Chapter 9
Enhancement of Feedstock Composition and Fuel Properties for Biogas Production



S. Chozhavendhan, G. Gnanavel, G. Karthiga Devi, R. Subbaiya, R. Praveen Kumar and B. Bharathiraja

Abstract Biogas production has materialized as an auspicious technology for the conversion of renewable energy sources such as agricultural, animal, industrial and municipal wastes into a beneficial form of energy. Biogas production is a very attractive and changeling task because of its slower degradation and requires higher retention time via anaerobic digestion (AD) process. Additionally, there is a chance of toxic intermediates in some of these feedstock may result in the decline of the biogas production process. This Biogas technology can be integrated with various strategies to mitigate the environmental pollution. high availability and low cost of these feedstocks promote new strategies for the minimization of waste. Considerable efforts in chic research are undertaken in order to upgrade the composition of the feedstock, efficiency in terms of fuel property and flexibility of biogas production to enhance the economic viability of biogas plants. Along with the methane, biogas consists of various compounds like CO_2, H_2S, water vapor, nitrogen, hydrogen and oxygen which tend to pull down the calorific value when compared with natural gas. Absorption, adsorption, cryogenic method and membrane-based gas permeation are several technologies employed to increase the fuel property of biogas.

Keywords Biogas · Anaerobic digestion · Absorption · Adsorption · Cryogenic method

S. Chozhavendhan (✉) · G. Gnanavel
Vivekanandha College of Engineering for Women (Autonomous), Tiruchengode, India
e-mail: scv.ibt@gmail.com

G. Karthiga Devi · R. Subbaiya
Saveetha Institute of Medical and Technical Sciences, Saveetha School of Engineering, Chennai, Tamil nadu, India

R. Praveen Kumar
Arunai Engineering College, Tiruvannamalai, India

B. Bharathiraja
Vel Tech High Tech Dr. RR Dr. SR Engineering College, Chennai, Tamil Nadu, India

© Springer Nature Singapore Pte Ltd. 2020

R. Praveen Kumar et al. (eds.), *Biomass Valorization to Bioenergy*,
Energy, Environment, and Sustainability,
https://doi.org/10.1007/978-981-15-0410-5_9

9.1 Introduction

On one hand, energy sector at present is focused on the generation of energy for industrial and domestic uses from traditional resources such as fossil fuels (Alexis 2016). However, these fossil fuels are not renewable hence it will lead to depletion of fossil fuels and emits greenhouse gases like carbon dioxide and carbon monoxide which contributes the global warming issues (Ganzoury and Allam 2015). In other hands, since from the industrial revolution, there is a constant increase in the CO_2 concentration in the atmosphere and is likely to go above 750 ppm by this century (Zhang et al. 2014). Because of this the CO_2 traps the infrared radiations thereby raising the atmospheric temperature of the earth, resulted in greenhouse effect. This effect has many shattering consequences, and therefore it becomes mandatory to search for alternative energy sources (Ganzoury and Allam 2015; Alexis 2016).

Biowastes are considered as one of the prevailing next generation renewable energy sources for providing continuous power generation, and these energies are renewable and environmental friendly (Appels et al. 2011). The quest for new forms of renewable energy in many countries has enthused worldwide research in the development of AD process during recent years. Biogas is a clean and accessible futuristic source of energy produced from AD sort out the solution for world's unquenchable energy demands (Shivali et al. 2018; Weiland 2010). At the same time, it helps in reducing the carbon footprints and protect environments which have paved the way for additional importance of anaerobic treatment processes (Kocar and Civas 2013).

Biogas can be considered as alternative green energy carrier for harnessing electricity, heat, and as a transport fuel (Shivali et al. 2018). The development of substrate for the biogas production was supported by a numerous basic research, consequent with a better understanding of microbiology and biochemistry of the process (Zhang et al. 2016). Production of biogas involves a series of four complex biochemical processes (hydrolysis, acidogenesis, acetogenesis and methanogenesis) depending upon different factors like type of substrates, temperature range, pH and inoculum concentration (Kadam and Panwar 2017; Chen et al. 2015; Van Stephan et al. 2016).

9.1.1 Feedstock Composition and Properties

The most and common benefitting substrate used for the biogas production is agricultural biomass residue, animal manure, human excreta, waste water from industries, livestock residue and organic fraction of municipal waste reside. The added advantage of this feedstock as a substrate is its availability, sustainability, energy and economic value.

9.2 Characteristics and Pretreatment of Feedstocks

The cheapest and abundant primary source for biogas production is agricultural residue which comprises crop-straws, sugarcane molasses, fruit- and nutshell, plant stovers, leaves etc. Lignocellulosic biomass can be employed as an effective source for the biogas production which replaces the limitations imposed by crude oil. All the agro-based residues are mainly comprised cellulose (polymer of glucose), hemicellulose (polymer of xylose, mannose and galactose) and lignin (complex chains of phenol molecules). The composition of lingo cellulose varies for each crop based on their origin (Bertero et al. 2012; Iqbal et al. 2013). Cellulose is most abundant on earth and makes up over 25% of plant biomass (Klemm et al. 2005). Hemicellulose is always associated with cellulose as a carbohydrate polymer and makes the interface more firmness (Laureano-Perez et al. 2005). Their structure comprises of sugar molecules arranged as polysaccharides of 100–200 sugar units. Lignin is one of the major cell wall components which act as a barrier to the enzymatic degradation f lignin has a complicated arrangement due to different linkages between the monomers of phenylpropane (Iqbal et al. 2011; Ladisch et al. 2010). This random structure arises from an enzymatically initiated free radical polymerization of lignin precursors in the form of p-hydroxycinnamyl alcohols. The composition of cellulose, hemicellulose, and lignin of various agro-based product (Bahaa et al. 2011; Ye and Jiayang 2002) are shown in Table 9.1.

