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Biogas Production from Biomass Waste – A Review

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***Abstract*- Biogas has been developed as an alternative renewable energy source. Biogas mainly consists of methane. It can be used as cooking fuel. This review paper provides a detailed summary of the research conducted on the anaerobic digestion of various biomass wastes. The effect of operational parameters such as temperature, pH, organic loading rate, mixing of ratio, etc. were studied. Co-digestion with other waste can significantly improves the yield of biogas. Pre-treatment before anaerobic digestion process enhances biogas production.**

***Index Terms* - Anaerobic digestion, Biogas, Biomass waste, Co-digestion, Pre-treatment.**

I. INTRODUCTION

Energy sources can broadly be classified into two categories; namely non-renewable and renewable sources. Sources like coal, oil and gas, power from thermal and nuclear systems that cannot be renewed are the non-renewable sources and sources like solar, wind, biomass and water that regenerate itself are renewable sources of energy. In developing countries, there has been an increased interest in the development of technologies for harnessing renewable energy sources such as biomass either directly or through conversion routes. One of the biological processes is anaerobic digestion. Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs. In fact proper functioning of biogas system can provide multiple benefits to the users and the community resulting in resource conservation and environmental protection [5].

Biogas is a product of anaerobic degradation of organic substrates, which is used for the treatment of industrial wastes, cattle manure, agricultural waste, municipal solid waste etc. Maritza has used the dairy cow manure (CM), the organic fraction of municipal solid waste (OFMSW), and cotton gin waste (CGW) was investigated with a two-phase pilot-scale anaerobic digestion (AD) system [2].

It is carried out by a consortium of microorganisms and depends on various factors like pH, temperature, HRT, C/N ratio, loading rate, particle size, based on biomass material etc. Motte has found that particle size reduction affected strongly the performances of the reaction due to an increase of substrate bio accessibility [1]. Rene examines effects of daily temperature variations on the performance of anaerobic digestion. The average volumetric biogas production rate for cyclic operation between 11and 25^oC was 0.22 L $d^{-1}L^{-1}$ with a yield of 0.07 m^3 CH_4 kg^{-1} VS added, whereas for operation between 15 and 29^oC the volumetric biogas production rate increased by 25% (to 0.27 L $d^{-1}L^{-}$with a yield of 0.08 m^3 CH_4 kg^{-1} VS added). In the highest temperature region a further increase of 7% in biogas production was found and the methane yield was 0.089 m^3 CH_4 kg^{-1} VS added [3]

Anaerobic fermentation being a slow process, a large HRT of 30–50 days is used in conventional biogas plants. Kinnunen studies methane production using a marine microalgae, Nannochloropsis sp. residue from biodiesel production. The thermophilic reactor was apparently inhibited due to ammonia with organic loading rate (OLR) of 2 kg VS $m^{-3}d^{-1}$ (hydraulic retention time 46 d), whereas the mesophilic reactor performed with OLR of 3 kg VS $m^{-3}d^{-1}$ (HRT 30 d) [7].

The objective of the present study was to review relevant information necessary to determine the applicability of anaerobic digestion to energy production from various biomass wastes. Accordingly, we will describe various factors to improve the biogas production. We will also review an overview of experience with anaerobic digestion pretreatment of these materials. In addition, we present energy utilization from the produced biogas.

II. MECHANISM AND PROCESS OF ANAEROBIC DIGESTION

Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. The decomposition of bio waste occurs in three stages:

hydrolysis (Liquefaction), acidogenesis (Acid Production), and methanogenesis (Biogas Production). Hydrolysis is the process of breaking down of the organic material to usable-sized molecules. In the second stage, acidogenic bacteria transform the products of the first reaction into acids. The final stage the acids are converted to methane gas. Fig.1. shows the process flow diagram of anaerobic digestion [43].

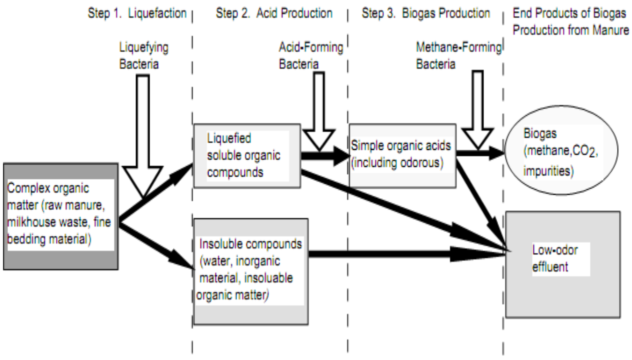

Fig.1. Process flow diagram of anaerobic digestion

III. BIOMASS RESOURSES

Rapid industrialization and urbanization have boosted the over-exploitation of natural resources in recent years. Table I shows total availability of agro industrial, agricultural and municipal solid wastes worldwide.

