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دراسة حالة عن توليد الطاقة من النفايات داخل حرم جمعية سينجاد للتعليم التقني، لونافلا، ماهاراشترا

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الملخص

تبحث هذه الدراسة في جدوى استخدام النفايات الصلبة ونفايات الطعام لتوليد الطاقة داخل حرم جمعية سينجاد للتعليم التقني، لونافالا، ماهاراشترا، الهند. وتم إجراء دراسة مستفيضة لتقييم أداء تكنولوجيا تغويز الكتلة الحيوية التي تعتبر نقطة أساسية لتقليل انبعاثات ثاني أكسيد الكربون المرتبطة بتوليد الكهرباء. لم يتم تطوير طاقة الكتلة الحيوية بسبب الحواجز الرئيسية مثل عدم وجود معرفة كاملة حول موارد الكتلة الحيوية، بالإضافة إلى الحواجز الاقتصادية المرتبطة بنقل وتخزين الموارد. توضح هذه الدراسة أيضا الطرق المختلفة لاستخدام الطاقة من موارد الكتلة الحيوية بما في ذلك مزاياها وعيوبها من خلال الموارد المتاحة داخل الحرم الجامعي، والمُتوقع إنتاج 40 كيلو وات في الساعة من الطاقة يومياً، وتعتبر التكنولوجيا الواعدة للتخلص من ظاهرة الاحتباس الحراري عن طريق تقليل انبعاثات جزيئات الكربون.

Case study on power generation from waste on the Sinhgad Technical Education Society (STES) Campus, Lonavala, Maharashtra

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Abstract

Biomass energy has yet to be fully developed due to the major barriers. These include a lack of knowledge concerning biomass resources and economic obstacles associated with transportation and storage. This study examines the viability of harnessing solid waste and food waste for power generation on the STES Campus in Lonavala, Maharashtra, India. The performance of biomass gasification technology is evaluated to understand its ability to reduce CO_2 emissions associated with electricity generation. This study clarifies the various methods of harnessing energy from biomass resources. With the available resources on the Campus, it is estimated that 40kWH of energy can be produced per day. The technology is a promising way to reduced local CO_2 emissions which degrade air quality and contribute to global warming.

Keywords: Anaerobic digestion; biomass; gasification; heating technologies; scrubbing.

1. Introduction

Researchers, planners, and regulatory authorities seek for an alternative high potential sustainable energy system development because of the reduction in fossil fuel reserves and an increasing demand for conventional energy resources. A sustainable energy system can be defined as a cost effective, steadfast and eco-friendly energy framework that successfully and proficiently utilizes naturally available resources. Sustainable energy from geothermal vents, wind action and solar energy are all promising technologies and are currently in use in many countries (Owusu, *et al*., 2016). However, one drawback associated with solar and wind energy is their unpredictable nature and dependence on climatic condition. This variability of renewable sources may be insufficient to instantaneously satisfy power demand in some areas. One of the best alternatives for solar and wind energy is biomass energy. It is estimated that this could possibly meet the current energy crisis (Navarro *et al*., 2010).

Biomass sources include agricultural waste materials, farm animal wastes from fields, slaughter houses, municipal solid waste, sewage sludge, and kitchen and restaurant waste. India is the seventh largest country in the world with an area of 328 million hectares. According to the Annual Report 2018-2019 issued by the Ministry of New and Renewable Energy of India, India has the potential of generating 18,000 MW power from agricultural and agro-industrial residues and about 8000 MW through bagasse cogeneration in sugar mills.

The Indian Institute of Science reports that 300 districts in India have the potential of producing between 10 MW to 100 MW of power from biomass resources (Biomass Resource Atlas (2002-04)). Although the availability of biomass makes it an excellent energy source, its development is delayed because: (i) there are no structured or prescribed biomass marketplaces; (ii) there are complications with biomass collection, transportation, distribution and storage; and (iii) there are no economical sub-megawatt systems for the transformation of biomass to energy in a uniform process. In fact, the price of biomass storage and transportation to power plants is another hindrance (Axaopoulos *et al*., 2001; Borges *et al*., 2010; Bhide *et al*., 2011; Bocci *et al*., 2014; Hajji *et al*., 2014). Hamed *et al.* (2017) identified another issue that can threaten human health, the management of industrial waste and how to solve the problem of lead contamination which comes from petroleum products. Mitigating lead contamination must be done now to ensure safe environments.