Rice straw, wheat straw, and corn stalks are the major agricultural waste in the World (Bharathiraja et al. 2016). Wheat straw possess a high C/N ratio and lignocellulose content which causes slower biodegradability in AD process and results in the lower efficiency of biogas production (Wang et al. 2012; Nkemka and Murto 2013). Biogas production was effectively observed in the co-digestion of cow manure

Table 9.1 Shows the composition of cellulose, hemicellulose and lignin of various agro based product

Lignocellulosic materials	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Hardwoods stems	40–55	24–40	18–25
Softwood stems	45–50	25–35	25–35
Nut shells	25–30	25–30	30–40
Grasses	25–40	35–50	10–30
Paper	85–99	0	0–15
Wheat straw	30	50	15
Leaves	15–20	80–85	0
Cotton seed hairs	80–95	5–20	0
Rice straw	32.15	28	19.64

and rice straw when compared with that of mono-digestion of cow manure (Li et al. 2015). Whereas in wheat straw along with cow manure does not show any significant improvement in biogas production.

The pretreatment of feedstock is a necessary step during the biogas production in order to avoid the process failures as well as to increase the degradation process quickly thereby increasing the yield of biogas (Mshandete et al. 2006). This practice has beeb followed since long time for the purpose of increasing the porosity of the material by reducing the cellulose crystallite structure and removing lignin and hemicellulose content for the effective utilization of the substrate by the microorganism (Ye and Jiayang 2002).

Pretreatment of lignocellulose material helps to avoid the formation of byproducts which acts as an inhibitory material for the fermentation process and it also prevents the degradation or loss of carbohydrate. It also helps to improve the formation of sugar or the ability to subsequently form the sugar by an enzyme or other hydrolysis processes. Physical physicochemical, chemical methods and biological processes have been played second hand for pretreatment of lignocellulosic materials (Sivers and Zacchi 1995). Based on the need, the combination of pretreatment can be done.

9.2.1 Animal Manures

Animal manure includes cattle, poultry, pig manure and considered a major carbon source for biogas. Animal manures comprises 90% moisture content and volatile solids of the total solids present. It acts as an ideal substrate due to its good buffering capacity (Fujino et al. 2005; Muller et al. 2004). The presence of diverse microbial flora in animal manure is added advantage because of elimination of inoculation digester. The nutrient content of the animal manure has not reduced significantly and hence it can be used as fertilizer (Risberg et al. 2013; Neshat et al. 2017).

The high nitrogen content of animal manures drags down its usage in anaerobic digestion for biogas production due to its C/N ratio (Tufaner and Avşar 2016). To address this issue, carbohydrate-rich source or nitrogen free the raw material is added to increase the carbon content in the animal manure before the anaerobic digestion process proceedings.

9.2.2 Municipal Solid Waste

The decomposition of organic matter in the municipal wastes has been done globally which resulted in CH_4 emissions over years (Cheng et al. 2016). Composition of OFMSW could vary from high-income countries to low-income countries which includes food and garden waste (Weiland 2010; He et al. 2012). Municipal Solid Waste (MSW) is chiefly comprised of organic matter which accounts for about 55% of organic solid waste. MSW as a substrate possess minimal carbon content which

makes delay in fermentation and also deficient in N and P. However, when MSW are digested properly it has the potential of high biogas production (Del et al. 1999). Municipal solid wastes are comprised of kitchen wastes which include residues of food from households, restaurants, hotels, etc. Kitchen waste is good in carbon source and co-digestion with animal manure significantly increases the biogas production of about 44% as compared to sole digestion of kitchen waste (Zhai et al. 2015).

To increase the biogas production pretreatment of MSW is processed to reduce the particle size reduction and co-digestion with municipal or animal sludge to increase the biogas production (Gomez-Lahoz et al. 2007). Another important thing is to ensure the efficient operation of anaerobic digester and prevention of equipment failure it is recommended to remove the inorganic compounds like metals and glass in material handling (Bernal et al. 1992).

9.2.3 Industrial Waste

The hasty increase in the industrialization provides a aggressive impact on the environment due to their incompetence in effluent treatment processes. Paper and pulp mills, coal manufacturing, pharmaceutical, textile, and petrochemical are the major sectors which releases the copious amount of impurities and known to cause negative impacts on the environment. A wide range of pretreatment methods are employed to lower the level of toxicity to comply with environmental standards (Ruben et al. 2016).

In which, paper has been used in many forms in our day to day activities and comprises more lignocellulose materials. Paper and pulp industrial waste creates an undesirable effect on environment due to its ion balance, disruption of carbohydrates and failure of enzyme activity (Desika et al. 2018; Kinnarinen et al. 2016; Kong et al. 2016). Paper wastes has been used majorly in biomethane production. Baba et al. (2013) reported that, when pretreated paper waste added with rumen fluid the methane yield was increased about 2.6 folds. The methane yield was increased promisingly on microwave pretreatment process in pulp mill sludge waste when compared with ultra-sonication and chemo-mechanical treatment on (Saha et al. 2011). In recent years, several studies have focused on new techniques by means integrated existing pretreatment approaches with the combination of UV pretreatment techniques (Jaafarzadeh et al. 2017). Ferrer et al. (2008) experiments resulted with 30% rise in biogas production on medium—temperature pretreatment process at 70 °C on both primary and secondary clarified wastewater. Thus pretreatment of substrate is mandatory to overcome the negative impacts of waste discharge and to increase the biogas production within a stipulated period of time (Sivagurunathan et al. 2017).

9.3 Influential Parameters of Biogas Production

Along with the biochemical process, pretreatment of feedstock for AD processes must be examined to ensure successful operation (Tiehm et al. 2001). The presence of inorganic and organic toxic material and variation in temperature causes the sudden upsets and failure of anaerobic reactors. The various performance parameters which enhance the biogas production are seeding, volatile fatty acid, pH, particle size reduction, thermal pretreatment, an addition of metals, etc., (Carlsson et al. 2012).