TABLE I: Total availability of biomass wastes in million tonnes/year

Wastes	India	Brazil	Sudan	USA	Sweden
MSW	135.5	44.0	2.3	148.0	5.3
Sewage	44.9	8.02	1.4	16.0	0.6
Manure	653.0	470.0	68.0	306.0	13.2
Agricultural residues	200.0	47.0	8.1	573.0	12.6
Biomass	140.0	496.8	192.3	427.0	14.0

Source [4].

Different types of biomass wastes were used to produce biogas. These biomass wastes were described as follows

A. *Cattle Manure*

Cow manure, is the waste product of bovine animal species. These species include domestic cattle cows, buffalo etc. Hamed was used a dairy manure and produce biogas by three different methods. The fine fraction of screened manure had the highest biogas yield, compared with the coarse fraction and the unscreened manure. After 30 days of digestion, biogas yield was calculated to be 436, 404, and 366 L kg^{-1} VS for the fine and coarse fraction, and the unscreened manure, respectively [9]. Quiroga used the mixtures of cattle manure with food waste and sludge. The mixture containing 70% cattle manure 20% food waste and 10% sewage sludge. Ultrasound pre-treatment allows operating at lower HRT, achieving higher volumetric methane yields: 0.85 $LCH_4L^{-1}day^{-1}$ at 36°C and 0.82 $LCH_4\,L^{-1}day^{-1}$ at 55°C respectively [14].

B. *Food Waste*

Food waste also used as to produce biogas. Food waste was used in separately or mixed with some other biomass waste. The food waste was composed of 31% potato, 41% koroke, 19% bread powder and 8% onion based in wet basis. This composition was based on a case study of food processing waste. The food waste was chopped into cubes of 2 cm in size and shredded into particles with an average size of 3.0 mm in diameter with a high speed shredder. The content of the total solids (TS) was adjusted to 14% by adding tap water [6]. Hamed was used two mixtures of food waste and manure; the first mixture was composed of 32% food waste and 68% dairy manure and the second mixture was 48% food waste and 52% dairy manure, based on the initial VS of 3 gVS L^{-1}. After 30 days of digestion, the biogas yield was 455 and 531 L kg^{-1} VS from the two mixtures, respectively [9].

C. *Corn Stover*

Mingxia was used the corn stover chopped by a paper chopper (PC500, Staida Co., Tianjing, China) and then ground into 5–10 mm particles by a hammer mill [10]. Zhengbo investigated the effects of corn stover as a supplemental feed on anaerobic digestion of dairy manure under different hydraulic retention times (HRT). The results elucidated that both HRT and corn stover supplement significantly influenced microbial community and corresponding anaerobic digestion performance. The highest biogas production of 497 mL per gram total solid loading per day was observed at a HRT of 40 days from digestion of manure supplemented with corn stover [11].

D. *Agricultural Waste*

Menardo was studied, four agricultural byproducts such as wheat, barley, rice straw and maize stalks. The samples resulted in the following methane yields according to biomass: 246 L kg ˉ1 VS for maize stalks, 240 L kg ˉ1 VS for barley straw, 197 L kg ˉ1 VS for rice straw, and 182 L kg ˉ1 VS for wheat straw [12]. Marcel had experimented the feasibility of wheat straw as a feedstock for biogas production is investigated using the newly developed upflow anaerobic solid-state (UASS) process. For a good process performance, addition of trace elements is necessary, though. At a SRT of 14–21 days, the thermo- and mesophilic UASS–AF systems yielded 38% and 50.1% of the substrate's methane forming potential, respectively. Additionally, the thermophilic systems outperformed the mesophilic counterparts with faster hydrolysis [13].

