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Agro Residues for Biomethanation- Prospectus

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Abstract:
Nowadays, the energy security as well as the environmental concerns has made great attempts to find economically and environmentally friendly energy resources. Biomethanation is a natural process of anaerobic degradation of organic materials resulting in production of biogas. Biogas production via anaerobic digestion has been shown as a sustainable, renewable and carbon neutral energy source which can reduce the global fossil fuels dependency. Agricultural activities generate huge amounts of organic residues annually worldwide. These are including crop residues, straw, stalks, branches, leaves, waste from pruning, bagasse, residue from cotton ginning, oil cakes and animal manure. They are the non-product outputs of production and processing of agricultural products that may contain material that can benefit man but whose economic values are less than the cost of collection, transportation, and processing for beneficial use. Traditional methods such as burning of these residues cause adverse effects on the environment such as greenhouse gas emission and pollution of air and water, while they could be sufficiently converted into valuable products through anaerobic digestion process [34]. It is estimated that about 998 million tonnes of agricultural waste is produced yearly. This large amount of waste could be utilized to produce biogas, biofuel, syngas and producer gas and feed stock for electricity generation to reduce the total energy demand of the rural area. The utilization of biomass in thermo-chemical processes (e. g., pyrolysis and gasification) involves higher capital costs
This paper presents a comprehensive review on the latest studies investigating the potential of agricultural wastes as feedstock for biogas. The review includes the investigations on the biomethane potential of agricultural residues as well as the investigated operational conditions for the improvement of anaerobic digestion of agricultural residues

Keywords: *Biomethanation, agricultural residue, characterization of biomass, prospectus of agricultural waste, prospectus of Biomethanation*

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I. INTRODUCTION

Biomethanation:

Biomethanation is a natural process of anaerobic degradation of organic materials resulting in production of biogas (a mixture of methane and carbon dioxide). It occurs in natural environments, such as landfills, rice fields, sediments, and intestinal tracts of animals, where light and inorganic electron acceptors (oxygen, nitrate, sulphate, iron, etc.) are not present or limiting [1]. The anaerobic degradation process is a multistep complex process performed by the combined action of three major physiological groups of microorganisms [1] primary fermenting (hydrolytic–acidogenic) bacteria, anaerobic oxidizing (syntrophic–acetogenic) bacteria, and methanogenic archaea. Fermenting microorganisms decompose the biopolymers (lipids, proteins, nucleic acids, carbohydrates, etc.) to soluble monomers (long-chain fatty acids, glycerol, amino acids, purines, pyrimidines, monosugars, etc.) that are further converted to short chain fatty acids (butyrate, propionate, acetate, etc.), alcohols (ethanol and methanol), hydrogen, and carbon dioxide by the same microbes. Short chain fatty acids and also alcohols are oxidized by proton reducing syntrophic acetogens to hydrogen, acetate, formate, and carbon dioxide. These end products are ultimately transformed to methane and carbon dioxide by the methanogenic archaea [2].

Bio-methanation is the process of conversion of organic matter in wastes to methane and manure by microbial action in the absence of air through a process called anaerobic digestion. Bio-methanation is the anaerobic digestion of biodegradable organic waste in an enclosed space under controlled conditions of temperature, moisture, pH, etc. It is a decomposing system wherein depending on the waste characteristics the waste mass undergoes decomposition anaerobically thereby generating biogas comprising mainly methane and carbon dioxide. In today’s world, the reduced organic and inorganic compounds produced by anaerobic microbial processes serve as carbon and energy reservoirs for photo synthetically fixed energy. Accordingly, two life styles are intimately coupled and function together for mutual benefit. A variety of waste sources like urban, agriculture, industrial sectors, vegetable markets, etc. generate huge quantities of solid waste containing a sizeable proportion of biodegradable organic matter with Municipal Solid Waste (MSW) having largest proportion If this waste processed anaerobically it will produce significant amount of bio-gas and manure also [3].

