Anaerobic Co-Digestion of Water Hyacinth : A Review

Manali Jadhav[1], Kiran Kangle[2]

[1]*MTech Scholar, Department of Environmental Engineering, KIT's College of Engineering (Autonomous), Kolhapur, Maharashtra, India*
[2]*Assistant Professor, Department of Environmental Engineering, KIT's College of Engineering (Autonomous), Kolhapur, Maharashtra, India*

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Abstract - *Increased urbanization has led to significant waste management and energy challenges, instead of simply disposing of waste, waste recovery processes offer environmental benefits. Anaerobic digestion is a promising technology for recovery of energy from organic fraction of solid waste. Anaerobic digestion involves controlled microbial decomposition of organic matter in absence of oxygen, resulting in the production of biogas composed primarily of methane and carbon dioxide. The process consists of four steps, initially hydrolysis, acidogenesis, followed by acetogenesis and last is methanogenesis. Co-digestion, which involves digesting multiple types of waste simultaneously, is an effective approach. This study focuses on the use of water hyacinth, an invasive aquatic weed, for co-digestion. Since presence of water hyacinth in water body causes various aquatic environmental issues, its removal and proper disposal is required. By properly providing pretreatment and anaerobic co-digestion with another substrate, the disposal problem can be addressed and energy can be recovered from biogas produced. However, its main disadvantage is sometimes it requires pretreatment and while feeding to digester proper mixing ratio needs to be maintained.*

Key Words: Anaerobic Co-digestion, Water hyacinth, Pre-treatment, Substrate ratio, Inoculum

1. Introduction

1.1 General

Rapid uncontrolled and unmonitored urbanization has created serious problems regarding waste management and energy requirement. Effective management of waste generation and disposal is critical for environment sustainability, economic prosperity and social equality. The economic development of a country is mainly dependent upon the use of energy in industrial, transportation, domestic, and agricultural domains. The dependence on fossil fuel as primary energy source has led to global climate change, environment degradation and human health problems [1] The use of fossil fuels as the primary energy source has contributed to global climate change, environmental degradation and various human health problems. Therefore, alternative energy sources such as solar, wind, biomass and geothermal energy have gained attention as renewable and long-term solution [2]

1.2 Anaerobic Digestion

Waste recovery is a waste management approach which aims to utilize the potential of waste and reduce the amount of matter that is ultimately discarded. In recent years, there has been a growing interest in converting biomass to methane through biological process. There are various technologies like incineration and refuse derived fuel (RDF) etc., have been developed for producing energy from solid wastes. Among these technologies, anaerobic digestion has become a promising method particularly for recovering energy from organic fraction of solid wastes. Anaerobic Digestion is an environment friendly technique that produces energy in the form of biogas, while residue which remained can be used as soil conditioner.

Anaerobic digestion is a controlled process involving microbial decomposition of organic matter in absence of oxygen [3]. Anaerobic digestion (AD) consists of a number of complex biochemical reactions carried out by several types of microorganisms that survive in oxygen free conditions. This process produces biogas which is predominantly composed of methane (CH_4) and carbon dioxide or (CO_2) as major gases along with trace amounts of hydrogen sulfide (H_2S), nitrogen (N_2), hydrogen (H_2) and water vapors. It's a four-step process that involves the participation of different trophic groups at each stage. In the hydrolysis stage, organic macromolecules are broken down into monomers like sugars, fatty acids, and amino acids. These components are further broken down into VFAs (volatile fatty acids: short-chained fatty acids like acetate, butyrate, or propionate), organic acids, and alcohols, along with small amounts of hydrogen in the second acidogenesis stage. The largest fraction of H_2 and acetate comes from the third step, the acetogenesis stage, in which bigger VFAs and other organic acids from the previous stage are converted into the two substances. Finally, in the methanogenesis stage, methane and carbon dioxide are produced [4]

1.3 Co-digestion

Co-digestion is the simultaneous digestion multiple types of waste in the same unit. The process offers several advantages, such as better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing [1] Numerous Studies have shown that co-digestion of several substrates, such as Food waste, Dry-thermophilic anaerobic digestion of organic fraction of the municipal solid waste: focusing on the inoculum sources - corn silage; restaurant waste digested mixed with rice hulls; cattle excrement; swine excrement; digested sludge and swine excrement mixed with digested sludge, kitchen waste and sewage sludge, activated sludge and organic fraction of municipal solid wastes, municipal solid waste and agricultural waste and the effect of codigestion with dairy cow manure, dairy manure and food waste, Food waste and yard waste and Kitchen waste and water hyacinth [5]. Shortly we can conclude that by combining different waste materials it was observed that the overall digestibility and methane yield can be improved leading to more efficient waste management and resource utilization.

