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The Role of Biogas Technologies in Environmental Protection: A Review

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Abstract—*Globally, fossil fuels are a major source of energy supply. They contain carbon that had been stored for millions of years in the earth's crust. The utilization of fossil fuels results in the conversion of this stored carbon into carbon dioxide (CO_2) which gets released into the atmosphere. CO_2 is a greenhouse gas (GHG), a substantial increase in its concentration in the atmosphere will cause global warming eventually resulting in climate change. Unlike fossil fuels, biogas is a renewable form of energy. The combustion of biogas also releases CO_2. However, the main difference, when compared to fossil fuels, is that the carbon in the biogas was recently taken up from the atmosphere, by photosynthetic activity of the plants. The carbon cycle of biogas is thus closed within a very short time (between one and several years). Biogas production also reduces emissions of methane (CH_4) and nitrous oxide (N_2O) from storage and utilization of untreated animal manure as fertilizer. Thus, we have concluded that biogas production is an excellent way for the utilization of organic waste for energy production, followed by the recycling of the digested substrate as fertilizer. Anaerobic Digestion can also contribute in reducing the volume of waste and also in the reduction of the cost of waste disposal. Also, a manifold increase in the production and utilization of biogas will not only improve the energy balance of a country but it will also make an important contribution to the preservation of the natural resources thereby ensuring environmental protection.*

Keywords*: biomass, anaerobic digestion, biogas, clean fuel, green technologies.*

1. INTRODUCTION

Biogas is produced when organic biomass undergoes anaerobic digestion over a period of time (retention period) with an optimum temperature of about 37 ^{0}C for maximum biogas yield. Tiwari et al.[1] have reported that the rate of biogas production and the retention period are functions of slurry temperature. Subramanyam S.[2] found that in northern India in winter season there is a 2°C drop in ambient air temperature (T_a) which either reduces or stops the production of biogas. Therefore, to increase the biogas production, the increase of slurry temperature (T_s) was recommended. Further, Tiwari et al.[3] have suggested the slurry heating in the digester through a heat exchanger connected to flat plate collectors in series under forced mode of operation. Agrahari and Tiwari[4] have experimentally tested and studied the performance of a metal made portable floating type biogas plant having a volume capacity of 0.018 m^3. The analysis was carried out by the use of kitchen waste taken in different ratios. The experiment was conducted in the outdoor climatic condition of New Delhi, India. Each biogas plant had a slurry capacity of 30 kg. For every measurement the slurry was introduced in batch system. During the experimental period various parameters like the temperature, solar radiation and relative humidity were periodically measured at regular intervals. They had analyzed the various constituents of the biogas produced and had determined the pH, volume and rate of biogas production at various temperatures. The observation was noted on a daily basis. They had studied the rate of biogas production from kitchen waste in comparison with other energy sources that are used for cooking purposes like LPG, Kerosene and Coal. Agrahari and Tiwari[5] have also designed and tested the performance of plastic made portable floating type biogas plant of volume capacity 0.018 m³ for outdoor climatic condition of IIT Delhi, New Delhi, India. They had compared the biogas production rate from cow dung and kitchen waste that were fed in a biogas digester having 30 kg slurry capacity. The slurry was introduced in batch system. Physical and chemical analysis of biogas and slurry were carried. A comparative study was done with other fuel sources that can be saved by the use of biogas plant. Bhatti et al. [6] have studied the photovoltaic thermal (PVT) integrated biogas system for a given capacity of slurry and derived an analytical expression for slurry temperature as a function of design and climatic parameters. They wanted to achieve optimum slurry temperature (T_s) of ~35 ^{o}C in order to ensure maximum biogas production. The photovoltaic thermal collectors (PVT) were arranged in a series combination. Exergy analysis of this system was carried out for the month of January for Srinagar (Kashmir), India. The effects of mass flow rate ($\dot{m}_f$), number of PVT collectors, length of heat exchanger (L) and heat capacity of slurry on slurry temperature (T_s) were studied under forced mode of operation. The results were analyzed for three cases namely: Case (i) conventional flat plate collectors, Case (ii) partially covered flat plate collectors and Case (iii) fully covered photovoltaic module. It was concluded that the system consisting of partially covered flat plate collectors as discussed in Case (ii) was highly sustainable and efficient for functioning in harsh cold climatic conditions that exists in Srinagar (Kashmir), India because it would produce both thermal as well as electrical energy simultaneously. Bhatti and Tiwari[7] had carried out exergy analysis of an active N- flat plate collector's (N-FPC's) integrated biogas plant by utilizing the analytical expression of slurry temperature (T_s) that they had derived. The calculations were performed by using MATLAB 2010a. They had concluded that the maximum annual exergy for flat plate collector and slurry were obtained for the months of June and July. The influences of various design parameters such as the mass of the slurry (M_s), the length of the collector pipe (L), the number of collectors in series (N) and the mass flow rate of the slurry; on slurry temperature were studied in order to achieve an optimum slurry temperature (Ts) of ~35 oC .

