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Technological Review of Biogas Generation from Bio-Degradable Wastes: Design, Performance and Scope

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***Abstract:** The appropriate management of biodegradable wastes by Anaerobic Digestion can not only solve waste-treatment problem, but also can provide an alternate solution to increasing global energy demand. Biogas is becoming popular worldwide as it is renewable and green energy resource. Intent of this review paper is to report global scenario of biogas generation and its technical advancement so far. Different technologies of biogas plants are available. A comparative discussion amon different types of biogas plants are added. Suitable design for biogas plants are required to operate it safely and efficiently. Different design and performance aspects are also added in this paper to motivate further research in this field.*

***Keywords:** Anaerobic Digestion, Bio-Degradable Wastes, Biogas, Biogas Digester, Design.*

1. INTRODUCTION

With the increasing demand of global energy supply, conventional energy resources like coal, crude oil and oil products, natural gas etc. are continuously decreasing day by day. Environment scientists are concerned about pollutions made by the burning of fossil fuels, which is not only hazardous to the health, but also taking a prominent role in emitting green-house gases [1]. Though we are talking on non-renewable energy resources, green energy since few decades, but it has been reported that a major part of the energy requirement (81%) still coming from fossil fuels like coal, oil and natural gas, whereas contribution of renewable energy resources (solar, wind, hydro, biomass etc.) is only nearly 14% as reported in World Bioenergy Association, 2021 [2]. In the present scenario, biogases can be an appealing alternative to fossil fuels, especially in developing countries like India, Brazil, Bangladesh, Nigeria, Nepal, Indonesia etc. where bio-wastes like food waste, bio-degradable municipal wastes, agricultural wastes, organic residues from industries, cattle & pig manures, poultry droppings are produced in large scales [3-7].

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Anaerobic digestion (AD) is presently a popular method to treat bio-degradable wastes. Human civilization is familiar with this method since thousands of years, and utilizing this method to produce biogas since last few decades [8]. The gas generated from anaerobic digestion of bio-degradable wastes is having 50-70% methane (CH_4) and 30-50% carbon dioxide (CO_2) in it [9]. The high calorific value [10] due to presence of methane makes it highly combustible and suitable fuel for different kind of uses. Biogas plants are designed to be operated in mesophilic and thermophilic temperature ranges with are 30-40^o C and above 40^o C respectively. Generated gas can be utilized for household cooking, heating, small scale electricity production etc. [11]. Furthermore, bio-fertilizers can be obtained as by-product of biogas. [12-13] Even, it can be used as fuel in transportation system [14].

In this paper an attempt has been made to report technical advancement in the production of biogas from various organic wastes and future prospect of this project in rural areas of the developing countries like India in order to provide cheaper fuel, electricity and bio-fertilizer.

Global Scenario of Biogas

Biogas can be utilized to generate electricity using fuel cells. [15] Biogas is a popular source of energy for cooking, heating water, lighting lamps and other domestic purposes in

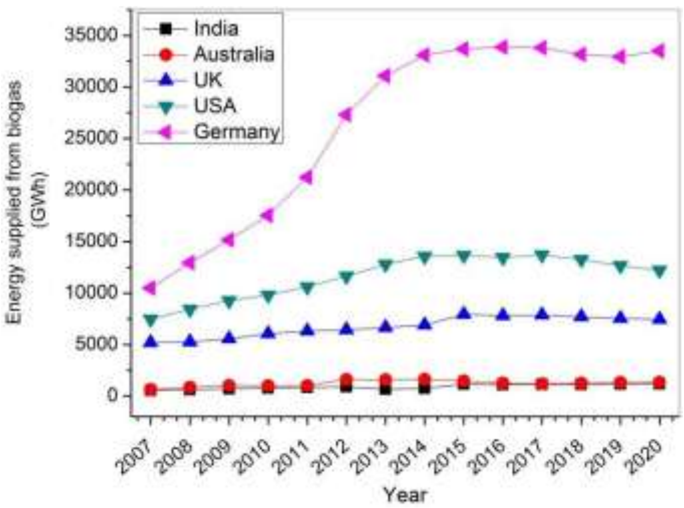

Fig.1 Global statistics of utilization of biogas as source of energy [Source of data: IEA (2022)] [16]

developing countries. Fig. 1 shows a global statistics about usage of biogas as source of energy across countries like India, Australia, United Kingdom, United States of America and Germany. The data is a clear indication of biogas being popular from 2007 to 2020.