Agricultural waste:

Agricultural wastes are defined as the residues from the growing and processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products, and crops. They are the non-product outputs of production and processing of agricultural products that may contain material that can benefit man but whose economic values are less than the cost of collection, transportation, and processing for beneficial use. Their composition will depend on the system and type of agricultural activities and they can be in the form of liquids, slurries, or solids. Expanding agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. It is estimated that about 998 million tonnes of agricultural waste is produced yearly. Organic wastes can amount up to 80 percent of the total solid wastes generated in any farm of which manure production can amount up to 5.27 kg/day/1000 kg live weight, on a wet weight basis [4].

In India, two seasons are main for agriculture activities, one is Kharif and Rabi (monsoon period in north-east). Agricultural sector in India produces a great amount of the agricultural residue as by product. The total residue availability is estimated at 877 Mt for 2030–31. Since, India is an agricultural country and a huge quantity of agro waste is available throughout the year. Approximate study shows, 350 million tonnes of agricultural waste is produced year round which can generate the 17,000 MWe of power. This large amount of waste could be utilized to produce biogas, biofuel, syngas and producer gas and feed stock for electricity generation to reduce the total energy demand of the rural area [5].

Plants of vegetables, crop straw, marine crop and manure which are having higher moisture content are more suitable for anaerobic digestion. Anaerobic digestion is the main principal for working for biogas plants in India. It is treatment of the biomass in absence of the air by naturally occurring microorganisms. Treatment of biomass produces mainly the mixture of methane (CH_4) and carbon dioxide (CO_2) with small traces of nitrogen (N_2) and hydrogen sulphide (H_2S). This mixture is commonly known as Biogas or Gobar gas in India. And the digested mass contains mainly N, P, K, which is very good fertilizer commonly known as bio fertilizer. The digestion process takes place in three basic steps. The first step is hydrolysis in which complex organic solids converted into soluble compounds. The second step is acidogenisis that involve the conversion of soluble organic materials into short chain acids and alcohols. And in third step which is methanogenesis, converts the yielding of second step into the gases by anaerobic bacteria. The methane content depends upon the type of waste and the percentage has been reported to vary between 50% to 80%. Biogas can be used for cooking purpose and the processed bio gas can be used for running I.C. engine to produce electricity and mechanical work. [5]

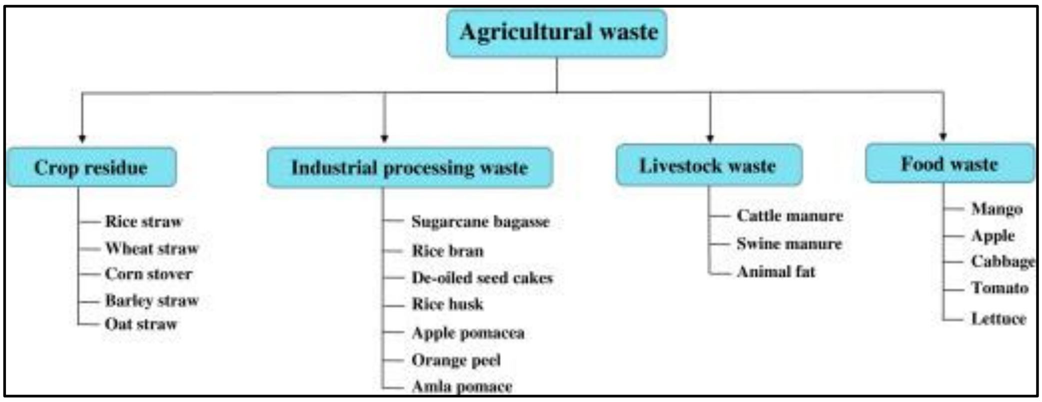

Figure 1: Classification of Agricultural Wastes [33]

Characterization of biomass as fuel:

More than 250 million tonnes of Agro-Residues are available in our country. At present these residues are either grossly underutilized or completely unutilized by in situ burning in the field as mean of disposal. Development of technologies, to utilize this major resource and their management need to be emphasised to meet the demands of domestic as well as industrial sectors [6-8].