9.3.1 Seeding

Seeding is the most common process of initiating the microbial growth of a in new plant by inoculating the material from already existing plant to the newly established setup. The ultimate aim of this method is to introduce set inoculant into the system. This method will help to reduce the time of digestion of animal manure or municipal waste for the newly commissioned biogas digester as the digested material is already loaded with sufficient quantity microorganisms (Ward et al. 2008).

9.3.2 Volatile Fatty Acid

The most common parameter which governs the AD is Volatile Fatty Acid (VFA) composition and concentration. AD of organic wastes produces series of VFAs include acetic acid, propionic acid, butyric acid, and valeric acid, (Zhang et al. 2014; Pham et al. 2012). Generally, syntrophic acetogens and methanogenic bacteria convert the VFAs produced during anaerobic process are transformed into CH_4 and CO_2. However, VFAs releases large mount of organic components which ultimately decreases the pH and even causes the failure of AD process (Zhang et al. 2013) VFA accumulation reflects a kinetic uncoupling between acid formers and consumers. This typical condition was caused by the presence of toxic or inhibitory compounds, by hydraulic or organic overloading and sudden variation in temperature etc.

9.3.3 pH

pH is an important parameter and has to be monitored and controlled during anaerobic digestion process of biogas production processes because of its activity on the microorganism. Ammonia toxicity is caused due to an increase in free ammonia concentration and controlling the pH levels helps to attain optimum microorganism's

growth on the feedstock. The optimum pH value for AD is in the range of about 6–7.8. The pH values less than 6.2 considerably results in decrease of methanogenic activity and causes several side effects in terms of permeability of microorganisms (Jiang et al. 2013; Mao et al. 2015).

9.3.4 Acid/Alkali Pretreatment

Acid/Alkali pretreatment solubilize hemicellulose, the presence of methanogens has the ability to adapt to inhibiting compounds. But due to the high acid cost, a menace of accumulation of inhibiting compounds and the problems of corrosion are considered to be the downsides of this process (Xiao and Clarkson 1997; Sumphanwanich et al. 2008). The alkali treatment in AD substrate was found to enhance biogas yield when plant material as feedstock (p1-190). The alkali solution often leads to saponification reactions in continuous plants. The bio toxicity phenomenon is less pronounced in alkali treatment since the substrate degradation process were in the range of 60–80% for acetate and glucose respectively (Mouneimne et al. 2003).

9.3.5 C/N Ratio

Carbon to nitrogen ratio gives a better idea in the nutrient composition of the substrate. C/N ratio has a great influence on AD process. The waste material used as a substrate may have unbalanced C/N ratio. The optimal C/N ratio for biogas production is between in the ratio of 20 to −30 or 20 to 30. Lower the ratio increases the risk of ammonia inhibition and higher the ratio results in nitrogen degradation by microbes which leads to insufficient nitrogen to maintain cell biomass (Hassan et al. 2016; Mao et al. 2015).

9.3.6 Particle Size Reduction

The particle size of the substrate mainly influences the digestion of the substrate by indicating the available surface area for hydrolyzing enzyme, especially with the plant fiber. Fiber degradation and methane yield are found to be improved when there is a decrease in feedstock particle size from 100 nm to 2 mm (Mshandete et al. 2006).

9.3.7 Temperature

Temperature is one of the influential parameters affecting the physiochemical properties of liquid phase in AD, because it directly influences the activity of enzyme

and co-enzyme which indirectly influence the methane yield and digestate quality (Appels et al. 2011). Generally, anaerobic bacteria has the ability to grow at psychrophilic mesophilic and thermophilic conditions (Sanchez et al. 2001). The performance of AD, however, increases with increasing temperature. The temperature has a potent effect on the partial pressure of H_2. Even preheating of the substrate before AD has found effectively improve the methane production which leads to reduction of volatile solid content (Carrere et al. 2009). Thermodynamics shows that higher temperature is the most favorable condition for endergonic reactions and less favourable for exergonic reactions (Appels et al. 2011).

9.3.8 Addition of Metals

The cations of heavy metals like Cr, Co, Cu, Zn, Ni, etc. play an important role in AD for synthesizing of enzymes and their maintenance apart from normal nutrients like C, H, O, N and light metal like Na, K, Mg, Ca, Al (Schattauer et al. 2011; Facchin et al. 2013). Heavy metals are not biodegradable and cause inhibition by disruption of enzyme function and a structure on its accumulation. Many literatures stated that cd and Ni addition had an impact in increasing yield of biogas on anaerobic co-digestion of combination of cattle manure with potato waste (Kumar et al. 2006), sodium and potassium presence could have also found to increase the performance of mesophilic and thermophilic organism on biogas production.

9.4 Ultrasonic Treatment

Generally, this method involves the anerobic digestion of sewage sudge as feedstocks in order to which effectively results in increase in biogas production. This technique introduces ultrasonic cavitation into the system by building up the mechanical shear forces for sludge disintegration to improve the physical properties of feedstocks.

9.4.1 Basic Principles Involved in Biogas Production

Anaerobic conversion of organic waste into biogas consists of a chain of interrelated biochemical process and which comprises a consortium of microorganisms (Merlin Christy et al. 2014). The overall process of biogas production includes Hydrolysis, Acidogenesis, Acetogenesis, Methanogenesis.

