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Biogas as an Entrusted Alternative for Fossil Fuels: A Review

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Abstract: *Global warming has become the greatest challenge for the world today. Now, researchers are trying to find out an alternative energy source of traditional fossil fuels to evict green house effect. From recent studies it is observed that, biogas has the potential to become an entrusted energy source for the current world as it can be extracted from solid wastes and the extraction processes are not only ecologically sound but also cost effective and is also an hygienic process to dispose the solid wastes. Basically, biogas is consists of methane (50-60%) and carbon dioxide (20-40%); with a small mixture of hydrogen sulfide and siloxanes as impurities. These impurities can damage the efficiency of biogas. But after successful removal of these impurities, the upgraded biogas can be used in different technologies, which are effective to turn biogas into energy source. But, the matter of fact is that, the lacking of knowledge to select proper substrate, not having sufficient knowledge to apply appropriate pre and post treatments of the raw materials creating obstacles to explore the vast application field of biogas. In this paper, we would like to focus on some familiar technologies by which the utilization of biogas can be extended and help to optimize and control the energy crisis of the world.*

Keywords: *Anaerobic digestion, Biomethane, Upgradation*

1. Introduction

At present, the limitation of fossil fuels and their effects on the environment have become the main reason for the world to search for a new and reliable energy source. There is no doubt that, within some decades we are going to face a severe scarcity of energy. Energy crisis throughout the world directed to the attention to the alternative sources of energy instead of underground fossil fuels as primary energy source has lead to global climate change, environmental degradation and human health problems which has been described in Budiyano, et al. [1]. According to Sen Z [19] and Mills, D M [13], global climate change will inevitably lead to drought, flooding, increases the rate of hurricanes and cyclones and possibly widespread crop failure and global warming. Despite of rapid urbanization, Bangladesh, like other third world agro based counties, among the total annual harvest, a significant portion of cultivable land is devoted for vegetable cultivation across the country. But due to the deficiency of efficient transportation and preservation process, a huge amount of these vegetables are wasted firstly in the land where it was grown and then in the vegetable markets as municipality wastes. Similar situation can be observed for other solid farm wastes. Due to their high moisture and organic contents and biodegradability, these wastes are the major contributors to the emission of greenhouse gases and volatile organic compounds. From the standpoint of Thassitou P K and Arvanitoyannis [24], pollution control, green and other solid wastes are not hazardous materials but their disposal in landfill poses serious environmental pollution. Therefore the security of energy supply, especially development of sustainable energy and reduction of carbon dioxide emission are the prior agenda worldwide. As it is proved in Kaygusuz K and Kayagusuz A [10], biogas is a renewable energy source appear to be one of the most effective and efficient solutions. From Maishanu et al. [11], it is described that, biogas is a carbon neutral, colorless, flammable gas produced from animal, plant, human, industrial and municipal wastes, to give mainly methane (50-60%), carbon dioxide (20-40%) and traces of other gases like hydrogen sulfide, nitrogen, water vapor etc.

The main challenge for producing biogas is to select proper substrate and then the pre-treatment of these raw materials. The substrates used to extract biogas is organic compounds which can be obtained from numerous source of wastes from food industries, kitchen wastes, vegetable and fruit wastes, wastes from slaughterhouses and wastes from green markets. This feedstock undergoes anaerobic digestion and generates biogas (energy source) and digestive (organic manure). Biogas produced here needs to be cleaned or upgraded as it is mixed with some chemical compounds and they decrease the quality of biogas. The efficiency of biogas system can be upgraded by refining (pre-treatment) feedstock, optimizing operating parameters and improving the process. Some post-treatment may be required to clean the biogas and to enrich the methane composition in it.