Agricultural wastes and forest residues are the most promising biomass feedstock for their abundance and relatively low cost [9]. By means of thermo chemical or biochemical conversion routes, lignocellulosic biomass can be converted into energy or energy carriers. Thermo chemical conversion uses heat and chemical processes to produce energy products from biomass, including combustion, pyrolysis, gasification, and liquefaction [10]. Biochemical conversion of biomass involves the use of bacteria, microorganisms or enzymes to breakdown biomass into gaseous or liquid fuels, such as biogas or bioethanol [11]. Typical biomass conversion technologies and their primary products and end-uses are illustrated in Figure 2[5].

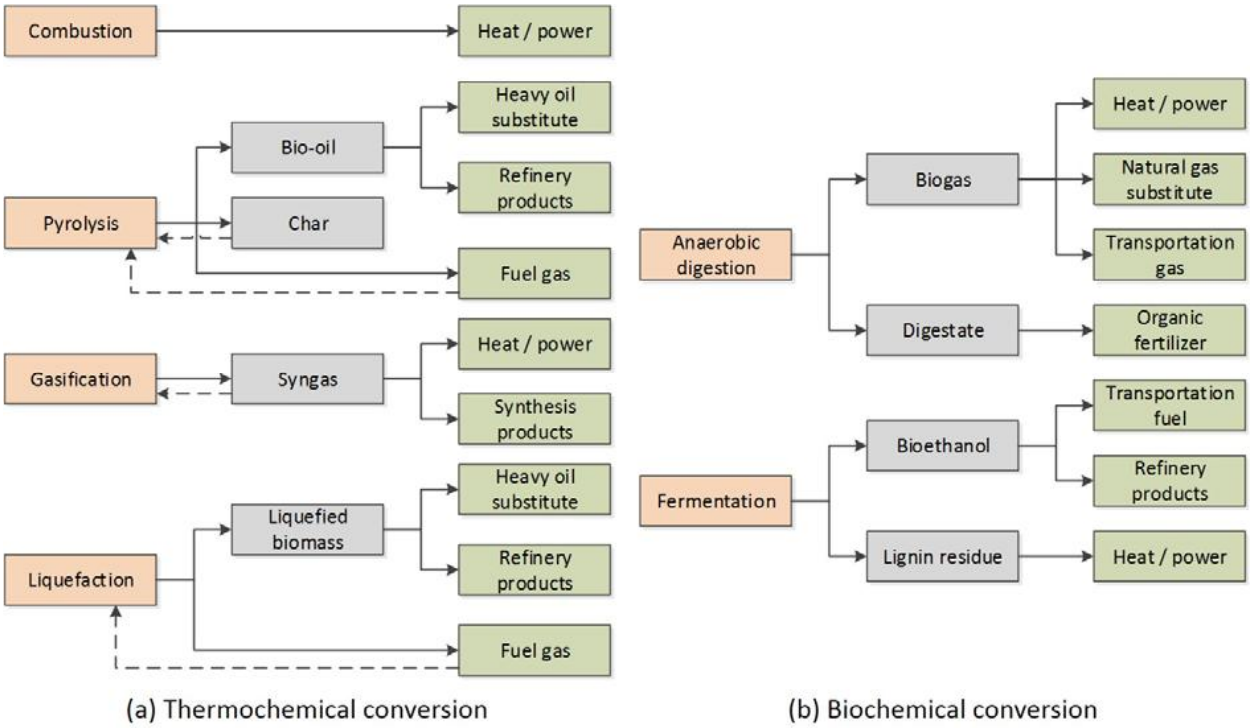

Figure 2: Thermo chemical and biochemical conversion of lignocellulosic biomass [5]

Biomass is a readily available renewable resource of energy having potential to replace conventional fuels in many applications mainly as bio-fuels. Biomass comprises of mainly three elementary components such as Carbon, Oxygen and Hydrogen. The composition of each biomass type varies depending on origin, species, plant type, climatic conditions etc. Heterogeneity is an inherent characteristic of biomass materials. The constituents of biomass fuel vary from region to region. Constituents of biomass also depend upon sources from which biomass is collected and method of preparation of bio-fuels. The viability and feasibility of bio-energy generation from agricultural biomass depends upon the characteristics of biomass available. Biomass could be employed for energy conversion by means of different processes, such as chemical, biochemical, thermal-chemical etc. The process choice specifically depends on the biomass characteristics; therefore biomass characterization is essential to study various biomass related properties, fuel value, ash handling, combustion, information for design, development and operation of biomass conversion system [12].