1.4 Water hyacinth

The management of waste generated by humans and animals always involves the production of biogas. Recently, energy crops like weeds and agricultural residues have been widely used for biogas production. The water hyacinth (Eichhornia crassipes) is an aquatic weed that is considered as an invasive species which is persistent in the environment and causes problems to aquatic environment. As this form a dense mat on water surface, it affects the quality of the water by blocking sunlight and the air-water interface leading to a decrease in oxygen levels and negatively impacting water quality [2]. Water hyacinth contains low lignin level of 7–26 % and a high cellulose content of 18–31 % and hemicellulose content of 18–43 percent. During AD process, cellulose and hemicellulose components are easily broken down by hydrolytic bacteria, to produce sugars and short chain fatty acids which are further converted to methane. Additionally, water hyacinth has a relatively high carbon-to-nitrogen ratio, which is a favorable feature in biomass for biomethane synthesis. However, its lignocellulose composition can slow down the hydrolysis process, impeding conversion to biogas. The lignocellulose structure can restrict water hyacinth decomposition, leading to sluggish digestion by bacteria and reduction in methane output. To enhance the biodegradability of water hyacinth, various approaches can be utilized, including pretreatment, dilution, and co-digestion with another. The co-digestion of water hyacinth with highly biodegradable substrate such as, food waste is simple and cost effective which can be a strategy for improving biodegradability. Food waste is rich in organic content and highly biodegradable, thus facilitating the breakdown of water hyacinth [6] Water hyacinth has gained the attention as a potential biomass due to its nitrogen content, essential nutrients and high fermentable matter content. Furthermore, the sludge produced during the biogas production process contains valuable nutrients and can be used as a fertilizer without detrimental effects on environment [1]

1.5 Different Substrates used with Water Hyacinth for Anaerobic Co-digestion

Banana Peels

Visva Bharati Barua et al., (2019) [7], have carried out BMP test for comparative evaluation between water hyacinth and banana peels as food whereas, cow dung was considered as inoculum. The set I consists of anaerobic co-digestion of untreated water hyacinth and banana peels and set II: anaerobic co-digestion of pretreated water hyacinth in hot air oven at 90^0C and banana peels having different mixing ratios 1.0, 1.5, 2.0 and 2.5 in triplicate. There are two reactors supplied, one with only cow dung as control 1 and the other filled with only water hyacinth as control 2. The batch setup experimentation results reveal that for retention time of 50days maximum biogas production was for set I 170 ± 10 mL on the 16th day having mixing ratio 2, whereas, for set II 197 ± 10 mL on the 11th day having mixing ratio of 1.5. In case of set I, maximum cumulative methane production was for mixing ratio of 2 was 3948 ± 12 mL similarly, in case of set II for mixing ratio of 1.5 maximum cumulative biogas production was 4954 ± 12 mL. Highest sCOD was accomplished in set I ratio 1.5 was 6200 ± 10 mg/L whereas ratio 2 in set II was 9400 ± 10 mg/L. Highest VS reduction of 45% was for set I for mixing ratio of 2, similarly for 53% for set II for mixing ratio of 1.5. The kinetic parameters of set I and II used in BMP examined were determined where methane for set II (6.3921 L CH_4) was observed to be higher than set I (5.5190 L CH_4). Mixing ratio 2 and 1.5 were illustrated to be the optimal mixing ratio for set I and II respectively.

S Soeprijanto et al., (2021) [8], objective was to assess the impact of water hyacinth, banana peel, and water spinach waste as a substrate for biogas production by using horizontal anerobic digester. The inoculum used for experiment was cow dung which was mixed with water to volume ratio of 1:2. The combination of feedstock feed to digester having different mixing ratios were water hyacinth WH (100%), banana peel and water spinach BP:WS (50:50%) and water hyacinth to banana peel to water spinach WH:BP:WS (50:25:25%). The digester was constructed for continuous mode having flowrate of 8 l/day which had retention time of 24 days. Cumulative biogas production for WH, BP:WS and WH:BP:WS was 518.768 l, 518.768 l and 402.012 l respectively. In this experiment the biogas was produced from BP:WS was CH_4 (71.23%), CO_2 (25.79%), H_2S (1.71%) and NH_3 (0.39%); from WH-BP-WS was CH_4 (71.97%), CO_2 (25.91%), H_2S (1.68%), NH_3 (0.38%); while for WH was CH_4 (70.97%), CO_2 (26.77%), H_2S (1.37%), NH_3 (0.61%), respectively. The study reveals that for co-digestion produces more biogas compared to mono digestion of single substrate.

