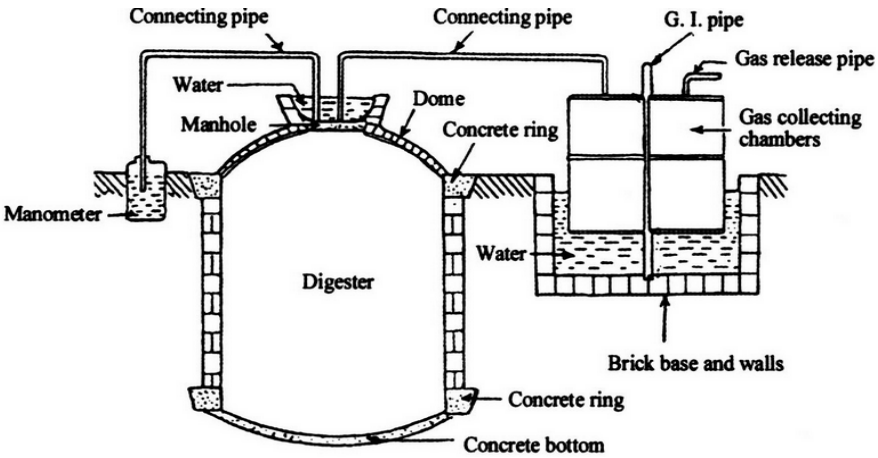

Figure 5. The Sri Lankan biogas digester [8]

The raw material (hay, grass, seaweed, and waste from the markets) is added and waste is collected by removing the cap on the top. The special advantages of the Sri Lankan bio-digester

i. When filled, biogas can be obtained for about five-six months.
ii. Therefore there is no need to add the raw material daily
iii. The main raw material is hay, which is abundant in Sri Lanka and is commonly burnt.
iv. Additionally, waste vegetables from markets (market waste), aquatic plants and other grass can be used. Even some factory waste can be used.
v. The remaining waste is organic manure full of nitrogen.
vi. This is an environmentally friendly method of generating energy and helps in the process of recycling waste that is otherwise a threat to the environment.

5. Conclusion

This paper has presented some important potential of biogas power plant produced by anaerobic digestion of biodegradable materials. Holistically, biogas could offer a clean, easily controlled source of renewable energy from organic waste materials for a small labour input, replacing firewood or fossil fuels which are becoming more expensive as supply falls behind demand. A biogas production system must be specially designed and requires regular attention by someone familiar with the needs and operation of the digester. Associated manure handling equipment and gas utilization components are also required. The digester does not remove significant nutrients and requires environmentally responsible manure storage and handling system. Biogas production using anaerobic digestion which is oxygen free is a biological treatment process to reduce odour, produce energy and improve the storage and handling characteristics of manure. The advantages of biogas are use as a renewable fuel, no additional greenhouse gas emissions where biogas plants significantly lower the greenhouse effects on the earth's atmosphere and the plants lower methane emissions by entrapping the harmful gas and using it as fuel, waste is disposed of at the same time and in the same operation, consumes methane that might otherwise leak into the atmosphere and increase the greenhouse effect, visible improvement in rural hygiene where biogas contributes positively to rural health conditions. Biogas plants lower the incidence of respiratory diseases. Diseases like asthma, lung problems, and eye infections have considerably decreased in the same area when compared to the pre-biogas plant times. The disadvantages of biogas are the loss of the organic waste for compost or fertiliser, very limited in the quantity of electricity it can produce on the global scale and there is little or no control on the rate of gas production, although the gas can to some extent be stored and used as required.

Acknowledgement

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