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Biogas Production from Organic Materials

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Abstract: - Anaerobic digestion is a microbiologic process through which organic materials are broken down in oxygen absence and occurs in many environments. Now, biogas production is done in the reactors resistant to air penetration called digesters. A wide range of microorganisms is involved in the anaerobic process producing biogas and digestion as the final products. Biogas is a kind of flammable gas that contains methane, carbon dioxide, and a small amount of other rare elements and gases. Digestion of the decomposed materials rich in nutritional micros and macros plays the role of proper plant manure. Like other biofuels, biogas is also among the crucial priorities of energy and transportation policies made in Europe. In Europe, biogas is an inexpensive renewable energy source and neutral carbon dioxide that provides the field for processing and recycling many agricultural wastes and byproducts based on a sustainable and eco-friendly method. Biogas brings many socioeconomic advantages to society as a whole and also to investors.

Keywords: Biogas, Landfill, Biogas Power Plant, Utilization, Biogas Energy

I. INTRODUCTION

The increase in the production of organic waste is one of the critical environmental problems in the current society. Many countries have adopted sustainable management and non-production or decline in waste production as their political priorities, which highly contributes to a reduction in pollution and emission of greenhouse gases to decrease climate changes in the world. Nowadays, uncontrolled waste disposal and even controlled waste disposal in landfill places and burning organic wastes are not acceptable as better methods because environmental standards have become more limited, and energy harvest and nutritional and organic materials harvest have been valued as the main goals [1].

Biogas consists of natural gases, which are obtained from available organic materials. Biogas production plays an important and underlying role in the economic, political, and health fields of a country or a region, which leads to industry growth in industrial companies, heat generation for residential houses during winters, and cooking in the kitchen. We can use biogas obtained from decayed organic materials, such as vegetables, fruits, agricultural weeds, human and animal wastes, and sewage sludges. All developed countries utilize biogas in their industrial and agricultural fields. Biogas production and collection from biological processes was registered in the UK for the first time in 1895, and then was developed more and used widely for wastewater treatment and sludge stabilization. The energy crisis of the early 1970s highlighted the importance of renewable fuels such as biogas. Many attempts have been made for fossil fuel substitution, and the necessity of finding sustainable environmental solutions for processing and recycling animal and organic wastes has increased the attention to biogas [2].

Nowadays, biogas installations that process agricultural materials are the most important utilizations of anaerobic digestion. Millions of families in Asia and countries such as China, India, Nepal, and Vietnam have small household digesters that use the produced gas for cooking and lighting. There are thousands of active agricultural biogas power plants in Europe and North America, and many of them use state-of-the-art technologies in this field. The number of these power plants is rising. More than 3700 agricultural biogas power plants have been active only in Germany during 2007 [3].

The enhancement of the EU has added new members to the family of European biogas producers that not only produce biogas and the profit obtained from its components but also decrease environmental pollution and increase sustainable development of rural communities.

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What is biogas?

Biogas is a gaseous mixture rich in methane that is obtained from air-free fermentation of some resources animal wastes and urban sewage sludge are the most important ones- in a fermentation chamber.

In general, biogas production resources include: [4]

1.2.1. organic wastes such as animal wastes, urban, industrial, and other sewages

1.2.2. agricultural products that are energy production sources, such as sweet maize, grape, sunflower, etc.

1.2.3. ordinary agricultural products such as maize, wheat, sugar, beet, etc.

1.2.4. other organic raw materials such as glycerin, etc.

In other words, organic materials that contain protein, cellulose, and fat compounds that are oxygen-free are decomposed in biogas devices in an air-less environment under the fermentation process, and finally, a part of them is converted to the gases that are called biogas. This process is shown in the table below:

Table 1. Constituent elements of biogas

Constituent elements of biogas	**percentage**
CH_4	50-75
CO_2	25–50
H_2O	5–10
N_2	<10
NH_3	<1
H_2	<1
H_2S	<3
O_2	<2

Biogas energy production methods

Biogas production from sewage

When oxygen does not reach the sewage, aerobic bacteria lose their growth, and anaerobic bacteria start their activity instead. These bacteria obtain their required oxygen from the decomposition of organic and mineral materials existing in the sewage.