World Health Organization is recommending biogas for cooking instead of using solid fuels like wood, coal, dung and agricultural residue, to reduce indoor air pollution [18]. Itodo *et al.* [19] has shown in their work, that biogas stoves can achieve upto 56% efficiency. These might be reasons why biogas is becoming popular as domestic energy supplier also, Fig. 2 (a)

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depicts contribution of biogas as domestic energy supplier worldwide. Fig. 2 (b) represents a scenario how biogas is servicing as domestic energy supplied across different continents.

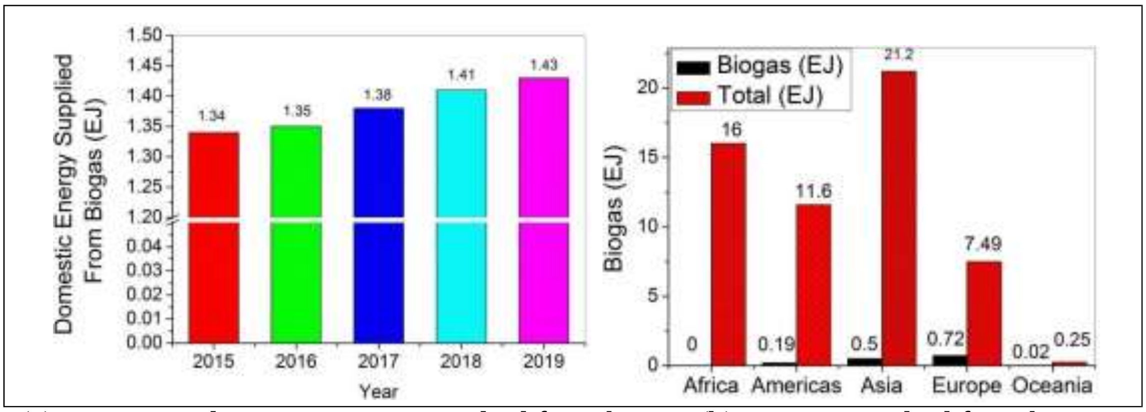

Fig. 2 (a) Year-wise domestic energy supplied from biogas (b) Energy supplied from biogas vs. Total energy requirement in different continants of world in 2019
[Data source: WBA (2021)] [17]

Methodologies for Biogas Generation
Anerobic Digestion (AD) is the popular most method to generate biogas from wastes [20-21]. The name itself suggesting that the process is carried out in absence of oxygen. The method typically needs small space, low operating cost, lower maintenance cost and produces methane-rich fuel treating the wastes. It converts bio-waste into biogas and digestate. The digestate can be used as fertilizers. The AD is done in three phases, namely hydrolysis, acitogenesis and methanogenesis. [22]

A. Hydrolysis
In hydrolysis long-chain components present in the biomass are decomposed into simple monomers. This occurs in the presence of different micro-organisms like fermentative bacteria, cellulytic bacteria, lipolytic bacteria. Enzymes excreted by them acts as a catalyst of the reaction. This is the slowest phase in the whole process.

B. Acitogenesis
Acitogenesis is composed of two reactive phases- fermentation and acetogenesis reaction. The microorganisms associated with this process are known as acid formers. [21] In this step, the product from Hydrolysis is converted into organic acids like acetic acid, propionic acid, butyric acid, and some other volatile organic compounds like ethanol etc. [23] Hydrogen and carbon di-oxide are also formed at this phase.

C. Methanogenesis
This is the third and final stage of AD. The reactions in this step is catalysed by the enzymes excreted from methanogen bacteria. Formation of methane is categorised in two reactions viz. fermentation of acetic acid and reduction of carbon di-oxide.