Sandhu Sonam and Kaushal Rajneesh (2019) [9], experimentation assesses the impact of blending proportion

(1, 1.5, 2 and 2 .5) and chemical pre-treatment on the anaerobic co-processing of banana strips and water hyacinth. The operation was carried out in continuous mixing mode having different mixing ratios of 1, 1.5,2.5 and 2, having feeding capacity to bio-digester is 20kg. During experimentation, set I consists of untreated water hyacinth blended with banana peels and set II consists of water hyacinth pretreated before co-absorption. Results show that mixing ratio 2 showed biogas production on 16th day 172 ± 15 mL in set I and mixing ratio 1.5 showed biogas production on 11th day 195.4 ± 20 mL. Blending ratio 2 in set II showed lower biogas production compared to set I. There is significant consistent improvement from the start-up, but after 51 days there was reduction in biogas production. In set I though blending proportion 2 displayed most elevated combined methane creation of 3900±10 mL before 51 days' over. It was observed that set II which has pretreatment shows high biogas compared to natural biogas produced in set I.

Food waste

Visva Bharati Barua et al., (2018) [10], novelty of study was related regarding comparison for set I: co-digestion of untreated water hyacinth and cooked food waste and set II: co-digestion of pretreated water hyacinth and cooked food waste, both executed in laboratory scale biogas digesters. The test was carried out for only cow dung as control 1, only water hyacinth as control 2 and different mixing ratios 1.0, 1.5, 2.0 and 2.5 in triplicate. By the end of 50 days, cumulative biogas generation of 5017 ± 15 mL was achieved by the ratio 1.5 in set II and in set I for ratio 2 highest cumulative methane production of 4328±12 mL. Mixing ratio 2 in set up I exhibited the highest decrease in VS of 43% while the mixing ratio 1.5 in set up II exhibited a highest decrease in VS of 55%. Similarly for highest VFA concentration in set I for mixing ratio 2 in set up I concentration was 3000±10 mg/L and in set up II for the ratio 1.5 was found to be 3938± 12 mg/L. Likewise, ratio 1.5 in set up I, achieved a maximum sCOD of 6400±12 mg/L while ratio 2 in set up II achieved a maximum sCOD of 10,400±10 mg/L. Considerably, it was observed that cumulative biogas production is more in case of co-digestion compared to mono digestion. Also, it revealed that pretreated codigestion substrates produces biogas approximately 1.5 times more than set I i.e. untreated substrate.

Zala Mayank et al., (2019) [11], conducted comparative study related to anaerobic digestibility of food waste as a mono digestion substrate and co-digestion of food waste with water hyacinth were tested which were analyzed in a batch type anaerobic digester having capacity of 60 l. The four samples were analyzed for anaerobic digestion are as follows, only food waste, only water hyacinth, and with food waste to water hyacinth in the ratio of 15:2 and 8:3 to maintain total. After crushing food waste was mixed with water in the proportion 1:1.2 and water hyacinth to water 1:10. The inoculum used was collected from already existed biogas plant based on fruits and vegetable waste. The anaerobic digester was fed with two parts as feeding substrate and one part as inoculum. The pH variations observed sample 1 dropped from 5.5 to 4.3 during the digestion period of 12 days, but by end of experiment it was improved to 6.9. Sample 2, which consisted of food waste and water hyacinth, showed pH value drop from 6.61 to 5.00 over a digestion period of 15 days, however the presence of water hyacinth caused the pH to increase to 7.20 at the end of the experiment. Similarly for sample 3 pH value ranged from 6.7 to 5.44 for 15 days retention period. In sample 4, where only water hyacinth was digested, pH remained with the optimum range for AD throughout the experiment. The TS reduction for sample 1, 2, 3, and 4 was reduced by 71.45%, 67.44%, 61.09%, and 67.10%, respectively, similarly VS reduced by 70.22%, 69.43%, 60.54%, and 66.02%, respectively after retention period of 40 days. Biogas yield obtained for samples 1, 2, 3, and 4 was 370.85 (ml/g VS), 320.54 (ml/g VS), 286.50 (ml/g VS), and 298.83 (ml/g VS), respectively. Therefore, it can be concluded that co-digestion of food waste with water hyacinth has higher operational stability compared to mono digestion of food waste.