E. Municipal Solid Waste

Piotr presented the co-fermentation; fermentation of sewage sludge (SS) and fermentation of organic fraction of municipal solid waste (OFMSW) were compared. Three batch experiments with above mentioned feedstock's were conducted in large scale laboratory reactor of working volume of 40 dm^3. The cumulative biogas production for sewage sludge (180.59 dm^3) was lower than that for co-fermentation (232 dm^3) or OFMSW (228.34 dm^3) [41]. Maritza was investigated the anaerobic digestion of dairy cow manure (CM), the organic fraction of municipal solid waste (OFMSW), and cotton gin waste (CGW) in a two-phase pilot-scale anaerobic digestion (AD) system. The OFMSW and CM were digested as single wastes and as combined wastes. The single waste digestion of CM resulted in 62 m^3 methane/ton of CM on dry weight basis. The single waste digestion of OFMSW produced 37 m^3 methane/ton of dry waste. Co-digestion of OFMSW and CM resulted in 172 m^3 methane/ton of dry waste [2].

F. Other Biomass Waste

Waste banana stem has a high organic content (83%); with 15±20% (w/w) lignin and cellulose which gives it a sheath-like texture. Banana stem slurries (BSS) at 2±16% total solids (TS) concentration were anaerobically digested under mesophilic (37±40°C) as well as thermophilic conditions (50±55°C) in batch culture. The ®nal biogas yields, 267±271 l/kg TS fed, were observed with 2±4% TS slurries, under mesophilic conditions. In the thermophilic range, the biogas yields, 212±229 l/kg TS fed, were found with 2±8% TS slurries [16]. Laxman focuses on production of biogas as an alternative energy by using biodegradable kitchen wastes. The maximum methane gas was recorded as 65% and average maximum carbon dioxide was recorded as 58%. The daily temperature inside the digester was found in the range of (25-34^{o}C) and pH value of the slurry was found in between (6.7-5.48). The average gas production was found to be 173 $Lday^{-1}$. The maximum burning period of the gas was approximately 62 min day^{-1} and average burning period was 26 min day^{-1} [18]. Isci revealed that cotton wastes can be treated anaerobically and are a good source of biogas. The anaerobic treatability and methane generation potential of three different cotton wastes namely, cotton stalks, cotton seed hull and cotton oil cake were determined in batch reactors. Approximately 65, 86 and 78ml CH_4 were produced in 23 days from 1g of cotton stalks, cotton seed hull and cotton oil cake [19]. Anaerobic digestion of a mix of fruit and vegetable wastes has been carried out in a 200-liter digester within 14 weeks. The wastes were taken based on grab sampling method with a composition of ± 78 % vegetable waste, ± 4% tuber waste and ±18% fruit wastes. The total waste weight was 160 kg, mixed manually once in the feeding. The highest methane content in the biogas was 65% with the biogas flow of 20-40 ml min^{-1} [20]. Rice husks (RH) derived from various rice mills in southeast Nigeria are promising feedstock for biogas production. The effects of various parameters such as water dilution, initial pH, heavy metals and nitrogen sources on digester performance were evaluated. The best feed to water dilution ratio was 1:6 w/v, which gave the biogas yield of 382 $mLday^{-1}$. Excess water dilution discouraged bacterial cluster formation and hence decrease in biogas production. The best biogas yields of 357, 279 159 mL/day were reported for pH 7, Ni^{2+} (100 ppm) and poultry droppings supplementation, respectively [21]. Gopi evaluated the performance of anaerobic digesters using a mixture of apple waste (AW) and swine manure (SM). The continuous test evaluated the performance of a single stage completely stirred tank reactor (CSTR) with different mixture ratios of AW and SM at mesophilic temperature. The ultimate biogas and methane productivity of AW in terms of total chemical oxygen demand (TCOD) was determined to be 510 and 252 mLg^{-1} TCOD added, respectively [22].

IV. METHODS TO IMPROVE ANAEROBIC DIGESTION PROCESS

A. Co-digestion

Co-digestion is the simultaneous anaerobic digestion of multiple organic wastes in one digester. Co-digestion is used to increase methane production from low-yielding or difficult to digest materials (i.e., feedstocks). For the co-digestion process, care must be taken to select compatible feedstock's that enhance methane production (and to avoid materials that may inhibit methane generation). In addition, an existing anaerobic digester system must be able to handle the significant increase in methane output that is common with co-digestion. Cunsheng was assessed the anaerobic co-digestion of food waste and cattle manure. The total methane production is enhanced in co-digestion, with an optimum food waste (FM) to cattle manure (CM) ratio of 2. At this ratio, the total methane production in batch tests was enhanced by 41.1%, and the corresponding methane yield was 388 mLg^{-1}-VS. In the semi-continuous mode, the total methane production in co-digestion, at the organic loading rate (OLR) of 10 g-$VSL^{-1}d^{-1}$, increased by 55.2%, corresponding to the methane yield of 317 mL g^{-1}-VS [23]. Co-digestion of rendering and slaughterhouse wastes was studied by Suvi, in laboratory scale semi-continuously fed continuously stirred tank reactors (CSTRs) at 35 and 55°C. All in all, 10 different rendering plant and slaughterhouse waste fractions were characterized showing high contents of lipids and proteins, and methane potentials of 262–572 $dm^3CH_4kg^{-1}$ volatile solids (VS) added [24]. Co-digestion of food waste and green waste was conducted with six feedstock mixing ratios to evaluate biogas production. Food waste/green waste ratio of 40:60 was determined as preferred ratio for optimal biogas production. About 90% of methane yield was obtained after 24.5 days of digestion, with total methane yield of 272.1 mLg^{-1}VS [25].

