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Sustainable Development in Energy and Environment

Select Proceedings of ICSDEE 2019

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Foreword

It is with deep satisfaction that we write this foreword to the proceedings of the International Conference on Sustainable Development in Energy and Environment (ICSDEE) held in Kamaraj College of Engineering and Technology, 18–20 July 2019. The Department of Biotechnology continues a tradition of bringing researchers, academicians and professionals together from all over the world and experts in economic and social sciences. This conference intended to bring the scientific community together to discuss various topics related to energy and environment, viz.

- Fuel and solar cells
- Biofuels and biorefineries
- Process design and intensification
- Sustainable synthesis analysis and design
- Hydrogen production and storage
- Materials for energy and environment systems
- Climate change and global warming
- Air pollution control
- Solid waste management
- Water policy and regulation
- Water and wastewater treatment
- Life cycle assessment
- Health care

One hundred fifty-seven abstracts were received under various themes, and 126 participants from multiple countries, including India, Vietnam, Thailand and South Korea, attended the conference. This volume consists of select papers presented at the conference.

Sustainable development in energy and environment approaches can be extremely rewarding when the efforts led to important discoveries potentially benefit many and be an essential strategy for the growth and development. Until recently, these sectors have operated independently with little collaboration between researchers. With the rise of demand and the need for alternative sustainable sources, several new trends and perspectives are emerging in these two important domains of research in engineering and technology.

We thank all the administrative authorities of our institution for the opportunity provided to organise this year's international conference. Support extended by the organising committee comprising of staff and students of the Department of Biotechnology right from the planning stage is highly appreciated, and we express our sincere thanks to each one of them.

We place on record our sincere thanks to all the delegates who graciously accepted our invitation and their willingness to share their research experience with the young participants. We thank all the authors and participants for their contributions. This proceeding will furnish the researchers all over the world with an excellent reference book, and this will be an impetus to do further study and research in these areas.

Madurai, India
July 2019

Dr. Anant Achary
Coordinator/ICSDEE'19

Dr. I. Ganesh Moorthy
Dr. S. Karthikumar
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About the Editors

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Dr. Arivalagan Pugazhendhi is currently working as an Assistant Professor in the Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam. He is the Head of Innovative Green Product Synthesis and Renewable Environment Research Group. He obtained his PhD in Environmental Biotechnology from Bharathidasan University, Tamil Nadu, India. During PhD period he was awarded the 'Canadian Commonwealth Scholarship (CCSP)' fellowship by the Canadian Government (Canada). He then worked for the Post-doctoral Researcher, Daegu University, South Korea for 1.5 years and he managed the Biohydrogen research. Thereafter, he joined Ton Duc Thang University as a lecturer and worked there between 2017 and 2019. And he promoted as an Assistant Professor at the same University. He is an Editorial Board Member of Nature Scientific Reports. His research interests include the development of biological processes (Waste to Energy) for Biofuels (Biohydrogen, Biodiesel, Bioethanol, Biobutanol, Bioplastics), wastewater and waste gas treatment, resource recovery of metals, Nanoparticles. He has published over 140 articles in refereed journals and conference proceedings volumes, and also contributed several chapters to books. His university teaching is mainly on Wastewater Treatment and Environmental Pollution.

Dr. I. Ganesh Moorthy is currently an Associate Professor in the Department of Biotechnology, Kamaraj College of Engineering and Technology, Madurai. He completed his B. Tech in Chemical Engineering from Erode Sengunthar Engineering College, Erode and his M. Tech in Chemical Engineering from National Institute of Technology, Tiruchirappalli. He received his PhD from Anna University, Chennai. His current areas of research include statistical and stochastical modelling and optimization, bioprocess modelling, enzyme engineering, bioremediation, bioenergy, environmental biotechnology and industrial effluent treatment. He has completed many funded projects and is currently associated with the Department of Biotechnology, Government of India. He has published 30 research articles in peer-reviewed journals and presented more than 100 articles in national and international conferences, on topics related to energy and environment. He has also contributed a few book chapters in the field of energy and environment. He has one patent granted and filed one patent. He organized many workshops, conferences to promote research activities among students. He is also a reviewer in 12 international peer-reviewed journals such as Biomass and Bioenergy, Trends in Food Science and Technology, Food Research International, Carbohydrate Polymers, Process Biochemistry, International Journal of Biological Macromolecules, Alexandria Engineering Journal, Arabian Journal of Chemistry, Polish Journal of Chemical Technology, International Journal of Environment and Sustainable Development, Journal of Molecular liquids and Preparative Biochemistry and Biotechnology. He acted as a session chair in many international and national conferences.

