A Review on Advancements in Biogas Technologies

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Abstract— The aim of this paper is to bring out the various methodologies applied in generating biogas and technologies used in improving the quality. Various feed materials are used as a biomass, ranging from MSW to kitchen waste is provided in detail. The usage of AD reduces the GWP considerably. 100% reduction in greenhouse gases may be possible by using biogas in incineration process. 95% methane content is made possible and the efficiency comes close to natural gas fueled systems, hence Biogas up-gradation methods are highlighted. Usage of sludge as a natural fertilizer had an added advantage of reduction in Abiotic Depletion Potentials. Lower NOx and SOx are found in biogas fuelled engines. In the dual fuel mode, it gave 26% (biogas+ diesel) efficiency close to that of diesel. Less modification is required for S.I engine to utilize biogas fuel, hence suitable for I.C engines. The applicability of Biogas as fuel from rural to urban areas with the availability of biomass, demonstrates the possibility of the nation to improve its economy and generate employment for the mass.

Keywords—Biogas, Anaerobic Digestion(AD), Gas upgrade, CHP.

I. INTRODUCTION

Biogas is an important renewable source of energy, which is generated by the action of methanogenesis bacteria on organic matter. It is produced by the decomposition of organic matter in anaerobic, damped and oxygen depressed environments. The constituents of biogas include Methane, as the main component and other gases such as carbon-dioxide, $\text{H}_2\text{S}$, water vapor, NO, SO etc. It has been stated that biogas is one of the most leading source of clean renewable energy which can replace fossil_fuels, hence reducing the environment problems affected by the non-renewable sources [1]. The basic composition of biogas is given herewith. MSW have been reported to have a huge potential for biogas generation throughout the states of India [2, 34]. Even though, a biogas may be a clean fuel, an upgraded biogas proves to be better than the untreated one. Upgrading includes various processes and one such important is the reforming of biogas into Syngas [3]. Other known sources of biogas up-gradation include CO2 capture and storage, as given by Renato B et al [6].

Anaerobic Digester or simply AD is the controlled degradation of biodegradable wastes in the absence of oxygen and presence of different groups of bacteria which catalyze a series of complex microbial actions. Main important aspects of using biogas, produced through AD’s include- depletion of GWP, continuous energy production without dependence on external sources, reduced the dependency of artificial fertilizers as the by-product of AD’s produce natural and eco friendly fertilizers. This has been agreed by various researchers over time. The bacterium grows and acts on the organic matter effectively under mesophillic conditions and thermophillic conditions. This has been illustrated by M.H Geradi et al.[5]

The paper provides insight knowledge in biogas production, utilization and end usage technologies. Findings from various researchers upon feed material of AD’s, expertise in gas production tools and methodologies in application of the gas in various Combined Heat and Power (CHP) process have been illustrated.

Table 1 Composition of Biogas

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular formula</th>
<th>% Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>$\text{CH}_4$</td>
<td>50-75</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>$\text{CO}_2$</td>
<td>25-50</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>$\text{N}_2$</td>
<td>0-10</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>$\text{H}_2$</td>
<td>0-1</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>$\text{H}_2\text{S}$</td>
<td>0-3</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$\text{O}_2$</td>
<td>0-0</td>
</tr>
</tbody>
</table>

II. FEED MATERIALS OF AD’S

Cow dung, pig dung, fresh rumen and water were utilized as feed material for biogas production by Aremo M.O et al. They have performed the experiment under mesophlic conditions with temperature ranging from 27-35 °C. The pH value for the whole experiment from feeding of materials to the...
end of the gas production varies from 6.2-6.8. Plastic biodigesters were utilized. They have concluded that cow dung and pig dung were a good energy source, which can later be purified and stored [7].