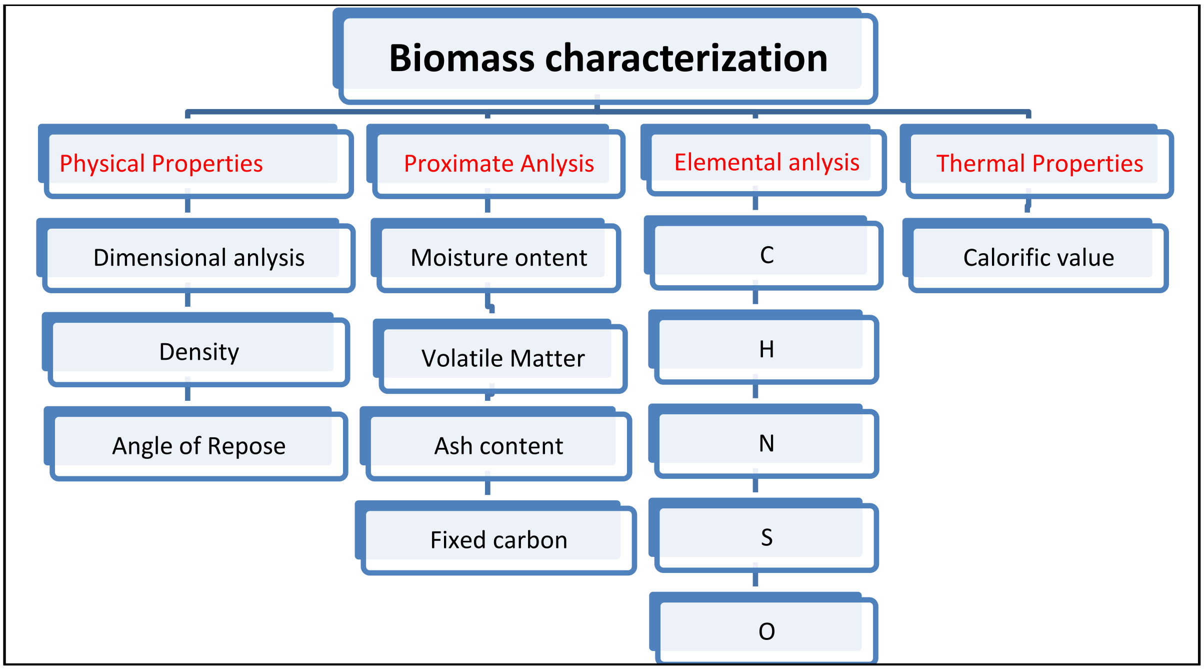

Figure 3: Biomass Characterization as fuel [12]

i. Dimensional Analysis: The dimensional characteristics are evaluated for three major perpendicular dimensions of biomass as length, breadth and thickness.
ii. Density: Density of biomass is usually classified as bulk and true density. Density of the biomass is the weight per unit volume and it depends on the size, shape of the biomass.
iii. Angle of repose: The angle of repose is the angle made by the biomass from the horizontal to the sides of pile under free falling conditions. It is a flow property of the material.
iv. Moisture content: The moisture content of the biomass can be determined by drying the sample in hot air oven till a constant weight obtained.
v. Ash content: The ash content is determined by heating the sample in a tarred silica crucible further placed in muffle furnace at a temperature of about 600 °C till a constant weight obtained.
vi. Volatile Matter: The volatile matter of biomass is that component of the carbon present in the biomass, which, when heated converts to vapor.
vii. Fixed Carbon Content: Fixed carbon is calculated by using mass balance calculations. Elemental analysis: Ultimate analysis gives information regarding the elemental composition of carbon, hydrogen, nitrogen and oxygen content of a biomass. CHNS analyser is used for the analyses of carbon, hydrogen, nitrogen and sulphur whereas oxygen can be determined by the difference.
viii. Calorific value: Calorific value is the heat released by the fuel under ideal combustion conditions [12].