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A Review on the Production of Biogas from Biological Sources

Yamini Vasudevan, Dhivyadharshini Govindharaj, Gowthama Prabu Udayakumar, Anusiya Ganesan, and N. Sivarajasekar

1 Introduction

Biogas is a renewable form of energy source obtained as a product of anaerobic digestion. It is a compromising replacement that has the potential to meet the world's energy demands and helps in the reduction of waste and Green House Gas (GHG) release [1, 2]. Anaerobic digestion, a classical method for the digestion of organic substrates from biological feedstock, is commonly employed for the sludge stabilization and industrial waste treatment [3, 4]. Global interest on anaerobic digestion research and its applications has been a serious concern due to the erupting fuel prices and awareness about global warming and greenhouse gas emissions. Research now focuses on the most abundant form of solid organic waste, cattle dung, due to its intensive waste disposal problems. Optimizing the treatment of cattle dung might enhance the commercial production [5, 6]. Anaerobic digestion of such organic matter produces biogas containing methane (CH_4) and carbon dioxide (CO_2) enabling it to be used as a fuel for gaseous vehicles, as an alternative for natural gas, as a source for the manufacture of chemicals and in bioenergy production [7]. Increasing capital investment and reduced revenue growth prospects depletes the part of anaerobic digestion using biological waste treatment.

National Biogas and Manure Management Program (NBMMP), Waste To Energy Program (WTE) and Off-Grid Biogas Power Generation Program (OGBPG) are some of the support schemes executed by the Government of India for the production of biogas. Despite several efforts, biogas synthesis is hindered by financial, social and institutional factors. Few researchers concentrate on the obstacle to bioenergy dissemination in rural India while others have focused on the view of the stakeholder and bioenergy potential. The energy content of 1.0m^3 of purified biogas equals 0.97m^3 of natural gas and 1.1L gasoline, 1.7L bioethanol [8]. For cleaning and improvising

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the biogas, several technologies have been developed and commercialized. Comparatively, methane is a clean fuel that produces minimum carbon dioxide per unit energy. Continuous research on biogas aims to enhance the overall efficiency and to meet the economic needs. Under the International Energy Agency (IEA), IEA bioenergy has executed about 10 tasks based on bioenergy, which focus on improving the information on utilization of biogas [9]. In addition to the production of biogas, the anaerobic mesophilic treatment of industrial wastewater with high primary load is implied to reduce the atmospheric pollution [10, 11]. The significance of the share and circulation rate of biogas in rural areas is negligible. The biogas development program has installed about five million small-sized family biogas plants and 400 biogas-based off-grid power plants with 5.5 MW power generating capacity. At present, there are fifty-six operational biogas plants in India, mainly located in Maharashtra, Kerala and Karnataka.

Methane, an essential component of the biogas was produced in large amounts by maize crop digestion carried in a small digester. Energy value model from crude protein, cellulose, crude fat of maize was calculated and the addition of glycerol increased the production and biomass growth [12, 13]. Biomass obtained from grasslands can be effectively utilized as a raw material for biogas production in green bio-refineries industry. Manure from cattle with minimum milk capitulate also plays a major role in production of methane [14–16]. The effective utilization of grassland biomass varies based on their specific properties. Hence, the crop feed stocks supplied during the production of biogas obtained a maximum methane yield per unit area (m^3 ha^{-1}) [17].

This review focuses on providing a collective knowledge about the various available sources for production of biogas and their corresponding yield from different sources. The process and the influencing parameters for the production considering the future perspectives for the growing need for an alternative fuel has been discussed.