Poultry droppings with corn hub and waste paper as co-substrate, under temperature range of 29-34 °C, with pH ranging from 4.2-8.0, was found to be suitable for good production of biogas. All the substrate, except the poultry droppings were pretreated as they are lingo-cellulosic materials, physical treatment by milling to reduce particle size and thermal hydrolysis were employed. The AD’s with treated co-substrates proved to yield better results than the ones untreated. [8]

Chompoonut A et al. [9] have reported to have used inoculums seeds and waste water from various agro industrial wastewaters, based on carbohydrate, protein and lipid manufacturers, including a concentrated rubber factory, Cassava starch factory, Palm oil mill factory, Swine farm and Soymilk processing factory. Most of the waste water was found to be acidic nature while swine manure is neutral. Methane production is found to be highest with combinations including- Rubber seeds with Cassava wastewater, Cassava starch seeds with Soy milk wastewater, Palm oil seeds with Soy milk wastewater, Swine seed with Palm oil wastewater and Soy milk seeds with Palm oil wastewater.

The possibility of mixing water-hyacinth with sheep waste in different combinations for anaerobic co-digestion, for biogas generation and digested sludge as an important agricultural product has been illustrated by Jagadish H. P et al. [10] Pretreatment of water-hyacinth was performed by alkali method. Mesophilic conditions were followed with 8% total solids, retention time of 60 days and pH of 6.7 and 6.4 for sheep waste and water-hyacinth. The fermentation slurry (Mixing ratio- 4:12:0.83:90 for Water-hyacinth: Sheep waste: Water) was found to be optimum with maximum biogas yield with composition of 60.81% CH₄, 21.53% CO₂ and 17.63% (H₂, N₂, H₂O, H₂S etc.)

Anaerobic co-digestion of canned seafood wastewater with glycerol waste (GW) and wolffia arrhiza(WA) was performed in Up-flow Anaerobic Sludge Blanket reactor (UASB). It has been found that by using GW and WA as co-substrate, a good biogas with methane content of 62.3% can be obtained [11].

Rafiq Kumar M et al.[12] have suggested in using of Weed Ipomoea in extraction of volatile fatty acids(VFA), comprising mainly of acetic acid and lesser quantities of propionic ad butyric acids. They are feed with methanogens under anaerobic conditions to produce biogas. The extraction of VFA was achieved by the usage of acid phase reactors and charging the leaves along with water inoculated with cow dung. The reactors are stirred intermittently and a conversion of 10% of biomass into VFA is observed.

Wild and Cultivated varieties of reed canary grass for biogas production and comparing the efficiencies of gas production of the two varieties have been suggested by Marta O et al[13]. The plant material were analyzed by Fourier Transform Infrared Spectroscopy (FTIR), which have shown that the wild variety have higher lignin content than the cultivated one as evident by absorbance values of 0.0071 and 0.0062 a.u respectively at wave frequency of 1512 cm⁻¹ to 898 cm⁻¹. The biogas yield was found to be higher in cultivated variety than the wild one, which led to the conclusion by the authors that high dry matter content and indigestible fraction of crude fiber have significant reducing effect on biogas quality and quantity.

Biogas production from food waste have been evaluated by Ojikutu A.O et al.[14] which include yam peels, plantain peels, orange rind and fish waste. The experiment was conducted under a temperature range of 30-37 °C and total solid concentrations of 8%. The mixture and individual waste digesters were studied and it has been found that the highest biogas yield was from the digester containing the mixture and the least from the fish waste alone.

Ravi P.A et al[15] have recommended the usage of kitchen waste as the best alternative for biogas production in a community level biogas plant. Different ratios of kitchen waste with water and manure were compared in a metal made portable floating type biogas plant. It has been suggested that aluminum metal is more efficient as it increases the temperature inside the digester, which in-turn increase the biogas production rate. High production of gas has been observed at ratio of 1:2 of waste and water.

Biogas from Waste Activated Sludge (WAS) using cattle inoculums was investigated by Maamri S et al[16]. Thermophilic conditions with temperature of 55 °C and retention period of 15 days have been applied. The authors found out that with increase in TS concentration, biogas production potential and gas production rate have been increased. This may be due to rich contents of Hydrogen, Nitrogen, Phosphorous, Calcium, Magnesium and a number of trace elements which are essential for anaerobic growth.