Hydrolysis is the first step in biogas production in which the larger organic compound is converted into smaller compounds by the aid of anaerobic hydrolytic bacteria (Ganzoury and Allam 2015; Jain et al. 2015). The fastest step in the anaerobic

Table 9.2 Chemical composition of biogas

Compound	Yield (%)
Methane	50–75
Carbon dioxide	25–45
Water vapor	2–7
Nitrogen	<2
Oxygen	<2
Hydrogen sulfide	<1
Hydrogen	<1
Ammonia	<1

digestion process is acidogenesis, in which the hydrolytic products are converted into small and volatile organic acids like butanoic, propionoic (acetic), ethanoic and lactic acid. The third stage of the AD process is the acetogenesis, is the third phase of AD process, in which acetogenic bacteria undergoes acidogenesis resulted in the acetic acid, hydrogen and carbon dioxide. This process is very important for methanogenesis process, as it converts the acidogenesis product into methanogenesis substrate by the microorganisms belong to various genera, including *Clostridium, Acetobacterium, Syntrophospora, Ruminococcus, Syntrophomonas, Sporomusa, Thermosyntropha, and Eubacterium* (Jain et al. 2015). Methanogenesis is the final phase in the biogas production, in which the methanogenic bacteria produces the end product methane from acetic acid, hydrogen and carbon dioxide obtained from the acetogenesis process. Methanogenesis is accomplished by the acetoclastic methanogenesis and hydrogenotrophic methanogenesis process (Chaudhary et al. 2013). 70% of the methane production was done by methanosaeta group of microorganisms in AD. The hydrogenotrophic process, the genus *Methanosarcina* accounts for the 30% conversion of hydrogen and carbon dioxide into methane in anaerobic digestion process (Kothari et al. 2014). The usual chemical composition of biogas composition is represented in Table 9.2.

9.4.2 Biogas Utilization

Biogas is an excellent fuel with a numerous application. The biogas is mainly used as a combined heat and power (CHP) application in worldwide and apart from it can be utilized in three aspects such as production of steam, electricity and fuels for vehicles. Biogas produced from renewable organic waste is considered an alternative energy for fossil fuels for its application in fuel and transportation sector (Appels et al. 2011; Ward et al. 2008). By changing the air ratio, the conventional gas burner technology has been utilized to produce biogas. CHP find its application in internal combustion engine as dual engine or spark-ignition. In future biogas is centered as a fuel cell with high efficiency and low emissions.

9.4.3 Need of Biogas Upgradation

The future potential of bioenergy is evident because of high demand on the dependence of bio-energy production from natural resources (Verdonk et al. 2007). Along with methane gas, biogas contains gases such as CO_2, H_2S, water vapor, nitrogen, hydrogen and oxygen. The efficiency of biogas fuel is determined by its calorific value generally, the calorific value of natural gas is 35.8 MJ/m^3 whereas for biogas is 21.5 MJ/m^3. The incombustible CO_2 value not only reduces the calorific value but also limits economic feasibility of biogas production in generating the power. The contaminants released during biogas production corrodes the downstream equipment. For the high quality of methane and wider application either as heat and electricity or fuel vehicles the impurities need to be removed (Shivali et al. 2018). The purified biogas emits fewer greenhouse gases when compared with fossil fuels and has numerous environmental benefits.

The improved quality of biogas is achieved by improving the feedstock quality or choosing the proper feedstock or eliminates the influencing the parameters of the production process or implementing the upgraded technologies for purification of produced biogas.

9.4.4 Biogas Upgradation and Purification Technologies

Technological development plays an important role in biogas upgradation and purification processes in large-scale commercialization of biogas. The improvement in biogas production is done by either conventional method or implementation of new technologies. The conventional method includes physical absorption chemical absorption, membrane infiltration and biological methods (Eze and Agbo 2010; Bharathiraja et al. 2018) and new technologies include cryogenic upgradation, membrane enrichment, multistage and high pressurized AD.

9.4.5 Physical Absorption

Absorption is a chemical or physical phenomenon in which the components of gas phases diffuse into liquid phase by passing through an interfacial area. The unwanted components of biogas are absorbed with the help of non-reactive fluids in physical absorption process. Either by depressurizing or by heating the spent absorbents are regenerated. In general, either we use water scrubbing or physical scrubbing processes (Cozma et al. 2013).

9.4.6 Pressurized Water Scrubbing

The absorbed gas components are physically bound to the scrubbing liquid. Water scrubbing based absorption technology is most commonly used in the world in recent years. This method is achieved by scrubbing the liquid with a higher solubility of CO_2 and H_2S at lower vapor pressure and usually, polyethylene glycol is employed (Kapoor et al. 2017). The pressurized raw biogas stream is introduced to an absorption vessel from the bottom of the tower and whilst water is flushed from the top. Usually, pre-treated H_2S is used to avoid the problem of corrosion. Raw biogas and water flow in a countercurrent flow in a scrubbing unit and due to the difference in mass transfer coefficient, high concentrated methane gas is collected in the stripper region and whereas the water and other observed heavier compounds are collected at rectifier section. Upgraded biogas is collected, dried and stored for further uses (Cozma et al. 2013). The water used in the scrubbing either by single pass system or it can be recirculated again for the upgradation process. The compression of biogas and recirculation of water through pumps leads to high energy consumption in pressurized water scrubbing process (Patterson et al. 2011).

9.4.7 Pressure Swing Adsorption

Pressure swing adsorption (PSA) is an interesting technology for biogas upgrading, due to compactness of the equipment, low energy requirements, low capital cost, and safety and simplicity of operation (Augelletti et al. 2017). At present, PSA is most commonly used when compared with other types of adsorption and for biogas upgradation. Zeolite, activated carbon, carbon molecular sieves (CMS), silicate, metal-organic framework, silico aluminophosphate sorbents are some of the most common adsorbents employed. PSA work on the principle on physisorption process in which the gas molecules are selectively adsorbed on the surface of the solids based their molecular size.

The design of PSA comprises four columns one is engaged in adsorption while the remaining columns are in regeneration of different phases. In PSA process the H_2S removal step is added since H_2S are absorbed by adsorbents irreversibly. After H_2S removal, is allowed to pass through the column at a given pressure, at which the given amount of CO_2 is absorbed by adsorbents. The equilibrium is attained when the loading of CO_2 also decreases as the pressure is decreased. The cycle is usually completed in approximately 3–5 min. A major drawback with PSA is 15–18% methane losses are observed and also proper treatment of vent is also required as it is directly released into the atmosphere (Sun et al. 2015).