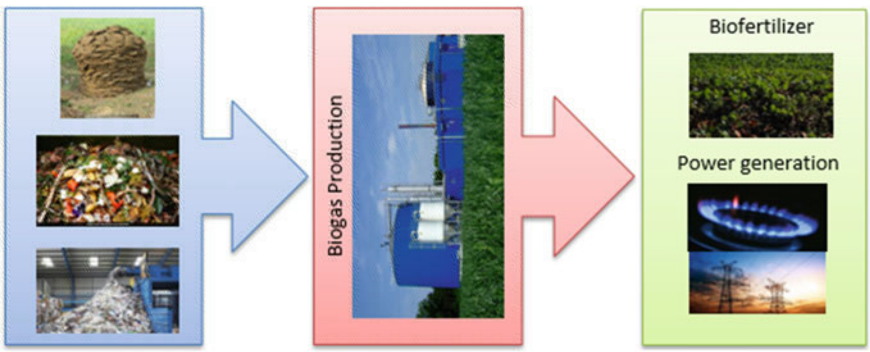

Fig. 1 Waste to energy cycle from solid/liquid effluents to power generation

2 Various Sources for Biogas Production

2.1 Municipal Waste

Household digesters are affordable and productive technologies that are available to distribute energy to the economically backward in the rural areas. The decomposition of tons of organic waste from various sources constitutes to the large-scale contamination of the environment (Fig. 1). For instance, anaerobic degradation of shells of *Lophira lanceolata* revealed a notable rise in the biogas production when added with co-digested pig waste and cassava [18, 19].

Conventional municipal solid waste (MSW) management disposed by land filling causes anthropogenic methane emission which is the main reason for global warming (IPCC 1996). Anaerobic digestion is renewable and environment friendly as a suitable alternative for other methods like incineration and composting. The wastewater containing high levels of microbial load from industries can be treated in-house using anaerobic mesophilic treatment [20]. For instance, the biological treatment methods for potato wastewater produced by a potato processing plant in Harare, Zimbabwe produce high amount of biogas. Anaerobic treatment installed at the potato processing plant was found to enable the plant to treat the potato wastewater with the required effluent quality devoid of the microbium present in it [9].

2.2 Agro-waste

The crop feedstock is applied as a source for the production of biogas to obtain maximum methane yield per unit area (m^3 ha^{-1}) which covers organic biomass dry matter yield (kg ODM ha^{-1}) and specific feedstock methane yield (m^3 kg ODM^{-1}) [21]. The composition of the organic gases in the biogas have been listed in Table 1.

For productive anaerobic digestion, degree of disruption is required as its chemical structure is highly resistant against microbes, degradation and oxidative stress [22]. Over the past few years, bioenergy production using grassland has been increasedand put into practice for biogas production. Subsequently afterthe production of biogas,

Table 1 Composition of agricultural plant biomass

Components	Amount present
Methane	48–65%
Carbon dioxide	36–41%
Nitrogen	17%
Oxygen	<1%
Hydrogen sulfide	32–169 ppm

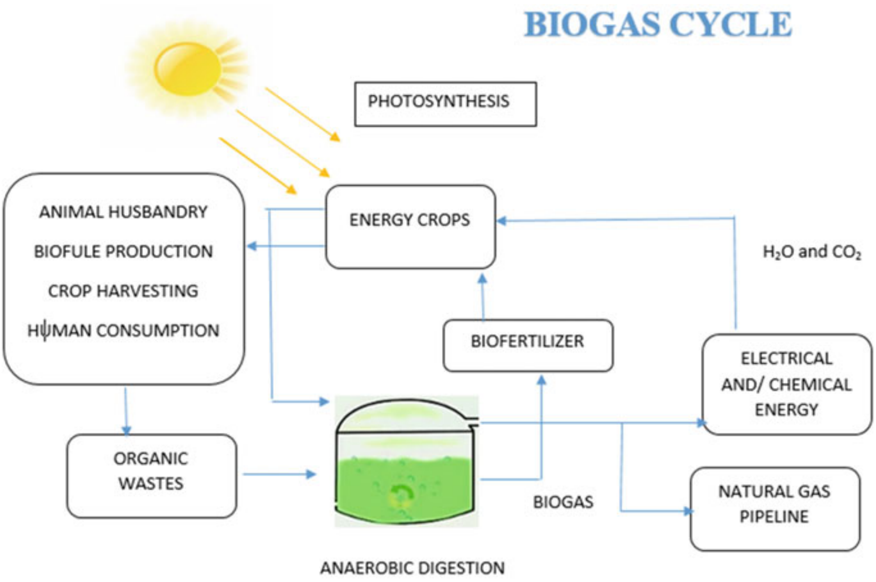

Fig. 2 Biogas cycle

grasses can be utilized to bring out synthetic biofuels/synthetic natural gas and lignocellulosic bioethanol or a solid fuel for combustion. The continually repeating biogas cycle has been represented in Fig. 2.

2.3 *Algae*

Algae, a third-generation feedstock used for the production of biogas, has numerous advantages when compared to the preceding sources.