Brewery wastes (BW) and Cattle dung (CD) have been reportedly used for biogas production, with mixing ratio of 30:70 of BW and CD as optimum ratio [17]. At maximum organic loading rate, of 3.3kgVS/m³.day in semi continuous mode, there was no clogging of the reactor. The stability of the process has been justified by the gradual reduction of the VFA reduction.

Pennisetum purpureum cv. Pakchong 1 grass and layer chicken manure have been used in completely stirred tank, for biogas production [18]. The experiment was carried out to check the effect of carbon to nitrogen (C/N) ratio and organic loading rate (OLR). The authors, through preliminary investigation have found out that grass and manure ratio of 50:50 and 70:30 by weight yield C/N ratio of 20 and 30 respectively. The average pH value was found to be 6.80 to 7.20. The average alkalinity of effluent was higher than 3000 mg/L, the VFA concentrations are found to be low throughout the experiment and the highest methane yield was found in C/N ratio of 20.

III. GAS PRODUCTION TECHNOLOGIES

Dasgupta B.V et al [19], conducted an experiment to convert the organic fraction of Varanasi’s Municipal Solid waste into biogas. They have preferred anaerobic digestion
since the organic fraction have very good moisture content of about 85% and C/N ratio ranging from 25 to 30. Sodium hydroxide is added to the substrate in the hydrolysis phase. The fraction of municipal waste used for this process includes vegetables, fruits, food waste, paper, grass, leaves and biodegradable textile fibers like wool, silk, cotton etc. and shredded to reduce particle size. Nitrogen gas is subjected into the anaerobic digester to maintain inert atmosphere, and the experiment was carried out in room temperature.

The Chemical Oxygen Demand (COD) value increased initially and decreases, which result in 30% COD solubilization in 0.1 NaOH solution. Correspondingly, high values of COD in 0.5% and 1% of NaOH were observed at the 1st day, and decreased, giving constant value of 60% and 70% respectively. The effect of NaOH on pH of the samples are evaluated and reported to be 5.97 after the alkali addition, rose to 8.7, 10.4 and 12 respectively for 0.1, 0.5 and 1%. The VFA production showed maximum value with addition of 1% NaOH on 4th day, while the pH value decreases with increase in VFA. Addition of Sodium bi-carbonate was made to regulate the pH of 6.8-7.4 which is ideal for methanogenesis. Slurry with 0.1% NaOH produced the greatest yield while slurry with 1% shows the least production with retention time of 15 days. It has been found that the addition of NaOH did not improve the conversion of soluble COD into biogas, as high concentrations of NaOH must have unfavorably affected the digester performance. Sludge with 0.5% NaOH has reduced volatile solids by up to 80%.

A research survey has been taken up by Debadayita R et al. [20] on the implementation of decentralized biogas plants in the state of Assam. Family sized AD (<6m³) and a community sized AD (>25m³) have been analyzed. A wide range of data collection methods including semi structured interviews with family members of the villages, ethnographic observations and pictorial evidence and semi-structured interviews with institutional actors in the reason, have been taken up. It has been found out that biogas plants have great impact on the lively hood on the villages of Assam. It helps in developing the economy of the general public while cutting down the usage of fire woods/manure cakes etc. resulting in reduction in pollution.

Wheat bran, sugarcane bagasse, Rice bran and rape straw were crushed and the sizes were reduced (particle size<180µm). The biomasses are pretreated in two ways- one in 2-3% H₂SO₄ and the other in 0.1mL of α-amylase enzyme. At pH 5 and 30 °C, the enzyme pretreatment was found to be optimum for fermentation, while 3% acidic pretreatment is found to be most favorable for further process. [22].

While Emil Nutiu et al[23], have provided a solution that does not consume energy from external sources. Animal and Bird wastages are used as feed material for the digester. The authors have presented that by the usage of these type of anaerobic fermentation techniques, external energy requirements have been eliminated, excessive production of mud is restricted, high degree of purification of 80-90% in a period of 15-20 days and a biogas with a calorific value of 5,500Kcal/Nm³ can be obtained.
The need for thermal stabilization of digesters of biogas plants by optimization of surface radiative properties of gasometer domes have been emphasized by Alberto M et al. [24].