Methods of Biomethanation of solid waste:

Solid waste is defined as organic material with solid content 10–40% TS, which is not fluid. The most important types of solid wastes with considerable biomethanation potential are municipal solid waste (MSW), kitchen waste, garden waste, energy crops (maize, grass, sugarcane, etc.), etc. The main obstacle in the processing of MSW is the separation of the organic biodegradable matter from other parts of MSW such as plastics and metals. Separation includes magnetic treatment, screening, pulping, gravity separation, or pasteurization. Also, source-sorting of biodegradable material has been practiced in many cases. Biological treatment of solid wastes includes technical challenges, such as feedstock pumping, homogenization, and mixing, which needs special consideration. Digestion can take place either under mesophilic or thermophilic conditions, and the HRT is 10–30 days, depending on the process temperature, the technology used, and the waste composition [13].

Currently, both batch and continuous processes for treatment of biodegradable fraction of MSW are used [14] according to the feeding mode of the wastes through the reactors (Fig. 4). Batch systems are basically engineered landfills (either confined or covered), with enhanced performance through recirculation of leachate. Three different batch configurations have been considered so far, including single batch (one tank with recirculation of the reactor effluent to the top of the same reactor), sequential batch (two tanks with recirculation of the effluent from first, acidogenic to the second, methanogenic reactor), and hybrid batch- UASB (combination of an acidification tank and methanogenic biofilm reactor where effluent from the tank is recirculated toward the methanogenic reactor).

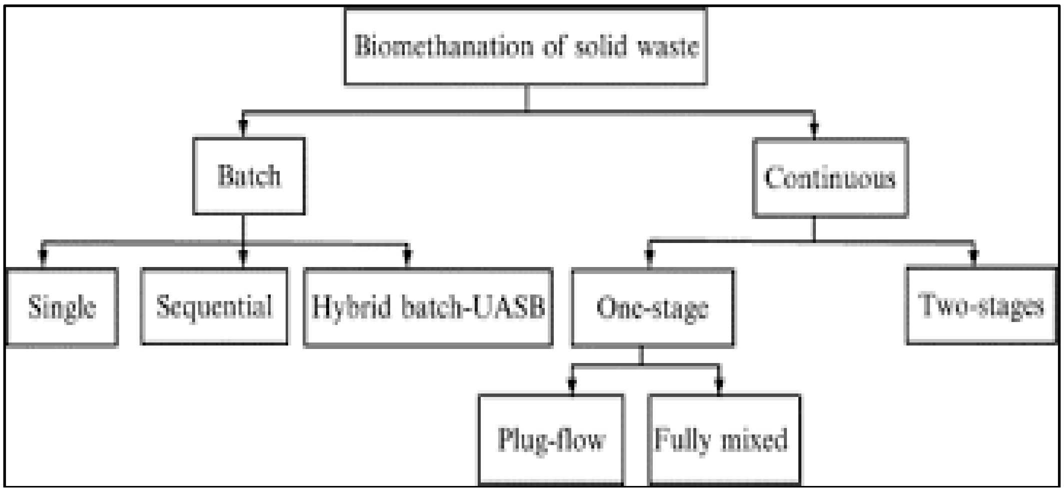

Figure 4: Process configurations for Biomethanation of solid wastes. [2]

Although very cheap, batch systems have not gained substantial market share so far, due to clogging of the bed late in the digestion stage, and manual requirements of loading and unloading. However due to their simple design and process control, they are very attractive for commercial applications in developing countries [15]. Continuous systems can be divided into one- or multistage (often two stage) processes. The one-stage process utilizes either fully mixed reactors, such as the Valorga process, or plug-flow reactors such as the Dranco process (with vertical plug-low reactor) or Compogas (with horizontal plug-flow reactor). For the fully mixed reactors, process water is separated from the effluent and is recycled in order to dilute the high total solid wastes, and thus make pumping and mixing possible. Moreover, lack of mixing inside plug-flow reactors, is not facilitating contact of substrate and microorganisms and therefore, recycling of digested effluent is applied to ensure effective inoculation of the influent substrate. With respect to two-stage process, many different process configurations were developed so far, the most simple one being applied includes two completely mixed or plug-flow reactors in series[14].