B. Two- phase digestion

Two- phase digestion is one where the acid formation stage is separated from the methane formation stage. A large, cold, batch or continuous first stage produces fatty acids for a smaller hot, continuously fed, second stage. This system needs only little heat and further it renders system monitoring easy. However, the two-phase digestion may not be economical for small-scale rural applications. These are also flow systems called phase systems to obtain enhanced digestion [30]. Two-stage anaerobic digestion should be more productive than traditional process. Schievano was tested four different substrates at nine different experimental conditions. Two-stage recovered 8%–43% more energy than one-stage and never significantly less. Bio methane generation resulted in ER in the range of 9–19 MJ kg^{-1}VS-added [26]. Zhuang was evaluated vegetable waste, which characterized by high moisture content, as a substrate for biogas production. The effects of recirculation rate (RR) on the performance of two-stage anaerobic digestion were investigated. The system was operated at an organic loading rate of 1.7 g $VSL^{-1}d^{-1}$ with varying RRs (0, 0.6, 1, and 1.4). Results demonstrated that volumetric biogas production rates in acidogenic reactor increased from approximately 0.27 $LL^{-1}d^{-1}$ to 0.97 $LL^{-1}d^{-1}$, when pH is increased from approximately 5.1 to 6.7 [27]. Boubaker investigates on laboratory scale, the possible exploitation of the advantages of two-phase anaerobic digestion for treating a mixture of olive mill wastewater (OMW) and olive mill solid waste (OMSW) using two sequencing semi-continuous digesters operated at mesophilic temperature (37 ± 2°C). Two-phase anaerobic digestion system has given the best performances concerning methane productivity. The best biogas productivity (54.26 LL^{-1} OMW fed) with 83% of methane content was achieved at a HRT of 36 days [29].

V. PHYSICO-CHEMICAL FACTORS

The transformation of the organic matter to biogas is brought about by bacteria and these bacterial groups employ several kinds of enzymes to catalyze this reaction. All enzymes for normal activity require specific physico-chemical condition under which the reaction rates are optimum. Some of the important physico-chemical factors that affect the overall biogas reaction are temperature, pH, C: N ratio, water content, retention time heavy metals etc. the effect of these factors on the different aspects of biogas production are as follows:

A. Temperature

In biogas production the temperature affect the rate of reaction. An increase in the ambient temperature generally increases the rate of reaction and therefore rate of biogas production. In biogas reaction, generally mesophilic (20-45°C) and thermophilic (45-65°C) is considered important.

Mesophilic Conditions

The normal biogas plants operate within this operating range and the bacterial species that are involved in this range is called mesophilic bacteria. The optimum temperature of mesophilic bacteria is 25-37°C. Waste banana stem has a high organic content (83%); with 15±20% (w/w) lignin and cellulose which gives it a sheath-like texture. Banana stem slurries (BSS) at 2±16% total solids (TS) concentration were anaerobic ally digested under mesophilic (37±40°C). The biogas yields, 267±271 l/kg TS fed, were observed with 2±4% TS slurries, under mesophilic conditions [16].

Thermophilic Conditions

The optimum temperature for biogas production in the thermophilic range is 55°C. Waste banana stem has a high organic content (83%); with 15±20% (w/w) lignin and cellulose which gives it a sheath-like texture. In the thermophilic range (50±55°C), the biogas yields, 212±229 l kg^{-1} TS fed, were found with 2±8% TS slurries. However, thermophilic digestion rates were 2.4 times faster than mesophilic. Methane accounted for 59±79% of the total biogas [16]. Forster was studied the influence of different organic fraction of municipal solid wastes during anaerobic thermophilic (55^{o}C) treatment of organic matter: food waste (FW), organic fraction of municipal solid waste (OFMSW) and shredded OFMSW (SH_OFMSW). The FW reactor showed the smallest waste biodegradation (32.4% VS removal) with high methane production (0.18 LCH_4 g^{-1} VS); in contrast the SH_OFMSW showed higher waste biodegradation (73.7% VS removal) with small methane production (0.05 LCH_4 g^{-1} VS) [32].