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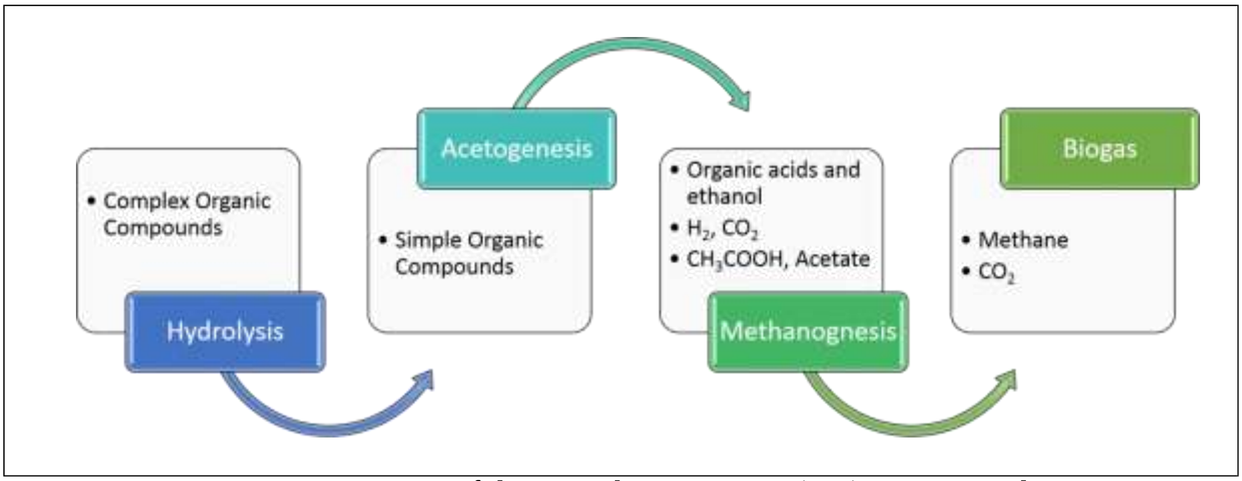

Fig. 3 Representation of the Anerobic Digestion (AD) process in chart

Design of Biogas Plant

There are different types of biogas plants according to its design such as Fixed dome type, Floating drum type, Baloon plants etc. A comparative discussion is given in Table 1. [24]

Table1: Comparison between biogas plants

Type	Details about the plant		
	Attributes	**Advantages**	**Disadvantages**
Fixed Dome Plants	• Gas holder is fixed. • Storage is at upper portion of the digester.	• Low manufacturing cost. • Underground construction. Long life.	• Pressure increases with the volume produced of gas. • Problem of leakage. • Expert design needed.
Floating Drum Plants	• Gas space is moving. • Drum rises with the increased volume of produced gas.	• Simplicity of design. • Easy operation. • Constant gas pressure maintained.	• Manufacturing cost is high. • Steel parts are required which me subjected to rusting. • Maintenance cost is high. • Life span is comparatively smaller than fixed dome type.
Baloon Plants	• Made of plastic or rubber bags. • Gas inlet and outlet are attached on the surface of the bag.	• Low manufacturing cost. • Easy to transport. • Easy maintenance.	• Very short life span.

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The Following Literatures Can Be Referred To Get Detailed Aspects About The Design-Deublein Et Al. [25], Ogur Et Al. [26], Otim Et Al. [27], And Muhammad Et Al. [28]. In The Present Paper, Detailed Design Of Fixed Dome Type Plant Will Be Discussed.

