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Energy Transition: Harnessing Biogas from Municipal and Agro Waste

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Abstract

The article aims to address the energy transition by focusing on the management of municipal solid waste, agro waste and its conversion into energy. Energy transition is the need of the hour due to Global warming. Conventional methods of energy production have to be minimized to prevent the build-up of greenhouse gases, which are driving global climate disruption and causing environmental challenges, including air and water pollution, that threaten our planet and way of life. The severe impacts of climate disruption are already evident, with rising temperatures leading to glacier melt, sea level rise, air pollution, wildfires, heatwaves, and extreme weather events. One of the major contributors to the Build-up of greenhouse gases is Power generation using fossil fuels. That effect is further accelerated by industrial development and urbanization, which lead to increased Power demand at more than 6 to 8 % on a year on year basis in the developing world. To mitigate these effects, it is essential to adopt alternative energy sources such as nuclear, solar, wind, hydro, tidal, geothermal and biogas. Among these, one sustainable approach to energy transition is harnessing biogas from agricultural waste and municipal solid waste through anaerobic digestion, as solid waste will continue to increase year after year especially in urban areas. The approach will significantly reduce the harmful effects of methane emissions from municipal solid waste dumps and also provide bio- fertilizer as an alternative to chemical-based fertilizers.

Key words: Municipal Solid Waste, Agro waste, Anaerobic Digestion, Bioenergy

Introduction

The energy transition to renewable and low-carbon energy sources is essential for addressing greenhouse gas emissions and combating climate change. By shifting to those energy sources, CO_2 and other greenhouse gas (GHG) emissions can be significantly reduced, contributing to climate change mitigation. In addition, diversifying energy sources will reduce reliance on fossil fuels, enhancing energy security. Less dependence on fossil fuels also leads to lower air pollution, resulting in improved public health.

There is a strong push towards a cleaner environment through the energy transition to renewable sources. In India, this transition to alternative energy production is already moving ahead with full momentum, with the aim of reducing fossil fuel consumption, addressing environmental challenges, and combating global warming.

Biogas production is playing a key role in replacing fossil fuels and controlling methane emissions by converting waste into energy and bio fertilizers. Biogas provides a cost-effective clean energy solution with significant potential, derived from abundant organic and agricultural waste. According to the 2020-21 annual report by the Central Pollution Control Board (CPCB), India generates 160,038.9 tonnes of solid waste per day (TPD) [1]. Of that, 50% is treated, 18.4% is landfilled, and 31.6% remains unaccounted for. Over the past five years, waste processing has increased from 19% to 49.96%, while landfilling has decreased from 54% to 18.4%.

India has the potential to produce 32 million tonnes of Compressed Bio Gas (CBG), but currently, only 0.06% of the potential is being realized.

Two primary methods have gained significant attention for converting municipal solid waste (MSW) into useful energy. This is by incinerating MSW in boilers to generate power using a steam-based cycle, and bio-methanization with anaerobic digestion to produce biogas and organic fertilizer. Recently, much more emphasis has been placed on recovering biogas for energy use, as it offers a cost-effective local solution with lower capital costs compared to steam-based power generation technologies. The approach is crucial for managing waste and significantly reducing greenhouse gas emissions, thus playing a vital role in mitigating climate change.

Waste-to-Energy: Turning Solid Waste into Power

Waste-to-Energy (WTE) is a process that converts municipal solid waste into electricity through combustion. The method not only helps to manage waste but also generates energy, providing the dual advantage of waste reduction and green power generation. However, WTE also has its shortcoming, especially air pollution from harmful emissions, high investment, and operational costs.

Compressed Biogas: Harnessing Energy from Organic Waste

Biodegradable organic waste, including agricultural residue, cattle dung, sugarcane press mud, municipal solid waste, poultry litter and sewage treatment plant waste can be converted into biogas through anaerobic decomposition. The biogas is then purified and compressed achieving a methane content of 90-97%, which is a clean and combustible fuel that can substitute compressed natural gas (CNG) during the energy transition, helping to reduce GHG emissions.

Biogas also has various applications - it can be directly burned for heating, utilized in gas engines to produce electricity, or upgraded to biomethane, which can be injected into the natural gas grid or used as vehicle fuel. The use of biogas not only decreases reliance on fossil fuels but also prevents methane emission from the municipal waste dump yard, a gas with a significantly higher global warming potential than carbon dioxide, from being released into the atmosphere.

In addition, CBG plants offer an environmentally friendly solution to crop residue burning, which has a major impact on air quality. The Solid Waste Management (SWM) Rules 2016, issued by India's Ministry of Environment and Forests, address waste management issues by promoting modern technologies like WTE and bio-methanization.