9.4.8 Chemical Absorption

Chemical absorption works on the principle of reversible reaction between absorbed substances and solvent. In general, amines are most commonly used solvent in chemical adsorption process, which chemically interacts by removing acidic gases (CO_2 and H_2S) from methane are diethanolamine (DEA), monoethanolamine (MEA), and methyl diethanolamine (MDEA) (Ryckebosch et al. 2011). Nowadays, a mixture of MDEA and piperazine (PZ), called as activated MDEA (AMDEA), is commonly used in this process. By this process, the high purity methane of more than 99% is achieved due to high selectivity of the chemical solvent towards CO_2 and secondarily to H_2S. In these techniques, high energy input is required for the regeneration of solvents and significantly lower operating pressure is needed but for breaking of bonds (Kapdi et al. 2005). The operating pressure in amine scrubbing plants will be slightly above atmospheric pressure when compared with all other upgrading technologies. The raw biogas and amine solution is get contacted in countercurrent manner in the column in which CO_2 present in the biogas is absorbed by the amine solution by the exothermic reaction and hence the temperature is raised in the column. In this cases increase in temperature increases the absorption of CO_2 in amine solution and pure methane is obtained as exit gas at the top (Deng and Hägg 2010). The major drawbacks with these techniques are massive investment, high operation cost and high energy input and increased chemical consumption have the risk of releasing potentially hazardous degradation products (Voice et al. 2013).

9.4.9 Membrane Separation

In solution-diffusion model is a method in which concentration difference exists through which permeates are dissolved in a membrane and then diffuse by means of convection through small pores (Rongwong et al. 2012). Some considerations are taken into account for upgrading the biogas plant as well as their production. In such separation, the carbon dioxide content will be high and it flows through the membrane while the methane remains as retentate (Baker and Lokhandwala 2008). The process operates at low capital cost and also it requires very less energy. For the purification purposes, mainly polymeric and inorganic membranes are employed as they offer high mechanical as well as thermal stability.

Membrane-based technology has many advantages over other systems as it requires low labor maintenance. The process of separation is based on the concentration of volatile organic compounds (Scholz et al. 2013). It has some limitations such as high cost and the sensitive to damage by the vibrations caused by colloidal solids.

9.4.10 Emerging Technologies

Removal of CO_2 from biogas is easy from the above-mentioned process. However, removal of trace elements like H_2S and other volatile organic compounds (VOCs) is a task for a search of new technologies. These trace elements are needed to be removed before utilization or else it creates a serious problem by corroding the pipelines. Thus an emerging technologies came into existence.

9.4.11 Cryogenic Upgradation

The continuous modification of biogas process leads to the development of cryogenic upgradation process to purify and bottling of biogas. Cryogenic separation of biogas is based on the principle that various gases liquefy under different operating conditions. This whole process operated at a very low temperature and high pressure conditions which are usually maintained by a number of compressor and heat exchanger (Zanganeh et al. 2009). This cryogenic technology is 4 stage process. In stage 1 all trace elements were removed before entering stage 2. Whereas in stage 2 the biogas is compressed and cooled subsequently. In stage 3 the biogas is further cooled to −50 °C and liquid CO_2 is removed before entering in stage 4 and in final stage finally, the remaining gas stream is further cooled to collect purified methane gas and CO_2 is removed in solid form (Imran et al. 2017). Cryogenic technology is demanding technique but it has limitations I high methane content (<99%) and low methane losses (<1%). Another advantage of this is an environmentally friendly technique and pure CO_2 is received as a byproduct. The main drawback of this process is the use of variety of process equipment and which raise its capital and operational costs.

9.4.12 In Situ Methane Enrichment

The major task involved in scaling up the biogas process involves the separation of methane-rich biogas from CO_2 which is highly expensive. In situ methane enrichment based biogas upgradation technology was done using desorption process When is flow is in counter flow direction, CO_2 dissolved in the sludge was desorbed with O_2 and N_2 in the desorption column from the digestion chamber. The circulated sludge is then sent back to digester from desorption column for absorption of an additional CO_2 present (Kadam and Panwar 2017). A simple in situ technique was developed to separation of CO_2 and CH_4 from biogas was done using in situ techniques based on solubility differences. The purity of methane gas was found at a greater percentage 98% (Richards et al. 1994).

9.4.13 Multistage and High Pressurized AD

A number of researches and ideas are proposed to evaluate different configurations in order to improve the efficiency of anaerobic digestion. The biogas production was carried out in four stages in two different reactors which increase the rate of bioconversion of organic material to methane. The major application of multiple bioreactor systems is to improve the process stability and higher efficiency with the drawback of cost of installation.

9.4.14 Cost Economics and Environmental Sustainability

Cost is one of the most crucial and determining factor involved in optimizing the particular production process. The production process largely depends on the capital and operating costs of biogas upgrading technologies involved in biogas production, quality of raw biogas produced, product quality, importantly the size of the plant (Yang et al. 2014). Maintenance cost is one of the key factors which biogas production as it increases the operation cost of the upgrading technologies (Campanaro and Treu 2016; Bassani et al. 2015). Utilization of biogas as a vehicular fuel requires a highly concentrated methane purity which can be ensured by several technologies. Chemical absorption technologies provide higher efficiency with higher investments where as the technologies like water scrubbing and in situ are economically viable (Bauer et al. 2013). However, cryogenic technology produces high pressurized liquid fuel and cost-effective in terms of maintenance cost in larger scale applications (Collet et al. 2017). For, membrane separation processes the operational cost is very low but the investment cost is apparently high, (Vrbová and Karel 2017).