Further, the above parameters were also been optimised to design an active system for the heating of the slurry. This flat plate collector integrated biogas plant has been observed to be self sustainable and showed a superior performance as compared to a simple biogas plant. Bhatti and Tiwari [8] have carried out the thermal performance analysis of an active N-flat plate collector integrated biogas (N-FPCIB) plant by deriving the analytical expression for calculating the slurry temperature (T_s). he effects of the design parameters such as the mass of the slurry (M_s), the length of the collector pipe (L), the number of collectors in series (N) and the mass flow rate of the slurry has been presented to design an active system. This N-FPCIB system has been observed to be self sustainable and showed a superior performance as compared to a simple biogas plant.

Agrawal and Tiwari [9] have carried out the performance analysis in terms of effect of carbon credit earned on annualized uniform cost of glazed hybrid photovoltaic thermal air collector on the basis of annual thermal energy and exergy for New Delhi climatic conditions. They found that there is a significant decrease in annualized uniform cost due to carbon credits earned.

Shyam et al [10] have studied two different configurations for series combination of N-PVT water collectors and partially covered with photovoltaic module namely for case A: Photovoltaic module at lower portion; case B: Photovoltaic module at upper portion. They have derived the analytical expressions for instantaneous thermal efficiency and temperature dependent electrical efficiency for the systems. They have concluded that at moderate mass flow rate, for large number of PVT water collectors connected in series both cases give nearly same results.

Prabhakant and Tiwari [11, 12] have estimated the carbon credits and return on capital energy payback time for different PV systems under Indian climatic conditions. Mishra and Tiwari [13] have carried out analysis of hybrid photovoltaic thermal (PVT) water collectors under constant collection temperature mode unlike constant flow rate mode. The analysis was carried out in terms of thermal energy, electrical energy and exergy gain for two different configurations. The first case studied was for a collector partially covered by PV module and the second case was for collector fully covered by PV module. They found that the system with collector partially covered by PV module was more favourable from thermal energy point of view and the second system with collector fully covered by PV module was more suitable from electricity generation point of view.

2. BIOGAS TECHNOLOGIES

Bioenergy is sustainable renewable energy. It is obtained from biomass that includes agricultural crops: maize, oak, grass, sorghum, clover and poplar and also from plant and animal wastes etc. Biogas refers to the gas produced by the controlled decomposition of biodegradable materials such as manure, sewage, municipal waste, green waste, plant material, and crops under managed conditions where free oxygen is absent (that is under anaerobic conditions), at temperatures suitable for naturally occurring mesophilic or thermophilic anaerobic bacteria , that convert the inputs to biogas and whole digestate. Biogas primarily comprises of methane (CH_4) and carbon dioxide (CO_2) and it may also have small amounts of nitrogen (N_2), hydrogen sulphide (H_2S) and hydrogen (H_2) as given in Table 1 below.

Table 1: Typical composition of biogas

Compound	Molecular Formula	Percentage (%)
Methane	e	50 - 75
Carbon Dioxide	CO_2	25 - 50
Nitrogen	N_2	0 - 10
Hydrogen Sulphide	H_2S	0 - 3
Hydrogen	H_2	0 - 1

The general equation for anaerobic digestion can be written as given in equation (1) below:

$$(C_6 H_{10} O_5)_{n +} n\ H_2O\ 3n\ CO_2 + 3n\ CH_4 \qquad (1)$$

Biogas installations and processing of agricultural substrates are some of the most important applications of anaerobic digestion today. In Asia alone, millions of family owned, small scale digesters are in operation in countries like China, India, Nepal and Vietnam, producing biogas for cooking and lighting.