2. Credibilities of Biogas

The short storage of fossils fuels is creating a red alarm to the industrialized world. The high rate of

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carbon emission also made us to be concern about the environment. Global warming is causing the raise of the sea level, which becomes a threat to the lives of different species of flora and fauna. Besides, environmental pollution is also becoming a source of various diseases to the human life. Fossil fuel like coal and other petroleum oils are the major sources of air pollution. Usage of natural gas in the industries is also a major cause to decrease the amount of natural gas. But the modernized world can't run without industrialization. So, this is the high time that, we should introduce biogas as the alternative of fossil fuels. From the extraction to upgradation, the biogas technologies are environment friendly. Besides, the wastes, which are being used as the raw materials for biogas production, can easily be drained without harming the surroundings. Not only had this, but the biogas technologies are also cost effectives.

3. Pre-treatment of Substrate

The growing global demand with the limited storage of fossil fuels, high price of the fuels, threat for the environment necessitate the use of biogas. Though the stock of raw material for biogas production is huge, but it is important to choose proper substrates and it is more important to treat them before the extraction of biogas. The abundance and availability of lignocellulosic biomass worldwide as well as their high carbohydrate content present them as an attractive feedstock for biogas extraction. Claassen, P A M et al. [3] told that, lignocelluloses have been accounted for nearly 50% of biomass in the world and the production of lignocelluloses can count up to 200 billion tons in every year. Recently Hendriks A T W M and Zeeman G [8] mentioned that, the lignocellulosic residues are being utilized as feedstock for methane production is not explored because of their recalcitrant structure and it is also a big challenge.

According to Teghammar, A et al. [23], at the first step of AD, i.e. during hydrolysis, the hydrolytic bacteria convert the insoluble complex organic matters into monomers and soluble oligomers such as fatty acids, amino acids and sugars. The enzymes involved in this process are celluloses, hemicelluloses, lipases, amylases and proteases. For this reason, in biogas extraction process, almost all kinds of substrates can be hydrolyzed. The rate of hydrolysis step is highly dependent on the characteristics of the chosen substrates. Deublien D and Steinhuser [4] told that, hydrolysis can proceed relatively faster if the required enzymes are produced by microorganisms and suitable surface area for physical content between the enzymes and the substrate is provided. But Vavilin, V A et al. [25] experimented that, the substrates like celluloses needs more time to be degraded and sometimes the degradation remain incomplete.

Therefore, by Zhang Y H P [30], an initial pre-treatment process, which converts raw materials to a form that is amenable to microbial and enzymatic degradation, is needed. A suitable pre-treatment by disruption of secondary cell walls structure will reduce biomass recalcitrance and thus accelerate downstream process. Basically, a pre-treatment should also be cost effective and yields a polysaccharide rich substrate with limited amounts of by-products. There are three major types of pre-treatments. Such as,

3.1 Physical Pre-treatment

This process involves mechanical size reduction method such as milling, shredding, cutting, chipping and so on. The methods described in Schnurer A and Jarvis A [17] and Shah, F A [20] helps to enhance the availability of organic content, to increase the surface area of the biomass, reduce the mass and heat transfer restrictions and the degree of polymerization and crystallinity of cellulose and increase the biodegradability rate of lignocelluloses. Some process like milling produces huge amount of biogas but the process is energy intensive.

3.2 Chemical Pre-treatment

This process includes different types of chemical species, for example, iron liquids, organic solvents, alkali and acids to break the structure of lignin inside the substrates. Some alkali like potassium and sodium hydroxide, anhydrous ammonia, calcium hydroxide and hydrazine swells the substrate by increasing their internal surface area. This results the reduction of degree of crystallinity and polymerization of the substance. It is written in Shah F A [20] that, dilute acid pre-treatment provides access to cellulose by hydrolyzing the hemicelluloses content to monomeric units.

3.3 Biological Pre-treatment

According to Shah F A [20], in this process, the microorganisms are used to breakdown the biodegradable biomass containing polyphenols, lignin and hemicelluloses. Basically, fungal species are used for this purpose. The white rot and the soft rot fungal species are found to break the lignocelluloses content of the substrate. On the other hand, brown rot fungal species are good at degrading the cellulose part in the substrate. Since biological pre-treatment is a slow method, for this reason it can't be suggested for biogas production procedure.