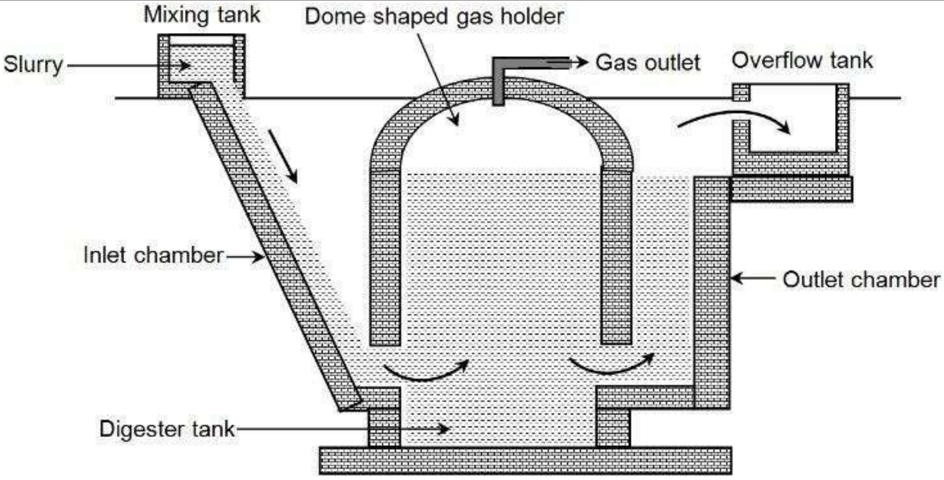

Fig. 4 Schematic setup of Fixed Dome type Biogas Plant
(Source: https://funscience.in/fixed-dome-type-biogas-plant)

The related nomenclature are as follows:
Biogas yield = 5 (m^3/kg)
Waste feed per day = F (kg/day)
Production rate = P (m^3/day)
Hydraulic retention time = t_{HR} (day)
Active Slurry Volume = V_S (m^3)
Height of the cylindrical part of the digester = h (m)
Diameter of the digester = D (m)
Digester volume = V_d
Production rate is calculated from biogas yield and waste feed per day. Theoretical value of production rate, $P = 5.F$
Hydraulic retention time (t_{HR}) is the theoretical time that some volume of waste would remain in the digester. The value of t_{HR} is typically 8 to 50 days. [29] Active slurry volume (V_S) is calculated from hydraulic retention time (t_{HR}) using the following formula:

$$V_S = \frac{1.4 \times F \times t_{HR}}{1000}$$

Daily feed is given as per the active slurry volume, $F = V_S/t_{HR}$.
Digester volume is designed for the slurry volume, but, additional 10% allowance is provided for gas disengagement.
Digester Volume, $V_d = 1.1 \times V_S$
Height and diameter of the digester is calculated from the value of digester volume.
Height to diameter ratio of digester, $\frac{h}{D} = 0.9$.
So, $V_d = \frac{\pi}{4} \times D^2 h$.

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Performance of Biogas Plant

Different parameters like C: N ratio, temperature inside digester, pH of fermentation medium, Hydraulic retention time (HRT), and additives affect the production and performance of biogas plants. C: N ratio is referred as the ratio of amount of carbon and nitrogen present in the mixture. The optimum range for C: N ratio is 15-25. [30] Depending on the C: N ratio, the mixtures can be classified into two categories viz. carbon-rich mixture and nitrogen-rich mixtures [31]. The process of AD is completely facilitated by the presence of mesophilic and thermophilic bacteria. Favourable temperatures for the former is 35-40^{o} C and latter is 50-60^{o} C. [32] If the temperature is considerably low, the digestion process can take even up to one year. Smith *et al.* [33] recommended some design modifications to the digester so that it can perform well even at lower temperatures. The value of pH is the measure of alkalinity or acidity of the mixture. It is well known that, pH is 7 for neutral, less than 7 for acidic mixture and more than 7 for alkaline mixture. Optimum value of pH must be 6.8-7.3 [30]. Hydraulic retention time (HRT) is also another factor that has to be chosen wisely [34]. The production rate is high at the initial level, but, gradually it becomes slower. HRT is chosen to achieve at least 2/3rd digestion of the mixture. [35] Additives play a vital role in the performance of biogas digester. Madamwar et al. [36] conducted an experiment to show addition of pectin to cattle dung slurry not only results additional biogas yield, but also stabilizes the process even at temperature fluctuations.

2. CONCLUSIONS

This study presented a detailed report on technological advancement in design and performance of biogas generation. Sustainability of this technology has also been discussed. Though this technology is becoming popular day by day, but miles to go. Priority must be given to the research and development of biogas technologies.

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