![Fig.5. Temperature of Digester bath for different domes color – Black (5%), Dark green (10%), White(78%) and White cool roof(85%) [24].](image)

The calculation model have been performed with Energy Plus, as a productive tool to check the impact on the change in solar reflectance of gasometer domes over the temperature of the digester bath. The findings yield a result that these gasometer domes have lower specific profitability and stability than larger plants. A solution to overcome may be rectified by providing the gasometer dome by cool roof materials having high solar reflectance, as without it may affect the production of biogas by affecting the lives of methanogenesis bacteria or the vent of biogas, due to overheating. For smaller plants, it has been specified that, every aspect should be carefully designed during operation in order to make certain of the adequate performance and in return of investments.

![Fig.6. Solar reflectance of gasometer domes [24].](image)

The method of carbon dioxide removal for up-gradation of biogas has proved to be efficient using Alkali Absorption with Regeneration (AwR) [6]. In this process, the CO₂ gas gets separated from the biogas by alkali aqueous solution, and the used absorption solution is again regenerated for repeating the process.

![Fig.7. Scheme of absorption with regeneration of biogas upgrading with CO₂ storage process [25].](image)

Special importance in studying the optimization hydrolysis substrate retention time and augmentation in order to increase biogas production using two-stage digester from Jatropha curcas Linn. Capsule husk is demonstrated by Hendroko Roy S et al [25]. Glass wool is used as immobilized growth into the methanogenesis digester, under mesophilic conditions. With a pH value of 6.20, a retention time of 14 days is not ideal for gas production at optimal condition. This is due to the formation of NH₃ in the hydrolysis digester, increasing the solution pH. The highest biogas yield has been found with a retention time of 4 days, but does not differ significantly with 7 days, at 90% NH₃. While a retention time of 14 days produced least biogas.

Another important aspect of biogas upgrading is the production of Syngas using an Al-based Ni Catalyst. Syngas is produced by dry reforming reaction using methane and carbon dioxide, which are actually the main components of biogas[3]. A chemical model was being implemented for prediction of dry reforming reaction, followed by experiment. Two ratios of biogas have been taken into consideration, CH₄:CO₂ =1:1 and CH₄:CO₂ =1.5:1, in temperature range of about 300-1000 °C at atmospheric pressure. For the dry catalyst reaction, γ-Al₂O₃ catalyst with 10% Ni is used.

![Fig.8. Syngas using reforming reactor [3].](image)

The chemical reaction which is in support of the investigation is given below, denoted as (1) and (2).

\[
2KOH + CO₂ = K₂CO₃ + H₂O \quad (1)
\]
\[
Ca(OH)₂ + K₂CO₃ = CaCO₃ + 2KOH \quad (2)
\]
With increase in temperature, CH$_4$ and CO$_2$ conversion increases, which result in lower CH$_4$ and CO$_2$ in the product gas. CO$_2$ was not present in product gas but higher amount of CO was observed, with considerably rich H$_2$. The carbon footprint will get reduced due to the presence of high H$_2$, and this enables the fuel to be used as a better option for automobiles applications, with concurrent reduction in pollution.

Cartmell E et al.[26] have portrayed the enhancement of biogas by carbon capture through carbon dioxide enrichment in AD treating food waste or sewage sludge. CO$_2$ is injected at 0, 0.3, 0.6 and 0.9M fractions, into batch ADs treating the wastes.

The injected CO$_2$ have been utilized to the levels prior to the enrichment or to other substrate limitation. The recovery of any initial acidification during first 24–48 hours of the digestion may point to the fact that CO$_2$ was consumed up-to the levels, preceding the enrichment. CH$_4$ production was found increasing by 96–138%, indicating the probability of AD’s to consume more CO$_2$.