Production of methane and carbonic gases, particularly hydrogen sulfide causes an unpleasant odor that severely affects the environment polluted. Hence, this technique also is called the rotting technique. The most important utilization of anaerobic bacteria is in the closed chamber of sludge digestion. The sludge contains 60-80% decomposable organic materials before entering the sludge digestion sources. Fresh sludge makes up around 1% of the whole sewage in terms of volume, but its treatment is highly expensive and complicated. The cost of the sludge digestion system sometimes covers about half of the whole treatment plant. Condensation of sludge and removal of its extra water facilitates the treatment process. Sludge digestion done by rotting and anaerobic bacteria function is implemented within two phases acid fermentation and methane fermentation [5].

Biogas production in landfills

Wet waste is a problem in most cities the countries, and its volume is rising, and a large amount of money is spent on preventing subsequent environmental pollution and health issues. There are various techniques for waste collection and removal processes. Waste incineration technologies and aerobic and anaerobic digestion are among these techniques.

The first step to a waste landfill is digging a well, which is an experimental step. To measure the accurate depth of the well, one must consider its distance from underground waters and the slope of flattened land. In this process, the important point is the location of the well and the highest surface of underground waters. The wetlands must not be chosen for landfills because their affluent becomes uncontrollable. Following biological, physical, and chemical changes occur during sanitary waste disposal:

1. Biological decomposition of organic materials in aerobic and anaerobic cases along with deformation of gases replaced with liquids
2. Oxidation of waste materials
3. Emission of gases from landfill place
4. The movement of liquids from various wastes
5. Dissolution of organic and non-organic materials when water and liqueur flow into the landfill
6. The flow of the dissolved materials, considering the concentration
7. Non-uniform settlement caused by materials stabilization inside the wells

The gases existing in landfill places include air, ammonia, CO_2, CO, Hydrogen Sulfide, methane, nitrogen, and oxygen. However, the main gases produced from the anaerobic decomposition of organic compounds of waste include methane and CO_2 [6].

Biogas plants

Construction principles of biogas plants

The construction of a biogas device mainly consists of two input and outlet tanks, one fermentation chamber, and one gas chamber, which is built in different shapes and is operated based on certain climate conditions and technical-financial facilities. It is tried in all models of biogas units to mix raw materials with water and send them inside the fermentation chamber through an inlet tank. These materials are transferred to the outlet or compost tank after fermentation and gas production by adding new materials and using features of relevant containers. The gas chamber of the tank is generally placed on the top part of the fermentation tank to collect and store gas. After the device starts working, the considered gas is daily sent to the consumption place through a gas-specific valve on the top of this tank to be used. Additionally, a stirrer installation for mixing the raw materials in the inlet tank and fermentation chamber are some usual operations done in many ordinary biogas plants. This process would accelerate and improve fermentation, which leads to more gas production [7].

Biogas unit exploitation

Biogas units must be tested for water or gas leakage before exploitation. The leakage place must be determined and repaired. When the plant is under operation, control, maintenance, and repairs must be done frequently. Required measures must be taken as soon as possible when any failure occurs. In this way, the unit will be utilized desirably. The exploitation of biogas plants with floating and fixed tanks is explained herein.

Safety of biogas units

Biogas units are risk-free if they are constructed based on the instructions and are exploited accurately. However, the possible adverse health hazards and avoidance methods must be determined. Some gases result in health risks and possible fire and explosion: methane, CO_2, hydrogen sulfide, and ammonia.

A mixture of 5-15% biogas air and atmosphere air results in an explosion. One can prevent an explosion in a gas unit by removing the whole air existing in the gas tank or biogas chamber of a fixed domed model and its pipes before being utilized. It is indicated in the table below:

Table 2. Effects of harmful gases existing in the biogas

Type of gas	*** Range**	**Explosive**	**** Physiological effects**
	Min %	Max %	
Ammonia	16	-	Stimulator

CO_2	-	-	Suffocating
Hydrogen sulfide	4	46	Poisonous
Methane	5	15	Suffocating

***Explosive range: a range is explosive in which, a mixture of gas and atmosphere air is exploded by creating a spark.**

**** Physiological effects: there are effects seen in an adult when is in exposure to gas for a certain duration.**

Thermal value of gas

Biogas is known as marsh gas and swamp gas, and is a clean, combustible gas lighter than air that is a kind of fuel providing the following characteristics [8]:

The combustion temperature of biogas is about 700˚C, and its flame temperature equals 870˚C. Like other gaseous fuels, biogas is combustible and is mixed with air based on a 1-to-20 ratio and has a high ignition speed. Its thermal value equals 5650kcal or around 6kwh/m^3. In general, the thermal value of produced biogas depends on the methane percentage, so the larger the volume of methane gas, the more ignitable the gas will be. Other produced gases like CO_2 are non-combustible or are insignificant and minor.