3. DIGESTION PRINCIPLE

Anaerobic Digestion is a microbiological process. It is the decomposition of organic matter in the absence of oxygen. The main products of this process are biogas and digestate. Biogas is a combustible gas, consisting primarily of methane and carbon dioxide. Digestate is the decomposed substrate, resulting from the production of biogas. During Anaerobic Digestion , very little heat is generated in contrast to aerobic decomposition (in presence of oxygen). The energy, which is chemically bounded in the substrate, remains mainly in the produced biogas, in the form of methane. The formation of biogas is a result of linked up process steps, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual step. These organisms successively decompose the products of the previous steps. The simplified diagram of Anaerobic Digestion process is shown in Fig 1. below. It highlights the four main process steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Also, the efficiency of anaerobic digestion is influenced by some critical parameters, thus it is crucial that appropriate conditions for anaerobic microorganisms are provided.

The growth and activity of anaerobic microorganisms is significantly influenced by conditions such as exclusion of oxygen, constant temperature, pH-value, nutrient supply, stirring intensity as well as presence and amount of inhibitors (e.g. ammonia).

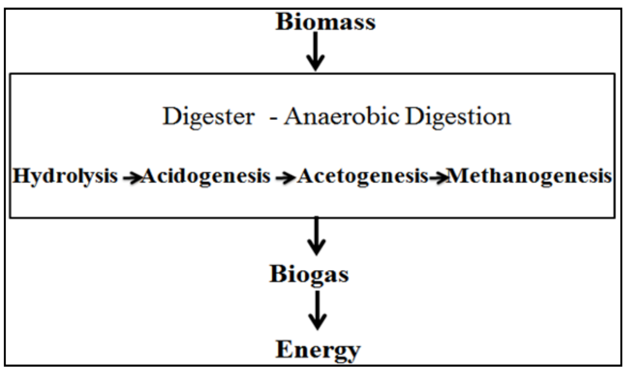

Fig. 1: Anaerobic Digestion pathway of complex organic matter

4. ADVANTAGES OF BIOGAS TECHNOLOGY

The production and utilization of biogas provides environmental and socioeconomic benefits to the society as a whole as well as for the involved farmers as shown in Fig. 2.

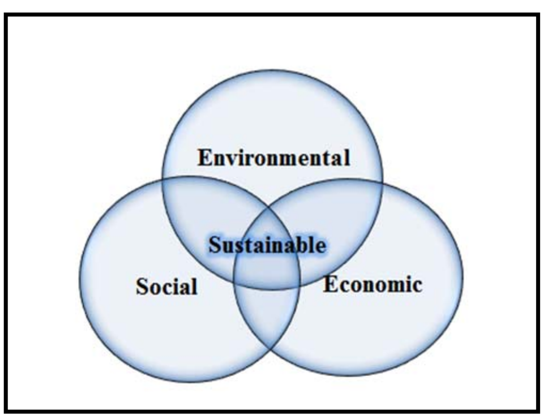

Fig. 2: Benefits of biogas technology

5. ADVANTAGES OF BIOGAS TECHNOLOGY TO THE ENVIRONMENT

Biogas technology not only improves the energy balance of a country but also makes an important contribution to the preservation of the natural resources and to environmental protection. Some of the major advantages are shown in Fig. 3. and stated below :

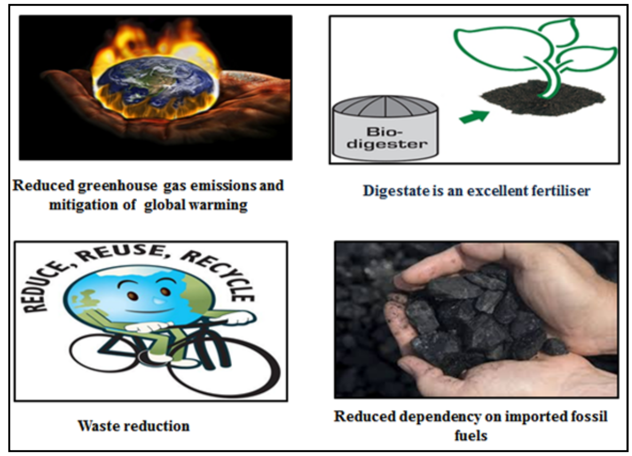

Fig. 3: Benefits of biogas technology to the environment.