The digestate is converted into Bio-fertilizer and can replace chemical fertilizers to some extent.

Description of Biogas Technology

1. **Characterization of MSW Feedstock**

   A waste characterization study must be conducted to assess the properties of the organic waste for designing the biogas plant. The evaluation will help to determine the bio- methanization potential of the organic waste that would be used as raw material for the plant. Typical Classification of Source Segregated Organic (SSO) Waste as obtained from one of the test results is given below in Table-1.

However, the analysis may change with different locations. The segregation should be done at the source in order to have minimum 85 % organic waste for optimizing the biogas production.

Table 1: Typical fractions of Source Segregated Organic (SSO) Waste

Source Segregated Organic (SSO) Municipal Solid Waste Constituents	
Waste Fractions	Approx. (%)
Food waste including Bone (Organic-1), SSO	87.80
Coconut shell (Organic-2)	0.55
Leaves (dry, wet and branches) (Organic-3)	0.73
Sugarcane waste (Organic-4)	0.18
Seeds (Organic-5)	0.70
Plastic/ rubber / insulation material	4.78
Cloth, jute bags, Paper/Cardboard	4.20
Inert (Stone/ Glass)	0.76
Metal (ferrous and nonferrous)	0.20
Wood and furniture waste	0.05
Other Sanitary Items/Napkin/Diaper	0.05

2. Pre-Treatment

Biogas generation relies on the microbial breakdown of substrate, which requires pre-treatment to make the substrate more accessible. That involves mechanical and microbial methods to reduce the complexity and the size, and thereby improving the efficiency of microbial digestion.

Mechanical pre-treatment includes shredding and crushing to standardize the size of organic waste and biomass, making it easier to handle and feed into digesters. Shredders cut waste into uniform pieces (15-20 mm), while crushers produce feed suitable for slurry making.

3 Anaerobic Digestion Process and Biogas Generation Process

Biogas is produced from anaerobic digestion of organic material. The process generates combustible gas and nutrient-rich fertilizer under controlled conditions, such as temperature, pH, and C/N ratio (Carbon/Nitrogen).

Anaerobic digestion is a natural process where organic material decomposes in the absence of oxygen, producing biogas - a mixture primarily of methane (50-65%) and carbon dioxide (35-50%). The process is harnessed in biogas plants using feedstocks like manure, organic waste, and agricultural residues, which are fermented in sealed digesters to generate biogas and organic fertilizer. The process involves several microbiological steps, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis, with microbes generating gas. The digestion process can be either mesophilic with digester temperature maintained between 37-43°C or thermophilic process with digester temperature maintained between 50-60°C.

During the Biogas productions the biological changes occur:

a. In Hydrolysis Process

Insoluble organic matter is broken down into simple sugars, fatty acids, and amino acids.

b. In Acidogenesis Process

Further break down of organic monomers of sugar, and amino acids into alcohol, aldehydes and volatile fatty acids (VFAs)

c. In Acetogenesis Process

Conversion of alcohol and volatile fatty acids (VFAs) into acetic acid, carbon dioxide (CO_2) and hydrogen (H_2).

d. In Methanogenesis Process

There are two pathways for methane production in methanogenesis process of anaerobic digestion. They are acetoclastic and hydrogenotrophic pathways. In Acetoclastic, the acetic acid is broken down directly to methane and carbon dioxide. This process is the dominant pathway in organic waste digestion. In hydrogenotrophic pathway the Hydrogen

(H_2) reacts with CO_2 to form methane and water. Figure-1 is a typical block diagram that is generally followed for biogas production by anaerobic digestion in most of the projects.

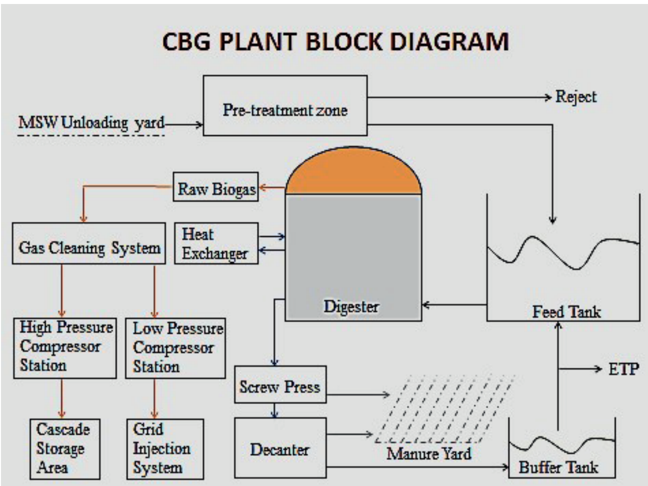

Figure 1: Typical Block Flow Diagram of CBG Plant

4. **Biogas Purification and Upgradation**

   Biogas produced in the digesters is collected in a double membrane balloon. The collected raw biogas is first passed through a caustic scrubber where Hydrogen sulphide is removed. The purified CBG is further passed through a Vacuum Pressure Swing Adsorption system (VPSA system) where CO_2 is removed and the methane percentage increased to 96 %.