Tasnim Farzana et. al., (2017) [12], study objective was to analyze and compare biogas production from various sources of waste material. Materials under study were Cow manure, Sewage Sludge, Kitchen Waste & Water Hyacinth. Sewage Sludge was added with Water Hyacinth instead of normal water. 1.5% NaOH was added in both digesters 50 gm CM was loaded with 500 ml SS and 50 gm of WH. Again, 50 gm KW was charged with 50 gm of CM with 500 ml water and 50 gm KW was loaded with 500 ml SS separately. KW+SS shows that production reached peak before KW + CM, the production level reached by KW +CM was noticeably higher than KW + SS. The lab scale experiment was conducted at mesophilic condition i.e. 37^{0}C and co-digestion was operated under organic loading rate of 100gm/l. After 254 hrs, total biogas production for Water Hyacinth, Cow Manure & Sewage Sludge was 812 ml with 65%Methane, 14%CO and 21% other gases, while lab results for combination of Kitchen Waste & Cow Manure produced 335 ml consisting of 60% Methane, 18%CO & 22%other gases. After 254 hrs, stated that WH with CM produces more than double the amount of gas in comparison to KW with CM for the same period.

Kinattinkara Sapna et. al., (2022) [2], objective of the study focused on examining biogas production using a mixture of cow dung, water hyacinth, and food waste and evaluate the effectiveness of the biogas. In experimental setup, mixtures were dissolved using cow urine and made at 3:1 ratio by the volume of cow dung and pretreated water hyacinth and food waste mixture. For laboratory setup, five different combination of substrates were taken in glass bottles as follows L1 (CD half bottle filled with cow dung and cow urine), L2 (CD: WH, filled with a mixture of 3:1 ratio volume of cow dung and 1 % NaOH treated water hyacinth), L3 (CD: FW, filled with a mixture of 3:1 ratio volume of cow dung and food waste), L4 (CD: WH: FW, filled with a mixture of 3:1 ratio of cow dung and 1 % NaOH treated water hyacinth and food waste), and L5 (WH only filled with 1 % NaOH alkali treated water hyacinth). The experiment was carried out for 20 days at room temperature ranging from 26 °C to 42 °C. The results show that as ambient temperature increases there is an increase in production of gas level. The laboratory setup results show that total yield of gas production for L1, L2, L3, L4 and L5 are 990 ml, 1.2 liter, 964 ml, 1.1 liter and 167 ml respectively. Similarly, methane percentages for L1, L2, L3, L4 are 70 %, 80 %, 76 %, 85 % respectively and L5 has no methane content in gas. Highest NPK values are for substrate L4 while lowest for L5. Initial Total Carbon content was high in L4 and low in L5 whereas, after digestion total carbon content is high in L3 and low in L5. Experimental setup was conducted for 32 days with varied temperature between 29 °C to 45 °C. The pH measured initially and after digestion was 7 and 7.9. The total gas yield was 8.5 liter and average biogas was 265 ml per day. The biogas produced was checked for flammability test using Bunsen burner for experimental setup.