4. Biogas Extraction

Schnurer A and Jarvis A [17] said that, biogas is extracted by anaerobic digestion (AD) process of biodegradable solid wastes which needs environmental factors like temperature, P^H, contents of salts, available food etc. The waste excreted by a microorganism is consumed as food by the next stage microorganism. The production of biogas is done by different biological reactions.

4.1 Hydrolysis

This is the first step in anaerobic digestion process. In this process, the organic matter is depolymerized. The complex insoluble and longer substrate units are hydrolyzed to smaller units. By Schnurer A and Jarvis A [17] and Merlin, C P [12], many hydrolytic microorganisms are used to do this as they secret enzymes like cellulose, amylase, lipase, protease etc. The colonies of facultative and anaerobic microbes cover the substrate particles and break it down to monomeric units.

4.2 Acidogenesis

This reaction is the fastest reaction in the anaerobic digestion process to convert the complex substrates to liquid formulation. Merlin, C P [12] has mentioned in their paper that, in this step, long chained fatty acids, sugars and amino acids formed after the hydrolysis reactions, are being utilized by fermentative bacteria. Thus these substrates are converted into short-chained fatty acids, hydrogen, carbon dioxide, alcohols and other organic acids.

4.3 Acetogenesis

The rate of this reaction is slowed down by the acetogens, as they are slow growing microbes. They are extremely oxygen sensitive, can easily fluctuated during the loading of the organisms and their optimum P^H is 6. After acetogenesis, electron sinks get developed because of the increment in hydrogen ion concentration, they are degraded by acetogens and hydrogen is produced which is used by the next step of microorganisms.

4.4 Methanogenesis

Merlin, C P [12] told that, in this stage, methanogenic bacteria produce methane as metabolic by-product in their anoxic conditions. These organisms use methylated C1 compounds, acetate, hydrogen or carbon as energy source and for their growth. The methane is produced in two ways, either by the cleavage of the acetic acid molecules that generates carbon dioxide and methane or through the reduction of carbon dioxide by producing hydrogen.

5. Challenges of Anaerobic Digestion

As it mentioned in Horvath, I S et al. [9] that, in AD process the organic materials need combined activity of several different groups of microbes with different metabolic capacity. For a stable biogas process, all the conversion steps involved in the degradation of organic matters and the microorganisms carrying out these steps should work in a synchronized pattern. Since methanogens are extremely sensitive bacteria as they have longer duplication duration, so it is important to prevent these groups of microorganisms from being washed away from the considered system. During the last decades, researchers have been developed some high rate systems to lower the effects of toxic compounds, by integrating the biological process with membrane separation techniques.

6. Desulphurization of Raw Biogas

The biogas produced by anaerobic process is mixed with several impurities like hydrogen sulfide, carbon dioxide and other gas. It is necessary to remove the impurities to upgrade the quality of biogas. Though carbon dioxide is the major contamination in the raw biogas, but the actual challenge is to demolish the presence of hydrogen sulfide from the biogas. As hydrogen sulfide is a hazardous gas and it is also a reason for the inefficiency of the biogas. For this reason, it is important to apply a proper method for hydrogen sulfide removal. There are several processes to remove sulfur contents, such as, in-situ desulphurization, biological desulphurization (biological scrubbing), chemical-oxidative scrubbing etc. Among them, in-situ desulphurization is one of the most cheap and reliable processes to demolish sulfur content there. In this process, a little addition of liquid mixture of various iron salts like iron sulfate and iron chloride in the digester tank prior to the digester results precipitation of the sulfur content of the substrate by producing of nearly insoluble iron sulfide within the biogas fermenter. Then the precipitation can be removed from there with the digester. Not only this, ammonia can also be removed from their using this technology. This method is relatively cost effective rather than other methods like biological desulphurization and chemical-oxidative scrubbing. Though biological scrubbing is very clean and stable way to drain the sulfur content, but it is not an effective process. Because, this method is proper if the presence of sulfur content in the biogas is not high and pure oxygen is easily available during the oxidation process. Besides, the chemical-oxidative scrubbing can be advantageous if the amount of hydrogen sulfide is relatively moderate or high and substrates used for biogas extraction are changing frequently. According to the recent writing of Vienna University [26] it is found that, after the successful removal of impurities, the biogas will taken for upgradation so that the amount of methane can be enriched and then the upgraded biogas is ready to be applied in different technologies.