The AD process is feasible and efficient; however, technical difficulties concerning collection, separation, and handling of the wastes constitute a major problem in implementation of solid waste technologies. Therefore, codigestion with more liquid waste streams might be an attractive and economical way to treat these types of wastes.[13]

Biomethanation of some Agricultural Wastes:

The utilization of biomass in thermo-chemical processes (e. g., pyrolysis and gasification) involves higher capital costs [16]. Direct combustion for energy conversion is inefficient and stockpiling of these wastes pollutes the environment significantly and is associated with hard labour and adverse health impacts on rural women and children [17]. The provision of alternative efficient and sustainable uses of these wastes will therefore not only produce useful energy but also benefit the rural people and the environment [18].

Anaerobic digestion (AD) is a key technology for: (i) producing high-value bio energy from organic wastes in the form of biogas as renewable energy sources [19], (ii) eliminating nuisance odors and (iii) reducing the content of pathogens in the digested effluent while obtaining better management of waste disposal [20-21]. Therefore, it has been recognized as an environmentally friendly and low-cost technology for bio energy conversion of organic wastes [22]. The efficiency of AD is affected by various parameters, among of these the TS content is one of the most critical parameters for the optimum performance of the AD. There are two main reasons for this: (a) water improves the movement and growth of bacteria, facilitating the dissolution and transport of nutrients, (b) water eases the mass transfer of non-homogenous or particulate substrates [23-24] and (c) TS concentration influences the contact between substrate and microorganisms, which is getting lower at higher TS concentration that may the cause of declining biogas yield at the higher TS concentration. Furthermore, in practice, the energy demand for heating and agitating is influenced by the rheological properties which depend on the TS content [25].

Bio methanation is a feasible and effective method of treatment of fruits and vegetable waste generated. Fruits and vegetable waste are solid organic waste having high calorific value and nutritive value to microbes that's why the efficiency of methane production can be increases by several order. The lab scale study was done in 1.5 L liters plastic bottles as digester kept at atmospheric temperature. The prepared vegetable and fruit waste were fed in different bottles with equal amount of water. All were properly sealed and joint should be leak proof to avoid any type of leakage. The 1.5 L plastic bottles were used as digester and fed with Fruit Vegetable Waste (FVW) & Cow dung (CD) in different proportion 1:0.5, 1:1, 1:1.5, and 1:2. The amount of FVW taken for study was 200gms and it is prepared with CD weighting 100, 200, 350 and 400gms with water for proper hydrolysis. The all 4 bottle digester were perfectly sealed and air tight to prevent the leakage of gas. The total gas production was observed for 15days of digestion period. The optimum amount of gas production was observed by water displacement method. In order to obtain the optimum gas production FVW & CD were mixed with water with equal amount of FVW. The co digestion study was carried out to investigate the generation of biogas from Vegetable waste (VW), Fruit waste (FW) and Cow dung (CD) mixture. It was observed from the study that co digestion of vegetable and fruit waste with cow dung decreases the digestion time because of cow dung increases the methanogenic activity in the digester. The composition of cow dung mixed with VW and FW found by experimenting the different CD ratio with VW and FW. The result of study shows that the gas production was maximum for 50% of CD (1:1) and further increasing the CD proportion with vegetable waste gas generation decreases beyond the 50%. Hence for vegetable waste CD should be added with same proportion for optimum gas generation. The water was added in order to dilute the organic substances and to increase the breeding of micro-organism. But in case of fruit waste the gas yield was observed maximum when the FW and CD proportion was 1:2 which shows the fruit waste is less degradable it needs the double amount of CD to digest it properly and increasing the gas yield. The co digestion of fruits and vegetable waste with cow dung balance the nutrient ratio required for the process [26].

A laboratory experiment was conducted to find out the biomethanation potential of dried and powdered Jatropha cake along with buffalo dung at 6% total solids [28]. The experiment was run on daily feeding basis in five litre capacity glass digesters for 180 days. Biogas production was recorded at 24 h interval. Quality of biogas and nutritive value of effluent slurry was also determined. Results show significantly higher (139.20%) biogas production in test (Jatropha cake + Buffalo dung) over control (Buffalo dung only) digesters with methane content of 71.74%. Nutritive value of effluent slurry of test digester was significantly higher in terms of available nitrogen and potassium; calcium; magnesium and carbonate contents than that of control digesters. Co-digestion results in 92.94% decrease in chemical oxygen demand [27].

