A Review- Pretreatment Methods and Anaerobic Co-Digestion of Biomasses for Biogas Production

Indesh Attri, Vipan K. Sohpal, Nakul Dewan
Beant College of Engineering and Technology, Gurdaspur, Punjab, India
(E-mail: indeshbiotech21@gmail.com)

Abstract— Due to the rapid increase in energy demand, there is an exponential rise in burning of conventional fuel releasing a lot of greenhouse gases into the atmosphere. To overcome this problem bioenergy in the form of biogas can be a suitable option as an alternate energy source. Biogas production can be enhanced using various methods of pretreatment and co-digestion for different biomasses. Pretreatment methods break down the tough polymers into monomers, which become accessible to the microorganisms in anaerobic digestion. In this paper, we focused extensively on pretreatment methods for lignocellulosic substrates. Similarly, co-digestion of different biomasses has been reviewed that improve biogas production, by diluting the toxic compounds, improving carbon to nitrogen ratio (C/N ratio) and nutrient value.

Keywords—Biogas, Co-digestion, Lignocellulosic, Pretreatment

I. INTRODUCTION

In the present scenario, it has been recognized globally that the climate change is an urgent and potentially irreversible threat to life on this planet. Therefore adequate and appropriate steps must be taken to reduce the global greenhouse gas emissions. Recently held UNFCCC Conference of the Parties or COP 21 in Paris, the decision has been made to limit the global temperature increase below 2 degree Celsius. In the 21st century where energy demand is rising rapidly with the increasing population, it is crucial to look for new environmental friendly alternative sources of energy [1]. As we know, combustion of fossil fuels leads to a big contribution to the increase in CO_2 level in the atmosphere, which is directly responsible for global warming [2]. So the alternate energy source now days have become the matter of concern as there is an exponential increase in the consumption of nonrenewable energy. It has been published in the literature about the biomass that it is the fourth largest energy source in the world [3]. One such energy source is biomethane which can be obtained by breaking down the organic matter in the absence of dissolved oxygen. Biogas (biomethane) can be the alternate source of energy. Biogas can be obtained by subjecting the biodegradable organic waste into anaerobic digestion (AD). Anaerobic digestion involves synchronized actions of mesophilic bacteria, where the product of the first step acts as a substrate for the next [4].The digestate which is left at the end of the process can be utilized as the soil fertilizer. Moreover, in comparison to energy content, 1 m^3 of purified biogas is equal to 1.7 L of bioethanol or 0.97, natural gas [1]. Organic matter that can be subjected to anaerobic digestion can be cow dung, food waste, lignocellulosic and agricultural refuge. These organic substrates are referred to as feedstock it can be subjected to AD either as a single substrate (e.g. Cow dung based biogas generation) or in a co-digestion manner in which two substrates are mixed and subjected to AD. Lignocellulosic substrates are used for the production of ethanol, but biogas production from lignocellulosic substrates gives better overall energy efficiency than ethanol [5]. A comparative analysis on the basis of energy from biogas obtained from various sources gives promising results that all these bio wastes can be a source of profit by fermentation. In India energy consumption now days is about 6500 $Twha^{-1}$, and it is supposed to get double as the energy demand will increase in coming future. Depending upon feedstock used a biogas plant generates 3-10m^3 biogas per day [3] as depicted in table I.

TABLE I Sources of biogas and their energy potential [3]

Sources for Biogas Production	Energy Potential [$TWha^{-1}$]
Landfill	6
Communal and industrial sewage water	18
Organic wastes from households and markets Organic wastes from industry Excrement (190Mio Mga^{-1}) By products of agriculture and food production Material from landscape conservation	47
Plantations of energy plants (area ca. 2.5 Mioha) (15 Mg/ha.a)	141
Wood (10 Mio ha forest area) (5 Mg/ha.a)	187
Urine	4
Nutrition in sewage water	5
Total	408

The next of paper will describe different feedstocks used for increasing the efficiency of anaerobic digestion in co-digestion method and pretreatment methods for easy degradation of feedstocks.

II. CO-DIGESTION

Co-digestion is the anaerobic process of degradation of two substrates together for biogas production to improve the efficiency of the biogas generation. Co-digestion of cattle manure and other organic wastes leads to increase in biogas production at proper thermophilic conditions [6]. There are varieties of biomasses available which can be used in co-digestion. Co-digestion of cattle manure with fruit, vegetable, and chicken manure has been reported to improve the carbon to nitrogen ratio (C/N) which plays an important role in anaerobic digestion process [7]. Algal sludge when co-digested with waste paper offered improved C/N ratio leads to maximum methane production rate 1607±17ml/l day [8]. Most commonly used wastes for co-digestion are presented in figure.1.