Oduor William W. et. al., (2022) [6], the aim of the study was to compare the anaerobic digestibility of FW as a mono substrate to co-digestion of FW with water hyacinth (WH) in order to enhance biogas production and organic matter removal efficiency in a laboratory batch reactor. During beginning of batch process, feeding of inoculum/substrate ratio was 1:1 and different mixing ratios were(%WH:%FW) 0:100, 15:85, 30:70, 55:45, 70:30, 85:15 and 100:0. The (C/N) ratios of WH and FW were 10.53 and 17.28 respectively. The total solids (TS) for FW and WH were 60.78 and 62.20 g/L of samples, similarly Volatile Solids (VS) present in FW and WH were 54.12 g/l and 44.68 g/L respectively. Total Chemical Oxygen Demand (TCOD) concentrations in FW and WH were 170 g/L and 140 g/L, respectively, indicating high and low content of organic matter in these substrates and SCOD for FW and WH were 85 and 60 g/l respectively. The cumulative biogas production for 81 days having different mixing proportion (%WH:%FW) 0:100, 15:85, 30:70, 55:45, 70:30, 85:15 and 100:0 biogas yield (ml/1gVS) was 357.85 ± 24, 305.01 ± 22, 280.27 ± 18, 548.91 ± 35, 616.01 ± 48, 270.27 ± 21 and 256.27 ±20 respectively. The Average methane content of Biogas (%) for different mixing proportion (%WH: %FW) 0:100, 15:85, 30:70, 55:45, 70:30, 85:15 and 100:0 was 58 ± 1, 53 ± 4.35, 56 ± 1, 54 ± 2.65, 63 ± 1, 71±1.15, and 68 ± 5.29 respectively. The study found that 70:30 mixing ratio resulted in improved the biogas production, with organic matter removal efficiency reached 79% having maximum methane content of 71%.

Primary sludge

Patil J. H. et al., (2011) [13], undertook to evaluate co-digestion of water hyacinth and primary sludge (PS) to improve biogas yield. For sample preparation oven-dried water hyacinth was then ground to fine powder and pretreatment of water hyacinth was done using alkali method. The different fermentation slurries were prepared in which total solids were maintained to 8% and operated at mesophilic temperature range (30°C to 37°C), having retention period of 60 days. The feed to digester consists of only water hyacinth WHB (8g), different combinations PS1 (2g), PS2 (3g), PS3 (5g) and only primary sludge PSB. Each digester PS1, PS2, PS3, PS4 and PSB produced flammable biogas on 9th day, while digester WHB produced on 13th day. Maximum cumulative biogas production was by PS3 (0.35 l/gVS) having biogas composition 69.6 %, 25.8 %, 0.8 % and 3.8 % for CH_4, CO_2, N_2 and O_2 respectively. It was observed that digesters PS2, PS4 and PS1 produced biogas 73%, 67.6% and 51.4%, which was more than the control digester WHB which contains only water hyacinth with no primary sludge. The results indicate that blending primary sludge with water hyacinth significantly enhances the biogas yield.

Slaughter House waste

Omondi E.A. et al., (2019) [14], study evaluated synergy in co-digestion of water hyacinth with ruminal slaughterhouse waste in biogas production. The materials considered for experiment are water hyacinth (WH) and co-substrate ruminal slaughterhouse waste (RSW) where digester was operated in batch mode. Eight reactor flasks labelled D1 to D8 having co-substrate mixing percentage of 0, 5, 10, 15, 20, 30, 50 and 100 and to understand effect of temperature the digester was operated at 24, 32 and 37^{0}C. The pH variations observed during operation of digester were RSW mix proportion of less than 15% had a pH less than 6.2 but increased to 6.8 to 7.5 for the RSW proportions of 20 -100%. The largest biogas cumulative yield was observed for 100% RSW (17.8 L CH_4/kg substrate) followed by 50 and 30% RSW while the smallest yield was for water hyacinth alone (0% RSW) at 8 L CH_4/kg substrate. Methane gas proportion increased with increase in RSW mix proportion in the reactor mixture, from 59% for water hyacinth alone (0% RSW) to a maximum value of 68% for 20% and 30% RSW mix proportions and then decreased to a minimum value of 58% for RSW alone (100% RSW). The study reveals that as there is increase in the temperature from 24 to 32ºC there is an increase in methane yield from 14 to 40 L/kg or 186%, but after increasing the operating temperature to 37ºC only increased the yield by a further 30% to 52 L/Kg. The study concludes that digestion of WH with 30% RSW at 32ºC showed improved biogas yield.

Omondi E. A. et al., (2020) [15], carried study using water hyacinth and ruminal slaughter house waste (RSW). The digesters labeled D0, D30, and D100, were fed with 150 g of

WH and RSW substrate mixture with respective RSW proportions of 0, 30 and 100%. At 60 days retention time, WH yielded 19.6 L CH_4 kg^{-1} about 47% of the 42 L CH_4 kg^{-1} yield for RSW. However, co-digestion of WH with 30% RSW increased the biogas yield to 40 L CH_4 kg^{-1} or 95% of the RSW yield indicating synergy in co-digestion. Co-digestion of WH with RSW at 70:30 ratio, maintained a more alkaline pH suggesting that co-digestion matched the rate of acidogenesis to that of methanogenesis.