Recycling of plant materials and agricultural residues for biomethanation was attempted in vials. The methanogenic activities of certain sewage samples have also been tested. Both sterilized and non-sterilized biomasses were used. Biomethanation was carried out with dung samples (cow, goat, buffalo, piggery wastes and poultry wash) as wild populations of microbes and in combination with other microbial isolates (isolated in the laboratory). Biomethanation had been observed to be good in most cases and particularly with the sterilized biomass. Mixed inoculum (dung samples and poultry wash) was found to be best for biomethanation. Of the microbe isolates, isolates from buffalo, pig and paper mill wastes appear to be most effective. Pretreated sawdust and rice straw were found to be good substrates for biomethanation. Of the different plant biomass used *Spirogyra* (algae), *Ipomea* and water hyacinth were most effective whereas *Jatropa gossypifolia* and *Parthenium* sp. were the least effective. Biomethanation of *Spirogyra* was carried out both in anoxic and oxic conditions. Though methane production decreased enormously under oxic conditions, definite methane production continued indicating that the biomethanation process is not exclusively anoxic. Similarly, biomethanation of sewage samples from different sewage treatment plants were carried out with and without isolated methanogens and methane production was found to be moderate. The potential of different agro-wastes like green grass (Cynodon dactylon (L.)), bagasse, algae (Enteromorpha spp.), banana stem and water hyacinth (Eichhornia crassipes) in combination with cattle dung for methane production by anaerobic digestion have been evaluated. The results indicate that these wastes can be exploited for methane generation in combination with cattle dung. Best results were obtained with green grass when it was combined with cattle dung in the ratio of 1:4 [28].

Producing bioenergy from the anaerobic digestion (AD) of poultry droppings (PD), press mud (PM), sugarcane bagasse (SB) and sugar beet roots and tops (SRT) could be an effective source of fuel and energy for processing sugar from sugar beet and sugarcane and for reviving and making the sugar industries profitable. The total solids (TS) content is crucial for an optimum performance of the AD process. In this study, batch assays were conducted to determine the optimal TS contents on the mesophilic AD of PD, PM, SB and SRT with TS contents of 5, 8, 11 and 15%, respectively. The highest biochemical methane potential (BMP) were found 254, 121, 205 and 23 NL kg^{-1}VS for PD, PM, SB and SRT after digestion for 90 days at TS content of 11%, 15%, 11% and 8%, respectively. The results indicate that the initial TS influenced the AD performance significantly and modeling showed that the optimal initial TS content for AD of PD, PM and SB ranged between 12 and 13%.The only exception was SRT, where an initial TS content of 8% is recommended [29].

Anaerobic bio digestion of fruit peel wastes is one of the potential for biogas production which subsequently reduces environmental pollution. In order to test the biogas potential of avocado fruit peel wastes co-digested with either cow dung or poultry manure, the raw materials were collected from juice vending house, dairy farm, and poultry farm, respectively. A finely grinded avocado fruit peel wastes was prepared for the different setups. The experiments include 100% avocado fruit peel wastes (T1), 100% poultry manure (T2), 100% cow dung (T3), 50% T1+50% T2 (T4), 50% T1+50% T3 (T5), 75% T1+25% T2 (T6) and 75% T1+25% T3 (T7). The total weight of the raw material was 100 g either solely or in mixture with the animal manure. 15 ml of rumen fluid collected from slaughterhouse was added into each treatment as inoculums. The total volume of the biodigesters was made 1800 ml by adding distilled water; and the setups were completely sealed in plastic bottles. The gas produced was estimated by water displacement method. Feedstocks containing both 100% poultry manure (T2) and 50% poultry manure (T4) attained maximum biogas production within 3-4 days of incubation. The highest in cumulative biogas was produced from the two treatments at 20thday. The optimum temperature, salt and pH for biogas production from the fruit wastes co-digested with animal manure were 25°C, 0.5% and 7 respectively. Under this environmental condition, the highest biogas (453.5 ± 0.5 mL) was produced by T6 that was significantly higher than the other treatments. In general, the feed stock containing poultry manure co-digested with avocado fruit waste was fast and high in biogas generation. Therefore, co-digestion of avocado fruit peel waste with animal manure is a good strategy to produce bioenergy and minimize urban solid wastes discharge although it demands controlling some physical parameters [30].