B. Effect of pH

pH is an important parameter affecting the growth of microbes during anaerobic fermentation. pH of the digester should be kept within a desired range of 6.8–7.2 by feeding it at an optimum loading rate. The amount of carbon dioxide and volatile fatty acids produced during the anaerobic process affects the pH of the digester contents [5]. Okeh found the pH 7 gave the best biogas yield 357mLday^{-1}. The accumulation of intermediate acids leads to pH drop during fermentation [21].

C. Heavy Metals

Additions of heavy metals to improve the biogas production have also been reported. Hong was revealed that the addition of Co, Ni for 1, 1 mg l^{-1} or Fe, Co, Ni for 10, 1, 1 mg l^{-1}, respectively to the mainly carbohydrate food waste resulted in improvements in the methane fermentation by factors of approximately 7.8 and 7.5, respectively, compare to control in which the trace metals were not added [6]. Okeh had studied the addition of heavy metals (Ni^{2+}, Zn^{2+}, and Cu^{2+}) enhanced digester performance. Production of biogas Ni^{2+} (100 ppm), Zn^{2+} (150 ppm) and Cu^{2+} (50 ppm) gave 279, 114 and 117 mLday^{-1} respectively [21].

D. Hydraulic retention time

The retention time is the time that a particle or volume of liquid added to a digester would remain in the digester. In tropical countries like India, HRT varies from 30–50 days while in countries with colder climate it may go up to 100 days. Zhengbo investigated the effects of corn stover as a supplemental feed on anaerobic digestion of dairy manure under different hydraulic retention times (HRT). The results elucidated that both HRT and corn stover supplement significantly influenced microbial community and corresponding anaerobic digestion performance. The highest biogas production of 497 mL per gram total solid loading per day was observed at a HRT of 40 days from digestion of manure supplemented with corn stover [11]. The effects of different hydraulic retention time (HRT) on (RS)-MCPP utilization was investigated by decreasing the feed flow rate in an anaerobic membrane bioreactor (AnMBR). The (RS)-MCPP removal efficiency fluctuated from 6% to 39% at HRT 3 d, however when it was increased to 7 and 17 d, the removal efficiency increased to an average of 60% and 74.5% [31].

E. Water Content

Water is essential for the survival and activity of micro-organisms, further, water is essential for the movement of bacteria, the activity of extra cellular enzymes, hydration of biopolymers to facilitate easy breakdown, etc. However, maintaining too much water in the digester will causes the digester to become large and unwieldy. Hence optimum water content has to be maintained within the digester. For most of the biogas systems, the ideal feed to water ratio is 1:1. In a laboratory scale biogas production from rice husks (RH) generated from different rice mills was investigated using cow rumen fluid as a source of inoculum. Feedstock to water dilution ratio of 1:6 w/v and gave the maximum biogas yield of 382 mLday^{-1} [21].

F. Organic Loading Rate

Gas production rate is highly dependent on loading rate. Methane yield was found to increase with reduction in loading rate [5]. James examines the impact of increasing organic loading in a two phase anaerobic digestion system treating commercial food waste. The first phase is a series of sequentially fed leach bed reactors (LBRs). The second phase is an upflow anaerobic sludge bed (UASB). Leachate from the leach beds, form the influent to the UASB. Effluent from the UASB is recirculates over the leach beds. The experiment was set up such that the theoretical OLR would rise from 7.1 to 8.8 to 11.8 kg CODm^{-3}day^{-1}. The system operated effectively at the lowest organic loading rate producing 384 L CH_4 kg VS^{-1}. At the highest loading rate total ammonia nitrogen (TAN) reached levels of 4500 mg L^{-1} with pH levels of 8.15. This resulted in significant reduction of methane production [28].