7. Conversion of Biogas into Energy Source

The mostly adopted biogas technology is combined heat and power system (CHP) to covert the biogas into electricity and heat. In the public grid system and district heating networks are the two respective utilization of this technology. Without this technology, the upgraded biogas can be applied as a substitute of natural gas for cooking and electricity and fertilizer production. Other promising biogas technology is the alternative transport fuel of diesel and patrol in automobiles. These technologies are described briefly below.

7.1 Electricity

In Goulding D and Power N [7], Shahnaz, A et al. [21] and Murphya J D et al. [14] it is written that, in this technology, the combustion of biogas is used to run the internal combustion engines, which can drive a power generator. This is the most popular technology according to Wellinger, A et al. [27], where mostly cleaned biogas having 55% methane concentration is used for gas-to-energy conversion, and then it makes a fine contribution in national electricity grid. Here, the heat is generated from the internal combustion is transferred via heat exchanging method and used in water heating, room heating, small heating networks etc. The energy produced in this process has a fair capability. From recent report of Goulding D and Power N [7] it is observed that, approximately 6.9% of total energy exerted from this process is utilized to fulfill the demand of energy such as energy for electrical components and computer support system in an agriculture anaerobic wet digestion plant. Usually, this self-capable technology is independent from the import of external energy source to be run. In general, the electricity input for running CHP system varies dependent on the capacity of the system. Literature of Poschl, M et al. [15] reveals that for a small scale biogas plant, 3% of total electricity is required for process requirement which may go up to 4.5% for a large scale biogas plant.

7.2 Fuel Cell Technology

This technology is performed by the conversion of chemical energy of the fuels through chemical reactions to electrical energy. Won Kang, D [28] said that, this is very promising biogas technology as it has higher efficiency, lower emission and possible for the use of multiple fuels like biogas, natural gas, water and different fluids, which contain hydrogen. By the writing of Galvagno, A et al. [6], this biogas technology can be classified into two familiar groups.

7.2.1 High Temperature Fuel Cells (HTFC)

The HTFC is consists of fuel cells that operate at temperature more than 873 K or 6000 C, such as Molten Carbonate Fuel Cell (MCFC) and Solid Oxide Fuel Cell (SOFC).

7.2.2 Low Temperature Fuel Cells (LTFC)

The LTFC is consists of fuel cells that work at temperature less than 473 K 2000 C, for example, Phosphoric Acid Fuel Cells (PAFC), Alkaline Fuel Cells (AFC), Direct Alcohol Fuel Cells (DAFC), Biological Fuel Cells (BFC) and Polymer Electrolyte Fuel Cells (PEFC).

But the drawback of this technology is the cells can easily be damaged by the impurities present in the biogas. Low temperature fuel cells are higher sensitive towards CO, CO_2, CH_4, H_2S, NH_3, and high temperature fuel cells; the catalytic process is sensitive to H_2S as sulfur is a poison for the catalysts present in anode of the fuel cell.

7.3 Micro Gas Turbines

The gas turbines, which have the size less than 1 MW, are defined as micro gas turbines (MGT). This is very attractive technology as it has low impact on the environment and less operation and maintenance cost. It is very lightweight, small and compact system. It consists of very small components like high speed magnetic generator, radial turbine, and single stage centrifugal compressor.