Kadiyala, *et al.* (2016) statistically evaluated CO_2 emission from biogas when used as a fuel. They conclude that biogas is a promising solution to reduce CO_2 emissions. This will improve local air quality. On a global scale, it could slow the effects of climate change.

In order to overcome the aforementioned issues, a full-bodied systematized biomass market should be established. Financial investment from venture capitalists and government would provide the capital needed for successful implementation.

This research explores biomass technology for electricity production with available resources on the STES Campus in Lonavala. Recent technological developments in biomass power generation are explained. In Section 2 an overall system block diagram is postulated. Section 3 illustrates the biomass harnessing technology. Section 4 gives the power calculation from biomass. Section 5 describes biogas heating technology, while Section 6 illustrates the purification process. Finally, conclusions are given.

2. Overall Block Diagram

The ultimate objective of the research was to generate electricity from food waste produced on the STES Campus using two phase bio digester system. Food waste was fed into a digester. A two-phase digester system was employed. The first phase involved the acidogenic reactor which maintains low pH, has hydraulic residence time (HRT), and produces hydrogen. In the second phase, a methanogenic reactor was used. This reactor increases the production of methane when compared to the single phase digester. The overall biogas production rate using the two-phase reactor is four times greater than a single-stage.

For this process, first, the food waste was collected and segregated. Non-biodegradable materials like plastics and polythene bags were removed before the waste was fed into the digester. Second, the waste materials underwent a pretreatment process in which they were mixed with water and a chemical solution that aids digestion. Third, through homogenization, large particles present in the waste were broken down into smaller particles, making digestion easier. The food waste was separately mixed and crushed using homogenizers. Next, the waste was fed into a digester for anaerobic digestion. The temperature, pH and various factors affecting the anaerobic digestion occurred in the digester. The produced biogas was further purified and fed into a storage container. The heat produced during this process would kill the pathogens and harmful bacteria inside the digester tank. The biogas consisted of a combination of gases, but methane was measured at 70% of the total. The methane was separated and fed into a gas generator for electricity production. This resulted in eco-friendly, green energy generation. The overall block diagram is illustrated in figure 1. (Daelman, *et al*., 2012)

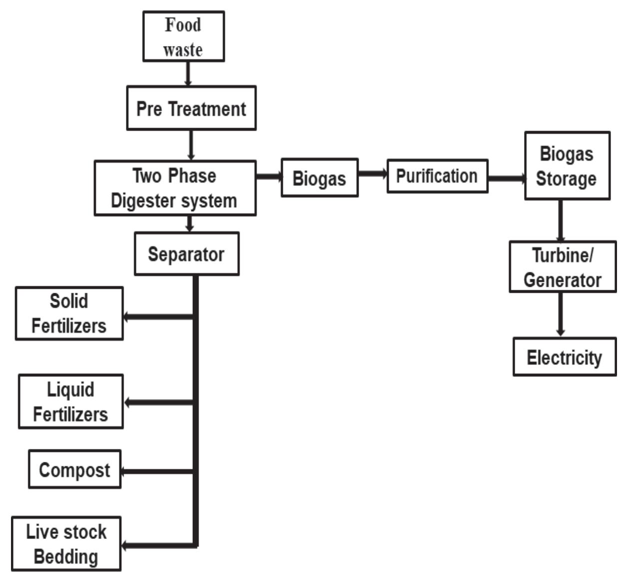

Fig. 1. Overall Block diagram for Electricity production using Bio-waste.