9.5 Conclusion

Biomethane is a promising renewable technology as well as an effective substitute for natural gas for grid and vehicular applications. Utilization of agricultural waste, industrial and municipal waste as a source of biogas production will make an economic feasibility. Methane gas and carbon dioxide are the major compounds produced along during biogas production along with various compounds in traces. The impurities present in trace level affects the commercial application of biogas in large scale and hence it has to be removed before utilization. For the past two decades, numerous different technologies have been employed for upgradation of biogas production and have an impact on reducing greenhouse gas emissions and ensuring a more sustainable environment. The proposed technologies like physical

and chemical absorption, adsorption, membrane separation, cryogenic separation and in situ upgrading can help to improve stability and reliability of the biomethane production chain.

References

Alexis N (2016) Mini review: update on bioaugmentation in anaerobic processes for biogas production. Anaerobe 46:3–12

Appels L, Joost L, Degreve J, Helsen L, Lievens B, Willems K, Impe VJ, Dewil R (2011) Anaerobic digestion in global bio-energy production: potential and research changes. Renew Sustain Energy Rev 15:4295–4301

Augelletti R, Conti M, Annesini MC (2017) Pressure swing adsorption for biogas upgrading. A new process configuration for the separation of biomethane and carbon dioxide. J Clean Prod 140:1390–1398

Baba Y, Tada C, Fukuda Y, Nakai Y (2013) Improvement of methane production from waste paper by pretreatment with rumen fluid. Bioresour Technol 128:94–99

Bahaa TS, Manal GM, Eman AG, Asker MMS, Ibrahim GS (2011) Enzymatic hydrolysis of rice straw and corn stalks for monosugars production. J Genet Eng Biotechnol 9:59–63

Baker R, Lokhandwala K (2008) Natural gas processing with membranes: an overview. Ind Eng Chem Res 47:2109–2121

Bassani I, Kougias P, Treu L (2015) Biogas upgrading via hydrogenotrophic methanogenesis in two-stage continuous stirred tank reactors at mesophilic and thermophilic conditions. Environ Sci Technol 49:12585–12593

Bauer F, Persson T, Hulteberg C, Tamm D (2013) Biogas upgrading—technology overview, comparison and perspectives for the future. Biofuels, Bioprod Biorefin 7:499–511

Bernal O, Llabres P, Cecchi F, Mata-Alvarez J (1992) A comparative study of the thermophilic biomethanization of putrescible organic wastes. Waste waters 1:197–206

Bertero M, de la Puente G, Sedran U (2012) Fuels from bio-oils: bio-oil production from different residual sources, characterization and thermal conditioning. Fuel 95:263–271

Bharathiraja B, Sudharsana T, Jayamuthunagai J, Praveenkumar R, Chozhavendhan S, Iyyappan S (2018) Biogas production—a review on composition, fuel properties, feed stock and principles of anaerobic digestion. Renew Sustain Energy Rev 90:570–582

Bharathiraja B, Sudharsanaa T, Bhargavi A, Jayamuthunagai J, Praveenkumar R (2016) Biohydrogen and biogas—an overview of feedstock and enhancement process. Fuel 185:810–828

Campanaro S, Treu L (2016) Metagenomic analysis and functional characterization of the biogas microbiome using high throughput shotgun sequencing and a novel binning strategy. Biotechnol Biofuels 9:1–26

Carlsson M, Lagerkvist A, Morgan-Sagastume F (2012) The effects of substrate pretreatment on anaerobic digestion systems: a review. Waste Manag 32:1634–1650

Carrere H, Sialve B, Bernet N (2009) Improving pig manure conversion into biogas by thermal and thermo-chemical pretreatments. Bioresour Technol 100:3690–3694

Chaudhary PP, Brablcova L, Buriankova I, Rulik M (2013) Molecular diversity and tools for ciphering the methanogen community structure and diversity in freshwater sediments. Appl Microbiol Biotechnol 97:7553–7562

Chen C, Zheng D, Liu GJ, Deng LW, Long Y, Fan ZH (2015) Continuous dry fermentation of swine manure for biogas production. Waste Manag 38:436–442

Cheng C, Wenshan G, Huu N, Duu-Jong L, Kuo-Lun T, Pengkang J, Jie W, Yun W (2016) Challenges in biogas production from anaerobic membrane bioreactors. Renew Energy 98:120–134

Collet P, Flottes E, Favre A, Raynal L, Pierre H, Capela S, Peregrina C (2017) Techno-economic and life cycle assessment of methane production via biogas upgrading and power to gas technology. Appl Energy 192:282–295

Cozma P, Ghinea C, Mămăligă I, Wukovits W, Friedl A, Gavrilescu M (2013) Environmental impact assessment of high pressure water scrubbing biogas upgradation technology. Clean 41:917–927

Del BA, Converti A, Palazzi E, Del Borghi M (1999) Hydrolysis and thermophilic anaerobic digestion of sewage sludge and organic fraction of municipal solid waste. Bioprocess Eng 20:553–560

Deng L, Hägg MB (2010) Techno-economic evaluation of biogas upgrading process using CO_2 facilitated transport membrane. Int J Greenh Gas Control 4:638–646

Desika P, Subha SK, Varshini TM, Thangavel M, Gopalakrishnan K, Eldon RR, Arivalagan P (2018) Pretreatment technologies for industrial effluents: critical review on bioenergy production and environmental concerns. J Environ Manage 218:165–180

Eze JI, Agbo KE (2010) Maximizing the potentials of biogas through upgrading. Am J Sci Ind Res 1:604–649

Facchin V, Cavinato C, Fatone F, Pavan P, Cecchi F, Bolzonella D (2013) Effect of trace element supplementation on the mesophilic anaerobic digestion of food waste in batch trials: the influence of inoculums origin. Biochem Eng J 70:71–77

Ferrer I, Ponsa S, Vazquez F, Font X (2008) Increasing biogas production by thermal (70 °C) sludge pre-treatment prior to thermophilic anaerobic digestion. Biochem Eng J 42:186–192

Fujino J, Morita A, Matsuoka Y, Sawayama S (2005) Vision for utilization of livestock residue as bioenergy resource in Japan. Biomass Bioenergy 29:367–374