IV. END USE TECHNOLOGIES

Life Cycle Assessment (LCA) is used as a tool to calculate the environmental impacts of AD-CHP system, following the ISO 14040/14044 methodology [27]. The authors took two common alternatives- Natural gas CHP and Electricity supplied from grid and heat generated by either oil or gas boiler. It has been estimated that 17 tones of Ammonium Sulphate and Nitrate mix per year have been saved. For, Abiotic Depletion Potentials, there has been huge savings due to displacement of artificial fertilizers by the digestate.

In Acidification & Eutrophication potentials (AP and EP), ammonia emissions are responsible for 95% AP and 97% EP. The ammonia is produced in the liquid digestate and escapes through its open air storage.
The Global Warming Potential (GWP) is estimated at 222 kg of CO₂ eq. /MWh, the vast majority (86%) of which is due to methane emissions from the digestate. CO₂ emissions from the biogas combustion in CHP are not considered as they are biogenic in nature. Ozone Depletion Potential (ODP) of 0.8 mg R11 eq. /MWh are caused by the release of halons such as bromotrifluoromethane during the combustion of biogas in CHP process (about 57%).

By using covered storage, large reduction in GWP and POCP occur (80% and 60%) owing to the avoided methane emissions. There is also 18% fall in both AP and EP, owing to reduction in ammonia emissions. It has been established that three most important parameters - feedstock type and source, digestate storage and its application on land, if regulated properly, can lower the majority of impacts compared to fossil fuels and even natural gas.

Bakul R et al.[28] have performed a multi criteria analysis of alternative biogas technologies by using Analytical Hierarchical Process (AHP) tool, with a perspective of overall self reliance of India for biogas technologies promoted by Govt. of India. The author performed the case study for a small biogas plant (2m³). The tool has been used for ranking and analyzing six biogas alternatives- Khadi and Village Industries Commission (KVIC) Digester, KVIC with ferro-cement digester, KVIC with Fiber Reinforced Plastic (FRP) gas holder, KVIC with FRP gas holder and digester, Deenbandhu digester and Bi-phasic digester. The analysis proved that, KVIC with FRP gas holder and digester has the highest ranking, owing to corrosion resistance, leading to less maintenance cost, ease of transport (high strength to weight ratio) and unskilled labor can be utilized with minimum training.

The need of portable electrification using biogas technology, as a means of providing Off-grid power supply system, has been emphasized by Calvin A.C et al. [29]. Portable Energy Storage Device (PESD) is used for charging the electricity generated by using biogas in an IC engine. The study was taken up at Uganda, where less than 10% of the populations have access to electricity, however 50% of them owns a mobile phone. Two scenarios have been taken into consideration- a large biogas system with relatively long distance from customer and a smaller system which is situated close to the customer locations and waste source. It has been found that, small and portable off-grid power source must be constructed close to the waste sources and customers, as it provides lower initial and operating cost. The assumption “bigger is always better” has been proved to be not suitable in all the conditions.

Another important milestone in the field of biogas technology is the conversion of a gasoline engine into a biogas engine to power an electric generator [30]. A single cylinder, 4 stroke S.I engine is considered for conversion methodology. Emphasis has been given to the fact that, for use of the gas as a fuel in the engine, it must be upgraded to zero H₂S and H₂O content. The experiment aims at designing a controlled algorithm to adjust the fuel and air ratio in order to attain lower NO₃ emission and higher generation efficiency. The study revealed that upgraded biogas contains almost 95% methane, which produce efficiency close to natural gas powered engine.

For biogas, the reduction in Green House emission can be as much as 100%. Lower NOx and SOx have been reported to be found in usage of biogas in engines.

In the 4 stroke, 196 cc, compression ratio of 8.5:1, and ignition system of Non-contact Transistor Ignition, the authors have found that biogas can fueled the engine without much modification. LPG mixing with biogas has also been investigated and mixing ratios of 95%, 90%, 85% and 80% (biogas: LPG) were performed. With 100% biogas, the maximum rpm was found to be 1500 rpm. Addition of 5% LPG increase the speed to 1600 rpm and maximum rpm was found to be 3600 rpm at 20% LPG.