They are one of the substantial groups of organisms from microalgae to macroalgae. The structure of seaweed/macroalgae looks indistinguishable from that of terrestrial plants but differs significantly in their biochemical compositions. As seaweeds are applied to remove the nutrients from algae, it paves way to lower the pollution and greenhouse gases [23]. In most of the algae, pretreatment is needless due to the absence of lignin components unlike the terrestrial plants. The production rate of a macroalgaeis 2–20 times higher than other techniques and these marcroalga produce biofuel through anaerobic degradation. Anaerobic digestion of algae differs in its biochemical composition mainly focused on environmental components, which is a great challenge. It not only differs among their phyla or genera but also in the group of similar species.

2.4 Industrial Effluents

The rapid increase in industries such as coal manufacture, paper, petrochemical, pharmaceutical and textile industries leads to many harmful effects to the environment caused by improper effluent discharge, and its complexity in reducing the toxicity makes the effluent treatment process more expensive.

Pretreatment of the paper effluents has focused on unified approaches in recent years and can be used in the biomethane production when treated with rumen fluid. Similarly, coal gasification effluent is badly biodegradable and had to be subjected to acid/alkali treatment method. Various applications after the pretreatment like zeolite synthesis and carbon dioxide capture can be continued by choosing the exact method of treatment [24].

At the industrial scale, the pretreatment of industrial effluents opens avenues in solving problems in waste ejection and in resource attenuation. It can be deduced that, rather than constructing multiple individual pretreatment units, designing an interlinked single effluent unit for receiving waste from multiple industries would cut the investment to a major level.

3 Various Steps in Biogas Production

3.1 Biochemical Process

Methane fermentation involves different consortia of microbes carried out in three phases which can partly withstand in interrelation with syntrophic consortia. The three phases are hydrolysis, acidogenesis and acetogenesis/dehydration (Fig. 3).

$$(C_6H_{10}O_5(C_6H_{10}O_5)n + nH_2O \rightarrow n\ (C_6H_{12}O_6)\text{---Hydrolysis} \quad (1)$$

$$n\ (C_6H_{12}O_6) \rightarrow n\ CH_3COOH\text{---Acetogenesis/Acidogenesis} \quad (2)$$

$$3nCH_3COOH \rightarrow n\ CH_4 + CO_2\text{---Methanogenesis} \quad (3)$$

Anaerobic bacterial consortia of *Bacteriocides*, *Clostridia, Bifidobacteria* and acetogenic bacteria *Acetobacterium woodii* and *Clostridium aceticum* were exploited for the process of hydrolysis and fermentation. The doubling time for methane-forming microorganisms is from 5 to 16 days while hydrogen acts as the limiting reactant for the methanogenic consortium where *Methanosarcina barkeri*, *Metanonococcus maizei* and *Methsnotrix soehngenii* degrades acetate into methane and carbon dioxide. The ingredients of biogas are represented in Table 2:

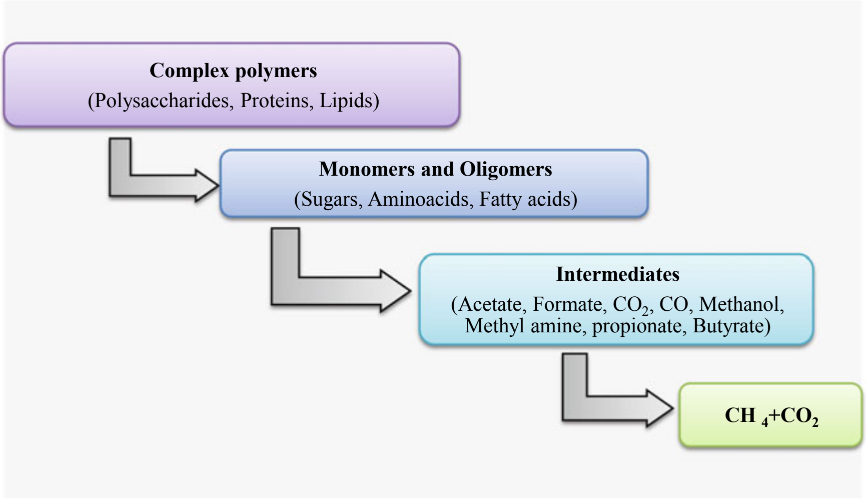

Fig. 3 Stages of the methane fermentation process

Table 2 Biogas composition

Ingredients of biogas	Concentration (%)
Combustible ingredients	
Methane (CH_4)	50–70
Hydrogen (H_2)	<1
Sulfurated hydrogen (H_2S)	2
Non-combustible ingredients	
Carbonic hydrogen (CO_2)	25–50
Water steam (H_2O)	2–7
Oxygen (O_2)	0–0.5