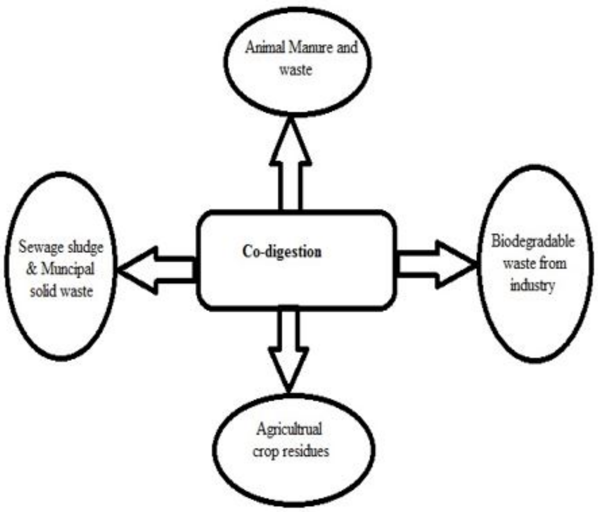

Fig.1: Sources of substrates for Co-digestion

Some researchers have shown that co-digestion also offers benefits like dilution of potentially toxic compounds, improved balance of nutrients leading to increase in biodegradation of organic matter by the synergistic action of microorganisms and better biogas yield [9]. Biomasses are selected for co-digestion is screened on the basis of high biogas potential, low water content, low retention requirement. In a comparative study of biogas production from the anaerobic digestion of filter pressed manure fibers, chemically precipitated manure fibers, raw pig slurry, maize silage and grass silage at 53.5˚C. It showed that pig manure yield higher biomethane production in terms of volatile solid (L/Kg VS) (330 L/Kg VS) as compared to filter pressed manure fibers (161 L/kg VS) and chemically precipitated manure fibers (231 L/kg VS). Concerning mass biogas production, it was higher in filter pressed manure fibers (54.5 L/kg substrate) as compare to pig manure (10.4 L/kg substrate) [10]. Biogas production form grasses can offer better energy balance by the reduction in green house gas emission [11]. Potential of cassava peel for the production of biogas under anaerobic condition can be enhanced by co-digestion with cow dung (CD) and swine dung (SD). In a study cassava peels were co-digested with cow dung (CD), poultry droppings (PD) and swine dung (SD). Co-digestion was done by mixing in equal ratio, showed significant improvement in biogas production. The mean flammable biogas yield (L/total mass of slurry) from digestion of cassava peel alone was 2.29±0.97, when co-digested with CD, PD and SD flammable biogas yield increased to 4.88±1.73, 5.55±2.17 and 5.65±2.62 L/total mass of slurry [12]. AD is known to stabilize organic wastes with the production of biogas having concentration about 50-75% methane and 50-25% of carbon dioxide. The calorific value of biogas can be utilized by combustion in combined heat and power (CHP) [13]. In waste water treatment plants where biogas generation becomes the source of energy when used in combined heat and power unit, biogas yield can be improved by co-fermentation of biogenic wastes during sewage sludge treatment [14]. Glycerol obtained as by-product of biodiesel production has the large potential to be used in co-digestion process. In a study glycerol is co-digested with the banana peel in a batch reactor. It has been found that when 7.5% of banana peel was used 181 ml of methane production and yield of 188 mL/g of total solid is obtained. When 7.5% banana peel is mixed with 7.5g/L pure glycerol, then maximum methane production was 467 mL with the yield of 151 mL/g. But 7.5% banana peel mixed with 7.5g/L waste glycerol gave 652 mL methane production with the yield of 281 Ml/g [15]. Co-digestion of cow manure (CM) and kitchen waste (KW) is done through anaerobic digestion. Individual degradation of cow manure and kitchen waste is compared with the co-digestion of CM and KW at room temperature (25-30˚C) and temperature 37˚C. Results showed that the rate of degradation is more rapid in the case of co-digestion than individual degradation. Another study was done in which effect of alkalinity was studied at 37˚C temperature and loading rate of 200 gm/L. They found that biodegradability increases when pretreatment of KW is done with 1.5% NaOH and biogas production also gets doubled. On the basis of obtained data they fabricated portable biogas plant which operates at 37˚C having loading rate of 200gm/L [16]. Investigation for methane production from Mono and Co-digestion of kitchen waste, corn stover, and chicken manure showed that kitchen waste can be more rapidly degraded but has a low buffering capacity, therefore, at higher (Substrate to inoculum ratio) S/I ratio poor methane production was observed. Corn Stover being lignocellulosic in nature cannot be digested easily and lead to low biogas production. Chicken manure has a good buffering capacity, but it has low C/N (carbon to nitrogen ratio) which also led to low biogas production. In co-digestion synergistic effect was found, which results in proper C/N ratio and reduced total volatile fatty acid to total alkalinity ratio; thus better buffering capacity and enhanced digestion.