Biogas properties

The energy content of biogas is chemically limited to methane. The composition and properties of biogas somewhat depend on the type of raw material, digestion software, storage time, etc. The average amount of biogas compounds mentioned in most references by consideration of the standard amount of methane existing in the biogas (50% of its thermal value) equals 21MJ/Nm^3, hardness equals 1.22Kg/Nm^3, and its density is similar to air and 1.29 Kg/Nm^3 [9].

Combined heat and power (CHP) generation

In many countries that have developed biogas systems, CHP generation is one of the standard and common biogas utilization. This biogas utilization provides a very high energy yield. Biogas must be dehydrated before converting to heat and power. In terms of hydrogen sulfide, there are halogenated hydrocarbons and maximum siloxanes for most gas engines. The engines that are based on the CHP software offer a high efficiency of 90% and generate 35% power and 65% heat. The power generated from biogas can be used for providing energy processes in some equipment, such as pumps, control software, and stirrers. In addition, the biogas heat can be used in industrial processes, agricultural activities, and or for buildings' heating.

Biogas enrichment (generation of biomethane)

It is possible to inject the biogas into the natural gas network or use it as gasoline for vehicles after compressing it. The biogas should pass the enrichment process before doing these steps so that all contaminants and CO_2 are removed from it to reach its common methane content from 50-70% to more than 95%. The enriched biogas is called biomethane. There are many technologies for the removal of contaminants and increasing methane content in biogas. CO_2 is removed to achieve the required gas web number. When CO_2 is removed, an amount of methane gas (CH_4) is also removed. There are two common techniques for CO_2 removal: absorption (washing through water and organic solvents) and adsorption (wave-power absorption). Other uncommon techniques include membrane separation, cryogenic separation, and process internal improvement, which is almost a new and developing technique [10].

Biogas plants

Amount of biogas

The amount of biogas is measured by using some equipment with the general name of the gas meter. The amount of biogas is measured to evaluate the process yield. Variations in gas production indicate the process difference, so proper methods are required for process regulation. Gas meters are usually placed in the gas pipelines directly. Biogas measured rates must be recorded to evaluate the biogas production, its process, and the general function of the biogas plant.

Biogas compounds

Biogas compounds can be determined continuously through gas analysis by using suitable measurement devices. The results can be used to control the anaerobic digestion process and subsequent processes. Determination of biogas compounds is done through sensors used for heat transfer, infrared ray absorption, chemical adsorption, and electrochemical assessment. Infrared sensors are appropriate for determining methane and CO_2 densities. Electrochemical sensors are used to measure hydrogen, oxygen, and hydrogen sulfur. Biogas compounds can be found manually or automatically.

Medium-pressure biogas storage tanks

Biogas can be stored in medium-high pressure (5-250 bar) tanks made of steel. This equipment has high operational costs and energy consumption rates. The tanks with pressure higher than 10 bar need around 0.22kwh/m^3, and this amount of energy consumption almost reaches 0.31kwh/m^3 for tanks with 200-300 bar pressure. These tanks are rarely used in agriculture biogas plants due to their high costs.

Biogas flares

The amount of produced biogas sometimes exceeds the consumed energy. High and irregular rates of biogas production and repair and maintenance operations in power generation units usually result in a production surplus. In such cases, an alternative solution, such as extra tanks for biogas maintenance or another software for power generation is highly necessary. Biogas storage without compression is possible for a short time, and it is not possible to store it for more than several hours due to the high volume of production. It is not cost-effective to launch another power plant for CHP generation (secondary plant). Hence, one flare is prepared in each biogas plant. The ignition process determines the superiority of a flare over others. Biogas burning is legislated by emission to atmosphere standards and efficiency criteria of flare. Two parameters of temperature and time determine the efficiency characteristics of an advanced flare [10].