Ganzoury MA, Allam NK (2015) Impact of nanotechnology on biogas production: a mini-review. Renew Sustain Energy Rev 50:1392–1404

Gomez-Lahoz C, Fernandez GB, Garcia HF, Rodriguez MJM, Vereda AC (2007) Biomethanization of mixtures of fruits and vegetables solid wastes and sludge from a municipal waste water treatment plant. J Environ Sci Health 42:481–487

Hassan M, Ding W, Shi Z, Zhao S (2016) Methane enhancement through co-digestion of chicken manure and thermo-oxidative cleaved wheat straw with waste activated sludge: a C/N optimization case. Biores Technol 211:534–554

He Y, Bagley DM, Leung KT, Liss SN, Liao BQ (2012) Recent advances in membrane technologies for biorefining and bioenergy production. Biotechnol Adv 30:817–858

Imran UK, Othman MHD, Hashim H, Matsuura T, Ismail AF, DashtArzhandi MR, Azelee IW (2017) Biogas as a renewable energy fuel—a review of biogas upgrading, utilization and storage. Energy Convers Manag 150:277–294

Iqbal HMN, Ahmed I, Zia MA, Irfan M (2011) Purification and characterization of the kinetic parameters of cellulase produced from wheat straw by *Trichodermaviride* under SSF and its detergent compatibility. Adv Biosci Biotechnol 2:149–156

Iqbal HMN, Kyazze G, Keshavarz T (2013) Advances in valorization of lignocellulosic materials by bio-technology: an overview. Bio Resources Technol 8:3157–3176

Jaafarzadeh N, Ghanbari F, Ahmadi M, Omidinasab M (2017) Efficient integrated processes for pulp and paper wastewater treatment and phytotoxicity reduction: permanganate, electro-fenton and Co_3O_4/UV/peroxymonosulfate. Chem Eng J 308:142–150

Jain S, Jain S, Wolf IT, Lee J, Tong YW (2015) A comprehensive review on operating parameters and different pretreatment methodologies for anaerobic digestion of municipal solid waste. Renew Sustain Energy Rev 52:142–154

Jiang J, Zhang Y, Li K, Wang Q, Gong C, Li M (2013) Volatile fatty acids production from food waste: effects of pH, temperature, and organic loading rate. Biores Technol 143:525–530

Kadam R, Panwar NL (2017) Recent advancement in biogas enrichment and its applications. Renew Sustain Energy Rev 73:892–903

Kapdi SS, Vijay VK, Rajesh SK, Prasad R (2005) Biogas scrubbing, compression and storage: perspective and prospectus in Indian context. Renew Energ 30:1195–1202

Kapoor R, Subbarao PMV, Vijay VK, Shah G, Sahota S, Singh D, Verma M (2017) Factors affecting methane loss from a water scrubbing based biogas upgrading system. Appl Energ 208:1379–1388

Kinnarinen T, Golmaei M, Jernstrcom E, Hcakkinen A (2016) Separation, treatment and utilization of inorganic residues of chemical pulp mills. J Clean Prod 133:953–964
Klemm D, Schmauder HP, Heinze T (2005) Cellulose Biopolym 6:277–312
Koçar GK, Civas N (2013) An overview of biofuels from energy crops. Renew Sustain Energy Rev 28:900–916
Kong L, Hasanbeigi A, Price L (2016) Assessment of emerging energy-efficiency technologies for the pulp and paper industry: a technical review. J Clean Prod 122:5–28
Kothari R, Pandeya K, Kumar S, Tyagi VV, Tyagi SK (2014) Different aspects of dry anaerobic digestion for bio-energy: an overview. Renew Sustain Energy Rev 39:174–195
Kumar A, Miglani P, Gupta RK, Bhattacharya TK (2006) Impact of Ni (II), Zn (II) and Cd (II) on bio gasification of potato waste. J Environ Biol 27:61–66
Ladisch R, Mosier NS, Kim Y, Ximenes E, Hogsett D (2010) Converting cellulose to biofuels. SBE Spec Suppl Biofuels 106:56–63
Laureano-Perez L, Teymouri F, Alizadeh H, Dale BE (2005) Understanding factors that limit enzymatic hydrolysis of biomass. Appl Biochem Biotechnol 2005:1081–1099
Li D, Liu S, Mi L, Li Z, Yuan Y, Yan Z, Liu X (2015) Effects of feedstock ratio and organic loading rate on the anaerobic mesophilic co-digestion of rice straw and cow manure. Bioresour Technol 189:319–326
Mao C, Feng Y, Wang X, Ren G (2015) Review on research achievements of biogas from an aerobic digestion. Renew Sustain Energy Rev 45:540–555
Merlin Christy P, Gopinath LR, Divya D (2014) A review on anaerobic decomposition and enhancement of biogas production through enzymes and microorganisms. Renew Sustain Energy Rev 34:167–173
Mouneimne AH, Carrere H, Bernet N, Delgenes JP (2003) Effect of saponification on the anaerobic digestion of solid fatty residues. Bioresour Technol 90:89–94
Mshandete A, Bjornsson L, Kivaisi AK, Rubindamayugi MST, Matthiasson B (2006) Effect of particle size on biogas yield from sisal fibre waste. Renew Energy 31:2385–2392
Muller JA, Winter A, Strunkmann G (2004) Investigation and assessment of sludge pre-treatment processes. Water Sci Technol 49:97–104
Neshat SA, Maedeh M, Najafpour GD, Pooya L (2017) Anaerobic co-digestion of animal manures and lignocellulosic residues as a potent approach for sustainable biogas production. Renew Sustain Energy Rev 79:308–332
Nkemka VN, Murto M (2013) Biogas production from wheat straw in batch and UASB reactors: the roles of pretreatment and seaweed hydrolysate as a co-substrate. Bioresour Technol 128:164–172
Patterson T, Esteves S, Dinsdale R, Guwy A (2011) An evaluation of the policy and techno-economic factors affecting the potential for biogas upgradation for transport fuel use in the UK. Energy Policy 39:1806–1816
Pham TN, Nam WJ, Jeon YJ, Yoon HH (2012) Volatile fatty acids production from marine macroalgae by anaerobic fermentation. Bioresour Technol 124:500–503
Richards BK, Herndon FG, Jewell WJ, Cummings RJ, White TE (1994) In situ methane enrichment in methanogenic energy crop digesters. Biomass Bioenergy 6:275–282
Risberg K, Sun L, Levén L, Horn SJ, Schnürer A (2013) Biogas production from wheat straw and manure–impact of pretreatment and process operating parameters. Bioresour Technol 149:232–237
Rongwong W, Boributh S, Assabumrungrat S, Laosiripojana N, Jiraratananon R (2012) Simultaneous absorption of CO_2 and H_2S from biogas by capillary membrane contactor. J Memb Sci 393:38–47
Ruben TF, Pierre B, Remy B (2016) Ensiling for biogas production: critical parameters. A Rev Biomass Bioenergy 94:94–104
Ryckebosch E, Drouillon M, Vervaeren H (2011) Techniques for transformation of biogas to biomethane. Biomass Bioenergy 35:1633–1645