In the MGT system the air is compressed using centrifugal compressor and sent to the regenerator. Here the compressed air is preheated by the exhaust gas from the micro gas turbine. The preheated compressed air is then used for combustion of fuel in the combustion chamber till inlet temperature requirement of turbine is achieved. The hot gases then expand in the turbine and conveyed to the regenerator for heating the compressed air.

The recent study of Caresana, F et al. [2] it has been revealed that, the use of a high speed magnetic generator can be introduced in this technology to convert the gained energy up to 1600Hz alternative current. The power generated by modulator of this technique can be ranged from 30 KW to 200 KW. The thermal energy of this technology can also be increased greater than 70% by integrating with CHP.

7.4 Heat from Biogas

The biogas can be served as a fuel for the technologies producing heat for several applications, for example, space heating or water heating. The heat generated by the biogas plant combined with combined heat and power generation technology or any other techniques can also be applied to the district heating networks is a centralized system to generate and distribute heat to the residential, institutional and commercial portions. In the recent survey of Poyry and Faber Maunsell [17], it has reported that the heat required by the houses, commercial and industrial sector results 49% demand of energy and this demand exert 47% of carbon emission. This growing demand varies with change in the season. Biogas powered heating networks are used for heating nearby greenhouse, horticulture houses, public amenities and public residential areas. Ericsson, K [5] mentioned that, the district heating networks can be applicable if two or more building connected to one heating source or if only one building having ten or more.

Without the above technique, biogas can also be used in the process of trigeneration of energy, which includes cooling, heating and electricity generation. This technology severally named as combined cooling, heating and power (CCHP). Trigeneration process is occurred through two ways, firstly the production of heat and power by CHP unit which is referred as cogeneration and secondly the utilization of the heat for cooling process in an absorber chillier. In this process, the after the power generation, the exhausted gas from the engine are conveyed to the chillier which generates chilled water for cooling purpose and the heat waste present in the exhausted gas passed to the heat exchanger to produce hot water. Therefore, the absorption chillier works to convert the heat generated from CHP to combine heat, power and cooling. Schuster, A [18] has made a successful survey on the application of such biogas technology.

7.5 Other Utilizations

Goulding D and Power N [7], Shahnaz, A et al. [21] have made the experimental validation that, purified biogas can also be used as substitution of transportation fuel. After taking the biomethane in the compression unit where it will be compressed to a pressure of 200 bars to make it suitable for the distribution systems and then it can be filled in the LPG cylinder. Then the compressed biogas can be used as transport fuel in the vehicles.

Another utilization of biogas is in the national grid system. This process of injecting biogas in the gas grid system can be an energy efficient solution. After compression of the biogas, its pressure increases and it becomes compatible for the pressurized lines of the gas grids. In many countries like Germany, USA, France, Austria and Ireland are using this process in their national gas grid system.

At last but not the least, the biogas technology has a huge probability of success in for cooking purpose. Yingjian, L et al. [29] and Surendra, K C et al. [22] mentioned that, in many developing countries, which have small scale biogas plants are using this technology for cooking. In countries like India and Bangladesh, where the main consumption of natural gas is for cooking, biogas has made its importance as a sustainable alternative as it a heating capability and thermal efficiency.

8. Conclusions

Biogas has created a new remark for the world with its versatile utilization and sufficient efficiency. Besides, the eco-friendly behavior of biogas production process and its application also have a great acceptance to the world. Thus the emerging energy demand for renewable energy compels us to explore new substrates and to develop new and sustainable technologies for biogas production and its utilization. New and stable techniques are also needs to be introduced for the removal of the impurities and upgradation of the biogas. Since AD is a complex microbial procedure of biogas production, a broad range of research is needed to find out the optimum conditions to get more production from less time period. Now the researchers are aimed to study the relationship between microbial community structure, operating conditions and processes to perform. Besides, it is now high time to broaden the field of gas to energy conversion technologies. The small and medium scale of utilization like utilization of biogas in the absorption chillers and cooking purposes needs more chance to be explored for the developing countries.

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