3. Biochemical Process

India is one of the densely populated countries in the world with the total population of about 1,296,834,042. (Central Intelligence Agency, United States of America). Thus, it has a massive quantity of municipal solid waste (MSW) discarded by the public. However, MSW can also refer to food waste. Approximately 115,000 million metric tons of wastes are generated daily (Gupta, *et al*., 2015), which is a major threat to the environment. With the advent of the latest technologies, this waste can be converted into electricity by incorporating an appropriate technique. Bio-chemical technology is a promising choice for converting wet waste to energy (Paritosh, *et al*., 2017). Biochemical conversion is a process in which MSW can be broken down with the help of microorganisms, enzymes and bacteria from its complex form to a simpler gaseous biogas and bio ethanol. The various methods involved in bio-chemical processing technology are: (i) anaerobic digestion and (ii) fermentation.

Anaerobic digestion is the most prominent method for extracting methane, as it is considered the best feasible solution for reducing energy scarcity. One of the major benefits of this method is that heat is produced during digestion. The temperatures are sufficient enough to kill harmful bacteria and pathogens inside the combustion chamber. It also aids the growth of some useful bacteria such as psychrophilic, mesophilic and thermophilic bacteria. (Gumisiriza, *et al*., 2017).

3.1 Anaerobic digestion

The MSW is a mixture of methane, carbon dioxide and some traces of nitrogen, hydrogen, hydrogen sulphide, ammonia and oxygen (Table 1) (Herout, *et al*., 2011).

Using this biogas production method, food wastes are the best resources because anaerobic bacteria are able to grow. These anaerobic bacteria degrade the food waste and convert it into the required biogas resulting in energy production. Anaerobic digestion takes place in following four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. These steps are represented in figure 2. (Holm-Nielsen *et al*., 2009, Jacopo *et al*., 2013, Cunsheng *et al*., 2014; Chunlan *et al*., 2015).

Table 1. Composition of gaseous components in biogas

Sl. No	Components	Composition in Biogas (%)
1	Methane	50-80
2	Carbon dioxide	20-40
3	Nitrogen	0-5
4	Hydrogen	0-1
5	Hydrogen sulfide	0.05-1
6	Ammonia	0.02-0.5
7	Oxygen	0-0.5

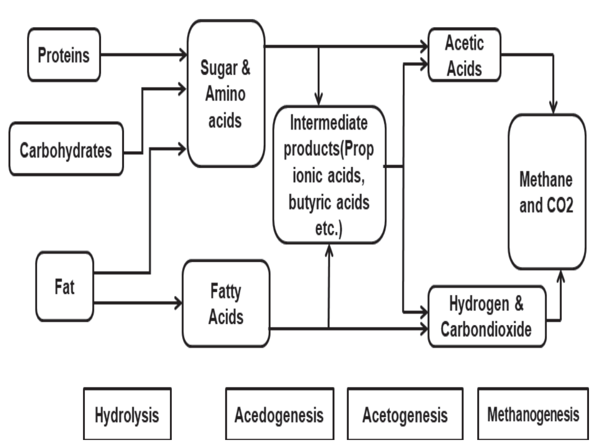

Fig. 2. Steps involved in anaerobic digestion.

3.1.1 Hydrolysis

Hydrolysis is the first stage involved in anaerobic digestion. The wastes that are collected from plants and animals contain carbohydrates, proteins, lipids, fats, and some traces of inorganic matters. The bacteria present in the waste break down these complex substances into simpler substances with the help of extracellular enzymes. During hydrolysis, bacteria convert the proteins and carbohydrates into sugar, amino acids and fats into fatty acids and polysaccharides into monosaccharides. The reaction equations involved in hydrolysis is described as follows:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2 \qquad (1)$$