III. PRETREATMENT

Pretreatment is the process used to make the substrate easily accessible and vulnerable to degradation in anaerobic digestion, which makes these substrates give better biogas yield. A large number of pretreatment methods have been studied in the last decade resulting in the high yield of biogas. Effect of pretreatment is studied in batch processes; these methodology gives effective results in the determination of optimum conditions of pretreatment, but extrapolation of these results to large scale continuous processes is uncertain [17]. An effective pretreatment method is the one which avoids the need for reducing the size of substrate minimizes the energy demand and limit the cost. Moreover, it also produces a disrupted hydrated substrate that can be hydrolyzed and avoids the formation of sugar degradation products and fermentation inhibitors [18]. There are different methods of pretreatment which can be broadly classified under Physical, chemical, physic o-chemical and biological methods [19] [20]. Physical methods include communition, steam explosion and hydrothermolysis, whereas chemical methods include treatment of the substrate with acid and base [19] Physico-chemical methods involve the steam explosion, ammonia fiber explosion and Co_2 explosion [21]. Biological pretreatment generally involves the use of fungi which has the potential to degrade lignin, hemicellulose and some part of cellulose, because cellulose is more resistant to biological attacks [22]. The substrates which are rich in cellulose, hemicellulose and lignin are required to be pretreated before subjecting to anaerobic digestion. Most lignocellulosic substrates contain 40-50% of cellulose and 20-40% hemicellulose by weight [23]. Some studies have shown that those pretreatment methods which can effectively remove hemicellulose and allow better interaction of cellulase enzyme with cellulose would greatly improve the digestibility of biomass substrate [24].

A) Physical Pretreatment

The size reducing methods using mechanical energy are generally categorized under physical pretreatment. It includes chipping, shredding, milling and grinding [18]. Effect of particle size on biogas yield has been shown by various research groups. In a study of the relationship between particle size of the feedstock and performance of anaerobic digestion, a 14 liters digester equipped with an integrated control is used; particle sizes of 10, 20, 30 and 100 mm diameter were evaluated. It has been found that under mesophilic conditions (40˚C) biogas production increased about 20% for the particles of the size of 10mm [25]. Biogas yield from sisal fiber waste can be enhanced by reducing the particle size. Size ranging from 2 to 100 mm was subjected to anaerobic digestion in 1 L digester; results showed that reduction in particle size leads to increase in biogas yield. Methane yield when the particle size is 2 mm was 0.22 m3 CH_4/kg volatile solids compared to 0.18 m3 CH_4/kg volatile solids for untreated fibers [26]. Physical pretreatment methods like grinding can be a very successful method in terms of reducing the volume of digester and increase in biogas yield [27]. Most important aspect in physical pretreatment methods is the input of energy for reducing the particle size, which is dependent upon the nature of the substrate and moisture content in biomass which significantly influence energy consumption in communition for finer size reduction [28][29].

B) Chemical Pretreatment

Chemical pretreatments method uses dilute acids, alkali agents, organic solvents, and ammonia. These chemical agents give better results in the short duration of time. Acid treatment of lignocellulosic biomass at higher temperature conditions improves enzymatic hydrolysis in later stages. Sulfuric acid, nitric acid, and Hydrochloric acids are the commonly used acids in chemical pretreatment methods [20]. It was concluded that pretreatment by HCL at pH-2 gave better results. Batch digestion yielded the same biogas after 13 days as compared to untreated waste activated sludge at 21 days digestion [30]. Pretreatment using acid can be done either by dilute or concentrated acids; however acid pretreatment produces some chemical products like acetic acid, furfural and 5 -hydoxymethylfurfural, which acts as inhibitors for microorganisms. Therefore additional step of detoxification is may be required in acid pretreatments [31]. Alkali pretreatment of pulp and paper sludge prior to anaerobic digestion for biogas production was investigated in a study, where 8 g NaOH /100 TS sludge was used, and highest methane yield was 0.32 m3 CH_4/Kg VS removal which is 183.5% of the control [32]. NaOH pretreated rice straw showed 27.3% - 64.5% enhancement in biogas production. 6% NaOH pretreatment increased the biodegradability of cellulose by 16.4%, 36.8% hemicellulose, and 28.4% lignin. This improvement in degradation was attributed to the fact that ester bond of LCC (lignin carbohydrate complexes) was destroyed by the hydrolysis reaction, resulting in the release of more cellulose and linkages of inter-units and functional groups of lignin. Cellulose and hemicellulose were broken down or destroyed, causing intra and inter molecular changes of chemical structures [33]. Cellulose Solvents are also included in the category of chemical pretreatment methods, such as alkaline H_2O_2, ozone, organosolv, glycerol, dioxane, and phenol [19].