Saha M, Eskicioglu C, Marin J (2011) Microwave, ultrasonic and chemomechanical pretreatments for enhancing methane potential of pulp mill waste water treatment sludge. Bioresour Technol 102:7815–7826

Sanchez E, Borja R, Weiland P, Travieso L, Martín A (2001) Effect of substrate concentration and temperature on the anaerobic digestion of piggery waste in a tropical climate. Process Biochem 37:483–489

Schattauer A, Abdoun E, Weiland P, Plol M, Heiermann M (2011) Abundance of trace elements in demonstration biogas plants. Biosyst Eng 108:57–65

Scholz M, Melin T, Wessling M (2013) Transforming biogas into biomethane using membrane technology. Renew Sustain Energy Rev 17:199–212

Shivali S, Goldy S, Pooja G, Rimika K, Subhanjan S, Priyanka S, Vandit V, Arunaditya S, Virendra Kumar V, Indu ST (2018) Review of trends in biogas upgradation technologies and future perspectives. Biores Technol 1:79–88

Sivagurunathan P, Anburajan P, Kumar G, Arivalagan P, Bakonyi P, Kim SH (2017) Improvement of hydrogen fermentation of galactose by combined inoculation strategy. J Biosci Bioeng 123:353–357

Sivers MV, Zacchi G (1995) A techno-economical comparison of three processes for the production of ethanol from pine. Bioresour Technol 51:43–52

Sumphanwanich J, Leepipatpiboon N, Srinorakutara T, Akaracharanya A (2008) Evaluation of dilute-acid pretreated bagasse, corn cob and rice straw for ethanol fermentation by *Saccharomyces cerevisiae*. Ann Microbiol 58:219–225

Sun Q, Li H, Yan J, Liu L, Yu Z, Yu X (2015) Selection of appropriate biogas upgrading technology—a review of biogas cleaning, upgrading and utilization. Renew Sustain Energy Rev 51:521–532

Tiehm A, Nickel K, Zellhorn M, Neis U (2001) Ultrasonic waste activated sludge disintegration for improving anaerobic stabilization. Water Res 35:2003–2009

Tufaner F, Avşar Y (2016) Effects of co-substrate on biogas production from cattle manure: a review. Int J Environ Sci Technol 13:2303–2312

Van Stephan F, Mathot M, Decruyenaere V, Loriers A, Delcour A, Planchon V, Goffart JP, Stilmant D (2016) Consequential environmental life cycle assessment of a farm-scale biogas plant. J Environ Manage 175:20–32

Verdonk M, Dieperink C, Faaiji APC (2007) Governance of the emerging bio-energy markets. Energy Pol 35:3909–3924

Voice AK, Closmann F, Rochelle GT (2013) Oxidative degradation of amines with high-temperature cycling. Energy Procedia 37:2118–2132

Vrbová V, Karel C (2017) Upgrading biogas to biomethane using membrane separation. Energy Fuels 31:9393–9401

Wang X, Yang G, Feng Y, Ren G, Han X (2012) Optimizing feeding composition and carbon–nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw. Bioresour Technol 120:78–83

Ward AJ, Hobbs PJ, Holliman PJ, Jones DL (2008) Optimisation of the anaerobic digestion of agricultural resources. Bioresour Technol 99:7928–7940

Weiland P (2010) Biogas production: current state and perspectives. Appl Microbiol Biotechnol 85:849–860

Xiao W, Clarkson WW (1997) Acid solubilization of lignin and bioconversion of treated newsprint to methane. Biodegradation 8:61–66

Yang L, Ge X, Wan C, Yu F, Li Y (2014) Progress and perspectives in converting biogas to transportation fuels. Renew Sustain Energy Rev 40:1133–1152

Ye S, Jiayang C (2002) Hydrolysis of lignocellulosic materials for ethanol production: a review. Biores Technol 83:1–11

Zanganeh KE, Shafeen A, Salvador C (2009) CO_2 capture and development of an advanced pilot-scale cryogenic separation and compression unit. Energy Procedia 1:247–252

Zhai N, Zhang T, Yin D, Yang G, Wang X, Ren G, Xiaojiao W, Guangxin R, Yongzhong F (2015) Effect of initial pH on anaerobic co-digestion of kitchen waste and cow manure. Waste Manag 38:126–31

Zhang C, Su H, Baeyens J, Tan T (2014) Reviewing the anaerobic digestion of food waste for biogas production. Renew Sustain Energy Rev 38:383–392

Zhang C, Xiao G, Peng L, Su H, Tan T (2013) The anaerobic co-digestion of food waste and cattle manure. Bioresour Technol 129:170–176

Zhang Q, Hu J, Lee D (2016) Biogas from anaerobic digestion processes: research updates. Renew Energy 98:108–119