3.1.2 Acidification

In the second step of anaerobic digestion, acid producing bacteria are involved. These acidogenic bacteria, along with intracellular enzymes, convert the glucose molecules produced during hydrolysis into different acids like acetic acid, butyric acids, propionic acids and ethanol. In order for the bacteria to create anaerobic conditions and to grow faster, these acidic conditions must prevail. These bacteria utilize dissolved oxygen or bounded oxygen to produce acetic acid. Methane-producing microorganisms increase in these anaerobic conditions, which were the result of acid-producing bacteria. Those microorganisms will convert the low molecular-weighted components into alcohols, organic acids, amino acids, carbondioxide, hydrogen sulfide and traces of methane. This includes acedogenesis and acetogenesis stages. The reaction equations can be written as:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \qquad (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \qquad (3)$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \qquad (4)$$

$$CH_3CH_2COO- + 3H_2O \leftrightarrow CH_3COO- + H - + HCO_3 - + 3H_2 \qquad (5)$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \qquad (6)$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO- + 3H_2 + H- \qquad (7)$$

3.1.3 Methanogenesis

The final stage for producing biogas involves the methane-producing bacteria. Compounds with low molecular weights are decomposed. These compounds make use of the available hydrogen, carbondioxide and acetic acid which were produced during the previous step as nutrients. This in turn produces methane and carbondioxide. Some of the common bacteria involved in methanogenesis are non-sporulating methanobacterium, sporulating methanobacterium, and sarcinaea. These bacteria, commonly called archaebacter, are anaerobic and highly sensitive to environmental changes. They differ from other bacteria since they belong to a group of organisms with heterogeneous morphology. The reaction equations for this process are:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (8)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (10)$$

The entire biochemical reaction involved in the above defined steps can be defined by Buswells' equations as follows (Nathan, *et al*., 2012):

$$C_nH_aO_b + (n - a/4 - b/2)H_2O \rightarrow (n/2 - a/8 + b/4)CO_2 + (n/2 - a/8 - b/4)CH_4 \quad (11)$$

4. Calculation of expected output energy from available resources on STES Campus

The amount of solid waste generated per person per day ranges from 0.2 to 0.5 kilogram; hence, an average value of 0.35 kg was considered. The output energy was calculated from the maximum of 40 units of electricity generated per day on the Campus (Nathan *et al*., 2012).

Table 2. Energy calculations with the available resources on the campus

Statistics for STES Lonavala Campus	
No. of people living on site	7000
Amount of wet solid waste generated per day = 7000*0.35	2450 kg
Food waste from restaurants and cafeterias per day	150 kg
Total amount of wet waste per day	2600 kg
Organic biodegradable fraction (33% of waste)	858 kg
Typical digestion efficiency (60%)	514.8 kg
Typical biogas efficiency (E) = 0.8*fraction destroyed	411.84 m^3
Amount of methane extracted from waste per day (60%)	246.73 m^3
12 KVA biogas generator consumption of biogas per hour	62.5 m^3/hr
Operation of generator for available biogas	3.9 hr/day
Generation of electricity per day	40 KWh

5. Biogas Digester Heating Technologies

In order to accomplish the optimal biogas harvest, the anaerobic digestion requires stable environmentally friendly circumstances, if possible adjacent to the optimal procedure. The temperature of the digester is the most important parameter for improving the biogas production. In moderate temperature area, a heater and an insulation of the digester are essential so that we can very well obtain the required temperature. But unfortunately due to higher cost heating systems are not provided in the small-scale biogas plants. It will be more advantageous if the substrate is warmed up by bio-methanation process to its proper process temperature before it is provided in the digester. If possible, cold zones in the digester should be avoided.

Biogas production significantly improves by heating manure in the biogas digester to the mesophilic range. The biogas digester heating equipment was designed to maintain a manure temperature of 40 °C.

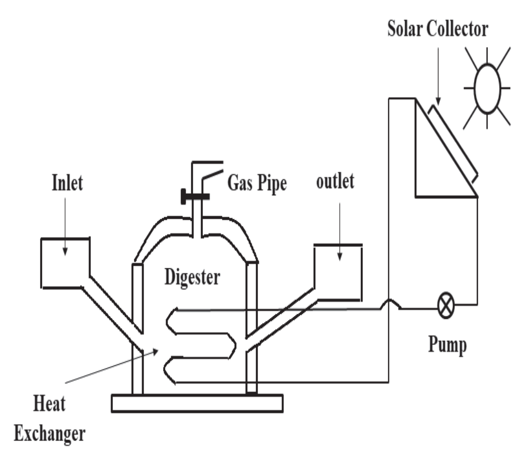

Fig. 3. Bio Digester with solar collectors for Heating.