Omid R et al. [32] have provided the technologies implemented in usage of usage of biogas in an IC engine. The author presented the impacts of biogas contaminants to the IC engine. H₂S has been found to be the main problem in an IC engine as it causes wear and tear. During combustion H₂S reacts and forms SO₂ and H₂O, further reacting forms H₂SO₄. Siloxanes can form thick silicate deposit in combustion chamber of the engine, exhaust manifolds, turbochargers and stacks. Ammonia is another component found in biogas (AD feed with poultry droppings), which when reacts with H₂O forms NH₂OH, thereby corroding the metals such as Al, Cu. The presence of high amounts of Dilsuents in biogas lowers the Wobble Index and lower heating value, causing lower flame temperature. The heat produced inside the engine chamber during combustion has been reported to be absorbed by CO₂. In order to use biogas in IC engine, certain modifications may be performed such as-usage of more corrosion resistant materials, forged steel pistons etc. The author reported that, biogas engines have reached 64000 working hours before major overhaul. Although there were many biogas fuelled power plants available today, research in this field is lot lesser than other technologies and hence theoretical and experimental works are required to understand the exact combustion mechanisms.

Murugan S et al. [33] have studied the emission characteristics and performance evaluation of a CI engine coupled with gasifier running in dual fuel mode. A downdraft gasifier was designed and developed and a Single cylinder, 4 stroke, CI
engine is used, running at 1500 rpm. Diesel (DF) and Producer gas (PG) (or Syngas) were used in dual fuel mode. The maximum efficiency achieved by a diesel engine was found to be 27.5%, while in dual fuel mode maximum efficiency was close to 26%. The exhaust gas temperature was found to be 330 °C at full load with diesel, and 388 °C at dual fuel conditions. The CO emission was found to be increasing in dual fuel mode compared to Diesel alone, which may be due to incomplete combustion. No emission is found to be lower in Dual fuel mode, compared to diesel. The smoke density is found to be 32% in dual fuel mode, while in Diesel alone accounts to 25%. The experiment yields important results and the authors concluded that, with the use of Syngas gas in CI engine in dual fuel mode, diesel fuel can be saved, although HC and CO emissions are increased at full load conditions compared to diesel, indicating to the insufficient amount of oxygen available in combustion chamber.

Thus the ideology of biogas powered I.C engine has been agreed by many researchers [29, 30, 31, 32 and 33].

V. CONCLUSION

This paper has presented approaches in usage of various feed materials for use in anaerobic digestion process. Various technologies which may be implemented for biogas upgrading and cleaning purpose were presented. Biogas may be used effectively for production of heat and power. The possibility of ceasing of all the non-renewable resources by 2020 provides a new regime in research of advanced renewable energy harnessing methods. Biogas is one among the top renewable resources, after solar, which might play a crucial role in energy production. Researchers must be encouraged to take up various proposals in Biogas sector, as there are many problems which hinder the establishment of biogas systems in today’s world. Use of sophisticated tools such as CFD, Energy Plus etc must be initiated for research and development purpose.

Addition of 0.1% of NaOH produced a great yield of slurry, but is it advisable not to use in high concentrations as it affected the digester performance. Pre-treatment of wastes in 2-3% H2SO4 or 0.1mL of a-amylase enzyme was found to be optimum at pH of 5 and 3°C, in fermentation and further processes. By using specific techniques, biogas with high degree of purification of 80-90% with a retention time of 15-20 days, can be obtained. Gasometer domes provided with cool roof materials having high solar reflectance provides a solution in improving stability and profitability in AD’s. Up-gradation by conversion into Syngas lowers the CO2 from 40% to almost 0%, at 600°C. While CO2 injection techniques with various fractions increases the CH4 content by almost 96-138%. Acidification Potentials and Eutrophication Potentials have fallen by 18%, owing to ammonia reductions. The applicability of biogas in IC engines have proved to be another important milestone in Biogas technologies.

Hence, biogas technology may expand our supply of energy, reduce our reliance on imported fuels, improve the atmosphere by reducing harmful gases and GWP, progress the economy of the Nation, creating jobs for the population, improving the conventional cooking methods and reduce the dependency on artificial fertilizers.

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