Biogas was produced from farmland and animal wastes; of which farmland manure were pumpkin pod (P) and maize bract (M), while animal manure were cow (C) and swine dung (S). The wastes were combined as: M:P, MP:C, MP:S and MP:CS, all in the ratio of 1:1 (waste to waste). The pumpkin garbage system acted as the control. Biodegradation was batch operated in reactors of the same size (41.0 L capacity) within 30 days under the prevailing atmospheric conditions. Results of digester behaviour during the experimental period indicated that cumulative gas yield was highly significant ($P \leq 0.05$) for MPC system; 103.2 L/total mass of slurry (TMS). This was followed by MPS - 72.1, MP - 66.0 and MPCS - 55.3 L/TMS, respectively. The total gas yield from the control was obtained as 30.0 L/TMS. All the systems also produced flammable gas at different days within the period. Pumpkin pod flamed on the 29th day while MP, MPC, MPS and MPCS produced flame on the 13th, 4th, 10th, and 11th day, respectively. Flammable gas composition analysis from MP, MPC, MPS and MPCS systems were carried out and each showed significant methane content. The overall results indicated that gas production was enhanced through blending, and the MPC system could be a rich source of renewable energy option to rural dwellers and relatively for urban dwellers if properly harnessed [31].

Biogas production from organic materials is a trending and prospective renewable energy production approach for electricity generation and can thereby ameliorate the greenhouse gas emissions. This scientific investigation was carried out on biogas production, a natural gas, obtained from equal weight of fresh and dry substrates (Cassava peels/Swine dung) using 2.8 liter batch type anaerobic digesters. The prototype metallic bio-digesters were fed with wastes for the retention period of 30 days within a mesophilic temperature range. The biogas yield was significantly ($p \leq 0.05$; t-test) influenced by the type of waste used. The cumulative average yield from fresh samples was 8.3, 30.8, 23.6, 29.8, 49.3, 32.8 and 52.7 cm3/g while the dry sample was 15.7, 23.0, 24.7, 19.3, 29.7, 40.3 and 35.8 cm3/g over the digestion periods. However, the highest volume of gas generated 52.7 cm3/g. The physico-chemical nature of respective feedstock in the digesters revealed an initial drop in pH from acidic range to a steady increase of 4.2- 8.2 at end of digestion. The temperature remained relatively constant throughout digestion period ranging from 29°C – 32°C. Microorganisms isolated were mainly anaerobes and methanogens such as *Clostridium sp. Methanococcus sp*. and *Methanobacterium sp*. The rising cost of fossil oil, potentially diminishing with petroleum and allied products as well as desert encroachment have provided the need to consider alternative source of energy and revenue to boost our economy [32].

II. CONCLUSION

Agriculture is the prime source of biomass in India which generates large quantities of crop residues as a waste. Agricultural waste is the material obtained due to crop production or from plant growth. Nowadays, the energy security as well as the environmental concerns has made great attempts to find economically and environmentally friendly energy resources. Biogas production via biomethanation (anaerobic digestion) has been shown as a sustainable, renewable and carbon neutral energy source which can reduce the global fossil fuels dependency. Agricultural activities generate huge amounts of organic residues annually worldwide. These are including crop residues, straw, stalks, branches, leaves, waste from pruning, bagasse, residue from cotton ginning, oil cakes and animal manure. Traditional methods such as burning of these residues cause adverse effects on the environment such as greenhouse gas emission and pollution of air and water, while they could be sufficiently converted into valuable products through anaerobic digestion process. In order to enhance the efficiency of anaerobic digestion of the agricultural residues, a sufficient pretreatment may be necessary to make the feedstock ready for microbial decomposition. Besides, the optimization of microbial activity of anaerobic digestion via manipulation and control of operational parameters is necessary and important.

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