Figure 3 shows a diagram of the digester. Solar collectors heat the water flowing inside the heat exchanger. With the help of the heat exchanger, the desired temperature is maintained inside the digester for the improved biogas production (Axaopoulos *et al*., 2001; Rong *et al*., 2007)

6. Biogas purification

Water and polyethylene glycol scrubbing CO_2 and H_2S are major components present in biogas and are highly soluble in water when compared to methane. The purification procedure is a completely physical process. In order to initiate the absorption process, biogas is processed under high pressure at the bottom of a packed column. At the same time, water is poured from the top portion (figure 4). H_2S is more easily soluble in water than in carbon dioxide. Thus, water scrubbing can be effectively used for H_2S removal. The water with absorbed CO_2 or H_2S that exits the scrubber column is regenerated and re-circulated for further use in the absorption column. This regeneration can be accomplished by de-pressuring the water or by stripping it with air inside the scrubber column itself. In order to avoid operational problems from elementary sulfur, water stripping is not usually done when there are high levels of H_2S. This is because the water becomes contaminated with elementary sulfur, causing major operational problems. Instead of water, polyethylene glycol can be used to dissolve both CO_2 and H_2S with the help of the same physical scrubbing process. This is because both CO_2 and H_2S are more soluble in this solvent as compared to methane. The commercial name for this solvent is Selexol.

Polyethylene glycol scrubbing is more advantageous than the water scrubbing process since CO_2 and H_2S are more soluble in Selexol. This leads to a lesser solvent demand and moderated pumping. Selexol scrubbing is often associated with recirculation. Stripping of the Selexol solvent is generally accomplished by using steam or an inert gas instead of air. These scrubbing methods are advantageous because they require no distinctive chemicals and can effectively remove both CO_2 and H_2S. The major demerits of water scrubbing include its need for a large quantity of water even after regeneration, and CO_2 decreases the pH of the entire solution, causing the equipment to corrode by H_2S (Chamoli *et al*., 2011).

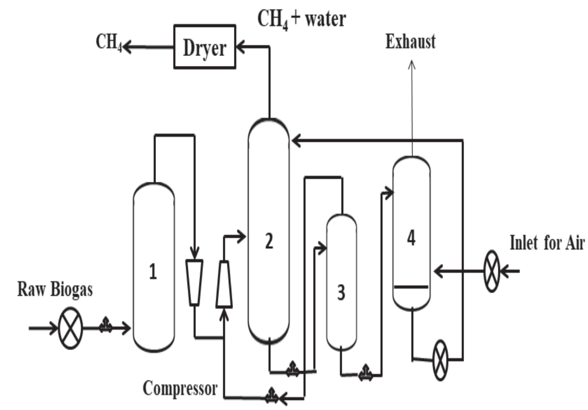

Fig. 4. Set up for Water Scrubbing 1. input separator; 2. scrubber, 3. release tank; and 4. stripper.

7. Conclusions

This study established a sustainable biogas-based power plant on the STES Campus by utilizing available resources. It has been calculated that 40 kWH of energy generation are possible per day. Various technologies involved in optimizing the biogas production by employing solar collector were also explained. These processes can effectively improve biogas production. Based on a review of various methods, the physical scrubbing method is an effective and economical method which increases the efficiency of an entire system. Biogas production is appreciably increased. Apart from its main use of electricity production, it can also be used for cooking, transportation, etc. Methane was produced due to the fermentation of the waste in the digester. Biogas by-products can be used as fertilizers and bio-manures. Therefore, it is proposed to carry out the same work in other campuses also.

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