C) Physico-Chemical Pretreatment

Physicochemical pretreatment methods involve the use of different physical conditions and various compounds that can affect the physical and chemical properties of substrates. There are many methods which are investigated under this category. Steam explosion is the most studied pretreatment method. In this pretreatment finely chopped or grounded substrate is treated with high-pressure steam about 0.7 and 4.8 Mpa and temperature of about 160-240˚C. After holding the pressure for several seconds to few minutes and then the pressure is released. This suddenly reduced pressure makes the substrate undergo explosive decompression; it removes most of the hemicellulose. Wheat straw and paper tube residues were pretreated with steam explosion the sensitivity analysis results showed that there is 5% improvement in the methane yield and 20% decrease in the raw material price which resulted in 5.5% and 8% decrease in the manufacturing cost of methane respectively. It has been concluded that economic feasibility of biogas production from wheat straw and paper tube residue improved by steam explosion pretreatment [34]. Steam explosion pretreated citrus waste when co-digested with municipal solid waste in a continuous reactor 0.537 m3CH_4/Kg VS (volatile solid) methane production was observed on the other hand when untreated citrus waste was subjected to anaerobic digestion the process failed indicating the significance of the pretreatment [35]. Ammonia fiber explosion is another technique under physico-chemical pretreatment, which involves the exposure of lignocellulosic materials to liquid ammonia at high temperature and pressure for the certain period and pressure is quickly reduced. It works on the same principle as the steam explosion; AFEX requires 1-2 kg ammonia/kg dry biomass, temperature 90˚C and time 30 mins [21].

D) Biological Pretreatment

Biological pretreatment involves the use of microorganism's mainly fungal species which are capable of producing hydrolytic enzymes and can degrade substrates like lignin, hemicellulose, and polyphenols. Various researchers have investigated the potential of different fungi which is capable of producing hydrolytic enzymes such as Brown, White and soft-rot fungi. Among these white-rot fungi seem to be the potential source of enzymes which can hydrolyse both cellulose and lignin [36] [37]. When White rot fungi (*Phanerochaete chryosporium*) and brown rot fungi (*Polyporus ostreiformis*) were used for the pretreatment of rice straw and biogas and methane production was analyzed. It showed 34.73% and 46.19% increase in case of white rotted rice straw where as 21.12% and 31.94% in case of brown rotted rice straw [38]. Although biological pretreatment methods require low energy input, it is environmental friendly and safe, but the rate of hydrolysis is very slow and requires certain improvements for making it commercially applicable [39]. Pretreatment of sweet chestnut (*Castanea sativa*) leaves and hay using wood-decaying fungus *Auricularia auricula-judae*. When these pretreated substrates were subjected to anaerobic digestion, in comparison it has been found that there was 15 % increase in biogas production from treated substrate that from untreated substrates [40]. Enhancement in biogas production from corn straw is also investigated by pretreating with complex microbial agents at ambient temperature (20˚C). A microbial dose of 0.01% (W/W) for 15 days resulted in 33.07 % more total biogas yield, 75.57% more methane yield and 34.6% lesser technical digestion time as compare to untreated sample. Increase in biogas production was attributed to the analysis of chemical composition which showed that 5.81%-25.10% reductions in total lignin, cellulose and hemicellulose content and 27.19-80.71% increase in hot-water extractives [41].

IV. CONCLUSION

This review showed that co-digestion not only increases the biogas production as well as it dilutes the toxic substances and it helps in anaerobic digestion by maintaining the pH during the process. It also gives the advantage in the management of different organic wastes. On the other hand pretreatment methods increase the biodegradability of the biomass by modifying the chemical and physical properties of the substrates. An efficient pretreatment method also helps in economy of the process by reducing the energy input during the process. The future research may be directed towards the use of various organic substrates in co-digestion and the use of combinatorial methods of pretreatment.

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Indesh Attri is working as Assistant Professor in Beant College of Engineering and Technology, Gurdaspur. His area of interest is microbial enzymes.

Dr.Vipan Kumar Sohpal has received his PhD in Chemical Engineering from Punjab Technical University during the period of 2014. Currently, he is working as Senior Assistant Professor in Beant College of Engineering & Technology of Punjab Technical University.

Nakul Dewan is working as Assistant Professor in Beant College of Engineering and Technology, Gurdaspur. His area of interest is Biomedical Engineering.