Biogas purification

Biogas contains a percentage of hydrogen sulfide, CO_2, and steam. The biogas must be purified before being consumed to separate its elements and increase the fuel value of the biogas.

Separation of hydrogen sulfide (H_2S): adsorption towards a liquid, such as water, or an absorption base solution towards a solid such as activated carbon or saturated activated carbon (that contains iron oxide) of bioconversion in which sulfur compounds become pure sulfur by adding air oxygen.

Removal of CO_2 element: purification of biogas from CO_2 would increase the gas value up to around 15%. This purification is necessary in cases that need more thermal value and is not highly considered usually in all cases. The CO_2 gas purification is done by passing the gas flow through the lime water, which leads to CO_2 adsorption into the lime water. However, it should be noted that the pressure of the lime water column's height on the top of the gas outlet duct should not exceed the gas pressure. Lime stirring effectively accelerates the purification or upgrading process.

Steam absorption: biogas generally contains an amount of steam that should be separated; otherwise, the water is distilled and accumulated in the gas pipe and stops or blocks the gas duct. Steam absorption is usually done by a steam distillation machine.

Advantages brought by biogas technology utilization

Energy production

Biogas units prevent burning animal wastes as a fuel material. Biogas is a clean and sufficient fuel material for cooking and helps to save the consumption of oil, coal, and wood. Biogas is known as a new fuel material in the mechanization of agriculture and rural industries. Biogas can be used to run the diesel and petrol engines. It can be even used for electricity generation. The low cost of biogas production has made it more acceptable [11].

Enriched fertilizer production

The fertilizer produced in a biogas unit provides a relative advantage over ordinary fertilizer in terms of quantity and quality. The fertilizer obtained from biogas is a good source of some micronutrients such as aluminum, iron, magnesium, and copper which are among the scarce metals in most agricultural soils. Full digestion of animal wastes in biogas units would destroy the weed seeds and organisms causing plant disease. It has been proved that the utilization of biogas-digested slurry as fertilizer would improve soil fertility and create up to 10-20% increase in productivity. The amount of fertilizer consumed for this purpose is about 10 tons/hectare in dryland farming and 5 tons/hectare in rainfed farming [12].

Economic and social effect of biogas technology utilization

Biogas technology and the development of biogas power plants not only solve the problems mentioned above but also provide numerous economic and social effects some of which are mentioned herein [13]:

- Earning money by selling energy (biogas, heat, power, or electricity), organic fertilizer, and water usable for agriculture, and expanding green space to the public or governmental network
- Purifying solid waste materials without long-term costs, such as water and soil contamination
- Improving soil and its exploitation in agriculture due to the use of organic fertilizer produced in biogas power plants
- Harvesting recyclable materials with organic wastes (metal, glass, paper, and plastic) and selling them to recyclable industries
- Achieving technology for the construction of biogas power plants in the country
- Promoting health status, especially for people who work in the waste industry
- Creating jobs in the recycling sector and biogas power plant

Major utilization of biogas

Biogas consumption

Cooking ovens, lamps, refrigerators, and engines work with biogas in some developing countries. Biogas can be converted to electricity through fuel cells opening a window to study this very clean and inexpensive gas compared to fossil fuels. On the contrary, the use of biogas as a fuel for combustion engines and power generation indicates that many proper generators can be used for this purpose [14].

Biogas units of agriculture

Biogas units of agriculture mean those projects in which, the raw metrical process has an agricultural nature. The most common raw materials used in these types of units include animal wastes, vegetable residues, and byproducts, power plants that are built for biogas production (DEC), and residues remaining from food industries and fish farming. Pig and cow manure are the most common materials used for anaerobic digestion in Europe; however, power plants have been widely used in recent years.

Domestic biogas power plant

There are millions of biogas power plants on a domestic scale in some countries, such as Nepal, China, and India. These power plants use very simple technologies. The raw materials used in the anaerobic digestion of these units have domestic origin or are obtained from small farming activities. The produced biogas is this way is used in the cooking and lighting system of the house.