G. Inoculum

Su was reported an appropriate ISR (inoculum to substrate ratio) to enhance the hydrolysis rate and reduce the solid retention time of food waste in hydrolytic-acidogenesis leach bed reactor. A lower ISR of 20% was recommended in the hydrolytic-acidogenic process [8]. Yu was to evaluate the effect of different inoculum sources on the rice straw anaerobic digestion. Six different digestates (DM, SM, CM, MS, AGS and PS) were applied as inoculums and their effects were evaluated in batch reactors. Reactors inoculated with digested manures achieved higher, biogas production and lignocelluloses degradation. DM had the best effect among all three digested manures. Reactors inoculated with DM achieved the highest biogas production (325.3 mL/g VS) and enzymes activities [17]. The influence of bovine rumen fluid inoculum during anaerobic treatment of the organic fraction of municipal solid waste (MSW) was studied by Wilton. The proportions between MSW/inoculum loaded in the reactors were Reactor A (100%/0%), Reactor B (95%/5%), Reactor C (90%/10%) and Reactor D (85%/15%). The average of methane concentration in the biogas produced was 3.6%, 13.0%, 25.0% and 42.6% for Reactors A, B, C and D, respectively. The data obtained affirm that the inoculum used substantially improved the performance of the process [42].

VI. PRETREATMENT

Feedstock's sometimes require pretreatment to increase the methane yield in the anaerobic digestion process. Pretreatment breaks down the complex organic structure into simpler molecules which are then more susceptible to microbial degradation [5].

A. Alkaline Pre-treatment

The NaOH dose of 2% and the loading rate of 65 gL^{-1} were found to be optimal in terms of 72.9% more total biogas production,73.4% more methane yield, and 34.6% shorter technical digestion time, as compared to the untreated one.WS pretreatment used 86% shorter treatment time and 66.7% less NaOH dose than solid state one. The analyses of chemical compositions and chemical structures showed that 9.3–19.1% reduction of the contents of total Lignin, cellulose, and hemicelluloses (LCH), and 27.1–77.1% increase of hot-water extractives contributed to the enhancement of biogas production [10]. Sambusiti was conducted the alkaline pretreatment at 40^{o}C for 24 h with the addition of 1% and 10% $gNaOHg^{-1}TS$. The highest increase in methane yield (up to 32%), compared to the untreated substrate was observed at 40^{o}C with 10% NaOH for sorghum. As for wheat straw, significant increases in methane yield were observed at 40^{o}C with 10% NaOH (43%) [35]. Chandra was experimental batch methane fermentation (at 37^oC) study carried out on untreated and pretreated substrates of rice straw using NaOH pretreatment. The study revealed into 140.0 $Lkg^{-1}VS$ biogas and 59.8 $Lkg^{-1}VS$ methane from untreated rice straw substrate. However, NaOH pretreated substrate resulted into 184.8 $Lkg^{-1}VS$ biogas and 74.1 L/kg VS methane [38].

B. Thermal pretreatment

Ferreira was evaluated the biochemical methane potential of steam exploded wheat straw in a pilot plant under different temperature–time combinations. The optimum was obtained for 1 min and 220^oC thermal pretreatment (3.5 severity factor), resulting in a 20% increase in methane production respect non-treated straw. Four agricultural byproducts (wheat, barley, rice straw and maize stalks) underwent various thermal treatments prior to anaerobic digestion, the heat application to 90^oC and 120^oC. Thermal pre-treatment improved byproduct methane yields more than 60% for wheat and barley straw [12].

C. Ultrasound Pre-treatment

Quiroga studied the effect of ultrasound on methane yield in the co-digestion of waste. Ultrasound pre-treatment allows higher energy yields per digester volume. An experiment was carried out the mixture of biomass materials, 70% cattle manure, 20% food waste and 10% sewage sludge. Ultrasound pre-treatment allows operating at lower HRT, achieving higher volumetric methane yields: 0.85 L $CH_4L^{-1}day^{-1}$ at 36^oC and 0.82 $CH_4L^{-1}day^{-1}$ at 55^oC, when cattle manure and sewage sludge were sonicated. With respect to the non-sonicated waste, these values represent increases of up to 31% and 67% for mesophilic and thermophilic digestion, respectively [14]. Castrillon studied after pre-treatment of the cattle manure or mixtures of cattle manure with different amounts of added glycerin with ultrasound. The best results were obtained under thermophilic conditions using sonicated mixtures of ground cattle manure with 6% added glycerin (348 L methane kg^{-1} COD removed were obtained) [15].