   In the purification system the challenges are to be addressed. During caustic scrubbing for the removal of hydrogen sulphide (H_2S), sulphates are produced, and proper disposal of the same shall be addressed. To remove unwanted gases such as CO_2, N_2, O_2, H_2O, and residual H_2S, PSA (Pressure Swing Adsorption) or VPSA (Vacuum Pressure Swing Adsorption) systems are used. In the purification process the tower is filled with adsorption materials such as alumina, silica, activated carbon, and zeolite, which have the capacity to adsorb specific unwanted gases and allow high-purity methane to exit for further processing. It is essential to ensure the use of high-quality adsorption materials in the design to optimize performance and efficiency.

5. **Biogas distribution**

   The upgraded biogas is distributed through a cascade system after being compressed to 250 bar(g) in a high-pressure compressor, or it is connected to the gas grid after compressing in a low-pressure compressor.

6. **Byproduct as Manure**

   The digestate removed from the digester is passed through a screw press and decanter to reduce its water content. The solids extracted from the screw press and decanter are taken to the manure yard for the production of bio-fertilizer, used for forming, promoting sustainable farming and reducing the need for chemical fertilizers.

7. **Compressed Biogas Composition**

   The composition of upgraded compressed biogas as specified in IS 16087: Biogas (Biomethane) – Specification, is reproduced in Table-2.

Table-2: Typical Composition of CBG

IS 16087:2016: Biogas (Biomethane) – Specification			
Sr. No.	**Characteristic**	**UOM**	**Require-ment**
1	CH_4 (minimum)	%	90.00
2	CO_2 (maximum)	%	4.00
3	(CO_2 + N_2+O_2) (maximum)	%	10.00
4	O_2 (maximum)	%	0.50
5	Total Sulphur (including H_2S), maximum	mg/m³	20.00
6	Moisture, maximum	mg/m³	5.00

The Indian standard IS 16087 specifies the methane percentage as minimum 90%. The technology that is being implemented in the present CBG projects is yielding methane percentage between 96 - 97%.

Power and Water Consumption

The power and water required for generating

Compressed Biogas (CBG) from municipal waste vary depending on the technology, capacity of the plant, and operational efficiency. Following are the Power consumption and Water Consumption based on the some of the running the plant:

1. **Power Consumption**

   Power is required for the entire CBG generation process, including waste pre-processing, anaerobic digestion, biogas upgrading, compressing CBG, and effluent treatment, up to the bagging system. Typical specific power consumption ranges from 1.4 to 1.6 kWh per kg of CBG. This may vary based on the type of feedstock, pre-treatment requirements, and effluent treatment system.

2. **Water Consumption**

   Water is required for preparing the feed for the digester and flushing of various equipment. Typical water requirement ranges from 4 to 8 liters per kg of CBG. Water consumption may vary based on the type of feedstock, moisture content of the feed stock, solid-liquid separation process, and the efficiency of the effluent treatment system.

Conclusion

The growing volume of MSW management has turned out to be a significant challenge and has major environmental impact. Traditional waste management practices, such as landfilling and incineration, have harmed the environment, prompting efforts to reduce their use. In response, innovative approaches that convert waste into valuable products or energy are gaining momentum. These methods encompass both biological and thermochemical conversions, and extensive research over the past decade has led to enhanced yields of products and energy, along with reduced environmental impacts. These advancements also play a crucial role in supporting the broader energy transition by promoting sustainable waste-to-energy solutions.

References

1. Mansi Singh, Madhulika Singh, Sunil K. Singh, Tackling municipal solid waste crisis in India: Insights into cutting-edge technologies and risk assessment, Science of The Total Environment, 917, 2024, 170453.
2. IS 16087-2016: Biogas (Biomethane) – Specification (First Revision)

Holtec Experience

Holtec has been a front runner in building green energy projects. The company has engineered over 600 MW of green power from waste heat and are currently implementing projects with a biogas production overall capacity of approx. 98 tonnes per day. Holtec recognizes significant potential in this area as only less than 1% is realised at present.