4 Pretreatment Methods

Pretreatment is an essential step for the crop-based waste as it contains high amounts of cellulose or lignin and to increase the efficiency to remove the hemicellulose network linked between cellulose and lignin. The main objective of this pretreatment is to extend the attainable surface area for hydrolases to break down intractable polymers physically as well as chemically and biologically [25]. Considerable increase in the yield of methane could be witnessed in the pre-treated wastes of bagasse, fibers from coconut, sisal, maize bran and water hyacinth when compared to the untreated wastes. Organic and inorganic additives improves the biogas plant performance for instance, *Okara*, a soybean curd residue is used as an additive for wood-based effluents [26, 27].

The comparison between pre-treated and untreated samples with their Biogas yield from Municipal solid waste is shown in Fig. 4.

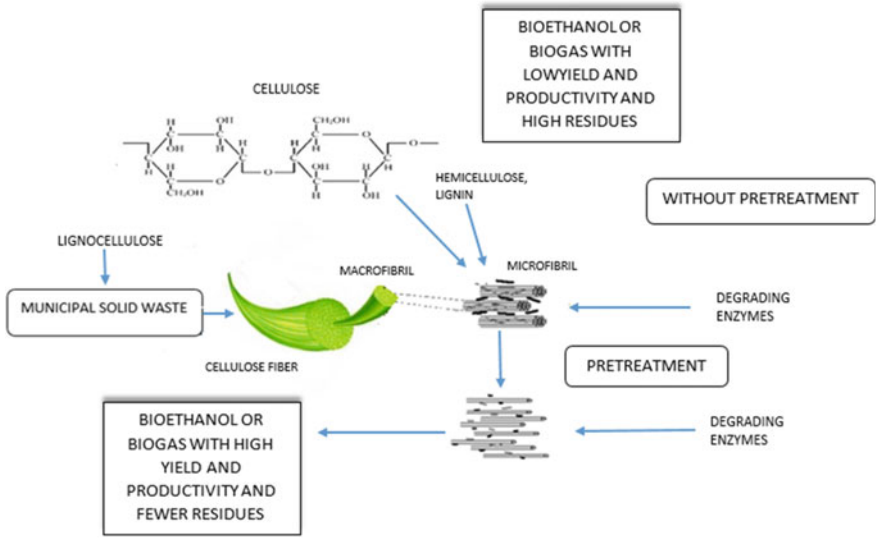

Fig. 4 Comparison of pretreatment and non-pretreatment process

The pretreatments are classified based on the method used, as

(i) Mechanical (milling of dry materials),
(ii) Thermal (using hot water; using steam at 150–180 °C; using high-pressure steam for 20 min at 140–260 °C which causes significant disruption and defibration of the biomass),
(iii) Acidic (using inorganic acid),
(iv) Alkaline (using a base, lime or ammonia),
(v) Oxidative (e.g., with hydrogen peroxide or per-acetic acid) and
(vi) Different combinations from (i) to (v).

4.1 Co-digestion of Organic Wastes

Co-digestion is an evident technology where solid and liquid organic wastes are treated simultaneously. One such example for methane production is by treating Municipal Solid Waste (MSW) with sisal leaf decortications mixed with coffee hulls and chicken/cow dung manure or fish waste, which improves the degradability [28].

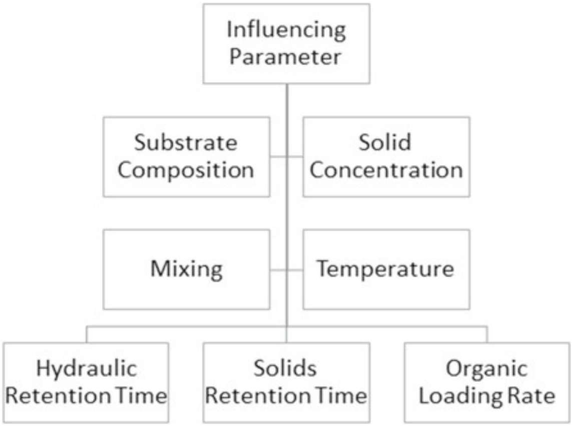

Fig. 5 Parameters influencing the anaerobic digestion [17]

5 Influencing Parameters

C/N ratio is the ratio between carbon sources provided and other nutrients mainly nitrogen, along with phosphorus and sulfur in the substrate. Optimum C/N ratio was found to be 15–45. Higher C/N ratio slower the reaction rate, whereas lower C/N ratio influences the ammonium inhibition [29]. Methanogens grow at neutral pH (6.7–7.5), and the concentration of total solids range from low (2–15%) to high (15–40%) solids in the digester [30]. The parameters influencing anaerobic digestion in the solid waste treatment are listed in Fig. 5.