D. Acid Pretreatment

The effects of acid pretreatment (pH 6–1) using HCl on subsequent digestion and dewatering of WAS have been investigated by Devlin. Optimization of acid dosing was performed considering digestibility benefits and level of acid required. Pretreatment to pH 2 was concluded to be the most effective. In batch digestion this yielded the same biogas after 13 days as compared to untreated WAS at 21 days digestion. In semi-continuous digestion experiments (12 day hydraulic retention time at 35^{o}C) it resulted in a 14.3% increase in methane yield compared to untreated Waste activated sludge [34].

E. Thermo-Alkaline Pretreatment

Sambusiti was conducted the thermo-alkaline pre-treatments at 100^{o}C, and 160^{o}C for 30 min, with the addition of 1% and 10% gNaOHg^{-1}TS. The pre-treatments tested led to a solubilization of the organic matter, with a maximum concentration obtained at 100^{o}C with 10% NaOH. The highest lignin reduction, compared to untreated samples, was found at 100^{o}C with 10% NaOH dosage (53% and 72% for wheat straw and sorghum, respectively). Under this pre-treatment condition a high hemicelluloses reduction yield was also found (63% for both substrates). The highest increase in methane yield at 100^{o}C with 1–10% NaOH 48% and 67%, for wheat straw and sorghum, respectively [35]. The anaerobic digestion of streptomycin bacterial residues, solutions with hazardous waste treatments and bioenergy recovery, was tested in laboratory-scale digesters at 35^{o}C at various organic loading rates (OLRs). The methane production and biomass digestion were efficient at OLRs below 2.33 gVS L^{-1}d^{-1}. The thermal–alkaline pretreatment with 0.10 NaOH/TS at 70 C for 2 h significantly improved the digestion performance. With the thermal–alkaline pretreatment, the volumetric reactor productivity and specific methane yield of the pretreated streptomycin bacterial residue increased by 22.08–27.08% compared with those of the unpretreated streptomycin bacterial residue [36].

F. Hydrothermal Pretreatment

Wei was used the hydrothermal pretreatment to accelerate digestion and increase biogas production. After hydrothermal pretreatment at typical condition (170^{o}C at 1 h), the biogas production of pig manure, cow manure, fruit/vegetable waste, and municipal sewage sludge increased by 7.8, 13.3, 18.5, and 67.8% respectively. For treated food waste the biogas yield decreased by 3.4%. For pig manure, fruit/vegetable waste, and municipal sewage sludge the methane gas yield increased by 14.6, 16.1 and 65.8%, respectively. For treated cow manure and food waste, the methane gas yield decreased by 6.9% and 7.5% [37]. Chandra was experimental batch methane fermentation (at 37^{o}C) study carried out on untreated and pretreated substrates of rice straw using hydro-thermal pretreatment. The hydrothermal pretreatment was given for 10 min at 200^{o}C. The study revealed into 140.0 Lkg^{-1}VS biogas and 59.8 Lkg^{-1}VS methane from untreated rice straw substrate. Hydrothermal pretreated followed by 5% NaOH added substrate resulted into highest biogas and methane production yields as 315.9 Lkg^{-1}VS and 132.7 Lkg^{-1}VS, respectively [39].

G. Milling Pretreatment

Motte was studied the effect of milling pretreatment on performances of Solid-State Anaerobic Digestion (SS-AD) of raw lignocellulosic residue. Three batch reactors treating different straw particle sizes (milled 0.25 mm, 1 mm and 10 mm) were followed during 62 days (6 sampling dates). Although a fine milling improves substrate accessibility and conversion rate (up to 30% compared to coarse milling), The study concluded that particle size reduction affected strongly the performances of the reaction due to an increase of substrate bioaccessibility [1]. Hajji was determined the influence of particle size on the performance of anaerobic digestion of municipal solid waste. The particle size of 10 mm, 20mm, 30mm and 100 mm in diameter were evaluated; the laboratory reactor was operated under mesophilic conditions (40°C) and with a retention time of 21 days. The pretreatment of substrates by the reduction of the size of the particles has led to an improvement of the performance of the process results in an increase in the production of biogas to approximately 20% more for the particles of size 10mm [33].

VII. ENERGY UTILIZATION

Nathan investigates that the maximum of 165 tonnes of food waste is diverted from landfill each year; a savings of $21,615 per year ($131tonne^{-1}) in transportation costs is gained. Additionally if 18,350m^3 of biogas is produced and 7% of it is used to heat the system, then 17,066 m^3 of biogas is available to send to the building's natural gas heating system representing a savings of $8553 at 50 cents m^{-3} of natural gas. The total annual savings from this part of the process is $30,168 [38].