- Reduced Greenhouse gas emissions and mitigation of Global Warming - The first and the most important advantage of using biogas technology is reduced greenhouse gas emissions. The combustion of biogas also releases CO_2. However, in comparison to fossil fuels the carbon in the biomass that is used for biogas production was recently taken up from the atmosphere during the process of photosynthesis that is carried out by all green plants. The carbon cycle of biogas is thus closed within a very short time (between one and several years).The greenhouse gas (GHG) potential of methane is higher than the GHG potential of carbon dioxide by 23 fold and in comparison to nitrous oxide it is 296 fold higher. When biogas displaces fossil fuels from energy production and transport, a reduction of emissions of CO_2, CH_4 and N_2O will occur, contributing to mitigate global warming.
- Waste reduction - Another major advantages of producing biogas is the ability to transform waste material into a valuable resource, by using it as a feedstock. Many European countries are facing enormous problems associated with over production of organic wastes from industry, agriculture and households. Biogas production is an excellent way to utilize organic wastes for energy production, followed by recycling of the digested substrate as fertilizer. Anaerobic Digestion can also contribute in reducing the volume of waste and also in the reduction of the cost of waste disposal.

- Reduced dependency on imported fossil fuels - Fossil fuels are limited resources, concentrated in few geographical areas of our planet. The countries that don't have sufficient fossil fuel reserves are insecure as they are majorly dependent on their import. Most European countries are strongly dependent on fossil energy imports from Russia and the Middle East. Developing and implementing renewable energy systems such as biogas technology, based on national and regional biomass resources, will increase national energy supply security and will diminish dependency on imported fuels.
- A biogas plant is not only a supplier of energy. The digested substrate, usually named digestate, is a valuable soil fertiliser, rich in nitrogen, phosphorus, potassium and micronutrients, which can be applied on soils with the usual equipment for application of liquid manure. Compared to raw animal manure, digestate has improved fertiliser efficiency due to higher homogeneity and nutrient availability, better C/N ratio and significantly reduced odours.
- Biogas is a flexible energy carrier, suitable for many different applications. One of the simplest applications of biogas is the direct use for cooking and lighting, but in many countries biogas is nowadays used for combined heat and power generation (CHP) or rather it is upgraded and fed into natural gas grids, used as vehicle fuel or in fuel cells.

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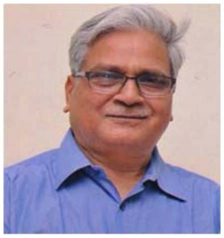
About the Author

Ms. Jasleen Bhatti is a research scholar at Centre for energy studies, Indian Institute of Technology Delhi, India. Ms. Bhatti was born on July 2, 1982 at New Delhi, India. She has completed her Masters in Analytical Chemistry from Dr. B. R. Ambedkar University, Agra (U.P.) India in 2007. Thereafter, she has worked with Genpact, American Express and Foundation for Innovation and Technology Transfer at I.I.T Delhi, India. She has over 4 years of rich experience in industrial research and operations. She joined as a Research Scholar under the supervision of Prof. G. N. Tiwari in December 2011. Her fields of interest include environment and development, socio economic impact assessment, sustainable energy, solar energy and its applications and biogas issues



Dr. Gopal Nath Tiwari was born on July 1, 1951 at Adarsh Nagar, Sagarpali, Ballia (U.P.) in India. He has completed his M.Sc. (Physics) and Ph.D in 1972 and 1976 from Banaras Hindu University, Varanasi (U.P.), India. He is recipient of JRF, SRF and PDF from CSIR, Govt. of India during 1972-1978. He joined as a Research Associate at I.I.T

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