- Digestion period
- Temperature
- pH.

Methanogenesis is highly reliable on temperature where the optimal temperature for growth of psychrophilic organisms is 10–15°C, mesophilic is 35–40 °C, and thermophilic is 58–68 °C. Similarly, pH ranges for different methanogens, the acidogens grow at pH 5.5–6.5, methanogens grow at pH 7.8–8.2, and the pH of anaerobic digesters is neutral (pH 7–8). Another important parameter mixing determines production, causing shear stress with excess mixing and foaming when no mixing is involved.

6 Design of Anaerobic Digestion

Anaerobic digestion involves the absence of oxygen where the bigger organic matter is cracked down and modified into methane by various microbial species. It involves three stages of metabolism. Primary hydrolysis is where compounds like proteins, lipids are hydrolyzed to soluble ones like amino acids using hydrolytic bacteria and other enzymes. Secondary acidogenesis is where the compounds are cut down into short chain fatty acids and furthermore broken down to oxygen, hydrogen and carbon dioxide. Tertiary methanogenesis is where the methanogenic bacteria completely modifies the acetic acid into methane along with the release of carbon dioxide [31, 32].

Research mainly concentrates on the theory of anaerobic treatment of the organic portion in municipal solid waste as an attractive source for biogas production (OFMSW). However, municipal solid waste is characterized by a high ratio of moisture and volatile solids with very high digestibility greater than 90%. Keeping into consideration the frequency over technical failures and economic feasibility, one-stage system (separate wet and dry digesters) is favored than two-stage or multi-stage systems. Dry digestion degrades waste as received, but wet digestion consumes water to produce 12% total solids [33]. The anaerobic digesters currently in use are fixed dome-shaped digester, floating drum digester and tubular digester. The fixed dome digester is cylinder constructed underground using mortar and bricks to function without getting heated. It consists an inlet and outlet, which acts as the compensation tank where the biogas can be stored in the upper deck of the cylinder. The floating drum digester model, coined by Khadi and Village Industries Commission (KVIC) as Hindu-type digester model, is a cylinder-shaped digester constructed underground using steel and mortar with a floating drum where the gas is stored. The floating drum is built using steel or polyvinylchloride (PVC). The drum is movable based on the quantity of the collected gas above the digester. The tubular digester contains a tube like plastic bag, with a PVC inlet and outlet, and a pipe connected to store biogas from the digester to the tank. The tube-shaped polyethylene collector is concealed in a ditch or trough. Diluted feed passes through the collector from the inlet and then to the outlet. No mixing or heating is involved in tubular-type digesters. Biogas is stored in the top portion of the collector and gathered by means of a gas pipe [34]. In the future, the anaerobic digestion of algae carried out in domestic and commercial digester would be a reliable source for biofuel production due to its diversified cell morphology, biochemical composition and ecology [35].

7 Future Perspectives

The practicable applications of biogas include:

- Steam production by exposing it to flame
- Power production (electricity generation, also through fuel cells)
- Alternative to natural gas in cooking gas
- Fuel (when modified as biomethane)
- Chemical synthesis.

8 Conclusion

Biogas can be used as an alternative for natural gas in all aspects, but it cannot meet the gas requirements for some specific applications [36]. A huge leap in the biogas technology and economic sustainability for biogas plants was witnessed in the last 10 years. Membrane technology can be used instead of tradition separation process to satisfy the economic and environmental aspects in the future. Biogas technology has a very high potential to satisfy domestic energy demands. Loss of any biomass will increase the effect of biogas system to balance the supply chain. The monitoring and maintenance of biogas production turns laborious like the volatile fatty acid formation above a certain level becomes an obstacle to the production of methane. The pretreatment of the agricultural, domestic substrate and addition of micronutrients proved a significant rise in the production of methane and in the yield of biogas.

Hence, it is necessary to upgrade the discharge quality check parameters for the solid waste and liquid effluents to prevent them from polluting the environment, thereby increasing the number of biogas plants for energy production as a process of treating the wastes.

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