VIII. RESULT AND DISCUSSIONS

Table II shows the biogas production from various biomass wastes. The table shows that the maximum

TABLE II Biogas Production from Various Biomass Waste

Biomass waste	Pretreatment	Co-digestion	Process parameter	Biogas yield	Increase in biogas yield
Dairy manure	Fine fraction Coarse fraction Unscreened manure	-	HRT-30days	436 L kg^{-1} VS 404 L kg^{-1} VS 366 L kg^{-1} VS	-
70% Cattle manure	Ultrasound	20% food waste 10% sewage sludge	Temp- 36^oC Temp- 55^oC Lower HRT	0.85 L $CH_4L^{-1}day^{-1}$ 0.82 L $CH_4L^{-1}day^{-1}$	31% 67%
Dairy manure	-	Corn stover	HRT-40days	497 ml g^{-1} TS day^{-1}	-
32% FW 48% FW	-	68% dairy manure 52% dairy manure	HRT-30days	455 L kg^{-1} VS 531 L kg^{-1} VS	-
FW	-	Cattle manure	-	388 mLg^{-1}-VS	41.1 %
Barley straw	Thermal - 120^oC Mechanical -0.5cm	-	-	240 L CH_4 kg ¯1 VS	40.8 % 54.2 %
Wheat straw	Thermal - 120^oC Mechanical -0.2cm	-	-	182 L CH_4 kg ¯1 VS	64.3 % 83.5 %
Wheat straw	Anaerobic filter	-	Thermophilic Mesophilic	165 L CH_4 kg ¯1 VS 121 L CH_4 kg ¯1 VS	-
cow manure	-	-	-	62 m^3 methane/ton	-
OFMSW	-	-	-	37 m^3 methane/ton	-
OFMSW	-	cow manure	-	172 m^3 methane/ton	-
CGW	-	cow manure	-	87 m^3 methane/ton	-
MSW	-	Bovine rumen fluid inoculum	-	MSW/inoculum A (100%/0%) - 3.6% B (95%/5%) - 13.0% C (90%/10%) - 25.0% D (85%/15%) - 42.6%	
Waste banana stem	-	-	Temp(37±40°C) Temp(50±55°C)	267±271 l/kg TS 212±229 l/kg TS	-
Rice husks	-	-	Dilution 1:6 w/v pH-7	382 $mLday^{-1}$ 357 mL/day	-
Rice straw	NaOH pretreatment	-	Temp-37^oC	140.0 Lkg^{-1}VS 59.8 Lkg^{-1}VS CH_4	184.8 Lkg^{-1}VS 74.1L/kgvsCH_4
Rice straw	Hydro-thermal	-	-	140.0 Lkg^{-1}VS 59.8 Lkg^{-1}VS CH_4	315.9 Lkg^{-1}VS 132.7 Lkg^{-1}VS
kitchen wastes	-	-	Temp(25-34^oC) pH-(6.7-5.48)	35 L kg ¯1 dry waste	-
cotton stalks cotton oil cake cotton seed hull	-	-	HRT-23days	65 ml CH_4 g ¯1 78 ml CH_4 g ¯1 86 ml CH_4 g ¯1	-
78 % vegetable waste	-	4% tuber waste & 18% fruit wastes	HRT-14 weeks	20-40 ml min^{-1}/160 kg	-
MSW	particle size of 10 mm	-	Temp-40^oC HRT-21days	-	20%

OFMSW - Organic fraction of municipal solid waste, CGW - Cotton gin waste, FW - Food waste

biogas yield of 531 L kg^{-1} VS was obtained with co-digestion of 52% dairy manure and 48% food waste. The hydraulic retention time was 30 days for the above mentioned process. The hydro-thermal pretreatment on rice straw also improve the biogas production from 140.0 Lkg^{-1}VS to 315.9 Lkg^{-1}VS. The results show that co-digestion and pretreatment was reducing the hydraulic retention time and enhances the biogas production.

IX. CONCLUSION

Anaerobic digestion is an efficient waste treatment technology that reduces waste volume and generate biogas at the same time. Obtaining information on various biomass waste components is necessary for successful application of anaerobic digestion. The results show that the parameters like temperature, pH organic loading rate, stirring, and additives affect the yield of biogas. Co-digestion with other waste can significantly improves the waste treatment efficiency. Pre-treatment before anaerobic digestion provided an accelerated pre-hydrolysis of biomass and also it would help to reduce HRT considerably resulting in cost reduction of biogas plant without compromising on quantity and quality of biogas.

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