Agricultural biogas power plant

An agricultural biogas power plant is defined as a power plant that only processes the wastes of a farm. Many agricultural units use co-digestion of materials with high potential for methane production (such as oily residues obtained from fisheries or oil extraction industries) to increase methane efficiency. In the biogas units at the agricultural scale, the animal wastes of one or two nearby farms may be collected and processed (for instance, these units connect the farms to the considered co-digestion power plant through pipes). In Europe, some countries like Germany, Austria, and Denmark are leading in the field of biogas production at an agricultural scale. The Agricultural biogas units are different in terms of size, design, and technology. Many of them are very small and have simple technology, but the other ones (such as centralized co-digesters) are almost large and complicated. However, all of them have similar main parts. The manures are collected in a pre-storage tank near the digester and then are pumped into it. A digester is an impenetrable tank against gas, which is made of steel or concrete and is insulated to achieve a fixed operational temperature. Digesters are horizontal or vertical in shape and are equipped with stirrers. Stirrers are responsible for mixing and homogenizing materials and minimizing the risk of layers floating and sediment formation. The average hydraulic remaining time varies between 20 and 40 days based on the type of material and digestion temperature [15].

Sewage treatment plants

Anaerobic digestion is widely used for processing the primary and secondary sludge obtained from aerobic treatment of urban sewage. Many countries use this in combination with high-tech processing software to allow anaerobic digestion stabilizing and decreasing the final sludge. Many engineering companies that provide sewage treatment software can present anaerobic digestion plants. In European countries, about 30-70% of sewage sludge is purified through anaerobic digestion based on national rules and priorities. The waste from the anaerobic digestion of sewage sludge is used as fertilizer for agricultural lands. Because this process results in some negative environmental effects by leaking nutrient materials into underground waters or emission of greenhouse gases into the atmosphere, this process has been banned in many European countries [10].

Biogas industrial plants

It has been more than one century since anaerobic processes have been widely used to process industrial wastes and sewage. Now, anaerobic digestion is a standard technology used for treating industrial sewages resulting from food, agriculture, and pharmaceutical industries. Moreover, anaerobic digestion is applied as a pre-process for industrial sewages before final disposal. The current advances in treatment technologies have made dilute industrial wastewater digestible. Europe is leading in this kind of management. Energy considerations and environmental concerns have increased interest in the anaerobic processing of organic industrial waste over recent years. They also highly control the environmental rules and management of organic solid wastewater obtained from industry. following industries use anaerobic digestion for wastewater treatment [16]:

Food processing industries: such as vegetable canning, dairy product factories, slaughterhouses

Beverage production industries: such as beer, non-alcoholic and alcoholic beverages, coffee, fruit juices

Industrial products: such as paper and board, rubber, chemicals, starch, and medications

Biogas utilization as vehicle fuel

Biogas utilization in the transportation sector is a high-potential technology proving many social-economic advantages. Nowadays, biogas is used as vehicle fuel in some countries in Sweden, Germany, and Swiss. There is an increasing number of personal cars, public vehicles, and tillers that use biogas (biomethane) as fuel. Biomethane can be similarly used in vehicles that consume natural gas. Diesel Casters with biomethane fuel are used as alternatives in many European cities. Also, specific vehicles have been made to use biogas, so these vehicles have higher yields, and gas tanks have been placed without reducing space for the load. The biogas with 200-250 bar [pressure is stored in pressure tanks that are made of steel or aluminum composite. There are now more than 50 factories around the world that provide 250 models of light, heavy, and urban vehicles that work with gas. Those vehicles that use biomethane provide more advantages than those equipped with diesel or petrol engines. The total rate of CO_2 emission is considerably reduced depending on the raw material and the power resource (fossil or renewable resource) for gas enrichment and compression [6].

II. CONCLUSION

Biogas production from various organic materials is the most interesting renewable energy source. There is a rising rate of energy consumption in the world while fossil energy resources are decreasing worldwide, so many human needs may remain unmet. Hence, some new energy resources are required that are called new energies, including solar, nuclear, wind, and biogas energies. Biogas can be produced in different fields by using plant biomass, waste materials, and man-made waste. The most important applications in biogas production are seen in producing biogas production devices. An accurate selection of biogas production devices is necessary for successful and high-yield biogas production. The main components of these units include a fermentation tank, gas tank, outlet, and inlet ducts. Biogas provides a more significant thermal value than other types of fuels and can meet the fuel needs of people even in remote areas. This fuel is clean and inexpensive. The fertilizer produced in biogas units provides many advantages, including an increase in the quantitative and qualitative performance of soil.

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