Vegetable Waste

Chris Sheba Vivian et al., (2018) [16], used Vegetable waste (VW), Fruit waste (FW) and water hyacinth (WH) biomass with cow dung (CD) as inoculum for digestion process. The mixing ratio for VW was VW1, VW2, VW3, VW4 and VW5 similarly for FW were FW1, FW2, FW3, FW4 and FW5 in which both VW and FW were added 50g, 100g, 150g, 200g, and 250g respectively. The water hyacinth and cow dung were added 250g each to each mix. Results show that maximum % COD reduced and % VS reduced for VW2 38.5% and 76.5% respectively. Similarly, for FW2, maximum % COD reduced and % VS reduced was 43.9% and 88.9% respectively. Daily biogas production reached its peak condition at optimum conditions around 27 – 30 days and 24 – 26 days for vegetable waste and fruit waste, respectively. Maximum biogas production was for VW5 and FW4 1528.13 mL/(gVS) and 1638.61 mL/(gVS) therefore it can be concluded water hyacinth with fruit waste produces more biogas rather than vegetable waste.

M. A. Hernández-Shek et al., (2016) [17], studied co-digestion of WH and fruit and vegetable waste (FVW) in semi-continuous digestion experiments incubated at 37 ^{0} C for 60 days. WH alone and co-digestion of WH and FVW in a 70:30 ratio was used. In BMP test, the substrate concentration of 2 g VS L^{-1} was tested to determine methane potential while, total solids content was optimized under BMP conditions using total solids (TS) concentrations of 4 and 6%. The biogas produced by WH alone was 0.114 m3 kg^{-1} VS $_{added}$, while for WH and FVW had 0.141 m^3 biogas kg^{-1} VS_{added}. Analysis shows that methane content for WH alone was 57.5% while for WH-FVW it was 60.5%. Treatment with WH alone exhibited lightly greater release of ammonia, 414.4 $mgNH_3L^{-1}$ and 503.3mg NH_3 L^{-1} for the digestion of WH compared to 375.9 mg NH_3L^{-1} and 483.4 mg NH_3L^{-1} for the co-digestion, with 4% and 6% of TS, respectively final ammonia concentrations were 225 and 250 mg L^{-1} for WH and co-digestion WHFVW, respectively. The study reveals that relatively low TS concentration of 4% favored a rapid conversion of acids into biogas, while a higher solids concentration of 6% showed a reduction of 12% in biogas production; consequently, there was a drop in VS destruction (less than 16%).

Sheep Waste

Patil Jagadish H et. al., (2014) [1] have explored different combination of water hyacinth and sheep waste for anaerobic co-digestion. Batch mode experiments were carried out under mesophilic temperature range of 30°C to 37°C with different fermentation slurries of 8% total solids named as WHB 8g, similarly SW1 2g, SW2 3g, SW3 4g, SW4 5g and only sheep waste as SWB. The retention time of anaerobic co-digestion was of 60 days and results show that Digesters SW1, SW2, SW3 and SW4 began biogas production from 5th day and evolved flammable biogas from 9th day. In Digester WHB it was observed that biogas production was after 10 days and evolved flammable biogas on 14th day. Fermentation slurry SW3 showed the highest biogas yield of 0.36 l/gVS and composition of CH_4, CO_2 and others (H_2, N_2, H_20 and H_2S) in the biogas were found to be 60.84%, 21.53% and 17.63% respectively. The biogas compositions for the other digesters were also found to be in the same range. The results show that anaerobic co-digestion of dried water hyacinth and sheep waste improved biogas yield.

3. CONCLUSIONS

Based on the above study, it can be concluded anaerobic Co-digestion improves biogas production and methane yield. Utilizing different substrates for co-digestion can improve shows biogas production and also improves waste management. Water hyacinth, a wide spread aquatic weed which causes interference in aquatic environment, can be effectively utilized for anerobic co-digestion with substrates like food waste, kitchen waste and cow dung. The use of Water hyacinth offers environmental benefits by producing renewable energy and addressing the problem of its disposal. However, study reveals that providing pretreatment and increased mixing requirements causes a significant improve in biogas yield. Overall, anaerobic co-digestion technology has the potential to benefit the environment and contribute to energy production.

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